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DETERMINATION OF MINIMUM FLOWS FOR SILVER GLEN SPRINGS, MARION AND LAKE COUNTIES, FLORIDA

by

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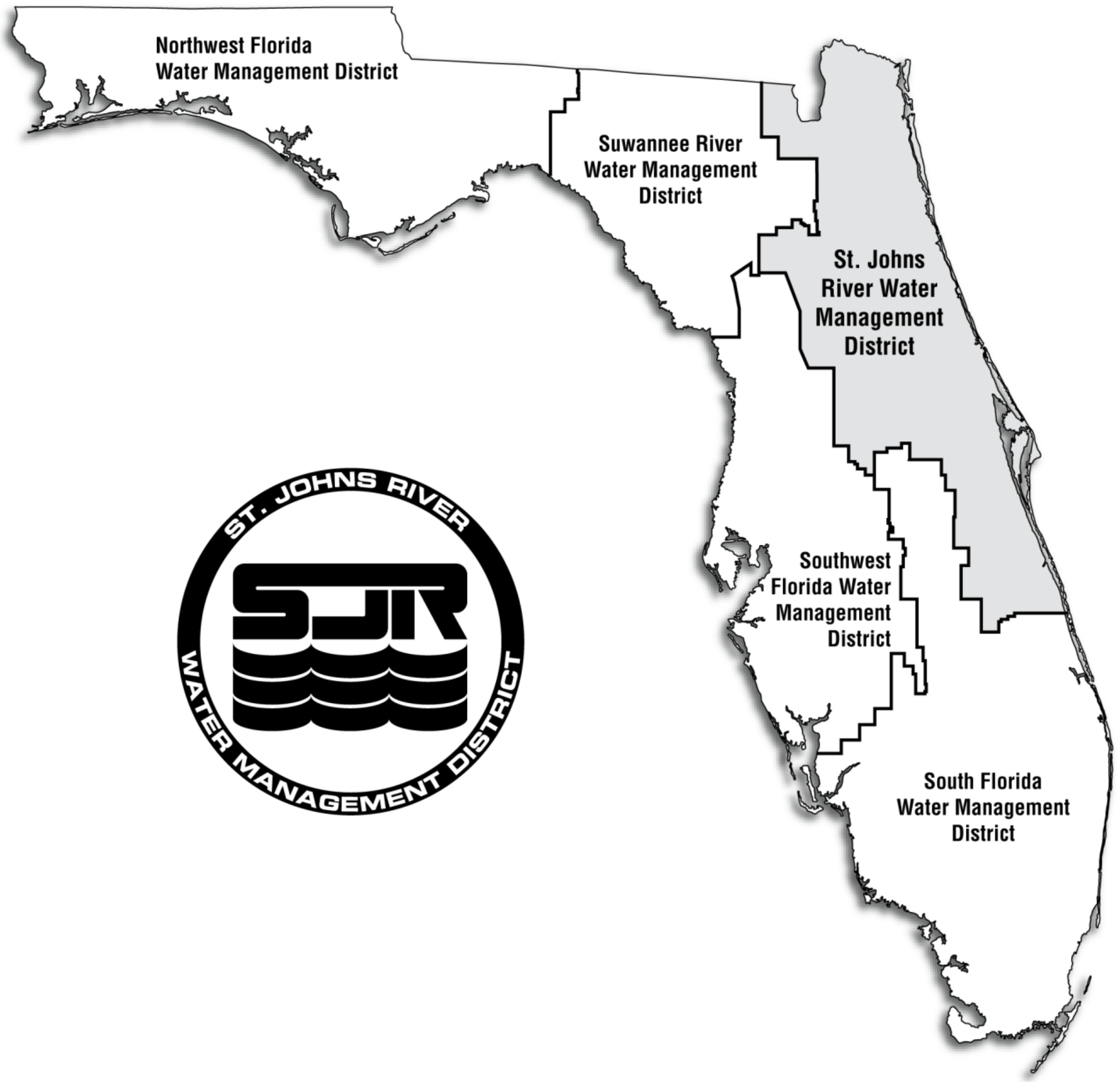

The St. Johns River Water Management District was created in 1972 by passage of the Florida Water Resources Act, which created five regional water management districts. The St. Johns District includes all or part of 18 counties in northeast and east-central Florida. Its mission is to preserve and manage the region's water resources, focusing on core missions of water supply, flood protection, water quality and natural systems protection and improvement. In its daily operations, the district conducts research, collects data, manages land, restores and protects water above and below the ground, and preserves natural areas.

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EXECUTIVE SUMMARY

As a part of fulfilling its mission and statutory responsibilities, the St. Johns River Water Management District (SJRWMD) establishes minimum flows and levels (MFLs) for priority water bodies within its boundaries. MFLs define the limits at which further consumptive use withdrawals would be significantly harmful to the water resources or ecology of the area. MFLs are one of many effective tools used by SJRWMD to assist in making sound water management decisions and preventing significant adverse impacts due to water withdrawals. Section 373.042, *Florida Statutes* (F.S.), requires the adoption of minimum flows and levels for Outstanding Florida Springs (OFS), including Silver Glen Springs by July 1, 2017.

Silver Glen Springs is a first-magnitude spring located in the Ocala National Forest, between the unincorporated communities of Salt Springs and Astor, Florida. The spring emerges from one of the largest and longest underwater cave complexes in the St. Johns River basin, and flows down a 0.6-mile spring run to Lake George along the St. Johns River. Evidence of human use at Silver Glen Springs dates back at least 7,000 years, and includes the remains of two massive shell mounds built atop mortuaries near the spring pool and the mouth of the spring run at Lake George. The spring is a popular destination for swimming, boating, fishing, wildlife viewing, and viewing the spring.

All relevant environmental values were evaluated pursuant to rule 62-40.473, Florida Administrative Code (F.A.C.) to determine appropriate basis for setting the MFL for Silver Glen Springs. The ecological resource of warm-water habitat for Florida manatees was determined to be the most sensitive of the environmental values for the determination of a minimum flow regime at Silver Glen Springs.

Silver Glen Springs is federally designated as critical habitat for Florida manatees, and is identified as a warm-water refuge for manatees by both the U.S. Fish and Wildlife Service (FWS) and the Florida Fish and Wildlife Conservation Commission (FWC). 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 Silver Glen Springs.

FWS recently downlisted Florida 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 Silver Glen Springs, is listed in the FWS Florida Manatee Recovery Plan as a criterion for downlisting. According to FWS, 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.

Spring flow is the source of warmer water in the spring run in winter, and water temperature modeling indicates that reductions in spring flow can lead to decreases in water temperatures in portions of the spring run. Given the need for the protection of warm-water habitat for manatees, the minimum flow regime recommended by SJRWMD for Silver Glen Springs is intended to allow no significant decrease in warm-water habitat due to water withdrawals from current conditions.

For the period of 1984 to 2015, average spring flow at Silver Glen Springs was 102.2 cubic feet per second (cfs). The estimated reduction in spring flow at Silver Glen Springs, currently occurring due to consumptive use, is approximately 2.1% or 2.1 cfs. Of this 2.1 cfs reduction in flow, approximately 2.0% (2.0 cfs) is due to the consumptive use of water near (2 to 4 miles from) the springs. Other regional ground water pumping is responsible for an additional 0.1% (0.1 cfs) flow reduction. Because Silver Glen Springs is an important refuge for a federally threatened species and harbors other species of special concern, the minimum flow regime is intended to allow no significant decrease in warm-water habitat due to water withdrawals.

Based on the results of temperature modeling and consultation with resource agencies, additional spring flow reductions in excess of 5% (5.0 cfs) from the current condition would result in a significant decrease in warm-water habitat within the spring run and would be considered harmful to manatees, while an additional reduction of 0.5% (.5 cfs) would not cause significant harm to manatees or any other environmental values. Temperature modeling indicates that an additional 1% (1.0 cfs) flow reduction from current conditions may begin to lead to changes in manatee habitat in downstream portions of the spring run, which is less than the 5% (5.0 cfs) reduction that had been determined would result in significant harm. Therefore, the limit at which further consumptive use withdrawals would cause significant harm is between 2.5% (2.6 cfs) and 6.9% (7.1 cfs) total reduction in spring flow from the no-pumping condition. To ensure the prevention of significant loss of warm water habitat for federally threatened Florida manatees at Silver Glen Springs, due to water withdrawals, SJRWMD recommends a minimum flow regime that is at the lower end of these two values, allowing for no more than a 2.5% (2.6 cfs) reduction from the no-pumping condition. The “no-pumping” condition represents the annual mean spring flow (based on data from 1984–2015) in the absence of groundwater withdrawals. Based on this allowable reduction, the recommended minimum flow for Silver Glen Springs is a mean flow of 99.6 cfs. Based on a 2.5% (2.6 cfs) allowable flow reduction, under the recommended minimum flow, and a current condition of 2.1% (2.1 cfs) reduction, there is an additional allowable reduction in flow of 0.4% (0.5 cfs), prior to the minimum flow not being met.

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 must remain at or below a 2.5% (2.6 cfs) reduction from the no-pumping flow regime. Silver Glen Springs is surrounded primarily by the Ocala National Forest. An evaluation of the expected water use demands during the 20-year planning horizon in the area that has the potential to influence flow at the spring indicates that water use is not expected to cause the spring flow to drop below the proposed MFL during this 20-year period. Therefore, neither a recovery nor prevention strategy is required.

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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 water body, a permit cannot be issued. If a water body 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

Rather than a single value representing an absolute minimum, minimum flows and levels are typically a “minimum flow regime” or “minimum hydrologic regime” representing the range and timing of flows and/or levels needed to maintain the characteristics and functions of a water body 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. D. 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 10values described in rule 62-40.473, F.A.C.).

A report from the National Research Council (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 inter-annual 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 SILVER GLEN SPRINGS

Silver Glen Springs (29°14'44.9"N, 81°38'36.9"W) is a first-magnitude spring located in the Ocala National Forest, between the unincorporated communities of Salt Springs and Astor, Florida (Figure 1) (Scott et al. 2002). At Silver Glen Springs, water from the upper and lower Floridan aquifers emerges mainly from two vents (Walsh et al. 2009). The primary vent is located at a depth of about 18 ft in a large swimming area, and a secondary vent is located at a depth of about 40 ft in an adjacent smaller pool (Walsh et al. 2009). Numerous small sand boil springs also emerge nearby and join the spring run. The spring run flows about 0.6 miles to Lake George along the St. Johns River, and is bordered by both national forest and privately owned land (Figure 2 and Figure 3).

The underwater cave system below Silver Glen Springs is one of the largest and longest underwater cave systems in the St. Johns River basin, with more than 2000 ft of mapped passages (Hutcheson 1990); Pete Butt, Karst Environmental Services, Inc., pers. comm. 2017). One part of the cave system is a huge cavern named the Aussum Pit, which extends from 50 to 160 ft below ground and is similarly wide. Another part of the cave system includes a tunnel with white walls leading to a room with underwater sand boils (Morris 2017).

Swimming, snorkeling, boating, fishing/bowfishing, hiking, picnicking, wildlife viewing, and viewing the spring are popular activities at Silver Glen Springs (Figure 4). The spring is a popular destination for summer leisure, with sometimes hundreds of boats packed into the spring run on weekends and holidays (Pandion Systems Inc. 2003). SJRWMD purchased the spring as part of a 511-acre parcel for $3.8 million from the St. Joe Paper Company in 1989 and sold the parcel for $3.9 million to the U.S. Forest Service in 1990 (Lake Co. 2017; Marion Co. 2017). As of 2002, the Silver Glen Recreation Area within the Ocala National Forest received at least 39,000 visitors per year by land, and thousands more accessed the spring run by boat (Bonn 2004). Most visitors by land were non-local, and came from other counties and states (Bonn 2004). For more than 20% of visitors by land, it was their first visit to a spring (Bonn 2004).

Evidence of human presence at Silver Glen Springs dates back at least 7,000 years, and the cultural resources there are important aspect of the site (Randall et al. 2011). By about 4,000 years ago, the upland areas on both sides of the spring run "...were covered with the remains of thousands of years of pre-ceramic habitation and ceremony" (Gilmore 2016). Two shell mounds at Silver Glen Springs were some of the largest pre-Columbian structures built in Florida, and large-scale mortuaries have been found within or underneath the shell mounds (Gilmore 2016). Jeffries Wyman, a professor who traveled the St. Johns River between 1867–1874 (Randall 2015), wrote:

> *[Silver Glen Springs Run]...has upon its banks the most gigantic deposits of shells met with on the waters of the St. John's. There are two distinct portions; one forming an amphitheater which surrounds the source or "boil"...and the other occupying the right bank of the creek at its mouth, as well as the shore of the lake. (Wyman 1875)*

The shell mounds were mined for shell material in the 1920s, and the material was mainly used to pave roads (Randall et al. 2011). The morphology of the spring run was significantly altered by both the ancient construction and more modern mining of the mounds; the mounds narrowed and constrained parts of the run, and their removal widened parts of the run (Randall et al. 2011). Investigations of the remaining parts of the shell mounds and other areas around Silver Glen Springs have yielded information about past inhabitants as well as the cultural significance of the site (Randall et al. 2011; Sassaman 2011); over several thousand years, many different cultural groups contributed to the archaeological records at Silver Glen Springs, often in a manner suggesting those groups used and revisited the spring as a short-term gathering place (Gilmore 2016).

Figure 1. Map of the area near Silver Glen Springs.

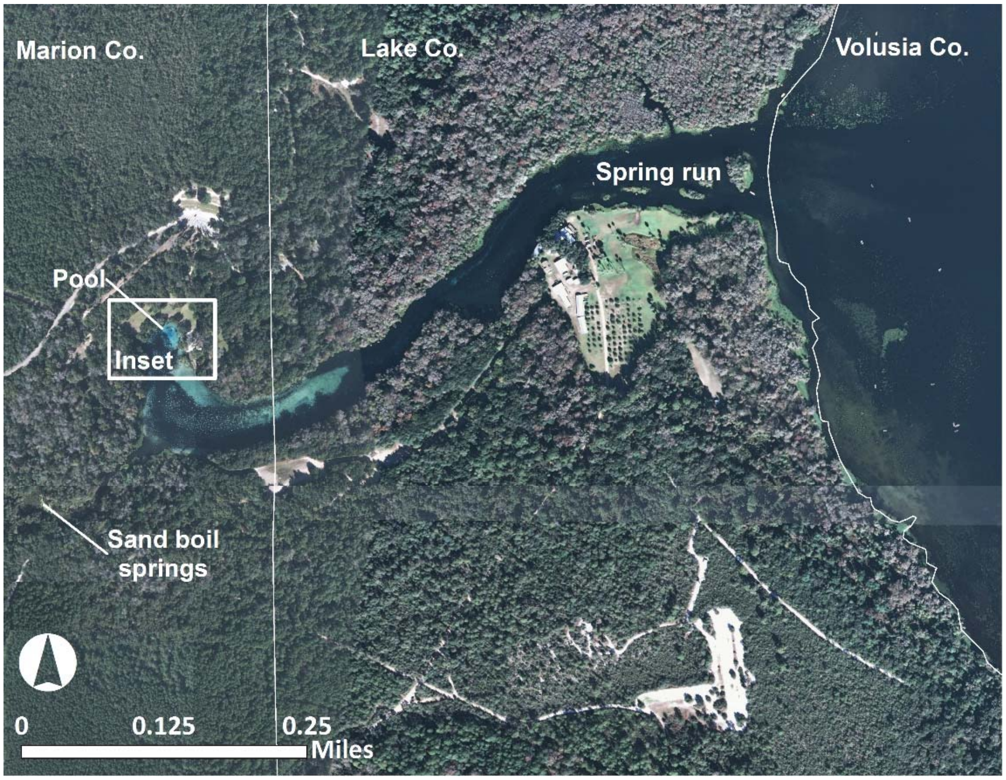

Figure 2. Map of Silver Glen Springs. Inset shown in the next figure.

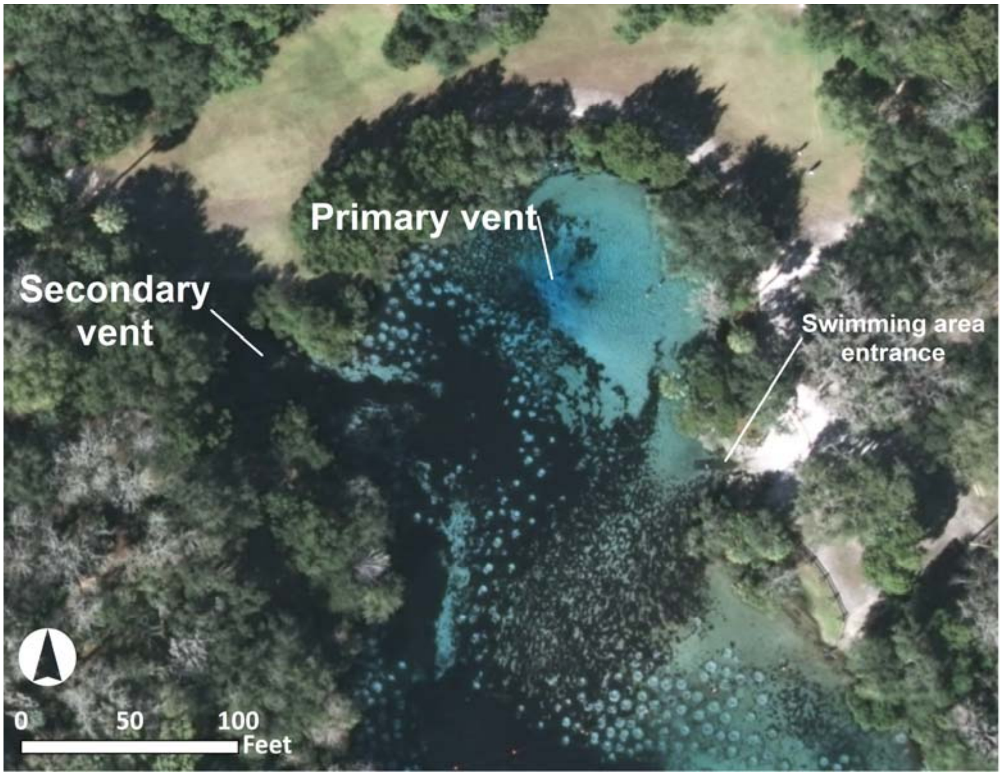

Figure 3. Inset area from the previous figure. Spring vents in the swimming area at Silver Glen Springs.

Figure 4. The primary vent in the spring pool (upper), the entrance to the swimming area (lower left), and sand boil springs down a boardwalk near the swimming area (lower right).

POPULATION, LAND USE, AND GROUNDWATER USE

Land use near Silver Glen Springs has changed little within the Ocala National Forest since the 1970s. Beyond the national forest, especially west and southwest of Silver Glen Springs, large areas of agricultural land use have been replaced by residential, commercial, or industrial land use (Figure 5). Overall, the population of the three counties southwest of the spring has grown considerably (it has quintupled) since the 1970s, although the portion of the population within the national forest has remained small. From 1970 to 2015, the population of Marion County increased from 69,030 to 343,254, Lake County increased from 69,305 to 328,875, and Sumter County increased from 14,839 to 118,891 (U.S. Census Bureau 2016).

In the immediate vicinity of the spring, the south shore of the spring run has been owned and operated as a private hunt club since 1909, around the same time the Ocala National Forest was established, and currently includes a few buildings. Around the spring pool and the north shore of the spring run, a privately owned campground closed in the late 1980s when the land was sold to SJRWMD and later became a recreation area within the Ocala National Forest. The recreation area currently includes picnic areas, a boardwalk and walking trails, a parking lot, and small visitor center without in-ground plumbing. The areas about 2 to 4 miles north of the spring along Florida Highway 19 and the shore of Lake George are in private ownership. Housing subdivisions consisting of about 750 parcels have been built in these areas starting in the 1970s. This area also includes several large groundwater wells with water use estimated to be several million gallons per day for recreational and/or commercial purposes (SJRWMD Bureau of Water Supply Planning, 2017). Water use in this area is not included in the graph of springshed water use because the area is not within the springshed. However, water use in this area was included in the groundwater model when it was used to estimate pumping impacts on Silver Glen Springs (see "Groundwater pumping impact assessment" section).

In addition to the water use described above, groundwater use in an area of about 240-square-miles extending southwest from the spring increased from about 0.1 million gallons per day (mgd) in 1950 to about 1.3 mgd in 2015, and is expected to reach about 2.1 mgd by 2035 (Figure 6) (SJRWMD Bureau of Water Supply Planning, 2017). The increase expected by 2035 is mainly due to domestic self-supply and agricultural use in the southwest portion of the area. Groundwater use in the SJRWMD portion of Marion County, which encompasses a much larger area extending further to the west and northwest, was 36.8 mgd in 2010 and is expected to reach 62.7 mgd by 2035 (SJRWMD Bureau of Water Supply Planning, 2017).

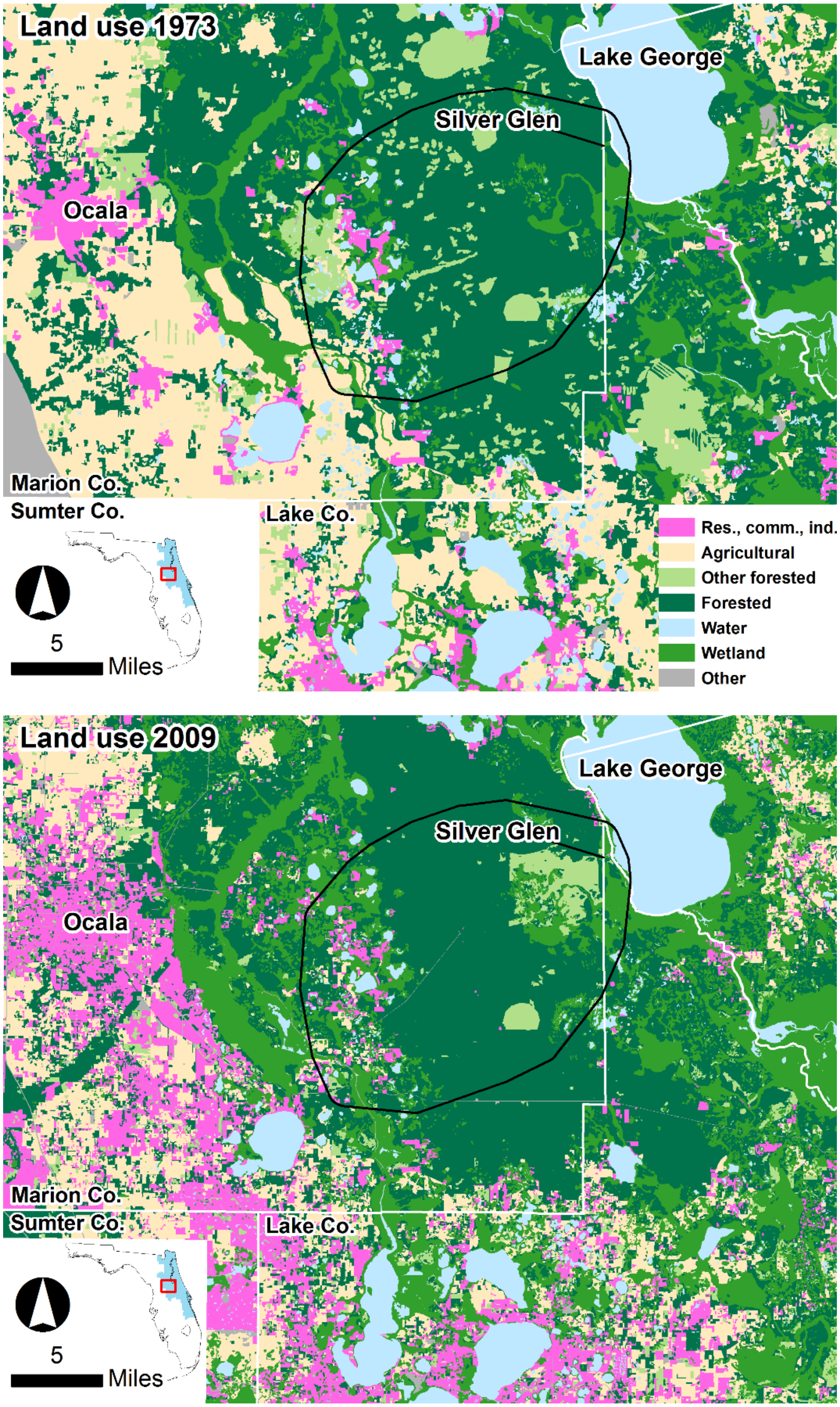

Figure 5. Land use near Silver Glen Springs as of 1973 (top) and 2009 (bottom). Note that land use classification methods differed between 1973 and 2009, and that the SJRWMD's land use layer did not cover Sumter County in 1973, and only partially covered Sumter County in 2009. The black outline indicates the area used for the graph of groundwater use in the next figure.

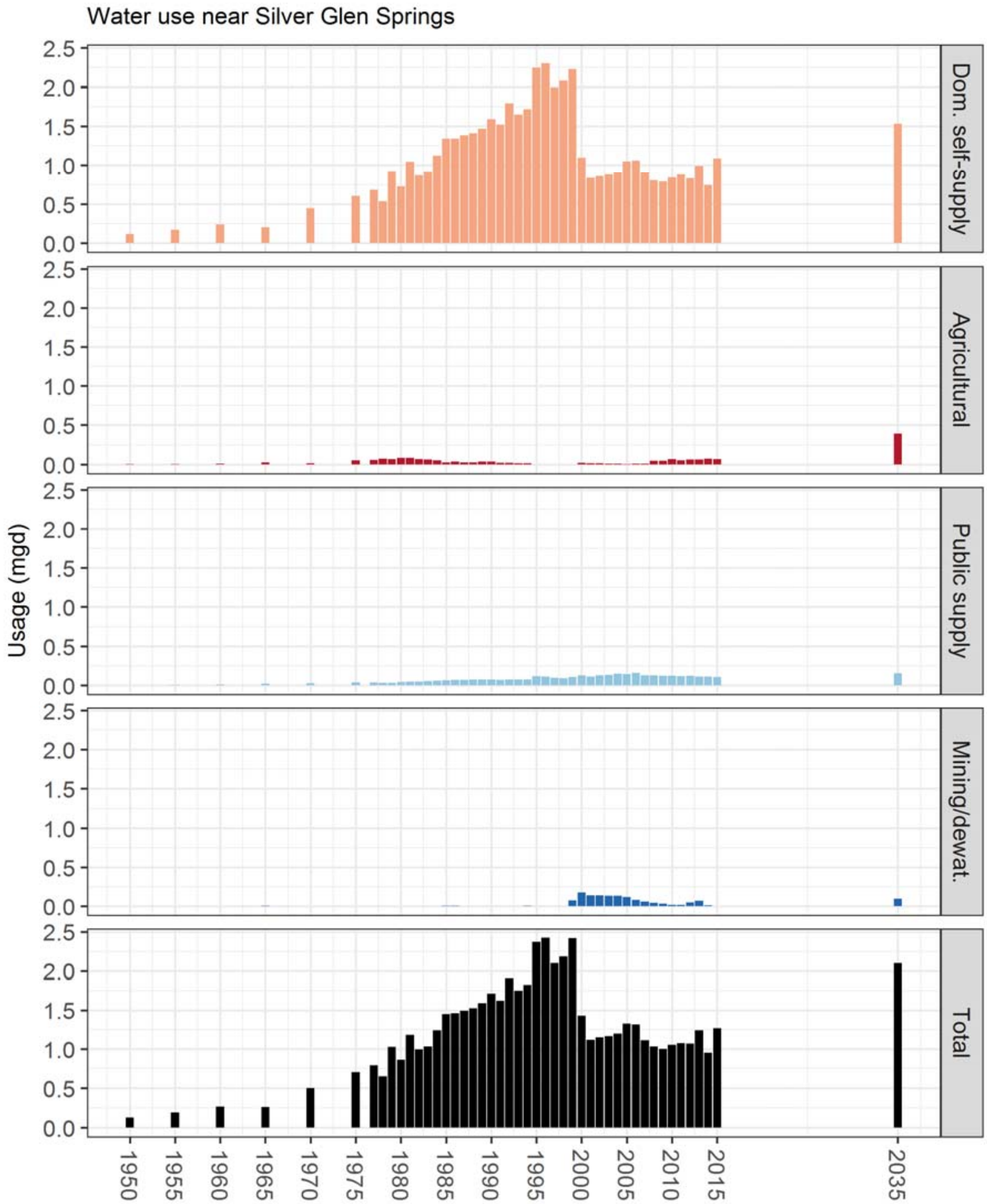

Figure 6. Groundwater use in an area of about 240-square-miles extending southwest from Silver Glen Springs (as indicated in the previous figure), from 1950–2015 with 2035 projections. Note that 1) The downward shift in domestic self-supply around 2000 is due to a change in the method used to estimate water use, rather than an actual decrease in water use, and 2) This graph does not include groundwater use in the area 2 to 4 miles north of the spring, but all water use in the Northern District model domain (figure in Appendix B) was considered in the determination of the MFL (SJRWMD Bureau of Water Supply Planning, 2017).

Warm-water habitat for Florida manatees

Silver Glen Springs is a warm-water refuge for Florida manatees (*Trichechus manatus latirostris*). Exposure to water temperatures below 20°C (68°F) often results in "cold stress syndrome" in Florida manatees, 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 Silver Glen Springs, where warm water is provided by spring flow that exits the spring vents at temperatures typically above 22°C.

Other warm-water refuges in the St. Johns River system include Blue Spring Run, Salt Springs Run, and Spring Garden Run at De Leon Springs (Figure 7) (FWS 2007). As part of the St. Johns River system, all of these refuges, including Silver Glen Springs 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 allows manatees to access more foraging opportunities in winter (Ross 2011). At Silver Glen Springs, manatees are able to forage in the spring run and vegetated areas along the western edge of Lake George (Ross 2011), and the spring provides necessary warmth while Lake George and the St. Johns River remain below 20°C for most of the winter and often reach below 15°C for some portion of the winter.

All of the warm-water refuges in the St. Johns River system are springs, but the major refuges on the Atlantic coast are power plants. As these aging power plants are eventually decommissioned or replaced by newer and more efficient power plants, the amount of warm-water discharges will decline, increasing the reliance of manatees on springs for winter refuge (FWC 2007). Over the next several decades, major shifts in the geographic distribution of manatees are expected, with some of the largest increases expected to occur in the St. Johns River system (Runge et al. 2015). The manatee population in the St. Johns River system currently represents only about 5% of statewide synoptic counts, while the manatee population on the Atlantic coast represents about 46% of statewide synoptic counts (FWC 2007; Laist et al. 2013).

Silver Glen Springs is an important warm-water refuge with additional future potential, and maintaining flow to prevent the loss of warm-water habitat is a critical concern for the overall recovery of Florida manatees (FWS, pers. comm. 2017). FWS recentlydownlisted manatees from endangered to threatened under the Endangered Species Act, with the expectation that warm-water habitat loss is being addressed (81 *Federal Register* at 1012, 2016). The loss of warm-water habitat currently remains one of the largest threats to manatees, second only to watercraft collisions (81 *Federal Register* at 1014, 2016). Criteria for recovery include the protection of natural warm-water refuges, the management of regional warm-water networks, and ensuring that minimum flows and levels are established to protect resources of importance to manatees (FWS 2001). FWS has stated that the focus of recovery is not on how many manatees exist, but instead on "implementing, monitoring, and addressing the effectiveness of conservation measures to reduce or remove threats" and ultimately leading to a healthy and self-sustaining population (FWS 2001).

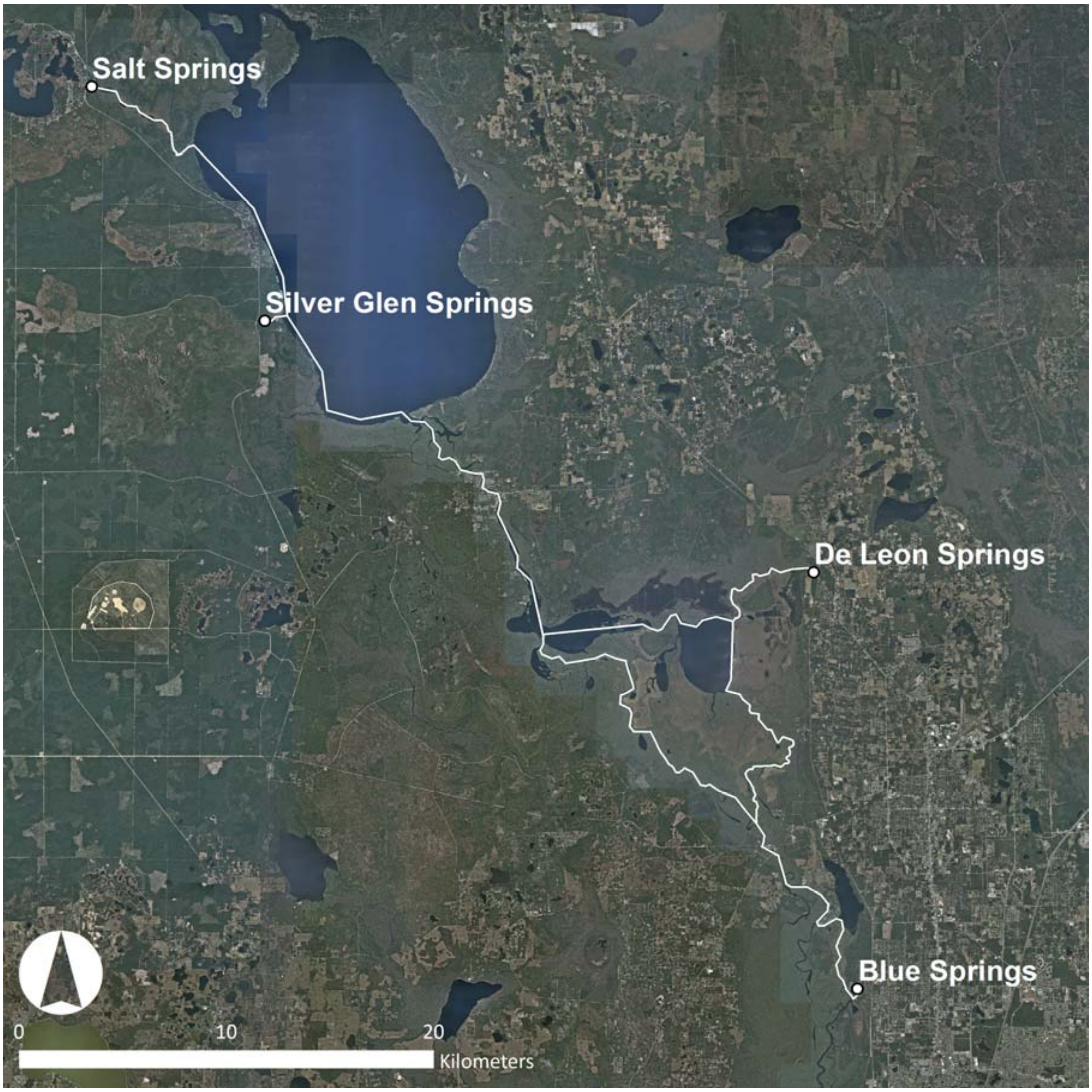

Figure 7. Network of warm-water refuges in the St. Johns River system

OTHER SPECIES OF SPECIAL INTEREST

Silver Glen Springs cave crayfish

The Silver Glen Springs cave crayfish (*Procambarus attiguus*) is endemic to Silver Glen Springs and was first identified around 1990 (Franz et al. 1994). The specific epithet "attiguus" means "neighboring," referring to the fact that the Silver Glen Springs cave crayfish is a close neighbor of the big-cheeked cave crayfish (*P. delicatus*) endemic to Alexander Springs. Cave crayfish generally forage on detritus that enters through the vents of cave systems, and the transport of detritus as well as maintenance of water quality and prevention of contamination are thought to be important considerations for the protection of cave crayfish (USFS 2011). In 2011, the US Fish and Wildlife Service recommended listing both *P. attiguus* and *P. delicatus* under the Endangered Species Act, but the listing has not yet been finalized (76 *Federal Register* at 59858, 2011).

Hobbs and Franz (1992) described the crayfish as being found at a depth of 49 m, 213 m from the main entrance of Silver Glen Springs cave, with individuals observed in cave crevices or on the cave substrate. Hobbs and Franz (1992) also suggested that the crayfish may feed on bacterial growth as well as scavenging dead material. Information available through IUCN states, “The life history of this species is unknown, but due to the low levels of nutrients reaching the cave chamber due to the strong outflow current, it can be assumed that this species has a late reproductive maturity and a long life-history making it susceptible to loss of individuals” (Cordeiro et al. 2010).

Striped bass

Striped bass (*Morone saxatilis*) are a large game fish that historically spawned in the Ocklawaha River and lived throughout the St. Johns River system, at the extreme southern end of the species” range (Jay Holder of FWC, pers. comm., 2017). The construction of the Kirkpatrick Dam and Rodman Reservoir on the Ocklawaha River in the 1960s removed the access, flow velocities, and distances needed for striped bass spawning. Since that time, striped bass have been stocked in the St. Johns River by FWC and federal hatcheries. Striped bass in the St. Johns River system typically eat small fish and crustaceans. Researchers have noted a decline in striped bass populations at the spring vents since about 2010, coinciding with a decline in submerged aquatic vegetation at the spring vents (Jay Holder of FWC, pers. comm., 2017).

Striped bass rely on springs along the river for thermal refuge during summer, as optimal temperatures for striped bass are typically below 25°C while water temperatures in the St. Johns River are typically above 25°C between May and September. Silver Glen is one of the most important, most-used thermal refuges for striped bass in the St. Johns River system, followed by Croaker Hole Spring (Jay Holder of FWC, pers. comm., 2017). Although populations have recently declined, historically thousands of striped bass would gather around the main spring vents in summer. Striped bass that occur at Silver Glen Springs typically occupy the deeper vent that is marked off-limits to swimmers, with some striped bass even remaining at the spring vents in winter. Interestingly, striped bass do not use Blue Spring or some of the other springs in the St. Johns River system as thermal refuges, possibly due to lower flow velocities and/or dissolved oxygen limitations (Jay Holder of FWC, pers. comm., 2017).

TECHNICAL APPROACH FOR DETERMINING A MINIMUM FLOW REGIME FOR SILVER GLEN SPRINGS

OVERVIEW

Warm-water habitat for Florida manatees is the most sensitive ecological resource evaluated for the determination of a minimum flow regime at Silver Glen Springs. The minimum flow regime at Silver Glen Springs is intended to prevent significant warm-water habitat loss for manatees due to water use, while also protecting any less-sensitive ecological resources and beneficial uses at Silver Glen Springs. The following are described in this section:

- Observations of manatees at Silver Glen Springs
- Manatee habitat reduction due to spring flow reduction
- Threshold of significant harm
- 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 SILVER GLEN SPRINGS

A 2009–2010 study documented the use of Silver Glen Springs by manatees during winter (Ross 2011). A total of 12 individually identifiable manatees were seen over 23 visits, and a maximum of seven manatees were seen per visit. Manatees were observed feeding, resting, and traveling in the spring run, most often in the cove and channel about halfway down the run and at the southern entrance to the run (Figure 8). Two particular manatees were observed at Silver Glen Springs every month, indicating that it was their primary warm-refuge site. Interestingly, another particular manatee at Silver Glen Springs had been identified at Blue Spring more than 30 years prior to the 2009–2010 study.

The 2009–2010 study also observed that vegetation was available for manatees throughout the area, and that human use of the spring run often directly overlapped with manatee use areas (Ross 2011). Water temperatures measured during daytime visits typically remained about 22°C in the upper half of the run, and only reached 20°C near the mouth of the run. Water temperatures measured by a continuous logger placed at the bottom of the water column in the cove about halfway down the run only occasionally dropped below 20°C during the study (Ross 2011).

Although cold stress syndrome is more likely to affect manatees in water temperatures below 20°C, manatees typically seek out and prefer even warmer temperatures (Ross, pers. comm. 2017). In addition to seeking warmer temperatures, manatees also typically prefer areas of slower-moving water for resting, areas with vegetation for foraging, and areas where they can avoid conflicts with humans (Figure 9). These factors may contribute to manatee use of the areas shown in Figure 8, which are a combination of the manatee use areas identified by the 2009–2010 study and an earlier study conducted in 2003 (Pandion Systems Inc. 2003; Ross 2011).

Although the number of manatees observed using Silver Glen Springs is relatively low, the site has the potential to become a primary warm-water refuge for manatees in the future, according to FWS (pers. comm. 2017). Blue Spring started with a maximum daily count of 11 manatees in 1971–1972 and now, following protective measures, has maximum daily counts exceeding 300 manatees (FWS, pers. comm. 2017). Given growth in the upper St. Johns River manatee management unit, Silver Glen Springs could see an increase in manatee use if warm-water habitat remains protected.

Figure 8. Areas of the spring run where manatees are frequently observed in winter, according to Pandion (2003) and Ross (2011).

Figure 9. Manatee known as “Flash” near Area 1, winter 2016–2017.

MANATEE HABITAT REDUCTION DUE TO SPRING FLOW REDUCTIONS

Based on a model developed for Silver Glen Springs Run using the Environmental Fluid Dynamics Code (EFDC), reductions in spring flow result in lower cold-weather water temperatures in the spring run (see report by Stewart (2017) for model details, Appendix F). Flow scenarios over the time periods from November 2010–March 2011 and November 2014–March 2015 were modeled to examine changes in water temperatures with reductions from observed flow. Winter 2010–2011 represents a period with low spring flows and low water levels within the period of record, while winter 2014–2015 represents a period also with low spring flows but high water levels. Weather in winter 2010–2011 reached colder temperatures than winter 2014–2015; water temperatures in the St. Johns River at Astor from 2008–2016 are shown in Figure 10.

Within the model, the water column at Silver Glen Springs Run was divided into six layers of equal depth. Results for the following flow scenarios are discussed for two of those layers, the top and bottom layers:

- actual flow recorded during that time period (observed flow)
- 1% additional flow reduction from the current actual flow
- 5% additional flow reduction from the current actual flow
- 10% additional flow reduction from the current actual flow

The EFDC model is mechanistic and can be used to look at any size incremental change for any input data, in this case spring flow. The minimum temperature response is determined by the resolution of the HOBO pendant temperature sensors used for model calibration, which was 0.14°C. To evaluate changes in water temperature as a function of spring flow, the minimum spring flow reduction that should be used for decision making purposes will produce a temperature response of at least 0.07°C if error is not biased in either the colder or warmer direction, or 0.14°C if error is entirely biased in either the colder or warmer direction.

A comparison of model-estimated temperatures and observed temperatures from loggers in the middle portion of the run in February–March 2015 indicated that the model tended to overestimate water temperatures, especially during the night and early morning hours. Model-estimated temperatures were typically at least 0.5°C higher and sometimes as much as 1.5°C higher than observed temperatures. More data would be needed to determine if this trend holds true in other portions of the run and in colder periods where water temperatures are closer to 20°C. The EFDC model is best used to estimate changes between flow scenarios rather than as a predictor of actual temperature. Overall, the EFDC model for Silver Glen Springs shows that temperatures in the run are most sensitive to changes in flow toward the end of the spring run where it flows into Lake George (Appendix C).

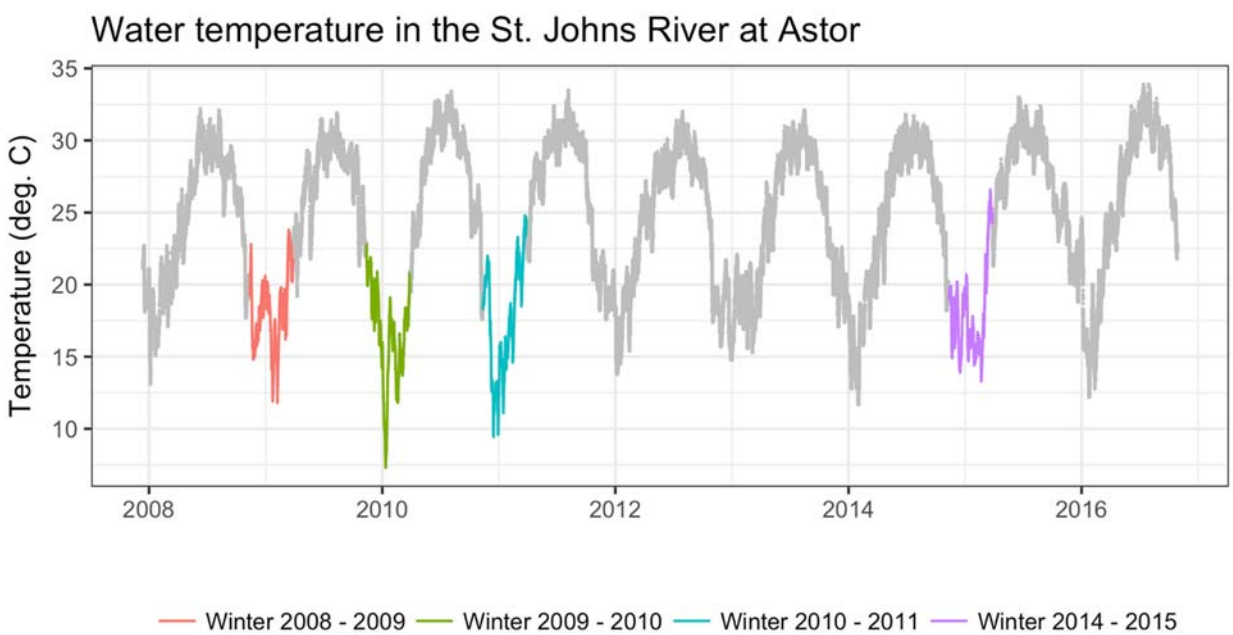

Figure 10. Water temperatures in the St. Johns River at Astor, with the winter temperatures during each of the four available model periods highlighted.

To evaluate changes in water temperatures needed to provide warm-water refuge for manatees at Silver Glen Springs, modeled hourly temperatures in the observed flow scenarios for 2010–2011 and 2014–2015 were compared with modeled hourly temperatures in the 1%, 5%, and 10% additional flow reduction scenarios for each of these time periods. Both the frequency and duration of water temperatures below 20°C were evaluated, as well as the frequency and duration of water temperature changes greater than 0.14°C (Appendix C). Figure 11 and Figure 12 show the additional number of hours (frequency) that modeled temperatures were below 20°C in the 1%, 5%, and 10% additional flow reduction scenarios compared to the observed flow scenarios. Figure 13 and Figure 14 show the additional maximum number of continuous hours (duration) that modeled temperatures remained below 20°C in the 1%, 5%, and 10% additional flow reduction scenarios compared to the observed flow scenarios. These results indicate depths and areas of the run where water temperatures most often fell below 20°C in winters 2010–2011 and 2014–2015, but should be interpreted with caution because the model was only calibrated at one location in the middle portion of the run. Model results indicate that in Manatee Use Area 1 in the middle portion of the run temperatures typically remained above 20°C. Temperatures in Area 2 in the lower portion of the run were more dynamic, due to the effects of mixing from Lake George.

Threshold of significant harm

For both the 2010–2011 and 2014–2015 modeling scenarios, no additional hours below 20°C were estimated to occur in either winter period in Manatee Use Area 1 (toward the middle of the run) as a result of any of the additional flow reductions that were modeled (1%, 5%, or 10%). This was also true for the majority of the spring run. Modeling did indicate that under certain antecedent temperature conditions, a 1% reduction in flow could sometimes cause water temperatures in certain locations within the spring run to fall below 20°C for additional periods of time when compared with modeled temperatures for actual flows.

When modeling 2010–2011 flow conditions, with a 1% additional reduction in flow, the model estimated it could lead to at least 13 additional hours below 20°C in some parts of Manatee Use Area 2 (in the lower one-third of the run near Lake George) when compared to the modeled scenario of actual recorded flows (Figure 11). When the 2014–2015 flow conditions were modeled, the model estimated that a 1% additional reduction would not result in any additional hours below 20°C within Manatee Use Area 2, but could lead to at least 144 additional hours below 20°C slightly upstream of Manatee Use Area 2 (Figure 12).

Preventing a significant loss of warm-water habitat due to water use is a critical concern for the overall recovery of Florida manatees. Based on the results of the temperature modeling and consultation with resource agencies, additional spring flow reductions in excess of 5% (5.0 cfs) from the current condition would result in a significant decrease in warm-water habitat within the spring run and would be considered harmful to manatee, while an additional reduction of 0.5% (.5 cfs) would not cause significant harm to manatee or any other environmental values. Temperature modeling indicates that an additional 1% (1.0 cfs) flow reduction from current conditions may lead to changes in manatee habitat in downstream portions of the spring run even before the 5% (5.0 cfs) reduction that had been determined would result in significant harm (Appendix C). Therefore, the limit at which further consumptive use withdrawals would cause significant harm is between 2.5% (2.6 cfs) and 6.9% (7.1 cfs) of total reduction in spring flow from the no-pumping condition. The "no-pumping" condition represents the annual mean spring flow (based on data from 1984–2015) in the absence of groundwater withdrawals. To ensure the prevention of significant loss of warm water habitat at Silver Glen Springs due to water withdrawals, SJRWMD recommends a minimum flow regime that is at the lower end of these two values, allowing for no more than a 2.5% (2.6 cfs) reduction from the no-pumping condition.

Based on this allowable flow reduction, the recommended minimum flow for Silver Glen Springs is a mean flow of 99.6 cfs. This minimum flow regime will limit reductions in spring flow, due to water use, to no more than 0.5 cfs (0.4%) over 2010 conditions. 2010 was the most recent year that flow reduction estimates were available from the NDM groundwater model (see the "Hydrologic data analysis" section for more detail). The recommended flow regime, including recommended mean flow, are discussed in more detail in the next section.

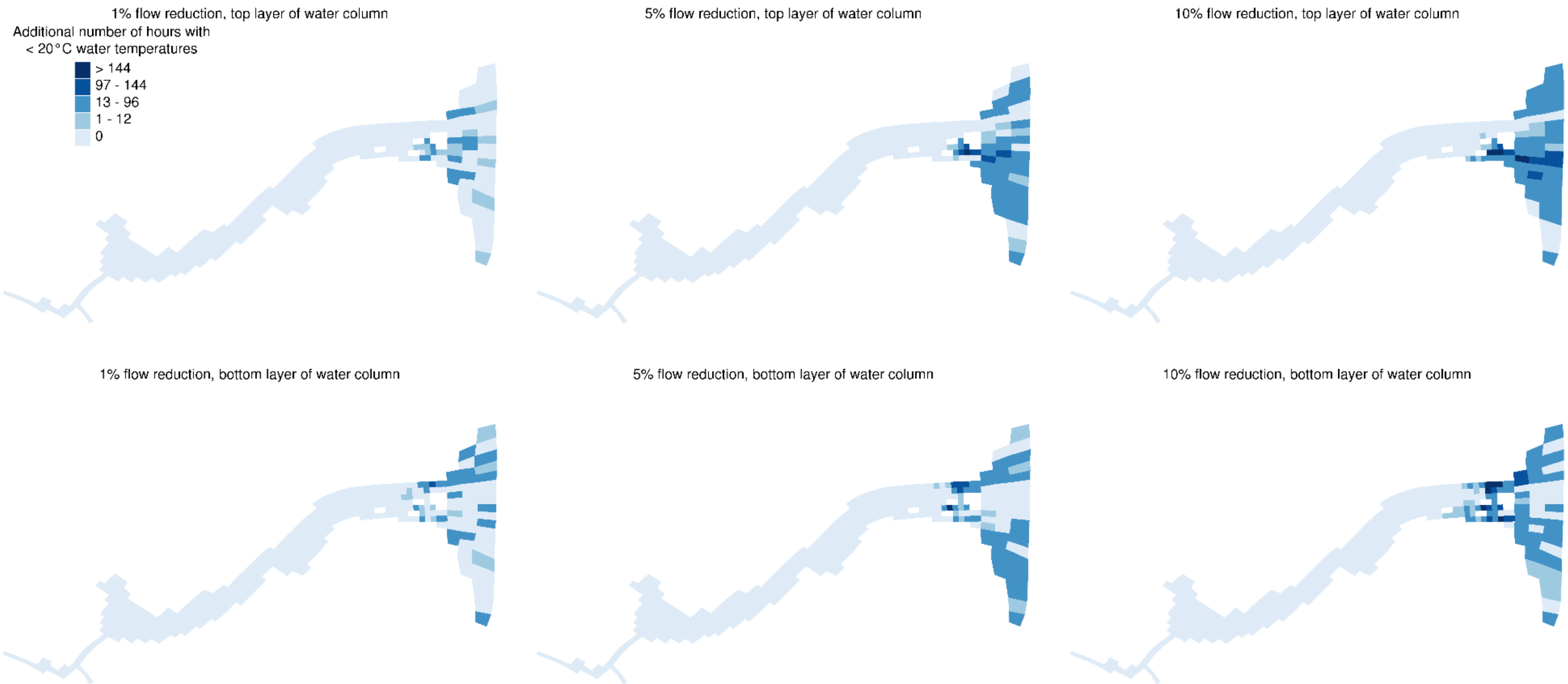

Figure 11. Maps of Silver Glen Springs Run showing the additional number of hours in each cell that water temperatures were below 20°C, beyond the number of hours that water temperatures were below 20°C in the observed flow scenario, for winter 2010–2011.

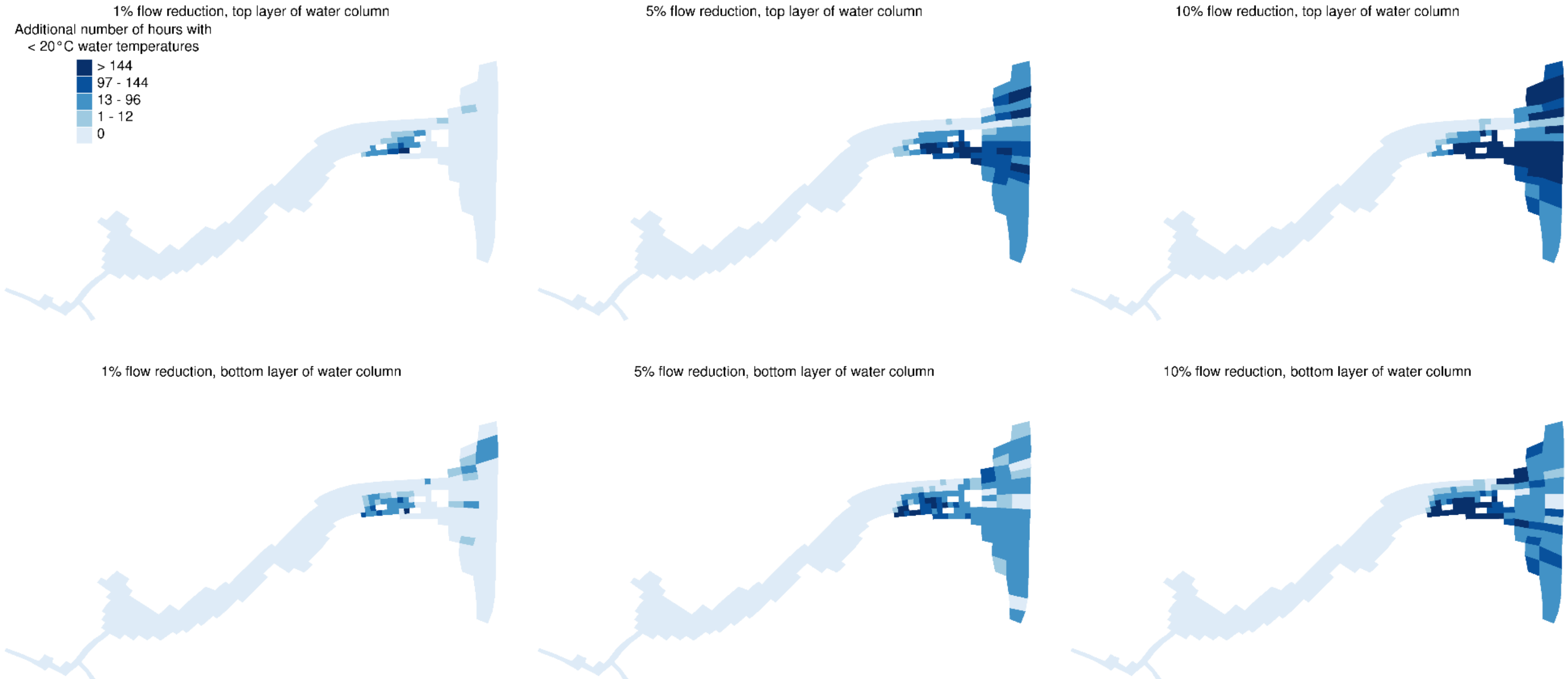

Figure 12. Maps of Silver Glen Springs Run showing the additional number of hours in each cell that water temperatures were below 20°C, beyond the number of hours that water temperatures were below 20°C in the observed flow scenario, for winter 2014–2015.

Figure 13. Maps of Silver Glen Springs Run showing the additional maximum number of continuous hours in each cell that water temperatures remained below 20°C, beyond the maximum number of continuous hours that water temperatures remained below 20°C in the observed flow scenario, for winter 2010–2011.

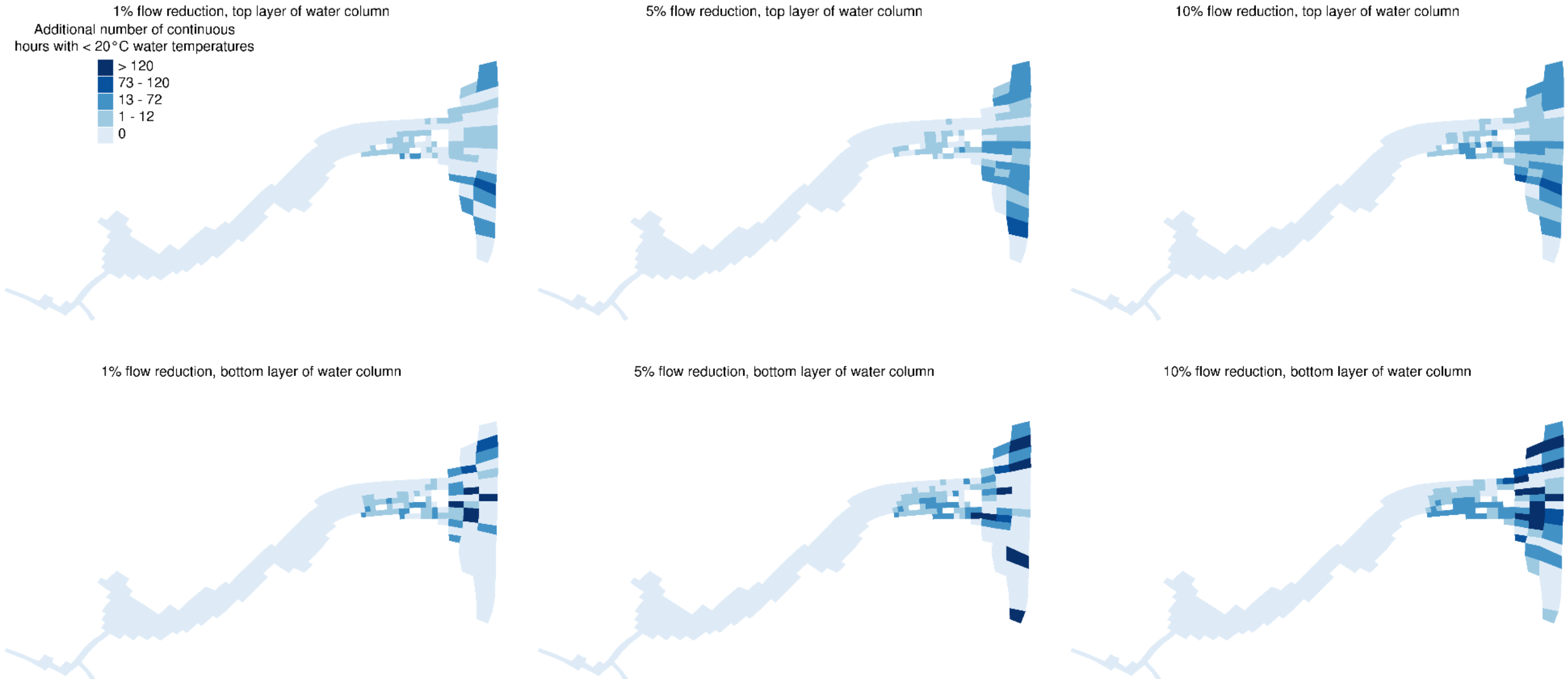

Figure 14. Maps of Silver Glen Springs Run showing the additional maximum number of continuous hours in each cell that water temperatures remained below 20°C, beyond the maximum number of continuous hours that water temperatures remained below 20°C in the observed flow scenario, for winter 2014–2015.

HYDROLOGIC DATA ANALYSIS

Spring flow and water level data

Spring flow data were obtained from U.S. Geological Survey (USGS) for site number 02236160, Silver Glen Springs near Astor (*https://waterdata.usgs.gov/nwis/inventory/?site_no=02236160&agency_cd=USGS)*. Manual measurements of spring flow were available from 1931–2017 (Table 1), and computed daily spring flows calculated from rating curves were available from 2002–2017. Details of the rating curves used to compute daily spring flows are available through USGS.

From this data, daily mean spring flows were calculated by averaging the available values for each day, monthly mean spring flows were calculated by averaging the daily means, and annual mean spring flows were calculated by averaging the monthly means (Figures 15-17) The overall mean spring flows for various periods were calculated by averaging the annual means (Table 2).

Spring flow and water level data for Silver Glen Springs (site number 02236160) and the St. Johns River at Astor (site number 02236125) were compared for 2002–2017, the period with computed daily measurements (Figures 18-20). All daily, monthly, and annual means were calculated as described above. Note the similarity between Silver Glen and St. Johns River water level fluctuations; since water level fluctuations at Silver Glen are significantly influenced by St. Johns River conditions, the minimum flows and levels recommended for Silver Glen include only spring flows.

Table 1. Summary of USGS spring flow data available for Silver Glen Springs, USGS site number 02236160.

Measurement	Period	N	Frequency
Manual	1931–1983	13	13 total measurements
Manual	1984–2002	41	1 to 4 measurements per year
Manual	2003–2017	154	6 to 12 measurements per year
Computed	2002–2017	5,192	daily

Table 2. Average annual mean spring flows for various periods at Silver Glen Springs.

Period	Mean
1931–2016	102.1 cfs
1984–2016	99.1 cfs
2002–2016	93.7 cfs
2011–2016	73 cfs

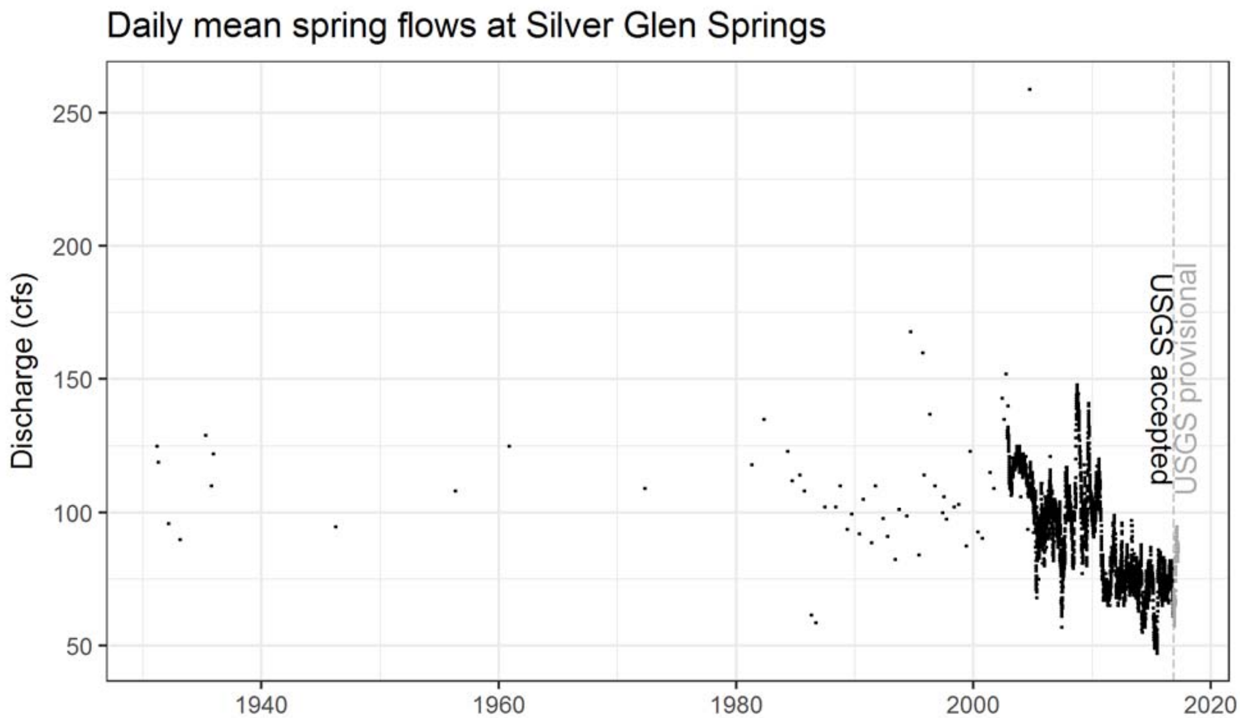

Figure 15. Daily mean spring flows at Silver Glen Springs.

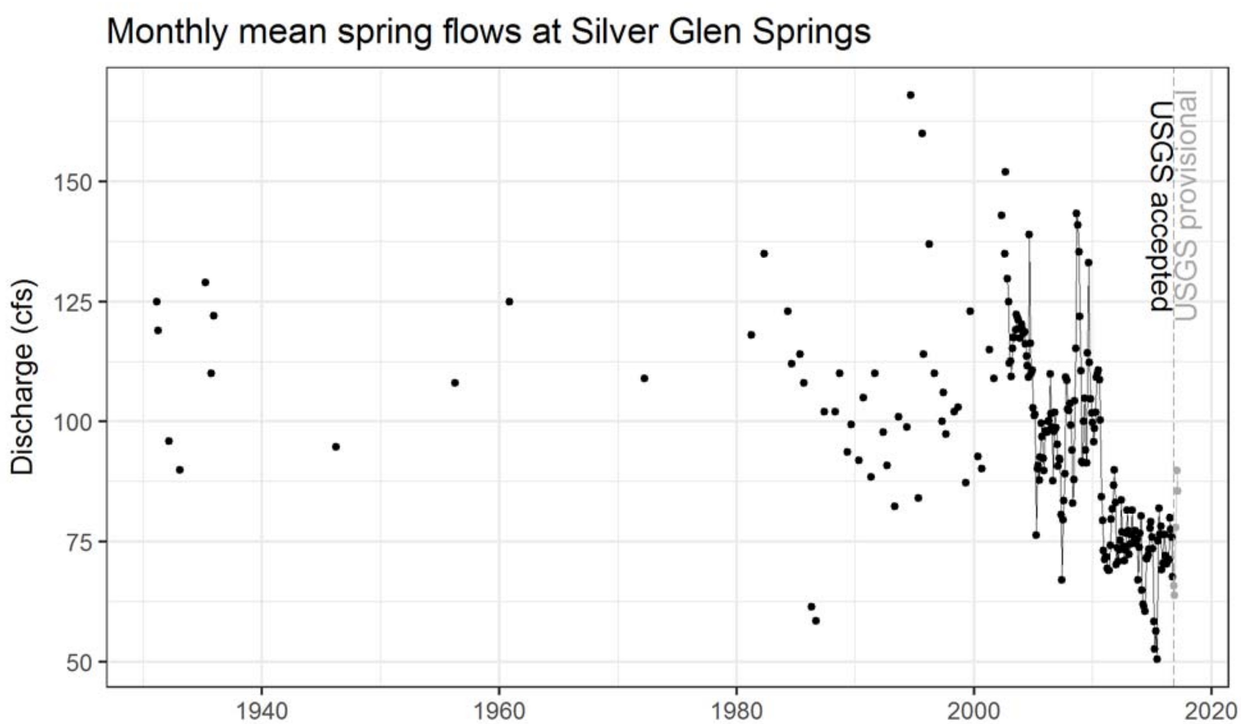

Figure 16. Monthly mean spring flows at Silver Glen Springs.

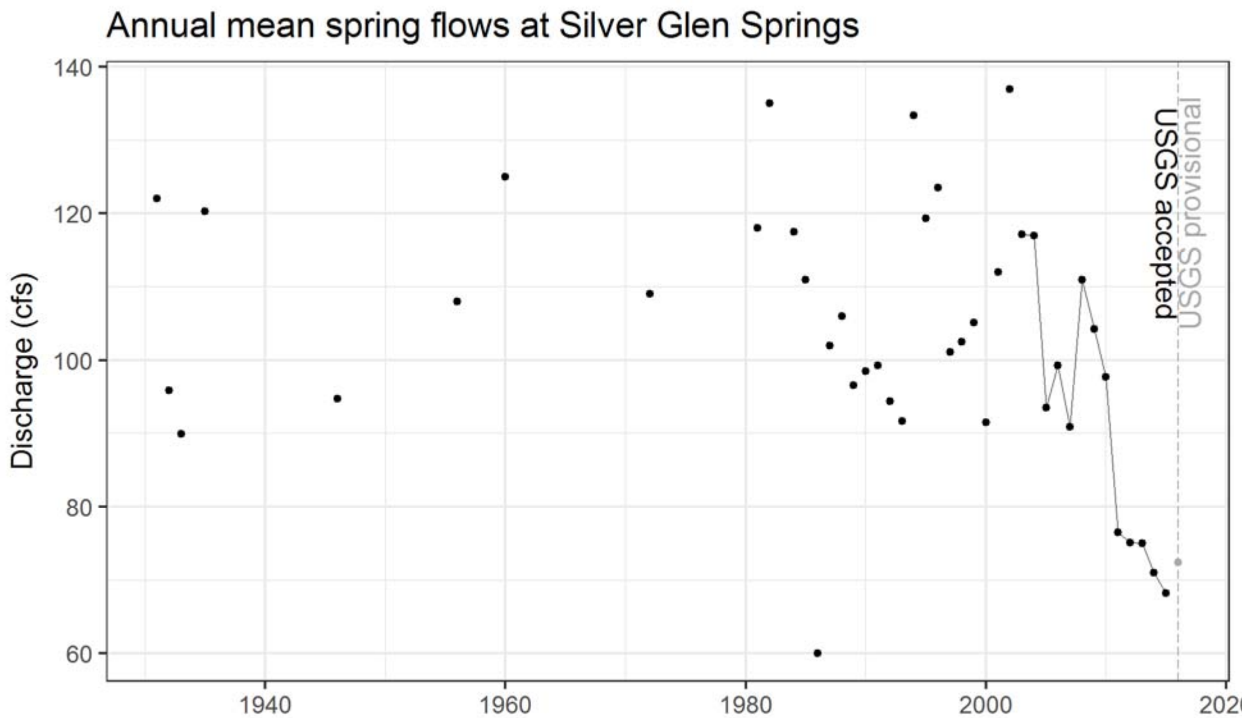

Figure 17. Annual mean spring flows at Silver Glen Springs.

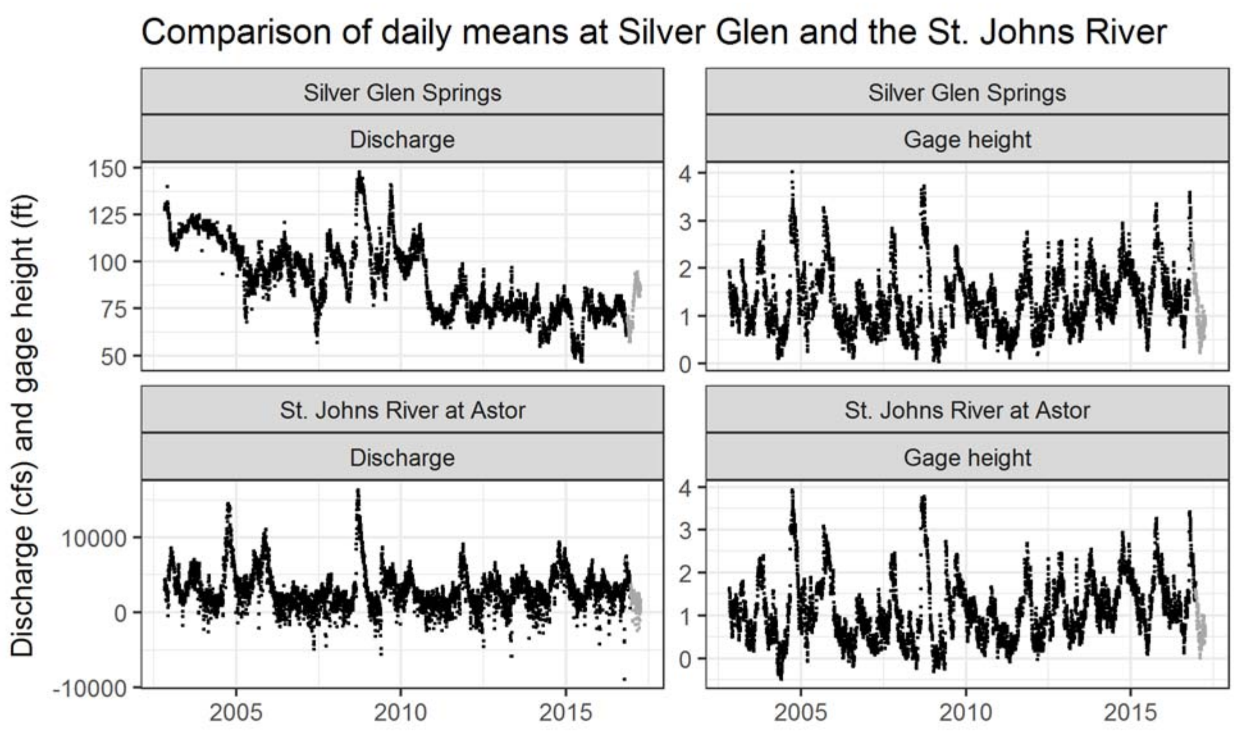

Figure 18. Daily mean flows and water levels at Silver Glen Springs and the St. Johns River at Astor. A discharge measurement of 259 cfs at Silver Glen on Sep. 28, 2004, was omitted to preserve plot detail. USGS provisional data is indicated in gray.

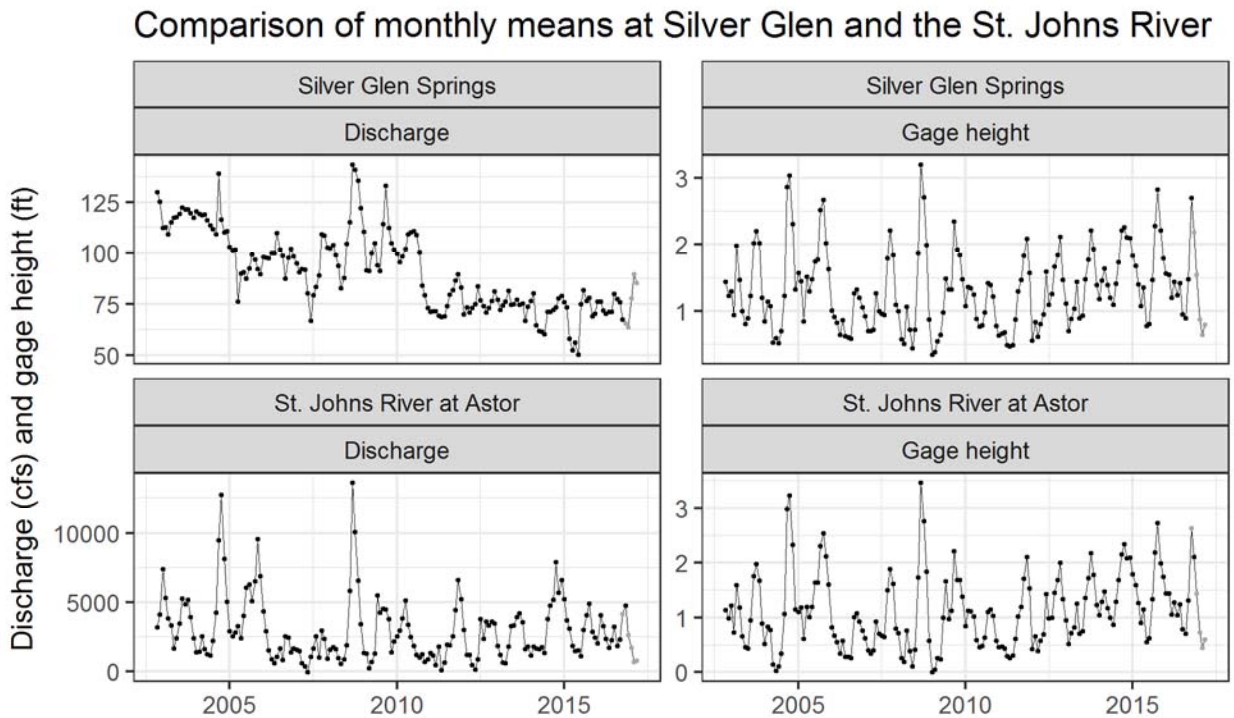

Figure 19. Monthly mean flows and water levels at Silver Glen Springs and the St. Johns River at Astor.

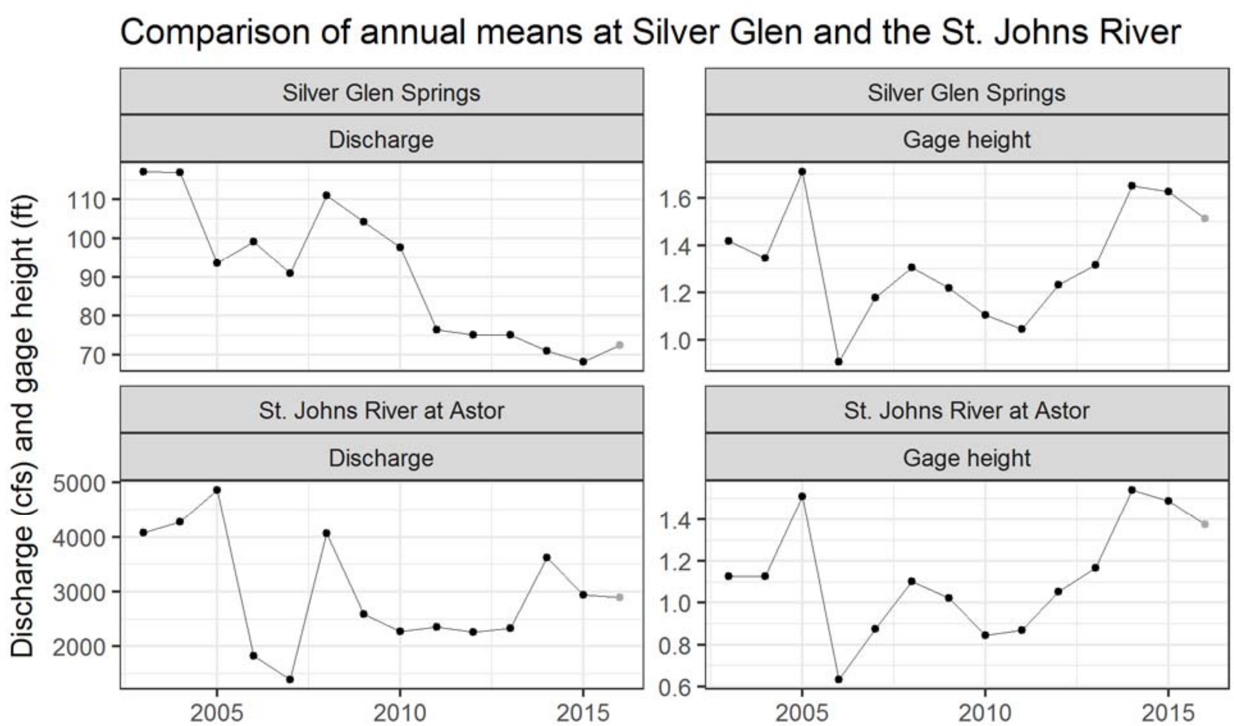

Figure 20. Annual mean flows and water levels at Silver Glen Springs and the St. Johns River at Astor.

It appears that a downward shift occurred in the spring flows after 2010 although the water elevations has been increasing since then. Unfortunately, there is not sufficient quality long-term flow data that can be used to determine whether this shift is permanent or a part of climatic cycle as discussed in Appendix B.

Because of uncertainties in flow dataset, a review of trends in water levels and flows on water bodies in the vicinity of Silver Glen were conducted. Appendix E of the MFL report includes the discussion about the Silver Glen springs flow trend and comparison with the nearby water bodies. Because setting MFL requires the use of best available information, the data collected after 1984 were used in the MFL data analysis.

GROUNDWATER PUMPING IMPACT ASSESSMENT

The amount of flow reduction due to groundwater withdrawals, was estimated using the best available tool, version 5 of the Northern District Model (NDMv5) regional groundwater model. This assessment involved the development of two synthetic datasets. A “no-pumping” dataset was generated to represent annual mean spring flows that would have occurred from 1984–2015 in the absence of groundwater use. A current or “Baseline Pumping” dataset was generated to represent annual mean spring flows that would have occurred from 1984–2015 if 2010 groundwater use occurred throughout the period of record. For Silver Glen Springs the 2010-pumping condition was the latest pumping and hydrologic condition to which the NDMv5 was calibrated. Therefore, it represents the best available information regarding the impact of current groundwater withdrawals on spring flow at Silver Springs. Pumping during more recent years has been less than the amount pumped in 2010. The modeling results estimate that Baseline Pumping (2010) reduces spring flow by an average of 2.1 cfs (1.4 million gallons per day) or 2.1% compared to the no-pumping condition (see Appendix B).

CALCULATION AND COMPARISON OF THE MINIMUM FLOW REGIME

Based upon the temperature analysis previously described and consultations with FWC regarding the effect of flow reduction on warm-water refuge habitat use by manatee, significant harm is anticipated to occur with reductions in spring flow due to groundwater pumping of greater than 5% (5.1 cfs).

Significant harm is not expected to occur with spring flow reductions due to groundwater pumping of 2.5% (2.6 cfs) or less (Appendix D). As detailed in the next section, most minimum flows that have been set for springs in Florida allow for a flow reduction ranging between 0% and 10%. Due to the use of Silver Glen Springs by a federally threatened species, the presence of other species of special concern and the cultural and recreational significance of this spring, the recommended minimum flow regime for Silver Glen Springs is a mean flow of 99.6 cfs. This represents a 2.5% reduction from the mean of the no-pumping dataset.

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 water resource values of interest at each spring and the measures needed to adequately protect them. Table 3 shows a summary of minimum flow definitions adopted in the *Florida Administrative Code* for Florida springs.

Some of the minimum flow definitions listed in Table 3 have been based, at least in part, on protecting winter warm-water habitat for manatees, including Blue Spring and De Leon Springs 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.

Table 3. Minimum flows adopted for Florida springs.

District or agency	System name	Adopted definition	Reference
St. Johns River WMD (SJRWMD)	Silver Glen Springs	97.5% of the no-pumping flow regime will be maintained[1]	--
SJRWMD	De Leon Springs	90.7% of the no-pumping flow regime will be maintained	40C-8, F.A.C.
SJRWMD	Blue Spring (Volusia County)	Flows will meet a specified mean flow that increases over time	40C-8, F.A.C.
SJRWMD	Wekiva River System springs	Flows will meet a specified mean flow and mean groundwater level	40C-8, F.A.C.
Southwest Florida WMD (SWFWMD)	Chassahowitzka River system and springs	97% of the natural flow regime will be maintained	40D-8, F.A.C.
SWFWMD	Homosassa River system and springs	97% of the natural flow regime will be maintained	40D-8, F.A.C.
SWFWMD	Weeki Wachee River system and springs	90% of the natural flow regime will be maintained, and flows will meet specified 5- and 10-year moving averages of annual mean and median flows	40D-8, F.A.C.
SWFWMD	Gum Slough Spring Run	94% of the natural flow regime will be maintained, and all flows will be above a minimum threshold	40D-8, F.A.C.
SWFWMD	Zolfo Springs	95% of flows will be above a minimum threshold	40D-8, F.A.C.
SWFWMD	Sulphur Springs	Flows will be above various minimum thresholds depending on downstream conditions	40D-8, F.A.C.
SWFWMD	Lower Alafia River system and springs	Flows will meet specified 5- and 10-year moving averages of annual mean and median flows	40D-8, F.A.C.
SWFWMD	Crystal Springs (on Hillsborough River)	Flows will meet specified 5- and 10-year moving averages of annual mean and median flows	40D-8, F.A.C.
Suwannee River WMD (SRWMD)	Manatee, Fanning, and Little Fanning Springs	90% of the historic flow regime will be maintained, and flows will meet an additional specific flow duration during winter months	40B-8, F.A.C.
SRWMD	Blue Spring (Levy County)	90% of the historic flow regime will be maintained	40B-8, F.A.C.

SRWMD	Wacissa River system springs	93.5% of the historic flow regime will be maintained	40B-8, F.A.C.
SRWMD	Upper Santa Fe River (including Santa Fe Spring)	Flows will meet the 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles on a specified flow duration curve	40B-8, F.A.C.
Florida Dept. of Environmental Protection (DEP)	Lower Santa Fe River springs	Flows will not be reduced by more than 8% compared to the median baseline[2] flow	62-42, F.A.C.
DEP	Ichetucknee River springs	Flows will not be reduced by more than 3% compared to the median baseline[2] flow	62-42, F.A.C.

[1]Flows will not be reduced by more than 2.5% of the no-pumping flow regime at Silver Glen Springs and 9.3% of the no-pumping flow regime at De Leon Springs. The no-pumping flow regime is similar in concept to the natural flow regime referenced by SWFWMD, the historic flow regime referenced by SRWMD, and the baseline flow regime referenced by DEP.

[2]The term "baseline" as used by the DEP refers to a historic hydrologic condition, not a condition adjusted for 2010 levels of groundwater pumping as used in this report for Silver Glen 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 Silver Glen Springs and whether they would be protected under the recommended minimum flow (Table 4). See Appendix A for the WRVs report for Silver Glen Springs.

Table 4. Summary of water resource values for Silver Glen Springs.

Water resource value	Relevance to Silver Glen Springs	Relevance to the minimum flow	Protected by minimum flow regime?
Recreation in and on the water	Recreation includes swimming, snorkeling, boating, fishing, and wildlife viewing	Decreased water velocities or water clarity could negatively affect recreation	Yes
Fish and wildlife habitat and the passage of fish	Provides habitat for many species of fish, macroinvertebrates, and other wildlife including manatees	Decreased water temperatures in winter, increased water temperatures in summer, and changes in water quality or chemistry could negatively affect wildlife	Manatee habitat is protected; the protection of some other species is unclear
Estuarine resources	Flow eventually reaches estuaries far downstream	The overall contribution of flow to estuaries is small	Yes
Transfer of detrital material	Flow transports material downstream	Decreased water velocities could negatively affect detrital transfer	Yes

Maintenance of freshwater storage and supply	Flow indicates the condition of the aquifer potentiometric surface	Maintaining flows at the main vents may help maintain both water levels and flows at the nearby sand boils	Yes
Aesthetic and scenic attributes	Many visitors come to simply view the spring and nearby sand boils	Decreases in water velocity and water clarity in the spring run, and water levels near the sand boils could negatively affect aesthetics, including the preservation of archaeological records	Yes
Filtration and absorption of nutrients and other pollutants	N/A	N/A	N/A
Sediment loads	Flow moves sediment downstream	Decreased velocities could lead to increased sedimentation	Yes
Water quality	Wildlife and vegetation depend on water quality	Changes in water quality could negatively affect wildlife and vegetation	Yes
Navigation	The spring run is navigable for boaters, although large boats scrape the bottom	Flow does not maintain water levels in the spring run, the SJR does	N/A

MINIMUM FLOW STATUS ASSESSMENT

The current status of spring flow at Silver Glen Springs and the status at the 20-year planning horizon were assessed using the NDM5 (SJRWMD 2016). Based on the results of the assessment, Silver Glen Springs is not in recovery or prevention status. The recommended minimum flow is currently being achieved and is expected to be maintained throughout the 20-year planning horizon. The details of the assessment are available in the SJRWMD compliance memo (SJRWMD 2017).

CONCLUSIONS

Silver Glen Springs is an important refuge for a federally threatened species and harbors other species of special concern. According to FWS, FWC, and other researchers, the potential loss of warm-water habitat over the next several decades is one of the most serious concerns for the continued recovery of Florida manatee populations. Water temperature modeling for Silver Glen Springs indicates that reductions in spring flow can lead to decreases in water temperatures in parts of the spring run, including areas used by manatees.

The estimated reduction in spring flow at Silver Glen Springs that has occurred due to consumptive use is approximately 2.1 cubic feet per second (cfs). Based on temperature modeling, this reduction in flow leads to temperature decreases in parts of the spring run where manatees seek refuge in winter, and an additional reduction of 1% (total ~3.1 cfs) leads to further temperature decreases. The minimum flow regime is intended to allow no significant decrease in warm-water manatee habitat due to water withdrawals.

Based on the results of the temperature modeling and consultation with resource agencies, additional spring flow reductions in excess of 5% (5.0 cfs) from the current condition would result in a significant decrease in warm water habitat within the spring run and would be considered harmful to manatee, while an additional reduction of 0.5% (.5 cfs) would not cause significant harm to manatee or any other environmental values. Temperature modeling indicates that at an additional 1% (1.0 cfs) flow reduction from current conditions may lead to changes in manatee habitat in downstream portions of the spring run, which is less than the 5% (5.0 cfs) reduction that had been determined would result in significant harm. Therefore, the limit at which further consumptive use withdrawals would cause significant harm is between 2.5% (2.6 cfs) and 6.9% (7.1 cfs) of total reduction in spring flow from the no-pumping condition. To ensure the prevention of a significant loss of warm water habitat for the federally threatened Florida manatee at Silver Glen Springs, due to water withdrawals, SJRWMD recommends a minimum flow regime that is at the lower end of these two values, allowing for no more than a 2.5% (2.6 cfs) reduction from the no-pumping condition. The "no-pumping" condition represents the annual mean spring flow (based on data from 1984–2015) in the absence of groundwater withdrawals. Based on this allowable reduction, the recommended minimum flow for Silver Glen Springs is a mean flow of 99.6 cfs. Based on a 2.5% (2.6 cfs) allowable flow reduction, under the recommended minimum flow, and a current condition of 2.1% (2.1 cfs) reduction, there is an additional allowable reduction in flow of 0.4% (0.5 cfs), prior to the minimum flow not being met.

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 must remain at or below a 2.5% (2.6 cfs) reduction from the no-pumping flow regime. Silver Glen Springs is surrounded primarily by the Ocala National Forest. An evaluation of the expected water use demands during the 20-year planning horizon in the area that as the potential to influence flow at the spring indicates that water use is not expected to cause the spring flow to drop below the proposed MFL during this 20-year period. Therefore, neither a recovery nor prevention strategy is required.

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APPENDIX A: WATER RESOURCE VALUES AT SILVER GLEN SPRINGS

OVERVIEW

This appendix considers the impact of the recommended minimum flow regime on the water resource values at Silver Glen Springs. The recommended minimum flow regime for Silver Glen Springs is a mean flow of 99.6 cfs. This represents a 2.5% reduction from the mean of the “no-pumping” flow time series. The no-pumping condition represents the annual mean spring flow (based on data from 1984–2015) as though no groundwater pumping occurred each year.

RECREATION IN AND ON THE WATER

Recreation at Silver Glen Springs includes swimming and snorkeling in the spring pool and fishing, boating, and wildlife viewing in the spring run. Reductions in spring flow could negatively affect recreation, especially due to decreases in water velocities. With decreased water velocities, more particles may settle out of the water column and onto the bed of the spring run. Additionally, decreased water velocities may allow more algae to persist in the water column and to attach to aquatic vegetation, and more detritus may settle onto the bed of the spring run. Decreases in water velocities have been associated with higher algal 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). In other spring-fed systems of Florida, cover by filamentous ma~~i~~croalgae has been found to vary inversely with water velocities, while not varying significantly with water quality parameters (King 2014).

Water velocity

The Environmental Fluid Dynamics Code (EFDC) model by Stewart (2017; Appendix C) was used to estimate water velocities in Silver Glen Springs Run in four locations during four winter periods representing a variety of stage and flow conditions (Table A-1, Figure A-1). Two flow scenarios were evaluated – a scenario with the actual spring flows recorded during that period, a 1% reduction from recorded flows, and a 10% reduction from recorded flows. The model divided the water column into six layers of equal depth, and results are shown for the second-from-bottom layer (Figure A-2). Differences in mean velocities in the second-from-bottom layer between the scenario with recorded flows and the flow reduction scenarios were less than 0.001 m/s after reducing the flow by 1%, and less than 0.005 m/s after reducing the flow by 10% except in 2014–2015 near the mouth (Table A-2 and Table A-3).

Further discussion of particle transport is in the “Sediment loads” section of this appendix.

Table A-1. Descriptions of time periods evaluated with the EFDC model.

Model period	Mean flow	Mean stage (NAVD88)	Summary
Winter 2008 - 2009	109 cfs	-0.09 ft	Average flow / low stage
Winter 2009 - 2010	101 cfs	0.18 ft	Average flow / high stage
Winter 2010 - 2011	73 cfs	-0.1 ft	Low flow / low stage
Winter 2014 - 2015	70 cfs	0.19 ft	Low flow / high stage

Figure A-1. Locations where water velocities were estimated at Silver Glen Springs. Mean daily and seasonal velocities were calculated for each group of model cells near the pool, below the pool, near the middle of the run, and near the mouth.

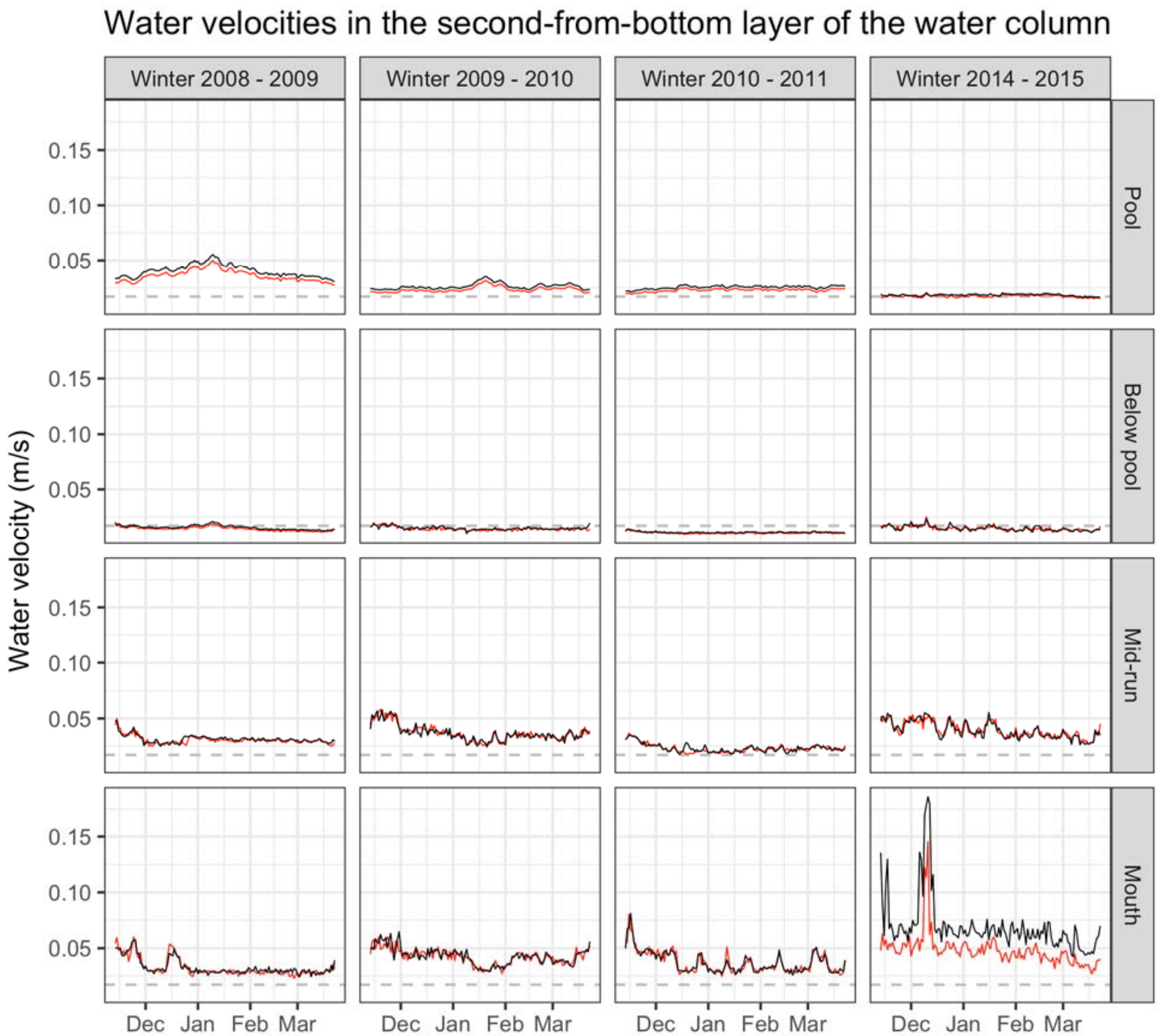

Figure A-2. Water velocities in the second-from-bottom layer of the water column, with recorded flows (black) and a 10% reduction from recorded flows (red). The gray dashed line indicates a velocity of 0.017 m/s, the minimum velocity required for the transport of the mean particle size found in the thalweg of Silver Glen Springs Run.

Table A-2. Water velocities in the second-from-bottom layer of the water column, with recorded flows and a 1% reduction from recorded flows.

Location	Winter period	Mean (m/s), scenario with recorded flows	Mean (m/s), scenario with 1% flow reduction	Difference (m/s)
Pool	2008 - 2009	0.0403	0.0399	0.0004
	2009 - 2010	0.0262	0.0260	0.0003
	2010 - 2011	0.0254	0.0251	0.0003
	2014 - 2015	0.0184	0.0182	0.0002
Below pool	2008 - 2009	0.0155	0.0154	0.0001
	2009 - 2010	0.0148	0.0146	0.0002
	2010 - 2011	0.0111	0.0110	0.0001
	2014 - 2015	0.0147	0.0148	-0.0001
Mid-run	2008 - 2009	0.0313	0.0305	0.0008
	2009 - 2010	0.0367	0.0365	0.0002
	2010 - 2011	0.0231	0.0232	-0.0001
	2014 - 2015	0.0392	0.0400	-0.0008
Mouth	2008 - 2009	0.0326	0.0332	-0.0005
	2009 - 2010	0.0427	0.0429	-0.0001
	2010 - 2011	0.0370	0.0370	0.0000
	2014 - 2015	0.0693	0.0720	-0.0028

Table A-3. Water velocities in the second-from-bottom layer of the water column, with recorded flows and a 10% reduction from recorded flows.

Location	Winter period	Mean (m/s), scenario with recorded flows	Mean (m/s), scenario with 10% flow reduction	Difference (m/s)
Pool	2008 - 2009	0.0403	0.0360	0.0043
	2009 - 2010	0.0262	0.0234	0.0029
	2010 - 2011	0.0254	0.0227	0.0027
	2014 - 2015	0.0184	0.0173	0.0011
Below pool	2008 - 2009	0.0155	0.0142	0.0013
	2009 - 2010	0.0148	0.0143	0.0005
	2010 - 2011	0.0111	0.0105	0.0006
	2014 - 2015	0.0147	0.0146	0.0001
Mid-run	2008 - 2009	0.0313	0.0306	0.0007
	2009 - 2010	0.0367	0.0369	-0.0002
	2010 - 2011	0.0231	0.0228	0.0003
	2014 - 2015	0.0392	0.0397	-0.0005
Mouth	2008 - 2009	0.0326	0.0323	0.0004
	2009 - 2010	0.0427	0.0423	0.0004
	2010 - 2011	0.0370	0.0369	0.0001
	2014 - 2015	0.0693	0.0480	0.0212

FISH AND WILDLIFE HABITAT AND THE PASSAGE OF FISH

Silver Glen Springs serves as habitat for many species of fish (at least 36 species recorded), macroinvertebrates (at least 65 taxa recorded), and other wildlife (Phelps et al. 2006; Walsh et al. 2009; Wetland Solutions, Inc. 2010; Mattson 2013~~; UF 2014~~). Florida manatees use the spring as a warm-water refuge, and warm-water habitat for Florida manatees was the focus of the minimum flows and levels determination for the spring. Two other species of special interest include the Silver Glen Springs cave crayfish and striped bass.

The Silver Glen Springs cave crayfish (*Procambarus attiguus*) is endemic to Silver Glen Springs and was first identified around 1990 (Franz et al. 1994). The Silver Glen Springs cave crayfish is a close neighbor and likely relative of the big-cheeked cave crayfish (*P. delicatus*) endemic to nearby Alexander Springs. Cave crayfish generally forage on detritus that enters through the vents of cave systems, and the transport of detritus as well as maintenance of water quality and prevention of contamination are thought to be important considerations for the protection of cave crayfish (USFS 2011). In 2011, the FWS recommended listing both *P.attiguus* and *P.delicatus* under the Endangered Species Act, but the listing has not yet been finalized (76 *Federal Register* at 59858, 2011).

Striped bass (*Morone saxatilis*), a large game fish, historically spawned in the Ocklawaha River and lived throughout the St. Johns River system, which is at the extreme southern end of the striped bass range (Jay Holder of FWC, pers. comm., 2017). The construction of the Kirkpatrick Dam and Rodman Reservoir on the Ocklawaha River in the 1960s removed the flow velocities, distance, and/or access needed for striped bass spawning. Since then, FWC and federal hatcheries have stocked striped bass in the St. Johns River. Striped bass rely on springs along the river for thermal refuge during summer, as optimal temperatures for striped bass are typically below 25°C while water temperatures in the St. Johns River are typically above 25°C between May and September.

Silver Glen Springs is one of the most important, most-used thermal refuges for striped bass in the St. Johns River system, followed by Croaker Hole Spring (Jay Holder of FWC, pers. comm., 2017). Interestingly, striped bass do not use Blue Spring or some of the other springs in the St. Johns River system as thermal refuges, possibly due to lower flow velocities and/or dissolved oxygen limitations. Although populations have recently declined, historically thousands of striped bass would gather around the main spring vents in summer. Striped bass that occur at Silver Glen Springs typically occupy the deeper vent that is marked off-limits to swimmers, with some striped bass even remaining at the spring vents in winter. Interestingly, striped bass do not use Blue Spring or some of the other springs in the St. Johns River system as thermal refuges, possibly due to lower flow velocities and/or dissolved oxygen limitations (Jay Holder of FWC, pers. comm., 2017). Striped bass in the St. Johns River system typically eat small fish and crustaceans.

Water temperature

The impacts of flow reductions on winter water temperatures in the spring run and the maintenance of warm-water habitat for manatees were described in the main report. Depending on winter conditions, reductions in flow have the potential to reduce water temperatures in parts of the spring run, including portions of the areas that manatees typically use as warm-water refuges. Water temperatures near the mouth of the spring run were more sensitive to reductions in flow compared to water temperatures closer to the spring vents.

Summer water temperatures were not modeled, although summer water temperatures are important for striped bass. Summer water temperatures near the mouth of the spring run are expected to be more sensitive to reductions in flow compared to water temperatures closer to the spring vents. Though striped bass mainly gather near the spring vents, they may benefit from foraging downstream at night and/or as temperatures allow (Jay Holder of FWC, pers. comm. 2017).

Salinity

Silver Glen Springs has higher salinities than Lake George, with about a 0.34 ppt change occurring between the head pool of the spring and Lake George (Stewart 2017). In winter, at the interface between the spring run and Lake George, the warmer water from the spring tends to remain toward the top of the water column as it spreads out into Lake George, and the colder water from Lake George tends to remain toward the bottom of the water column as it intrudes up the spring run. This results in higher salinity toward the top of the water column, despite the fact that higher-salinity water has a greater density. In summer, the opposite may occur and may be more pronounced, with colder, higher-salinity spring water remaining toward the bottom of the water column. Summer salinity may be important for the blue crab fishery in Lake George.

The EFDC model was used to estimate salinities in Silver Glen Springs Run and part of Lake George during winter 2014–2015, as salinity appeared to have the greatest sensitivity to spring flow during that year compared to the other three years considered. Two flow scenarios were evaluated – a scenario with the actual spring flows recorded during that time period, a 1% reduction from recorded flows, and a 10% reduction from recorded flows. The model divided the water column into six layers of equal depth, and results are shown for the top and bottom layers of the water column (Figure A-3).

Results indicate that salinities decrease at the interface between the spring run and Lake George when spring flows are reduced. The differences appear to be within the known salinity tolerance ranges for the fish species found at Silver Glen Springs (Table A-4) and for blue crabs, although blue crab salinity tolerances are complicated and vary by life history stages, sex, acclimation conditions, and water temperature (Jacoby 2012).

Figure A-3. Model-estimated salinity in the top and bottom layers of the water column. Salinity under the scenario with recorded flows is shown on the left (green), and changes in salinity with 1% and 10% reductions from recorded flows are shown on the right (pink).

Table A-4. List of fish species found at Silver Glen Springs and known salinity tolerances. Compiled from Phelps (2006), Walsh et al. (2009), Wetland Solutions, Inc. (2010), and Mattson (2013)~~, UF (2014), and SJRWMD (2008)~~.

Species	Common name	Salinity range (ppt)
Amia calva	Bowfin	0 – 7
Anguilla rostrata	American eel	0.3 - 29.9
Caranx hippos	Crevalle jack	0 – 43
Dasyatis sabina	Atlantic stingray	.09 – 41
Elassoma okefenokee	Okefenokee pygmy sunfish	
Elops saurus	Ladyfish	0 – 35
Erimyzon sucetta	Lake chubsucker	0.6 - 14.4
Fundulus chrysotus	Golden topminnow	0 – 5
Fundulus seminolis	Seminole killifish	0 - 7.3
Gambusia holbrooki	Mosquitofish	0 – 30
Gobiosoma bosc	Code goby	
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 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
Lutjanus griseus	Grey snapper	
Menidia beryllina	Inland silverside	
Micropterus salmoides	Largemouth bass	0 - 17.5
Morone saxatilis	Striped bass	
Mugil cephalus	Striped mullet	0 - 39.0
Notemigonus crysoleucas	Golden shiner	1.3 - 10.7
Notropis cummingsae	Dusky shiner	
Notropis harperi	Redeye chub	
Notropis petersoni	Coastal shiner	
Oreochromis aureus	Blue tilapia	
Poecilia latipinna	Sailfin molly	0 – 33
Pterygoplichthys disjunctivus	Vermiculated sailfin catfish	
Strongylura marina	Atlantic needlefish	0 - 23.0
Syngnathus scovelli	Gulf pipefish	

Importance of water quality for other macroinvertebrates

In 2005, researchers noted two rare snails from Silver Glen Springs (Shelton 2005). The first, *Aphaostracon pycnum*, is endemic to Silver Glen Springs and Alexander Springs, while the second, *Floridobia floridana*, is endemic to 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. Snails of the genera Aphaostracon 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.

ESTUARINE RESOURCES

Water quality in Lake George is strongly influenced by inputs from higher-salinity and higher-conductivity springs, to the extent that the lake supports a blue crab fishery as well as other estuarine and marine species. Conductivity is actually higher in Lake George than in the St. Johns River either upstream or a short distance downstream of the lake, due to inputs from springs. Other springs flowing into to Lake George (with a variety of salinities) include Salt, Juniper, Sweetwater, Fern Hammock, and Morman Branch Springs as well as unidentified springs. As groundwater in the Ocala National Forest generally flows from the west and southwest toward Lake George (Adamski and Knowles 2001), the groundwater contributing areas of these springs may overlap or nearly overlap with the groundwater contributing area of Silver Glen Springs.

Spring flow from Silver Glen Springs eventually reaches estuaries far downstream and may help maintain the gradient from freshwater to saltwater in the St. Johns River. With a typical salinity of 1.0 ppt and a mean flow of approximately 100 cfs from Silver Glen Springs, and a typical salinity of 11 ppt and a mean flow of 5,700 cfs for the lower St. Johns River at Jacksonville (Spechler 1995) and with the recommended minimum flow only allowing a reduction of 0.5 cfs above baseline conditions (or 2.6 cfs above the no-pumping condition) the effect on the far downstream estuarine resources this small reduction in flow would not be significant.

TRANSFER OF DETRITAL MATERIAL

Spring flow transports detrital material downstream. Reductions in spring flow could lead to reductions in the transfer of detrital material downstream, due to decreased water velocities in the spring run. Water velocities are discussed in the “Recreation in and on the water” section and in the “Sediment loads” section. Spring flow helps remove periphyton – a mixture algae, cyanobacteria, heterotrophic microbes, and detritus – from submerged aquatic vegetation through the rubbing motion of leaves. Based on the small changes in velocities, reductions in flow due to the recommended minimum flow are not expected to have a significant impact on transport of particulate organic matter in the spring run.

MAINTENANCE OF FRESHWATER STORAGE AND SUPPLY

Spring flow depends on the level of the potentiometric surface, which changes over the short- and long-term due to trends in rainfall and groundwater use (Adamski and Knowles 2001). The long-term maintenance of spring flow may indicate that the relationship between the potentiometric surface and the surficial aquifer is being maintained, on average, over the long-term, along with associated freshwater storage and supply in the Floridan aquifer. However, other factors may complicate this relationship over time, such as changes in the number or size of springs vents (Ryder 1985).

Maintaining long-term spring flow may also help maintain the structural integrity of the underwater cave system below Silver Glen Springs. The cave system consists of cavernous rooms and numerous passages, including one room measuring over 100 ft in both length and width (Figure A-4) (Hutcheson 1990; Morris unknown date). The cave system has developed along the contact between the Hawthorn Formation and Ocala Limestone Formation, and the entrances and "maze" portion of the cave are in sediments from the Hawthorn Formation (Franz et al. 1994).

Figure A-4. The cave system below Silver Glen Springs.

AESTHETIC AND SCENIC ATTRIBUTES

The clarity of the water, along with an abundance of wildlife, may be the most prominent aesthetic and scenic attributes of Silver Glen Springs. The sandboil springs and cultural resources are also prominent aesthetic attributes. Although reductions in spring flow of sufficient magnitude could potentially affect these attributes, the relatively small increase in spring flow reduction allowable under the proposed MFL for Silver Glen Springs (.5 cfs) is not expected to significantly impact these attributes.

Water clarity

Water clarity, or turbidity, is determined by the amount of suspended particles and amount/type of dissolved solids in water. Algal growth in the water column, as well as human and wildlife activities or hydrologic conditions that suspend or re-suspend particles, affect turbidity. At Silver Glen Springs, turbidity in the lower portion of the spring run can be dramatically affected by intrusion of water from Lake George. Water from Lake George typically contains more suspended particles and dissolved solids darker in color than water from Silver Glen Springs.

The EFDC model was used to estimate mean percent spring water vs. percent water from Lake George as a rough comparison of turbidity in the spring run in winter 2014–2015. Two flow scenarios were evaluated — a scenario with the actual spring flows recorded during that time period, a 1% reduction from recorded flows, and a 10% reduction from recorded flows. The model divided the water column into six layers of equal depth, and results are shown for the top and bottom layers of the water column (Figure A-5).

Mean percent spring water was very high (>99%) in the upper two-thirds of the run, with progressively lower percent spring water out into Lake George. In the lower one-third of the run, higher percent spring water was estimated toward the top of the water column. The scenario with a 1% reduction from recorded flows did not lead to more than a 1% reduction in mean percent spring water in any of the model cells. The scenario with a 10% reduction from recorded flows did lead to higher reductions in mean percent spring water, mainly near the interface of the spring run and Lake George.

Mean daily percent spring water was also very stable in the upper two-thirds of the spring run, where the decrease in percent spring water between the scenario with recorded flows and a 1% or 10% reduction from recorded flows was less than 5% on all days in winter 2014–2015. In the lower one-third of the run, days with decreases of more than 5% were more numerous toward the top of the water column (Figure A-6). The threshold of 5% was chosen to illustrate differences between the scenarios, and may not be ecologically significant.

In summer, warmer and more turbid water from Lake George may intrude farther up the spring run and for longer periods of time than shown in these winter scenarios. At some point, higher percentages of darker water from Lake George may begin to negatively affect the growth of submerged aquatic vegetation or other aspects of the spring such as visitor experiences. However, with a 1% reduction in spring flow, mean differences in percent spring water were not greater than 1% in any of the model cells. With a 10% reduction in spring flow, the number of days with at least 5% less spring water than the scenario with recorded flows was greater than 20 days in parts of the lower one-third of the spring run.

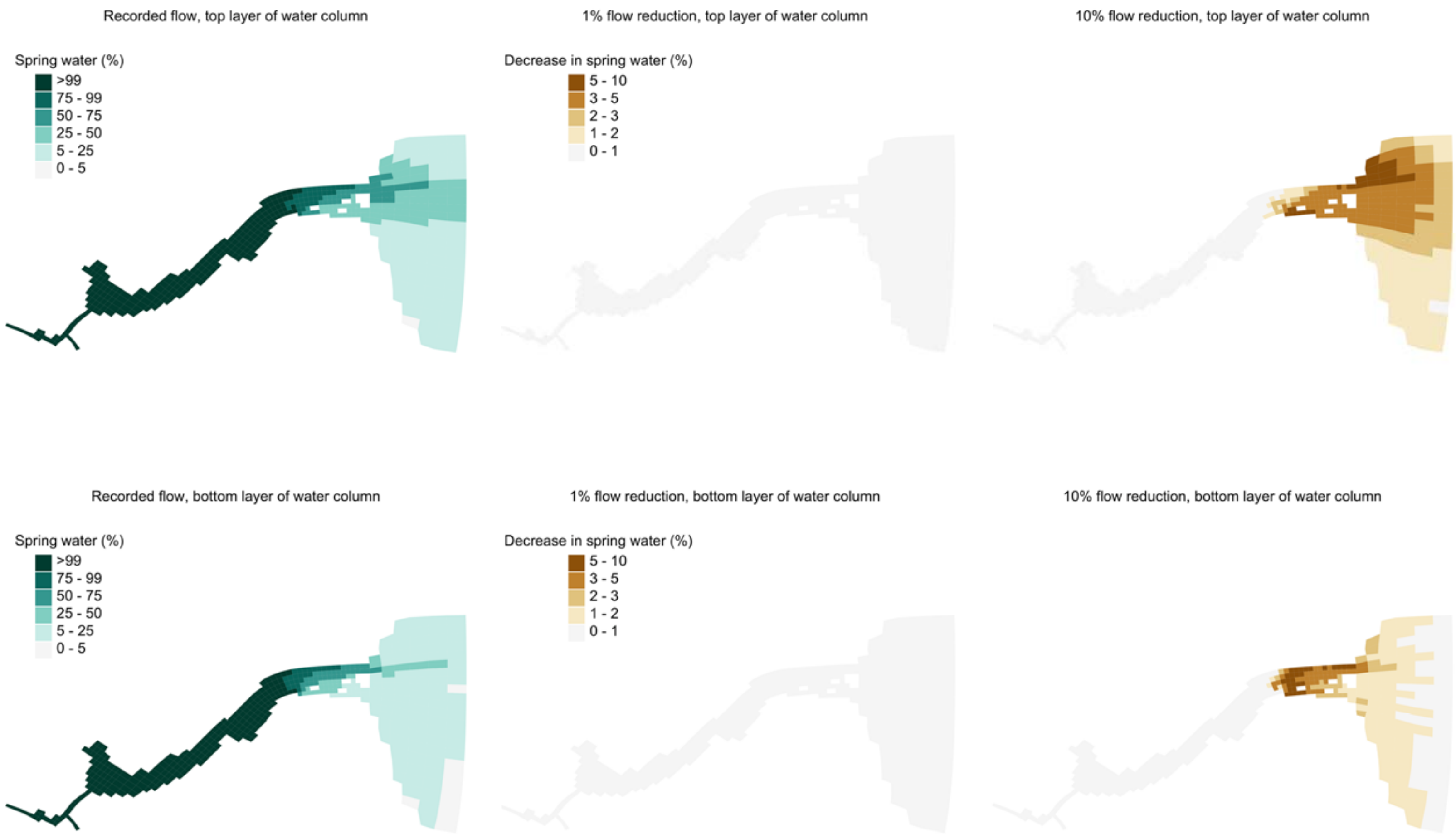

Figure A-5. Model-estimated percent spring water in the top and bottom layers of the water column. Percent spring water under the scenario with recorded flows is shown on the left (teal), and changes in percent spring water with 1% and 10% reductions from recorded flows are shown on the right (yellow).

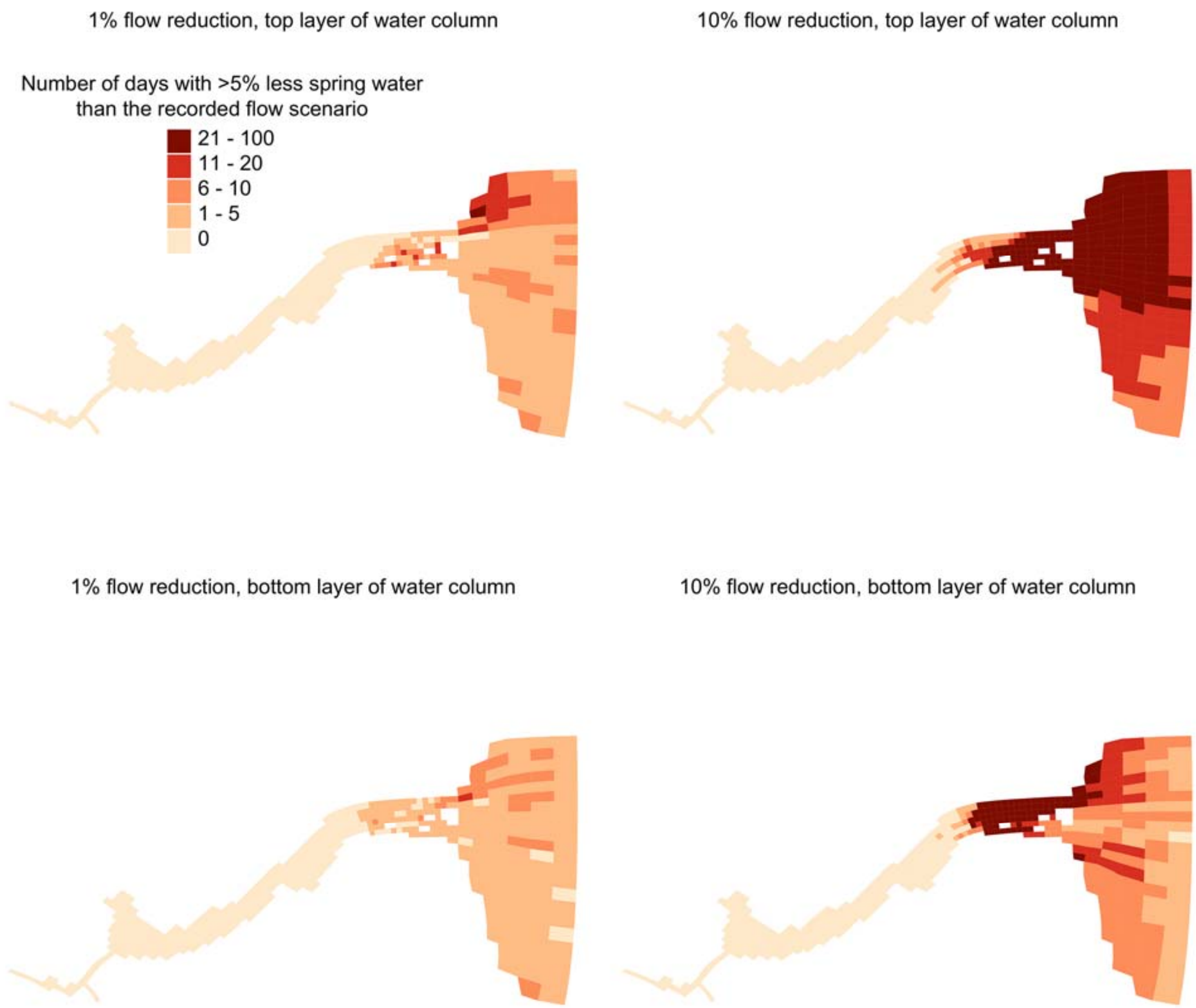

Figure A-6. Number of days in each model cell where the decrease in percent spring water was at least 5% between the recorded flow scenario and scenarios with a 1% or 10% reduction from recorded flows.

Sandboil springs

Featured in the film *The Yearling*, based on Marjorie Kinnan Rawlings' novel by the same name, the Sandboil Springs at Silver Glen Springs provide a unique visitor experience. The aesthetic quality of the sandboil springs lies in the magnitude, or robustness, of the boiling activity. Water quality samples at Silver Glen Springs indicate that water flowing from the sandboil springs is slightly warmer and has slightly lower salinity than water discharging from the main vents at Silver Glen Springs (Stewart 2017). These differences indicate that some, but not all, of the water flowing from these two areas are of different origins. The volume of the different water sources contributing to the sandboil springs is currently unclear, but evidence suggests that a relationship between the discharge of the main vents and discharge at the sandboil springs does exist.

At a higher elevation than the main vents, the Sandboil Springs may act as a "canary in the coal mine" for the effect of reduced discharge at Silver Glen Springs. To better understand the relationship between the discharge from the main vents and discharge from the sandboil springs, we conducted a study to attempt to gage, both qualitatively and quantitatively, the connection of these two areas. A pressure transducer was deployed to measure the depth of water in the pool of the sandboil springs. The depth of the pool was a surrogate for the amount of discharge emanating from the boils. Along with depth measurements, a video recorder was placed to monitor the degree of activity of the sandboils. The goal of this study was to correlate the magnitude of discharge with the aesthetic interest created by the bubbling sand.

Above approximately 0.3 ft NAVD88, water elevation of the sandboil springs area is influenced by the water elevation of Silver Glen Springs Run. During the duration of this study, elevations of Silver Glen Springs Run dropped below this level on Dec. 26, 2016 (Figure A-7). After this point, a disconnect between the sandboils and Silver Glen Springs Run water elevations is clearly defined. Four distinct time periods were chosen in an attempt to distinguish a pattern of sandboil activity during this time period of disconnect. These time periods were chosen because they provided instances of the greatest swings in both spring flow from the main vents and water elevations from Silver Glen Springs Run.

Results of this study show that below 0.3 ft NAVD88, water elevations in the sandboil springs remained relatively constant despite fluctuations in both Silver Glen Springs flow and Silver Glen Springs Run water elevations. Although the elevations remained constant, changes in Silver Glen Springs discharge does appear to affect boiling activity of the Sandboil springs. A 15% increase, followed by a decrease of the same amount, in spring discharge occurred from Jan. 4–Jan. 27, 2017. During lower discharge periods (62–63 cfs; Jan. 4, Jan. 20, and Jan. 27, 2017), the sandboils exhibited a more erratic, disjoined bubbling of smaller diameter (Figure A-8). Conversely, images recorded during the highest discharge (73 cfs; Jan. 10, 2017) show sandboils with a more consistent, uniform bubbling of larger diameter. Changes in boil activity indicate that the sandboil springs are sensitive to reductions in discharge from Silver Glen Springs. Routinely measuring the flow of the sandboil springs, increasing the duration of this study, and improving camera placement, would provide better insight to the spring flow and boil activity relationship.

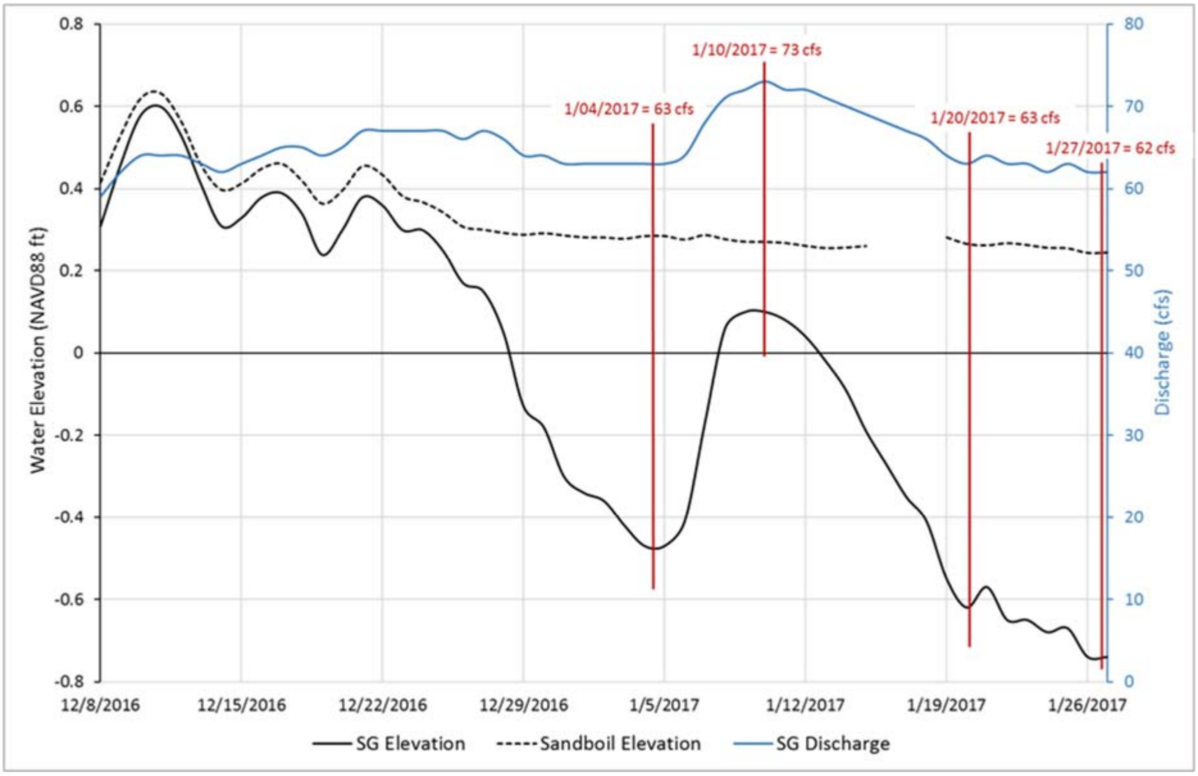

Figure A-7. Silver Glen Springs Run and Sandboil Springs pool water elevations with Silver Glen Springs discharge.

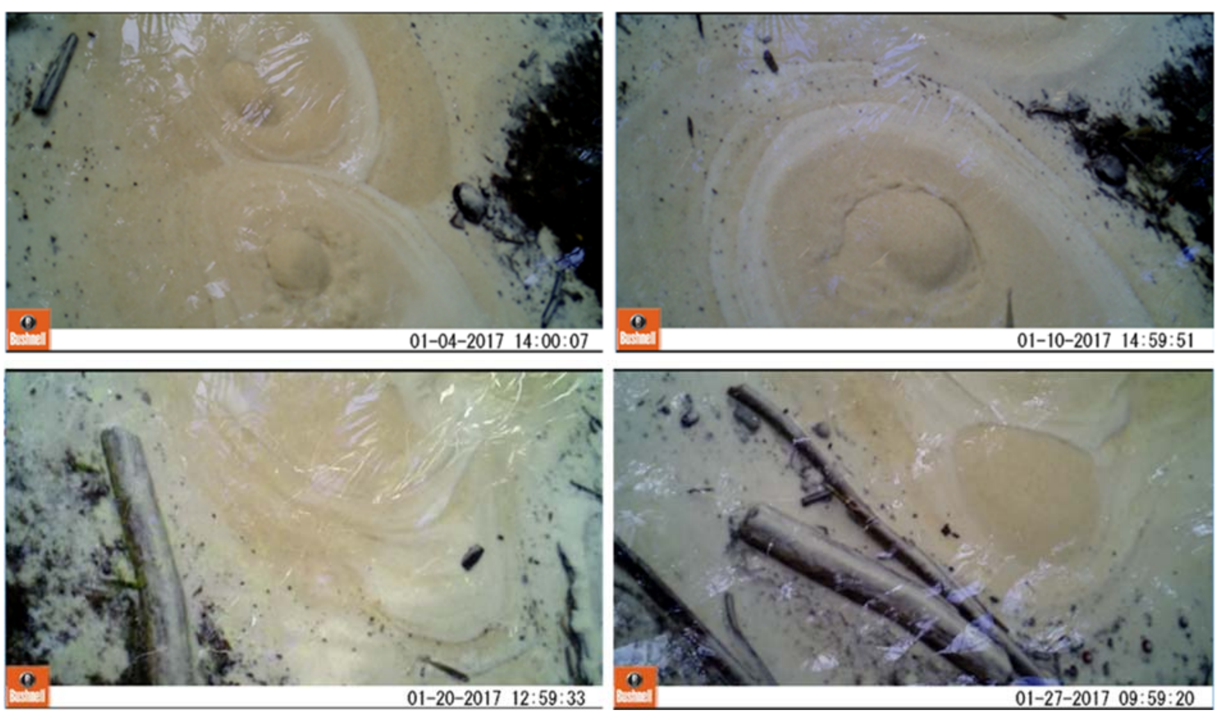

Figure A-8. Sandboil Springs video images.

Cultural resources are a well-known and important aspect of Silver Glen Springs. Thousands of years of human occupation have resulted in a wide range of anthropogenic deposits, from organic-free sands to well-preserved organic wetsite deposits (Randall et al. 2011). Permanently saturated soils have allowed excellent preservation of shell, bones, seeds, nuts, and other organic artifacts due to anaerobic conditions that inhibit microbial decomposition. Water levels around Silver Glen Springs and along Silver Glen Springs Run are crucial for maintaining long-term saturation of waterlogged soils. Periodic or prolonged de-watering destroy artifacts and organic remains (Ray Willis, pers. comm., 2016).

Water levels in the spring run are dictated by the St. Johns River stage and will therefore not be affected by a decrease in discharge. But, below water elevations of 0.3 ft NAVD88 the pool water elevation at the sandboil springs is controlled by discharge from the sandboils. Reductions in discharge from the main vents at Silver Glen Springs that decrease discharge and water levels at the sandboil springs risk cultural resource degradation in that area. The relatively small reduction in spring flow allowable under the proposed MFL for Silver Glen Springs (.5 cfs) is not expected to significantly impact the sandboil springs.

FILTRATION AND ABSORPTION OF NUTRIENTS AND OTHER POLLUTANTS

This water resource value was not considered relevant for the determination of minimum flows and levels at Silver Glen Springs.

SEDIMENT LOADS

Sediment is introduced into the spring run by runoff, wind, and by reverse flows when wind and tidal effects push water upstream into Silver Glen Springs Run. The bed of the spring run currently includes more dark muck or silt than in past decades, in areas where whitish or tan limestone and sand were previously exposed (pers. comm. with visitors, USFS employees, and FWC employees 2016–2017). Such changes in bed substrate alter the appearance of the spring run and could alter submerged aquatic vegetation dynamics as well. The factors leading to sediment inputs, including erosion from uphill, are being addressed, but it may not be possible to eliminate the inputs entirely. Spring flow helps maintain the movement of particles down the spring run, and periods of high spring flow can also help re-suspend previously settled particles and export them from the spring run.

Particle size fraction analysis was performed to determine the mean particle size (D_{50}) of sediments in the thalweg of Silver Glen Springs Run. The results show a mean particle size of 0.228 mm, which would require minimum critical velocities of approximately 1.7 cm/s for transport and 20 cm/s for entrainment in the water column (Figure A-9Figure A-11). Model results for the scenario with actual recorded flows indicate that velocities of at least 1.7 cm/s were continuously maintained in at least 25% of Silver Glen Springs Run during all modeling periods, while entrainment velocities were rarer. Model results for the scenario with a 10% reduction from recorded flows indicate that velocities fell below 1.7 cm/s in more than 75% of Silver Glen Springs Run on three separate occasions in winter 2010–2011 (Figure A-12 Figure A-13). The 0.5 cfs additional reduction in flow from current conditions allowable under the recommended minimum flow is not expected to cause significant harm from a reduction in sediment transport in the system.

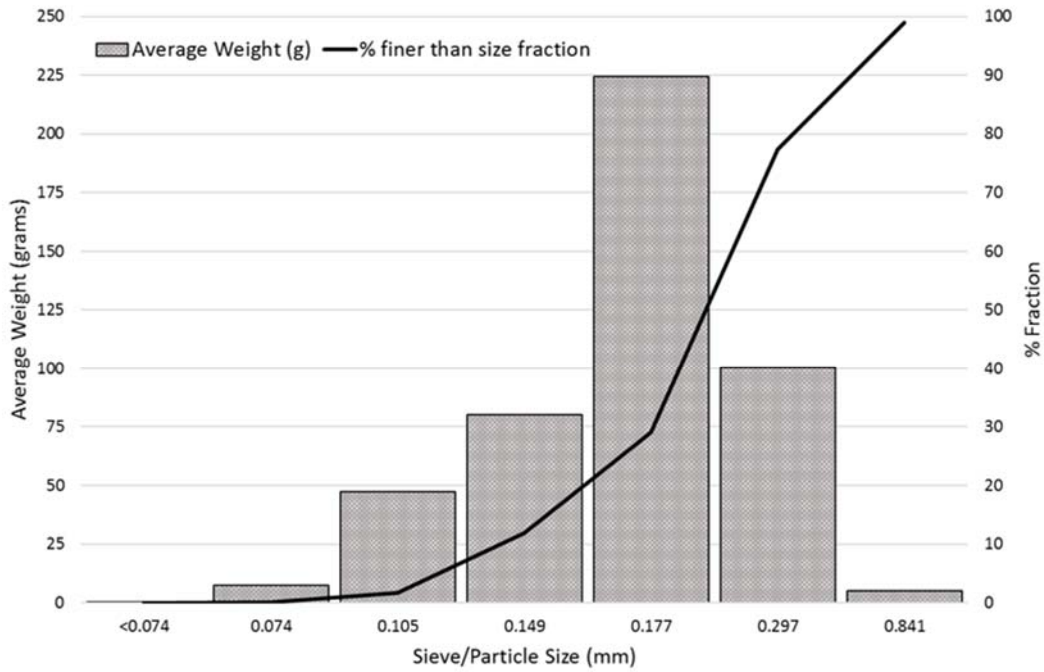

Figure A-9. Percent fraction and average weight per particle size retained on screen, excluding organics (shell and bone).

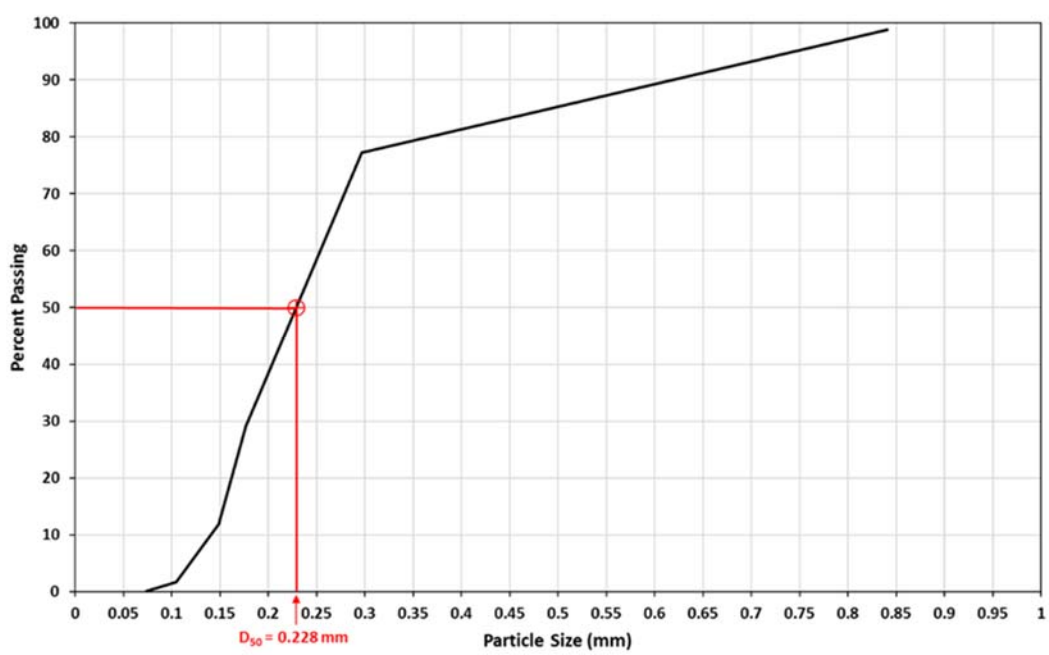

Figure A-10. D50 particle size.

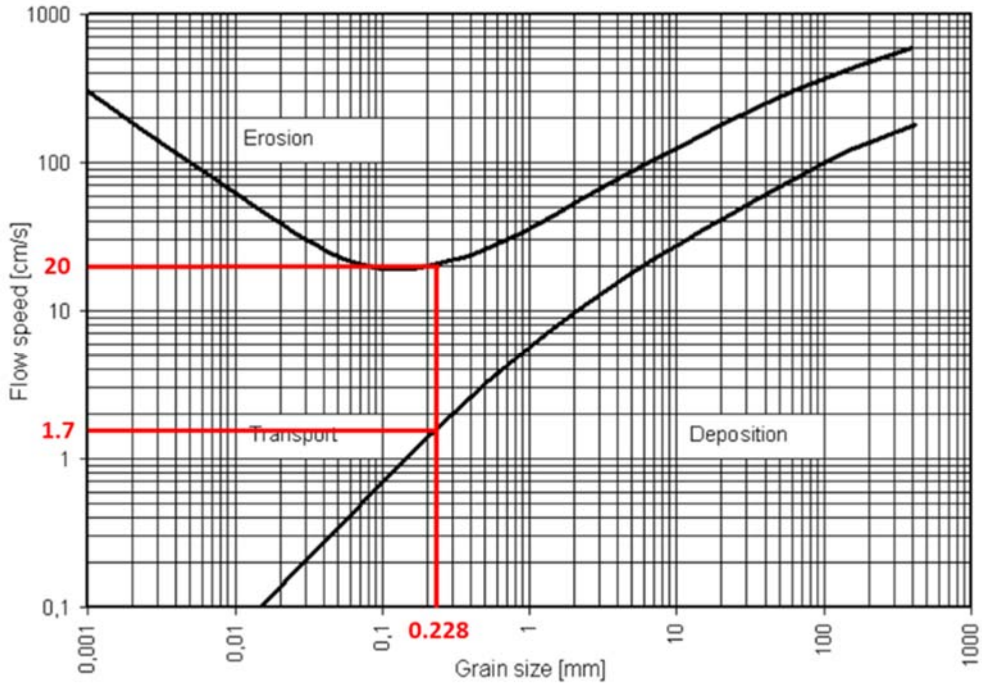

Figure A-11. Hjulstrom curve indicating minimum flows for transport and entrainment of Silver Glen Springs Run D50 particle size.

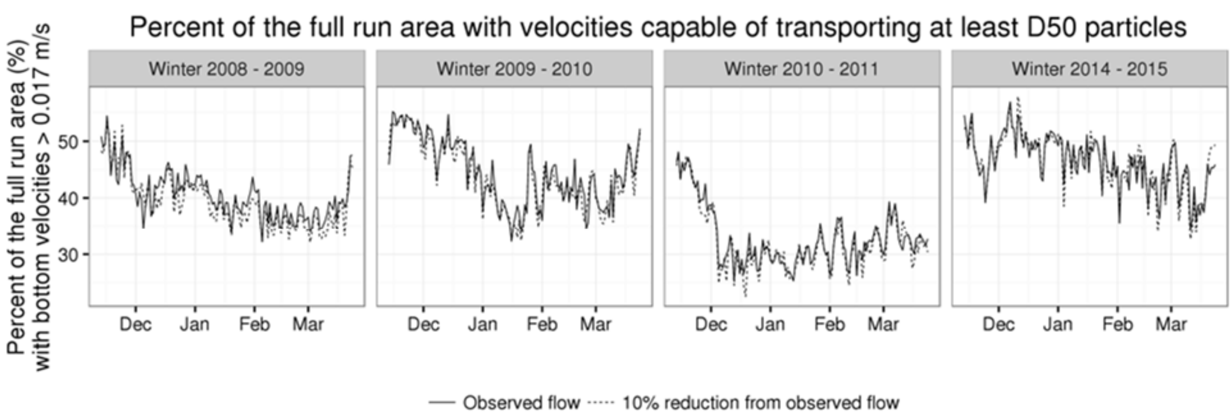

Figure A-12. Percent of run area with D50 transport velocities greater than .017 m s-1 under the scenario with recorded flows and the scenario with a 10% reduction from recorded flows.

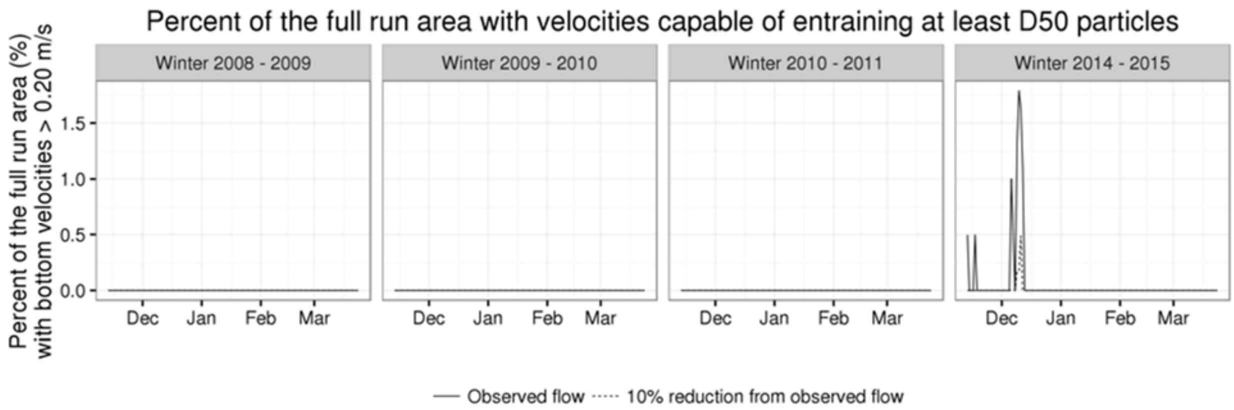

Figure A-13. Percent of the run area with D50 entrainment velocities greater than 0.20 m s-1 under the scenario with recorded flows and the scenario with a 10% reduction from recorded flows.

WATER QUALITY

Springs flows between late 2010–2016 were much lower than average spring flows prior to 2010. ~~(As of March 2017, spring flows at Silver Glen Springs may be rising again, according to provisional USGS data).~~ This has provided an opportunity to compare water quality parameters between the two time periods, and to see whether any associations between spring flow and water quality parameters are apparent (Figure A-14). Further data quality checks and application of statistical tests are needed.

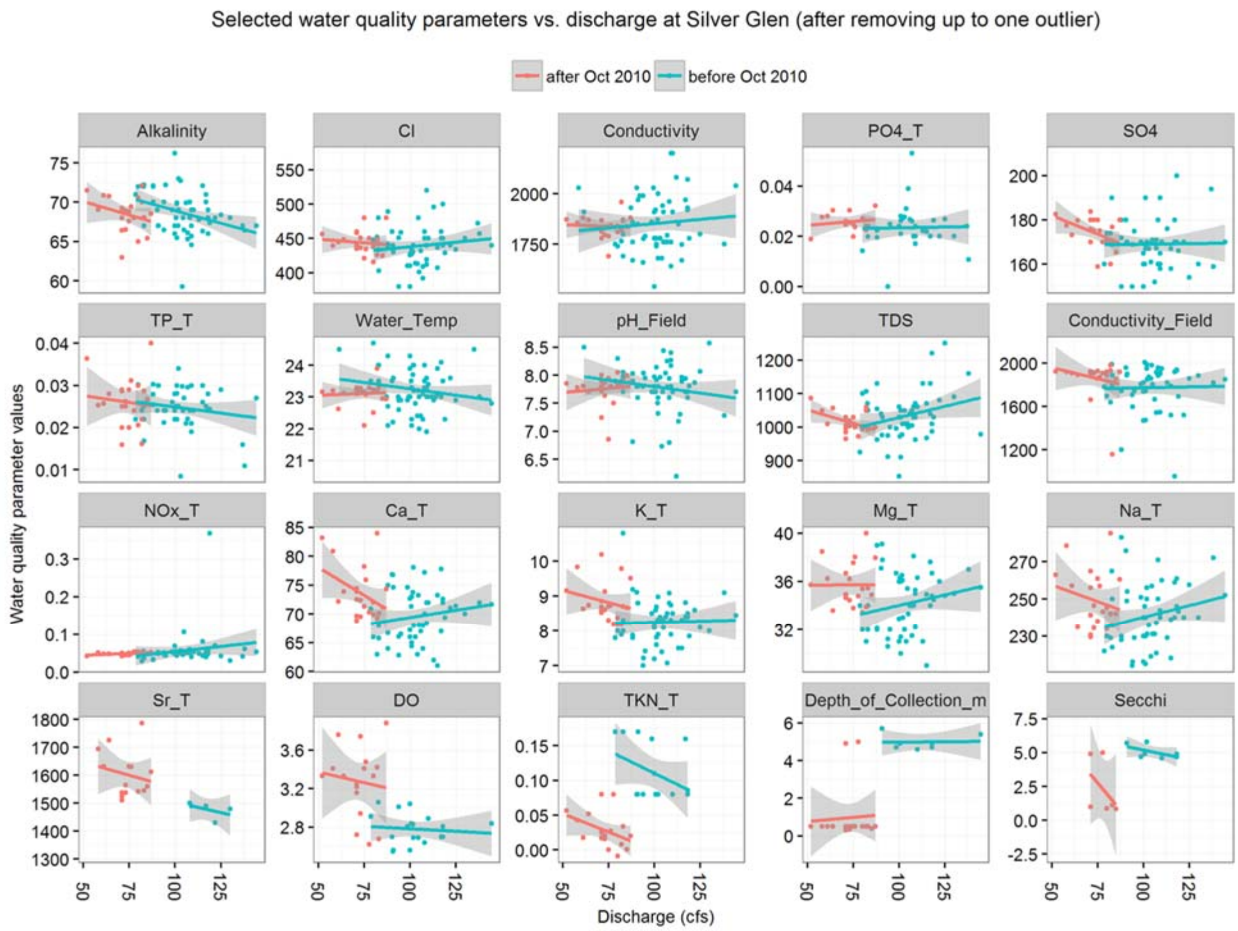

Figure A-14. Spring flow vs. selected water quality parameters at Silver Glen Springs. Further data quality checks and application of statistical tests are needed for this data. The trendlines shown do not necessarily indicate statistically significant trends.

NAVIGATION

Navigation was not considered a relevant water resource value for determining the minimum flow regime at Silver Glen Springs. Navigation at Silver Glen Springs generally depends on water levels rather than spring flow, and water levels in the spring run are determined more by stage in the St. Johns River than spring flow. The spring run is generally navigable for boaters using canoes, kayaks, jet skis, and motor boats, although boat propellers often scrape the bed of the run in shallower areas.

Appendix B: 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 Silver Glen springs.

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 baseline conditions

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

DATA REVIEW

Silver Glen Springs is located in Marion County. The Upper Floridan aquifer is the source of discharge for most springs in this region, including Silver Glen Springs. Silver Glen Springs is classified as a first magnitude spring (SJRWMD 2017).

Spring flow data were obtained from USGS for site number 02236160, Silver Glen Springs near Astor *(https://waterdata.usgs.gov/nwis/inventory/?site_no=02236160&agency_cd=USGS)*. Manual measurements of spring flow were available from 1931–2017 (Table B-1). Computed daily spring flows calculated from rating curves were available from 2002–2017. Details of the rating curves used to compute daily spring flows are available through USGS.

From this data, daily mean spring flows were calculated by averaging the available values for each day, monthly mean spring flows were calculated by averaging the daily means, and annual mean spring flows were calculated by averaging the monthly means (Figure B-1Figure B-3). The overall mean spring flows for various periods were calculated by averaging the annual means (Table B-2).

Spring flow and water level data for Silver Glen Springs (site number 02236160) and the St. Johns River at Astor (site number 02236125) were compared for 2002–2017, the period with computed daily measurements (Figure B-4–Figure B-6). All daily, monthly, and annual means were calculated as described above. As shown in the figures, there is clear similarity between Silver Glen and St. Johns River water level fluctuations. Since water level fluctuations at Silver Glen are significantly influenced by St. Johns River conditions, the minimum flows and levels recommended for Silver Glen include only spring flows.

Table B-1. Summary of USGS spring flow data available for Silver Glen Springs, USGS site number 02236160.

Measurement	Period	N	Frequency
Manual	1931 - 1983	13	13 total measurements
Manual	1984 - 2002	41	1 to 4 measurements per year
Manual	2003 - 2017	154	6 to 12 measurements per year
Computed	2002 - 2017	5192	daily

Table B-2. Average annual mean spring flows for various periods at Silver Glen Springs.

Period	Mean
1931 – 2016	102.1 cfs
1984 - 2016	99.1 cfs
2002 - 2016	93.7 cfs

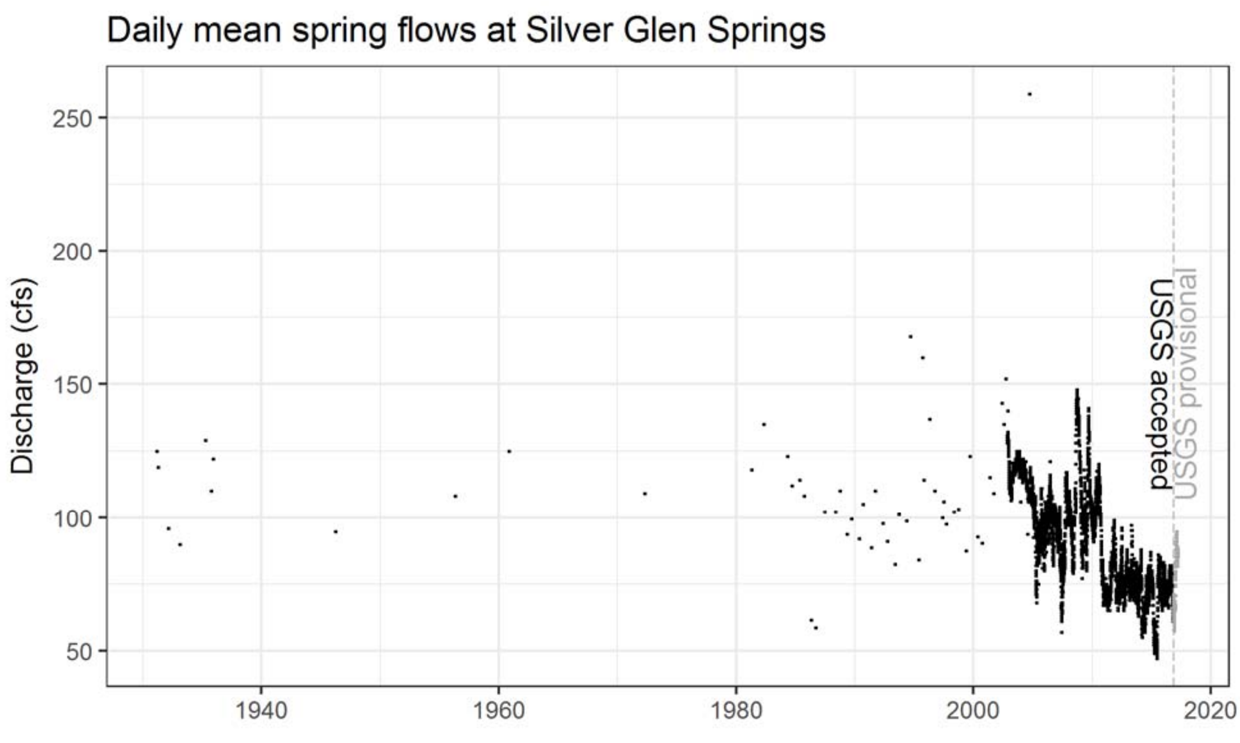

Figure B-1. Daily mean spring flows at Silver Glen Springs.

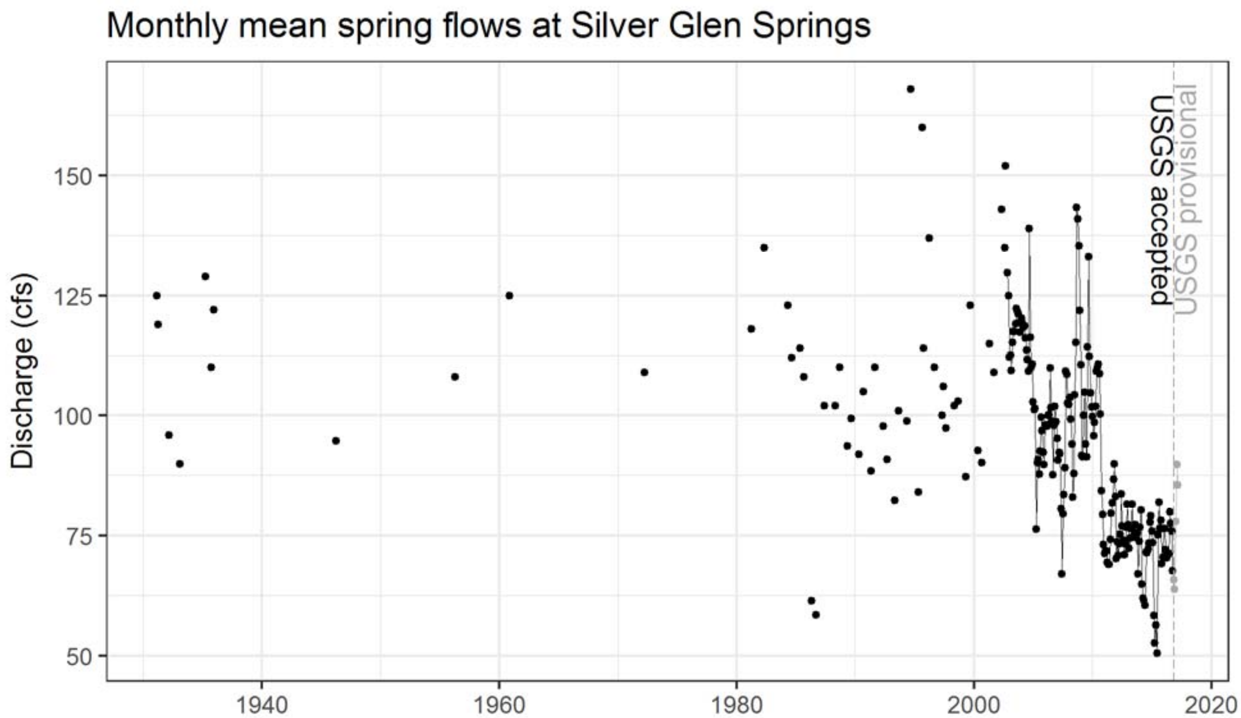

Figure B-2. Monthly mean spring flows at Silver Glen Springs.

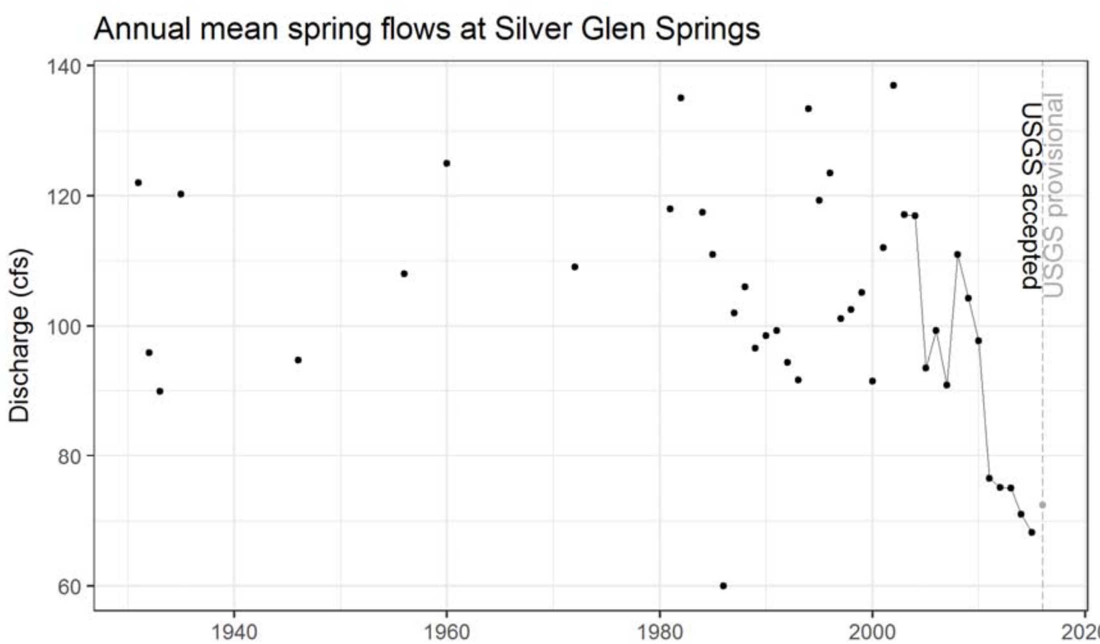

Figure B-3. Annual mean spring flows at Silver Glen Springs.

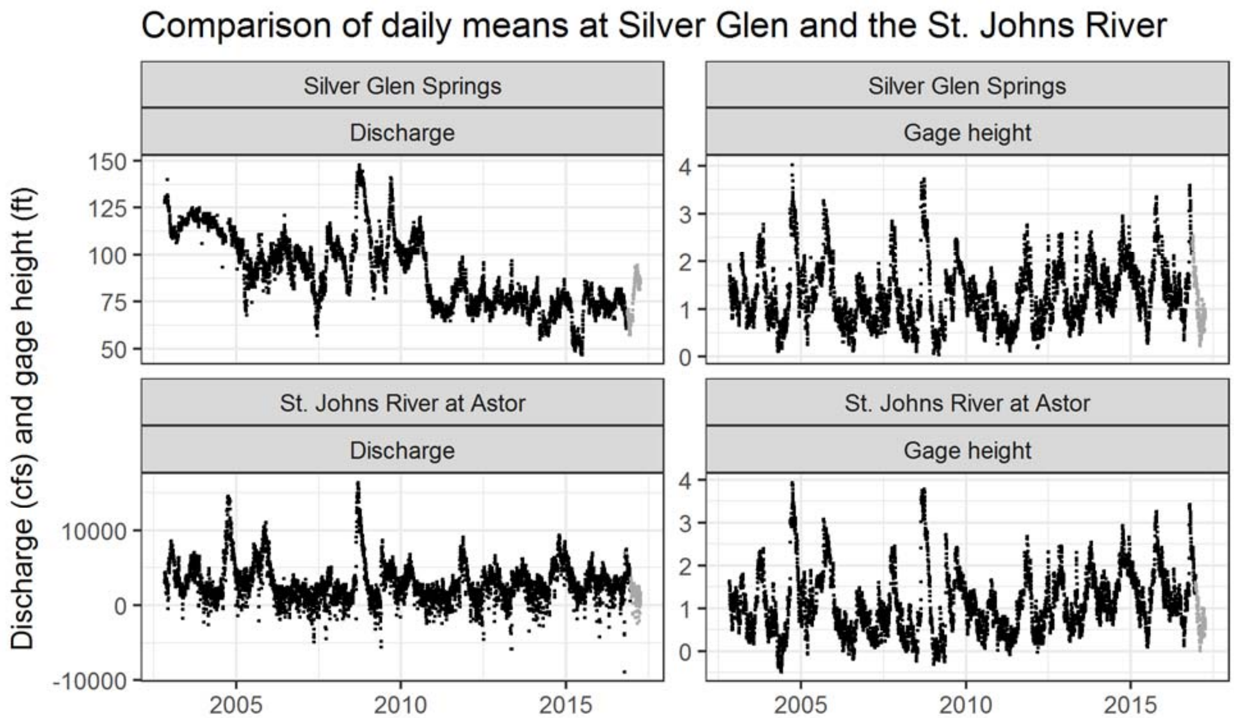

Figure B-4. Daily mean flows and water levels at Silver Glen Springs and the St. Johns River at Astor. A discharge measurement of 259 cfs at Silver Glen on Sep. 28, 2004, was omitted to better view the rest of the plot. USGS provisional data is shown in gray.

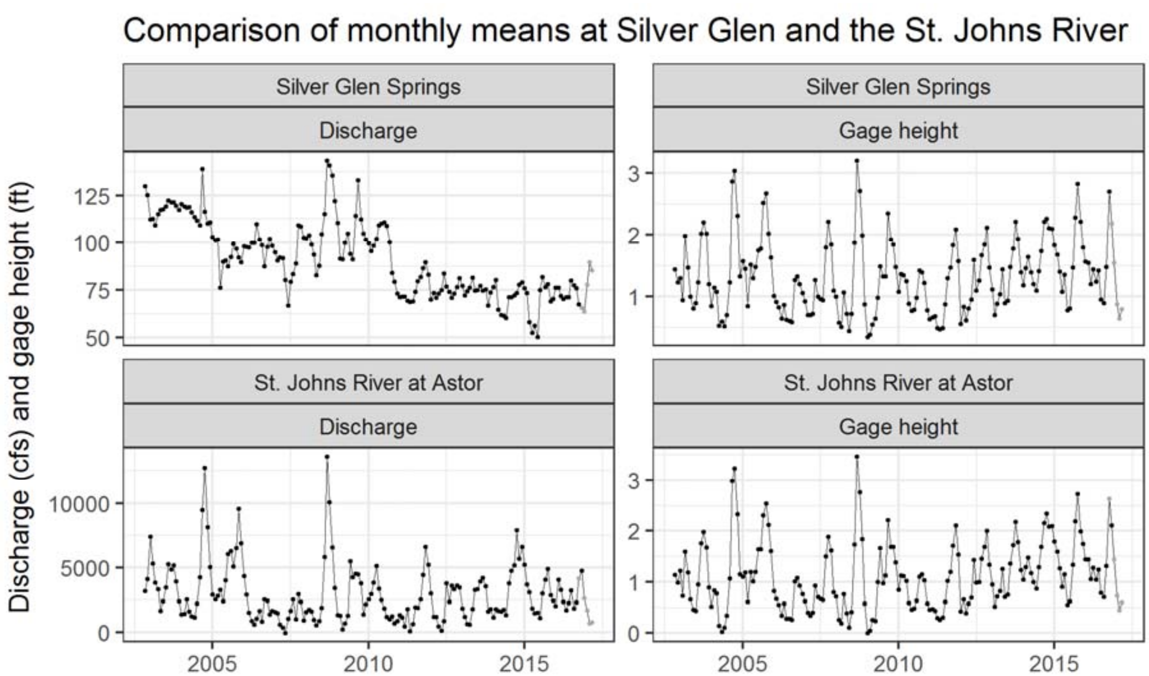

Figure B-5. Monthly mean flows and water levels at Silver Glen Springs and the St. Johns River at Astor.

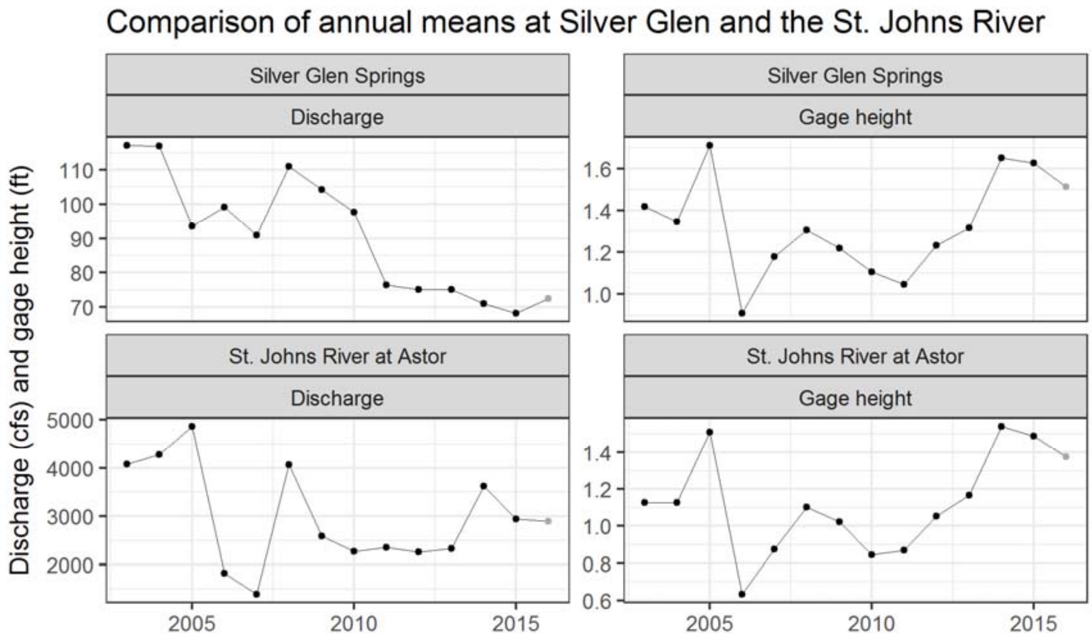

Figure B-6. Annual mean flows and water levels at Silver Glen Springs and the St. Johns River at Astor.

Although there is a downward shift observed in the estimated flows after 2010, the water levels have been increasing during the same period. Thus, the cause of the shift could be something in addition to or other than climate. Unfortunately, there is not sufficient quality long-term flow data that can be used to determine whether this shift is permanent or a part of climatic cycle for the following reasons:

1) The flow data that can be used is available only after 1984. More importantly, the continuous flow data is only available after 2002.
2) Different methods were used by the USGS to estimate the flows between 2002 and 2010
3) SJRWMD has not evaluated how USGS estimated the flows after 2010
4) The USGS indicates the flow estimates are poor. With all the other factors, the uncertainty in the flows could be as high as % 42 (Harmel, R. D. et al, 2006).

Because of uncertainties in flow dataset, a review of water levels and flows on water bodies in the vicinity of Silver Glen were conducted. Appendix E of the MFL report includes the discussion about the Silver Glen springs flow trend and comparison with the nearby water bodies. Because setting MFL requires the use of best available information, the period of record discussed in the following section was used for MFL data analysis.

Period of Record

As discussed in Section 1, Silver Glen Springs discharge data are not continuous daily data until 2002. They were generally random measurements and for some years, monthly data was available. There were only 13 records available from 1931 to 1983 (see Table B-1). The review of available data indicated that there was not sufficient data available before 1984 to be used for the MFL data analysis. Therefore, only the data collected after 1984 were used in the MFL data analysis.

GROUNDWATER PUMPING ASSESSMENT

Groundwater use

To estimate the potential impact on spring flows from pumping, annual groundwater use from 1984 to present was estimated within the Silver Glen springshed plus a one-mile buffer (Figure B-7). The springshed was developed using the most recent Upper Floridan aquifer potentiometric surfaces and one-mile buffer was added to account for potential variations in springshed boundaries under different hydrologic conditions (i.e, springshed may expand during wet season).

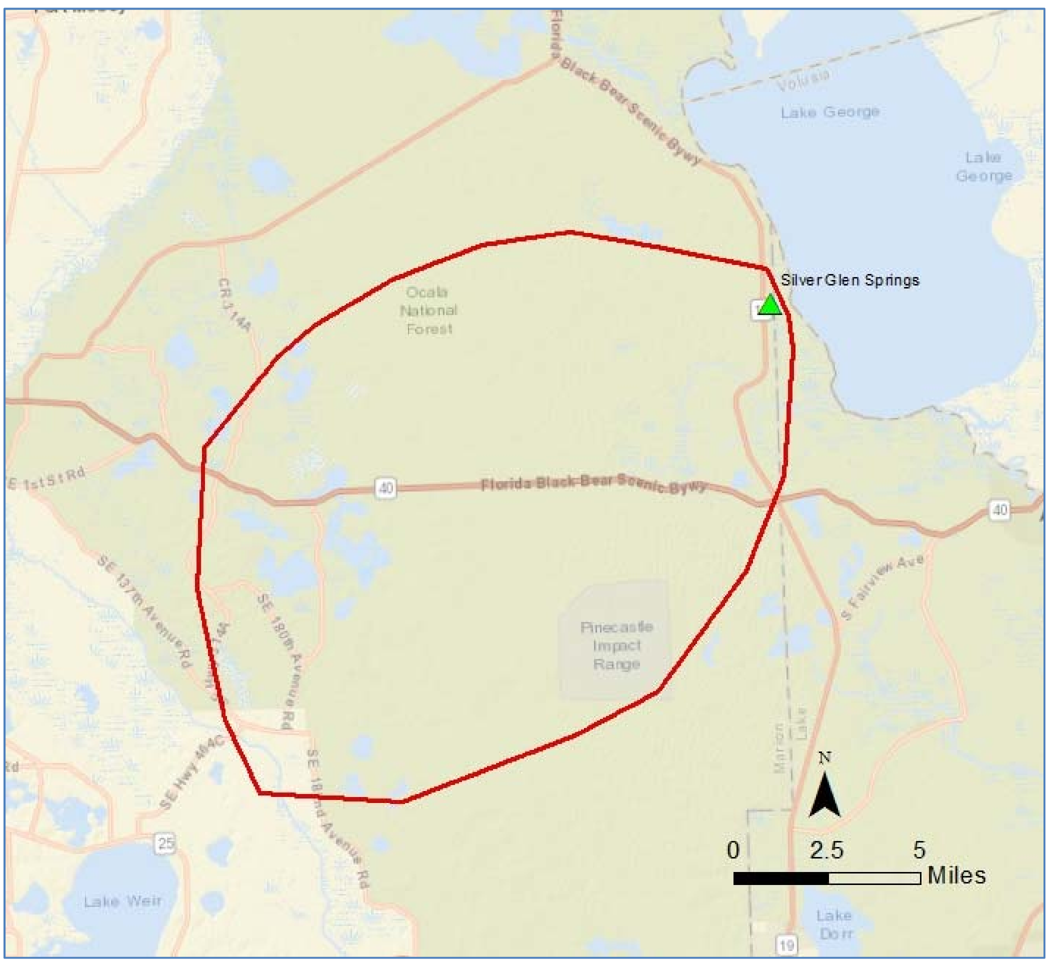

Figure B-7. Silver Glen springshed plus one-mile buffer.

Groundwater pumping was estimated using the reported annual groundwater use data from the SJRWMD water use database from 1995 to 2015. For the period from 1984 to 1994, groundwater use was estimated using the average proportion of groundwater usage in the springshed compared to Marion County groundwater usage from 1995 to 2015 multiplied by the USGS annual groundwater use estimates for Marion County from 1984 to 1994. Figure B-8 shows the estimated groundwater use within the adjusted springshed.

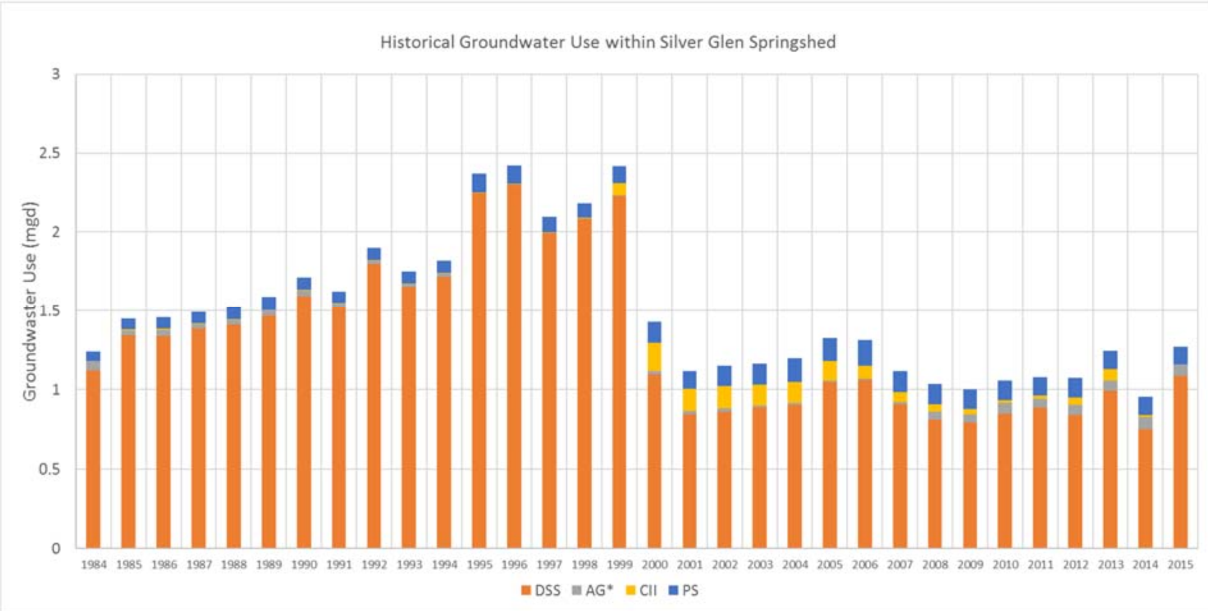

Figure B-8. Estimated groundwater use within Silver Glen springshed plus one-mile buffer.

Estimated impact on spring flows

It should be noted that the estimated springshed shown in Figure 5 represents the possible maximum extent of the groundwater contribution area for Silver Glen Springs. Any groundwater pumping outside the springshed can still have an impact on the spring flows which, however, could be limited. In addition, because of presence of other springs in the area, springs can interact each other, which means springsheds could overlap. Therefore, the impact of any pumping within the springshed could also extend beyond the springshed boundary. Because of the complicated nature of groundwater flow dynamics, the groundwater models, which take into account the interaction of springs with other water bodies and complex aquifer system, are the best available tools to evaluate the impact of groundwater pumping on spring flows.

The reduction in spring flow due to pumping was estimated using version 5.0 of the SWFWMD Northern District Groundwater Flow Model (NDMv5 model) (HGL and Dynamic Solutions, 2016). The NDMv5 groundwater model estimated a reduction of Silver Glen Springs flow of 2.1 cfs in 2010 due to pumping. The 2010-condition is the latest pumping and hydrologic condition NDMv5 was calibrated to. Therefore, it represents the best available information regarding the impact of current withdrawal on spring flow at Silver Glen Springs.

Next, the relationship between the groundwater pumping and the reduction in spring flow due to pumping was developed using the NDMv5 groundwater model. Figure B-9 shows the relationship between the pumping in the model within springshed plus one-mile buffer and the reduction in flow. It should be noted that the reduction in flow shown in Figure B-9 reflects the impact not only from the pumping within the springshed but also from the pumping within the rest of NDMv5 model domain (Figure B-11). Because of this, the flow reduction is more than the pumping within the springshed.

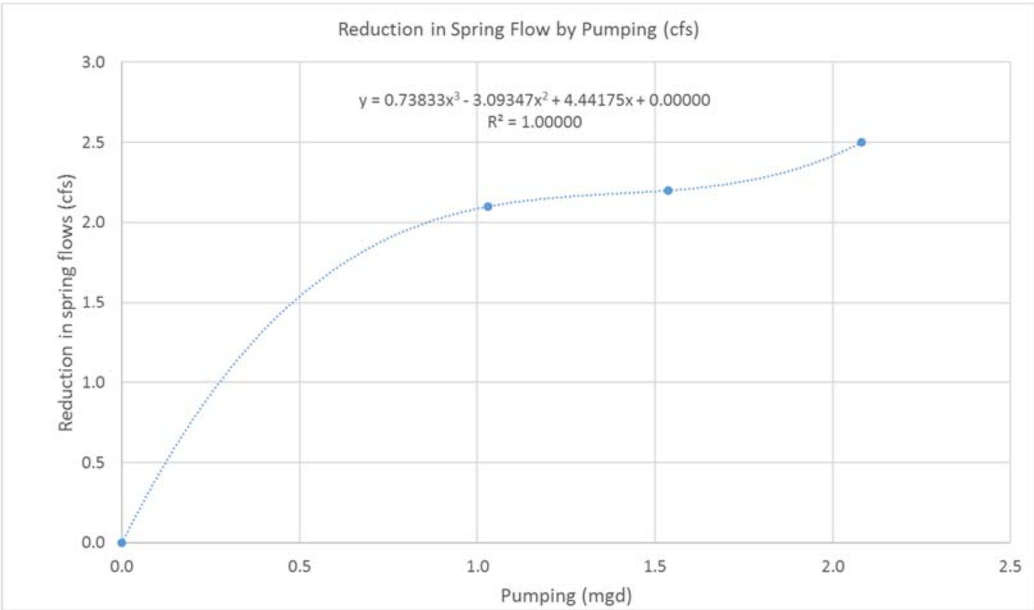

Figure B-9. Relationship between pumping and change in spring flow.

Using the estimated groundwater pumping from 1984 to 2015 and the relationship between pumping and the reduction in spring flow (polynomial function shown in Figure B-9), annual impact to the spring flow from historical pumping was estimated (see Figure B-10).

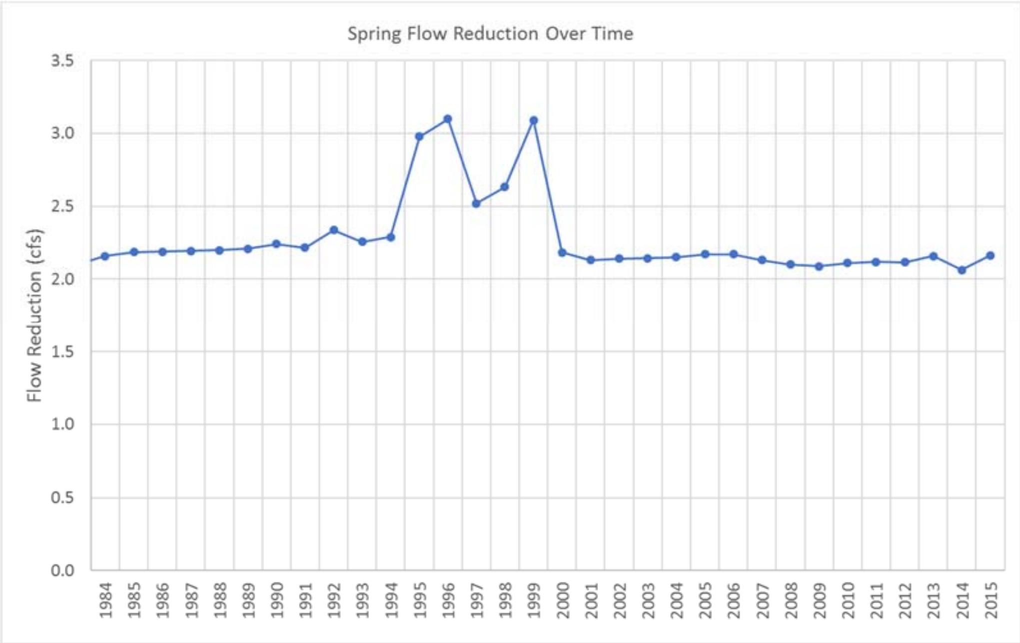

Figure B-10. Estimated impact of pumping on spring flow over time.

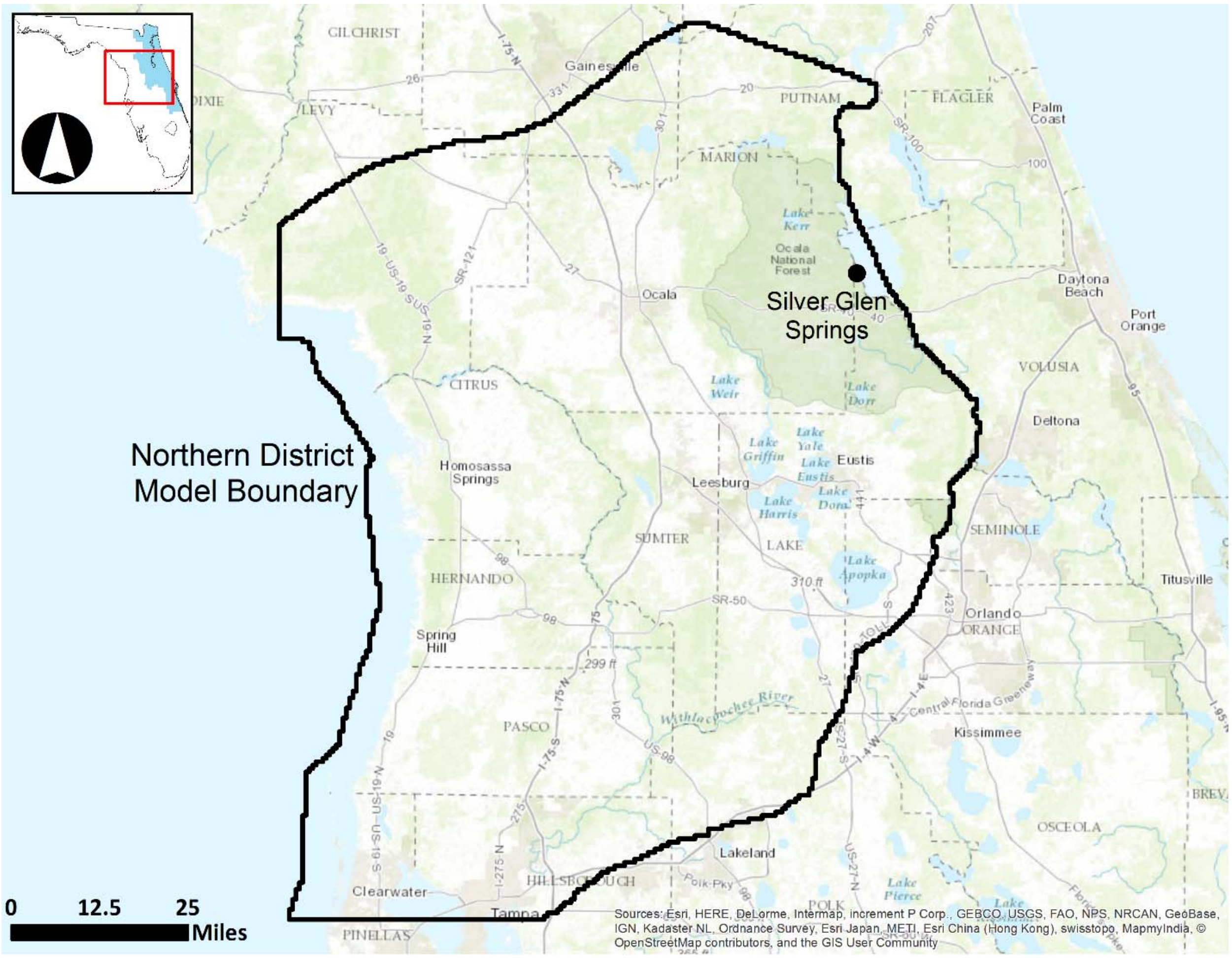

Figure B-11. NDMv5 model domain.

DEVELOPMENT OF SYNTHETIC FLOW TIME SERIES

Silver Glen spring MFL determinations and assessment are based on the mean discharge calculated using a baseline flow dataset representative of current pumping condition. The first step in creating the baseline 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 “no-pumping 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 B-10 were added to the annual means of observed spring flow data to create a “no-pumping condition” flow time series. This synthetic flow time series constitutes a reference hydrologic condition of the spring in which the impact from groundwater pumping is assumed to be minimal.

"Baseline condition" flow time series

The NDMv5 groundwater model estimated a reduction of spring flow of 2.1 cfs in 2010 due to pumping. This amount was subtracted from monthly synthetic no-pumping condition flow time series dataset to estimate a baseline condition flow time series dataset for Silver Glen Spring. The synthetic baseline flow time series dataset represents a reference hydrologic condition of spring in which the impact from groundwater pumping on spring flows is constant over time at a rate of 2.1 cfs. Assuming climatic, rainfall, and other conditions present from 1984 – 2015 are repeated over the next 20 years, the baseline 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 Silver Glen Springs. Figure B-12 shows the observed, no-pumping and baseline condition flows.

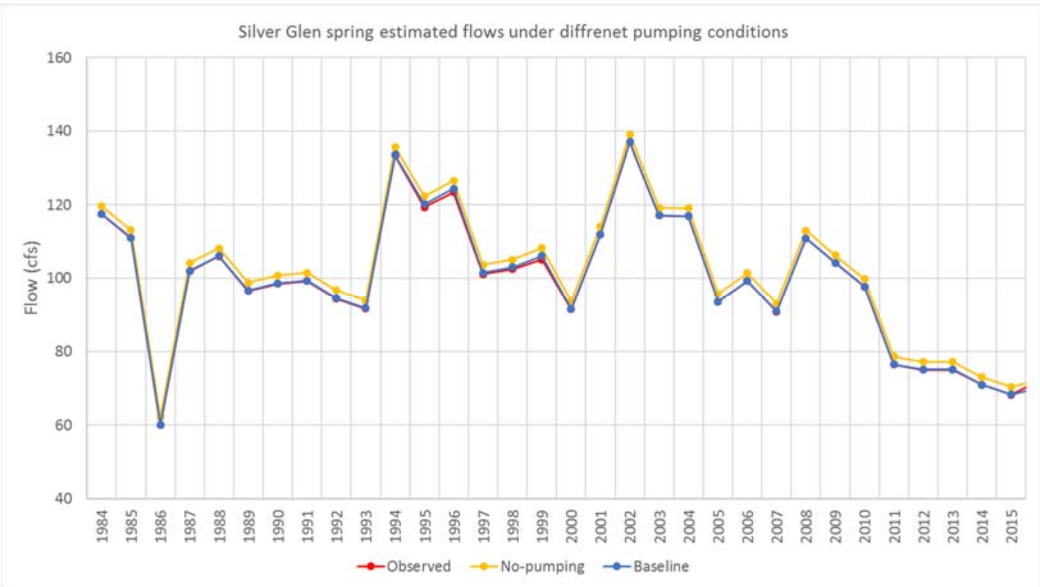

Figure B-12. Observed and Estimated spring flow datasets.

REFERENCES

Harmel, R. D., R. J. Cooper, R. M. Slade, R. L. Haney, and J. G. Arnold. 2006. Cumulative uncertainty in measured streamflow and water quality data for small watersheds. Trans. ASABE 49(3): 689-701

HGL and Dynamic Solutions, 2016. Northern district groundwater flow model version 5.0. Report prepared for the St. Johns River Water Management District and Southwest Florida Water Management District.

SJRWMD 2017. *www.sjrwmd.com/springs/silverglen.html*

Appendix C: APPENDIX C: ADDITIONAL TEMPERATURE MODELING ANALYSIS

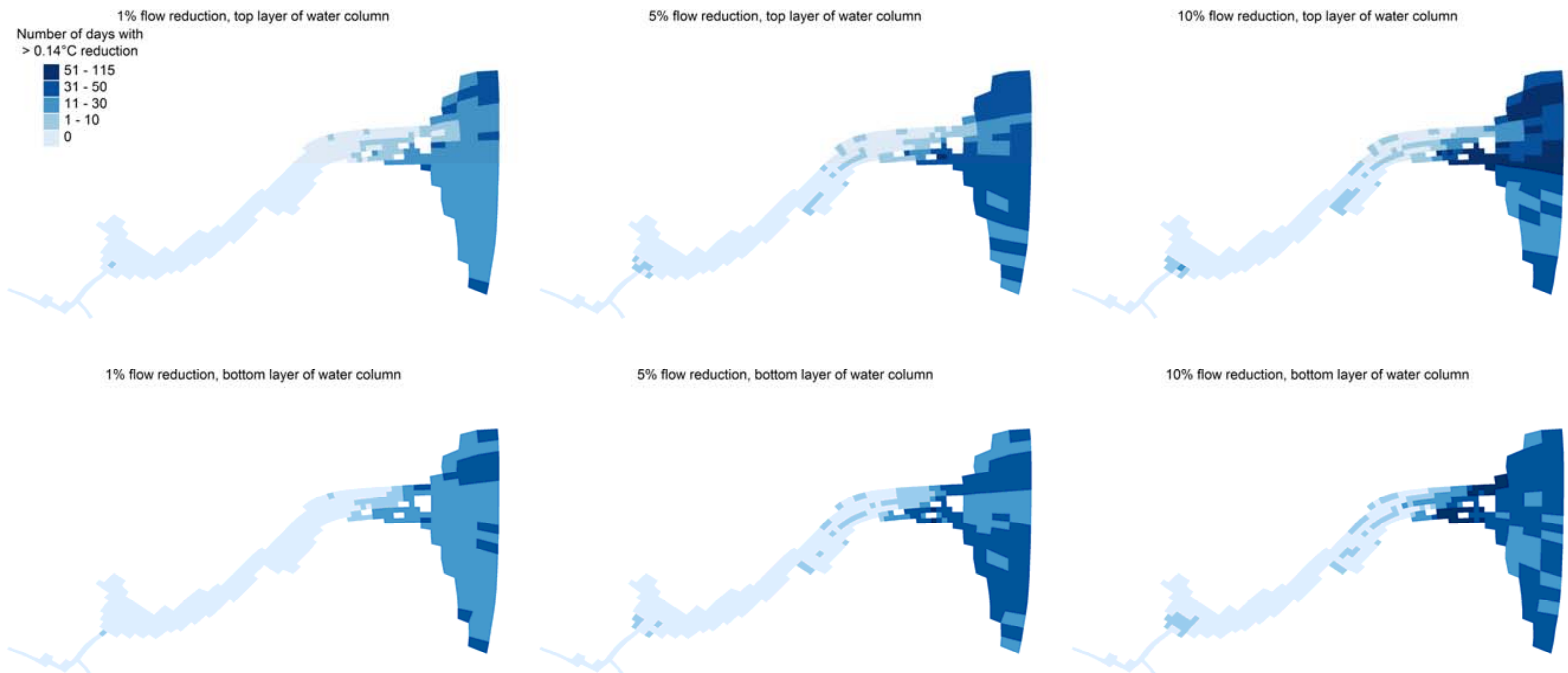

Figure C-1. Maps of Silver Glen Springs Run showing the total number of days in each cell that resulted in an at least 0.14°C simulated change under each flow reduction scenario for winter 2010–2011. Water levels in the St. Johns River in winter 2010–2011 were relatively low, likely leading to less cold water intrusion from Lake George. The flow reductions shown are in addition to the estimated 2.1% loss of flow due to 2010–2011 water use.

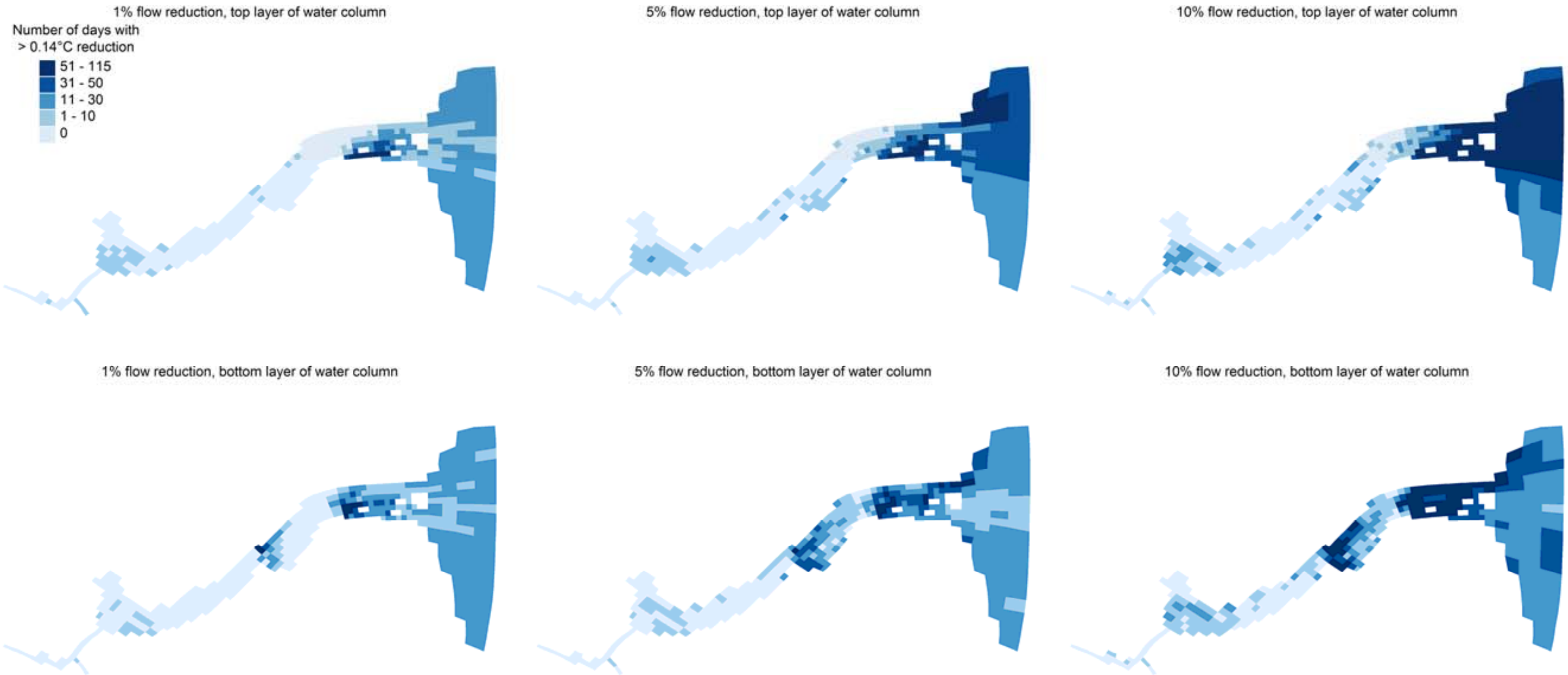

Figure C-2. Maps of Silver Glen Springs Run showing the total number of days in each cell that resulted in an at least 0.14°C simulated change under each flow reduction scenario for winter 2014–2015. Water levels in the St. Johns River in winter 2014–2015 were relatively high, likely leading to greater cold water intrusion from Lake George. The flow reductions shown are in addition to the estimated 2.1% loss of flow due to 2014–2015 water use.

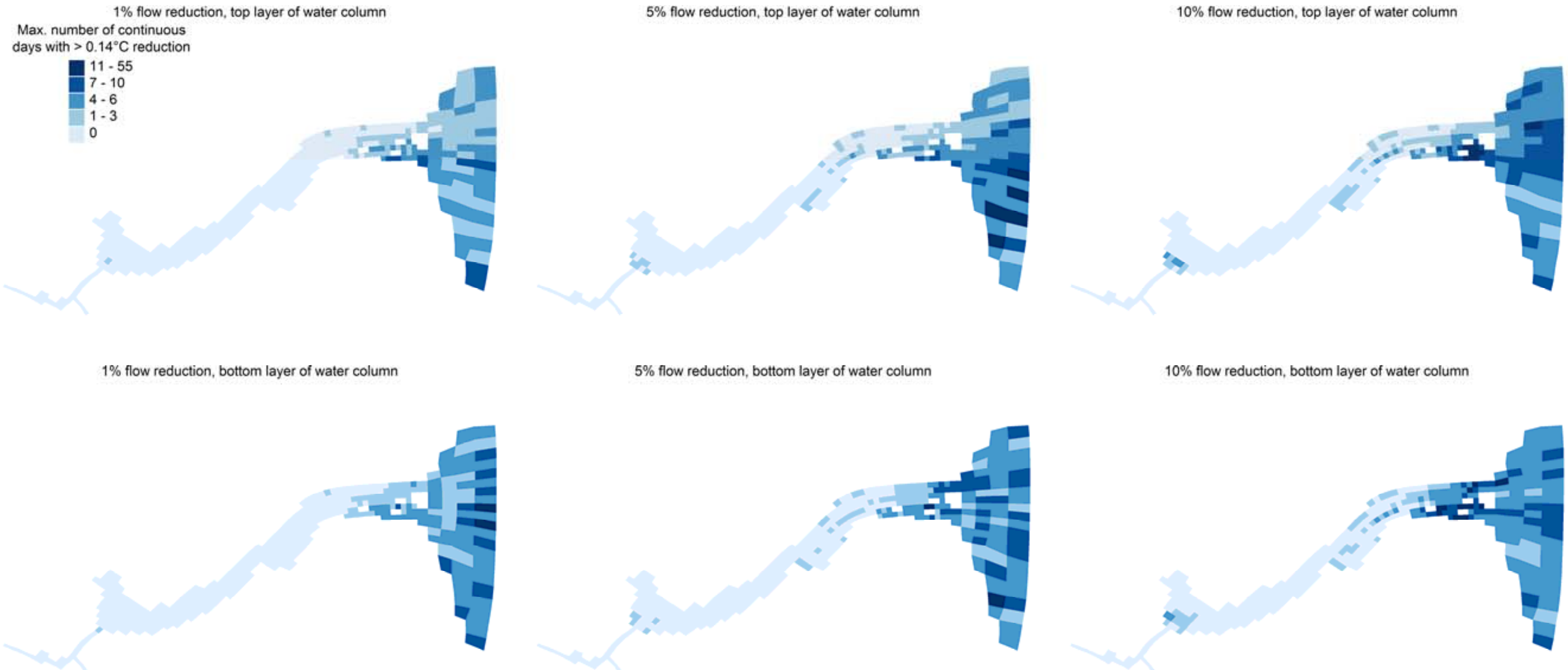

Figure C-3. Maps of Silver Glen Springs Run showing the maximum number of continuous days in each cell that resulted in an at least 0.14°C simulated change under each flow reduction scenario for winter 2010–2011.

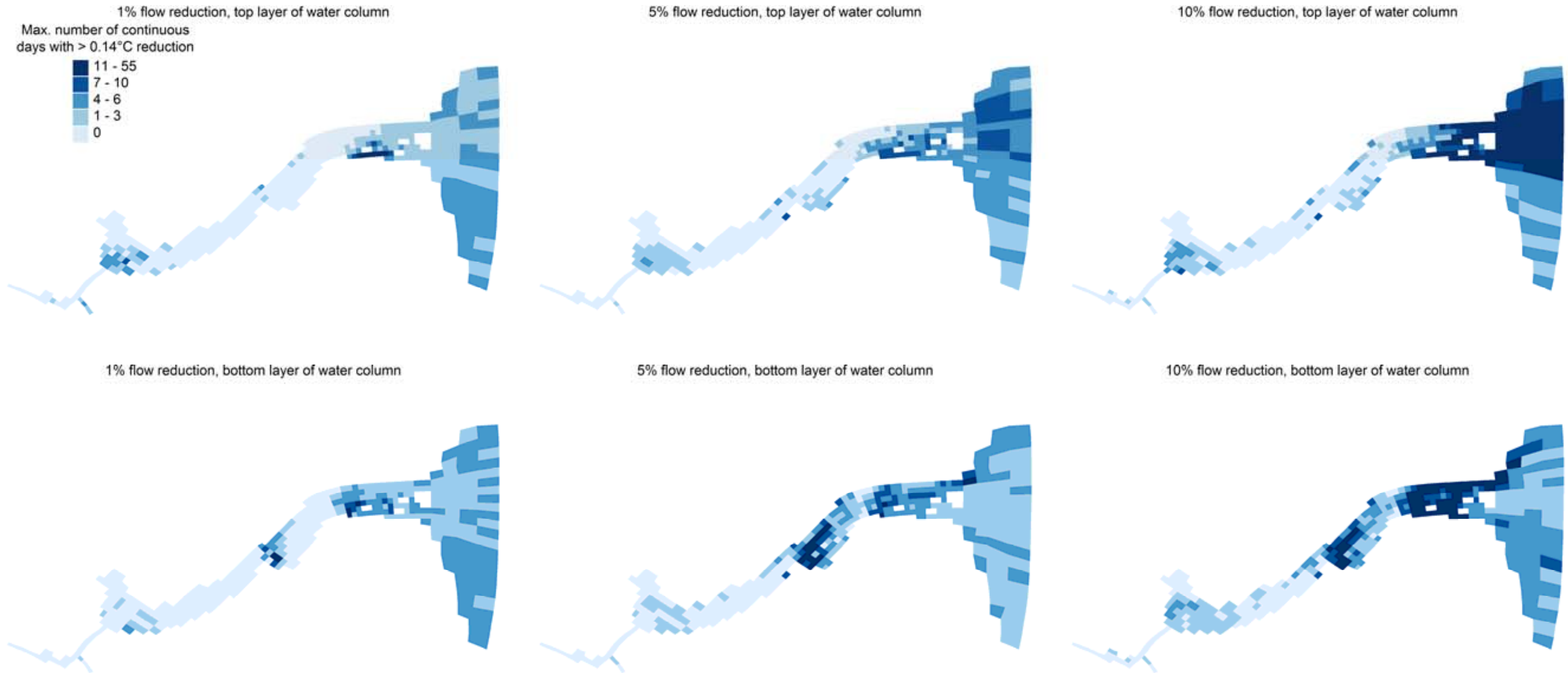

Figure C-4. Maps of Silver Glen Springs Run showing the maximum number of continuous days in each cell that resulted in an at least 0.14°C simulated change under each flow reduction scenario for winter 2014–2015.

Appendix D: APPENDIX D: LETTER FROM FISH AND WILDLIFE CONSERVATION COMMISSION (FWC)

Florida Fish and Wildlife Conservation Commission

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March 3, 2017

Andrew B. Sutherland, Ph.D.
MFLs Technical Program Manager
Bureau of Resource Evaluation and Modeling
St. Johns River Water Management District
P.O. Box 1429
Palatka, FL 32178-1429
asutherl@sjrwmd.com

RE: Silver Glen Springs Minimum Flows and Levels, Marion County

Dear Dr. Sutherland:

We appreciate the presentation that the St. Johns River Water Management District (SJRWMD) provided on February 16, 2017, on the approach and modeling that is being taken regarding the development of the Silver Glen Springs Minimum Flows and Levels (MFL).

During the discussion, SJRWMD staff requested that the Florida Fish and Wildlife Conservation Commission (FWC) staff provide wildlife-related technical information that would assist their determination of "at what percent flow reduction does significant harm to manatees occur?" and information on usage of the spring-run by other species that may also need to be considered in the development of the MFL.

Maintaining adequate warm water for manatees has been identified by SJRWMD as the guiding parameter for determining the Silver Glen Springs MFL. Silver Glen Springs is a secondary warm water site and a critical component of the network of natural warm water sites utilized by hundreds of manatees each winter in north-central Florida. SJRWMD modeling efforts indicate that reductions in flow could affect this wintertime manatee thermal refuge, located in the St. Johns River system. We understand that only limited data collection occurred near the St. Johns River portion of the spring-run (Area 2) resulting in a less than desirable amount of data used in the modeling efforts. We recommend that additional data collection occur in the vicinity of the St. Johns River portion of the spring run (Area 2) due to its consistent use by manatees. The SJRWMD modeling and the 2035 pumping projections indicated a potential 0.4 cfs change in flow from 2010 conditions. We have no indication that the proposed 0.4 cfs change in flow will affect the current extent of warm water habitat. The 5% change in flow also modeled would likely affect the amount of warm water habitat available for manatees; however, the extent of the affect is unclear based on the information currently available. FWC supports the establishment of MFLs to ensure that warm water habitat that is accessible to manatees is protected.

The St. Johns River is the southernmost extent of the Atlantic striped bass (*Morone saxatilis*) range. Silver Glen Springs is a primary summer thermal refuge habitat which holds one of the largest aggregations during the summer and fall months. Spring-flow reductions during the summer months that limit passage to this thermal refuge may affect the Atlantic striped bass population in the St. John River. The current SJRWMD analysis

Andrew B. Sutherland
Page 2
March 3, 2017

only models water temperature during the winter months. We recommend incorporation of water temperatures during the summer and fall months during future modeling efforts.

Additionally, bluenose shiner (*Pteronotropis welaka*, State Threatened) has disjunct populations in the Florida panhandle and the St. Johns River drainage, which may include Silver Glen Springs. Bluenose shiners from the St. Johns River population typically occupy spring-fed rivers and spring runs that contain dense emergent and submersed aquatic vegetation. The bluenose shiner Species Action Plan lists several threats pertinent to the Silver Glen Springs MFL including changes in water quality and quantity, and habitat alteration. FWC staff supports the establishment of MFLs that is protective of water quality and quantity that supports habitat for this species.

We appreciate the opportunity to provide you technical assistance as part of the development of the Silver Glen Springs MFL. We look forward to reviewing the draft Silver Glen Springs MFL document when it is completed. If you need any further assistance, please contact Jane Chabre either by phone at (850) 410-5367 or at FWCConservationPlanningServices@MyFWC.com. If you have specific technical questions regarding the content of this letter, please contact Ted Hoehn at (850) 488-8792) or by email at Ted.Hoehn@MyFWC.com.

Sincerely,

Jennifer D. Goff

Jennifer D. Goff
Land Use Planning Program Administrator
Office of Conservation Planning Services

jdg/th
ENV 1-12-2
Silver Glen Springs MFL_32549_030317

cc: Mike Register, SJRWMD, MREGISTE@sjrwmd.com

Appendix E: APPENDIX E: COMPARISON OF FLOWS AND LEVELS AT SILVER GLEN SPRINGS AND OTHER WATER BODIES

The results of our review of best available information and water levels and flows of other water bodies near Silver Glen are summarized as follows

1) Although there is a downward shift observed in the estimated flows after 2010, the water levels have been increasing during the same period. Thus, the cause of the shift could be something in addition to or other than climate. However, there is not sufficient long-term reliable flow and level data to do a conclusive analysis to determine the cause.

2) Other water bodies in the region have shown a similar pattern of low levels in recent years, indicating that the recent period of low flows at Silver Glen Springs may not be explained only by factors specific to Silver Glen Springs (Figure E-1Figure E-6).

3) Groundwater pumping impact analysis using the groundwater model has shown that no additional reductions in spring flow due to water use have occurred after 2010 (Figure B-8 in Appendix B). Therefore, the recent period of low flows cannot be explained by the impacts from water use.

It is difficult to determine the cause of the downward shift in low flows after 2010 due to significant uncertainties in the flow dataset and the absence of long-term flow and level data as discussed in Appendix B. Because of this, no determination can be made whether the recent period of low flows indicates a change in the longer-term hydrologic regime or not. In addition, the purpose of MFLs is to establish the limits “at which further withdrawals would be significantly harmful”. The groundwater pumping impact analysis discussed in Appendix B indicated that the low flows after 2010 are not the result of impacts from water use. As a result, the best available dataset discussed in Appendix B was used to determine and assess the MFLs.

If additional information becomes available in the future indicating that the longer-term hydrologic regime of the spring has permanently changed for reasons other than withdrawals, it may be appropriate to re-evaluate the MFL under the new flow regime.

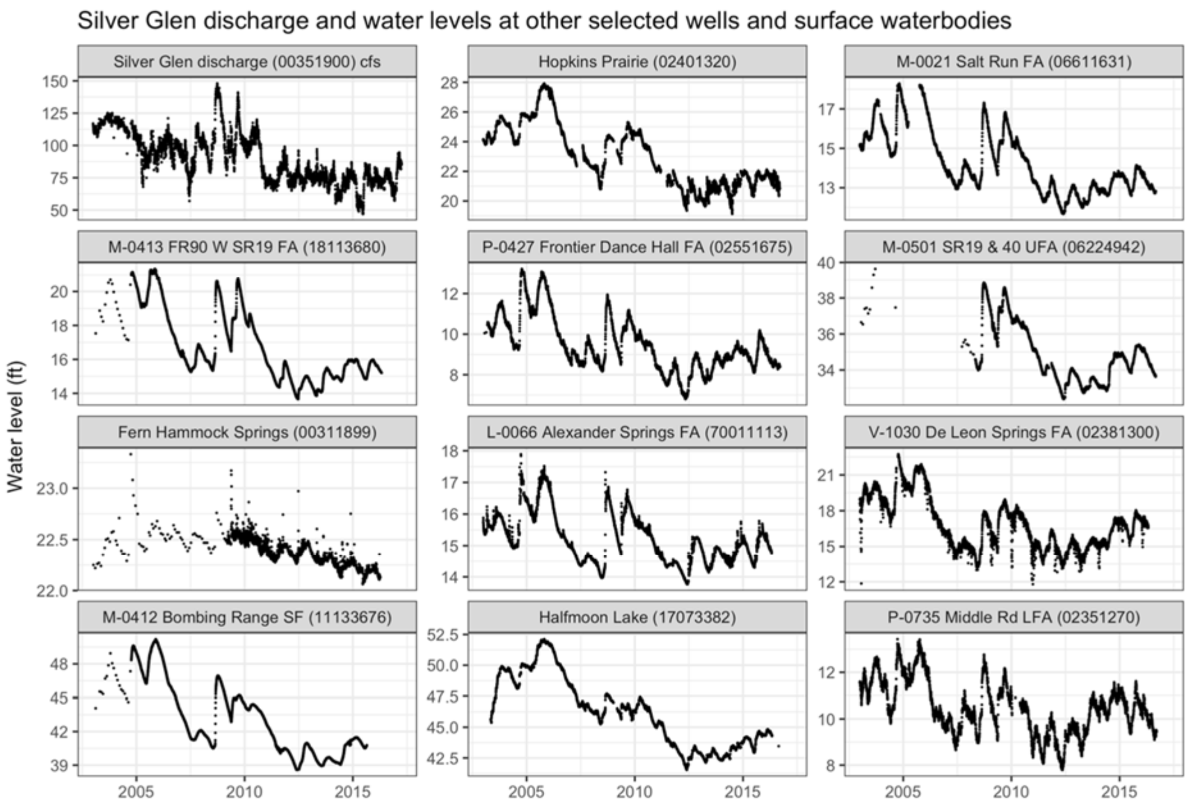

Figure E-1. Comparison of discharge at Silver Glen and water levels at other sites, selected based on proximity and similarity to the hydrograph of Silver Glen.

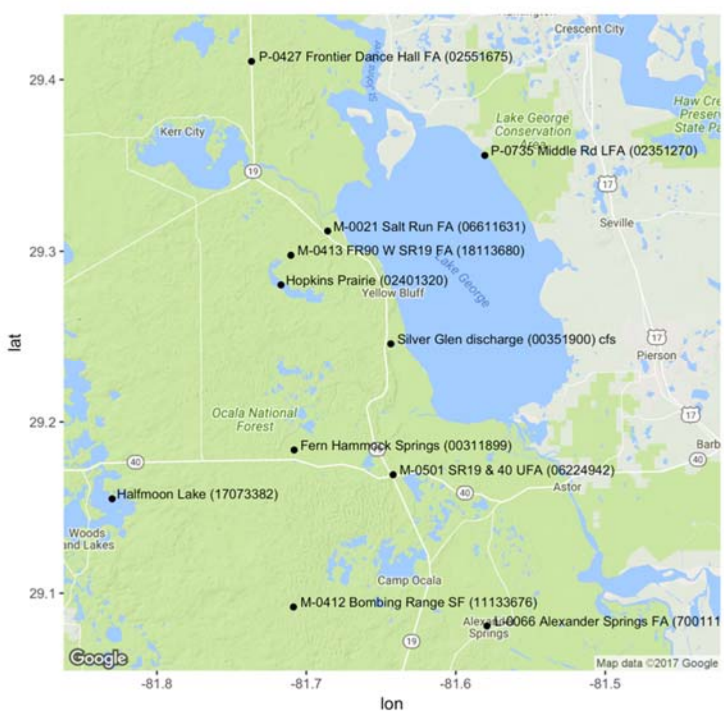

Figure E-2. Map of selected wells and surface waterbodies shown in the previous figure.

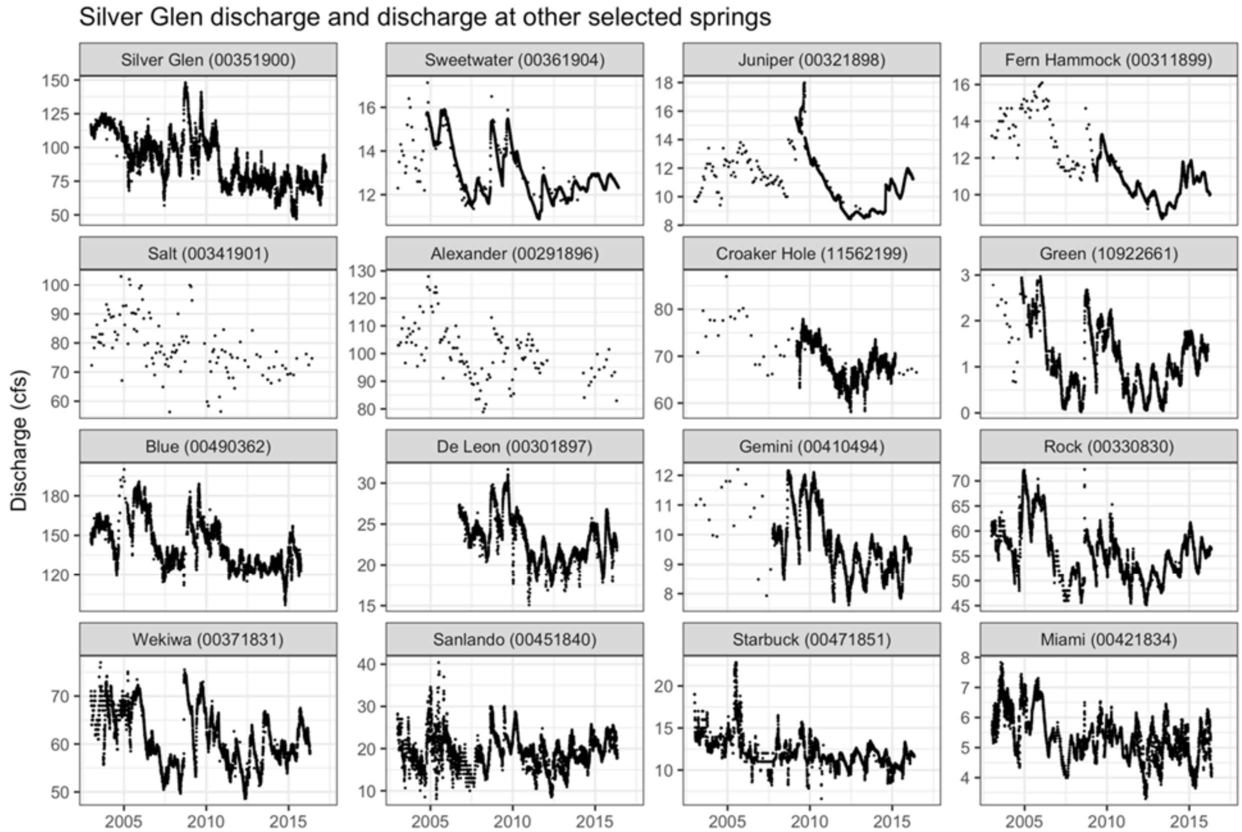

Figure E-3. Comparison of discharge at Silver Glen Springs and other selected springs.

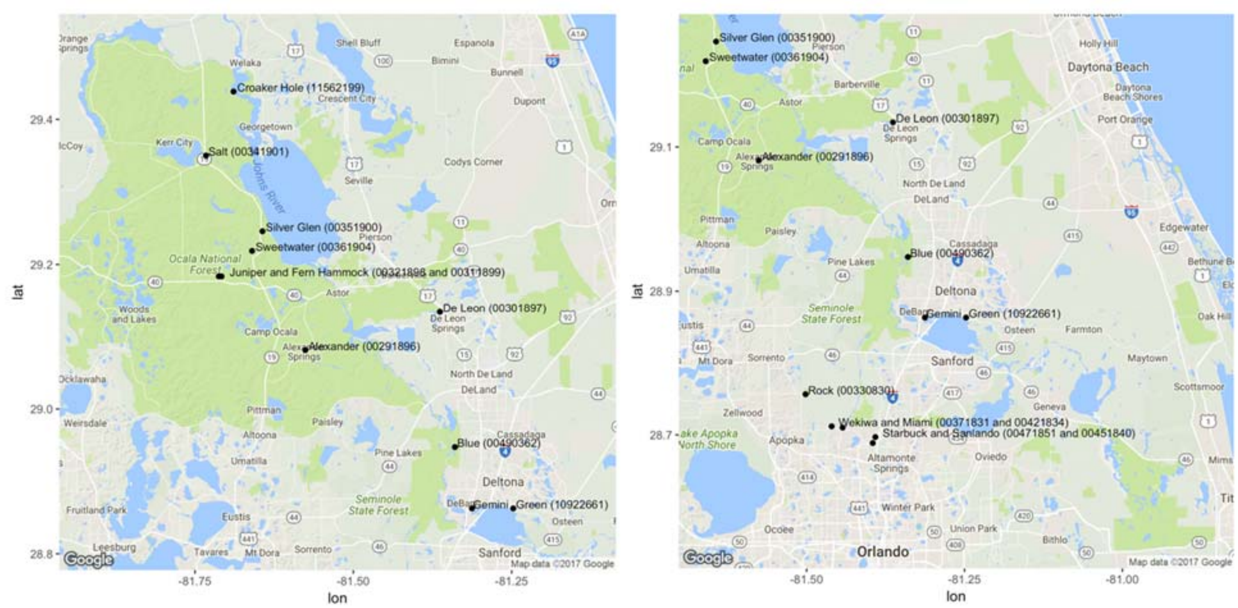

Figure E-4. Maps of selected springs shown in the previous figure.

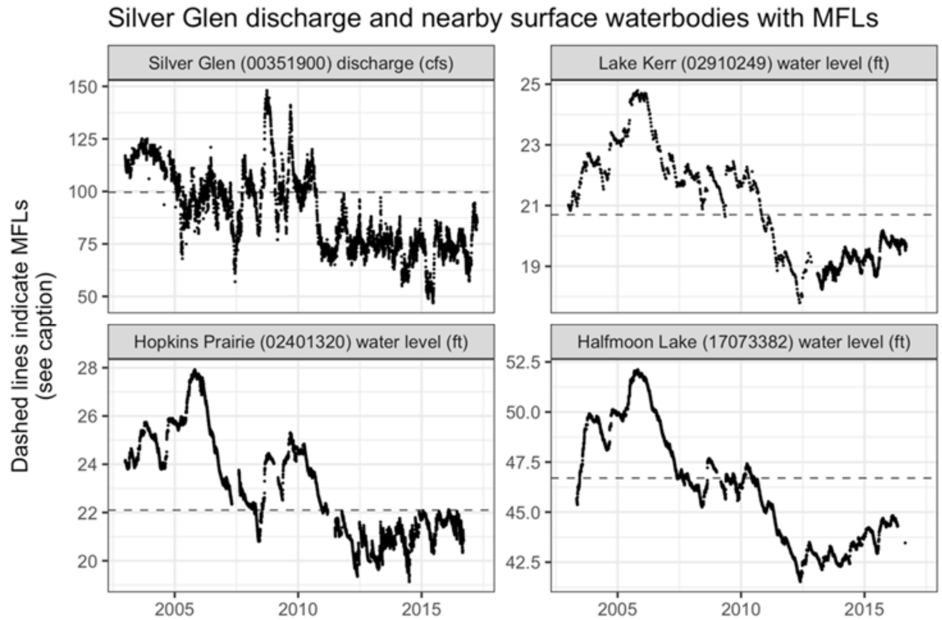

Figure E-5. Waterbodies with established MFLs near Silver Glen. The dashed lines indicate the recommended mean flow for Silver Glen, and the established minimum average water levels for each of the other sites.

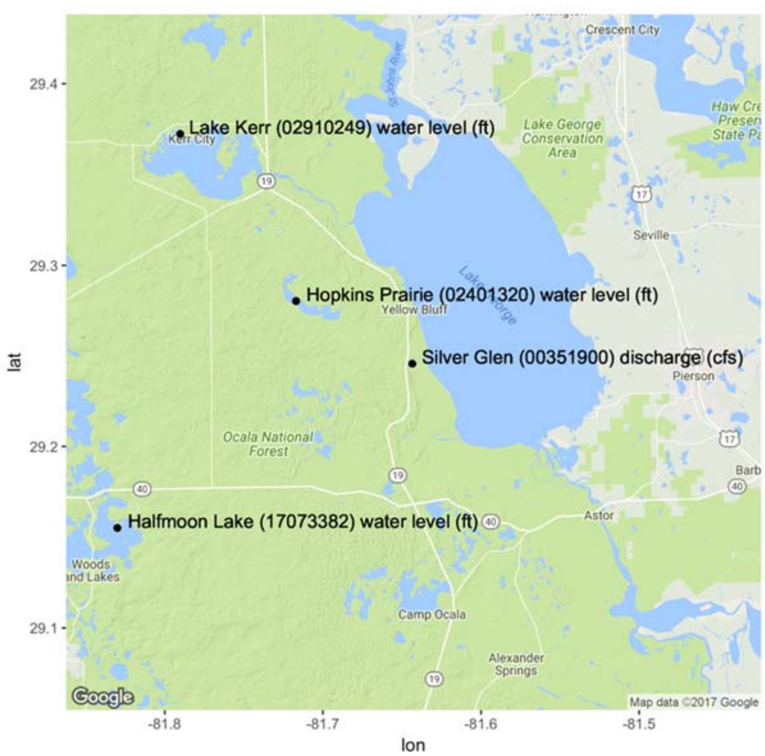

Figure E-6. Map of sites with MFLs shown in the previous figure.

Appendix F: APPENDIX F: SILVER GLEN SPRINGS RUN TEMPERATURE MODEL: HYDRODYNAMIC ANALYSIS AND MODEL SUMMARY

Appendix B: 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 Silver Glen springs.

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4. Development of flow time series representing no-pumping and baseline conditions

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Silver Glen Springs is located in Marion County. The Upper Floridan aquifer is the source of discharge for most springs in this region, including Silver Glen Springs. Silver Glen Springs is classified as a first magnitude spring (SJRWMD 2017).

Spring flow data were obtained from USGS for site number 02236160, Silver Glen Springs near Astor *(https://waterdata.usgs.gov/nwis/inventory/?site_no=02236160&agency_cd=USGS)*. Manual measurements of spring flow were available from 1931–2017 (Table B-1). Computed daily spring flows calculated from rating curves were available from 2002–2017. Details of the rating curves used to compute daily spring flows are available through USGS.

From this data, daily mean spring flows were calculated by averaging the available values for each day, monthly mean spring flows were calculated by averaging the daily means, and annual mean spring flows were calculated by averaging the monthly means (Figure B-1Figure B-3). The overall mean spring flows for various periods were calculated by averaging the annual means (Table B-2).

Spring flow and water level data for Silver Glen Springs (site number 02236160) and the St. Johns River at Astor (site number 02236125) were compared for 2002–2017, the period with computed daily measurements (Figure B-4–Figure B-6). All daily, monthly, and annual means were calculated as described above. As shown in the figures, there is clear similarity between Silver Glen and St. Johns River water level fluctuations. Since water level fluctuations at Silver Glen are significantly influenced by St. Johns River conditions, the minimum flows and levels recommended for Silver Glen include only spring flows.

Table B-1. Summary of USGS spring flow data available for Silver Glen Springs, USGS site number 02236160.

Measurement	Period	N	Frequency
Manual	1931 - 1983	13	13 total measurements
Manual	1984 - 2002	41	1 to 4 measurements per year
Manual	2003 - 2017	154	6 to 12 measurements per year
Computed	2002 - 2017	5192	daily

Table B-2. Average annual mean spring flows for various periods at Silver Glen Springs.

Period	Mean
1931 – 2016	102.1 cfs
1984 - 2016	99.1 cfs
2002 - 2016	93.7 cfs

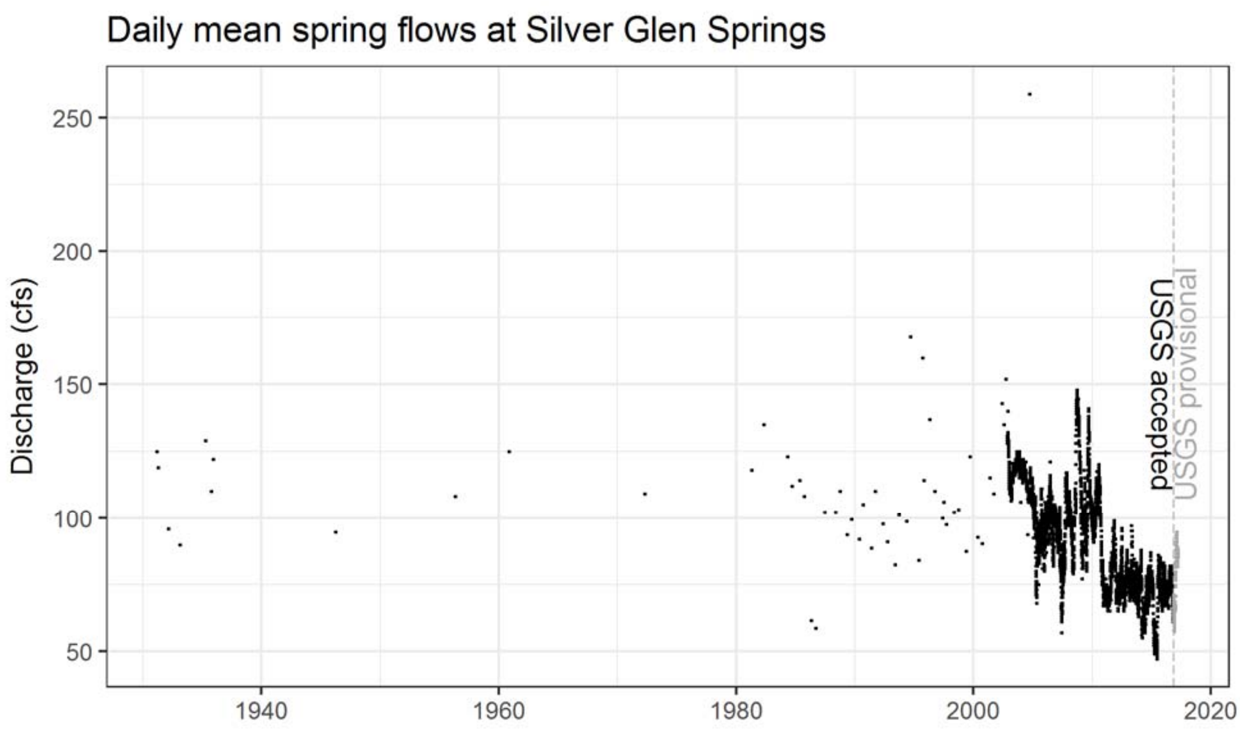

Figure B-1. Daily mean spring flows at Silver Glen Springs.

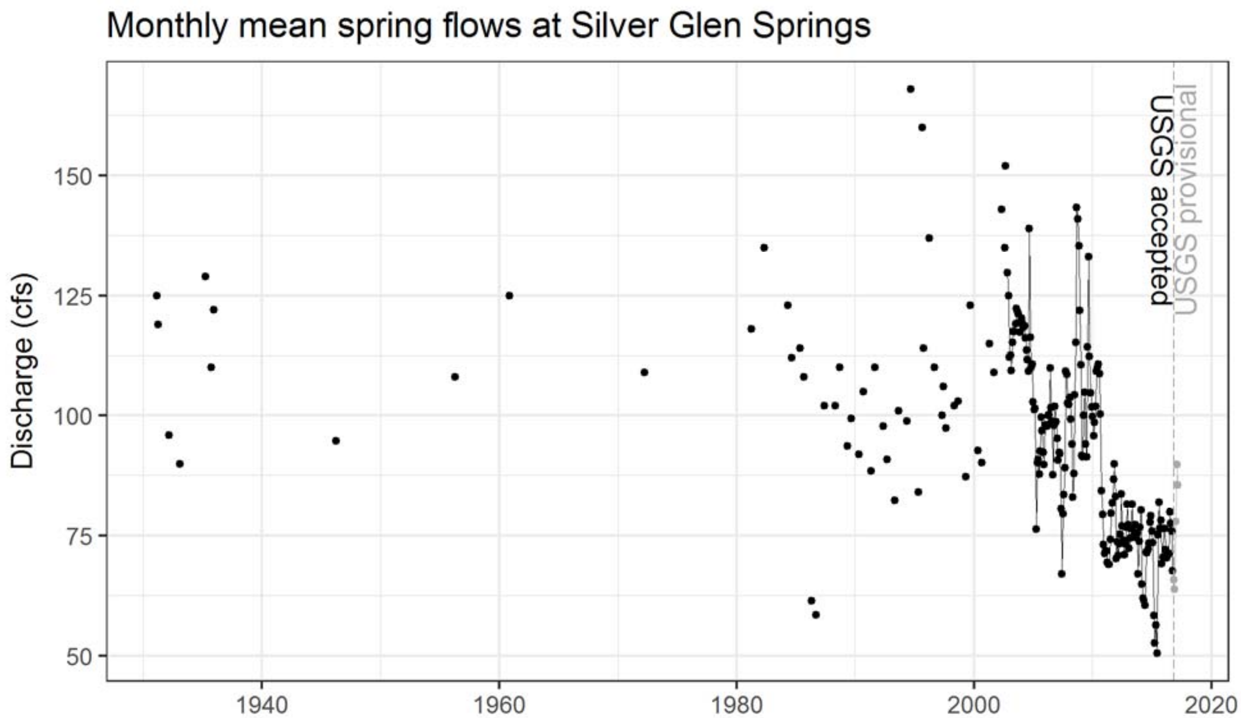

Figure B-2. Monthly mean spring flows at Silver Glen Springs.

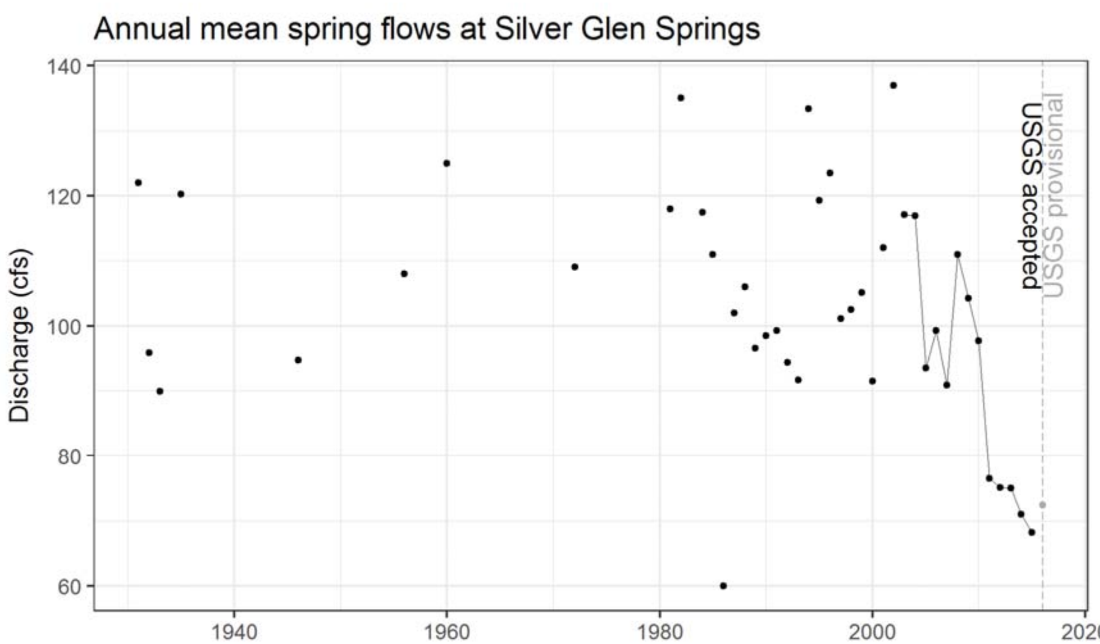

Figure B-3. Annual mean spring flows at Silver Glen Springs.

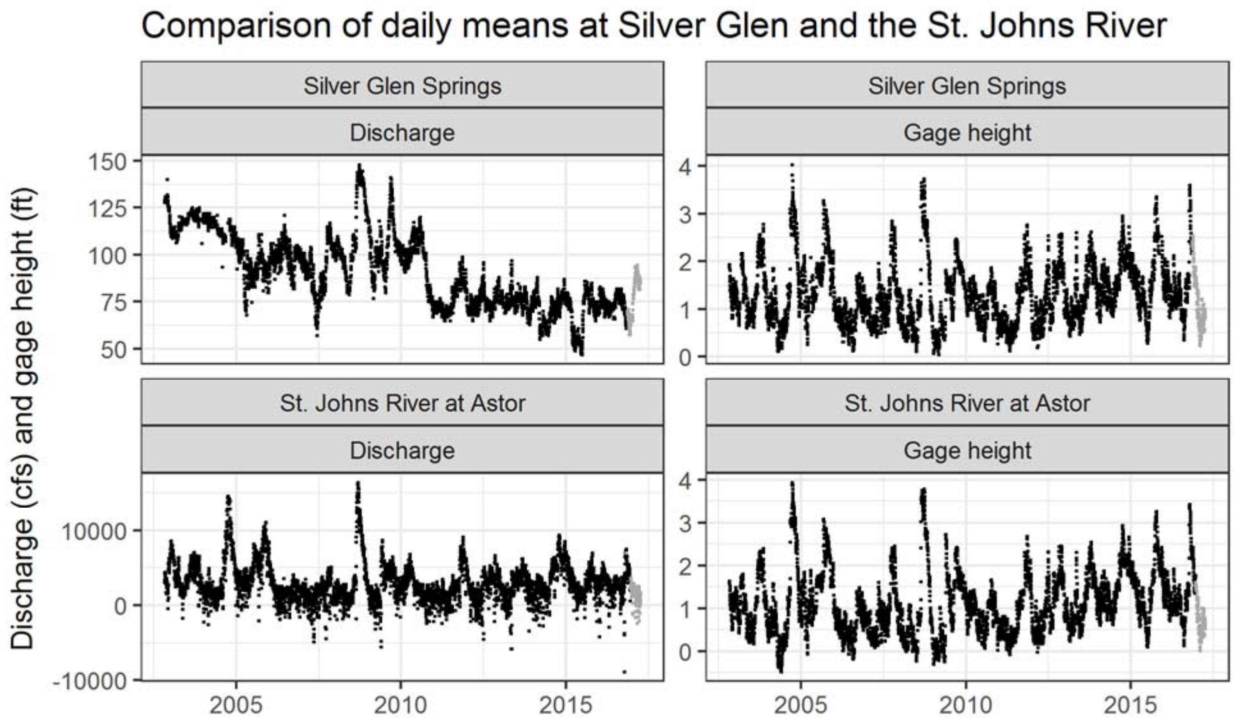

Figure B-4. Daily mean flows and water levels at Silver Glen Springs and the St. Johns River at Astor. A discharge measurement of 259 cfs at Silver Glen on Sep. 28, 2004, was omitted to better view the rest of the plot. USGS provisional data is shown in gray.

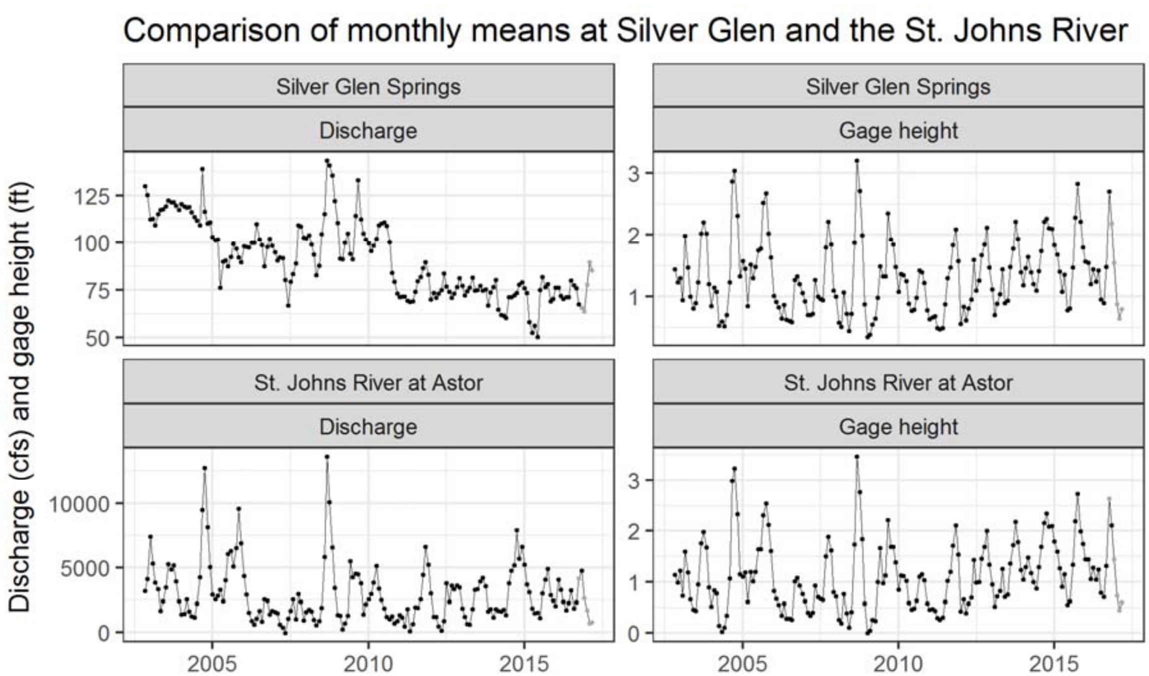

Figure B-5. Monthly mean flows and water levels at Silver Glen Springs and the St. Johns River at Astor.

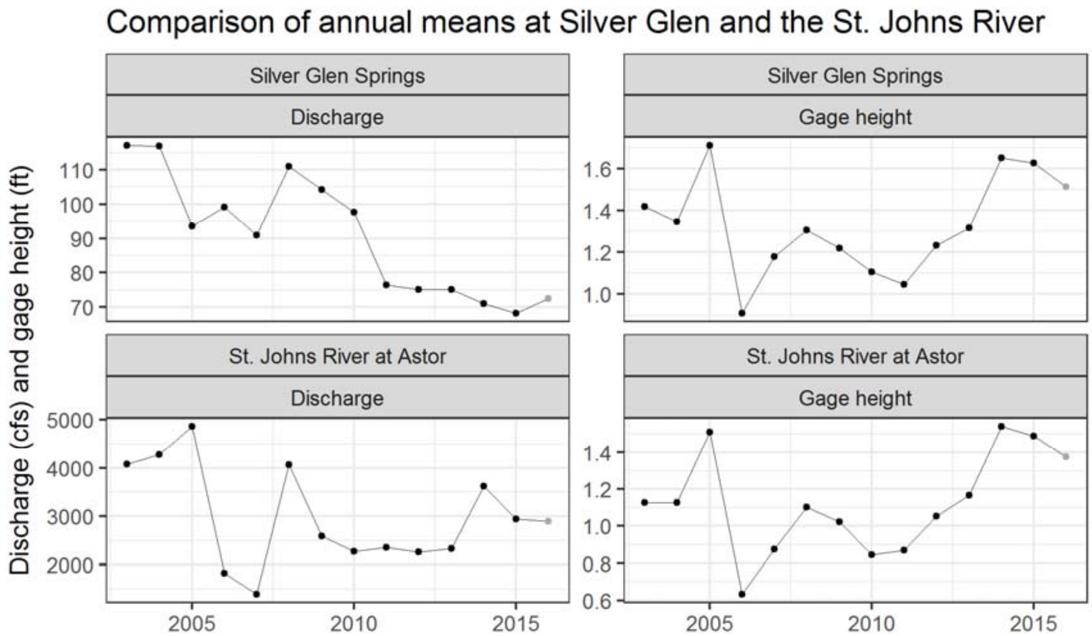

Figure B-6. Annual mean flows and water levels at Silver Glen Springs and the St. Johns River at Astor.

Although there is a downward shift observed in the estimated flows after 2010, the water levels have been increasing during the same period. Thus, the cause of the shift could be something in addition to or other than climate. Unfortunately, there is not sufficient quality long-term flow data that can be used to determine whether this shift is permanent or a part of climatic cycle for the following reasons:

1) The flow data that can be used is available only after 1984. More importantly, the continuous flow data is only available after 2002.

2) Different methods were used by the USGS to estimate the flows between 2002 and 2010

3) SJRWMD has not evaluated how USGS estimated the flows after 2010

4) The USGS indicates the flow estimates are poor. With all the other factors, the uncertainty in the flows could be as high as % 42 (Harmel, R. D. et al, 2006).

Because of uncertainties in flow dataset, a review of water levels and flows on water bodies in the vicinity of Silver Glen were conducted. Appendix E of the MFL report includes the discussion about the Silver Glen springs flow trend and comparison with the nearby water bodies. Because setting MFL requires the use of best available information, the period of record discussed in the following section was used for MFL data analysis.

Period of Record

As discussed in Section 1, Silver Glen Springs discharge data are not continuous daily data until 2002. They were generally random measurements and for some years, monthly data was available. There were only 13 records available from 1931 to 1983 (see Table B-1). The review of available data indicated that there was not sufficient data available before 1984 to be used for the MFL data analysis. Therefore, only the data collected after 1984 were used in the MFL data analysis.

GROUNDWATER PUMPING ASSESSMENT

Groundwater use

To estimate the potential impact on spring flows from pumping, annual groundwater use from 1984 to present was estimated within the Silver Glen springshed plus a one-mile buffer (Figure B-7). The springshed was developed using the most recent Upper Floridan aquifer potentiometric surfaces and one-mile buffer was added to account for potential variations in springshed boundaries under different hydrologic conditions (i.e, springshed may expand during wet season).

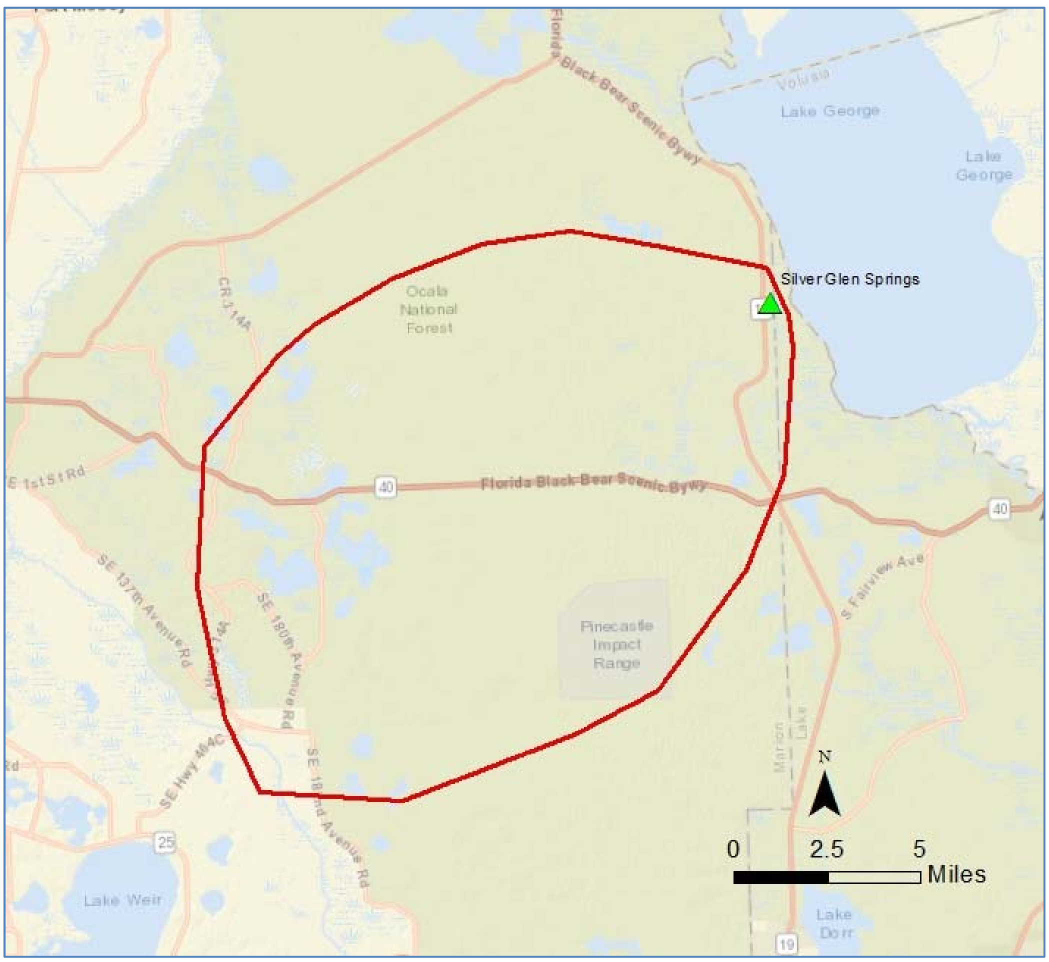

Figure B-7. Silver Glen springshed plus one-mile buffer.

Groundwater pumping was estimated using the reported annual groundwater use data from the SJRWMD water use database from 1995 to 2015. For the period from 1984 to 1994, groundwater use was estimated using the average proportion of groundwater usage in the springshed compared to Marion County groundwater usage from 1995 to 2015 multiplied by the USGS annual groundwater use estimates for Marion County from 1984 to 1994. Figure B-8 shows the estimated groundwater use within the adjusted springshed.

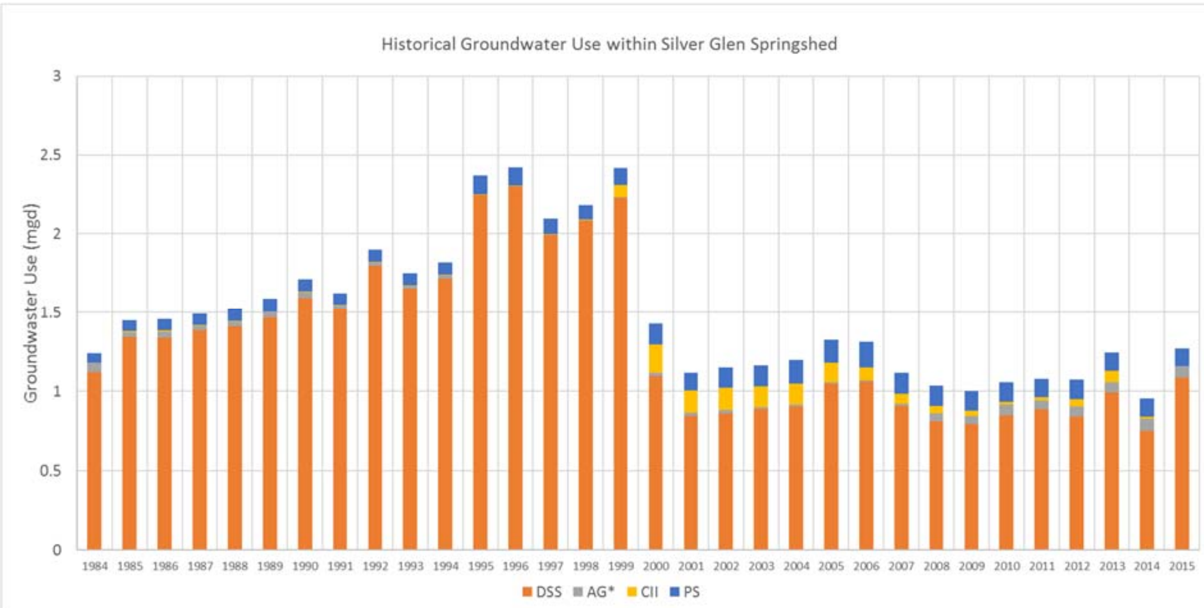

Figure B-8. Estimated groundwater use within Silver Glen springshed plus one-mile buffer.

Estimated impact on spring flows

It should be noted that the estimated springshed shown in Figure 5 represents the possible maximum extent of the groundwater contribution area for Silver Glen Springs. Any groundwater pumping outside the springshed can still have an impact on the spring flows which, however, could be limited. In addition, because of presence of other springs in the area, springs can interact each other, which means springsheds could overlap. Therefore, the impact of any pumping within the springshed could also extend beyond the springshed boundary. Because of the complicated nature of groundwater flow dynamics, the groundwater models, which take into account the interaction of springs with other water bodies and complex aquifer system, are the best available tools to evaluate the impact of groundwater pumping on spring flows.

The reduction in spring flow due to pumping was estimated using version 5.0 of the SWFWMD Northern District Groundwater Flow Model (NDMv5 model) (HGL and Dynamic Solutions, 2016). The NDMv5 groundwater model estimated a reduction of Silver Glen Springs flow of 2.1 cfs in 2010 due to pumping. The 2010-condition is the latest pumping and hydrologic condition NDMv5 was calibrated to. Therefore, it represents the best available information regarding the impact of current withdrawal on spring flow at Silver Glen Springs.

Next, the relationship between the groundwater pumping and the reduction in spring flow due to pumping was developed using the NDMv5 groundwater model. Figure B-9 shows the relationship between the pumping in the model within springshed plus one-mile buffer and the reduction in flow. It should be noted that the reduction in flow shown in Figure B-9 reflects the impact not only from the pumping within the springshed but also from the pumping within the rest of NDMv5 model domain (Figure B-11). Because of this, the flow reduction is more than the pumping within the springshed.

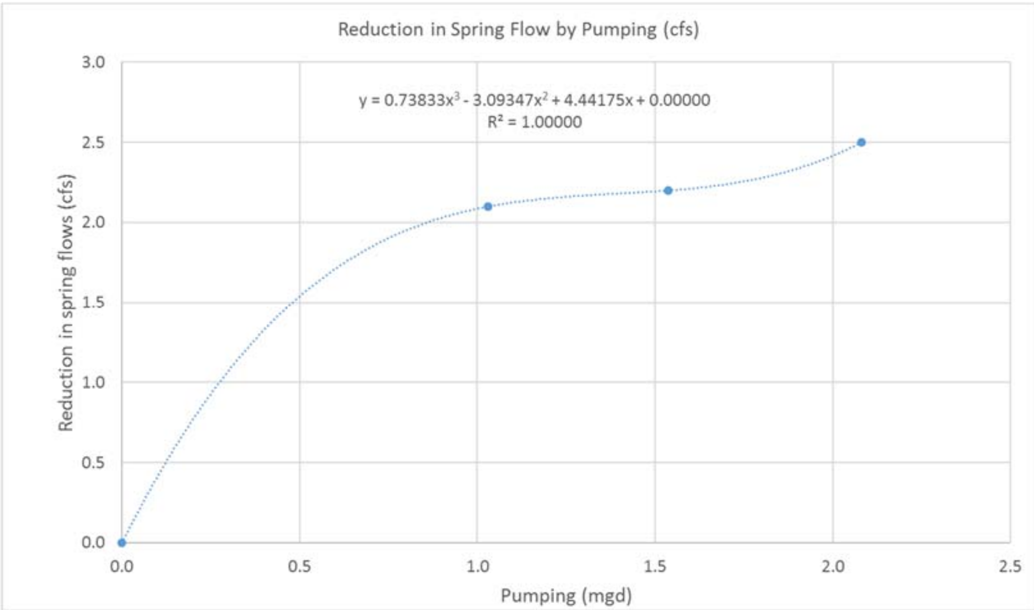

Figure B-9. Relationship between pumping and change in spring flow.

Using the estimated groundwater pumping from 1984 to 2015 and the relationship between pumping and the reduction in spring flow (polynomial function shown in Figure B-9), annual impact to the spring flow from historical pumping was estimated (see Figure B-10).

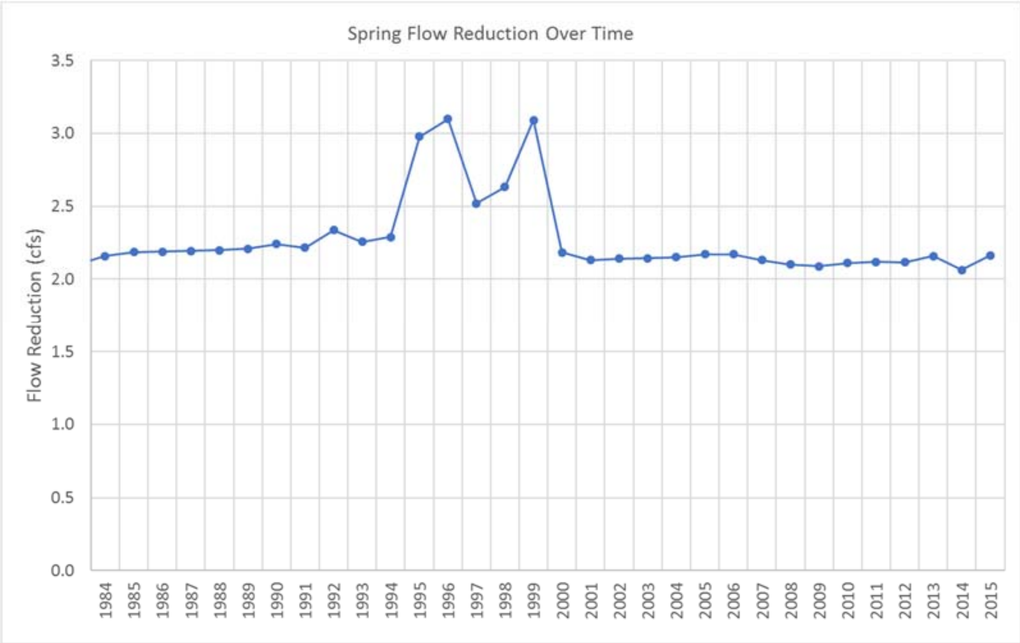

Figure B-10. Estimated impact of pumping on spring flow over time.

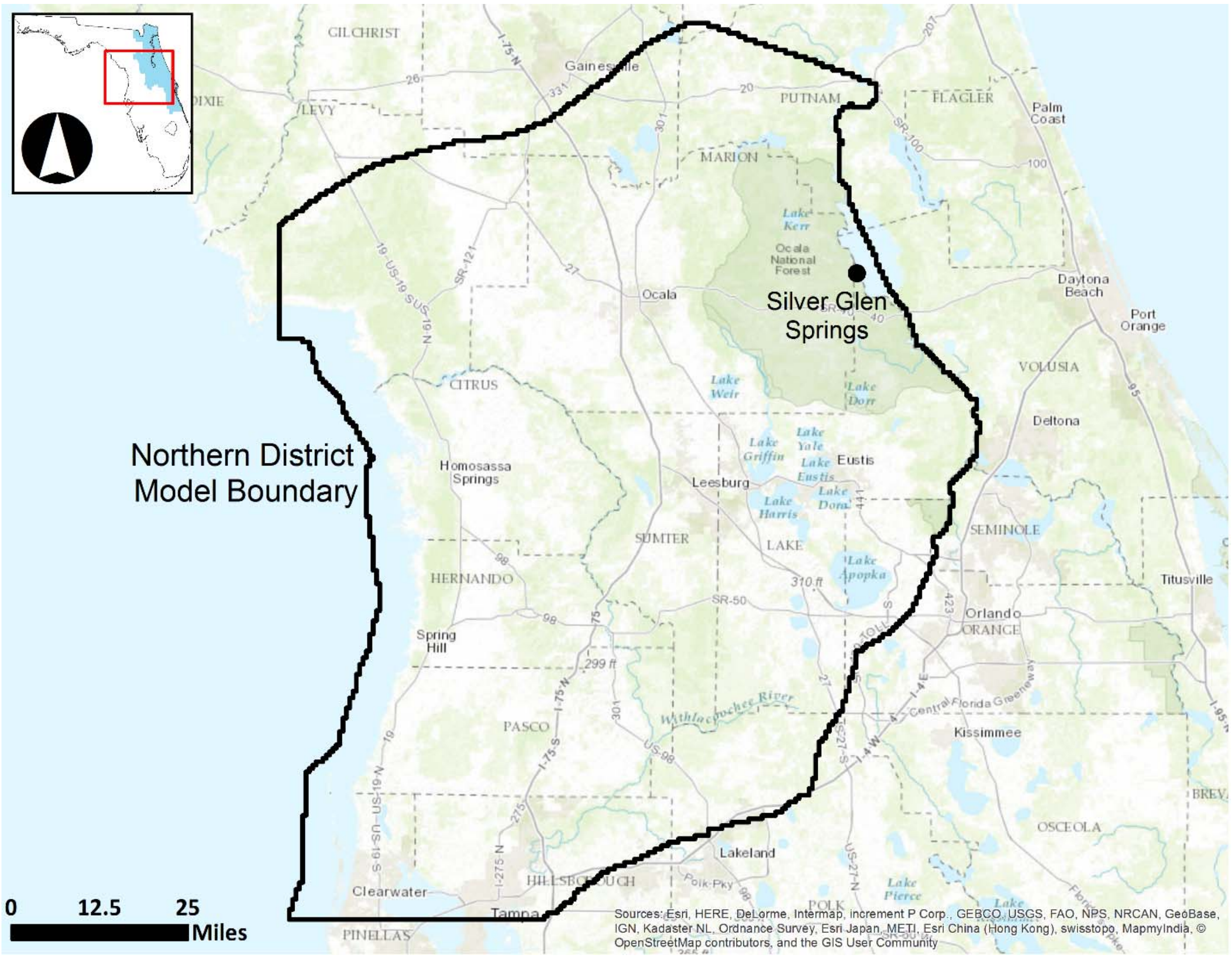

Figure B-11. NDMv5 model domain.

DEVELOPMENT OF SYNTHETIC FLOW TIME SERIES

Silver Glen spring MFL determinations and assessment are based on the mean discharge calculated using a baseline flow dataset representative of current pumping condition. The first step in creating the baseline 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 “no-pumping 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 B-10 were added to the annual means of observed spring flow data to create a “no-pumping condition” flow time series. This synthetic flow time series constitutes a reference hydrologic condition of the spring in which the impact from groundwater pumping is assumed to be minimal.

"Baseline condition" flow time series

The NDMv5 groundwater model estimated a reduction of spring flow of 2.1 cfs in 2010 due to pumping. This amount was subtracted from monthly synthetic no-pumping condition flow time series dataset to estimate a baseline condition flow time series dataset for Silver Glen Spring. The synthetic baseline flow time series dataset represents a reference hydrologic condition of spring in which the impact from groundwater pumping on spring flows is constant over time at a rate of 2.1 cfs. Assuming climatic, rainfall, and other conditions present from 1984 – 2015 are repeated over the next 20 years, the baseline 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 Silver Glen Springs. Figure B-12 shows the observed, no-pumping and baseline condition flows.

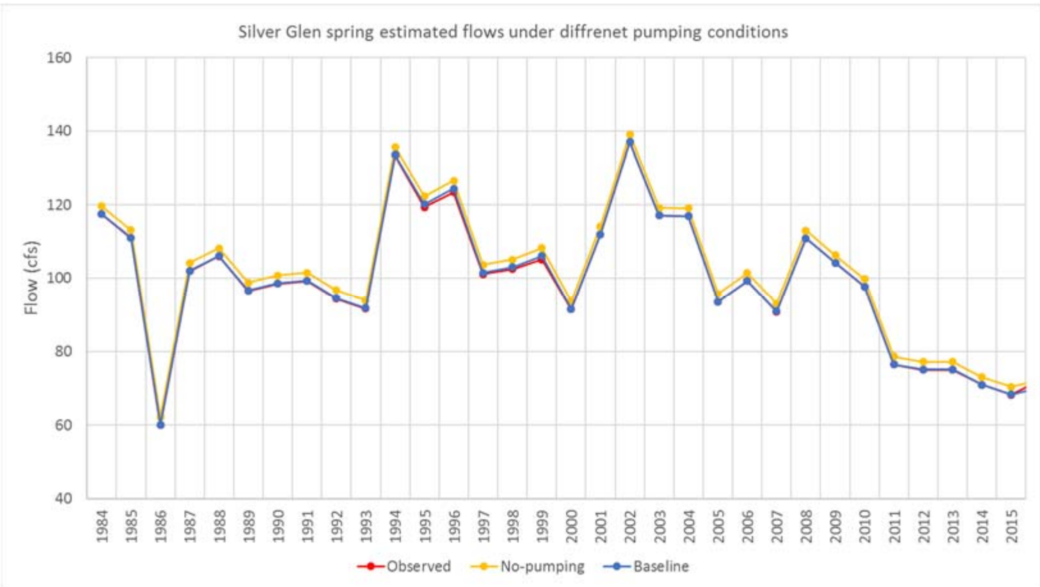

Figure B-12. Observed and Estimated spring flow datasets.

REFERENCES

Harmel, R. D., R. J. Cooper, R. M. Slade, R. L. Haney, and J. G. Arnold. 2006. Cumulative uncertainty in measured streamflow and water quality data for small watersheds. Trans. ASABE 49(3): 689-701

HGL and Dynamic Solutions, 2016. Northern district groundwater flow model version 5.0. Report prepared for the St. Johns River Water Management District and Southwest Florida Water Management District.

SJRWMD 2017. *www.sjrwmd.com/springs/silverglen.html*

Appendix C: Appendix C: Additional temperature modeling analysis

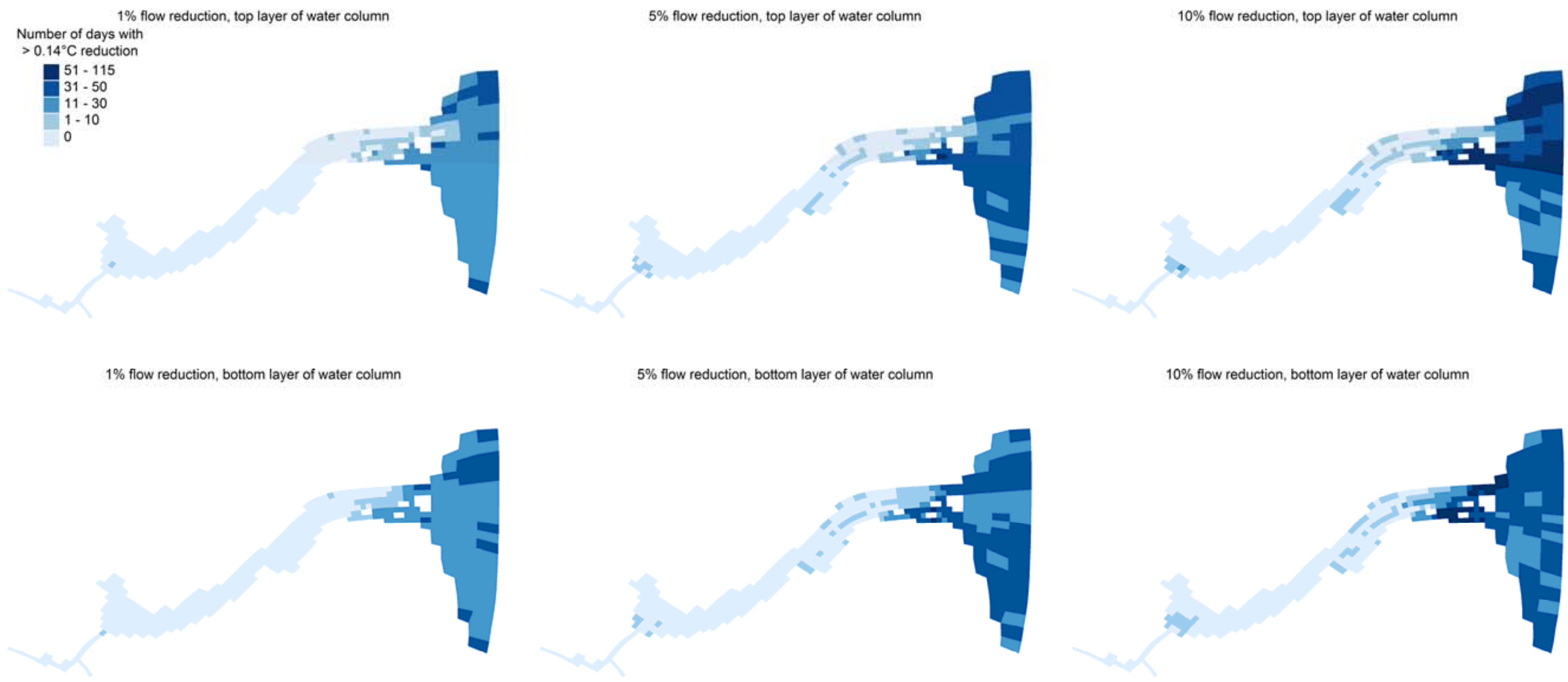

Figure C-1. Maps of Silver Glen Springs Run showing the total number of days in each cell that resulted in an at least 0.14°C simulated change under each flow reduction scenario for winter 2010–2011. Water levels in the St. Johns River in winter 2010–2011 were relatively low, likely leading to less cold water intrusion from Lake George. The flow reductions shown are in addition to the estimated 2.1% loss of flow due to 2010–2011 water use.

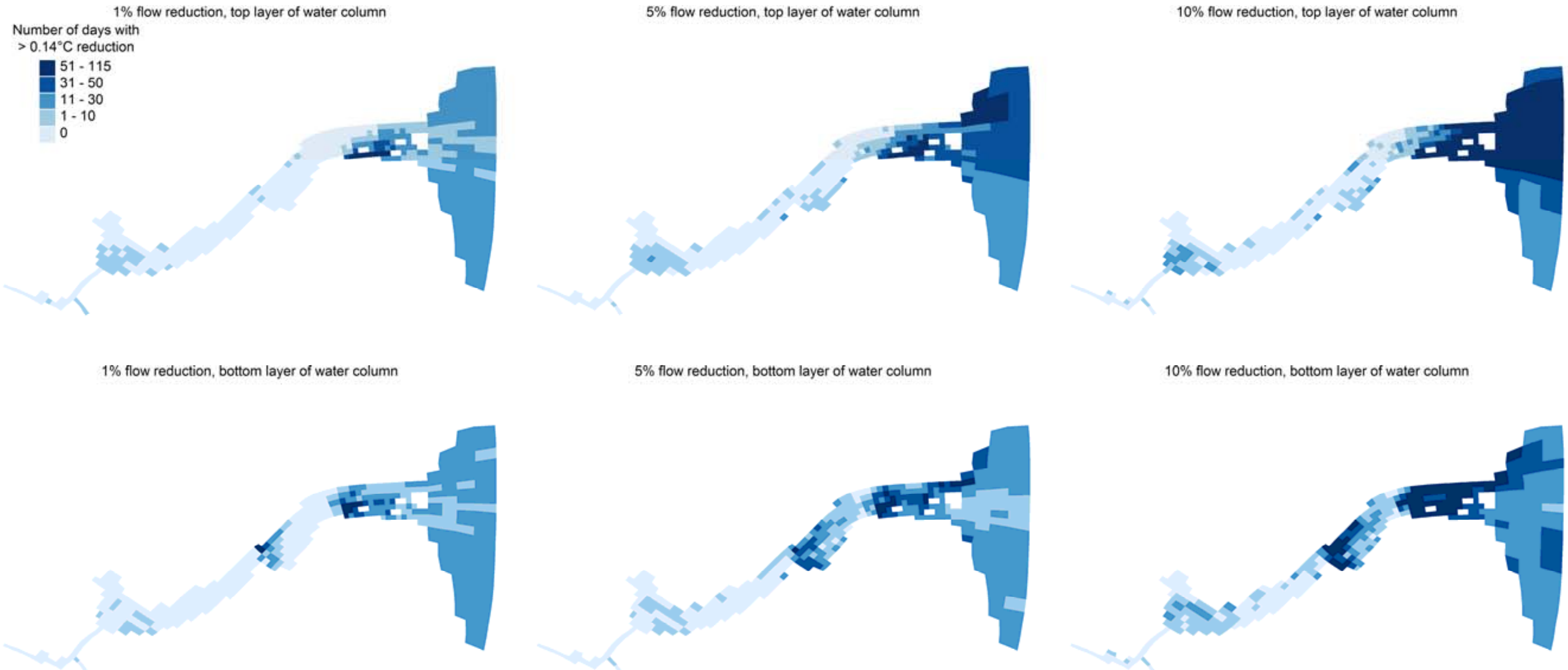

Figure C-2. Maps of Silver Glen Springs Run showing the total number of days in each cell that resulted in an at least 0.14°C simulated change under each flow reduction scenario for winter 2014–2015. Water levels in the St. Johns River in winter 2014–2015 were relatively high, likely leading to greater cold water intrusion from Lake George. The flow reductions shown are in addition to the estimated 2.1% loss of flow due to 2014–2015 water use.

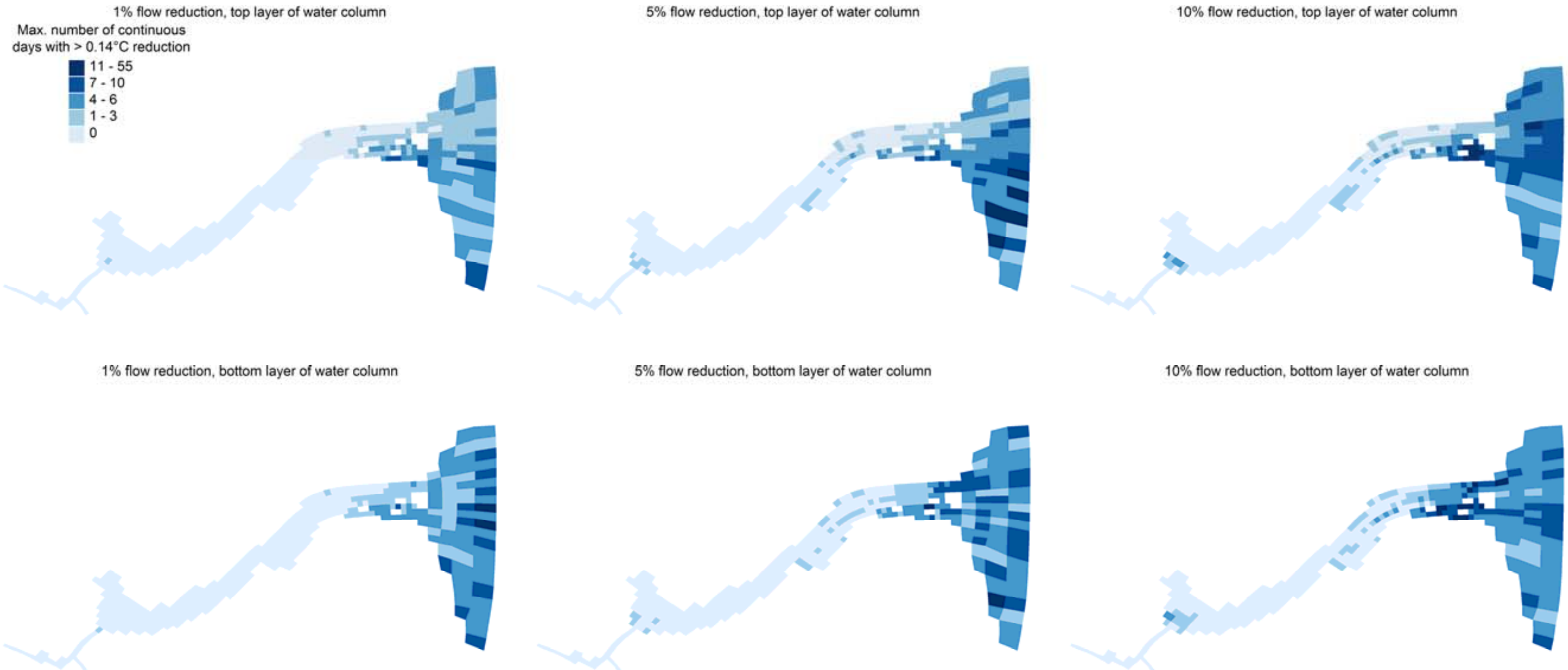

Figure C-3. Maps of Silver Glen Springs Run showing the maximum number of continuous days in each cell that resulted in an at least 0.14°C simulated change under each flow reduction scenario for winter 2010–2011.

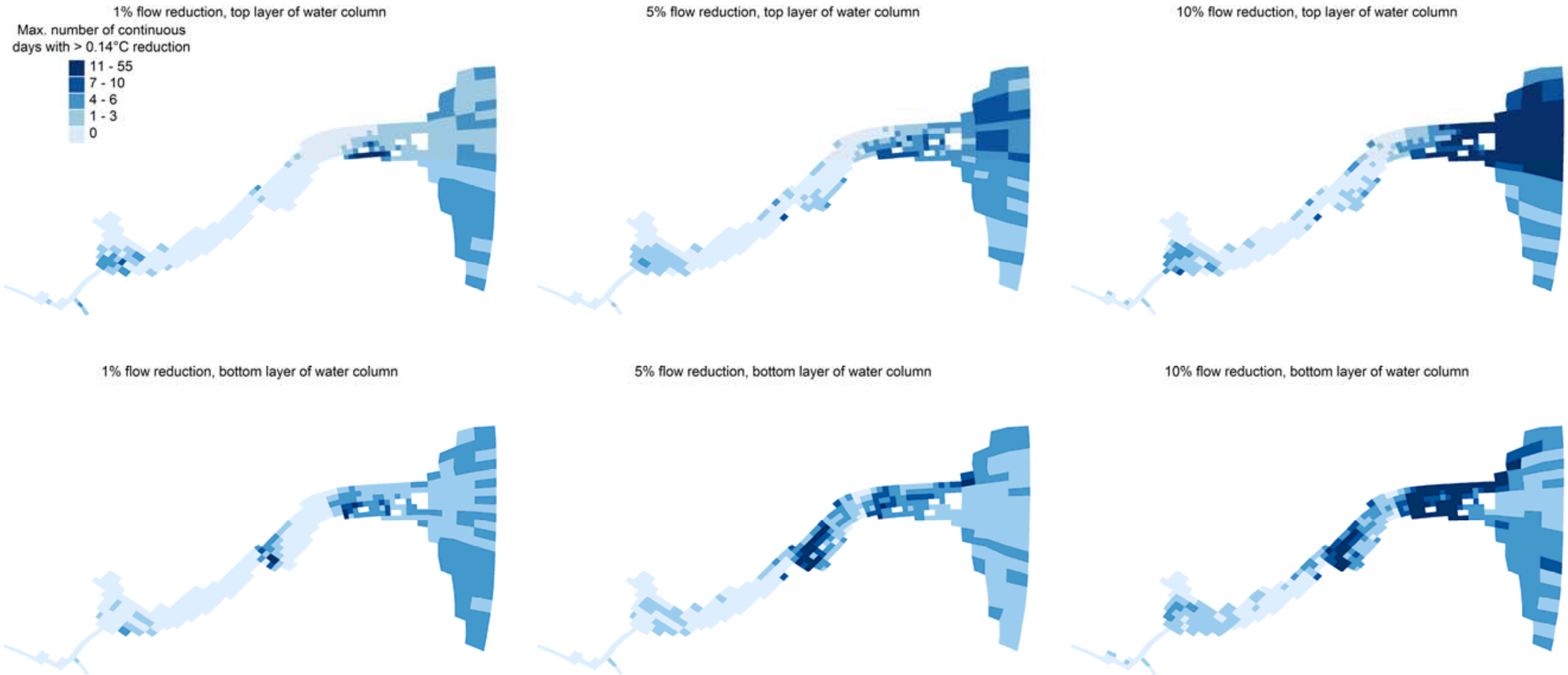

Figure C-4. Maps of Silver Glen Springs Run showing the maximum number of continuous days in each cell that resulted in an at least 0.14°C simulated change under each flow reduction scenario for winter 2014–2015.

Appendix D: Appendix D: Letter from Fish and Wildlife Conservation Commission (FWC)

March 3, 2017

Andrew B. Sutherland, Ph.D.
MFLs Technical Program Manager
Bureau of Resource Evaluation and Modeling
St. Johns River Water Management District
P.O. Box 1429
Palatka, FL 32178-1429
asutherl@sjrwmd.com

RE: Silver Glen Springs Minimum Flows and Levels, Marion County

Dear Dr. Sutherland:

We appreciate the presentation that the St. Johns River Water Management District (SJRWMD) provided on February 16, 2017, on the approach and modeling that is being taken regarding the development of the Silver Glen Springs Minimum Flows and Levels (MFL).

During the discussion, SJRWMD staff requested that the Florida Fish and Wildlife Conservation Commission (FWC) staff provide wildlife-related technical information that would assist their determination of "at what percent flow reduction does significant harm to manatees occur?" and information on usage of the spring-run by other species that may also need to be considered in the development of the MFL.

Maintaining adequate warm water for manatees has been identified by SJRWMD as the guiding parameter for determining the Silver Glen Springs MFL. Silver Glen Springs is a secondary warm water site and a critical component of the network of natural warm water sites utilized by hundreds of manatees each winter in north-central Florida. SJRWMD modeling efforts indicate that reductions in flow could affect this wintertime manatee thermal refuge, located in the St. Johns River system. We understand that only limited data collection occurred near the St. Johns River portion of the spring-run (Area 2) resulting in a less than desirable amount of data used in the modeling efforts. We recommend that additional data collection occur in the vicinity of the St. Johns River portion of the spring run (Area 2) due to its consistent use by manatees. The SJRWMD modeling and the 2035 pumping projections indicated a potential 0.4 cfs change in flow from 2010 conditions. We have no indication that the proposed 0.4 cfs change in flow will affect the current extent of warm water habitat. The 5% change in flow also modeled would likely affect the amount of warm water habitat available for manatees; however, the extent of the affect is unclear based on the information currently available. FWC supports the establishment of MFLs to ensure that warm water habitat that is accessible to manatees is protected.

The St. Johns River is the southernmost extent of the Atlantic striped bass (*Morone saxatilis*) range. Silver Glen Springs is a primary summer thermal refuge habitat which holds one of the largest aggregations during the summer and fall months. Spring-flow reductions during the summer months that limit passage to this thermal refuge may affect the Atlantic striped bass population in the St. John River. The current SJRWMD analysis

Andrew B. Sutherland
Page 2
March 3, 2017

only models water temperature during the winter months. We recommend incorporation of water temperatures during the summer and fall months during future modeling efforts.

Additionally, bluenose shiner (*Pteronotropis welaka*, State Threatened) has disjunct populations in the Florida panhandle and the St. Johns River drainage, which may include Silver Glen Springs. Bluenose shiners from the St. Johns River population typically occupy spring-fed rivers and spring runs that contain dense emergent and submersed aquatic vegetation. The bluenose shiner Species Action Plan lists several threats pertinent to the Silver Glen Springs MFL including changes in water quality and quantity, and habitat alteration. FWC staff supports the establishment of MFLs that is protective of water quality and quantity that supports habitat for this species.

We appreciate the opportunity to provide you technical assistance as part of the development of the Silver Glen Springs MFL. We look forward to reviewing the draft Silver Glen Springs MFL document when it is completed. If you need any further assistance, please contact Jane Chabre either by phone at (850) 410-5367 or at FWCConservationPlanningServices@MyFWC.com. If you have specific technical questions regarding the content of this letter, please contact Ted Hoehn at (850) 488-8792) or by email at Ted.Hoehn@MyFWC.com.

Sincerely,

Jennifer D. Goff

Jennifer D. Goff
Land Use Planning Program Administrator
Office of Conservation Planning Services

jdg/th
ENV 1-12-2
Silver Glen Springs MFL_32549_030317

cc: Mike Register, SJRWMD, MREGISTE@sjrwmd.com

Appendix E: APPENDIX E: COMPARISON OF FLOWS AND LEVELS AT SILVER GLEN SPRINGS AND OTHER WATER BODIES

The results of our review of best available information and water levels and flows of other water bodies near Silver Glen are summarized as follows

1) Although there is a downward shift observed in the estimated flows after 2010, the water levels have been increasing during the same period. Thus, the cause of the shift could be something in addition to or other than climate. However, there is not sufficient long-term reliable flow and level data to do a conclusive analysis to determine the cause.

2) Other water bodies in the region have shown a similar pattern of low levels in recent years, indicating that the recent period of low flows at Silver Glen Springs may not be explained only by factors specific to Silver Glen Springs (Figure E-1Figure E-6).

3) Groundwater pumping impact analysis using the groundwater model has shown that no additional reductions in spring flow due to water use have occurred after 2010 (Figure B-8 in Appendix B). Therefore, the recent period of low flows cannot be explained by the impacts from water use.

It is difficult to determine the cause of the downward shift in low flows after 2010 due to significant uncertainties in the flow dataset and the absence of long-term flow and level data as discussed in Appendix B. Because of this, no determination can be made whether the recent period of low flows indicates a change in the longer-term hydrologic regime or not. In addition, the purpose of MFLs is to establish the limits “at which further withdrawals would be significantly harmful”. The groundwater pumping impact analysis discussed in Appendix B indicated that the low flows after 2010 are not the result of impacts from water use. As a result, the best available dataset discussed in Appendix B was used to determine and assess the MFLs.

If additional information becomes available in the future indicating that the longer-term hydrologic regime of the spring has permanently changed for reasons other than withdrawals, it may be appropriate to re-evaluate the MFL under the new flow regime.

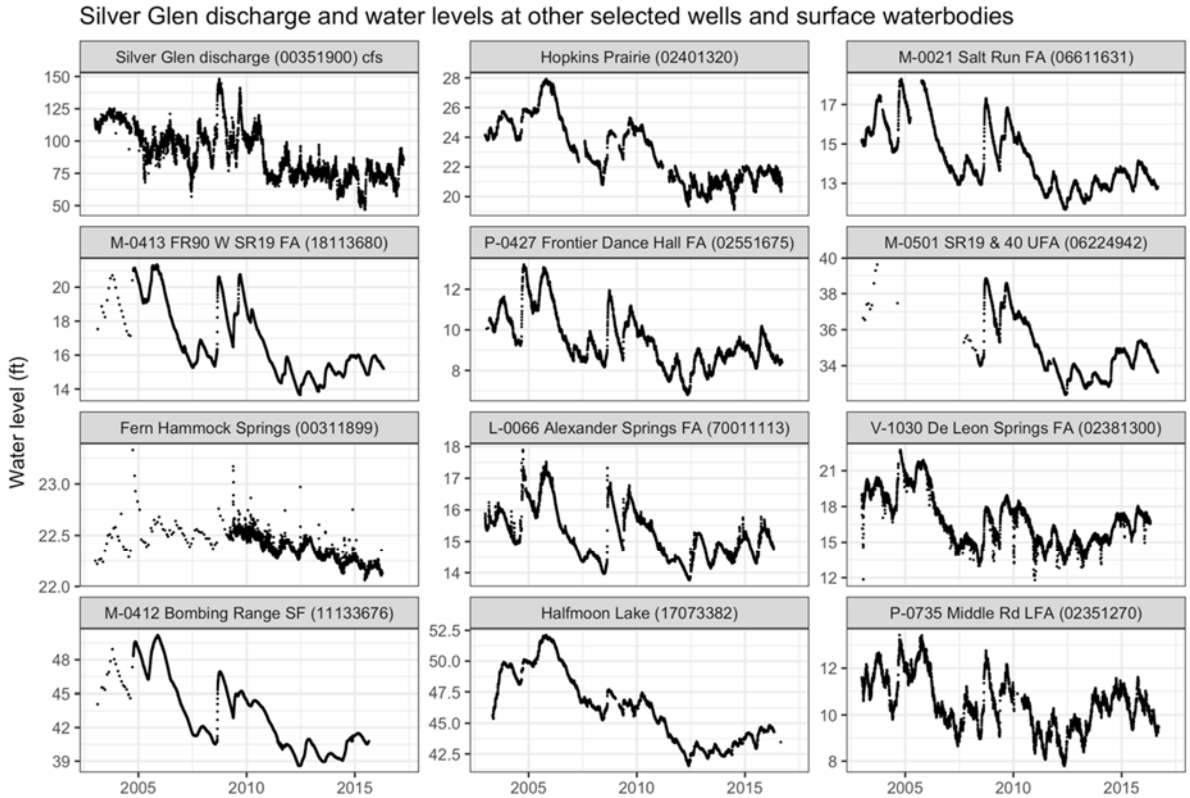

Figure E-1. Comparison of discharge at Silver Glen and water levels at other sites, selected based on proximity and similarity to the hydrograph of Silver Glen.

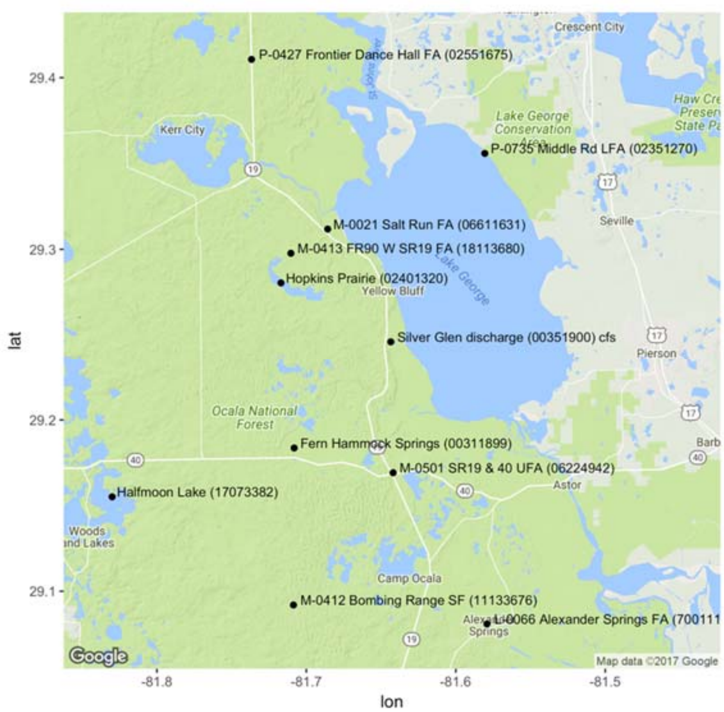

Figure E-2. Map of selected wells and surface waterbodies shown in the previous figure.

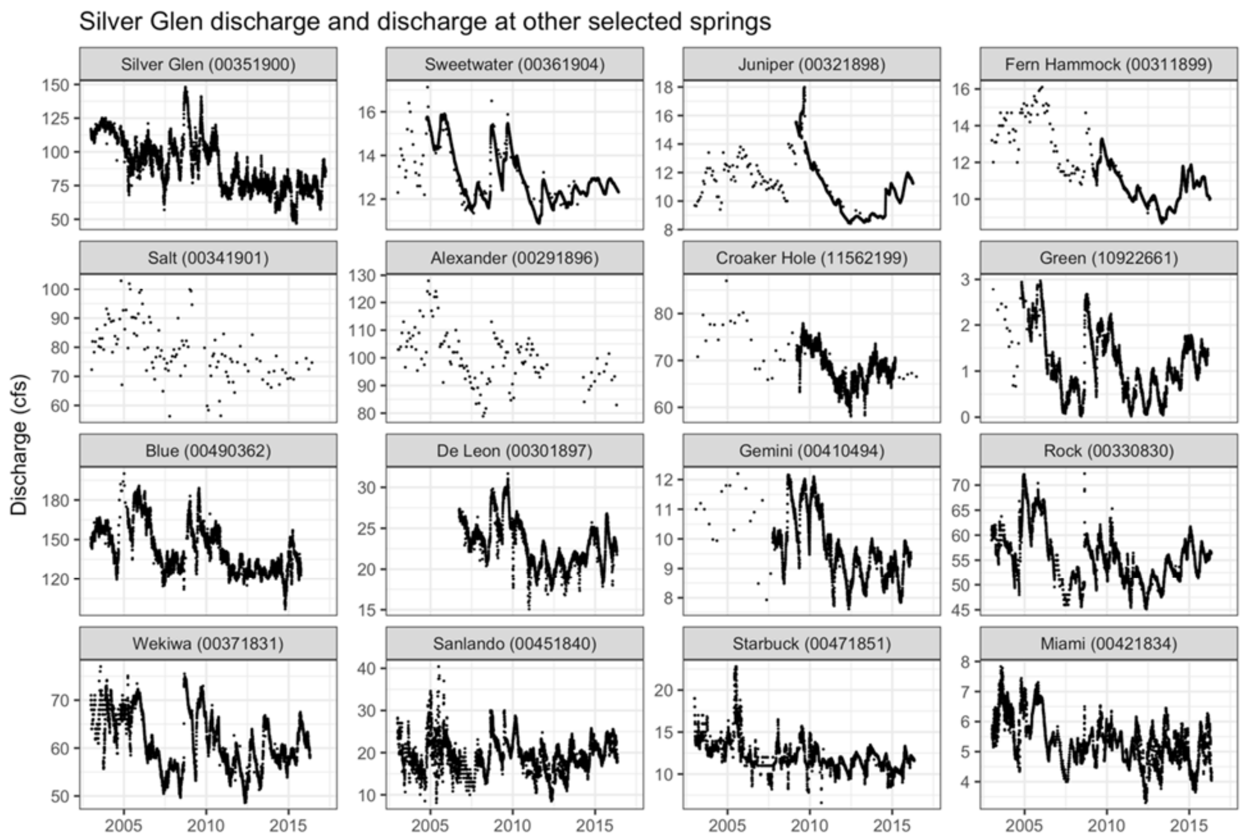

Figure E-3. Comparison of discharge at Silver Glen Springs and other selected springs.

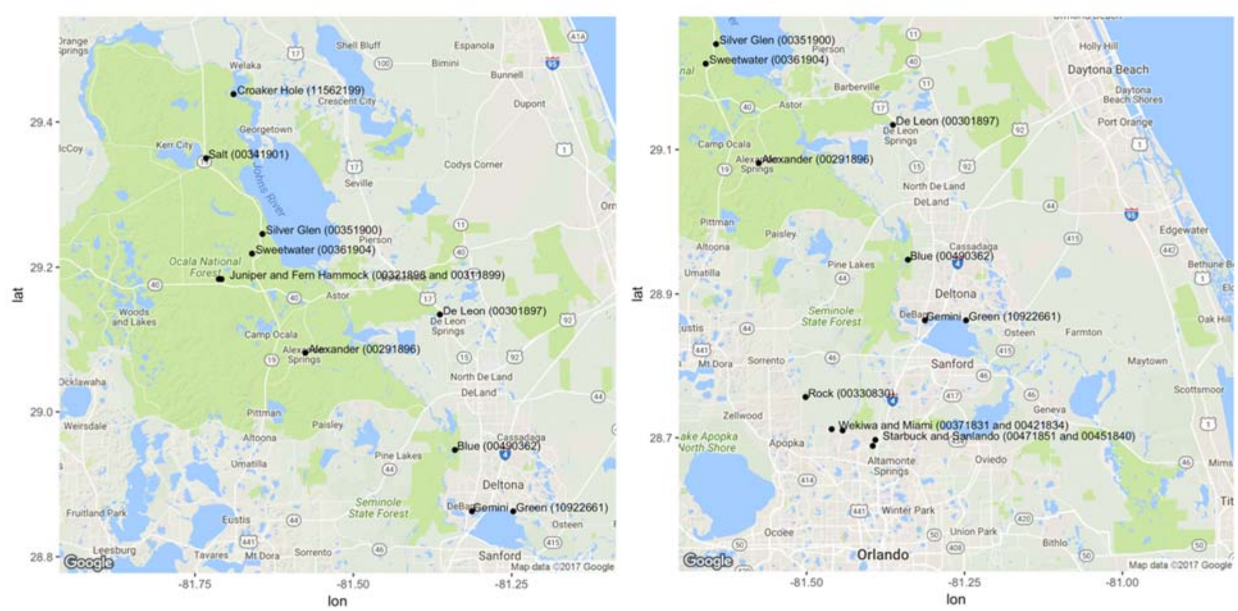

Figure E-4. Maps of selected springs shown in the previous figure.

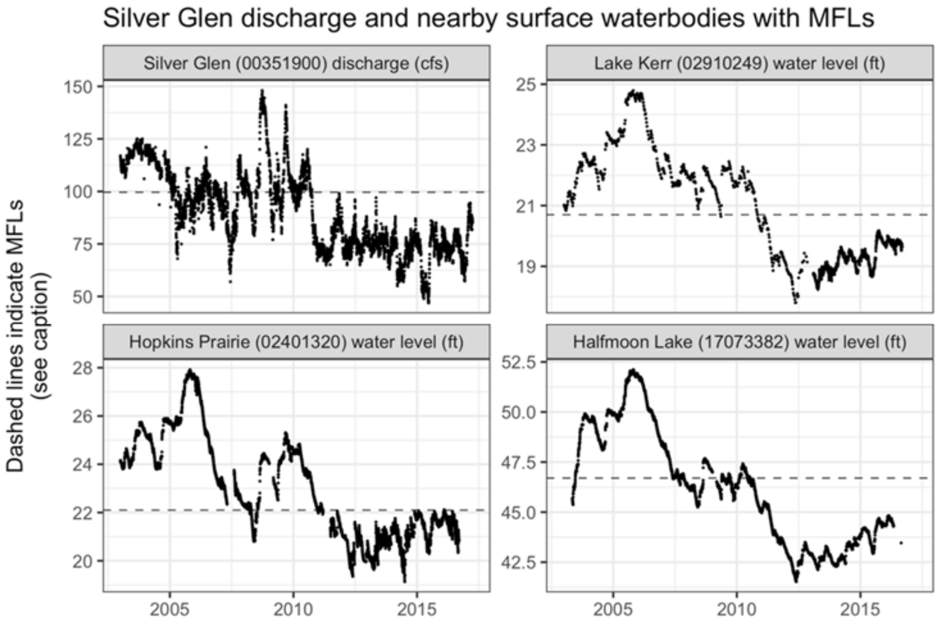

Figure E-5. Waterbodies with established MFLs near Silver Glen. The dashed lines indicate the recommended mean flow for Silver Glen, and the established minimum average water levels for each of the other sites.

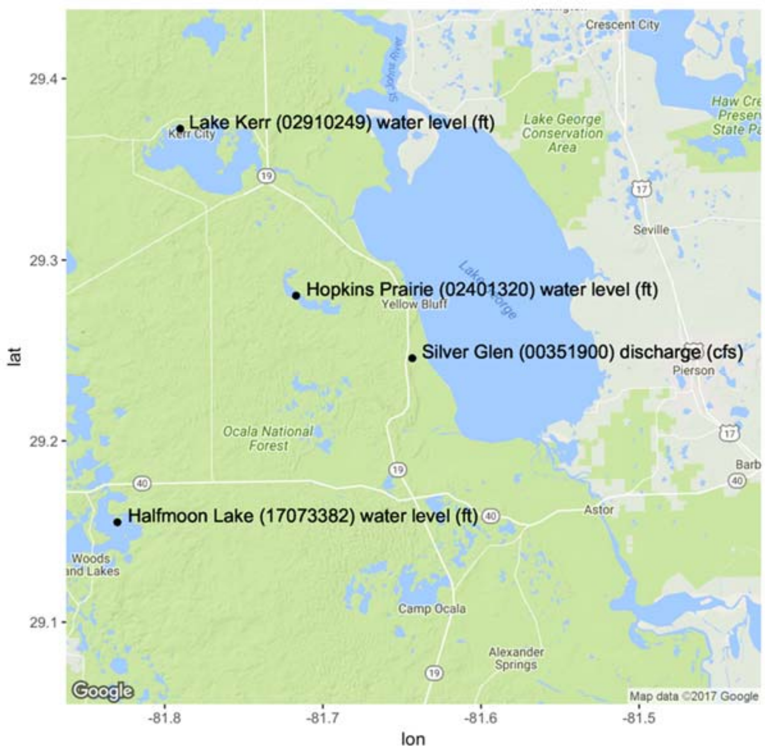

Figure E-6. Map of sites with MFLs shown in the previous figure.

Silver Glen Springs Run Temperature Model: Hydrodynamic Analysis and Model Summary

By

Joseph B Stewart, P.E
Engineer-Scientist

St. Johns River Water Management District
Palatka, Florida

4 April 2017

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Contents

INTRODUCTION

Silver Glen Springs produces 1st magnitude flow (average 102 cfs) to Silver Glen Springs Run, located in the Ocala National Forest, Florida (SJRWMD, 2016). In support of the development of the Silver Glen Springs MFL, a hydrodynamic model for diurnal water temperature was developed for the Run using EFDC. This report summarizes hydrodynamic analysis, model calibration and validation. To evaluate the sensitivity of Run temperature to changes in discharge, the calibrated model is compared to a 20 percent reduction in spring flow. Salinity and water age estimations for the system, and a basic sensitivity analysis of other parameters is also provided. The model was calibrated from 11/01/2013 to 4/30/2014, focusing on cold weather incursions in the winter.

1 DESCRIPTION OF STUDY AREA

The model domain consists of five major components: The head pool, the upper and lower halves of Silver Glen Springs Run (SGSR), the Sandboil Run, and a portion of Lake George outside of the SGSR (Figure 1-1). The word 'Run' when used alone stands for SGSR. Table 1-1 contains a summary of the major features discussed in this report. A surface area of 21.75 acres was estimated from aerial imagery for the system including Sandboil Run. The SGSR is approximately 1000 meters (1 km) in length. The upper portion extends from the swimming area barrier to 500 m downstream and the lower portion encompasses the reach from 500 to 1000 m. Two major springs, the 'Main Vent' and 'Natural Well' are shown in the inset in Figure 1-1.

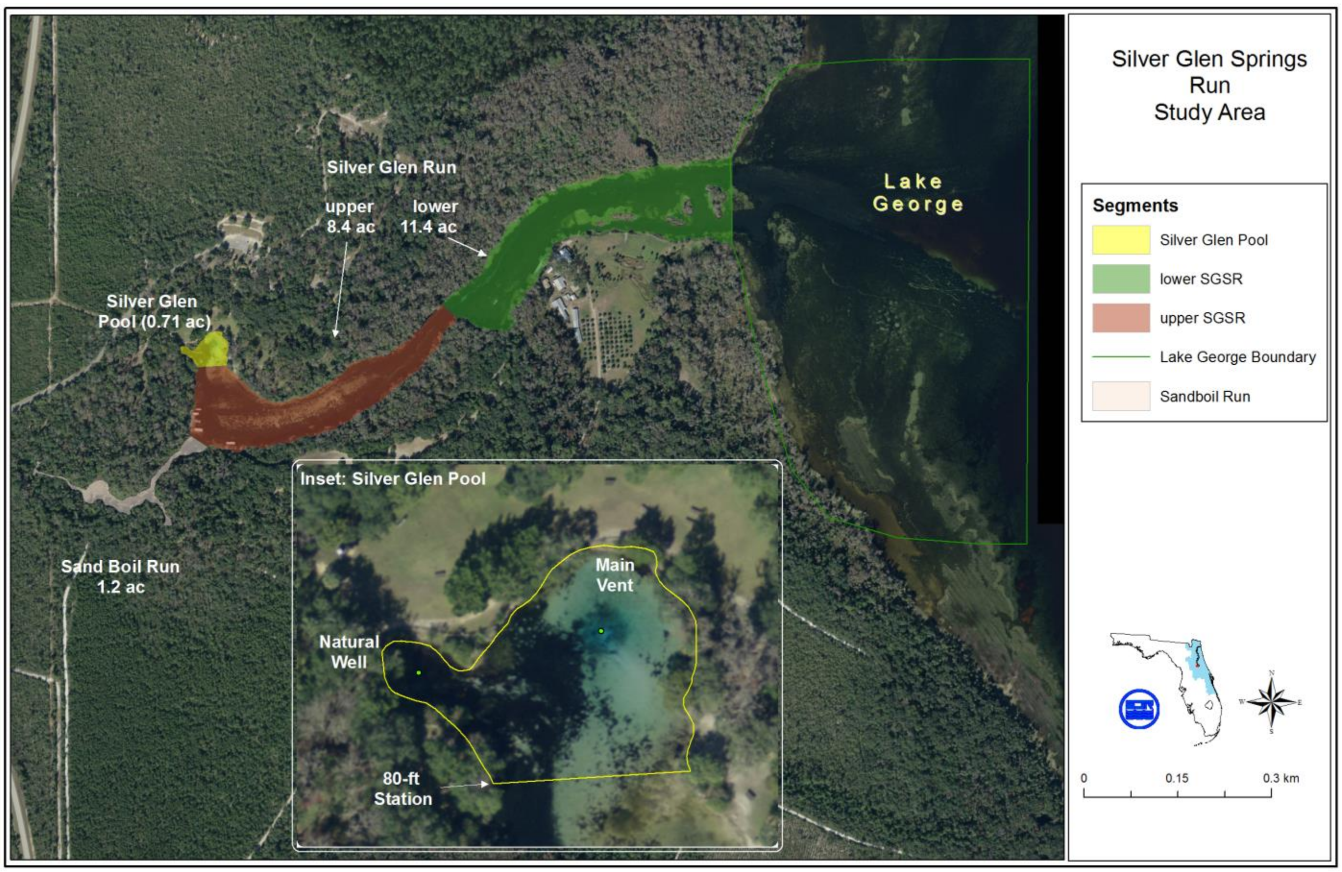


Figure 1-1. Major surface water features discussed in this study

Table 1-1. Description and areal extent of surface features used in this report

Feature	Description
Silver Glen Springs Pool	A free-flowing spring pool generally located at 3235577.5 m N, 437467.6 m E. Model domain includes the pool and spring vents.
Main Vent	The larger of the two major Silver Glen springs, located centrally in the head pool
Natural Well	The smaller of the two major Silver Glen springs, located in a small basin on the west side of the head pool
USGS 80-foot station	Location of cross section where discharge and stage measurements for Silver Glen Springs are collected, used to demarcate the pool (swimming area) from the Run. It is 80 feet downstream of the Main Vent. USGS Stn # 02236160
Upper Silver Glen Springs Run	Upper 500 meters of the 1 kilometer SGSR
500-m location	Location where temperature sensors have been previously deployed (Ross, 2016; WSI, 2010). Halfway down the Run.
Lower Silver Glen Springs Run	Lower 500 meters of the 1 kilometer SGSR
Sandboil Run	Approximately 350 m spring run with small springs that connects to SGSR
Ocala National Forest	Region surrounding Silver Glen Springs and encompassing most of the Silver Glen springshed
Lake George	Silver Glen Springs Run discharges to Lake George, a flow-through lake of the Saint Johns River

1.1 Spring and Surface Watershed Contribution

In addition to the Main vent and Natural Well, several small springs and numerous seeps enter the system in Sandboil Run (Inset, Figure 1-2). Seepage is also evident in the tributary on the south side. At present SGSR is encompassed by the Ocala National Forest on the north and west side, while the south side of the Run is under private ownership. Discharge from the springs and sand boils is unstructured (free-flowing). The stage in SGSR is controlled by water level in Lake George. Figure 1-2 also includes the locations of data collection sites discussed in this report.

From field reconnaissance, the local contributing watershed to SGSR was estimated to be about 236 acres, with about twice as much contributing area on the north than on the south side of the Run (Figure 1-3). Recharge rates are very high in the region and thus watershed runoff is likely low. Local drainage is directed to the head of Sandboil Run, and two small tributaries enter SGSR—on the south side about midway and on the north side near the end of the Run. Yellow arrows in Figure 1-2 indicate the location and approach angle of the tributaries, Figure 1-3, shows where the runoff was applied as a model boundary. A field visit to evaluate the drainage features surrounding the Run indicated that the runoff is flashy, with near zero baseflow. About a third of the drainage area is focused through the tributaries, while the remaining runoff enters the system as overland flow from the adjacent uplands.

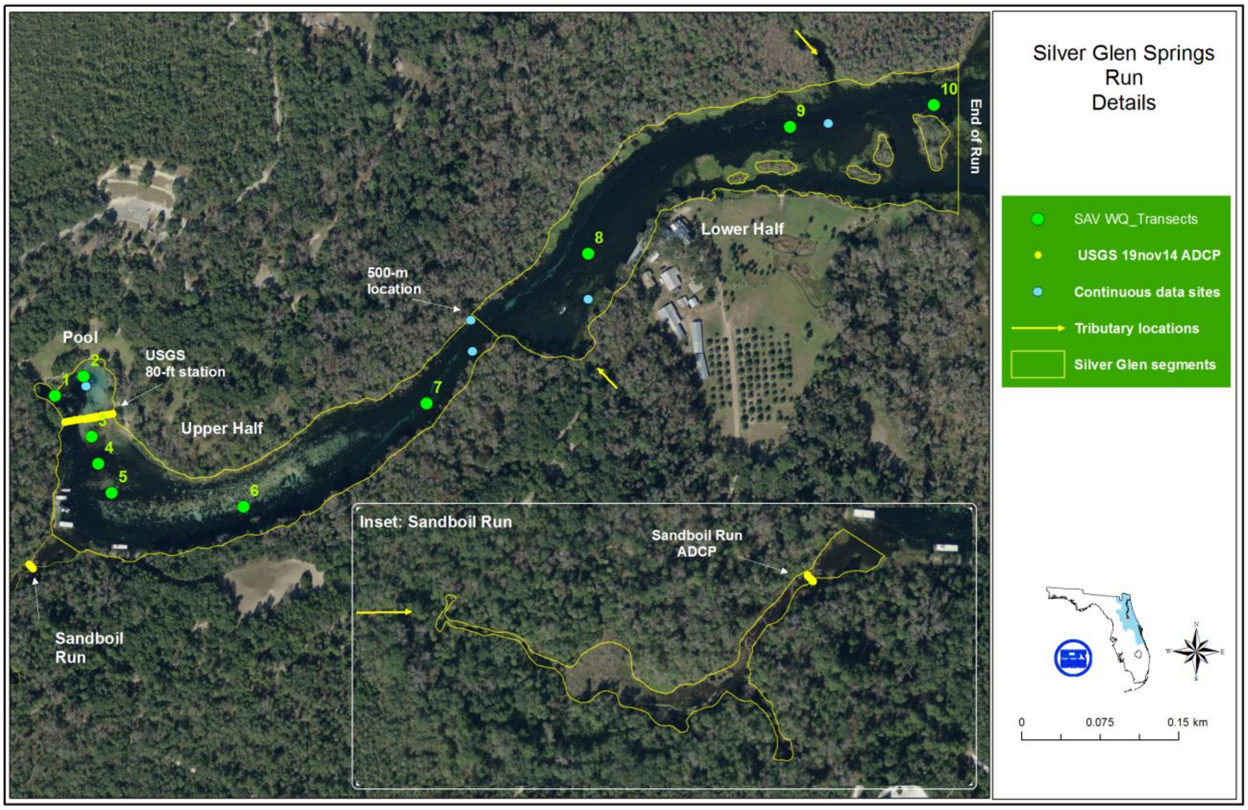


Figure 1-2. Silver Glen Springs Run Details.

Figure 1-3. Silver Glen Springs Run Watershed

An estimation of tributary inflow was made from an HSPF model of the region (SJRWMD, 2012a) by proportioning the area of the HSPF data to the size of the SGSR watershed (Figure 1-4). Since no observed temperature data exists for runoff a time series was produced by correlating Pierson air temperature to the Econlockhatchee River, a stream in the region with six years of daily temperature data (1/1/2010 to 12/31/2015). To do this first a six-day moving average of the daily Pierson air temperature was calculated. Then a linear regression (T_bnd = 0.93 * T_mv_avg + 2.84) was used to fit the moving average to the Econlockhatchee River water temperature, producing a fit of $r^2 = 0.94$ for the 6-year period. In this way, the Pierson air temperature could be used to supply a daily temperature time series for runoff whenever needed. Salinity was assumed constant at 0.1 for watershed runoff. The model response to the addition of surface runoff was nominal as shown in Section 7.2. For this reason, and since the hydrograph and temperature time series can only provide a crude estimation of watershed contribution, it was omitted from the final model setup and calibration. The features of the SGSR watershed suggest response to rainfall is quick, so a typical runoff peak lasts a few hours. It is the large slug of initial runoff that will have the most noticeable effect on diurnal temperature.

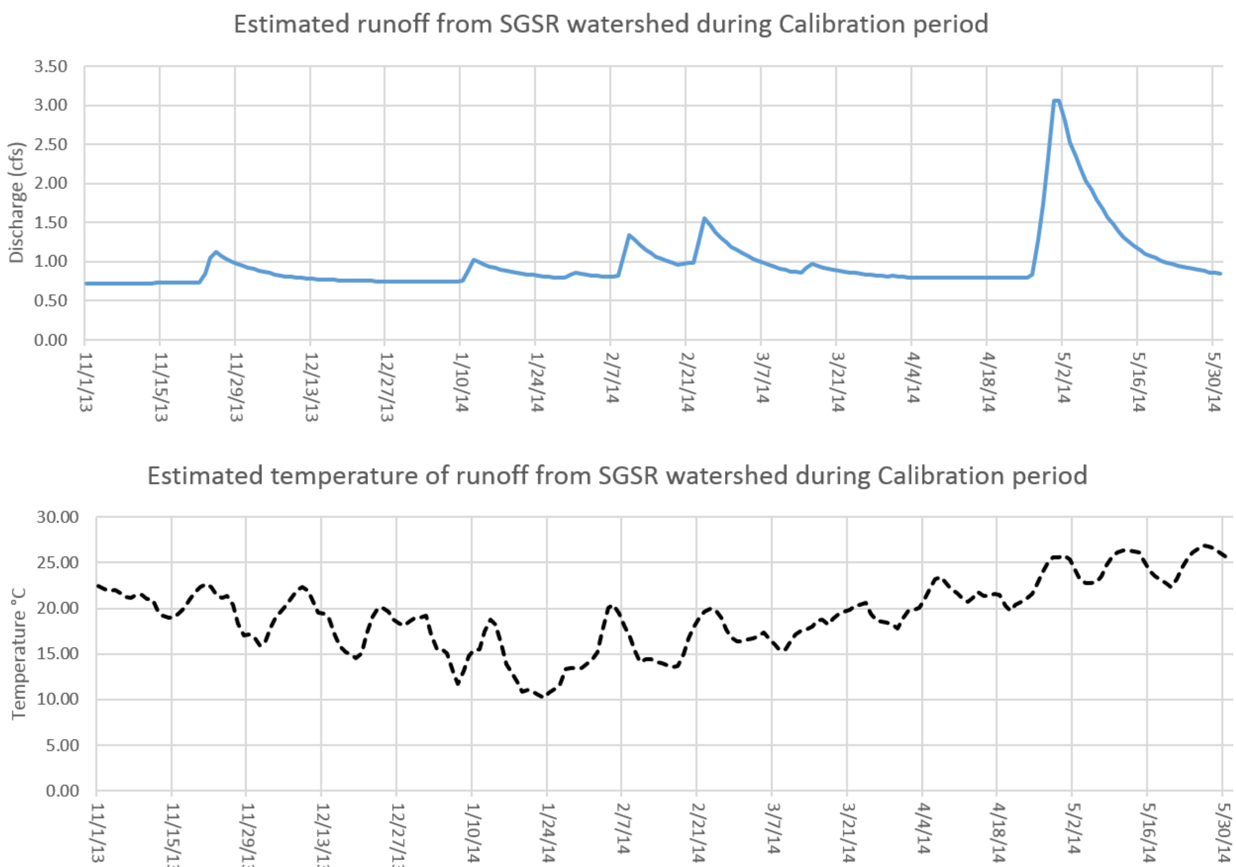


Figure 1-4. Estimated temperature and discharge for SGSR watershed runoff during Calibration period

1.2 Anthropogenic influences on Silver Glen Springs Run

The area around SGSR has been utilized by humans for thousands of years. Occupation of the site by Native American villages had a major influence on structure of the Run (Randall, 2011). As successive generations enhanced mounds along the Run, the shorelines and bottom became hardened by shell substrate. In the early 20th century, mound substrate was excavated, expanding the width of SGSR along most of it's length, expanding the volume of the upper segment and almost tripling the volume of the lower segment (Sassaman, 2011). Some material remains in the bottom of much of the Run, resulting in a system with a hard bottom in many areas as discussed in Section 2.3.

A dredged canal approaching the Run is evident from the 1941 historical imagery (Appendix 11.2). The continuous use by boat traffic has worn down the features of the canal, and there is no evidence that it has been dredged since the 1941 image, but from the 2014 bathymetric survey (Figure 2-3), the deeper approach to the SGSR is still evident. The islands in the lower Run are noticeably larger in 1941 than in recent images. In the upper 1/3 of the Run, continuous foot and boat traffic has reduced the amount of vegetation. A review of historical aerial imagery indicates that prior to the 1980s, the Run appears to predominantly vegetated in the upper part of the Run as in the 1972 imagery (Appendix 11.2). From inspection of the 1941 image the light-colored areas within the Run appear to be topped-out submerged aquatic vegetation (SAV) with some floating vegetation like what is visible outside of the SGSR in Lake George (Figure 2-10). In areas of heavy boat traffic like the approach to the mouth of SGSR shown in Figure 2-10, SAV coverage is visibly reduced. The presence and/or absence of vegetation influences the hydraulics and mixing within the Run, and to some extent light penetration.

1.3 THERMOGRAPHY OF SILVER GLEN SPRINGS RUN AND LAKE GEORGE

Thermography was flown in February 2003 in the region of Lake George and the Ocala National Forest (Davis, 2007). The thermal image provides a winter time snapshot of the distribution of temperature within SGSR and out into Lake George. The thermal image indicates that the upper part of the Run is somewhat thermally insulated (note more persistent red color) from mixing with Lake George. The lower part of the Run contains spring water that is mixing with colder Lake George water. The Sandboil Run is colder than the upper part of SGSR (see inset), due to the shallowness and residence time of the segment. It was decided to include the Sandboil Run in the model domain to allow the model to calculate temperature in the back reach before it enters the main body of SGSR just downstream of the main pool. That way, Sandboil Run water takes on some of the diurnal character due to day-night variations in air temperature, solar radiation, etc.

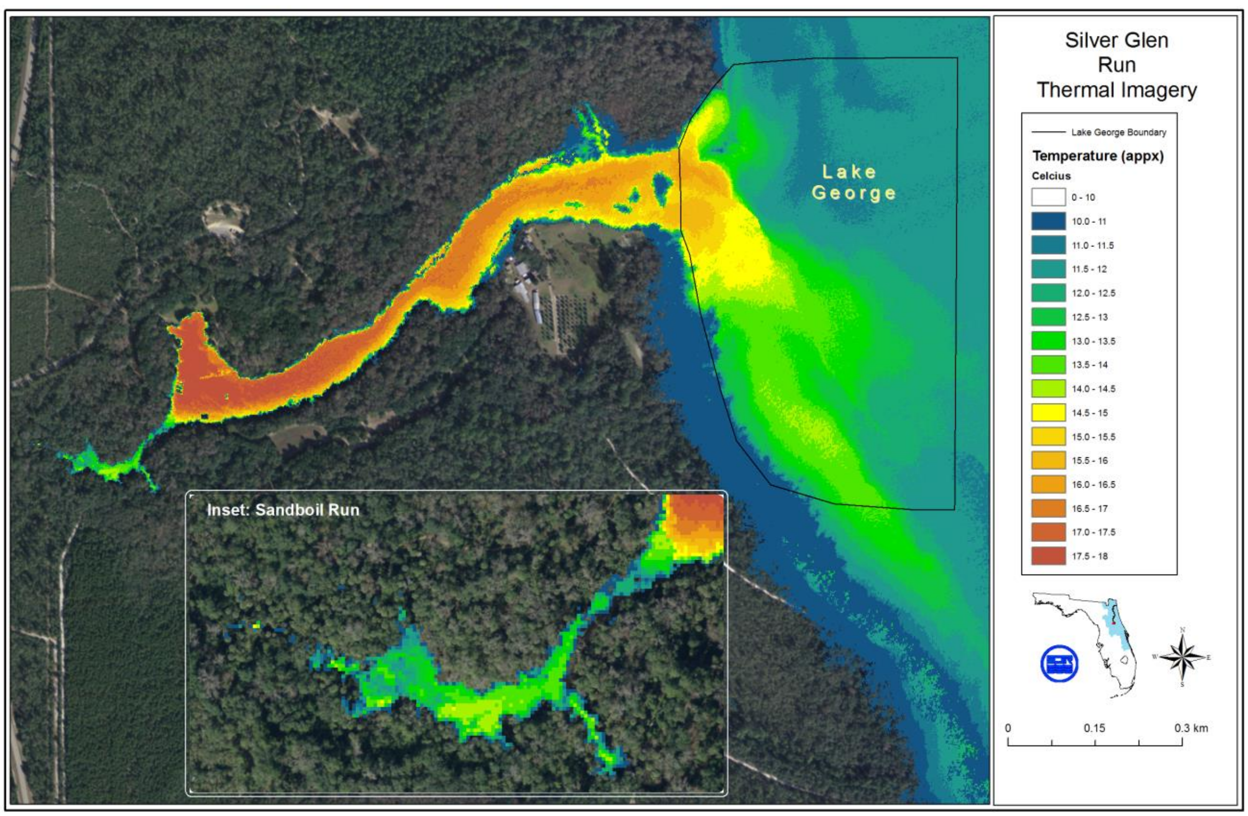


Figure 1-5. SGSR thermal imagery

1.4 Regional salinity/chloride character

Chloride concentration of the underlying Upper Floridan Aquifer is shown in Figure 1-6. The springshed is in the mostly undeveloped Ocala National Forest. The 5-year capture zone was estimated during previous District work. USGS, 2001 provides analysis of the regional surfical aquifer characteristics, and USGS, 2002 provides an analysis of the regional Floridan Aquifer system. Based on an analysis of available data, the average for Silver Glen Main Vent salinity is 0.91 is high in comparison to the UFA chloride / salinity concentrations shown in the figure. For reference, the threshold for shifting from freshwater to oligohaline conditions is a salinity of 0.5 (Venice, 1958). Much of the Silver Glen springs 5-year capture zone and SGSR overlays a salinity of 0.1 to 0.5, while the rest of the springshed overlays a salinity of 0 to 0.1, indicating at some point the water passes through or is mixed with sources from higher salt concentrations to result in the average for the Silver Glen Main Vent, perhaps from lower in the Floridan, or from east of the spring where UFA concentrations are higher.

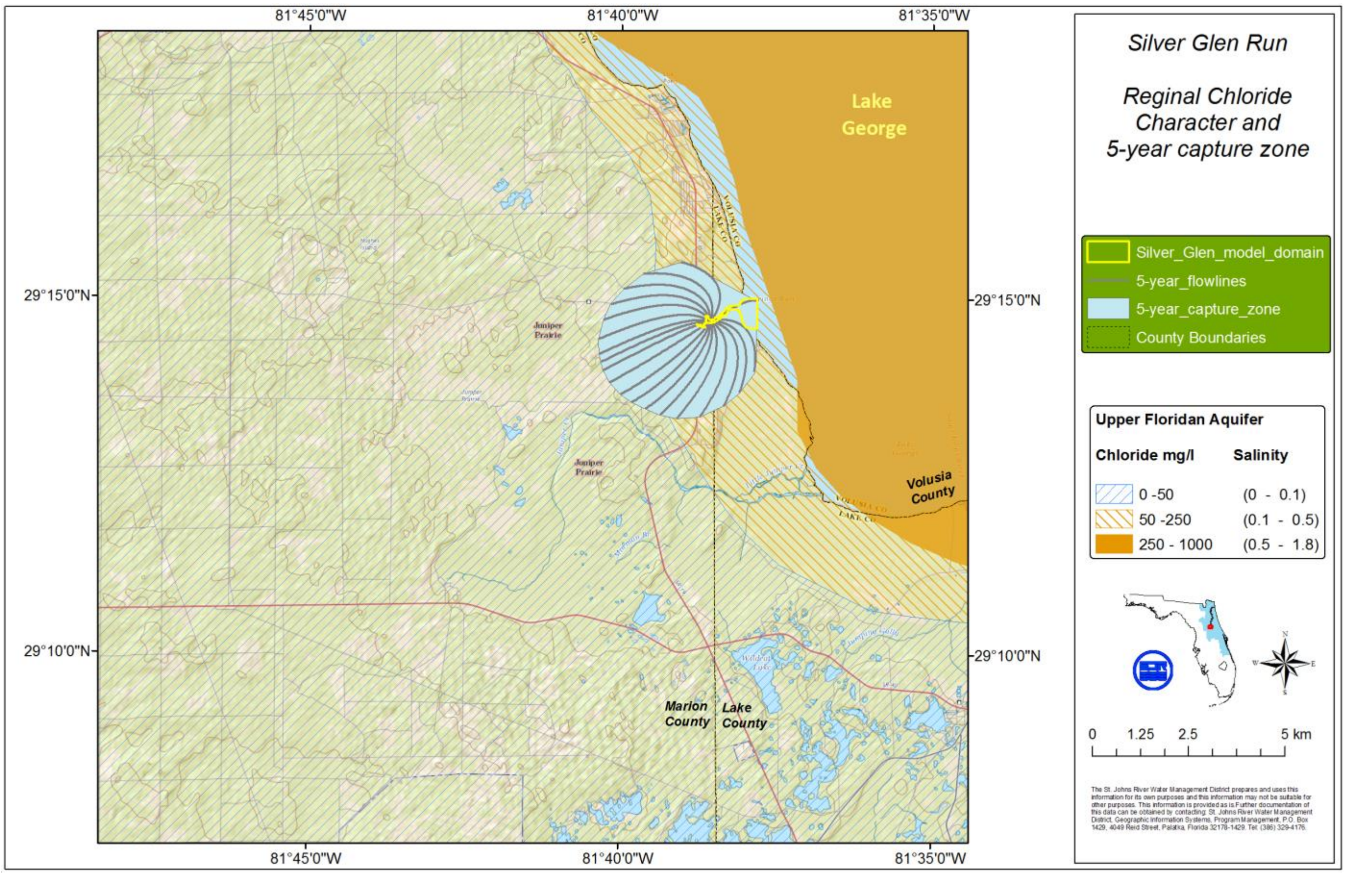


Figure 1-6. Regional chloride character and 5-year capture zone for Silver Glen Springs.

2 OBSERVED DATA

2.1 ROD-AND-LEVEL SURVEY

Survey data was collected by Cardno, Inc (Cardno, 2015) in November 2014 under contract for the District in support of this study and the MFL work for SGSR (Figure 2-1). Data was collected by a rod-and-level survey from a boat, at two elevations, at first contact with the bottom and with the rod pushed to refusal down into the substrate to estimate the firm bottom of the system. The focus of the survey was SGSR and the adjacent Lake George. In addition to point data, two cross-sections within the Run were also collected at 500 m and 900 m downstream. Bathymetry was collected previously (Pandion, 2003) but the original survey report could not be located. The USGS ADCP transect at the 80-ft station was combined with GIS data from the Pandion study to develop bathymetry for the head pool reach.

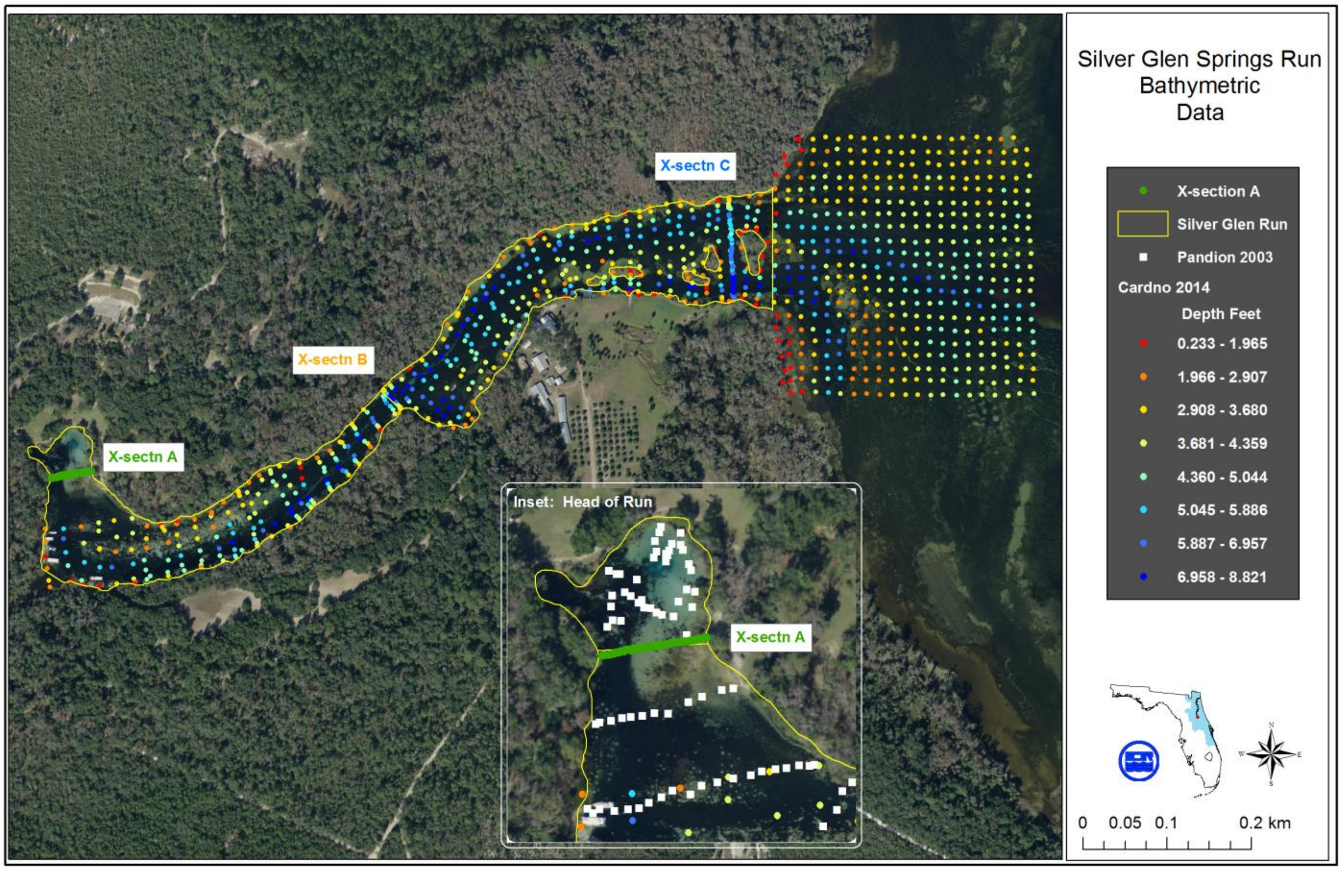


Figure 2-1. Silver Glen Springs Run bathymetric data summary

In response to Intera, 2016 where-ever data was provided by Cardno, 2015 it was sufficient to populate the EFDC model grid with bathymetry, so ADCP cross-section data was not used. Refer to Pandion, 2003 for discussion on bathymetry data pertaining to that study. The 80-ft ADCP cross-section, ‘X-sectn A’ in Figure 2-1, was used to supplement the Pandion data. No bathymetry data was available in the upper part of the Sandboil Run. A field reconnaissance indicated that the system is shallow, typically 1-2 ft depth so the depth was set to be 0.5 m, then gradually deepening towards the confluence with the SGSR.

A comparison of cross-sections of SGSR for the 80-ft station (X-sectn A), 500 m downstream (X-sectn B), and near the mouth (X-sectn C) shows a wide variation in depth and width. The cross-sections are oriented looking upstream so the left side of the plot is the south bank (or west bank in the case of the 80-ft station. For all plots the edge of bank is adjacent to the data. There is a retaining wall on the east bank of X-sectn A, so the data ends abruptly at about 3 feet deep. The cross-sectional area of X-sectn A is 516 ft^2. The narrowest segment at X-sectn B also has the smallest cross-section (489 ft^2). Continuous, winter-time, temperature data is available for several years at X-sectn B (Ross, 2016; WSI, 2010). The cross-section 900 m downstream near the mouth is at the widest point in the Run and has the largest cross-section (1607 ft^2).

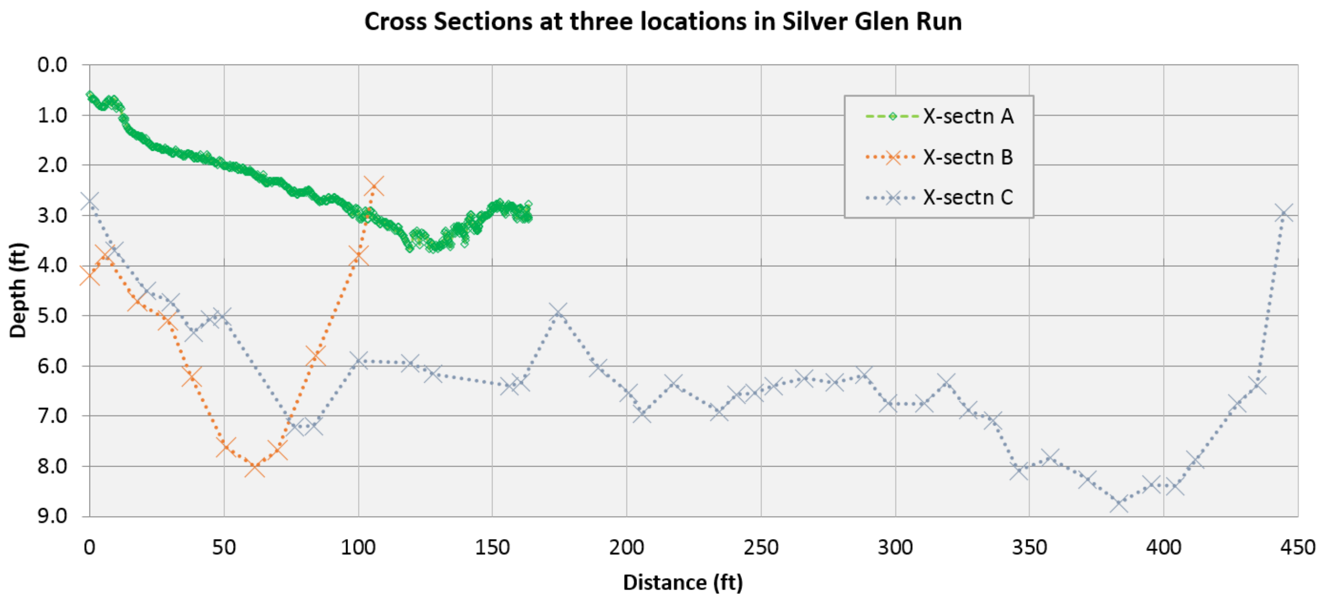


Figure 2-2. Cross-sections at three locations in Silver Glen Springs Run

2.2 Digital Elevation Model for SGSR and the Adjacent Area

The average elevation from the 'top' and 'bottom' survey was combined with Pandion, 2003 data for the pool segment and USGS 80-ft ADCP data to develop a DEM for SGSR and the adjacent Lake George (Figure 2-3). The Main Vent stands out prominently as the deepest location with a shallow bench just downstream. Survey data was not available for the area of the Natural Well pool or Sandboil Run, so it was not included in the DEM. A deeper channel extends from just downstream of the pool, follows along the south side of the upper part of the Run and continues downstream along the north side of the Run out into Lake George, following the dredged channel visible in the 1941 image in Appendix 11.2. Two deeper areas are located just downstream of X-sectn B, and on the south side of the Run where it enters Lake George.

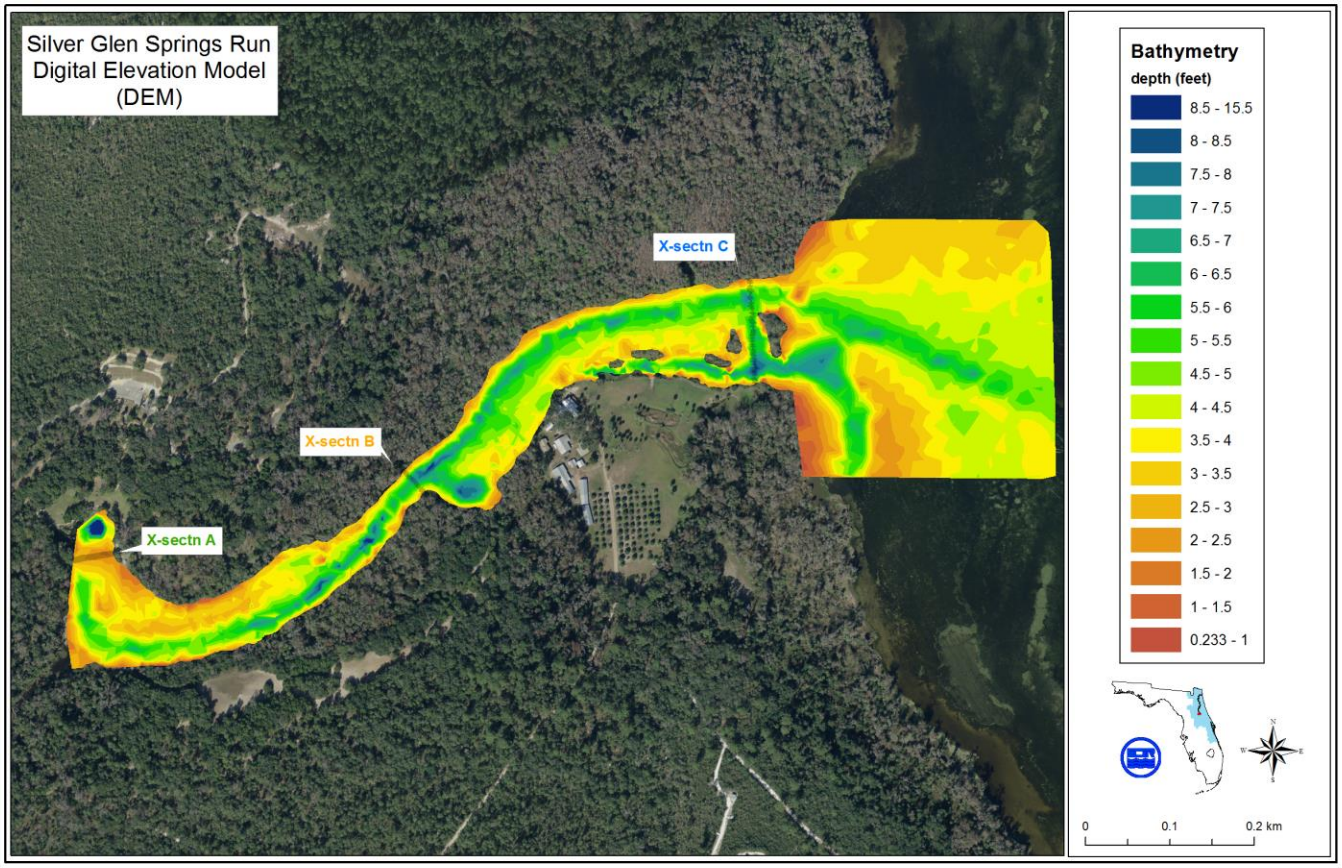


Figure 2-3. Digital Elevation Model (DEM) of Silver Glen Springs Run and adjacent Lake George

2.3 BOTTOM SUBSTRATE OF SILVER GLEN SPRINGS RUN

The conventional rod-and-level survey provided a useful insight into the benthic structure of the system. Survey data was collected at two depths, at initial contact with the bottom and the rod pushed-to-refusal into the sediment. A raster was developed for the two datasets and the difference (referred to as sediment thickness) was calculated (Figure 2-4). The average sediment thickness derived from the Cardo, Inc survey was 5 inches (0.42 ft). The areas where the sediment is softer are generally associated with a few deeper holes and large meadows of submerged aquatic vegetation especially in the lower reach of the Run. The pool area and Sandboil Run were not surveyed. Limestone rock is visible in Natural Well only a few feet below the surface. For large several areas in the upper part and a couple of patches in the lower part of the Run, there was no difference between the two survey data sets.

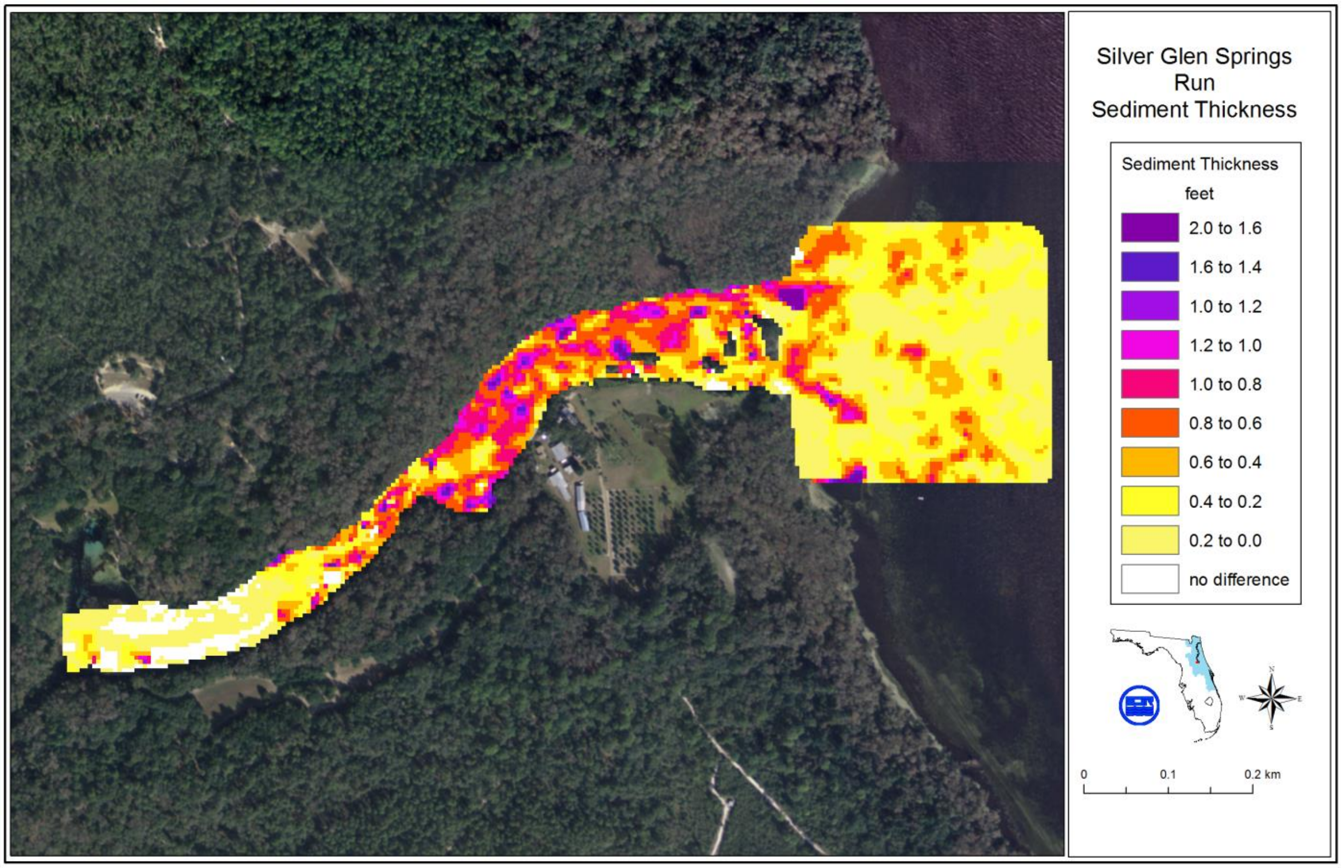


Figure 2-4. Sediment thickness in Silver Glen Springs Run and a portion of Lake George outside the Run determined from bathymetric rod-and-level survey

2.4 M9 ACOUSTIC DOPPLER DATA: VELOCITY

Acoustic Doppler data was collected by USGS staff in November of 2014 in support of this study using a SonTek M9 River Surveyor system (Figure 2-5). The 'M9' data was collected by boat, with the unit mounted at a depth of 0.2 ft (0.06 m). A plot of the depth-averaged velocity from the *11/17/2014* survey is included in Appendix 11.7. Useful products from collecting the M9 data including velocity measurements and soundings (estimation of depth), and discharge. Getting a sense for the typical velocities in SGSR was useful in gaining understanding of the hydraulics of the system. Since the sonar reflects off the vegetation canopy, it can also provide a sense for the general thickness of SAV.

The depth averaged point velocity from ten M9-ADCP transects indicates a range of velocity from 0 to 137 cm/s, with an average velocity of 5.45 cm/s. The average velocity from the eight cross sections was in general twice as fast (3.6 cm/s) in the upper part than the lower part (2.0 cm/s) of the Run. Summary statistics for the velocity measurement of the Run are summarized in Table 2-1.

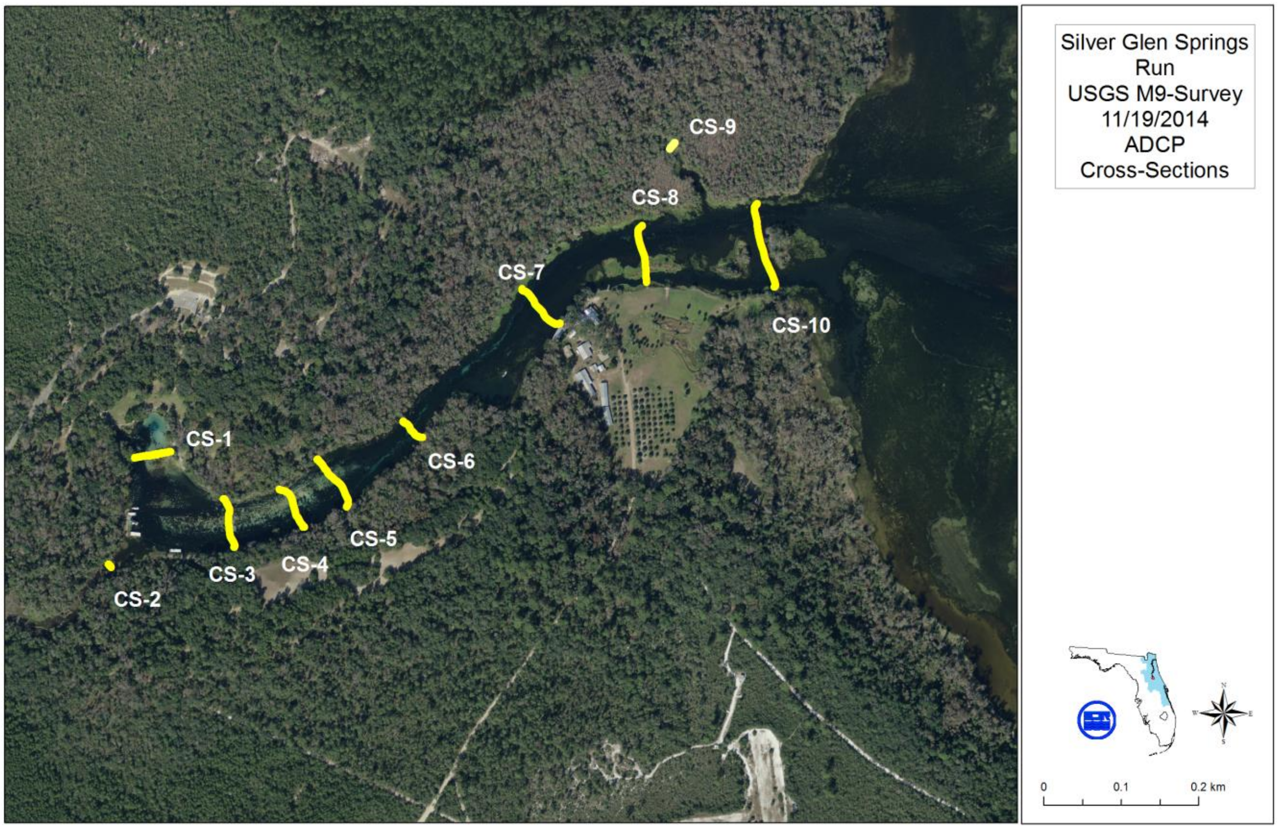


Figure 2-5. M9 acoustic Doppler velocity cross-sections, SGSR *11/17/14*

Table 2-1. Summary stats, M9 velocity, (cm/s) depth averaged cross sections, *11/17/14*

Cross Section	Distance downstream or Location	Velocity (cm/s)			M9 depth
		Minimum	Average	Maximum	Avg (m)
CS-1	80-ft station*	0.0	9.8	136.8	0.93
CS-2	Sandboil Run	0.1	1.2	3.7	0.75
CS-3	500 ft (152 m)	0.0	0.6	3.0	1.04
CS-4	700 ft (213 m)	0.0	6.7	53.6	1.12
CS-5	890 ft (271 m)	0.4	5.8	35.7	1.09
CS-6	1280 ft (390 m) **	0.0	8.2	41.5	1.13
CS-7	1772 ft (540 m)	0.1	5.5	32.9	1.24
CS-8	2172 ft (662 m)	0.2	5.8	53.3	1.19
CS-9	Downstream tributary	0.1	2.1	7.3	0.69
CS-10	2592 ft (790 m)	0.3	5.8	39.9	1.24

* downstream of Main Vent and Natural Well, official USGS measurement site for reported USGS data.
** close to 500-m half way point

ADCP profiles are shown for CS-1, CS-6, and CS-10 (Figure 2-6). The cross-sections provide a sense for the velocity distribution[1] through out the water column at the three locations (Figure 2-6). The profile shows that velocity and thus discharge is unevenly distributed through a cross-section, so that an any given location the influence of the bottom structure (like SAV) and the sides can produce eddy currents and near zero velocity in addition to higher velocity produced by the bulk of the spring discharge, and high velocity where water is flowing around underwater obstructions like remnant logs from fallen trees. Eddy currents and tidal interaction can also mean that water can at times be moving in both the upstream and downstream direction as indicated by the positive and negative velocities in the figure.

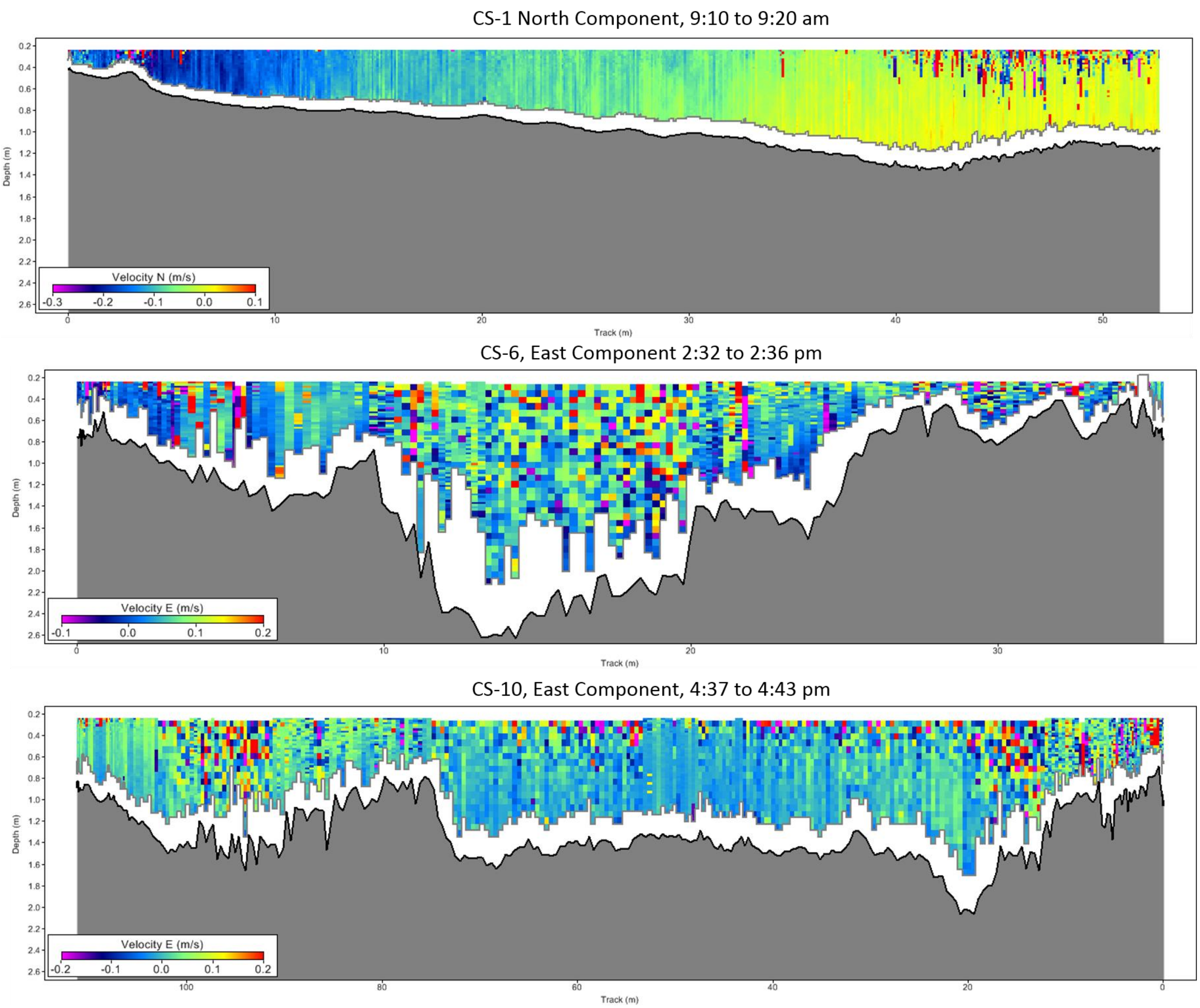


Figure 2-6. Acoustic Doppler profiles of velocity (m/s), at three locations in Silver Glen Springs Run *11/17/14*

[1] The scale bar on the figure is a product of River Surveyor Live, the software used to produce the plot. The dataset includes larger values than what is indicated by the scale bar, as in Table 2-1.

2.5 OBSERVED TEMPERATURE AND SALINITY PROFILES

Temperature and specific conductivity (used to calculate salinity) are typically co-measured since they are among the most basic parameters collected using a water quality sonde. Based on data collected in 2005 and 2006 (Stewart, 2006), most of the SGSR is understood to be vertically well-mixed, especially in the upper segment. There may be some stratification induced by solar radiation locally in quiescent areas within the Run, for example, due the effect that vegetation canopy has on mixing (Moore, 2012). At the mouth of the Run stratification can occur due to differences in temperature and salinity between SGSR and Lake George. For example, on *3/3/2005* there was no stratification of the water column at 100 m and 500 m from the Main Vent, while at the mouth (1000 m downstream) stratification did occur (Table 2-2). Interestingly, temperature produced the stronger density gradient than salinity, as indicated by the lower values for salinity (fresher Lake George water) being in the bottom of the water column. A comparison of other profiles collected in 2005-06 (Appendix 11.3) shows that the approximate interface of lake and spring water at the mouth can vary, sometimes producing stratification at 900 m and other times at 1000 m downstream. Figure 2-7 shows the location of the 2005-06 vertical profiles included in this report.

Table 2-2. Vertical profiles at three locations in SGSR, 03/03/2005

Date	Location	Depth (m)	Temperature C	Salinity
3/3/2005	100 m	0.2	22.66	0.98
		0.5	22.62	0.98
		0.75	22.33	0.98
		1	22.36	0.94
		1.4	22.60	0.96
	500 m	0.2	22.48	0.97
		1	22.45	0.97
		2	22.42	0.97
		2.3	22.36	0.97
	1000 m	0.2	20.71	0.93
		0.5	20.47	0.89
		0.75	17.14	0.66
		1	17.20	0.69
		1.2	16.25	0.56

To better understand the horizontal variability of temperature and salinity in the Run, a synoptic survey of temperature and salinity in SGSR was conducted on the morning of *2/21/2015* in support of this modeling effort (Figure 2-7). The goal was to obtain horizontal profiles of temperature and salinity during a cold weather event, when there is the largest difference in temperature between Silver Glen Springs and Lake George. A sonde was towed through the water at generally from 0.5 to 1.0 m depth as SAV canopy permitted. District staff went out on the second morning after a cold front passed through. This gave the Silver Glen system and Lake George two full nights to respond to ambient air temperatures. The low at Pierson was -3.21°C and 0.66°C on 2/20 and 2/21, respectively. Figure 2-7 shows the horizontal profile collected in the Run.

Most the data collected was at a depth of approximately 0.75 m (~2.25 ft). The data shows that salinity is essentially uniform, varying by 0.1 throughout SGSR. This is consistent with previous work (Stewart, 2006; Mattson, 2010; WSI, 2010) where spatially varying data was collected within the run. The salinity and temperature difference (between the head pool and Lake George) was 0.34 and 10.5 °C, respectively.

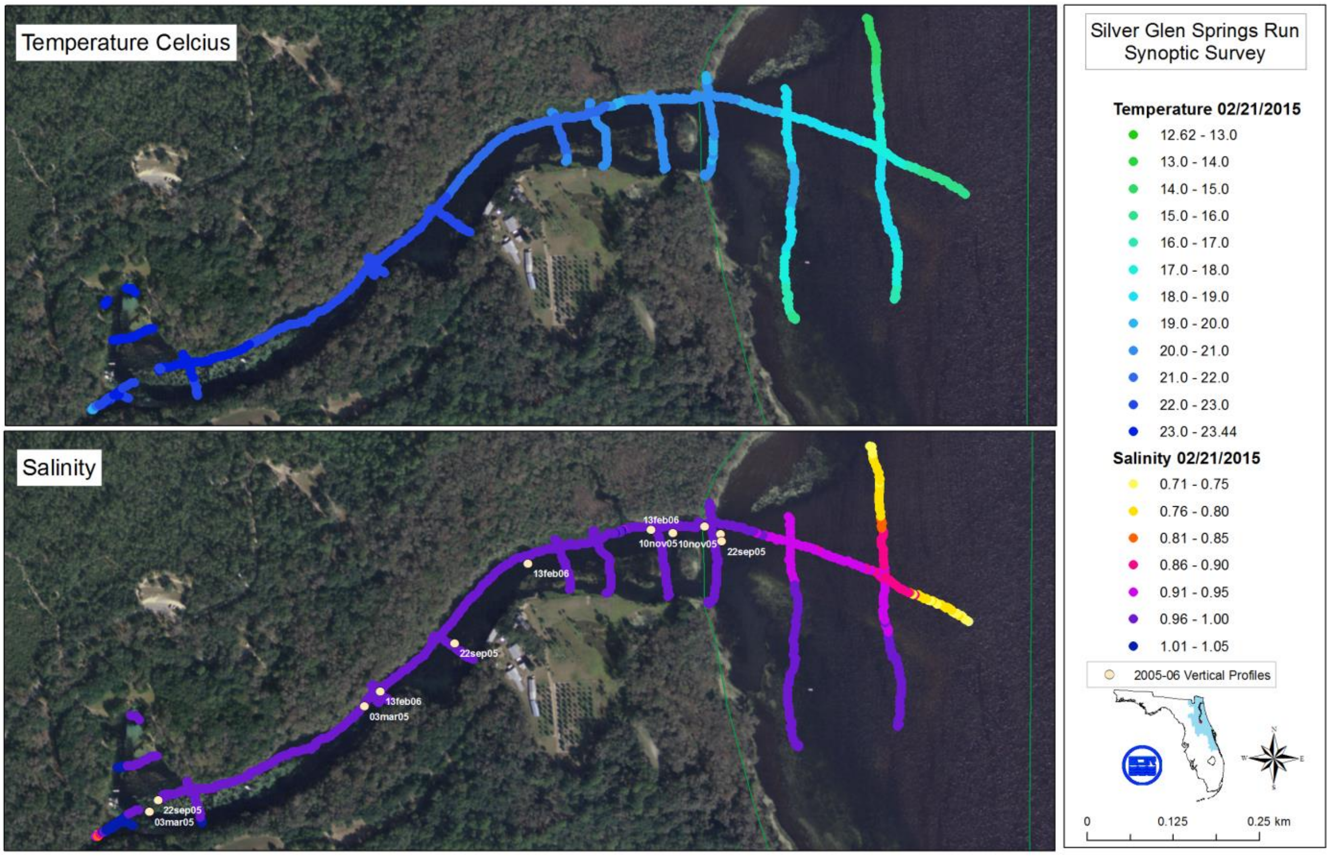


Figure 2-7. Synoptic survey *2/21/15* of Silver Glen Springs Run, temperature and salinity, with vertical profile locations from 2005-06 in bottom image

Mattson, 2010 reports that the specific conductivity (use to calculated salinity) in the SGSR was spatially and temporally consistent throughout the Run over several years of data collection. This can be seen in box and whisker plots of the of the temporal (Figure 2-8a) and spatial (Figure 2-8b) distribution of salinity during that study. The transect numbers correspond with the locations indicated in Figure 1-2.

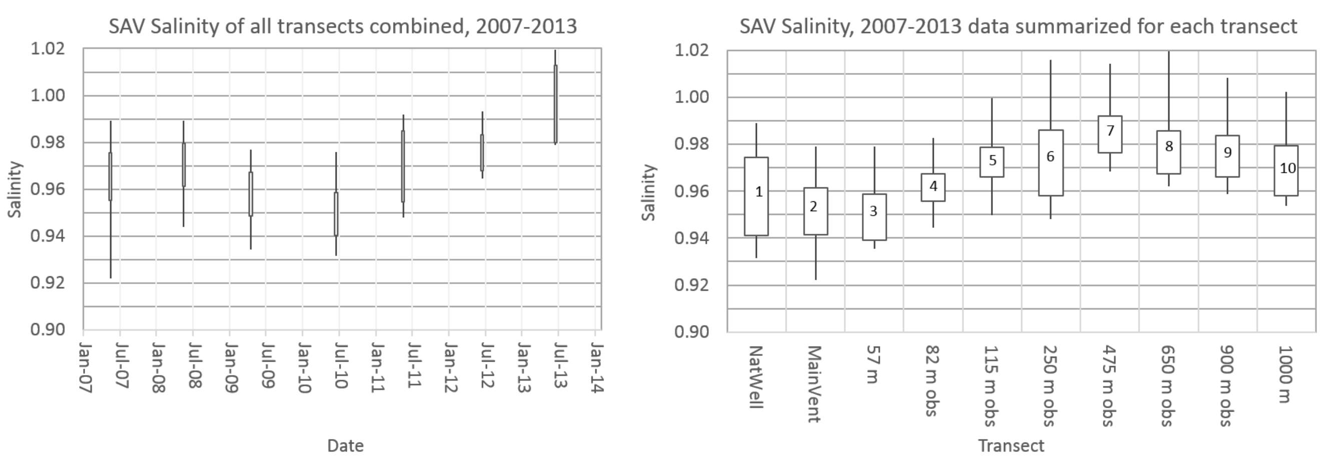


Figure 2-8. Salinity data for the SGSR at ten locations from SAV monitoring 2007-2013, see Figure 2-1 for locations

2.6 SUBMERGED AQUATIC VEGETATION

SGSR (Figure 2-9) and the adjacent area of Lake George outside of the Run (Figure 2-10) contain a substantial amount of submerged aquatic vegetation. SAV was surveyed for several years by SJRWMD staff (Mattson, 2010), and it was found that typically, 60% of the bottom of the Run is covered by vegetation. In many areas, SGSR and the adjacent lake have a white sandy bottom that is visible in high resolution aerial imagery like the pool in Figure 1-1, the upper part of the Run in Figure 1-2 and Lake George in Figure 2-10. There are a few deeper holes that may have a darker, muddy substrate, but typically where aerial images show dark areas in the system it is due to the presence of SAV, and emergent vegetation in shallow areas. The ability to see the bottom throughout the study area in high resolution aerials provides a clue that if sunlight can reveal bottom features then likewise solar radiation can penetrate the whole water column and to some extent warm the sediment bed.

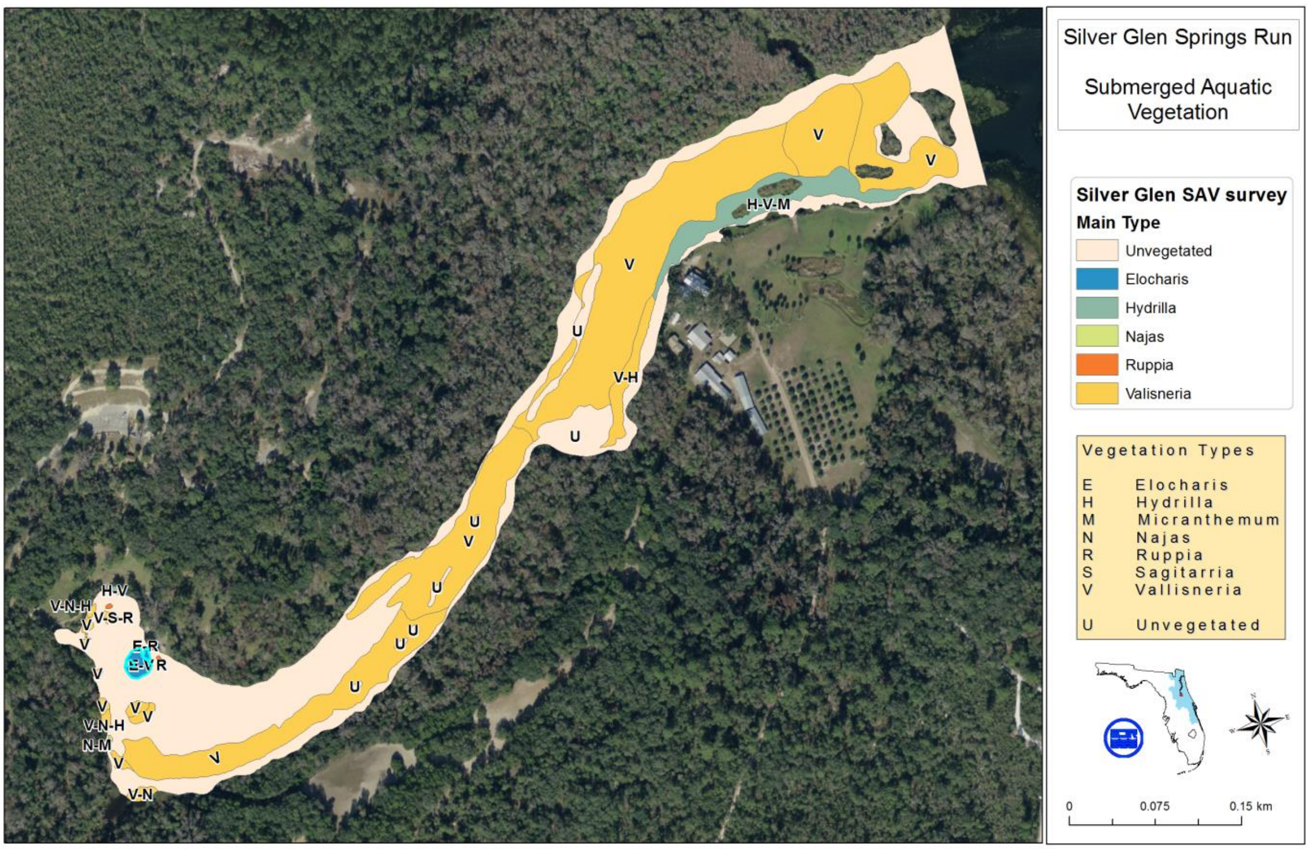


Figure 2-9. Submerged aquatic vegetation distribution in Silver Glen Springs Run

In addition to affecting light penetration, SAV effects the hydraulics of the system, affecting the vertical structure by imparting friction on the flow, and by occupying a portion of the water column creating areas near zero velocity within the vegetation canopy. Large groves of dense SAV influence the horizontal flow distribution and create preferential flow paths within the Run. Conversely the unvegetated areas are where the friction is lowest, and the flow is distributed through the most of water column. Field reconnaissance and review of aerial imagery revealed SAV extends out into Lake George (Figure 2-10). Photographs of SAV topping out near or at the water surface are included in Appendix 11.9.

Figure 2-10. Lake George outside of Silver Glen Springs Run, with description of benthic features visible in aerial imagery

3 EFDC MODEL DESCRIPTION

3.1 SELECTION OF EFDC FOR ANALYSIS

The study area is along the St. Johns River in an area (Lake George) that is tidally influenced. A previous analysis also found that low frequency ocean water levels influence the system (SJRWMD, 2012b). The Environmental Fluid Dynamics Code (EFDC) was selected for its ability to model salinity, temperature, numerical dye, and water age as potential products of interest (Hamrick, 1992). EFDC is also ideal since it can handle:

- Unsteady, non-uniform flows and backwater effects
- Advection-diffusion calculations to simulate salinity and temperature
- Surface wind stress at hourly time scales
- Two-dimensional horizontal flows and circulation in lakes
- Three-dimensional return flows generated by wind set-up in lakes
- Three-dimensional flows driven by density gradients

Because the EFDC is a mechanistic model based on physical equations of fluid motion, it is robust in predicting system alterations including the influence of reduced spring discharge on temperature and water age in SGSR. EFDC is an open-source model that is flexible in being able to produce times-series at select locations as well as three-dimensional output that can be used for spatial analysis, depending on application.

3.2 PERIOD OF RECORD

Based on the availability of continuous temperature data within SGSR (WSI, 2010; Cohen, 2011; Ross, 2016), the model study period focused on winter periods from November 2008 to April 2015. A typical scenario is thus 181 days from November 1st to April 30th of the following year. The winter of 2013-14 and 2012-13 was selected as Calibration and Validation periods, respectively. The calibrated model is used as the Baseline scenario to evaluate the influence of a 20% reduction of Silver Glen springs discharge on SGSR.

Specific conductivity data, used to calculate salinity, and temperature data is available as co-measured grab samples for Silver Glen Springs typically on a bimonthly basis during the 2008-2015 period of record. A field data collection effort was conducted in early 2015 in support of this work. From 2009 to 2015 the focus is temperature data collected in the winter time consisting of a bottom measurement of temperature approximately 1640 feet (500 m) downstream of the Main Vent (Ross, 2016).

3.3 LAKE GEORGE-SILVER GLEN (LG-SG) EFDC MODEL GRID

The focus of this study is temperature sensitivity within SGSR, so the boundary was set far enough away to minimize its effects on the area of interest. Stage, salinity, and temperature data are needed for boundary inputs. Since there was insufficient data to develop time series boundary data at the end of the Run, an existing model of Lake George that had been previously calibrated for stage and salinity (Stewart, 2006; SJRWMD, 2012b) was modified to include Silver Glen and calibrated for temperature to produce boundary conditions of stage, salinity, and temperature for the SGSR model (Figure 3-1) using the CVL grid generator (DSI, 2016). The LG-SG grid extends from Astor to the south of and Buffalo Bluff to the north of Lake George. The LG-SG model was calibrated for diurnal temperature at two locations noted in the figure: Marker 5, a long-term continuous USGS site (USGS, 2016b) and 'The Corral', a structure at the entrance to Lake George near Astor where temperature was collected in the winter (Ross, 2016). Calibration data at those locations is included in Appendix 11.4.

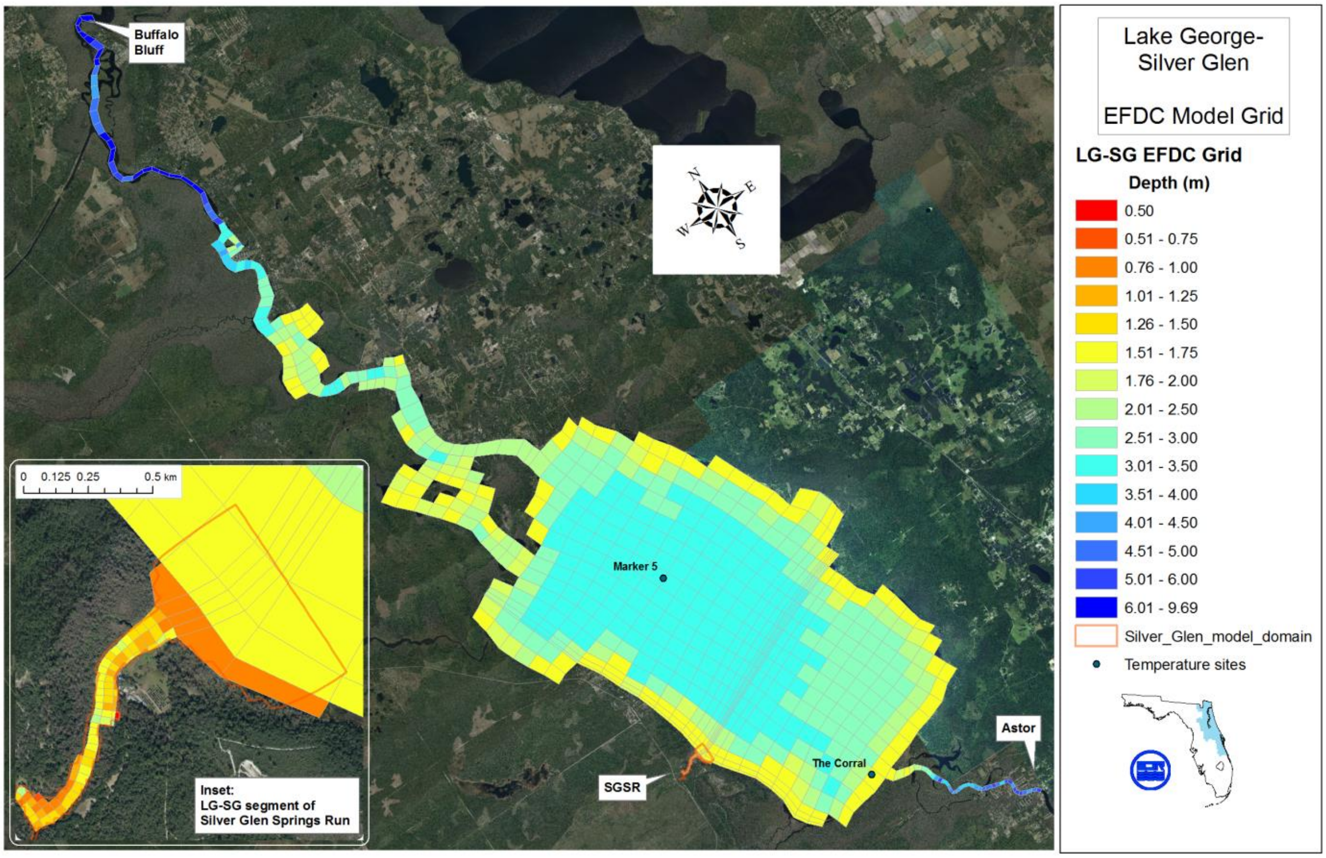


Figure 3-1. EFDC grid of Lake George and Silver Glen (LG-SG)

3.4 SILVER GLEN SPRINGS RUN (SGSR) EFDC MODEL GRID

Figure 3-2 shows the Silver Glen system model grid. In comparison to typical applications of EFDC, the overall grid size of 101.8 acres is small (Ji, 2008). The grid in most place provides a good fit to the shoreline. Thermal imagery (Figure 1-5), and the horizontal profile collected on *02/21/15* (Figure 2-7) shows the thermal plume extending into Lake George. This information was used to set the boundary for the SGSR model out about 500 m into the Lake (see area denoted as 'Lake George Boundary' in Figure 1-5 and Figure 2-7). The lakeward extent of the model domain is set beyond the SAV beds and into the open water of the lake. In general, the observed data suggests the edge of the SAV beds outside SGSR are an ideal demarcation for lake versus spring-lake mixed water.

Cell depth is noted in Figure 3-2. Bathymetric data was discussed previously. Since the lowest stage recorded at the USGS site in SGSR was -1.28 ft (-0.39) m NAVD88, the minimum cell depth was set at 1.64 ft (0.5 m) navd88. The reference elevation is 0 m navd88 (effectively sea level) so the model static depth equals -1 times the bottom elevation of the cell. Based on a review of historic survey data, the recent survey data, and field visits, it was determined that the rest of the Lake George segment had depths like the areas where data was collected by Cardno, Inc in 2014. In the lower SGSR islands were represented in the model domain as dry features by having no associated water cells (see inset Figure 3-2).

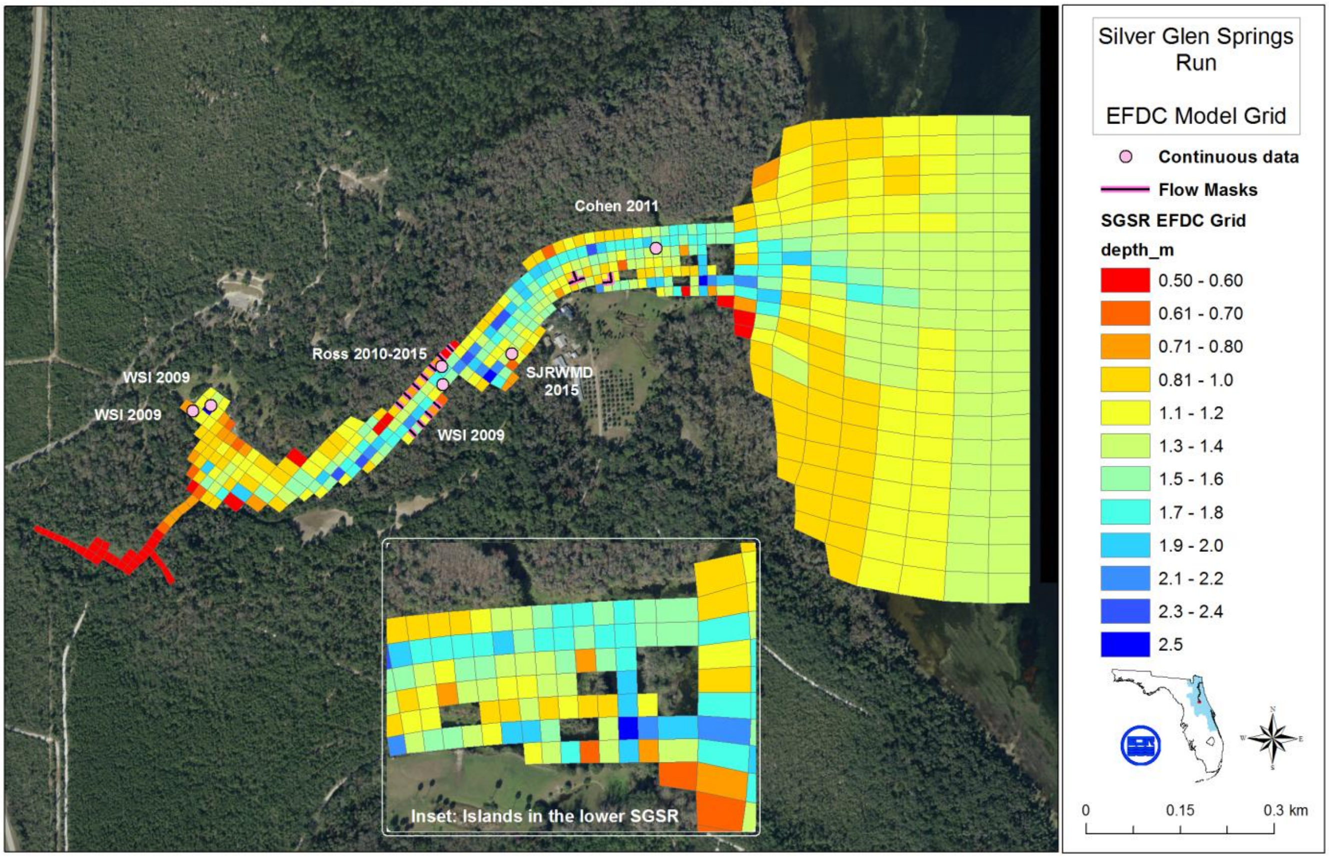


Figure 3-2. The Silver Glen Springs Run EFDC grid, model cell depth, and observed continuous data locations

The model has 514 horizontal cells and 6 vertical layers. SGSR contains 338 cells with an average cell size of approximately 0.07 acres. The goal was to optimize the resolution of the SGSR while maintaining computational efficiency. Model results from the regional LG-SG grid shown in Figure 3-1 are applied at the eastern boundary of the SGSR grid. Table 3-1 provides a summary of the area and average depth of grid segments. Overall the model grid maintains good orthogonality, however the cells in the upper segment near the pool are not well-aligned with the channel. This was considered a reasonable compromise for the overall orthogonality, especially with the focus being further downstream in the model domain.

Table 3-1. Area and depth comparison of SGSR model grid segments

Grid Segment	Avg Depth (m)	Total Area (ac)	Avg Cell Size (ac)	Number of Cells
Pool Segment	1.17	0.75	0.07	11
Upper Segment	1.19	9.27	0.08	110
Lower segment	1.36	11.53	0.06	184
Lake George segment	1.23	78.70	0.45	176
Sandboil Run	0.54	1.53	0.05	33
Total	1.22	101.78	0.20	514

4 EFDC INPUT DATA

For a given simulation, hourly input time series were developed for a 6-month simulation from 1 November to 30 April. A hot start file was used to initialize the model runs. Table 4-1 summarizes input data as applied in the model. Most of the atmospheric data came directly from the Pierson, Florida Automated Weather Network (FAWN) site operated by the University of Florida (FAWN, 2016). Wind data came from the National Land Data Assimilation Systems (NLDAS, 2016) dataset. Daily cloud cover fraction was calculated using the method described in Martin, 1999. Salinity and temperature for Silver Glen springs came from observed grab samples. Daily spring discharge came from data published by USGS for Silver Glen Springs (USGS, 2016a). Boundary stage, temperature, and salinity for the SGSR model was produced by the larger LG-SG model.

Table 4-1. Description of data used in this analysis

Data	Source	Description
Wind speed (m/s) and direction (degree)	NLDAS vector (UV) wind	NLDAS provides 0.125-degree grid (about 14 km^2) modeled wind and other parameters
Air Temperature (°C)	Pierson FAWN Weather site, hourly	Dry air temperature measured at Pierson FAWN site
Relative Humidity	Pierson FAWN Weather site, hourly	Relative humidity measured at Pierson FAWN site
Total Solar Radiation (W/m^2)	Pierson FAWN Weather site, hourly	Total solar radiation measured at Pierson FAWN site
Evaporation (mm/d)	Pierson FAWN Weather site, hourly	Evaporation (Evapotranspiration) measured at the Pierson FAWN site
Rainfall (in/d)	Pierson FAWN Weather site, hourly	Rainfall measured at the Pierson FAWN site
Barometric Pressure (mb)	Pierson FAWN Weather site, hourly	Barometric Pressure measured at the Pierson FAWN site
Cloud Cover Fraction	Calculated, daily	Cloud Cover Fraction calculated using the heat budget method described in Martin, 1999)
Boundary Salinity	LG-SG EFDC model	Salinity produced by calibrated EFDC model for Lake George
Boundary Temperature	LG-SG EFDC model	Temperature produced by calibrated EFDC model for Lake George
Spring Temperature	Grab samples (bi-monthly) and continuous data (hourly) when available from SGSR pool	Samples collected by SJRWMD, USGS, Researchers
Spring Salinity	Grab samples (bi-monthly) and continuous data (day-average) from SGS pool	Samples collected by SJRWMD, USGS, Researchers
Spring Discharge	Daily discharge provided by USGS measurement site (02236160)	Measured bi-monthly discharge correlated with well stage to produce a daily discharge time-series
Boundary Stage	LG-SG EFDC model	Stage produced by calibrated EFDC model for Lake George

4.1 STAGE AT THE LAKE GEORGE BOUNDARY

Hourly stage for the SGSR model was produced using the larger LG-SG model. Stage in the Silver Glen system is directly affected by stage of the Atlantic Ocean; this influence can be seen in a comparison of monthly averaged stage in SGSR to the Mayport Bar Pilot dock at the mouth of the St Johns River (Appendix 11.1) with a high stage in the fall followed by a decline to a low stage in winter. The tidal range at the mouth of SGSR is about two inches. While this tidal range is small, the daily variation of stage is a fundamental component of mixing within the system. Thus, a tide of about 2 inches is superimposed over the larger low-frequency seasonal variability of the Atlantic Ocean (about 1 foot) mixed in with stage variability (1-2 feet) that is due to seasonal and storm event runoff to the St Johns River. The stage variation has a significant effect on the flow and mixing dynamics of SGSR. At lower stages SAV tops out at or near the water surface (see photographs, Appendix 11.9). Under this condition, many areas are blocked or inhibited from exchange and mixing. At higher stages, there is typically a foot or more of open water over the top of the SAV.

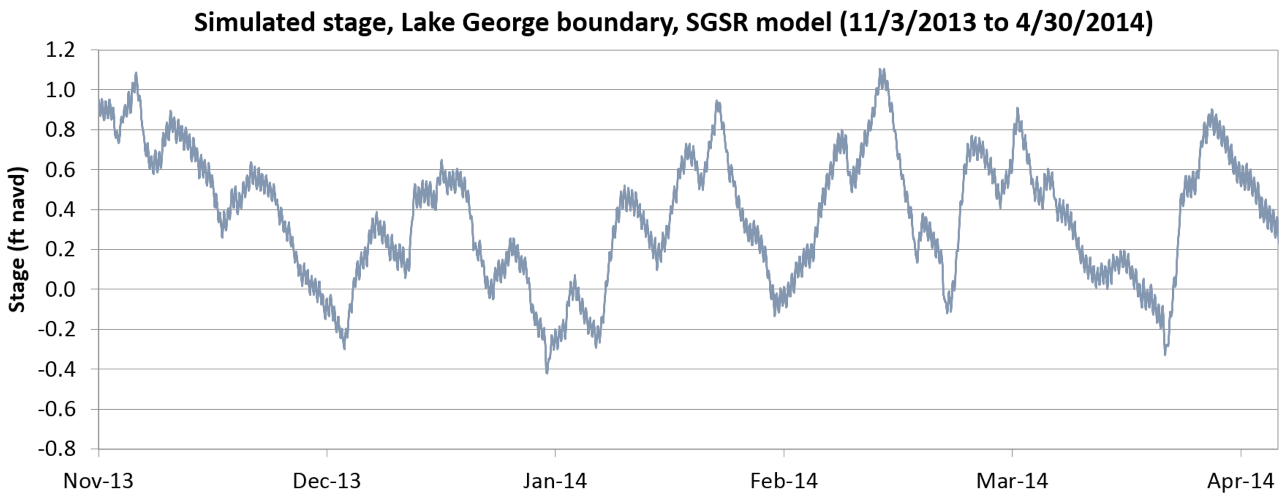


Figure 4-1. Simulated hourly Lake George stage near SGSR, *11/1/2013 to 4/30/2014*

4.2 SILVER GLEN SPRINGS DISCHARGE

Discharge is reported by USGS for the head pool of SGSR (USGS, 2016a). Field measurements of discharge are correlated by USGS with stage to produce a rating curve, then continuous stage data is used to produce a discharge time series for the site. The methods of computing discharge are included in Appendix 11.1. Temperature was modeled for the winter scenarios from 2009 to 2015. For the 2009 and start of the 2010 scenario, discharge was computed from a well stage—spring discharge relationship. From January 2010 to present, a pool stage—spring discharge relationship is used. The reported discharge does not include Sandboil Run.

The reported discharge was applied as a single time series in the EFDC model that was proportioned to the respective sources by percent fractioning in the EFDC.INP master file. An inspection of the discharge data clearly shows that there are larger discharges and wider variability earlier in the period, but a detailed analysis of the reasons for the yearly differences in discharge are beyond the scope of this work (Figure 4-2). What is evident from the meteorological record, is that spring discharge responded to Tropical Storm Fay late in 2008 (peaking above 140 cfs) and again to a major rainfall event in May of 2009 (peaking again near 140 cfs). Since that time there have been no similar major events (producing rainfall greater than 5 inches per day) contributing to the springshed.

To address Intera, 2016, discharge was not computed by the author from stage data in this analysis, it is computed by USGS and then published for the site, therefore it is applied to modeling as reported. Additionally, differentiating the merits of one method for computing discharge from another for SGSR is beyond the scope of this analysis. Statistics for the goodness-of-fit for the site are available from USGS.

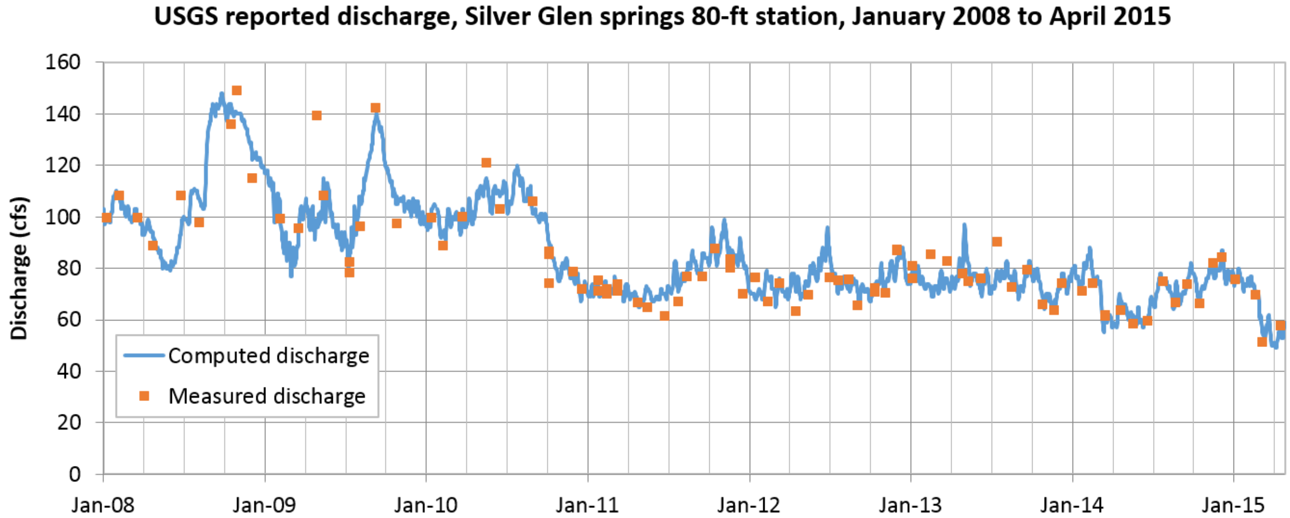


Figure 4-2. USGS reported discharge, Silver Glen Springs 80-ft station, January 2008 to April 2015.

Data for the individual discharge from the Main Vent, Natural Well, and the Sandboil Run is very limited. Independent measurements one day apart of Natural Well and the 80-ft station in 2001 by USGS produced an estimation of 33.1 cfs the Natural Well in comparison to 92.6 cfs on the following day. If we assume the two values are comparable this results in a split of 36 % to Natural Well and 64% to the Main Vent. During the November 2014 M9 field data collection, a discharge measurement of Sandboil Run was made in conjunction with the regular field measurement at the 80-ft station (see cross-sections, *11/19/2014*, Figure 1-2) resulting in an additional 3% of the reported discharge to account for Sandboil Run (Table 4-3).

Table 4-2. USGS measured data comparing Natural Well and Sandboil Run to the 80-ft station

Location	STATION NUMBER	DATE	DISCHARGE (cfs)
80-ft station	2236160	1/18/2001	92.6
Natural Well	10863094	1/19/2001	33.1
80-ft station	2236160	11/19/2014	81.9
Sandboil Run		11/19/2014	2.6

For the Calibrated 2014 scenario, the data was applied based on the allocation in Table 5.3. The decision to allocate 0.74 of the flow fraction to the Main Vent and 0.26 to the Natural was based on the modeler's discretion to conservatively allocate flow (and subsequently mass and heat flux) with a greater portion to the Main Vent since most of the observed water quality data is collected downstream of the Main Vent as described in Section 4.4. To check the influence of fractioning discharge, a sensitivity test was conducted using 0.64 for the Main Vent and to 0.36 for Natural Well and the result is included in Section 7.

Table 4-3. Summary of discharge allocation for USGS reported discharge from the 80-ft station.

Source	Description
Main Vent	74% of the reported 80-ft station discharge
Natural Well	26% of the reported 80-ft station discharge
Sandboil Run	3% of the reported 80-ft station discharge
Total	103 % of Reported USGS discharge for the 80-ft station

4.3 MODEL DOMAIN BOTTOM FRICTION

Bottom roughness (z_0) affects bottom drag on the water column in the system. In a domain like the LG-SG model, the effect of vegetation on friction is a part of the total of bottom drag in littoral cells. Typical for the LG-SG model the bottom roughness: z_0 = 0.001 m bottom of channels, 0.006 m transition from channels to middle of lakes, 0.013 m for middle of lakes, and 0.025 m for littoral sides. During calibration, these values were applied to the Silver Glen portion of the LG-SG model.

For the stand alone SGSR model, the volume of SAV in the model domain takes up a large fraction of the surface area as well as the water column. From Luhar 2013, Manning's n can be estimated using the Blocking Factor (B_f):

$$n_m = \left(1 - B_f\right)^{-3/2}, \text{ where}$$

n_m= Mannings friction coefficient
B_f = fraction of channel blocked by vegetation = H/h
H = Total depth (water column height)
h = vegetation height, (H-h = overflow depth)

From WSI, 2010, SAV:PVI is the percent volume index—the percent of the total reach volume that is occupied by SAV. The following relationship was used to determine *an initial* global estimation of Manning's friction for the pool and Run using SAV:PVI values (Table 4-4).

$$\frac{1}{SAV:PVI} = \frac{H}{h} = B_f$$

Table 4-4. Pool and Run percent of cross-section occupied by vegetation and subsequent Manning's friction

Location	SAV:PVI*	B_f	n_m
Pool	0.12	8.3	0.05
Run	0.28	3.57	0.24

The Pool value (calculated at the 80-ft station) included a mix of vegetated and unvegetated areas, while the Run value (calculated halfway down the run) includes mostly vegetated areas. The resulting Manning's friction for the pool is consistent with typical reported values for natural streams (Sturm, 2001), while the values for the Run are a magnitude higher, consistent with results for estimating bottom roughness for SAV (Wu, 1999) indicating that friction is dominated by the vegetation and not bottom drag where SAV is present in the SGSR. The relationship between Manning's friction and bottom roughness is reviewed in Martin, 1999 and is described in SJRWMD, 2012b. for the 'Pool' and 'Run' Mannings values, a set of bottom roughness values were calculated based on depth to get a sense for the influence of stage (Table 4-5).

Table 4-5. Relating calculated Manning's friction and bottom roughness based on depth

	Bottom Roughness z_o (m)	
Depth (m)	For n_m = 0.05	For n_m = 0.25
0.5	0.026	0.16
1	0.039	0.29
1.5	0.049	0.42
2	0.057	0.55
2.5	0.064	0.67

The model does not have the mathematical capability to resolve the actual presence of SAV. The goal is to develop a dataset that represents the influence of the *spatial distribution* of SAV on bottom roughness. Since the entire system is on average was only 1.22 meters deep it was decided to create the roughness distribution based on the friction magnitude from the Pool data. The higher value would represent a significant portion of the water column since units of bottom roughness are in meters.

The SAV survey in Figure 2-9 was used to apply the results above to the entire SGSR (Figure 4-3). The survey included an estimation of the percent of the area in each polygon that was occupied by the major species. This was used to create 5 groups in increasing coverage from z_o = 0.005 m (unvegetated) to 0.075 m (fully vegetated) distributed throughout the SGSR. This dataset was then used to populate the EFDC grid with bottom roughness data. When a grid cell falls on more than one polygon, the average value is produced, that is why adjacent cells may have the same depth but a different bottom roughness, to address concerns in Intera, 2016. Some minor adjustments were made during model development, producing the distribution in Figure 4-4. To check the result, the average depth (0.73 m) of the pool cross section during the WSI, 2010 study was used to interpolate a bottom roughness of 0.032 m from Table 4-5, in comparison to average value calculated for the cells for the same location (the 80-ft station) of 0.031 m.

To account for flow obstructions within the water column, masks were used to block flow along select cell faces. The photograph in Figure 11-5 (Appendix 11.9) shows an example of a condition along the shoreline where a mask was applied. In the lower segment, cells were removed during grid development to represent islands (see Inset, Figure 3-2).

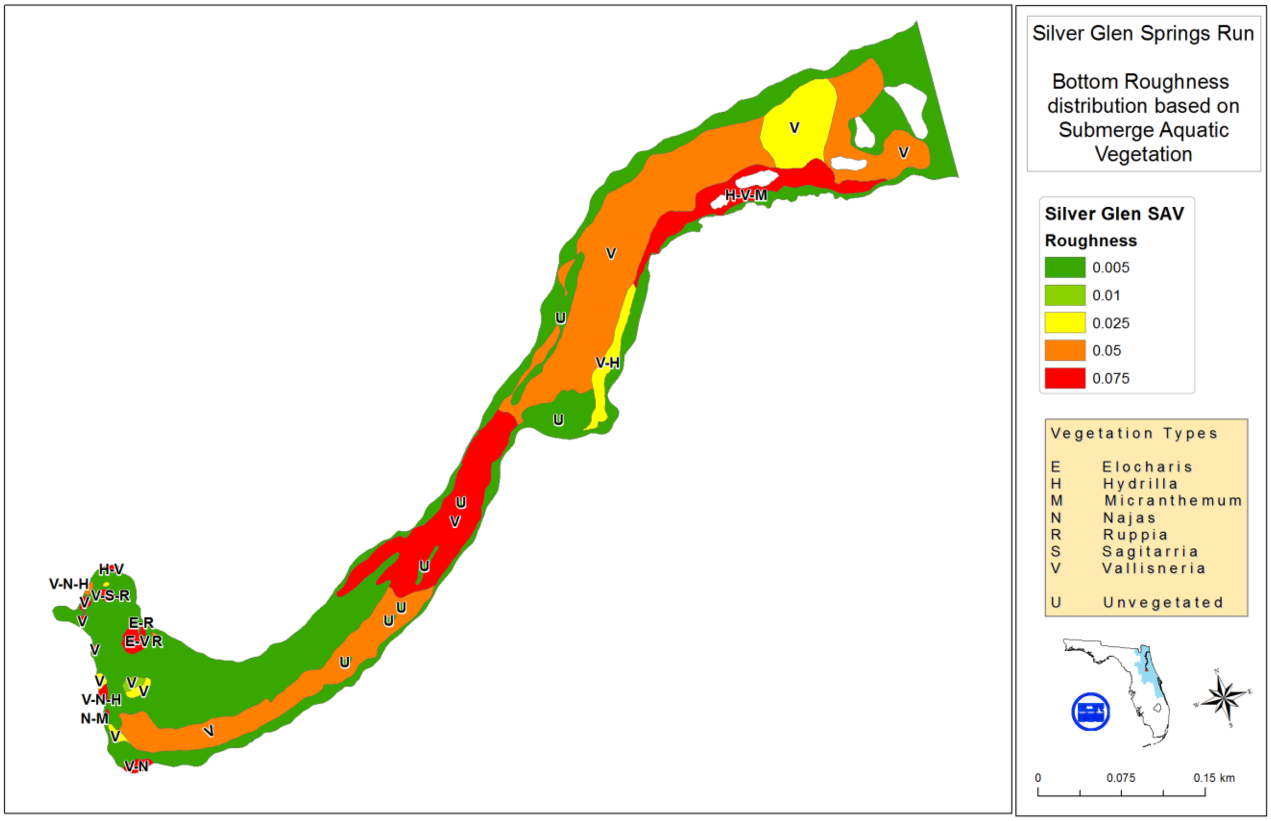


Figure 4-3. Bottom roughness values assigned based on the amount SAV coverage

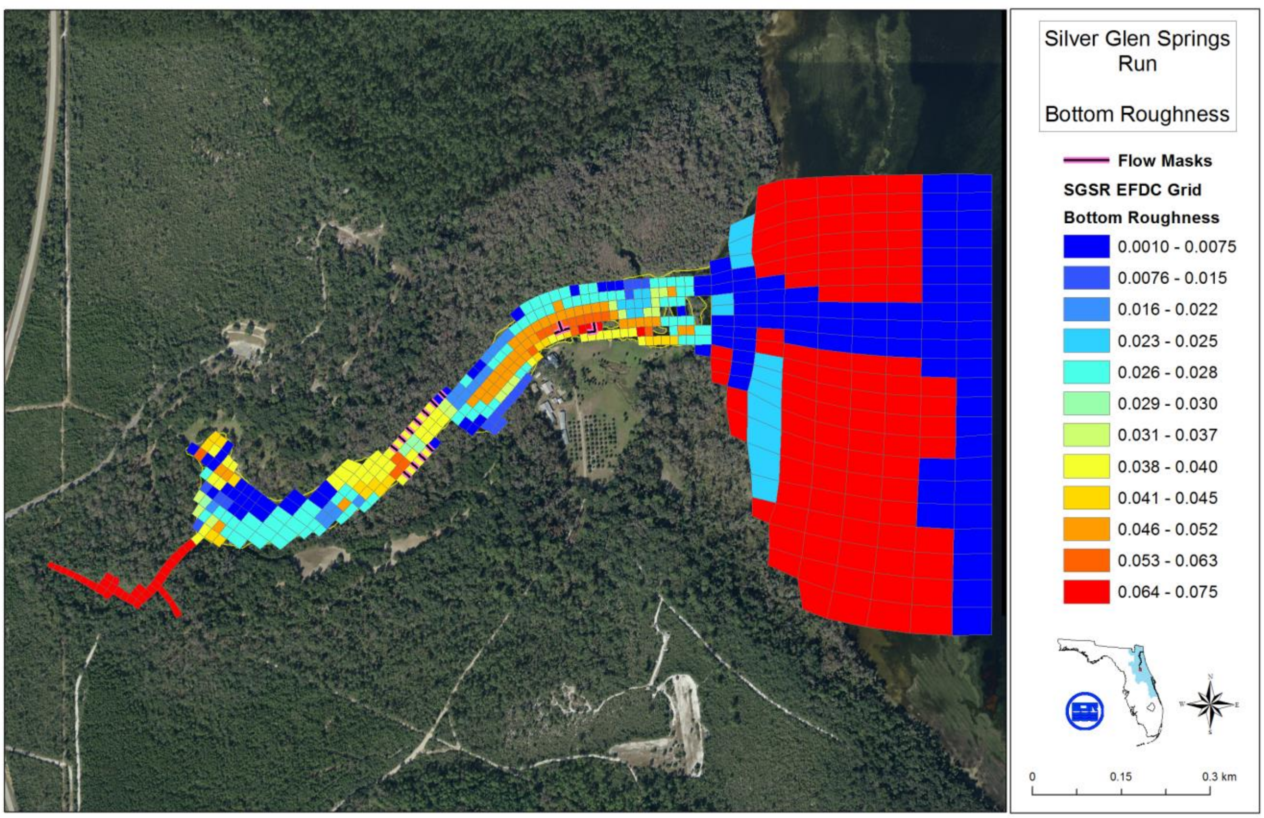


Figure 4-4. Bottom roughness, SGSR EFDC model grid

4.4 TEMPERATURE FOR SILVER GLEN SPRINGS AND LAKE GEORGE BOUNDARIES

Grab samples from long-term monitoring were combined with data collected during research projects to develop time-series of temperature for the Springs. The monitoring data is collected either at or very near the Main Vent, or just downstream at the 80-ft station (the swim barrier). Data was combined from vent and downstream measurement locations to create the input timeseries (Figure 4-5). Eight co-measured samples from Foss, 2012 and data collected in 2015 (Table 4-6) indicates the Natural Well is typically slightly cooler, and the Sandboil head pool slightly warmer, than the Main Vent. Therefore an adjustment of -0.17 °C and +0.17 °C were applied to adjust the temperature of the Nature Well and Sandboil Run sources, respectively. In response to Intera, 2016, no algorithm was used, the adjustment factor was applied based on modeler's discretion. The adjustment factor is simply added to or subtracted from the Main Vent value. Data collection at the various sources is required to better understand their temperature and salinity character. Previous horizontal cross-sections of temperature (USGS, 2009) and the data collected in 2015 (Figure 2-7) indicated that at least as far downstream as the 80-ft station, a consistent trend showing the slight variation between the Main Vent and Natural Well.

Table 4-6. Observed Temperature and Salinity, 3/3/2015 SGSR springs.

	Temperature °C	Salinity
Main Vent	23.40	0.964
Sandboil Run head pool	23.57	0.899
Natural Well	23.14	1.115

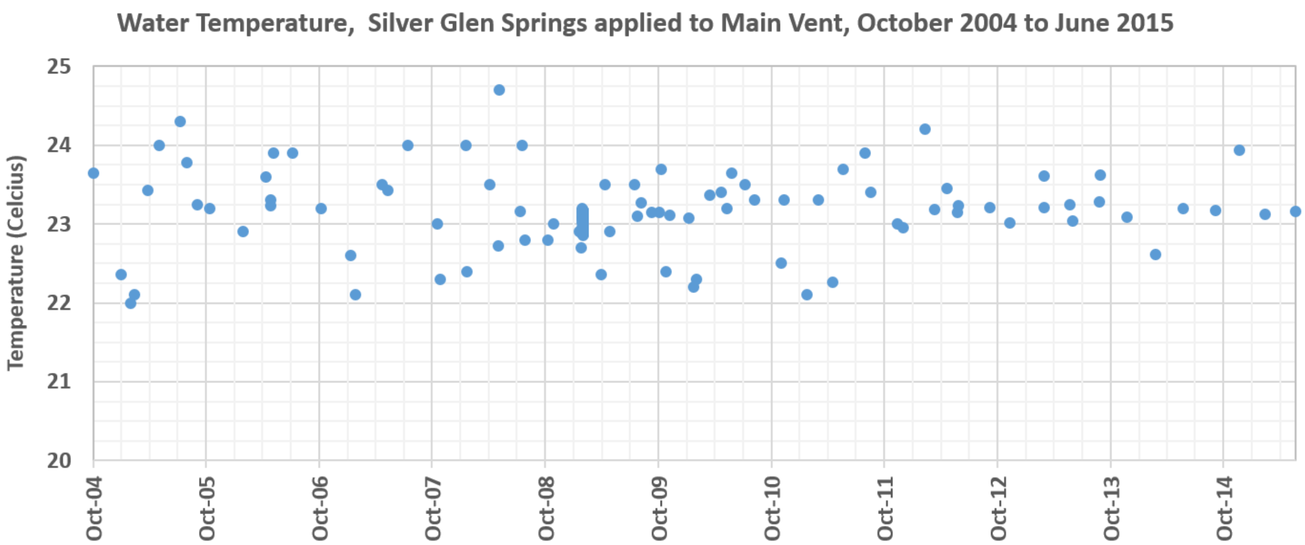


Figure 4-5. Observed temperature applied to the Main Vent, November 2008 to February 2016

The regional LG-SG model was used to generate temperature as a boundary input for the SGSR model (Figure 4-6) Calibration period, 11/01/2012 to 4/30/2013. For comparison, grab sample spring temperature is included in the figure. The LG-SG model produces stratification through the water column. The 6-layer vertical output from the LG-SG model was applied as-produced to the SGSR model. The plot shows that Lake George temperature can vary significantly from the relatively constant spring temperature.

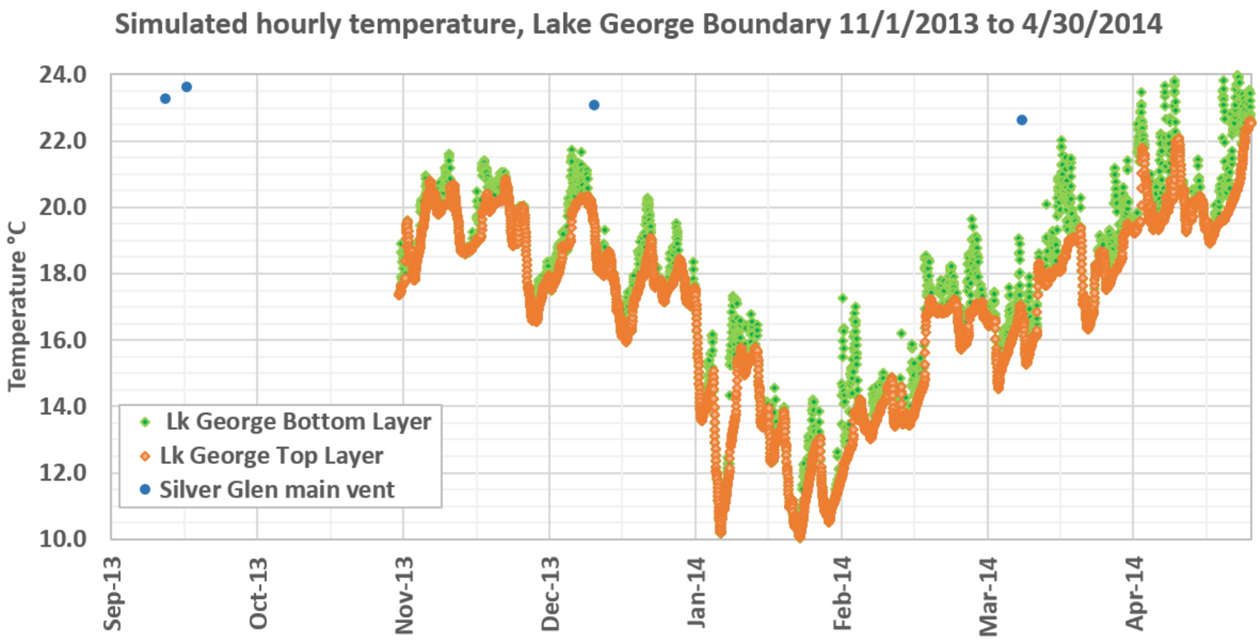


Figure 4-6. Silver Glen Springs and Lake George hourly temperature, *11/01/2012 to 4/30/2013*

4.5 Salinity for Silver Glen Springs and Lake George boundaries

Specific conductivity, used to calculate salinity, was co-measured with temperature for Silver Glen Springs. As with temperature, it appears that the salinity is relatively stable. (Figure 4-7). Eight co-measured samples from Foss, 2012 and data collected in 2015 (Table 4-6) indicates the Natural Well is typically slightly more saline and Sandboil Run springs slightly less saline than the Main Vent, so an adjustment was applied to the Main Vent data to correct for Natural Well (+0.07) and Sandboil springs (-0.11). In response to Intera, 2016, no algorithm was used, the adjustment factor was applied based on modeler's discretion. The adjustment factor is simply added to or subtracted from the value applied to the Main Vent. Silver Glen springs salinity variability is also gradual, so daily salinity in SGSR is relatively homogeneous, especially in the upper half that is dominated by spring discharge. Both temperature and salinity variability appears to decrease from 2004 to 2015 in a manner like the discharge from Silver Glen Springs. This is consistent with findings of research into the response of Karstic springs water quality to discharge (Birk, 2006).

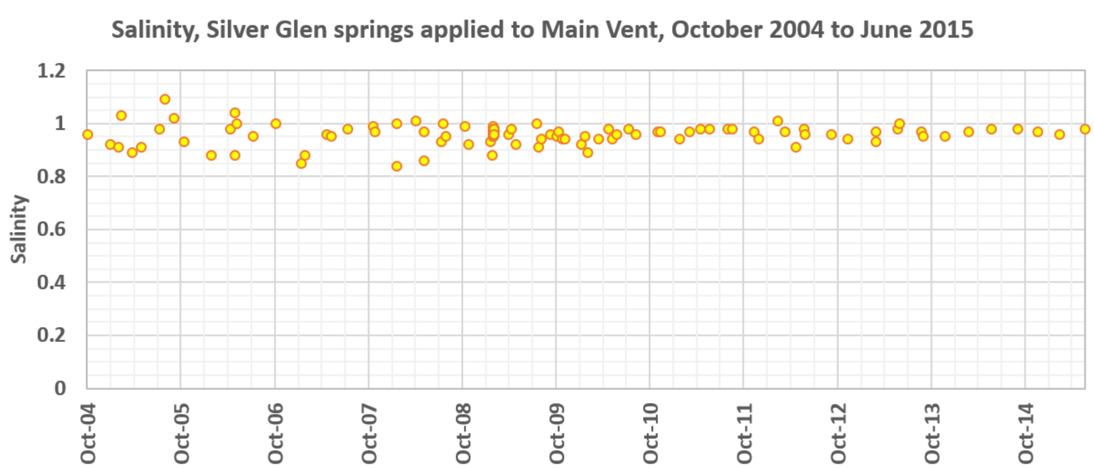


Figure 4-7. Silver Glen Springs grab sample salinity October 2004 to June 2015

Near the mouth of the Run salinity is controlled by mixing of Silver Glen Springs and Lake George water. Lake George salinity response to discharge is like the St Johns River, occurring at weekly to monthly time-scales (USGS, 2004b), The salinity character of Lake George is dominated by the incoming discharge of the St Johns River from Astor, secondarily by local spring runs like Juniper, Salt and Silver Glen (SJRWMD, 2012b). The boundary data produced by the LG-SG model considers the local effect of spring inputs by including the Run and the accounting for the attenuation of spring water into the Lake, so that the larger LG-SG model includes the mixed sources (Figure 4-8). This can be seen in Figure 4-8 with the boundary salinity about a tenth higher on average and having larger variability then out in the lake at Marker 5 (see Figure 3-1 for locations). Comparison of the modeled Lake George boundary salinity with the observed data also shows that the trend of increasing salinity is not an artifact of model initial conditions, addressing concerns in Intera, 2016.

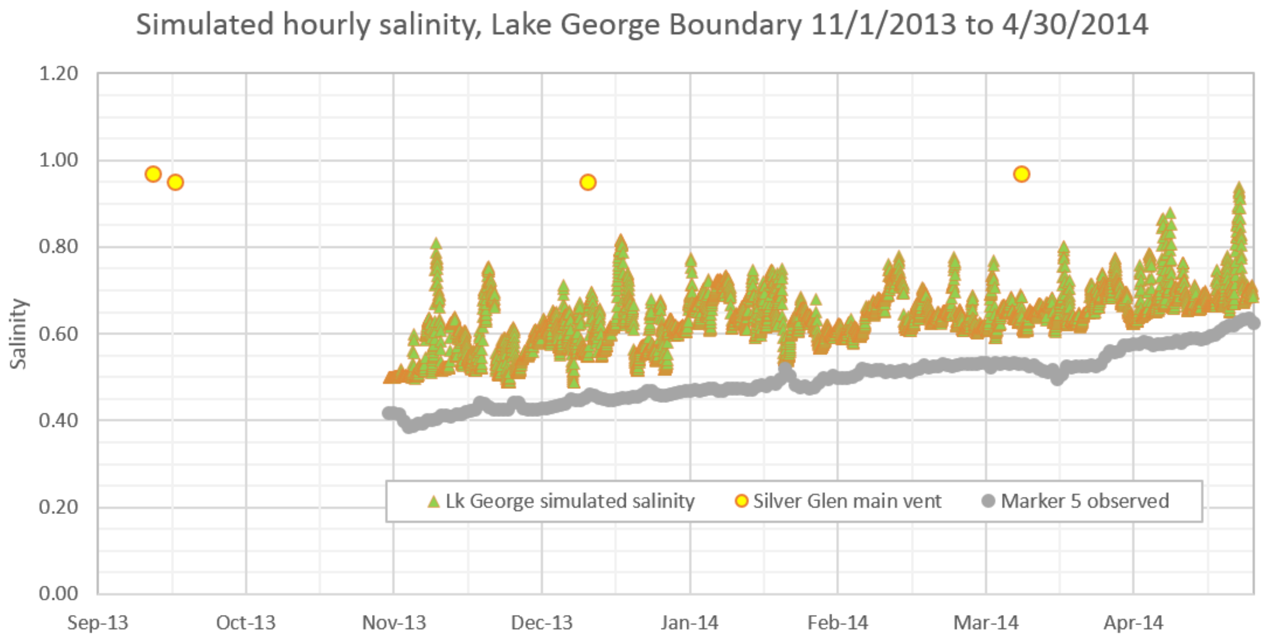


Figure 4-8. Silver Glen Springs and Lake George hourly salinity, *11/01/2012 to 4/30/2013*

4.6 HEAT BUDGET SUMMARY

4.6.1 ATMOSPHERIC DATA INPUT SUMMARY

Table 4-7 provides summary statistics for the atmospheric input data for the winter simulation from 11/01/2013 to 4/30/2014 (Calibration), and 11/01/2012 to 4/30/2013 (Validation). The two years are similar in many respects. One noticeable difference is that the rainfall was significantly lower than evaporation during the 2012-13 winter, while it was greater than evaporation for the 2013-14 winter. Both years had freeze events (air temperature less than 0). The observed wind time series was adjusted by 0.9 to account for the sheltering effect of the sides of the Run and topped out SAV on wind-induced mixing.

Table 4-7. Summary stats, 2012-13 winter, hourly data from the atmospheric and wind input files

	Calibration 2013-14				Validation 2012-13			
	Min	Avg	Max	Stdev	Min	Avg	Max	Stdev
Air Temperature C	-2.1	16.6	34.6	6.4	-3.0	16.7	32.8	6.3
Barometric Pressure mb	1000.0	1016.3	1030.0	4.6	1003.1	1017.7	1025.7	4.0
Relative Humidity %	0.22	0.83	1.00	0.18	0.19	0.79	0.99	0.19
Solar Radiation W/m2	0.0	124.8	949.3	214.0	0.0	141.5	955.0	231.5
Wind speed ft/s	0.04	11.66	36.1	5.8	0.15	11.62	34.8	5.9
SUM		Sum				Sum		
Rainfall inches		18.7				5.7		
Evaporation inches		14.1				14.7		

4.6.2 HEAT TRANSFER PARAMETERS

Detailed discussion on the theory and physics of temperature modeling can be found in Ji, 2008 and Martin, 1999; Turbulence and mixing with respect to salinity and thermal density gradients in Knauss, 2005; and Fischer, 1997; Theory of light/heat penetration in natural waters and bed sediments in Scheffer, 1998; and Singh, 1996. The main components of the ASER.INP input file that have a bearing on temperature calibration are included in Appendix 11.5.

In general, for natural water bodies, higher color and turbidity corresponds with lower Secchi readings and results in reduced light/heat (photon) transfer into the water column. The main calibration tools for water temperature are the parameters in the atmospheric forcing file ASER.INP (Table 4-8). Three parameters in the table—REVC, RCHC and SWRATNF—can be considered variable based on local conditions *within* the model domain. Indeed, the major constraint of the model is only having a single value for these parameters to apply to the entire model domain. REVC controls loss to the atmosphere, RCHC is the conductive loss through the 'side' of a cell, representing the heat transfer rate through the water column.

Table 4-8. Parameters for the meteorological input file ASER.INP used in this study

EFDC Parameter	Value	Description
SOLRCVT	0.90	Unit conversion for Solar Radiation
IASWRAD	0	solar energy distribution (equal 0 shallow water, to column and bed)
REVC	1.6	evaporative loss (to air from water surface)
RCHC	1.8	conductive loss through 'side' of cell
SWRAT NF	1.28	fast transfer coefficient
SWRAT NS	0	slow transfer coefficient equal 0 for shallow water
FSWRATF	1	fraction to fast transfer
DABEDT	1	Bed layer thickness (m)
TBEDIT	22.3	initial bed temperature °C
HTBED1	0.35	heat transfer coefficient to bed layer
HTBED2	3.09E-05	heat transfer rate m/s (1 m/d, 1 day = 86400s)

Sediment bed heat transfer values are consistent with those found for a nearby Florida estuary of similar depth (Smith, 2002). Research has shown there is a correlation between Secchi and the heat fast transfer coefficient SWRATNF ('NF' for the remainder of the report). NF is analogous to the light extinction coefficient in the Beer's law equation for shallow water conditions (Martin, 1999; Ji, 2008). Martin provides an estimation of NF = 1.1*Secchi(m)^-0.73. Comparing grab sample data from Silver Glen springs and Lake George, the variation in light/heat extinction can be estimated for the model domain (Table 4-9). There is an inverse relationship between Secchi and NF, so minimum Secchi values correlate with maximum NF values. In the field, the larger the extinction coefficient, the less distance (shallower depth) into the water column the features of the Secchi disk can be seen. Lake George conditions are widely ranging, as indicated by data for color, stage, Secchi, and light extinction. The calibration value for the LG-SG model (NF = 2.25) is consistent with Table 4-9. For reference the calibrated SGSR model NF = 1.28. However, SGSR is clear and shallow enough that in general the bottom is always visible so Secchi (and calculated NF) is not available. The average temperature of the Main Vent during the Calibration and Validation period (both = 23.13 °C), is consistent with the average for the period from 2004 to 2015 in Table 4-9.

Table 4-9. Summary Water Quality data, Silver Glen springs and Lake George

	Silver Glen	Lake George	Silver Glen	Lake George	Lake George		
	Temperature (°C)		Salinity		Color	Secchi (ft)	NF
Minimum	22.0	6.0	0.84	0.29	20	3.61	1.03
Average	23.2	23.1	0.96	0.57	111	1.97	1.60
Maximum	24.7	32.0	1.09	0.97	400	0.16	9.98
POR	2004 to 2015	2009-2015	2004 to 2015	2009-2015	2005-2015	2005-2015	2005-2015
Data Type	grabs	continuous	grabs	continuous	grabs	grabs	grabs

5 MODEL CALIBRATION AND VALIDATION

The focus of temperature calibration was at the 500-m location halfway down the Run where continuous (30-minute) data was collected for several consecutive winters (Ross, 2016). The calibrated model was then compared to additional locations. A study of the upper segment SGSR in 2009 included 3-day continuous deployments near the head pool and downstream near the 500-m location (WSI, 2010). A study in 2011 collected continuous data near the mouth of the Run for two weeks in April 2011 (Cohen, 2011). Data was collected in February 2015 by District staff 650 m downstream in the Run. The locations of the sites are included in Figure 3-2.

5.1 SILVER GLEN SPRINGS RUN SIMULATED STAGE

Stage is continuously recorded by USGS at the 80-ft station. The simulated stage shows a good fit with the observed data (r^2=Nash-Sutcliffe = 0.94). The initial stage boundary for the LG-SG model is at Buffalo Bluff, 30 miles north of SGSR. The quality of the fit indicates the larger LG-SG model accurately reproduces stage, including tidal response, at the mouth of SGSR.

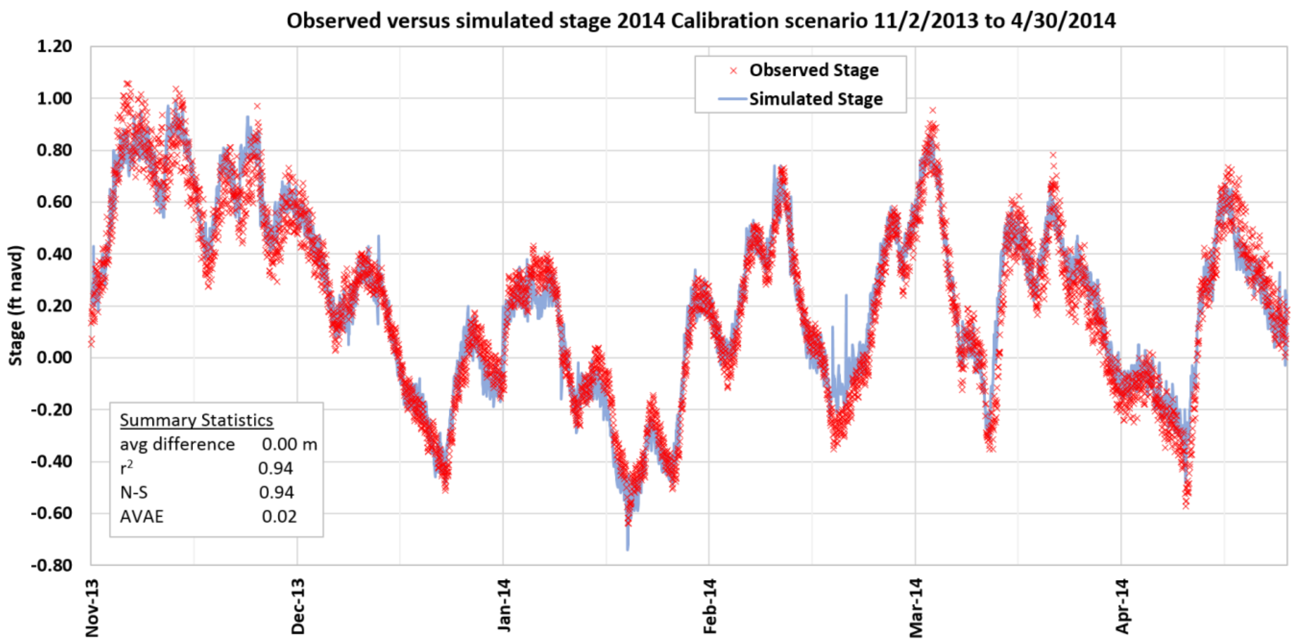


Figure 5-1. Comparison of observed and modeled stage, Silver Glen Springs Run, *11/02/13 to 4/30/14*

5.2 SILVER GLEN SPRINGS RUN SIMULATED DISCHARGE

The SGSR system is relatively flat and through the connection to Lake George and the broader St Johns River, experiencing suppressed flow when the stage at the downstream end (Lake George) is higher than upstream end (the spring pool). The dominant force in maintaining positive (downstream) flow in SGSR is the head gradient produced by Silver Glen discharge. While there was no continuous observed data to compare to, simulated discharge at the 500-m location provides a sense of the flow exchange between the lower and upper segments of the SGSR (Figure 5-2).

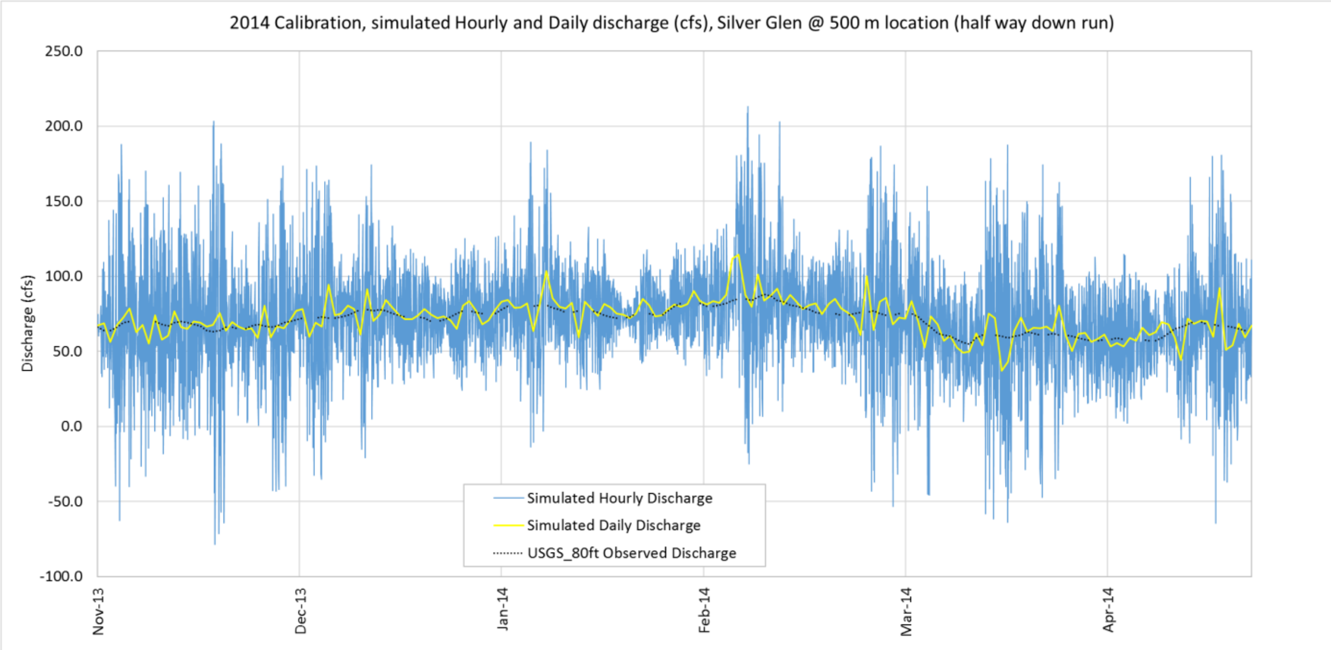


Figure 5-2. Hourly and daily simulated discharge for Silver Glen Springs Run, *11/2/2012 to 4/30/2013*

A summary for simulated discharge, velocity, and stage is presented at 80 ft (24.4 m), 500 m and 1000 m downstream in the Run (Table 5-1). The reported discharge at the 80-ft station for the period averaged 70.8 cfs. A negative sign indicates reverse (upstream flow) into the system. The difference in stage is also shown. The simulation shows that the system can experience a change in stage of up to 0.25 ft in an hour. The basin above the 500-m location is small so it could only hold water for a few hours before equilibrium is met and forward flow is reset, mainly because there is always spring discharge entering the system. An increase in stage in Lake George backs up the system. A quick drop in Lake George stage can produce a large hourly flow as the SGSR quickly drains. When the stage is at its lowest the flow at the 500-m location converges with upstream discharge, indicating the spring discharge has greater ability to prevent upstream incursions in the small cross-sectional area where the Run narrows during low stages.

Table 5-1. Data summary SGSR simulated discharge, velocity and stage 11/1/2012 to 4/30/2013, 80 ft, 500 m and 1000 m downstream of Main Vent

Condition	500 m Discharge (cfs)	1000 m Discharge (cfs)	80 ft Velocity (cm/s)	500 m Velocity (cm/s)	1000 m Velocity (cm/s)	80 ft Stage (ft-navd)	Stage difference (ft)
Maximum hourly	213.1	380.1	5.3	7.1	4.2	--	0.25
Minimum hourly	-78.7	-208.2	1.6	-5.0	-1.9	--	-0.24
Average daily	72.0	72.4	3.8	2.7	1.3	0.39	0.00
Maximum daily	114.5	111.1	4.9	4.1	2.3	1.15	0.38
Minimum daily	37.0	30.8	2.8	1.1	0.6	-0.28	-0.25

A comparison was made of flow exchange on the north side and south side of the island at the mouth of SGSR. The average daily discharge was 108.5 cfs and -36.3 cfs, and the average daily velocity was 5.3 and -2.7 cm/s for the north side and south side cells respectively. While the combined discharge on both sides of the island at the mouth of the Run (72.4 cfs) is consistent with magnitude of spring discharge from the vent and at the 500-m location, model results indicate that the south side connection facilitates incoming discharge from the lake while the north side cells facilitates outgoing flow from SGSR to Lake George during the simulation period.

5.1 Silver Glen Springs Run simulated salinity

With respect to salinity, most of the Run is essentially homogenous since the major salt source is spring discharge. Thus, most of the available data for salinity within SGSR is remarkably consistent, regardless of when or where the data was collected. No salinity data was available for comparison during the calibration period. However, once per year water quality data was collected at ten sites in SGSR (shown in Figure 1-2), from 2007 to 2013, as part of a SAV monitoring program (Mattson, 2010). The observed data from the 2007-2013 transects 3 to 8 were compared with the simulated salinity from the 2014 Calibrated model (Figure 5-3). Since the data collection depth is unknown, a comparison was made from about 25 meters to 700 meters downstream where it can be assumed salinity is vertically well-mixed by taking the average salinity from the 6-layer model output. The comparison shows that the model salinity resolution is like the observed data, with a range of salinity of about 0.1, and a general variability in the hundredths.

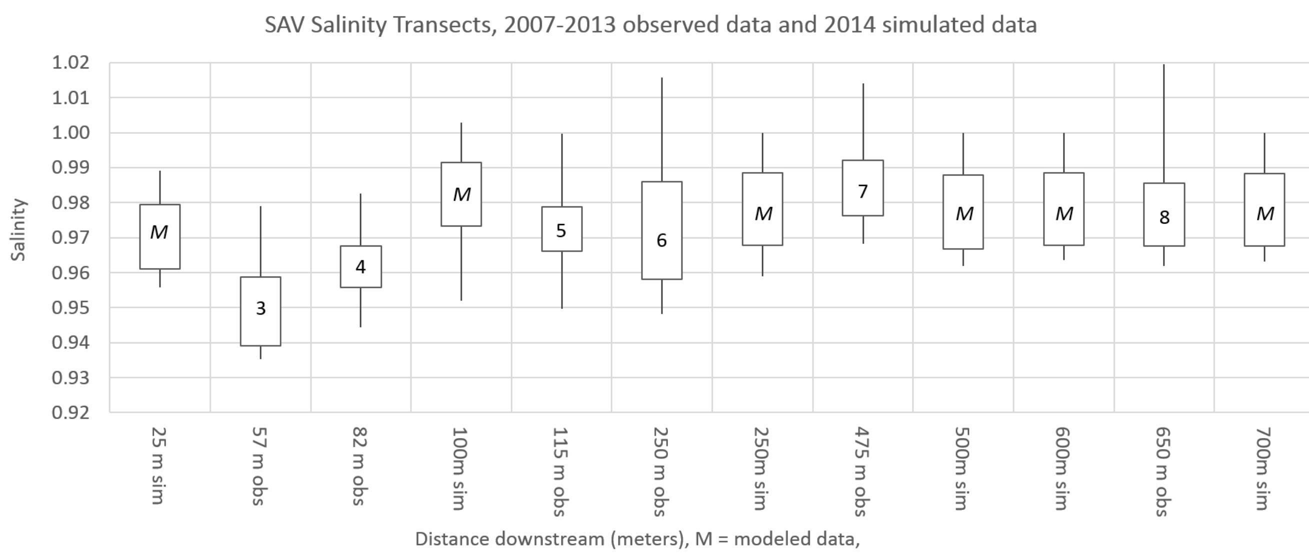
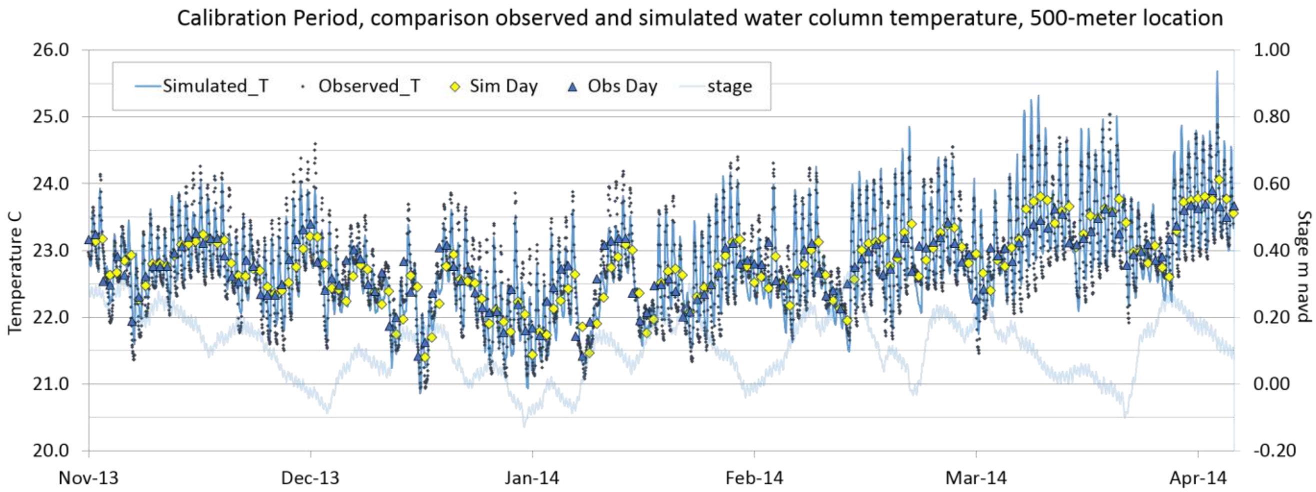


Figure 5-3. Comparison of observed and simulated salinity proceeding downstream in the SGSR.

5.2 Calibration and Validation, observed versus simulated temperature

Simulated and observed temperature are shown for the Calibration and Validation scenarios (Figure 5-4) using temperature data at the 500-m location (Ross, 2016). Simulated temperature was interpolated 1 ft from the bottom from the vertical six-layer model output based on the description of the deployment provided by the researcher. At this location, the SGSR is relatively unstratified as indicated by vertical profiles (recall Table 2-2), one sensor is reasonable to represent the whole water column temperature. From visual inspection, the model successfully reproduces the diurnal amplitude and responds to synoptic events produced by cold snaps and stage variation in both periods.



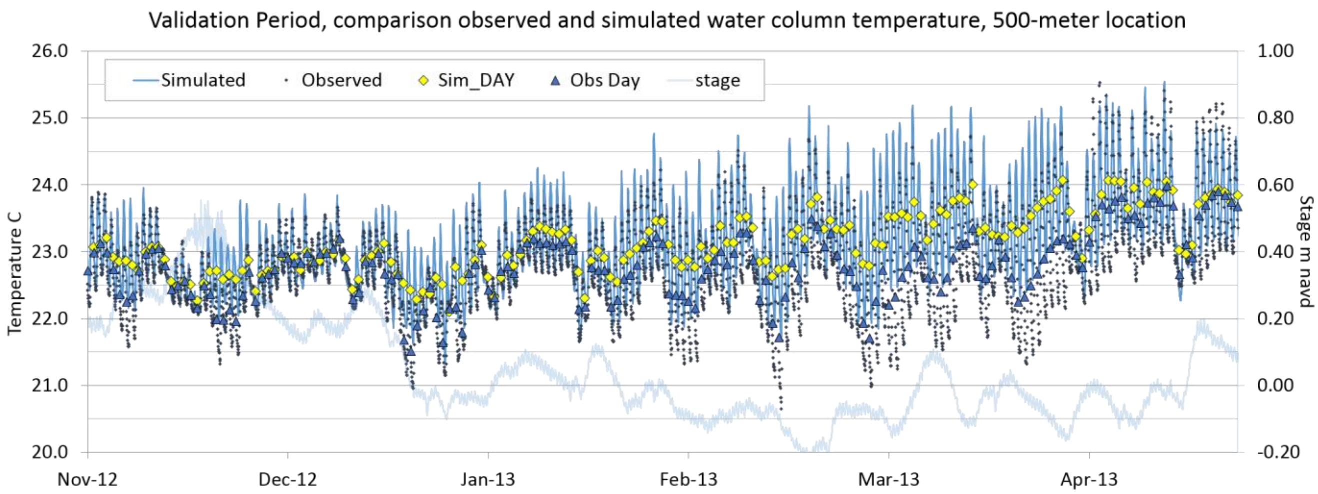


Figure 5-4. Comparison of observed and simulated temperature for the Calibration (top) and Validation (bottom) periods.

5.3 SIMULATED WATER AGE AND SALINITY, CALIBRATION PERIOD

Simulated salinity and water age are shown for the Calibration period (Figure 5-5) for four locations within the Run designated by distance from the head spring. The locations are shown in Figure 6-4. The salinity of the upper SGSR is predominantly a product of Silver Glen springs input over previous hours as indicated by the almost constant values in the upper part of the run. In the lower SGSR spring and Lake George water mix and the salinity varies from around 0.6 to .0.9. In general, the upper half of the Run is dominated by spring inputs, and the lower half a mix of spring and lake inputs.

Water age is the average age of the water in each model cell. It is like hydraulic residence time but it considers mixing and the introduction of water from downstream. Water is assigned an initial value of 0 (zero) at the boundaries, the 'packet' of water accumulates time while it travels within the model domain. Close to the spring head, water age is nearly constant at 0.5 hours. It increases to 4.7 hours at 250 m and 10 hours at 500 m. In the lower segment water age approaches a maximum of near 14 hours. The average water age for SGSR was 9.9 hours. Water age in comparison to temperature indicates that in general, the greater the water age the larger the amplitude of diurnal temperature variation at a given location within the Run.

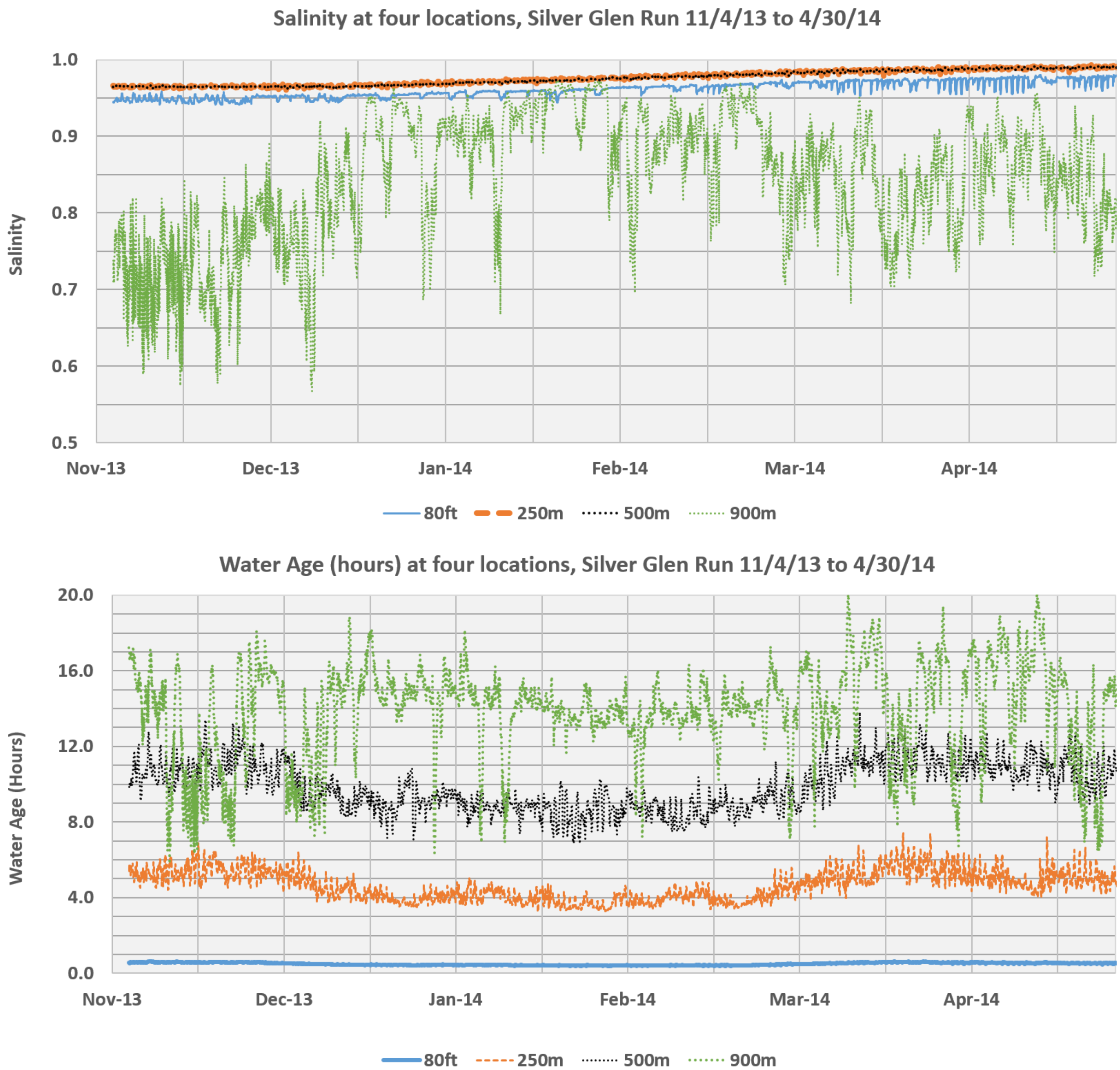


Figure 5-5. 2012-13 Calibration period simulated salinity and water age (hours)

For comparison, the average discharge during the Calibration period was 70.8 cfs (2.00 m^3/s). Assuming spring discharge is the only source of water to the SGSR and using the model grid to estimate the volume of SGSR, the volume above the 500-meter location (50,940 m^3) produced a hydraulic residence time of 7.08 hours and for the entire SGSR a volume of 114,209 m^3 produced a hydraulic residence time of 15.86 hours. The typical spring discharge can turn over the entire volume of SGSR in less than a day. Spring input, running continuously, thus dominates the temperature character of the run.

5.4 STATISTICAL SUMMARY, CALIBRATION AND VALIDATION SCENARIOS

Summary statistics are presented for the observed and simulated temperature in the of the water column at the 500-m location (Table 5-2).

Table 5-2. Summary Statistics for observed and simulated temperature, 2013-14 and 2012-13 simulations at the 500-m location

Temperature (°C)	Calibration 2013-2014 At 500 m		Validation 2012-2013 At 500 m	
	Sim	Obs	Sim	Obs
Minimum	20.85	20.94	21.35	20.65
Average	22.79	22.78	23.13	22.79
Maximum	25.56	25.04	25.54	25.53

To evaluate model performance, the *difference* between the observed and simulated hourly temperature was calculated and statistical analysis was conducted on the differences (Table 5-3). The difference-datasets are normally distributed so suitable statistical tests were conducted. The 2012-13 and 2013-14 time periods had 4295 and 4272 matched hours, respectively.

Table 5-3. Statistical comparison of the difference between observed and simulated temperature, 2012-13 and 2013-14 scenarios

	Calibration 2013-14	Validation 2012-13
Average	-0.01	-0.34
Median	-0.01	-0.27
Variance	0.06	0.14
Standard Deviation	0.25	0.37
Number of samples	4295	4272
r^2 (0 to 1)	0.88	0.75
MPE %	0.07	-1.53
N-S	0.88	0.53
AVRE %	0.88	1.69
AVAE (°C)	0.20	0.38
RMSE (°C)	0.25	0.37

The model calibration was evaluated by statistical comparison of matched pairs of simulated and observed time series. The comparative statistics were calculated using the formulas found in Appendix 11.6, descriptions of the formulas can be found in standard statistics textbooks.

The Calibration produced average and median *difference* values near zero. The validation scenarios, the model prediction is within about three-tenths of a degree °C of observed data. The coefficient of determination (r^2) indicates the model can reproduce the general character of the hourly time-series of the observed data. Likewise, values for the mean percent error (MPE), a measure of bias, are low (less than 2 %) and the Nash-Sutcliffe (N-S) values of 0.88 for the Calibration and 0.53 for the Validation scenarios indicate 'very good' and 'satisfactory' performance (Moriasi, 2007).

The sample standard deviation of the differences between predicted and observed values RMSE = 0.25 °C. The average absolute error (AVAE) provides an estimation of the amount of physical error in observed measurement. The average relative error (AVRE) indicates how good the observed measurement is relative to the 'size' of what is being measured—in our case this is the range of observed temperatures. AVRE values indicate the model comes within 2% of predicting the observed temperature, while AVAE indicates the actual amount, about 0.3 °C over the entire distribution. These results show that the model can be used to make temperature predictions for SGSR.

6 RESULTS

6.1 CONTINUOUS TEMPERATURE IN THE UPPER SGSR

Additional continuous data beside what was collected at the 500-m location is sparse. Data is available for three days in February of 2009 from a study of the upper half of SGSR (WSI, 2010). Sensors were deployed at near the vents, and at one 500 m downstream, (Figure 3-2). Results show that the model successfully captures the increase in amplitude of the diurnal temperature signal. The diurnal signal in the Main Vent observed data is due to the mixing of water from the Run mixing with new spring water. The model successfully captures this process.

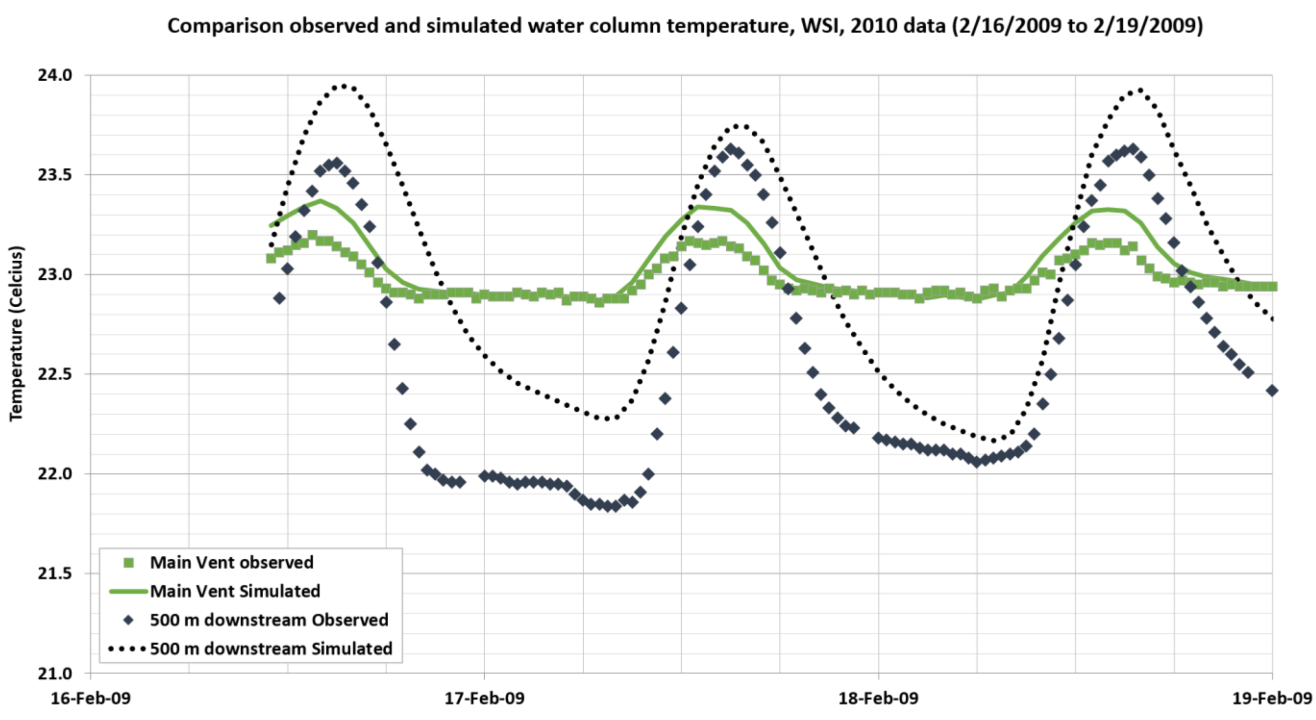


Figure 6-1. Comparison of observed and simulated water column temperature at the Main Vent and 500 m downstream, February 2009

6.2 CONTINUOUS TEMPERATURE IN THE LOWER SGSR

Data was collected in April 2011 900 m downstream near the mouth (Cohen, 2011). The outputs from all six vertical layers are included for comparison to the observed data. The Calibrated model parameters were applied to the 2011 data. Over the two-week period in April, the model accurately predicted the character (r^2 = 0.70), the peak daily temperature and the wavelength, but tended to over predict the minimum temperature (avg difference = 0.49 °C).

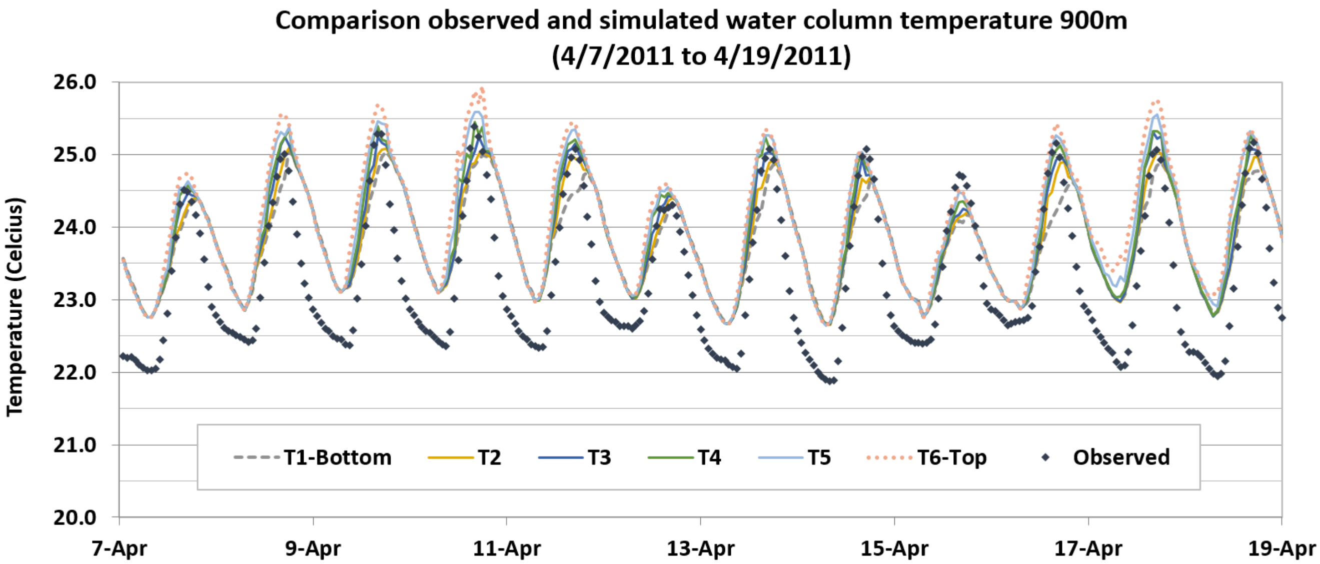


Figure 6-2. Comparison of observed and simulated temperature, 1000 m downstream Silver Glen Springs Run, *4/07/2011 to 04/19/2011*

A temperature sensor was deployed by District staff in February 2015 to get a sense for the response of temperature at the expansion of SGSR downstream of the 500-m ‘narrows’ (Figure 6-3). The goal was to get a few weeks of data that could be compared to the 500-m location. The r^2 was 0.79 and 0.86 for the 500-m and 650-m locations, with an average difference of -0.35 and -0.54 °C, respectively. Visual inspection of the observed data shows that the diurnal temperature signal amplitude is larger at the downstream location.

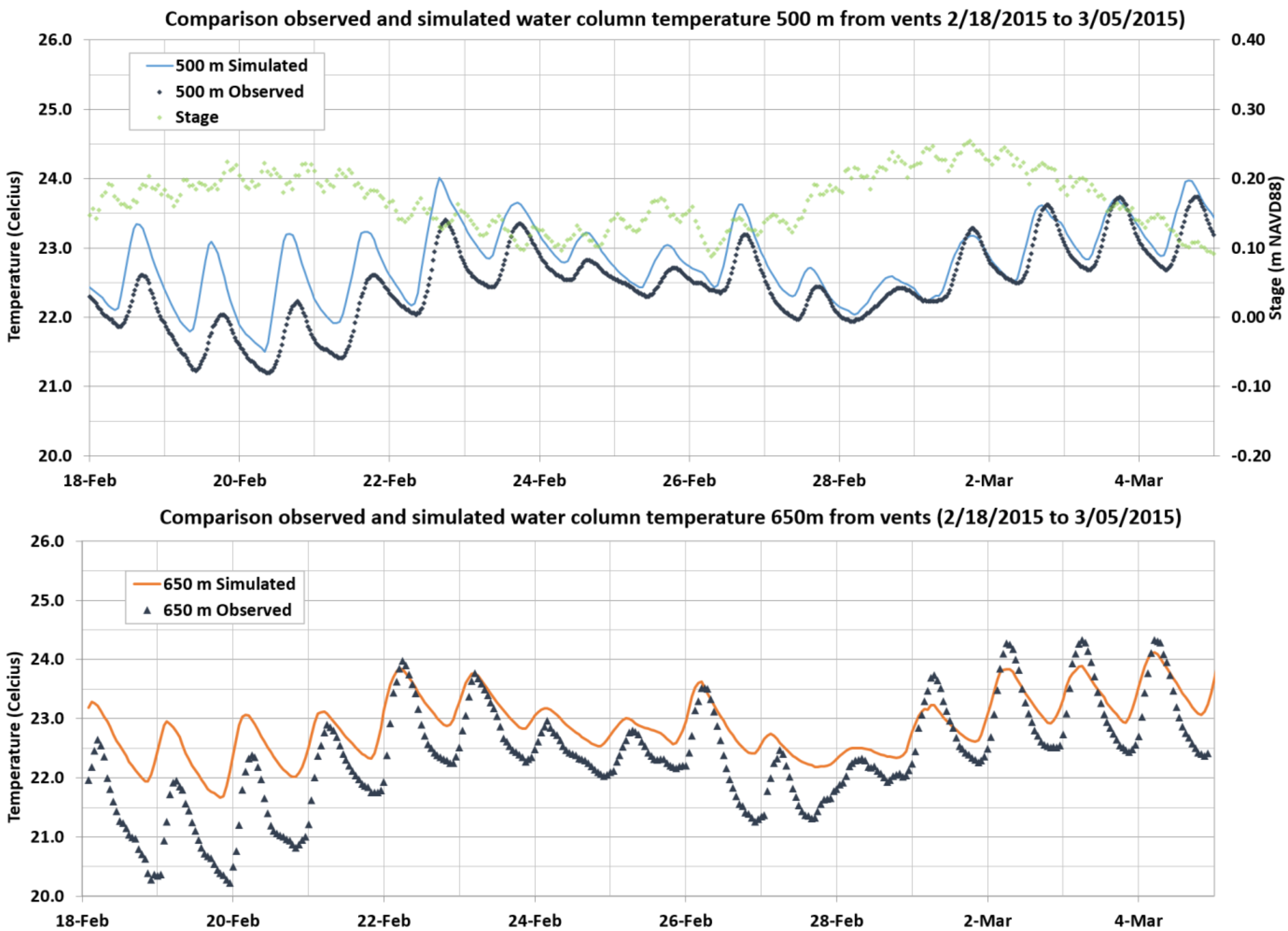


Figure 6-3. Comparison of observed and simulated temperature, 500 m and 650 m downstream Silver Glen Springs Run, *2/18/2011 to 03/05/2011*

Since the model uses a single set of input parameters for heat budget for the entire model domain, the output represents a homogeneous condition for water clarity characteristics and thus heat attenuation for the entire grid. The reality in the lower segment is there is a gradual increase in the amount of Lake George water that is mixed in, so clarity is reduced proceeding downstream due to the added color (Table 4-9). This may explain why the model simulated amplitudes are similar among the two locations in Figure 6-3. It could also be related to how well the model reproduces the influx of Lake George water into SGSR. The model does a good job of capturing subtle responses in the diurnal temperature as indicated by Figure 7-2. Sampling color and other water quality parameters at several locations proceeding downstream would be improve understanding of the degree of lake mixing into SGSR.

6.3 Comparison of the Calibrated Model to a 20% Reduction in Spring Discharge

The 2013-14 Calibration scenario was used as a Baseline reference, and a 20% reduction in spring flow was applied to test temperature sensitivity to a reduction in discharge. Temperature was output for locations along the main channel of the Run to compare horizontal temperature variability in the SGSR for the Baseline scenario and a 20% reduction of flow (bottom) for the same period (Figure 6-4), using the average temperature from the six vertical layers, averaged over the 6-month model run. In the lower segment, cells at 800 m, 900 m and, 1000 m along the south side of the Run are also provided. Appendix 11.8 includes the data used to produce the plots in this section.

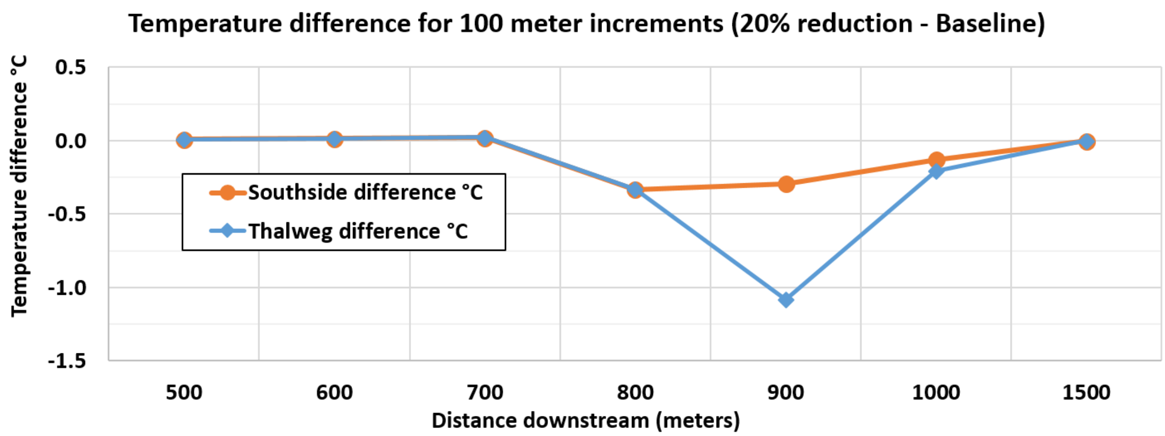
Figure 6-4. Model output locations for scenario comparison

6.3.1 COMPARISON OF RIVER SEGMENTS IN THE LOWER SGSR, BASELINE AND 20% REDUCTION IN SPRING DISCHARGE

The difference in temperature between the 20% reduction and the Baseline scenario shown in the top plot in Figure 6-5. Results indicate that the upper half of the SGSR was relatively insensitive to the flow reduction, showing virtually no visible effect from discharge reduction, like segments 500 m to 700 m in the figure. The percent change (the difference divided by the Baseline temperature) is shown in the bottom plot. The color of the plot corresponds with Figure 6-5, with blue representing the thalweg and orange the south side of the lower part of the run.

In response to a reduction in spring discharge, there was a noticeable change in Figure 6-5 from 800m to 1000m downstream with a decrease of over 1 °C at the 900-m increment on the north side of the Run along the main stem/thalweg. The reduction in temperature on the south side was smaller. The results are flipped when considering the amount of spring water, with the larger response occurring on the south side of the Run versus the north side along the thalweg. The maximum shift was at the 800m increment with an over 15% reduction in the amount of spring water, indicating the south side of the Run near the mouth is somewhat distinct from the north side. The percent reduction on the north side was between 5 and 10%, depending on location for the two scenarios.

Numerical dye was applied to the model with a value of 100 for the springs and 0 (zero) for the Lake boundary. This was used to estimated the amount (percentage) of spring water at 100 meter increments within SGSR ((Figure 6-6; see locations, Figure 6-4). Vertically averaged results show from the head reach downstream to 700 m; the Run is almost entirely occupied by spring water (versus Lake George water). From 700 m to the mouth, the Run is comprised of an increasing fraction of Lake George water. A summary of the data is included in Appendix 11.8. The dye simulation provides a strong indication that the reach between 700 and 900 m contains a somewhat definitive zone where the upstream water is predominantly spring source while downstream it is a mix of spring and lake water during the Calibration period.



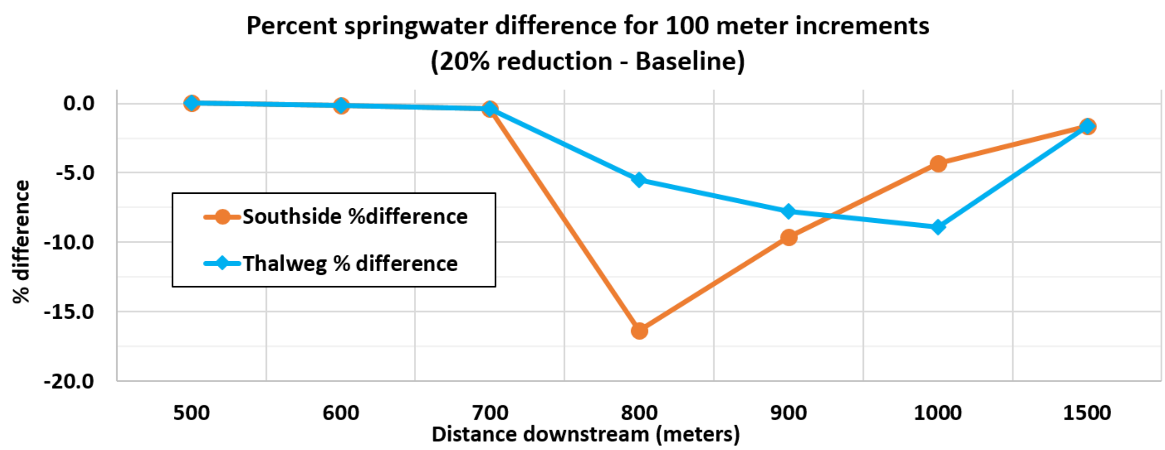


Figure 6-5. Lower SGSR response to 20% reduction in SGS discharge at 100 m increments

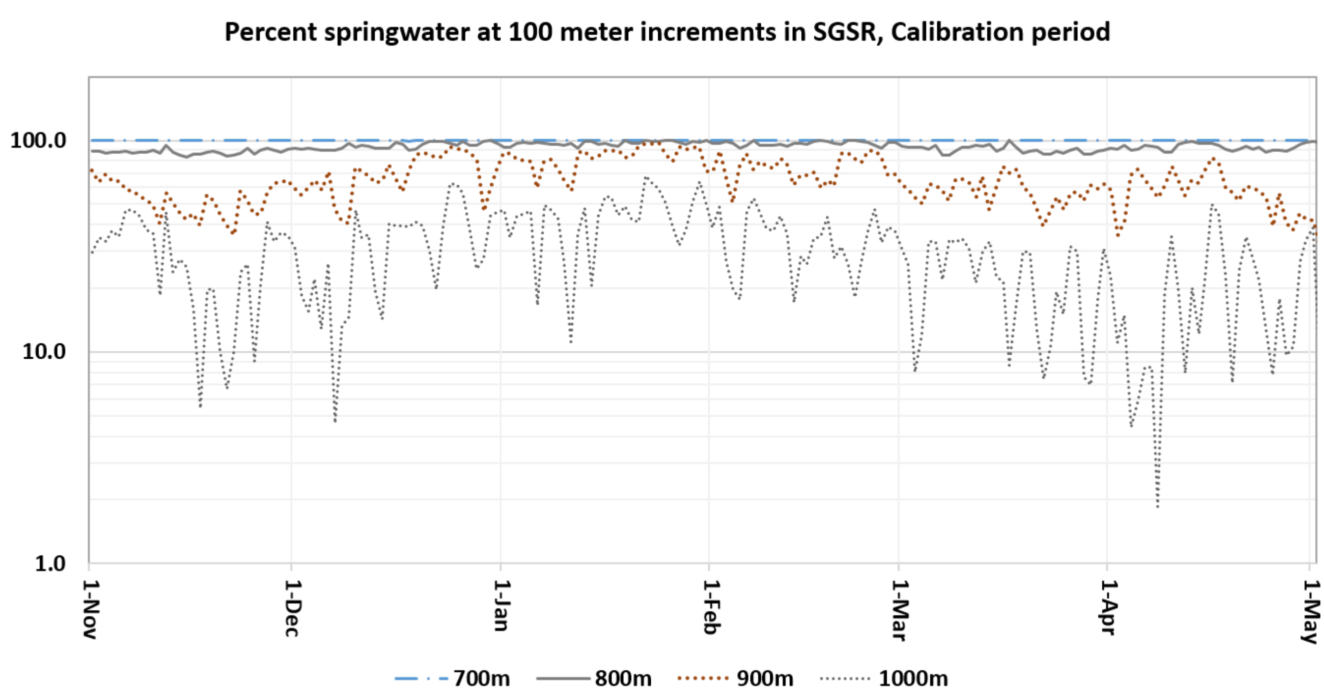
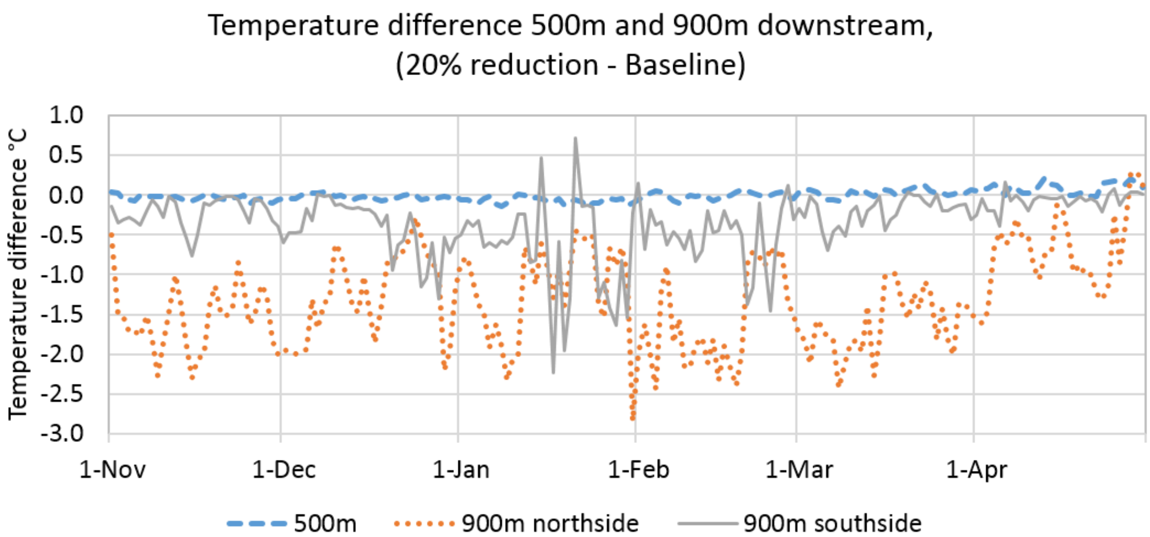


Figure 6-6. Percentage of spring water (versus lake water) at 100 m increments in the Lower SGSR

6.3.2 COMPARISON, BASELINE AND A 20% REDUCTION IN SPRING DISCHARGE AT 500 M AND 900 M DOWNSTREAM

The 2013-14 Calibration scenario was used as a Baseline reference, and a 20% reduction in flow from Silver Glen springs was applied to the simulation to test temperature sensitivity to a reduction in discharge. Vertically averaged results are shown for 500 m and 900 m downstream in the Run for temperature difference (Figure 6-7, top) and the difference in the amount of spring water between the 20% reduction and the Baseline (Figure 6-7, bottom). The 20% reduction in flow did not change the amount of spring water (~100%) at the 500-m location, and only had a minor effect on temperature, as can be seen in the figure over the simulation. The response 900 m downstream was more dramatic, and the influence on the SGSR was different depending if the north side or south side of the Run was evaluated. Additional data is summarized in Appendix 11.8. At 900 m, the 20% reduction in spring discharge reduced the average temperature by 7.8 °C on the north side and reduced it by 4.3 °C on the south side of the Run. The decrease was likely smaller on the south side since it is already colder on average due to the south side being a preferential flow path for incoming Lake George water (Table 5-1).



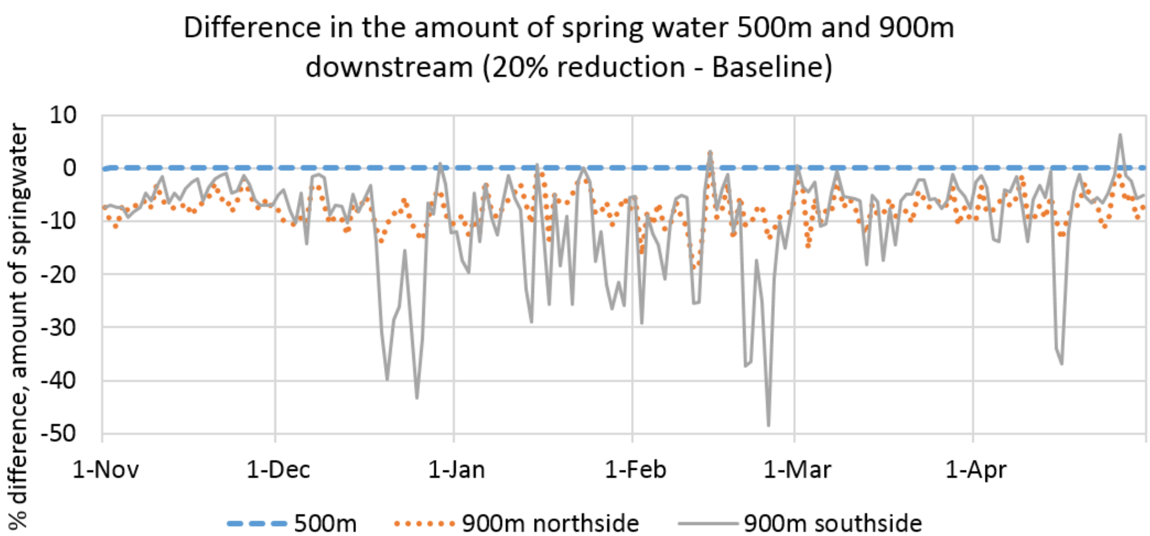


Figure 6-7. Temperature and Spring percentage difference between Baseline and 20% reduction scenarios for the 2013-14 winter simulation at the 500 m downstream based on hourly data

6.3.3 Simulated Stratification at the Mouth (1000 m Downstream)

The model can reproduce stratification of temperature and salinity at the mouth of the Run (Figure 6-8). This includes reproducing an inversion of salinity where temperature and salinity *decrease* with increasing depth) when Lake George is colder than SGSR (1/23/2014 data), similar to observed data in Table 2-2. During the summer when lake temperature is warmer than the Run (5/24/2014), the warmer water is in the top of the water column and the results is decreasing temperature and *increasing* salinity with increasing depth.

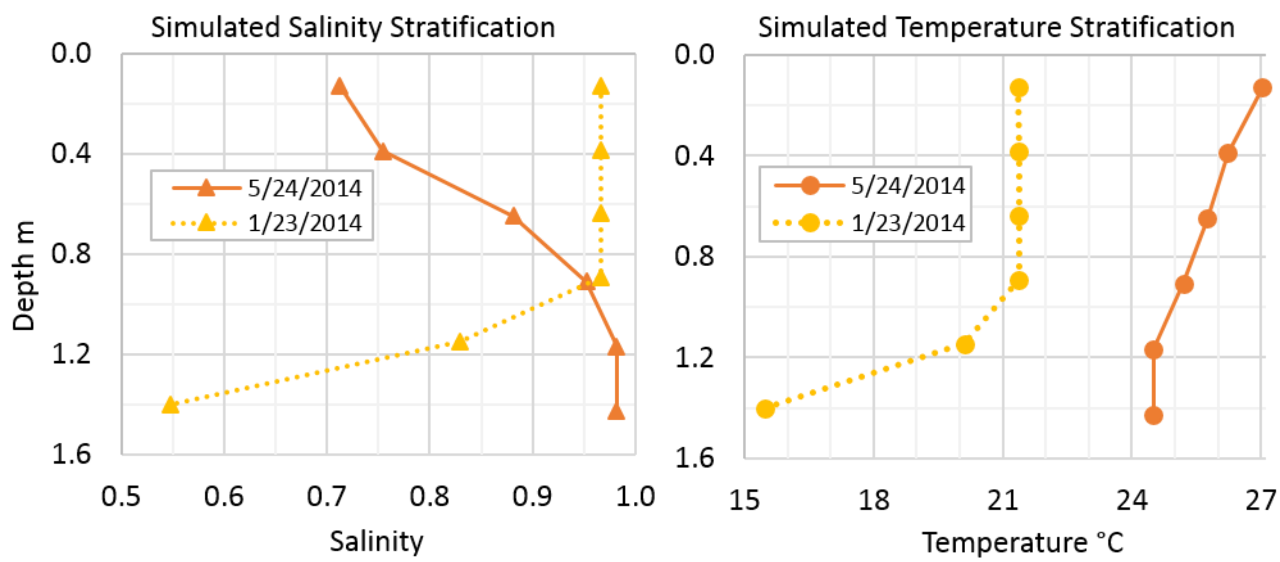


Figure 6-8. Simulated stratification of temperature and salinity at the mouth (1000 m downstream) of SGSR

7 Sensitivity Analysis

7.1 Recommended Resolution for Water Temperature Analysis

The minimum temperature response is determined by the resolution of the HOBO pendant temperature sensors used for calibration (0.14 °C). An engineering rule of thumb is half the increment. For our case, since the range of all sensors is 0.14 °C the calibration sensor is assumed to be middle of the road so if we compared it to a large set, it would have the other sensors cluster on either side + or - 0.07 °C. For example, assume we have 2 new sensors that vary by 0.07 °C. Imagine we are out measuring and the actual water temperature is 23.0 °C. We are using Sensor A and it measures 23.0°C for the baseline condition. If we had used Sensor B, it would measure 23.06°C. Later, we are measuring a discharge reduction scenario, the actual temperature has decreased to 22.94 °C but we are using Sensor B, so we detect 23.0 °C and assume no change in temperature has occurred. Since we are assuming the model is ‘middle of the road’ the discharge should produce at least the 0.07 °C shift. Use the more conservative 0.14 °C if you want to assume the original sensor was biased towards either end of +-0.7°C.

Thus, in using the model to evaluate changes to spring discharge, the minimum discharge reduction that should be used for decision making purposes will produce a temperature response of at least 0.07 °C at any location vertically or horizontally and at any single hour in the model domain between the baseline and reduction scenario, because the model in effect is an extension of the temperature sensor it is calibrated to. At least the last four rows of cells out in the lake should not be used for analysis, since the focus is on the SGSR and not Lake George.

7.2 SENSITIVITY ANALYSIS RESULTS

The Calibrated model was used as a Baseline to conduct a basic sensitivity analysis of meteorological conditions, bathymetry, bottom friction, and watershed runoff. Model performance in response to input adjustments is only available for the for the 500-meter location where observed data is available for comparison. Recall from Section 5.2, simulated temperature was interpolated 1 ft from the bottom from the six-vertical layer model output at the 500-meter location. A relative comparison was made in the upper and lower SGSR between the Baseline and sensitivity tests using output for 50 m and 1000 m downstream (see locations, Figure 6-4) was also made. Since no observed data is available, the average of six-vertical layer model output is provided at these locations, comparing Baseline to sensitivity scenario. A more thorough sensitivity analysis requires observed data in the areas of interest.

To address Intera, 2016 that "discussion should be added to the documentation to quantify the calibration / validation periods as wet, dry or average,". Categorizing a given period as wet dry or average would be misleading about the relative influence of rainfall and or evaporation on SGSR water temperature. It would take a thorough sensitivity analysis, beyond the scope of the work presented in this report, to determine which factors, not just rainfall and evaporation have the most effect on water temperature in the winter-time, in SGSR. A thorough sensitivity analysis if required would follow the model development and calibration. This section includes sensible examples of model response to various changes in inputs, providing a very basic sensitivity analysis.

The model was limited to using a single heat transfer value for the entire model domain. The concentration of color and suspended materials increases proceeding downstream in the lower SGSR—influences light penetration due to the increasing fraction of Lake George water in the Run. Evaluating the influence of color gradient on light / heat penetration and subsequent temperature response would require updating the EFDC source code to accommodate spatially varying heat transfer. As shown in Section 6, the lower segment of the SGSR is the most sensitive to changes in conditions. To provide a robust sensitivity analysis of the temperature model would require collecting sufficient spatial and temporal data in this region to gain a sense how the lower SGSR responds to different conditions in the real world, and thus evaluate how well the model reflects the relative influence of various forcing factors. Otherwise the only relative comparisons can be made between a baseline and other scenarios.

7.2.1 DAILY RAINFALL

To evaluate daily rainfall, the hourly Pierson FAWN rainfall and other meteorological data was aggregated to daily values, so Pierson daily rainfall used in the Baseline condition could be compared to another nearby rainfall station located at Crescent City, about 23 km northeast of SGSR with available daily rainfall data. Results indicate that when aggregated to daily values and using the Calibrated model, the selection of a different rainfall set from a local station had a nominal effect on water temperature at the 500-meter location when the data is at a daily resolution (Table 7-1). The short-term response due to rainfall has a minimal effect when looking statistically at an entire season using daily average values.

Rainfall is synoptic so the effect of spring temperature would be focused to the hours during and just after an event. However, the Run and Lake George are also being subjected to greater mixing due to the winds that are typically associated with a rainfall event. Rainfall typically adjusts to the temperature of the air that it falls through, so rainfall temperature is modulated to the air temperature. Thus, the air temperature on the day of a rain event likely has a greater influence than the rainfall on ambient water temperature.

Table 7-1. Comparison of Daily rainfall, Pierson (FAWN) and Crescent City (NOAA)

Simulated Temperature		
500-m location	Daily Rainfall comparison	
	Pierson daily (Baseline)	Crescent City daily
Minimum	21.473	21.472
Average	23.064	23.060
Maximum	24.358	24.305

Temperature, summary statistics of differences (Simulated - Observed)		
500-m location	Daily Rainfall comparison 2012-13	
	Pierson daily (Baseline)	Crescent City daily
avg diff (sim-obs)	-0.136	-0.132
r^2	0.895	0.896
MPE (%)	-0.588	-0.569
N-S	0.788	0.786
AVRE (%)	0.905	0.918
AVAE	0.208	0.211
RMSE	0.225	0.229

7.2.2 Sensitivity of Hourly Data

The remaining sensitivity analysis was conducted using hourly meteorological data. The rainfall and evaporation time series for the Calibration scenario was multiplied by 0.33 and 1.04, respectively, to reflect conditions present during the Validation period when there was considerably less rainfall and slightly more evaporation (see Table 4-7). A constant cloud cover fraction was applied for 0 % (clear sky), 50%, and 100% (completely cloudy). Watershed runoff was applied to SGSR at three locations where there is a distinct drainage feature (a small stream or ditch) entering the Run (Figure 1-3). Depth was decreased globally by 0.5 meter. The calibration stage time series was reduced by -0.23 m to test model sensitivity to water level. Bottom roughness values of 0.25m (maximum) and 0.025m (minimum) were applied to homogeneously to all cells to evaluate model sensitivity to friction. The model was Run from a cold start to compare the results to the Calibration where a hot start was used. The ratio of discharge allocation between the Main Vent and Natural well was tested by increasing the proportion of the total discharge to the Natural well by 10%.

- Baseline — Baseline condition using Calibration parameters
- Rain / Evap — Rainfall and evaporation adjusted to Validation period totals
- Cloud 0% — Apply constant 0 percent (clear sky) cloud cover
- Cloud 50% — Apply constant 50 percent cloud cover
- Cloud 100% — Apply constant 100% cloud cover
- Friction max — Apply constant bottom roughness of 0.25 m to all cells
- Friction min — Apply constant bottom roughness of 0.025 m to all cells
- Cold Start — Using a cold start to initiate model run
- Depth +0.5m — Increase depth globally by 0.25 m throughout model domain
- Stage -0.23m — reduce the stage time series by -0.23 m
- Runoff 236ac — include runoff from SGSR watershed
- Q ratio — Adjusted discharge proportion from 0.74 to 0.64 for the Main Vent and from 0.26 to 0.36 for Natural Well

Table 7-2 includes a statistical comparison for each scenario to the observed data at the 500-m location, along with the average, minimum and maximum water temperature at the 50 m and 1000 m increments for each scenario. Spring discharge is the dominant force influencing water temperature due to the small size in surface area and volume of SGSR relative to the first magnitude discharge of the spring. Recall from the estimation of water age and hydraulic residence time in Section 5.3 that it takes about 7 hours of spring discharge to turn over the volume of the upper SGSR, and 16 hours to turn over the entire Run.

Table 7-2. Comparison of the Calibrated (Baseline) model to adjusted input parameters at the 500-meter location, mouth of Sandboil Run and mouth of SGSR

Hourly Data Comparison 2014-15, 500-meter location												
	Simulated Temperature (°C)											
	Baseline	Rain/ Evap	Cloud 0%	Cloud 50%	Cloud 100%	Friction max	Friction min	Cold Start	Depth +0.5m	Stage -0.23m	Q ratio	Runoff 236ac
Min	20.854	20.853	20.623	20.826	21.049	20.451	20.813	20.860	21.093	20.396	20.845	20.850
Avg	22.794	22.795	22.590	22.782	22.968	22.793	22.790	22.801	22.801	22.764	22.783	22.792
Max	25.558	25.509	25.450	25.529	25.605	25.605	25.316	25.727	24.955	25.690	25.550	25.485

Hourly Data Comparison 2014-15, 500-meter location												
	Temperature, summary statistics of differences (Simulated – Observed)											
	Baseline	Rain/ Evap	Cloud 0%	Cloud 50%	Cloud 100%	Friction max	Friction min	Cold Start	Depth +0.5m	Stage -0.23m	Q Ratio	Runoff 236ac
avg diff	-0.014	-0.015	0.190	-0.003	-0.188	-0.013	-0.010	-0.021	-0.021	0.016	-0.003	-0.013
r^2 (0 to 1)	0.881	0.882	0.880	0.875	0.869	0.829	0.886	0.879	0.800	0.869	0.881	0.882
MPE (%)	-0.069	-0.073	0.833	-0.016	-0.838	-0.053	-0.052	-0.098	-0.122	0.076	-0.020	-0.061
N-S	0.877	0.877	0.795	0.869	0.798	0.780	0.883	0.873	0.783	0.822	0.877	0.877
AVRE (%)	0.876	0.875	1.148	0.909	1.111	1.191	0.859	0.887	1.170	1.072	0.878	0.877
AVAE (°C)	0.200	0.199	0.262	0.207	0.252	0.271	0.196	0.202	0.267	0.244	0.200	0.200
RMSE (°C)	0.248	0.248	0.259	0.257	0.257	0.332	0.242	0.252	0.330	0.299	0.249	0.248

Hourly Data Comparison 2014-15, 50 meters downstream												
	Simulated Temperature (°C)											
	Baseline	Rain/ Evap	Cloud 0%	Cloud 50%	Cloud 100%	Friction max	Friction min	Cold Start	Depth +0.5m	Stage -0.23m	Q Ratio	Runoff 236ac
Min	22.366	22.371	22.320	22.374	22.404	22.404	22.371	22.367	22.373	22.401	22.341	22.368
Avg	22.870	22.870	22.848	22.869	22.888	22.889	22.867	22.869	22.842	22.882	22.848	22.868
Max	23.540	23.543	23.514	23.539	23.556	23.596	23.535	23.541	23.660	23.577	23.514	23.540

Hourly Data Comparison 2014-15, at the mouth of Silver Glen Springs Run (1000 m downstream)												
	Simulated Temperature (°C)											
	Baseline	Rain/ Evap	Cloud 0%	Cloud 50%	Cloud 100%	Friction max	Friction min	Cold Start	Depth +0.5m	Stage -0.23m	Q Ratio	Runoff 236ac
Min	15.137	15.152	15.225	15.337	15.084	17.210	15.178	15.082	13.833	16.978	15.185	15.544
Avg	20.186	20.193	20.026	20.168	20.318	21.082	20.359	20.220	19.701	20.964	20.196	20.182
Max	25.531	25.470	25.534	25.506	25.520	25.520	25.491	25.533	25.882	25.488	25.487	25.518

Thus, the system recovers quickly from rainfall events (both as direct input and runoff) due to spring input. The statistics are presented for six months of data—the specific influence of a large rainfall/runoff event at an hourly scale is beyond the scope of this work. The author agrees with Intera, 2016 that storm event sampling can help to understand the temperature response of the SGSR to rain and runoff. The results also indicate that the model is somewhat insensitive to watershed runoff, likely for similar reasons to rainfall—boundary inputs of temperature are attenuated quickly due to the high turnover rate of the spring discharge. Runoff was applied to three locations, indicated in Figure 1-2. Diffuse baseflow was not simulated. To address Intera, 2016, it is reasonable to assume that the SGSR—as a body that radiates heat in the winter—will directly affect the temperature of the substrate surrounding it, modulating the temperature of baseflow in the last few meters before it enters the Run. Further analysis of watershed runoff is beyond the scope of this current work, requiring either observed runoff data or a hydrology model specifically developed for the SGSR watershed.

The difference between the Baseline and sensitivity test water temperature was calculated for each of the three locations (Table 7-3), to make it easier to see the difference between scenarios. The model is sensitive to the choice of cloud cover fraction with r^2 and N-S results for a constant 0%, 50% and 100% cloud cover varying by about 1-9% from the Calibrated model. The time varying cloud cover is considered an improvement over using a constant value. The general character of the simulated model as indicated by visual inspection of the time series, r^2, and N-S does not change significantly whether using a constant or a time-varying cloud cover fraction.

The use of a cold start versus a hot start produced little change from the Baseline condition. With a cold start of the model, an initial estimation of temperature and salinity is applied to all the cells using EFDC files TEMP.INP and SALT.INP. The initial estimation came from the synoptic data shown in Figure 2-7. This allows the model to quickly adjust to boundary inputs when a cold start is used. To address Intera, 2016, the benefit of a hot start is it can reduce computation time. It can also improve stability when a scenario is initialized, since the system operating conditions are more closely approximated than with a cold start. A hot start file in EFDC, called 'RESTART.INP' is a snap shot of all the physical and transport parameters being modeled—stage, discharge, salinity, water temperature, etc.

The model showed some sensitivity when the same maximum or minimum friction was applied to all cells. Likewise, the model shows some sensitivity with adjustment to depth and stage. Depth was increased by 0.5 meters for all cells. The stage time series was decreased by 0.23 meter to evaluate the sensitivity of the system to water surface elevation. The 0.23-meter decrease was the limit allowable to maintain model stability. Recall from Section 4.1, there is a daily tidal variation of about 2 inches and a seasonal low-frequency variability of about 1 ft due to the interaction of the Atlantic Ocean with the St Johns River. At lower stages SAV tops out at or near the water surface (see photographs, Appendix 11.9). Under this condition, many areas are inhibited from exchange and mixing. At higher stages, there is typically a foot or more of open water over the top of the SAV.

From this basic analysis, it appears that stage is major physical factor that is not related to system morphology influencing temperature response. The friction and bathymetry test indicate that morphology with respect to spring discharge is the primary factor influencing temperature in the upper part of SGSR. In the lower SGSR, water temperature and tail water stage from Lake George have an increasing influence proceeding downstream towards the mouth of the Run. The diurnal variability of air temperature a weekly basis is greater than that of solar radiation, so air temperature, depending on the difference between SGSR water and air temperature, can have a strong influence on the Run.

Table 7-3. Difference in simulated temperature (Baseline – Sensitivity test) at the 500-m location, mouth of Sandboil Run, and mouth of SGSR.

Hourly Data Comparison 2014-15, at the 500-meter location											
	Difference in Simulated Temperature (°C) from Baseline conditions										
	Rain/ Evap	Cloud 0%	Cloud 50%	Cloud 100%	Friction max	Friction min	Cold Start	Depth +0.5m	Stage -0.23m	Q Ratio	Runoff 236ac
Min	0.002	0.232	0.029	-0.195	0.403	0.042	-0.006	-0.238	0.458	0.009	0.005
Avg	-0.001	0.204	0.012	-0.174	0.002	0.004	-0.006	-0.006	0.030	0.011	0.002
Max	0.049	0.108	0.029	-0.047	-0.047	0.242	-0.169	0.603	-0.132	0.008	0.073

Hourly Data Comparison 2014-15, 50 meters downstream											
	Difference in Simulated Temperature (°C) from Baseline Conditions										
	Rain/ Evap	Cloud 0%	Cloud 50%	Cloud 100%	Friction max	Friction min	Cold Start	Depth +0.5m	Stage -0.23m	Q Ratio	Runoff 236ac
Min	-0.004	0.046	-0.008	-0.038	-0.038	-0.005	-0.001	-0.006	-0.034	0.025	-0.001
Avg	0.000	0.021	0.001	-0.019	-0.020	0.002	0.001	0.028	-0.012	0.021	0.001
Max	-0.002	0.027	0.001	-0.015	-0.056	0.005	0.000	-0.120	-0.036	0.026	0.001

Hourly Data Comparison 2014-15, at the mouth of Silver Glen Springs Run (1000 m downstream)											
	Difference in Simulated Temperature (°C) from Baseline Conditions										
	Rain/ Evap	Cloud 0%	Cloud 50%	Cloud 100%	Friction max	Friction min	Cold Start	Depth +0.5m	Stage -0.23m	Q Ratio	Runoff 236ac
Min	-0.014	-0.087	-0.200	0.053	-2.073	-0.041	0.055	1.305	-1.841	-0.047	-0.407
Avg	-0.007	0.161	0.018	-0.132	-0.896	-0.172	-0.034	0.485	-0.778	-0.010	0.004
Max	0.061	-0.003	0.025	0.011	0.011	0.039	-0.002	-0.351	0.043	0.044	0.013

8 DISCUSSION

8.1 PROPAGATION OF BIAS FROM BOUNDARY ASSUMPTIONS

Intera, 2016 expressed concerns with respect to the propagation of bias based on boundary assumptions. The LG-SG model represented the best available method to produce boundary conditions for the SGSR model. The limitation is that there was no continuous data at the SGSR boundary to compare to the LG-SG model output. Collecting observed data near the Run out in Lake George would improve model resolution in future work. The other major source of bias is assuming discharge, temperature and salinity of the Natural Well and the Sandboil Run springs always vary in the same proportions to the Main Vent. It is reasonable to assume that that there is some variation to these sources that is distinct from the Main Vent. Simultaneous measurement of discharge, temperature, and salinity at the downstream end of Sandboil Run and the Natural Well pool could be used improve understanding of the temporal variability of these sources with respect to the Main Vent and the 80-ft station.

8.2 EFFECT OF BENTHIC STRUCTURE, AQUATIC VEGETATION, AND ADJACENT FOREST ON TEMPERATURE DYNAMICS

The single value NF = 1.28 is applied to the whole Run is agreeable with a mixture of spring water and lake water in the Run. However, at the head of the Run the NF value may be at its lowest limit since the water coming out of the spring is among the clearest in Florida. The water is so clear that in theory, some of the solar radiation can reflect off the light-colored bottom and exit the surface of the Run (Warrior, 2007). There is a component of flocculent algae (Foss, 2012) that is typically present in the upper half of the Run that shades part of the bottom, in theory influencing light penetration.

The EFDC heat model does not account for the influence of vegetation on heat-related mixing dynamics. In SGSR, dense vegetation impedes the mixing in areas, RCHC adjustments can reflect this effect. The vegetation canopy is visible from aerial imagery through much of the model domain. The extinction coefficient NF is affected by the presence of SAV since the vegetation beds prohibit light from reaching the bottom. The extinction coefficient adjustment accounts for this light blocking. Seasonal variation in SAV density (growing and dying) can also affect mixing dynamics and water quality (Schefler, 1998; Wu, 1999; Moore, 2012).

In response to Intera, 2016, the influence of SAV on heat distribution comes primarily from its influence on mixing dynamics. While SAV subdues turbulent mixing, it does *not* prevent conduction—the direct transfer of heat between the open water column and water within the vegetation canopy. In open water, the temperature is constantly influenced by advective mixing of the input of new spring water that works to modulate the water temperature. Within the SAV canopy the *lack* of advection/velocity means the water is more affected by the full response to incoming solar radiation during the day and maximum heat loss at night, thus the amplitude of the diurnal signal would in principal tend to be slightly greater in vegetated areas versus open water/unvegetated areas (Moore, 2012).

The forested edge and emergent vegetation shade the Run by directly blocking sunlight (heat) transfer, especially when the sun angle declination is lower and thus the solar input is reduced. Full sun contact does not occur unless the sun is high enough to clear the trees around the Run. To account for the effect of shading the incoming solar radiation was multiplied by 0.90.

8.3 APPLICATION OF MODEL CALIBRATION TO OTHER PERIODS

The conditions of Lake George on a seasonal and inter-annual basis influence the heat transfer coefficients within SGSR. For this analysis, the parameters determined from the Calibration were applied to other years, but it is evident that adjusting NF, REVC, and RCHC within a given winter scenario can improve the fit somewhat within those years. Even so, results indicate that the model as calibrated is suitable for evaluating different years. The model was set up for the winters (November-April) of years 2009 into 2015. Continuous summertime data for temperature was not available so calibration is focused on the winter. The model can be calibrated for summer time conditions if data becomes available. Results from late April and the modeled stratification on 5/24/2014 shown in Figure 6-8 indicate the circulation, mixing, and stratification dynamics at the mouth would be different in the summer due to the Lake being warmer than the springs. The warmer and fresher Lake water (and thus more buoyant) during the summer can thus enter the SGSR in the top layer and migrate farther into the Run than it can in the winter, presumably the resulting mixing front within the lower SGSR would shift upstream.

9 CONCLUSION

With respect to diurnal (hourly) temperature modeling for SGSR, the main forces acting on the system are the input from Silver Glen springs, the resulting entrainment flow of colder water from Lake George (due mostly to tidal influence), and atmospheric interaction. At the hourly to daily time-scales the system is predominantly comprised of new spring water in the upper part of the Run, and in the lower part the mixing of older spring water with Lake George water. The morphology of the system, vegetation structure, spring discharge, and Lake stage define the general flow and circulation patterns in SGSR. The information presented shows that EFDC can effectively model diurnal temperature for SGSR. Likewise, the model can be used to predict the response of the system to changes in boundary input. As an example, a 20% reduction in spring discharge was evaluated, but stage, temperature and atmospheric data variability could also be evaluated.

Accurately describing the morphology of the system as well as boundary inputs was critical to successful calibration of the model. Since differences in temperature produce density driven flow in SGSR, it was important to resolve the salinity dynamics of the system, and it is reasonable to assume the model accurately predicts salinity. Rainfall is an insignificant component to the heat budget, and evaporation is a minor component that is included in the EFDC heat budget subroutine.

After working with the model and reviewing available data, it appears that a 2 degree °C difference in temperature between Silver Glen springs and Lake George is all that is needed to induce stratfication near the mouth of the run. The main flow path out of the Run is on the northside through the main channel / thalweg. A density-driven flow may set up that enhances the flow of water into the Run on the southside, and a review of the M9 velocity profile in Appendix 11.7 indicates that spring water leaving on the northside may be entrained in the return flow on the southside of the island. The southside flow path includes some of the deeper areas in the lower Run, and this may facilitate the return flow of colder water at the bottom while warmer spring water is exiting the system at the top of the water column.

The large volumetric input of Silver Glen springs into the comparatively small volume of the upper half of SGSR insulates the segment. A conservative residence time for the upper segment is 7 hours but due to tidal mixing the residence time is somewhat longer as indicated by the average water age of 10 hours at the 500-m location (Figure 5-5) during the Calibration period.

The single value NF = 1.28 was applied to the whole Run and is agreeable with a mixture of spring water and lake water in the Run. There is typically a gradient of increasing color and suspended materials that can affect light penetration due to the increasing fraction of Lake George water in the Run proceeding downstream. The decision to focus on Silver Glen with a small grid was made to optimize the use of a single set of heat transfer parameters. While the goal of this project was to produce a calibrated model for the entire SGSR, if the focus is on a segment (like the lower or upper half), then it is sensible to adjust the heat transfer parameters to fit available data in these areas prior to conducting sensitivity analysis. Additional data collection with simultaneous temperature measurements in the lower half of the Run and adjacent Lake George along with the 500-m location would be required to improve model resolution.

The model is considered robust enough to use for sensitivity analysis. The available continuous data 500 m downstream was essential to this analysis. The location is optimal for only having one sensor for the entire Run. While the upper half appeared insensitive to a 20% reduction in discharge, the noticeable effect in the lower half suggests that the Run should be evaluated with respect to sensitivity of the upper and the lower halves, depending on the questions being evaluated and the amount of discharge reduction being considered. Likewise, model results suggest that both the north and south side approaches between SGSR and Lake George should be evaluated (sensitivity analysis should not be focused on the main channel / thalweg).

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USGS. 2016b. USGS 291830081362200 Lake George at Marker 5 near Salt Springs, Fl 291830081362200

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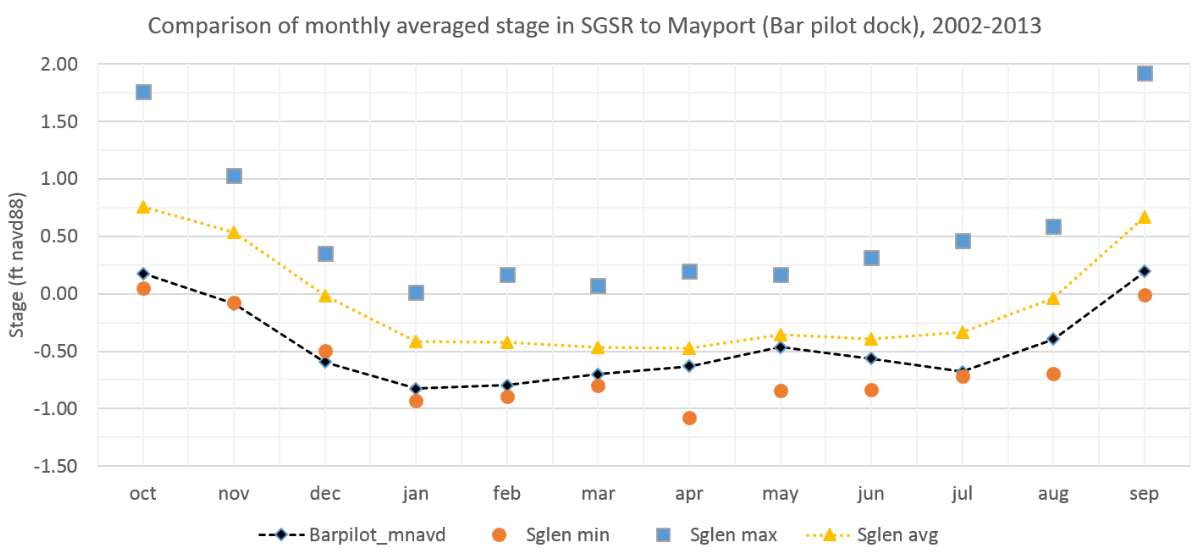
11 APPENDIX

11.1 SILVER GLEN SPRINGS DISCHARGE COMPUTATION METHOD

Table 11-1. Computation method for Silver Glen Springs (02236160) discharge (USGS, 2016a).

POR	Description
Nov-02 to Mar-05	Discharge computed from relation between artesian pressure at Lake George well, spring pool elevation, and discharge at the measuring site
Mar-05 to Oct-07	Discharge was computed using index velocity methods and discharge at measuring site
Oct-07 to Jan-10	Discharge computed from relation between artesian pressure at Astor Park Well at Astor Park (290950081315501) and discharge at measuring site
Jan-10 to Current	Discharge computed from relation between stage at the spring and discharge at measuring site

11.1 MONTHLY AVERAGED STAGE, SGSR AND MAYPORT BAR PILOT DOCK 2002-2013



11.2 HISTORICAL AERIAL IMAGERY

Figure 11-1. Historical Aerial Imagery, *3/12/1941*.

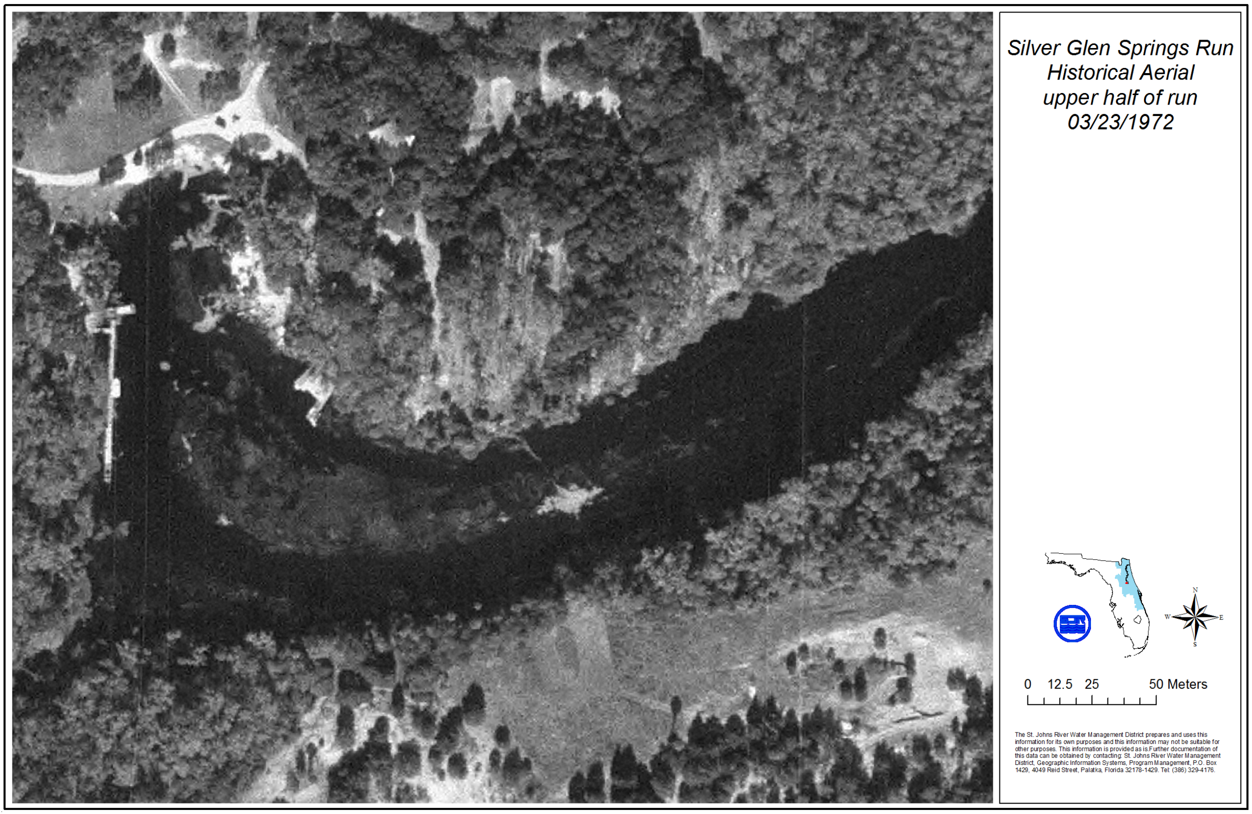


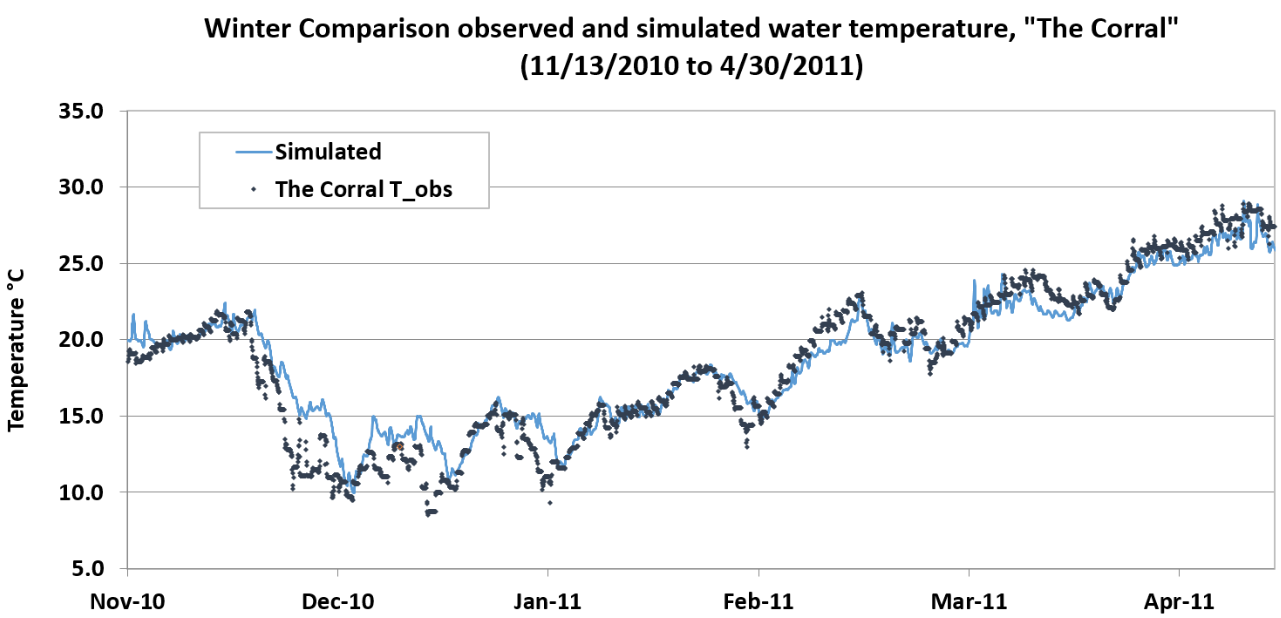
Figure 11-2. Historic aerial imagery, upper segment SGSR *3/23/1972*

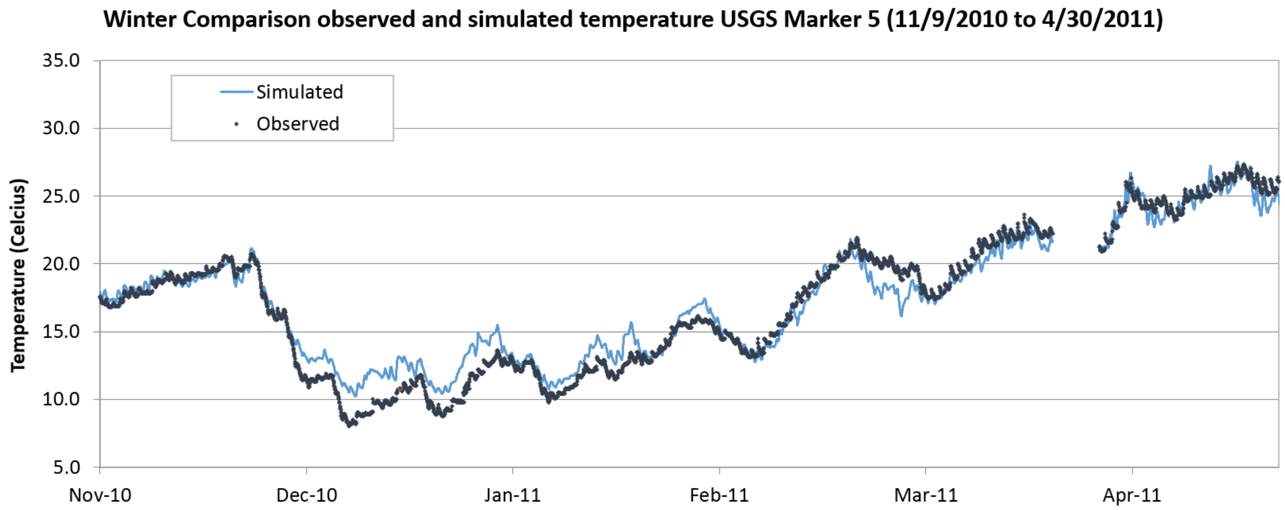
11.3 Observed temperature and salinity stratification SGSR, 2005-2006

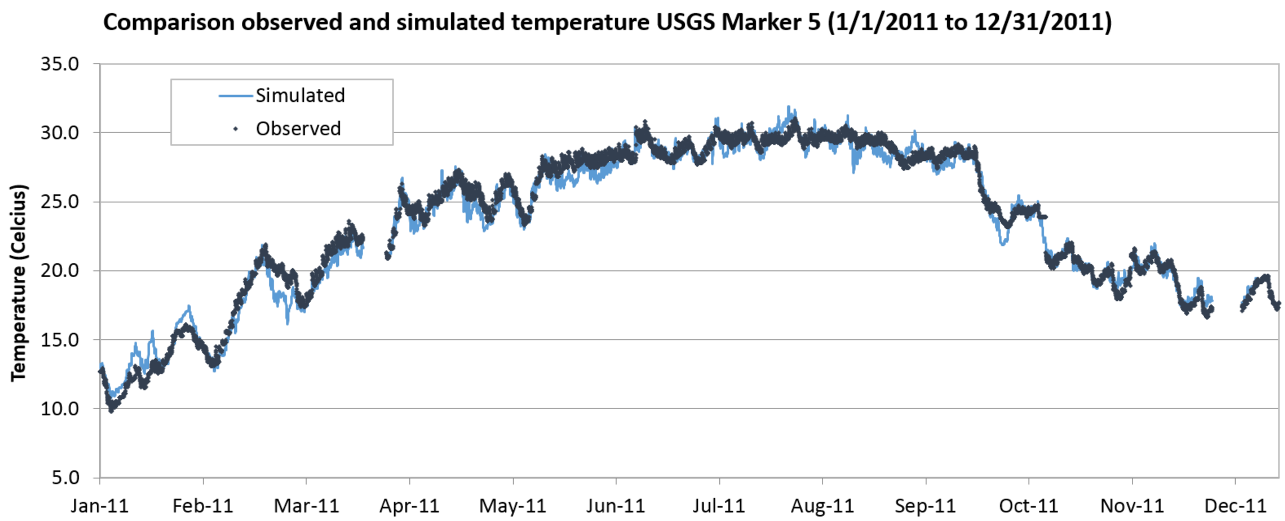
Date	Location	Depth (m)	Temperature C	Salinity
9/22/2005	100 m	1	23.28	0.96
		0.5	23.24	0.96
		0.25	23.24	0.96
	650 m	0.5	23.52	0.95
		1	23.50	0.95
		1.5	23.50	0.95
	1000 m	0.5	26.60	0.43
		1	26.25	0.47
		1.5	23.67	0.86
		1.75	23.51	0.93
2/13/2006	500 m	0.25	22.22	0.96
		0.5	22.19	0.96
		1	22.17	0.96
	750 m	0.25	21.86	0.96
		0.5	21.86	0.96
		1	21.69	0.96
	900 m	0.1	21.07	0.93
		0.25	21.05	0.93
		0.5	20.91	0.90
		0.75	19.64	0.85
		0.8	19.77	0.83
		0.9	15.75	0.63
		1	14.30	0.55
		1.1	13.16	0.51
11/10/2005	900 m	0.1	22.91	0.96
		0.2	22.91	0.96
		0.3	22.88	0.96
		0.4	22.89	0.96
		0.5	22.81	0.96
		0.6	22.79	0.96
		0.7	22.74	0.95
		0.8	22.73	0.95
		0.9	22.74	0.95
		1	22.71	0.95
		1.25	22.71	0.95
	1000 m	0.1	24.98	0.50
		0.25	24.13	0.58
		0.5	23.44	0.71
		0.75	23.08	0.82
		1	22.68	0.95
		1.25	22.64	0.95

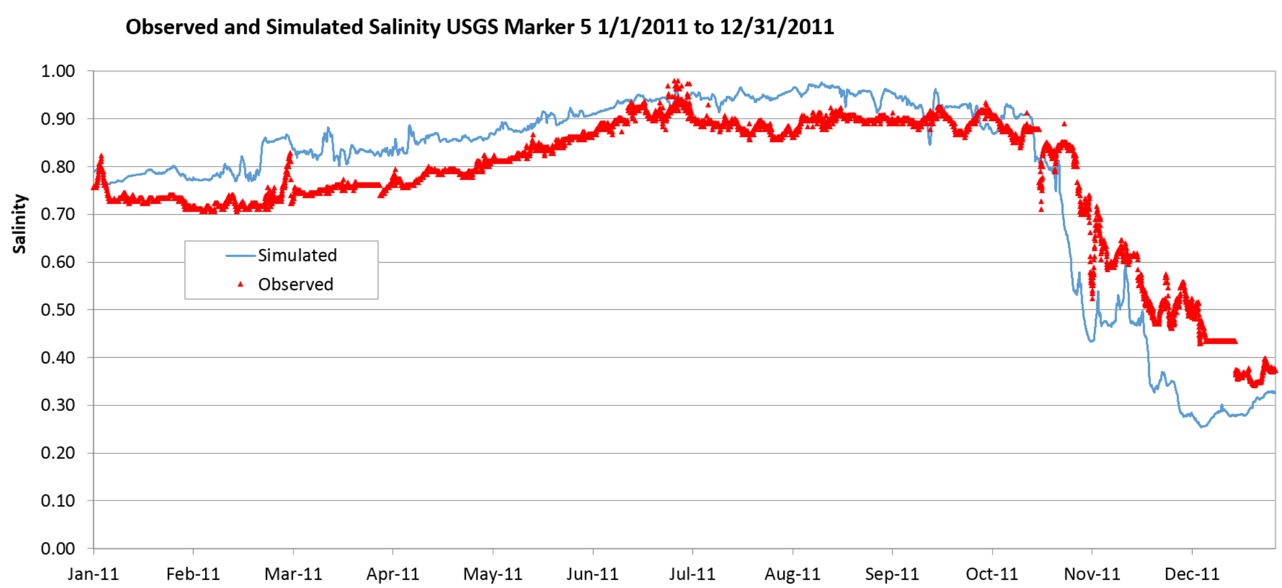
11.4 Calibration data for LG-SG model

Summary Statistics	Marker 5 Salinity 2011 Full Year 1/1/2011 to 12/31/2011	Marker 5 Temperature 2011 Full Year 1/1/2011 to 12/31/2011	Marker 5 Temperature Winter 2010-11 11/9/2010 to 4/30/2011	The Corral Temperature Winter 2010-11 11/13/2010 to 4/30/2011
Observed vs Simulated				
r^2	0.88	0.98	0.97	0.92
MPE %	-1.08	-0.20	-3.66	-3.80
N-S	0.62	0.99	0.97	0.91
AVRE %	9.79	3.08	6.45	7.11
AVAE	0.07	0.62	0.87	1.03
RMSE	0.08	0.80	1.08	1.44
Difference (Obs - Sim) mg/l				
Average	-0.02	0.07	-0.30	-0.34
Median	-0.05	0.07	0.02	-0.05
Variance	0.01	0.65	1.16	2.07
Standard Deviation	0.08	0.80	1.08	1.44
Number of samples	8377	8377	4080	3751




Winter Comparison observed and simulated temperature USGS Marker 5 (11/9/2010 to 4/30/2011)
Simulated
Observed
Temperature (Celcius)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11


Comparison observed and simulated temperature USGS Marker 5 (1/1/2011 to 12/31/2011)
Simulated
Observed
Temperature (Celcius)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Nov-11
Dec-11


Observed and Simulated Salinity USGS Marker 5 1/1/2011 to 12/31/2011
Salinity
Simulated
Observed
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Nov-11
Dec-11

11.5 EFDC ATMOSPHERIC INPUT FILE HEADER (ASER.INP)

```
C  aser.inp file  Silver Glen Springs Run (SGSR) Temperature model
C
C   MASER   TCASER   TAASER  IRELH    RAINCVT  EVAPCVT  SOLRCVT  CLDCVT
C
C  IASWRAD  REVC     RCHC     SWRATNF  SWRATNS  FSWRATF  DABEDT   TBEDIT  HTBED1  HTBED2
      10225    86400.0     0.0      1     0.278E-06  0.278E-06    0.90     1.0
         0    1.6  1.8  1.28     0        1       1     22.8     0.35    3.09E-5

C  aser.inp file  Lake George-Silver Glen Springs (LG-SG) Run Temperature model
C
C   MASER   TCASER   TAASER  IRELH    RAINCVT  EVAPCVT  SOLRCVT  CLDCVT
C
C  IASWRAD  REVC     RCHC     SWRATNF  SWRATNS  FSWRATF  DABEDT   TBEDIT  HTBED1  HTBED2
      10225    86400.0     0.0      1     0.278E-06  0.278E-06    0.90     1.0
         0    2.0  4.0  2.25     0        1       1     23.0     0.71    7.72E-6
```

11.6 SUMMARY OF STATISTICAL TESTS APPLIED TO DATA

If O_i represent the observed values and P_i the simulated (predicted) values for i = 1 to N, where N is the number of match pairs, then statistics are defined as follows:

$$\textit{Mean Percent Error:}\ MPE = \frac{100\%}{N}\sum_{i=1}^{N}\frac{(O_i - P_i)}{O_i}$$

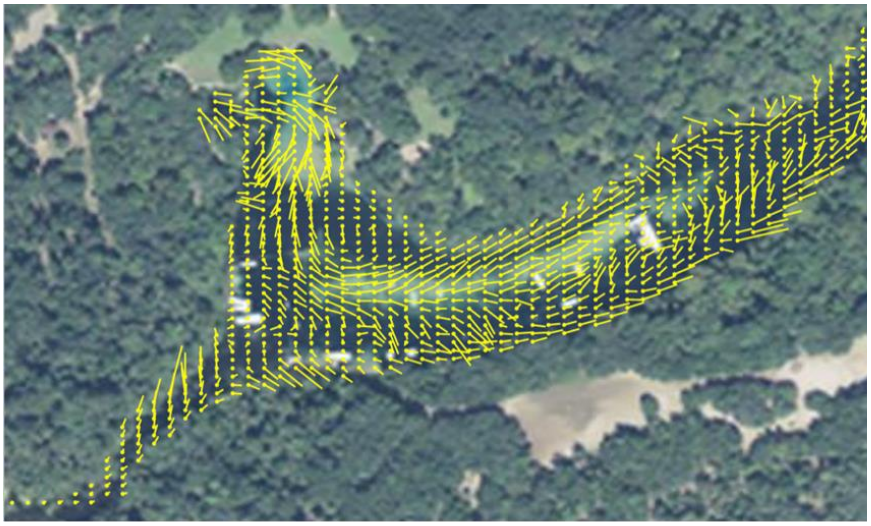
$$\textit{Nash-Sutcliffe:}\ NS = 1.0 - \frac{\sum_{i=1}^{N}(O_i - P_i)^2}{\sum_{i=1}^{N}(O_i - \bar{O})^2}$$

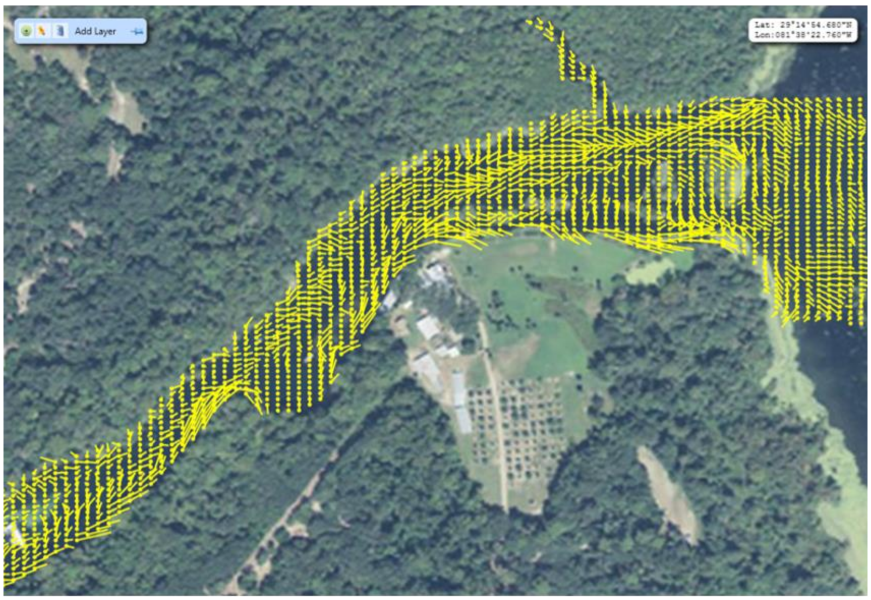
$$\textit{Average Relative Error:}\ AVRE = \frac{\sum_{i=1}^{N}\frac{|O_i - P_i|}{|O_i|}}{N}$$

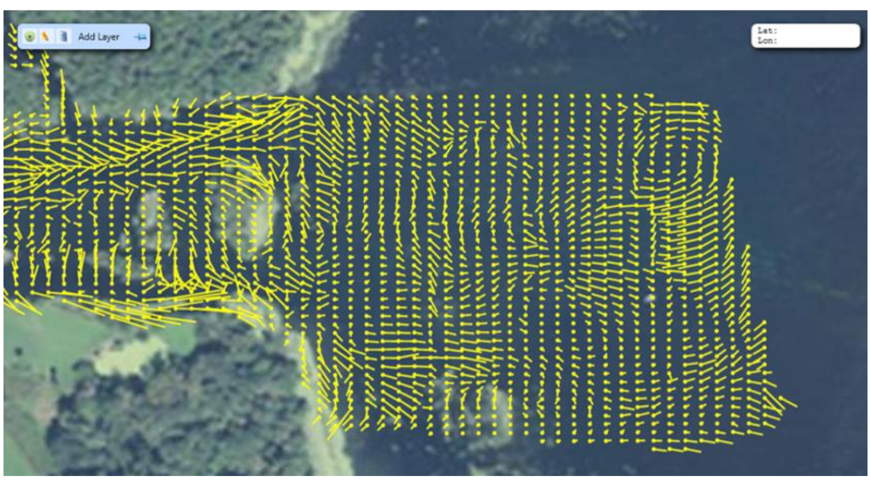
$$\textit{Average Absolute Error:}\ AVAE = \frac{\sum_{i=1}^{N}|O_i - P_i|}{N}$$

$$\textit{Root Mean Square Error}\ RMSE = \sqrt{\frac{\sum_{i=1}^{N}(O_i - P_i)^2}{N}}$$

11.7 Depth averaged velocity, M9 profile, *11/17/2014*







11.8 SIMULATED TEMPERATURE AND % SPRING WATER THE LOWER SGSR

Temperature Baseline										
	Thalweg Cells						Southside cells			
	500m	600m	700m	800m	900m	1000m	800m	900m	1000m	LG-bnd
min	20.9	21.1	21.0	21.0	21.0	18.1	19.2	16.7	15.1	10.1
avg	23.0	23.0	23.0	23.0	23.1	22.4	22.3	21.4	20.8	20.1
max	26.0	25.6	25.7	25.8	26.6	26.3	26.1	26.8	26.8	27.0

Temperature Differences (20%reduction- Baseline)										
	Thalweg Cells						Southside cells			
	500m	600m	700m	800m	900m	1000m	800m	900m	1000m	LG-bnd
min	-0.40	-0.46	-0.36	-1.95	-3.55	-2.00	-2.12	-3.80	-1.59	-3.48
avg	0.01	0.02	0.02	-0.33	-1.08	-0.21	-0.33	-0.30	-0.13	0.00
max	0.71	0.51	1.02	0.85	1.39	1.43	0.80	2.02	0.95	5.25

Percent Springwater Baseline										
	Thalweg Cells						Southside cells			
	500m	600m	700m	800m	900m	1000m	800m	900m	1000m	LG-bnd
min	99.9	99.9	96.4	61.9	20.9	26.1	5.0	0.4	0.2	0.0
avg	100.1	100.1	100.1	93.5	64.8	78.0	73.5	33.0	20.2	14.7
max	100.4	100.5	100.4	100.4	99.9	100.0	100.7	100.2	65.4	58.8

Differences in Percent Springwater (20%reduction - Baseline)										
	Thalweg Cells						Southside cells			
	500m	600m	700m	800m	900m	1000m	800m	900m	1000m	LG-bnd
min	-0.1	-6.1	-12.4	-36.7	-37.0	-55.1	-73.3	-85.3	-34.4	-22.8
avg	0.0	-0.1	-0.4	-5.5	-7.8	-8.9	-16.4	-9.6	-4.3	-1.6
max	0.2	0.2	2.0	22.0	21.5	35.4	33.7	57.4	22.6	46.1

11.9 PHOTOGRAPHS OF THE SILVER GLEN SYSTEM

Figure 11-3. Head pool segment looking northeast from towards Natural Well (center of image).

Figure 11-4. Head pool area looking North from near entrance to Sandboil Run towards the Main Vent

Figure 11-5. View near 500 m, looking downstream along the southern shoreline of the Run

Figure 11-6. View from 650 m downstream looking back towards 500-m 'narrows', sonde from 02/18/2015 deployment is visible (~2.5 ft deep) in lower right

Figure 11-7. View from 900 m downstream in the lower segment of SGSR, looking upstream

Figure 11-8. View from 900 m looking downstream out of the Run towards Lake George

Figure 11-9. Lake George looking north across the channel entering Silver Glen Springs Run

Figure 11-10. Lake George looking east from shore outside of Silver Glen Springs Run. Boats traversing near safety sign at 500 m outside of the Run near the model boundary

Figure 11-11. Example of SAV topping near 500 m downstream looking upstream along the southern shoreline of the Run

Figure 11-12. Example of SAV topping and emergent vegetation (top of image) 700 m downstream in the lower Run looking south

Figure 11-13. Sandboils at the head of Sandboil Run

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