Technical Publication SJ2017-5

DETERMINATION OF MINIMUM FLOWS FOR GEMINI SPRINGS, VOLUSIA COUNTY, FLORIDA

Gemini Springs reservoir, March 9, 2016

Gemini Springs west vent, September 30, 2014

By

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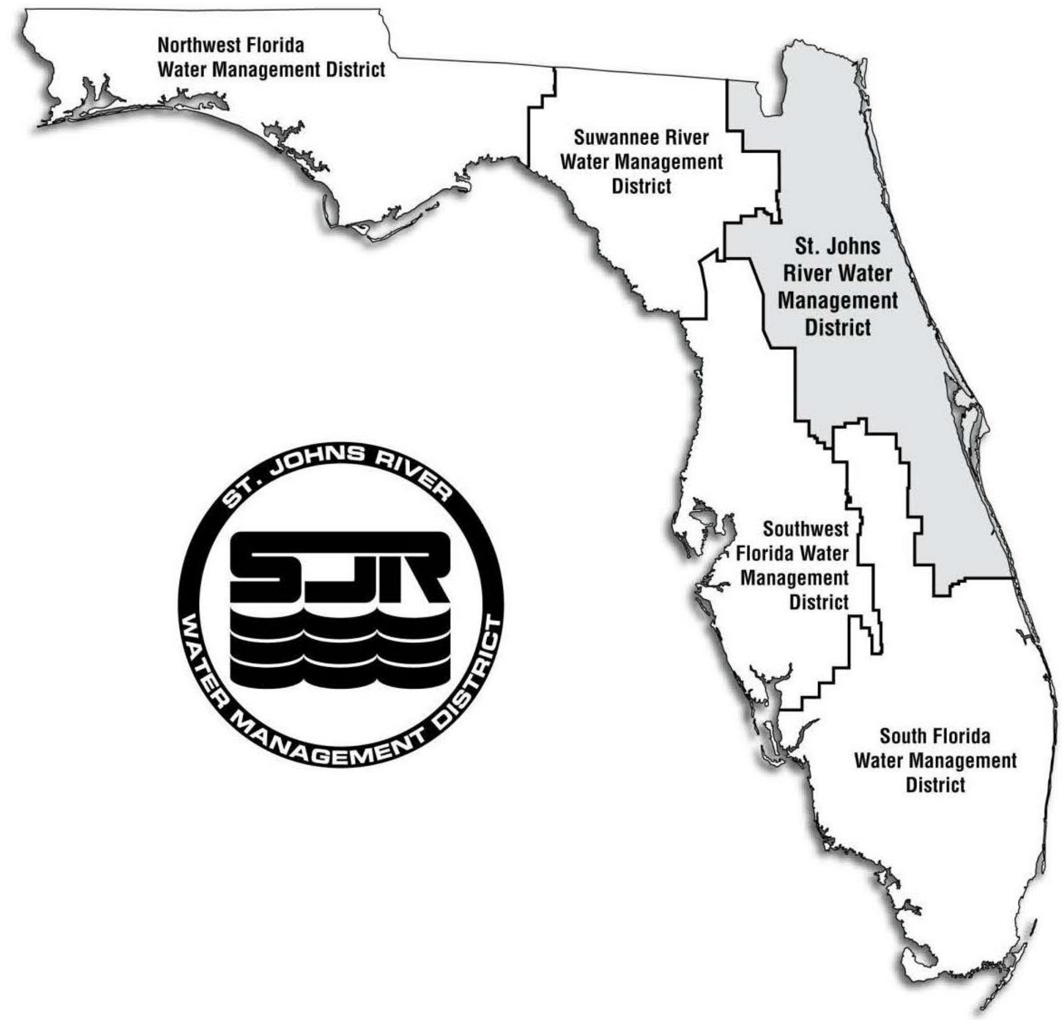
April 10, 2017



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, including Gemini Springs, by July 1, 2017.

Gemini Springs is a second-magnitude spring located in DeBary, Florida. Gemini Springs has been historically classified as a second magnitude spring even though, based on U.S. Geological Survey (USGS) and SJRWMD discharge data from 1995 to March 2015, the average annual discharge equals 9.8 cfs, which is just below the second magnitude spring minimum threshold of 10 cfs. Gemini Springs is also a Volusia County park and a popular destination for walking, bicycling, wildlife viewing and spring gazing. The area surrounding the springs has been the subject of significant man-made alteraterations, including the construction of a 1.3-acre reservoir impoundment. Flow from the impoundment is controlled by a fixed weir structure. The springs include two vents, approximately 150 ft apart with separate spring runs, which both flow into the constructed impoundment. The discharge over the weir flows into Gemini Springs Run, which meanders approximately two miles to Lake Monroe. The hydrology downstream of the weir is overwhelmingly influenced by Lake Monroe and the St. Johns River and not particularly sensitive to spring flow. Because of these factors, this Gemini Springs MFL determination focused on the hydrology upstream from the weir.

After reviewing the applicable environmental values, SJRWMD determined the critical environmental values for Gemini Springs are water quality, aesthetic and scenic attributes, and fish and wildlife habitats. Water quality at Gemini Springs is closely tied to aesthetics and scenic attributes, as well as fish and wildlife habitat. SJRWMD determined that water residence time, which is related to water quality and is associated with both aesthetics and fish and wildlife habitat values, is the most appropriate criterion available to calculate a minimum flow for Gemini Springs. Although it is not ideal because the primary determining factor of residence time within the impounded reservoir is actually the dimensions of the constructed impoundment itself, the relationship between water quality and water residence time in Gemini Springs' reservoir is the basis for this minimum flow determination.

A commonly applied MFLs determination criterion, which allows a 15% reduction in aquatic habitat or change in a resource when evaluating a change in flow, was used for Gemini Springs' MFL determination. The use of this habitat or resource threshold, as a measure of significant harm for MFLs development has been suggested by other water management districts and peer reviewers (Gore et al. 2002). This approach is deemed appropriate for Gemini Springs due to the previously constructed alterations to the system including the construction of the impoundment and weir structure, a lack of suitable ecological criteria, limited information regarding critical flow thresholds that will impact the environmental values, and because the springs hydrology are frequently dominated by the St. Johns River. A 15% increase in water residence time in Gemini Springs' impounded reservoir is the resource change applied to the Gemini Springs minimum flow determination and corresponds to an allowable 1.6 cfs total decrease in spring discharge from a no pumping condition due to consumptive use. Current pumping, as defined by 2010 conditions, has resulted in approximately a 1.0 cfs reduction in Gemini's spring flow from no-pumping conditions. Therefore, approximately 0.6 cfs of additional reduction in spring flow due to consumptive use would be allowable prior to the MFL being violated.

This maximum allowable flow reduction translates into a recommended minimum flow for Gemini Springs equal to a mean flow of 9.3 cfs. Based on the current best available information, including the Volusia groundwater model (SJRWMD 2016c); the predicted flow reduction resulting from projected water use for the 20-year planning horizon is less than the flow reduction allowed by the recommended MFL. Therefore, the proposed MFL for Gemini Springs is achieved for the 20-year planning horizon, and neither a recovery nor a prevention strategy is required.

Figures

Tables

Acronyms and Abbreviations

ATM	Applied Technology and Management Inc.
CFS	Cubic feet per second
F.A.C.	Florida Administrative Code
FDEP	Florida Department of Environmental Protection
F.S.	Florida Statutes
FT	feet
GIS	Geographic Information System
FH	minimum frequent high
FL	minimum frequent low
MA	minimum average
MFLs	minimum flows and levels
IH	minimum infrequent high
IL	minimum infrequent low
I-4	Interstate 4
Janicki	Janicki Environmental Inc.
NGVD	1929 National Geodetic Vertical Datum
NAVD	1988 North American Vertical Datum
NRCS	Natural Resources Conservation Service
OFS	Outstanding Florida Spring
OFW	Outstanding Florida Water
POR	period of record
SAV	submerged aquatic vegetation
SJRWMD	St. Johns River Water Management District
SRWMD	Suwannee River Water Management District
SWFWMD	Southwest Florida Water Management District
UFA	Upper Floridan aquifer
USGS	U.S. Geological Survey

Introduction

This report describes the St. Johns River Water Management District (SJRWMD) recommended minimum flows determination for Gemini Springs in Volusia County, Florida. Gemini Springs was designated an Outstanding Florida Spring (OFS) as part of Florida Senate Bill 552 and added to the SJRWMDs MFLs Priority Water Body List and Schedule for establishment of MFLs in 2017 (SJRWMD 2016a).

Legislative overview

SJRWMD establishes minimum flows and levels for priority water bodies within its boundaries (section 373.042, *Florida Statutes* [F.S.]). Minimum flows and levels for a given water body 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.).

Minimum flows and levels are established using the best information available (section 373.042(1), F.S.), with consideration 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." Water bodies experience variations in flows and levels that often contribute to significant functions of the system, such as the environmental values previously listed.

SJRWMD Minimum Flows and Levels Program Overview

SJRWMD is engaged in a districtwide effort to develop MFLs for protecting priority surface water bodies, watercourses, associated wetlands, and springs from significant harm caused by water withdrawals. MFLs provide an effective tool 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 with a MFL, or is expected not to be in compliance during the 20-year planning horizon due to withdrawals, a recovery or prevention plan must be developed and implemented.

The SJRWMD MFLs program includes environmental assessments, hydrologic modeling, independent scientific peer review, and rule making. A fundamental assumption of SJRWMD's approach is that alternative hydrologic regimes exist that are lower than the historical hydrology but will protect the ecological structure and function of priority water bodies, watercourses, associated wetlands, and springs from significant harm caused by water withdrawals. Significant harm is a function of changes in frequencies of water level and/or flow events of defined magnitude and duration caused by water withdrawals. These changes cause impairment or loss of ecological structure (e.g., permanent downhill shift in plant communities caused by water withdrawals) or function (e.g., insufficient fish reproductive or nursery habitat caused by water withdrawals).

MFLs typically define the frequency of high, intermediate, and low water events necessary to protect relevant water resource values. Three MFLs are usually defined for each system—minimum frequent high, minimum average, and minimum frequent low flows and/or water levels. In some cases, minimum infrequent high and/or minimum infrequent low MFLs may also be set (Neubauer et al. 2008). No matter how many MFLs are adopted, the most constraining (i.e., most sensitive to water withdrawal) MFL is used for water supply planning and permitting.

Gemini Springs Description

Gemini Springs consists of two springs located within the 210-acre Gemini Springs Park in Volusia County, Florida (Figure 1). Gemini Springs Park, purchased in 1994 from the Gray family, opened to the public as a Volusia County Park in 1996. The Gray family owned the property since 1969 and gave Gemini Springs its name. Under the Gray's ownership, the existing earthen dam and reservoir, which artificially impounds the spring pool as controlled by the weir structure, were created (*http://www.volusia.org/services/community-services/parks-recreation-and-culture/parks-and-trails/park-facilities-and-locations/ecological-nature-parks/gemini-springs-park.stml*). Land use changes adjacent to Gemini Springs Park are summarized in Appendix A.

Gemini Springs' two spring vents are approximately 150 ft apart, located in relatively steep ravines with separate spring runs. Water from the northwest vent flows southeast approximately 175 ft. to the 1.3 acre impounded reservoir while the second or east vent flows 15 ft. before entering the reservoir (Figures 2-6). An 8-in. well, once considered a third spring vent by Rosenau et al. (1977), augmented the total discharge until July 7, 2002, when it was sealed (Osburn et al. 2002). Gemini Springs discharge flows into the reservoir and then spills over the constructed fixed weir into Gemini Springs Run, also known as Padgett Creek. Gemini Springs Run meanders east approximately 2 miles, passing under Interstate-4 (I-4) before entering Lake Monroe on the St. Johns River (Figures 2–6).

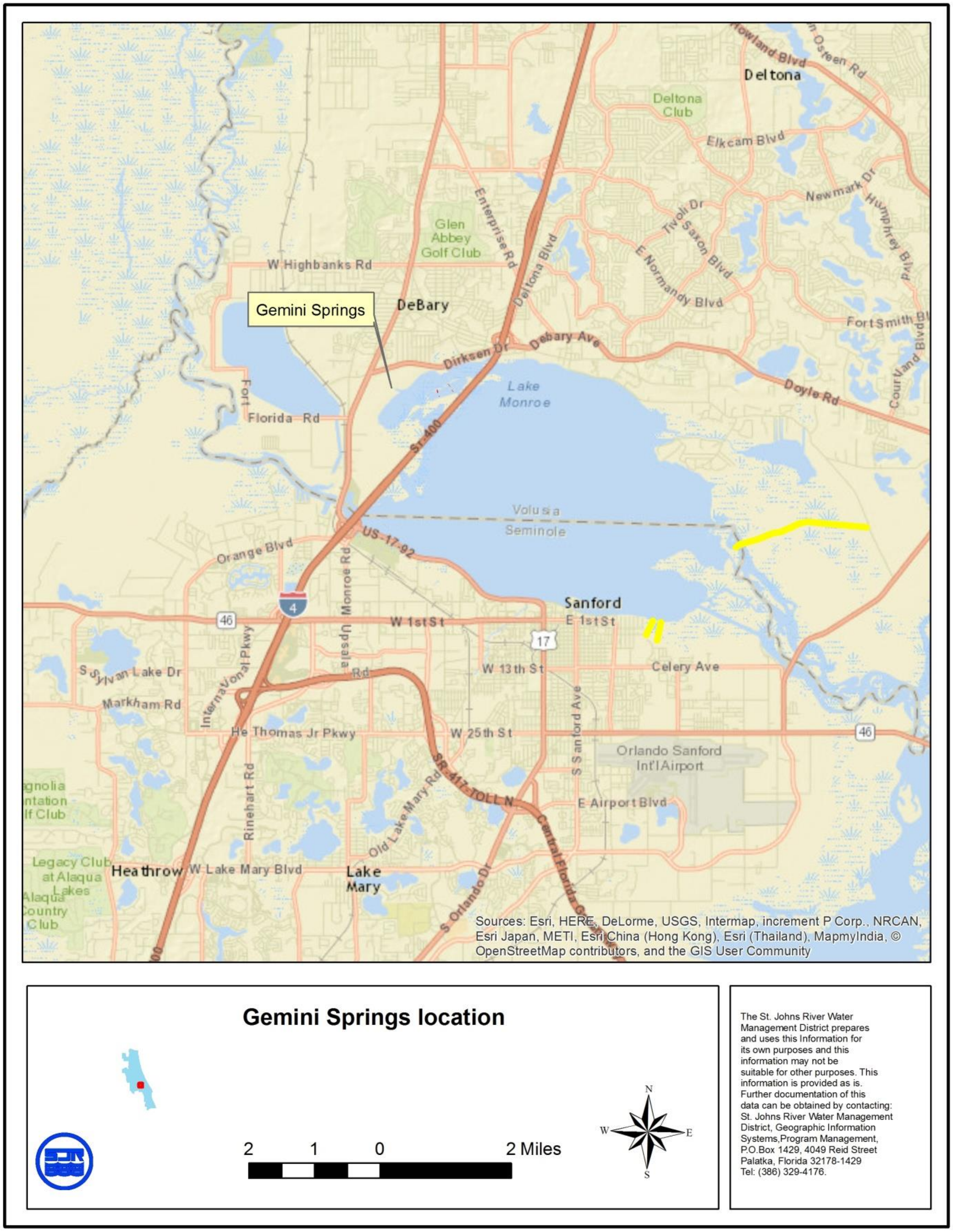


Figure 1. Gemini Springs location map

Figure 2. Gemini Springs and run 2009 aerial photo

Figure 3. Gemini Springs and Reservoir with additional detail

Figure 4. Gemini Springs vents (photos J. Mace)

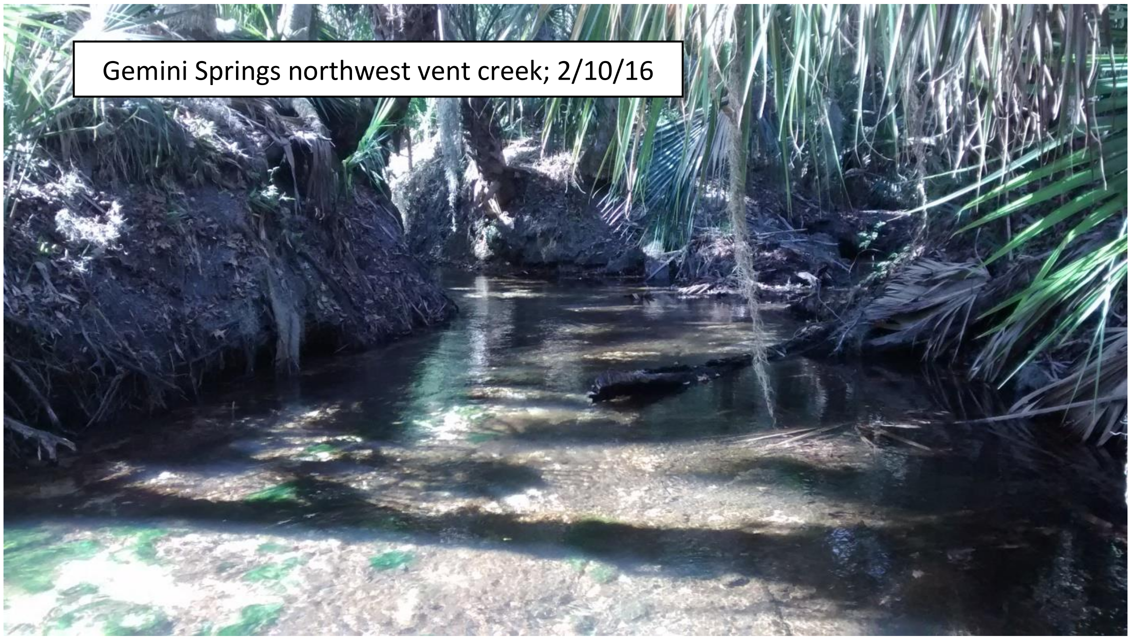


Figure 5. Gemini Springs northwest vent creek and reservoir (photos J. Mace)

Figure 6. Gemini Springs weir (photo J. Mace)

Gemini Springs Park Human Use

Gemini Springs Park is free for day-use and is regionally popular for picnics, walking, running, and bicycling with fishing and boating permitted downstream from the weir. Additional common activities include spring gazing, wildlife viewing, bird watching, dog play at an enclosed dog park, and tent camping. Swimming at Gemini Springs remains prohibited since 2000 due to high levels of *Enterococci* bacteria (Bonn and Bell 2004).

Gemini Springs Park contains a trailhead for the increasingly popular Volusia County Spring-to-Spring Trail, which draws additional recreational users to enjoy the aesthetic beauty of Gemini Springs. When complete, the Spring-to-Spring Trail will stretch north 26 miles from Gemini Springs Park to De Leon Springs State Park, as well as the completed easterly 4.5-mile segment connecting Gemini Springs Park to Green Spring Park with additional trail connections at Green Spring Park (*http://www.r2ctpo.org/bicycle-pedestrian-program/maps/*) (*http://www.volusia.org/services/community-services/parks-recreation-and-culture/parks-and-trails/trails/showcase-multi-use-trails.stml*). Additionally, Gemini Springs Park is immediately north of the 946-acre Gemini Springs Addition public land acquired by Volusia County in 2016. The Gemini Springs Addition parcel includes Gemini Springs Run and is dominated by marsh floodplain associated with Lake Monroe and the St. Johns River. Most of the recreational activity on this property occurs along the 2.5 mile paved multi-use trail that connects Gemini Springs Park to Lake Monroe County Park to the south. Additional recreation activities within the Gemini Springs Addition include fishing and small boating on Gemini Springs Run.

Gemini Springs Hydrology

Gemini Springs is located within the St. Johns Offset sub-district of the Central Lakes District (Brooks 1982), an area characterized by sandhill karst with solution basins. The Upper Floridan aquifer is the source of discharge for most springs in this region, including Gemini Springs.

Gemini Springs is historically classified as a second magnitude spring (Rosenau et. al, 1977; *www.sjrwmd.com/springs/gemini.html* (SJRWMD 2016b). Minimum and maximum-recorded discharges at Gemini Springs equal 6.2 and 13.0 cfs, respectively (SJRWMD 2016b). Based on USGS and SJRWMD discharge data from 1995 to March 2015 the median and average annual discharge equals 9.6 and 9.8 cfs, respectively, identifying Gemini Springs as a third magnitude spring, just below the second magnitude spring minimum threshold of 10 cfs. According to the Florida Geological Survey (2003), spring magnitude is to be based on the median value of all discharge measurements for the period of record. It is recognized that historically, many springs in Florida have kept one magnitude category, even though the discharge may have changed considerably from when it was first assigned a magnitude. For this reason, a historical category is accepted in the Florida Springs Classification System (Florida Geological Survey, 2003). Gemini Springs discharge, measured at the weir outlet, represents the combined flow from the two vents (Figure 7). Approximately 65% of the reported discharge occurs from the northwest vent, with 35% discharge from the east vent (Xiong and Zhang 2017).

Daily discharge measurements at Gemini Springs began in March 2009 and are based on the relationship between Gemini Springs discharge and the groundwater levels in nearby wells (S-1225, 2009─2011 and V-081, 2011 to present). Gemini Springs discharge is less than 0.5% of the St. Johns River flow immediately downstream from Lake Monroe at U.S. Highway 17 (ECT 2012). Thus, changes in Gemini Springs discharge have little effect on the receiving water body, Lake Monroe and the St. Johns River. Additionally, because the Gemini Springs weir outfall and hydrologic control elevation equals only 0.51 ft NAVD, Lake Monroe regularly (approximately 51% of the time; ECT 2012) backflows into the Gemini Springs reservoir and spring vents, reducing the springs discharge (Figures 8- 10). When Lake Monroe experiences average and low stages, resulting in small and zero backwater affect, surface water levels in the Gemini Springs Reservoir remain very stable (median stage of 1.4 ft NAVD) under a relatively wide range of spring discharges, indicating that the weir provides considerable stability to water levels in the reservoir over a range of discharge rates. Figure 8 illustrates the poor stage-discharge relationship for Gemini Springs based upon Gemini reservoir stage and Gemini Springs discharge.

<u>Hydrodynamic model of Gemini Springs reservoir</u>

A hydrodynamic model was developed for Gemini Springs to evaluate the effect of 5, 10, and 15% spring flow reductions on the water surface elevation, salinity, and water residence time in the Gemini Springs Reservoir (Xiong and Zhang 2017). Model results indicated that when no backwater occurs and average spring discharges decline by 5, 10, and 15% the water surface elevation in the reservoir drops 0.02, 0.05, and 0.08 ft, respectively. When median backwater occurs, the spring discharge reductions have even less influence on reservoir water level changes (0.01, 0.03, and 0.04 ft for each 5% reduction respectively) and as the reservoir becomes dominated by backwater, changes in spring discharge have very little impact (<0.01 ft) on reservoir stage (Xiong and Zhang 2017). Under the same 5, 10, and 15% discharge reductions, salinity in the Gemini reservoir remained nearly constant with and without backwater affects.

Water residence time without backwater influences at the Gemini Springs Reservoir increased slightly with every 5% decrease in springs discharge with reservoir water age increasing by less than 30 minutes for each 5% incremental decrease in springs discharge. Similar to water surface elevation, water residence time during backwater events is primarily controlled by Lake Monroe (Xiong and Zhang 2017).

Xiong and Zhang (2017) concluded that the influence of backwater from the St. Johns River on Gemini Springs is often overwhelming with reservoir hydrodynamic conditions and water age distribution both significantly affected by high backwater. Conversely, under free flowing conditions, decreases in springs discharge results in very small decreases in reservoir surface water elevations and small increases in water residence time. Specifically, each 5% decrease in springs discharge corresponds to approximately a 5% increase in water residence time.

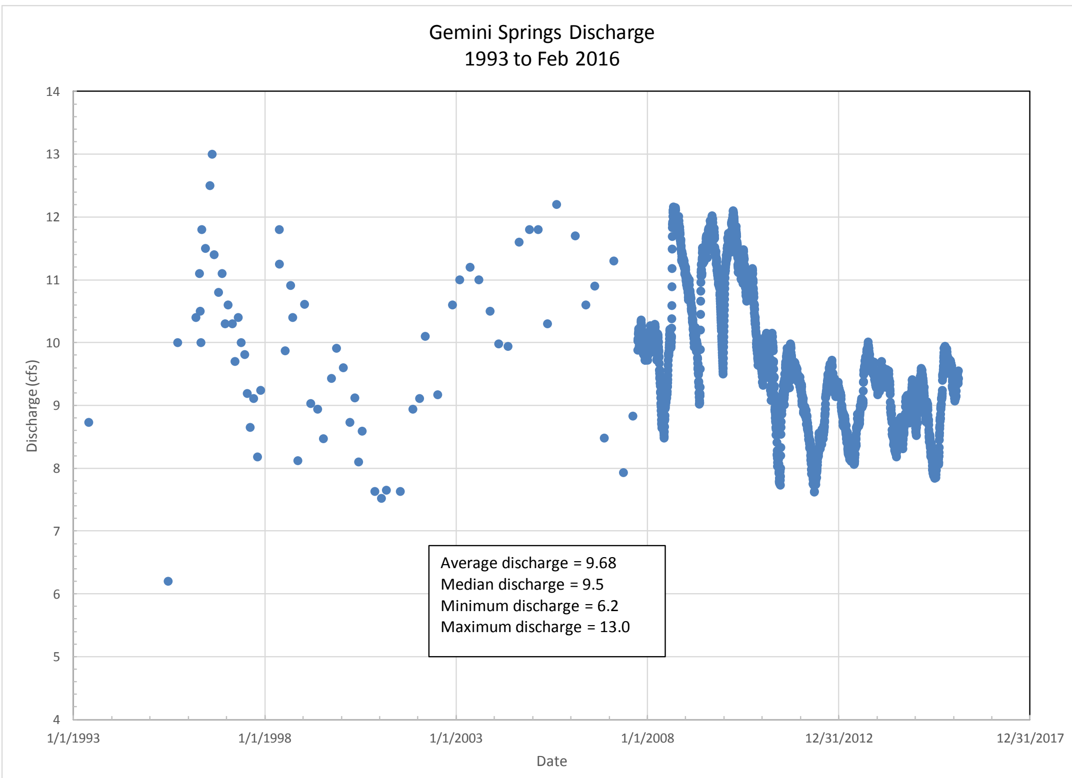


Figure 7. Gemini Springs period of record discharge

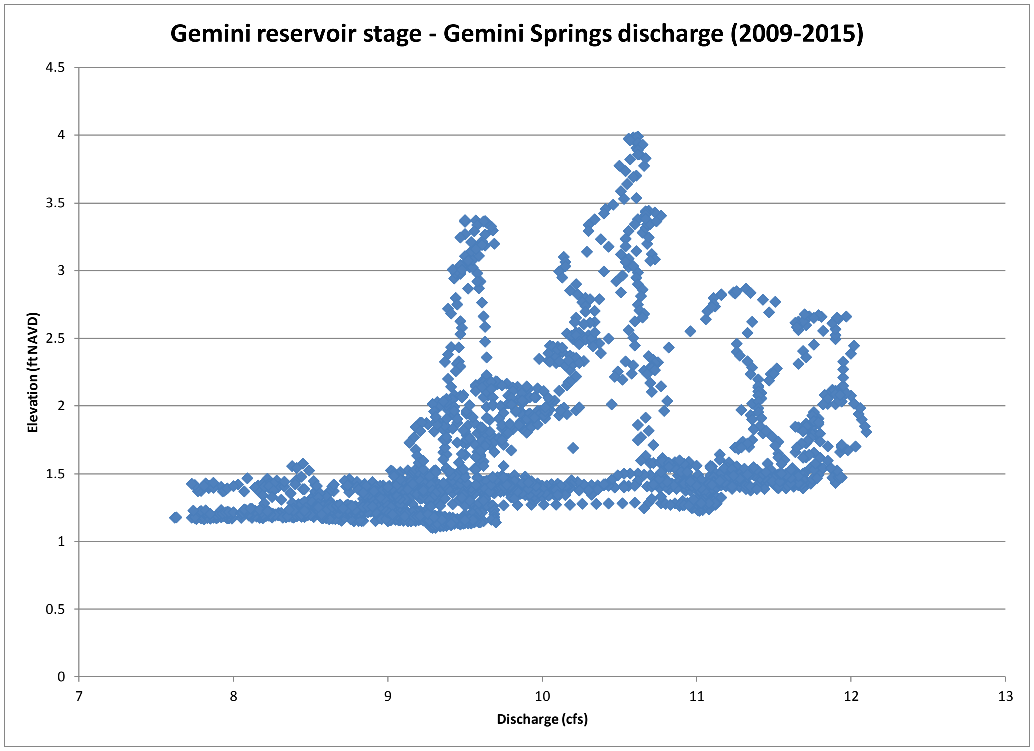


Figure 8. Gemini Springs reservoir stage-discharge relationship

Figure 9. High water floods into Gemini Springs Reservoir (photo T. Richardson)

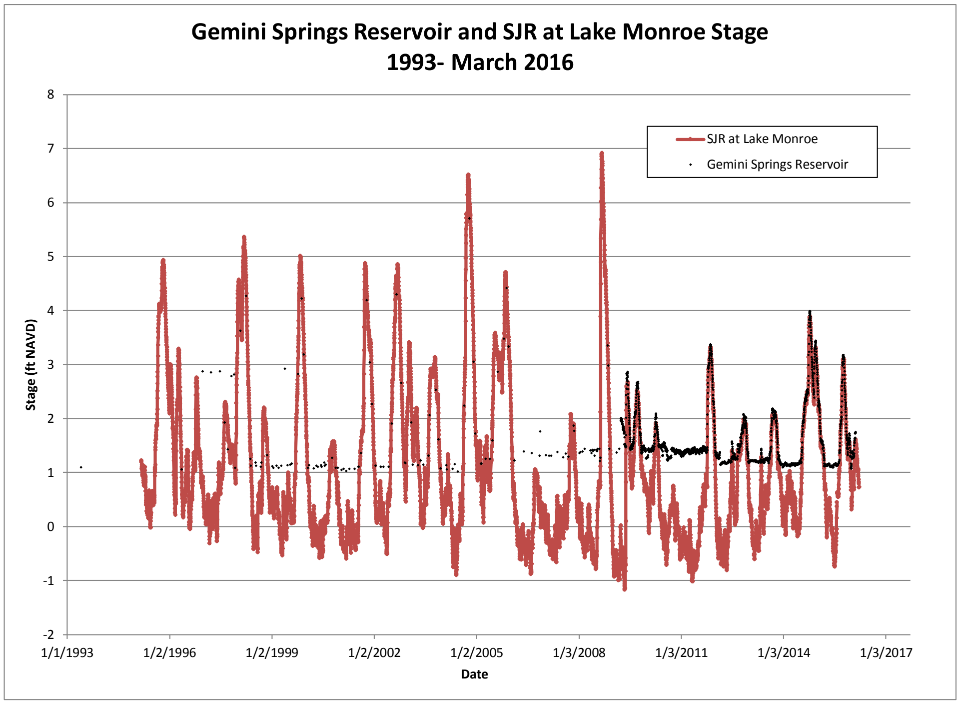


Figure 10. Gemini Springs Reservoir stage and the St. Johns River at Highway 17/92 stage

Groundwater pumping impact assessment

To estimate the potential impact to spring flows from groundwater pumping, annual groundwater use from 1995 to 2015 was estimated within the Gemini springshed plus a one-mile buffer (Figure 11). The groundwater use from 1995 to 2015 was used because this time period was used in setting the MFLs based on the availability of reliable spring flow data. Groundwater pumping was estimated using the reported annual groundwater use data from SJRWMD water use database (Figure 12).

The latest version of the SJRWMD Volusia County steady-state groundwater model (SJRWMD, 2016c) was used in the assessment of potential impacts of groundwater pumping on spring flows. Because the latest version of the Volusia model was developed for 2010, the assessment was estimated under the 2010 groundwater pumping condition and resulted in an estimated Gemini Springs impact of approximately 1.0 cfs.

There are many springs (more than 45), including Blue Springs (a first-magnitude spring), and river systems, such as the Wekiva River, in close proximity to Gemini Springs (see Appendix D for locations of the springs in the area). It should be noted that the springshed shown in Figure 11 is the best estimate of possible maximum extent of the groundwater contributing area. Because of the existence of many other springs and water bodies near Gemini Springs, delineating a springshed that encompasses a groundwater contributing area only for Gemini Springs is not possible. All the other springs and water bodies in the area most likely interact with each other and have overlapping groundwater contributing areas. Because of this, the groundwater wells within the estimated Gemini springshed withdraw water not only from the Gemini springshed but also from the groundwater contributing areas of the other springs and water bodies in the area. So, the impact from groundwater withdrawals spreads over many springs and water bodies.

Because the Volusia County groundwater model takes into account all the interactions among springs and other water bodies in the area, it is the best available tool to estimate the impact of groundwater pumping on Gemini Springs.

The baseline condition flow time series were developed using the groundwater use data and the Volusia County groundwater model results. The baseline condition represents a reference hydrologic condition of the spring in which the impact from groundwater pumping on spring flows is constant over time at a rate of approximately 1.0 cfs, which reflects the 2010-pumping condition. Assuming climatic, rainfall, and other conditions present from 1995–2015 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 Gemini Springs. Details of the Gemini Springs hydrologic data analysis are presented in Appendix D.

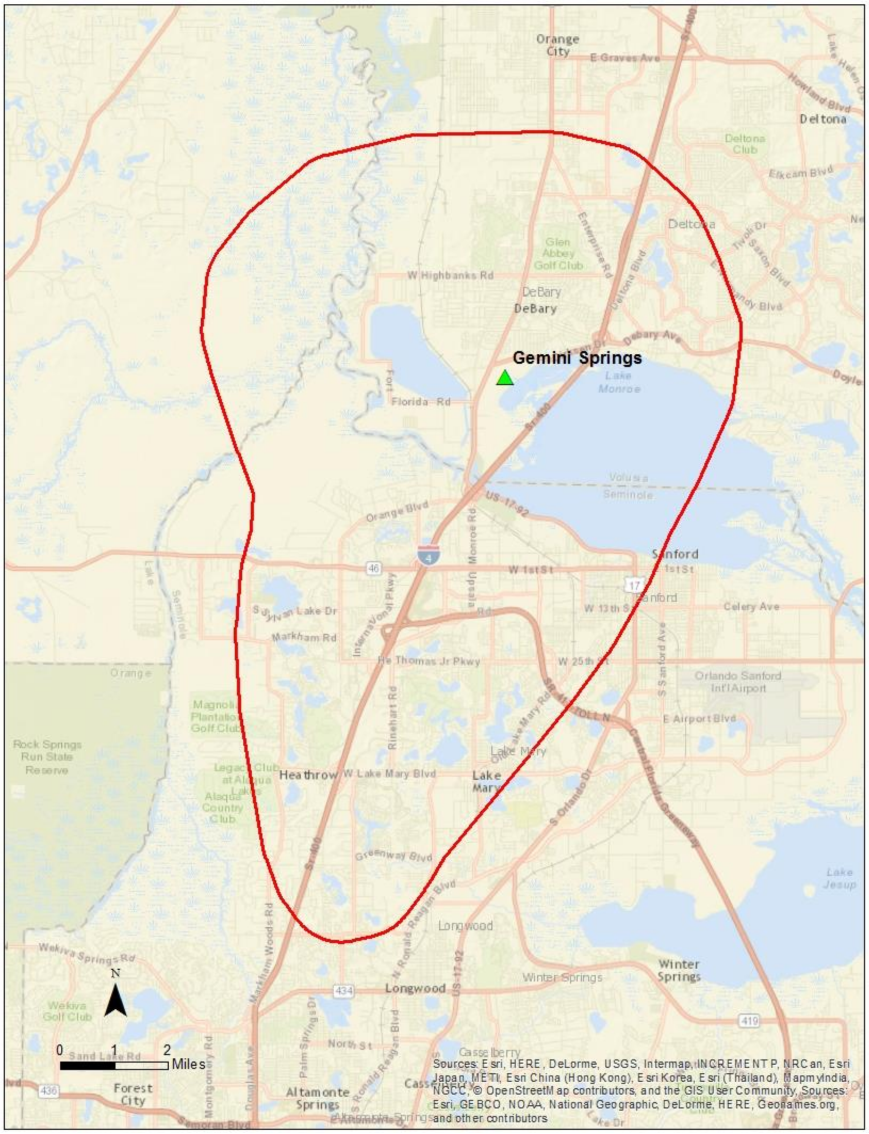
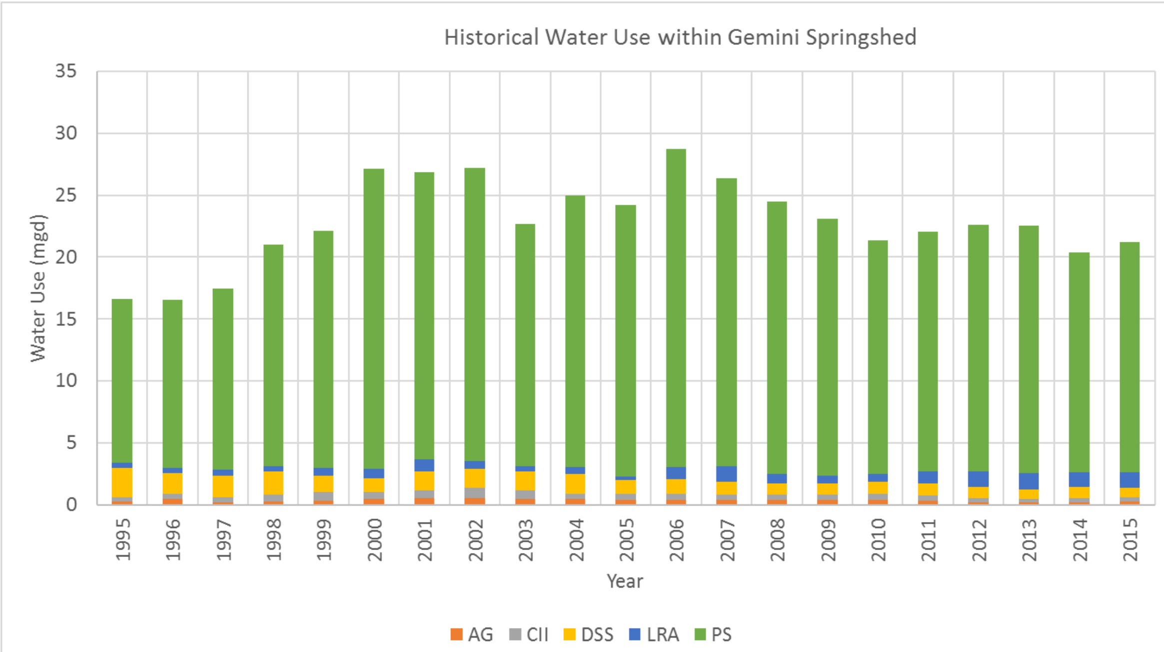


Figure 11. Gemini springshed plus one-mile buffer



PS: Public Supply; AG: Agricultural; CII: Commercial/Industrial/Institutional; LRA: Landscape/Recreational/Aesthetic

Figure 12. Estimated groundwater use within Gemini springshed plus one-mile buffer

Gemini Springs Water Quality

Water quality data has been collected at Gemini Springs by the USGS, Volusia County, and SJRWMD from 1972 to the present (Table 1). Florida springs have been classified by their water chemistry into four primary water types (Ca-HCO3, Ca-Mg-HCO3, mixed, and Na-Cl) (Walsh et al 2009). A recent study indicated that most springs in SJRWMD were the Ca-Mg-HCO3 type while Gemini Springs is a Na-Cl or salt spring (Walsh et al 2009). The springs classification scheme of Woodruff (1993) was associated with karstic geology and geography; salt and mixed springs emerge nearer coastal regions, whereas calcium-bicarbonate springs are more typical of river down cutting areas (such as the Suwannee River), although all three partially overlap in distribution (Walsh et. al 2009).

Increased nutrient concentrations occur in many Florida springs. Of particular concern is nitrate loading, which promotes eutrophication and can have toxic effects on aquatic organisms (Guillette and Edwards 2005; Edwards and Guillette 2007; Mattson et al 2007, Jacoby et al 2008). Mattson et al (2007) suggested that nitrate levels found in Rock Springs Run may contribute to chironomid larval mortality and may be chronically toxic to caddisflies and the amphipod *Hyalella sp*. Because these macroinvertebrates are important food sources as both larvae and adults for a variety of animals, there are implications of broad adverse effects on spring system food webs in general (Walsh et. al 2009). Water with nitrate concentrations above 0.2 mg/L is considered to be enriched by human activities (Toth 1999; Cohen and al 2007). Gemini Springs had a median nitrate concentration equal to 1.0 mg/L with a statistically significant ($p < 0.05$) increasing trend with time, as well as increasing nitrate concentrations as flow increases (Walsh et al 2009; Table 1 and Figures 13-14). Additional water quality information is located in the following Gemini Springs Environmental Values section.

Table 1. Summary Statistics of Water Quality at Gemini Springs

Gemini Springs	Mean	Median	Min	Max	Count	Period
Alkalinity, total, mg/L as CaCO3	137.8	138.3	125.0	158.0	55	1972-2010
Calcium, total, mg/L as Ca	137.8	136.3	86.0	110.0	54	1995-2010
Chloride, total, mg/L as Cl	622.4	621.5	525.0	760.0	56	1972-2010
Fluoride, total, mg/L	0.12	0.12	0.08	0.14	28	1995-2003
Magnesium, total, mg/L	38.0	38.0	31.0	46.0	53	1995-2010
Nitrate + nitrite, total, mg/L as N	1.04	0.98	0.5	2.2	55	1995-2010
Orthophosphate, total, mg/L as P	0.06	0.06	0.02	0.12	53	1995-2010
pH, field	7.37	7.39	6.67	8.46	55	1972-2010
Phosphorus, total, mg/L as P	0.08	0.08	0.06	0.13	29	1996-2010
Potassium, total, mg/L	8.1	8.1	6.8	9.4	53	1995-2010
Sodium, total, mg/L	322.8	323.6	264.9	380	53	1995-2010
Specific conductivity, field, µmhos/cm at 25 deg. C	2322	2374	1650	2809	52	1995-2010
Sulfate, total, mg/L	116.6	118.0	85.0	141.0	58	1972-2010
Total dissolved solids, mg/L	1408	1400	1240	1900	52	1993-2010
Water temperature, deg. C	23.1	22.9	21.5	25.4	58	1972-2010

Source: SJRWMD 2016b

Units: mg/L = milligrams per liter
µmhos/cm = microhos per centimeter

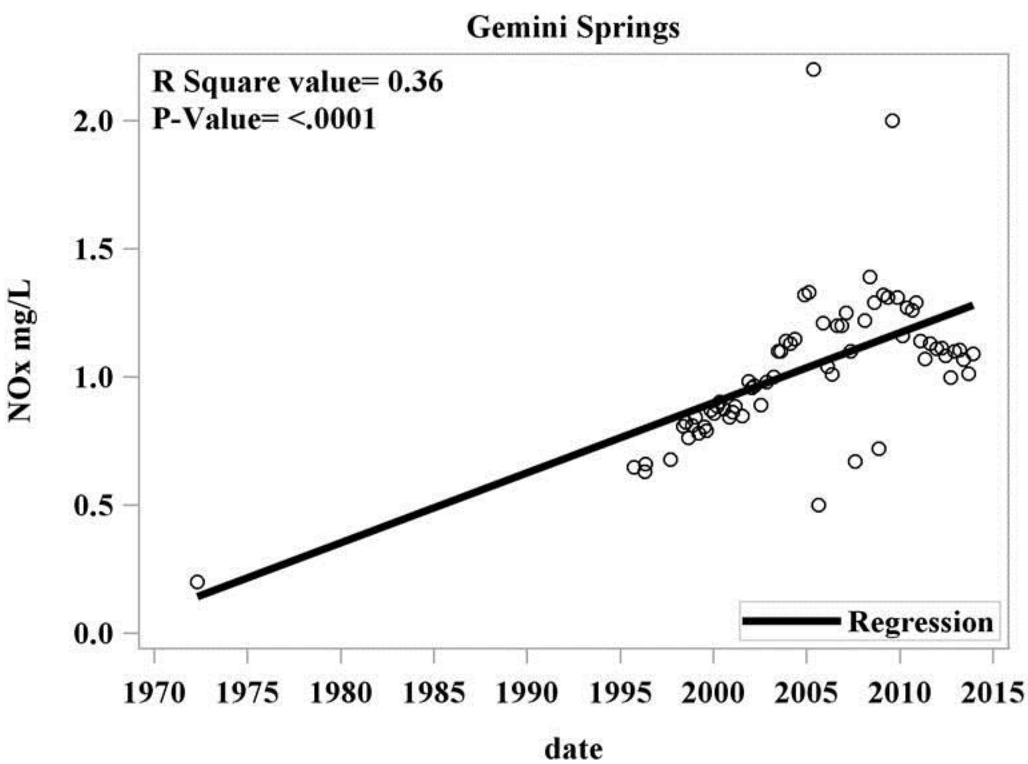


Figure 13. Gemini Springs NOx concentrations from 1972–2014 (Di and Mattson 2017)

Figure 14. Gemini Springs discharge and NOx concentrations (Di and Mattson 2017)

Gemini Springs Environmental Values

When establishing MFLs for water bodies pursuant to Sections 373.042 and 373.0421, F.S., SJRWMD identifies the environmental value or values most sensitive to long-term changes in the hydrology of each water body or watercourse. SJRWMD then typically defines the minimum number of flooding events and maximum number of low water events that would still protect the most sensitive environmental value or values. For example, water bodies for which the most sensitive environmental value may be fish and wildlife habitat, the recommended MFLs would reflect the number of flooding and low water events that result in no permanent loss of open water, wetlands, and organic substrates. Protecting the most sensitive environmental value or values for each water body provides the best opportunity to establish MFLs protective of all applicable environmental values identified in Rule 62-40.473, *F.A.C.*

SJRWMD uses the following working definitions when considering these 10 environmental values:

1. Recreation in and on the water—The active use of water resources and associated natural systems for personal activity and enjoyment. These legal water sports and activities may include, but are not limited to, swimming, scuba diving, water skiing, boating, fishing, and hunting.
2. Fish and wildlife habitat and the passage of fish—Aquatic and wetland environments required by fish and wildlife, including endangered, endemic, listed, regionally rare, recreationally or commercially important, or keystone species; to live, grow, and migrate. These environments include hydrologic magnitudes, frequencies, and durations sufficient to support the life cycles of wetland and wetland dependent species.
3. Estuarine resources—Coastal systems and their associated natural resources that depend on the habitat where oceanic salt water meets freshwater. These highly productive aquatic systems have properties that usually fluctuate between those of marine and freshwater habitats.
4. Transfer of detrital material—The movement by surface water of loose organic material and associated biota.
5. Maintenance of freshwater storage and supply—The protection of an adequate amount of freshwater for non-consumptive uses and environmental values associated with coastal, estuarine, riverine, spring, aquatic, and wetlands ecology.
6. Aesthetic and scenic attributes—Those features of a natural or modified waterscape usually associated with passive uses, such as bird-watching, sightseeing, hiking, photography, contemplation, painting, and other forms of relaxation that usually result in human emotional responses of well-being and contentment.
7. Filtration and absorption of nutrients and other pollutants—The reduction in concentration of nutrients and other pollutants through the process of filtration and absorption (i.e., removal of suspended and dissolved materials) as these substances move through the water column, soil or substrate, and associated organisms.
8. Sediment loads—The transport of inorganic material, suspended in water, which may settle or rise. These processes are often dependent on the volume and velocity of surface water moving through the system.
9. Water quality—The chemical and physical properties of the aqueous phase (i.e., water) of a water body (lentic) or a watercourse (lotic) not included in definition number 7 (i.e., nutrients and other pollutants).
10. Navigation—The safe passage of watercraft (e.g., boats and ships), which is dependent upon adequate water depth and channel width.

As part of a previous draft MFL determination for Gemini Springs, Applied Technology and Management, Inc. (ATM) and Janicki Environmental, Inc. (Janicki), evaluated the 10 environmental values as defined previously. ATM and Janicki's (2008) evaluation was applied to the current Gemini Springs minimum flow determination because the 2008 evaluation was performed for a similar minimum flow (9.6 cfs). ATM and Janicki determined that all relevant environmental values would be protected (ATM and Janicki, 2008; Richardson and Epting 2008). Their findings, along with updated information, are described herein.

The recommended minimum flow for Gemini Springs and the ATM and Janicki evaluation of environmental value protection is based on an analysis of the hydrology at Gemini Springs Park upstream from the weir. This is because the hydrology of the spring run downstream of the weir is primarily a function of Lake Monroe and the St. Johns River (ECT 2012; Stewart 2014, Xiong and Zhang 2017). Because recreation, as defined by the environmental values definition, is prohibited upstream of the weir, aesthetic and scenic attributes is the relevant human use oriented environmental value assessed for Gemini Springs. Additional relevant environmental values evaluated at Gemini Springs were fish and wildlife habitats and water quality.

Aesthetic and scenic attributes. Florida Senate Bill 552 describes springs as a unique part of Florida's scenic beauty, providing immeasurable natural, recreation, economic and inherent value. Maintenance of a minimum flow is essential to the aesthetic and scenic nature of Gemini Springs Park, which provides a natural sightseeing attraction for Volusia County, as well as nearby counties, and the state of Florida. Bonn and Bell (2004) studied the economic impacts and recreational and aesthetic values associated with eight springs in SJRWMD, including Gemini Springs. This study's data collection occurred while swimming was allowed at Gemini Springs, with the study indicating that visitor use will dramatically decrease with swimming prohibited. Current visitor usage data is unavailable. However, Gemini Springs Park has become increasingly popular due to the completion of multi-use trails traversing the park and connecting Gemini Springs Park to other recreation areas.

Recent efforts to quantify aesthetics and scenic attributes in Florida include a visitor survey of the St. Johns River parks in Duval County, Florida, where 16% of responders' primary activity or use of St. Johns River parks was to observe scenic views and nature, third behind motorized boating (26%) and fishing (21%) (University of North Florida and Jacksonville University 2016). However, translating aesthetic and scenic attributes into a specific flow requirement is difficult. In fact, a review of Florida springs MFLs (Appendix B) found that no Florida spring MFL used aesthetic and scenic attributes as a primary MFL determination criterion. Several Florida springs' MFLs declared aesthetic and scenic attributes as a high or top environmental value but each ultimately used a different environmental value when determining the minimum flow.

Florida springs MFLs that discussed aesthetic and scenic attributes as a significant environmental value included the Madison Blue Spring MFL determination (WRA 2004). This MFL described aesthetic features as a full pool, a flowing spring run, and water clarity. However, the Madison Blue MFL lacked data to assess the flow necessary to maintain these attributes and thus designated a minimum flow based upon fish passage metrics downstream in the Withlacoochee River. Similarly, Fanning and Manatee Springs MFL determinations recognized that these springs have high aesthetic and scenic value with MFL consideration including maintenance of these attributes by providing full spring pools, maintenance of stage in the spring runs and minimization of dark water backflow from the Suwannee River into the springs' pools. Meanwhile these MFL determinations were based on maintaining manatee habitat with the assumption that this would also protect the aesthetic and scenic attributes (WRA 2005). Likewise, both the Lower Santa Fe River and Ichetucknee River Springs MFL report (SRWMD 2013) and the Aucilla River, Wacissa River and Priority Springs draft report (HSW 2015) recognized the importance of aesthetic and scenic attributes while applying other environmental values thresholds to determine the

MFL hydrology, citing the lack of quantitative information linking aesthetics and flows suitable for the establishment of MFL criteria. At this time, aesthetic and scenic attributes evaluations for Florida springs MFLs determinations have been qualitative assessments and have generally been deemed less sensitive to flow reductions compared to other environmental values.

ATM and Janicki (2008) concluded that aesthetic and scenic attributes were protected at Gemini Springs by the maintenance of water depths in the reservoir pool and the presence of acceptable water depths flowing over the weir under the Richardson and Epting (2008) recommended 9.6 cfs average discharge. As described above, the hydrodynamic modeling conducted indicates that the recommended minimum flow will have minimal impact on reservoir pool depths or water residence time.

Fish and wildlife habitats; and water quality. Water quality is often closely related to fish and wildlife habitat environmental values, as is the case for criteria focused on maintaining freshwater zones for benthic habitat protection or maintaining winter warm water manatee habitat or summer cool and clear water snail habitat. Additionally, nutrients and phytoplankton abundance were important criteria analyzed in Florida springs MFL determinations and are closely related to water clarity and therefore aesthetic and scenic attributes, as well as fish and wildlife habitats.

Fish and wildlife habitats, along with water quality environmental values were also evaluated at Gemini Springs. Typically wetland vegetation, soils, and elevation data are key factors analyzed to ensure the MFL protects fish and wildlife habitats. However, the weir maintains very stable water levels within the reservoir over a wide range of springs discharges (Figure 10). Further, the characteristics of the reservoir, including relatively steep banks, along with park management (e.g., maintaining a sparsely vegetated littoral zone), result in a pool characterized by open water with little wetland vegetation. Because of the altered habitat conditions, the fish and wildlife habitats environmental values assessment at Gemini Springs focused on aquatic fauna water quality requirements.

Gemini Springs supports numerous fauna species (Walsh et al 2009), including accounts of manatee use (personal communication, R. Mezich, FFWCC, 2006) within the spring run; but no formal manatee sighting data is available. Suitable manatee warm water habitat exists immediately below the weir. However, the grate (Figure 6) and shallow water depths at the weir restrict manatee passage upstream into the reservoir, closer to the spring vents. Water temperatures recorded at the weir during February 2016 changed negligibly from water temperatures recorded near the northwest spring vent due to the short water residence time in the reservoir (Xiong and Zhang 2017), thereby providing suitable warm water manatee habitat immediately below the weir. Water depths immediately below the weir are also suitable for manatee habitat (minimum elevation equal to -5.0 ft NAVD), although water depths downstream from the weir in Gemini Run are often very shallow and largely a function of Lake Monroe stages (ECT 2012; Stewart 2014; Xiong and Zhang 2017). Deeper water depths, providing manatee access in Gemini Run, typically occur during late summer and early fall when the St. Johns River stage is high and manatee warm water habitat is not needed.

Of particular interest at Gemini Springs are the gastropod fauna of the St. Johns River drainage. Specifically, the Hydrobiidae snail family exhibits high rates of endemism within many Florida springs; some species exist only within a single spring (Walsh 2001; Thompson 2004, Shelton 2005). Hydrobiid snails were identified during several documented benthic macroinvertebrate sampling events at Gemini Springs Park (Walsh et al 2009). Generally, hydrobiid snails are sensitive to oxygen deficits, elevated water temperatures, and sedimentation. Regarding summer cool water snail habitat, model results (Xiong and Zhang 2017) along with water temperature data collected in February 2016 indicated that Gemini Springs pool water temperatures change negligibly between the spring vents and the weir outlet, maintaining summer cool water snail habitat even under relatively high flow reductions.

Calcium and pH are known to be important parameters in snail shell development and in some cases reproduction. However, specific ranges or threshold values for these water quality parameters are not known (ATM and Janicki 2008). ATM and Janicki (2008) confirmed this lack of information concerning key thresholds with Dr. Fred Thompson (personal communication 2007). Dr. Fred Thompson has discovered several endemic snail species associated with specific Florida springs (Thompson 2000).

Hydrobiid snails may also be endemic at Gemini Springs and may be susceptible to slight changes in water quality. These snails require clear water habitats and appear to be restricted to spring pools and that portion of the spring runs that maintains water quality conditions similar to those found in the spring pools. Table 1 contains water quality summary statistics for Gemini Springs and Figures 15 and 16 illustrate a weak and zero correlation between Gemini Springs discharge and Calcium and pH, respectively. Additionally, as mentioned previously, Figure 14 illustrates a slight positive relationship between nitrate-nitrite nitrogen (NOx) concentrations and discharge at Gemini Springs, indicating that to some extent increased discharge may have a negative influence on water quality at Gemini Springs.

A review of Florida springs MFL determinations that applied fish and wildlife habitat and the passage of fish as a primary criterion for developing the minimum flow recommendation identified manatee habitat, benthic habitat, fish habitat and fish passage as commonly applied criteria (WRA 2004, 2005, 2006; SWFWMD 2012a, 2012b; SRWMD 2012; HSW 2015). Many Florida springs MFLs analyzed estuary impacts and changes in salinity boundaries as environmental criteria (Table 2), with a typical goal focused on prohibiting more than a 15% decrease in freshwater or low salinity estuary habitat (SWFWMD 2012a and 2012b; HSW 2015). Similarly, many springs MFLs delineated warm water areas to ensure no more than a 15% decrease in winter warm water manatee habitat (WRA 2005 and WRA 2006). Since Gemini Springs is over 160 river miles from the Atlantic Ocean and provides a very small hydrologic contribution to the St. Johns River, changes in salinity boundaries and estuary impacts were not applicable for this MFL determination.

Additional water quality variables evaluated in Florida springs MFL determinations included dissolved oxygen and phytoplankton (algal) changes. However, definitive threshold flows were based on different criteria. For example, the Chassahowitzka Springs MFL evaluated flow reduction impacts of a) increased nutrients in the Chassahowitzka River system and b) increased water residence time leading to nuisance algal blooms or algal mats. Analyzes of these water quality parameters resulted in greater allowable flow reductions (13 to >40% depending upon the parameter) and concluded that the recommended 9% flow reduction based on manatee habitat protection would not result in an increase of nutrients or algae in the Chassahowitzka River system. Similarly, the Lower Santa Fe and Ichetucknee Rivers and Priority Springs MFLs (SRWMD 2013) and the Homosassa River System MFLs (SWFWMD 2012) considered phytoplankton biomass accumulation by analyzing chlorophyll *a* and flow. The SRWMD (2013) MFL determination concluded that while the highest chlorophyll *a* values occurred during periods of low flow, flow alone was an unreliable predictor of chlorophyll *a*, possibly due to the low chlorophyll *a* concentrations regardless of flows. Thus, the Lower Santa Fe and Ichetucknee Rivers MFL did not include this phytoplankton analysis in the MFL criterion development (SRWMD 2013). Chlorophyll *a* concentrations in the Homosassa River were also low, with highest values reported in the middle reach of the river, possibly associated with increased residence time associated with tidal forces in the area of transition between forested wetlands and marsh habitat (SWFWMD 2012; Frazer *et al.* 2006).

ATM and Janicki (2008) examined the relationship between hydrobiid snail habitat and water quality with a focus on Gemini Springs flow required to maintain clear water conditions within the spring pools and spring runs. As noted previously, water clarity is also a key metric for aesthetics and scenic attributes. Additionally, numerous studies have examined the relationships between flow, water residence time and phytoplankton (algae) abundance (Fulton and Hendrickson 2012). Often, when water residence time increases algal growth increases and water clarity decreases. However, due to the very small increase in water residence time at Gemini Springs reservoir at the recommended flow, ATM and Janicki (2008) found no clear relationship between the key water quality parameters and discharge at Gemini Springs. Thus, they concluded that the proposed MFL would maintain appropriate clear water conditions, sustaining both water quality and the conditions necessary for snail survival. As previously noted, ATM's review and conclusions are relevant to the current determination because the recommended minimum flow is very similar to conditions they assessed.

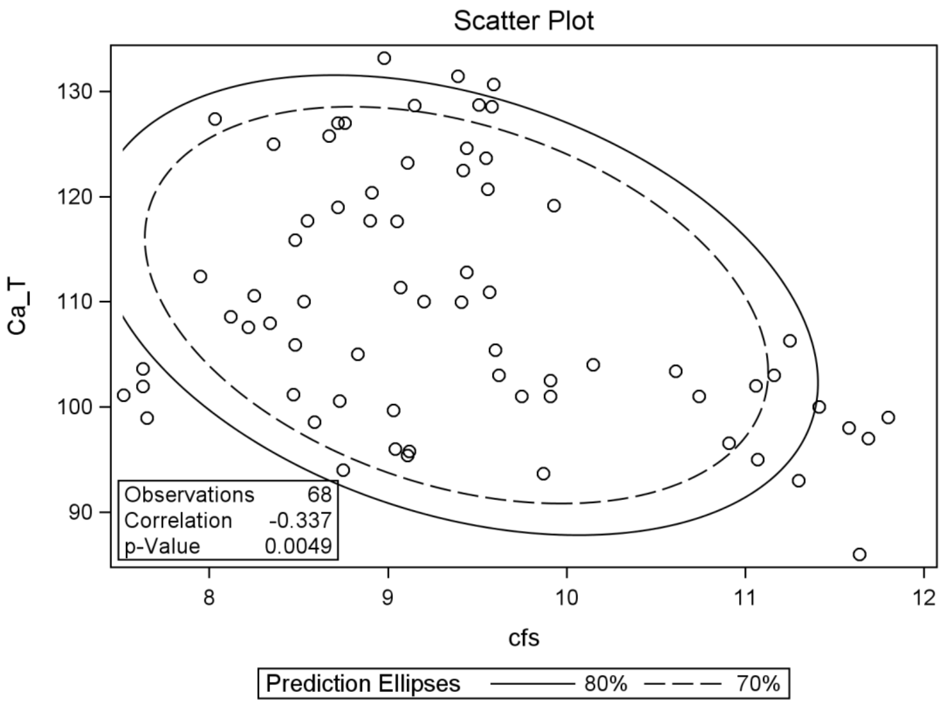


Figure 15. Gemini Springs discharge and Calcium concentration (SJRWMD 2016b)

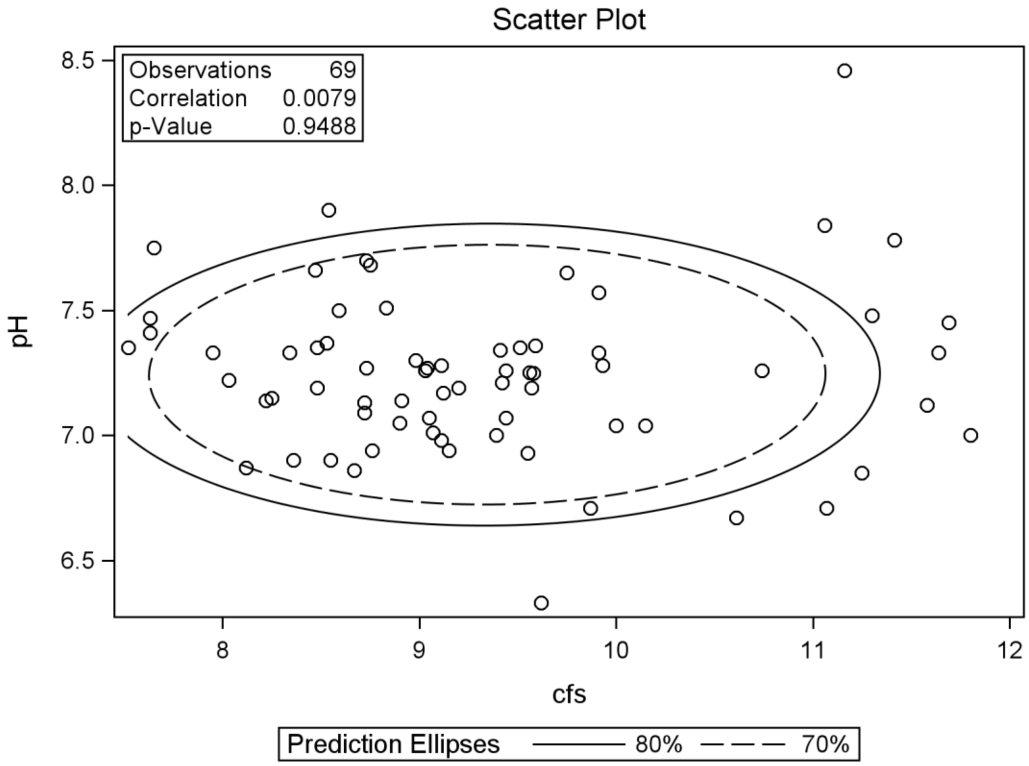


Figure 16. Gemini Springs discharge and pH observations (SJRWMD 2016b)

Table 2. Examples of habitat or resource metrics commonly applied in Florida springs MFLs

Habitat or Resource	**Criteria**
Salinity habitat – 2, 3, 5, 10, and/or 15 ppt area	15% loss in area for each salinity concentration
Salinity habitat – 2, 3, 5, 10, and/or 15 ppt volume	15% loss in volume for each salinity concentration
Salinity habitat – 2, 3, 5, 10, and/or 15 ppt length	15% loss in shore length for each salinity concentration
Manatee habitat refuge area	15% loss in habitat area
Manatee habitat refuge volume	15% loss in habitat volume
Floodplain habitat protection	15% reduction inundated floodplain wetland area
Number of paddling days	15% reduction in paddling days
Numerous riverine habitat metrics	Typically 15% reduction in metric
Mollusk abundance	15% loss from peak abundance
Benthos total abundance	15% loss from peak abundance
PHABSIM analysis	15% loss in habitat for fish and benthic fauna

Florida Springs MFLs Review

As more Florida springs MFLs are adopted, a growing quantity of literature describing these MFL determinations is available. Springs MFLs determinations (Appendix B) from SJRWMD, Southwest Florida Water Management District (SWFWMD), and Suwannee River Water Management District (SRWMD) were reviewed to evaluate and identify criteria and flow impact thresholds, in support of the current Gemini Springs MFL determination.

Florida springs MFLs typically focused on one or more environmental values especially relevant to the spring and/or the associated river ecology. A common MFL methodology focused on determining the flow reduction associated with a 15% reduction in a habitat or resource. Habitat and resource were defined by numerous ecological features (Table 2). This 15% reduction in habitat or resource was used due to the limited information regarding a critical threshold flow reduction that would no longer be protective of the selected resource. Thus, a flow reduction that results in no greater than a 15% reduction in a metric, such as usable area and/or inundation time, was considered for many of the resources evaluated (HSW 2015). Several Florida springs MFLs analyzed a 15% reduction of multiple resources and habitat metrics, which resulted in a range of associated flow reductions with the final MFL discharge equal to either the lowest discharge reduction from no pumping conditions or a reduction based on an average of the discharges resulting from the 15% habitat reductions (WRA 2004, 2005, 2006; SWFWMD 2012a, 2012b; SRWMD 2012; HSW 2015).

Gemini Springs Minimum Flow Determination

The goal of this minimum flow determination is to protect Gemini Springs from impacts due to decreases in springs discharge resulting from the consumptive use of groundwater. Key environmental values focused upon in this MFL determination were water quality, aesthetic and scenic attributes, and fish and wildlife habitat.

Water quality at Gemini Springs is closely tied to aesthetics and scenic attributes, as well as fish and wildlife habitat. The relationship between water quality and water residence time in Gemini Springs' reservoir is the basis for this MFL determination.

The specific criterion applied to calculate this minimum flow was based on allowing a 15% increase in Gemini Springs reservoir water residence time, which corresponds to a 15% decrease in spring discharge from the historic no pumping flow condition. This allowable reduction in flow results in a minimum mean flow of 9.3 cfs (Table 3). As mentioned previously, a 15% change in aquatic habitat is commonly applied in other Florida springs MFLs when evaluating a resource or habitat condition. The use of this habitat threshold, as a measure of significant harm for MFLs development has been suggested by other water management districts and peer reviewers (Gore et al. 2002). This MFL is based on water residence time because this is the most appropriate criterion available, and it is associated with both aesthetics and fish and wildlife habitat values. Allowing a 15% reduction in flow was also based on hydrodynamic modeling results that indicate this flow reduction will result in a small change in water residence time.

Water Residence Time as the Quantitative MFL criteria

In a balanced ecosystem, phytoplankton (algae) provides food for a wide range of creatures, including fish and snails. When nutrient concentrations are excessive, phytoplankton may grow out of control and form harmful algal blooms. These blooms can produce extremely toxic compounds that have harmful effects on aquatic fauna, mammals, birds, and even people (Source: *http://oceanservice.noaa.gov/facts/phyto.html* 2016). Furthermore, algal blooms can shade desirable submersed plants and increase nitrogen (N) loading through N_2-fixation (Scheffer 1998, Paerl et al. 2001a, Paerl and Fulton 2006), while also negatively affecting the aesthetic and scenic values. A further negative impact of increased algal blooms is the increase in decomposition of senescent algae, with the associated increase in potential for anoxic conditions. Low oxygen due to decomposing algal blooms is commonly associated with declining habitat conditions for fish and invertebrates.

Hydrologic conditions affect phytoplankton in lakes, rivers, and estuaries. Higher flows generally mean greater water velocities in rivers and shorter water residence times through river reaches and riverine lakes. Conversely, lower flows result in longer water residence times and greater phytoplankton nutrient uptake, increasing the potential for algal blooms (Phlips et al. 2002). In the St. Johns River downstream from Gemini Springs Run, when longer water residence times and low color conditions took place, phytoplankton more fully utilized nutrients and algal blooms occurred (Coveney et.al., 2012). Research, primarily in discharge lakes, suggests that the diversity and abundance of planktonic algae and cyanobacteria are positively correlated with hydraulic retention time (average time to remove a given particle) (Verspagen et al. 2006, Roelke et al. 2009, Roelke and Pierce 2011). Periodic hydraulic flushing can terminate algal blooms and remove them from the system (Mitrovic et al. 2011).

For the Gemini Springs MFL determination, the evaluation of water quality as a sensitive environmental criterion, focused on the potential link between reduced spring flows, increased water residence time in the springs reservoir, and increased phytoplankton abundance upstream of the weir. Based on the hydrodynamic modeling described above, water residence time within the Gemini Springs reservoir increased by approximately 1 hour and 14 minutes with a 15% decrease in spring discharge from average discharge, under free flowing conditions (Table 4). This is a small increase in water residence time and should not significantly increase algae abundance and decrease water clarity. Thus, the water quality, aesthetic and scenic attributes, as well as Hydrobiid snail habitat at Gemini Springs (Flannery et al 2008; Phelps et. al 2006) remains protected at the recommended flow.

<u>Additional Considerations for Gemini Springs' MFL Determination</u>

As mentioned previously, MFLs are established using the best information available (section 373.042(1), F.S.), with consideration 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...," (section 373.0421(1)(a), F.S.).

The man-made weir at Gemini Springs is a structural alteration, adding an unnatural reservoir and greatly influencing the hydrology at Gemini Springs Park. The presence of the weir results in reservoir water levels that are not sensitive to flow reductions. Specifically, hydrodynamic model results indicate that when Gemini Springs discharge decreases by 15% and backwater affects are absent, water surface elevation in the reservoir declines by only 0.08 ft. Moreover, when backwater from Lake Monroe directly influences Gemini Springs reservoir stage and spring discharges, high reservoir stages occur independent of springs discharge. Thus, the hydrodynamic modeling results indicate that the recommended minimum flow will have very little effect on reservoir stage (Xiong and Zhang 2017).

Past efforts to develop Gemini Springs MFL determination criteria included an evaluation of wetlands within the reservoir and along the spring runs in 2016. This evaluation failed to provide a level or discharge criterion due to the scarcity of wetland vegetation in the reservoir, the lack of quantifiable ecological criteria in the springs runs, the weir structure maintaining very stable water levels within the reservoir, and the relatively steep banks of the reservoir where changes in water levels result in very small changes in the wetted perimeter area within the reservoir. Figure 17 illustrates the reservoir bank topography with the elevation surveys located at the least steep bank slopes (Figure 18).

Analyzes of nitrate and calcium did not result in a basis for the Gemini Springs' MFL determination. As mentioned previously, nitrate loading promotes eutrophication and can have toxic effects on aquatic organisms (Guillette and Edwards 2005; Edwards and Guillette 2007; Mattson et al 2007, Jacoby et al 2008), while calcium is important to aquatic fauna, including snails. However, recent data analyzes found nitrate concentrations increased as flows increased while calcium concentrations were not correlated with Gemini Springs discharge (Figures 13 and 14).

Lastly, a 2014 study reconfirmed the hydrologic characteristics regarding the weir at Gemini Springs Park with one conclusion that a Gemini Springs MFL could not be based directly on Gemini Springs Run stages downstream of the weir because the spring run stages below the weir are dominated by the hydrology of Lake Monroe (Stewart 2014).

Table 3. Recommended minimum flow for Gemini Springs, Volusia County, Florida

Minimum Flow Metric	**No pumping average flow 1995-2015 (cfs)**	**Recommended Minimum Mean Flow (**cfs)
Average Flow	10.91	9.3

Table 4. Calculated Gemini Reservoir water residence times, in hours (Xiong and Zhang 2017)

Free Flow Hydrology Discharge (cfs)*	**Baseline* Water Residence Time (hours)**	**Water Residence Time with 5% flow reduction (hours)**	**Water Residence Time with 10% flow reduction (hours)**	**Water Residence Time with 15% flow reduction (hours)**
Average (9.67)	8.21	8.58	8.98	9.44
High (11.40)	7.13	7.44	7.8	8.2
Low (8.40)	9.27	9.69	10.15	10.68

*Baseline EFDC model scenarios where under free flowing conditions average discharge equals 9.67 cfs, high discharge equals 11.4 cfs and low discharge equals 8.4 cfs.

Minimum Flow Status Assessment

The current status of the recommended minimum mean flow for Gemini Springs and the status at the 20-year planning horizon were assessed using the Volusia Regional Groundwater Flow Model (SJRWMD 2016). Based on the results of this assessment, the recommended minimum flow is currently being achieved and is expected to continue to be achieved at the 20-year planning horizon. Therefore, Gemini Springs is not in prevention or recovery. Appendix D contains details of this assessment.

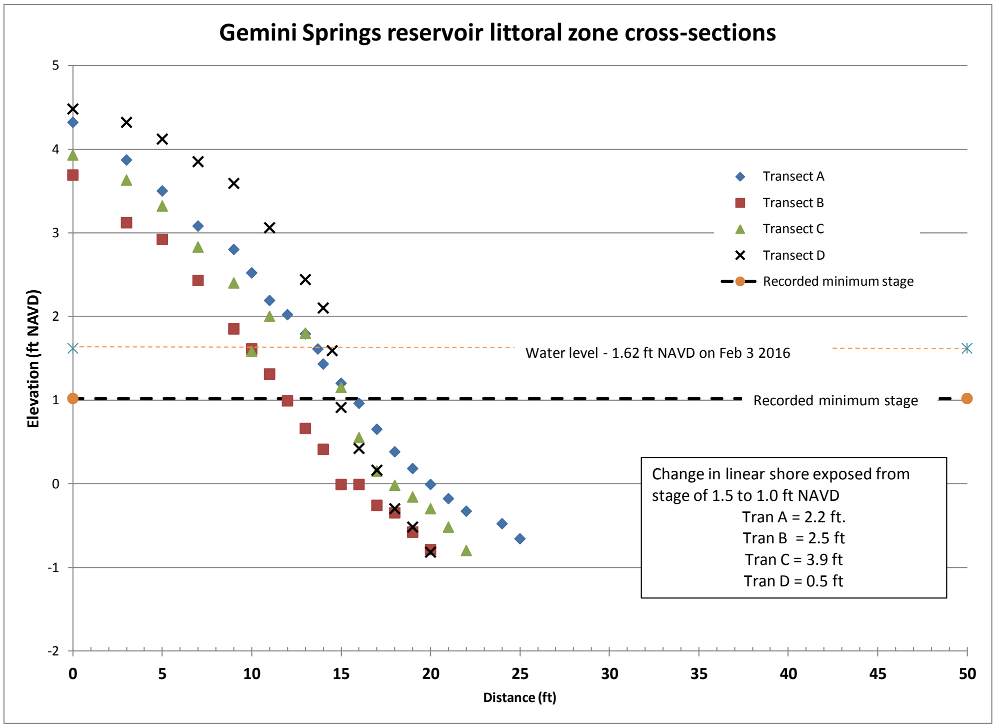


Figure 17. Gemini Springs Reservoir littoral zone cross-sections

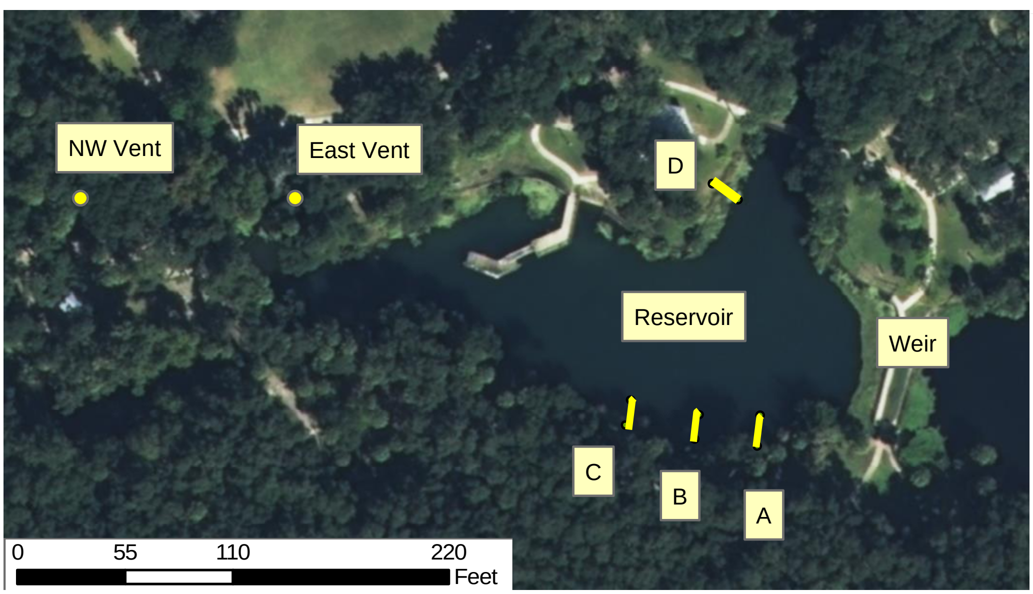


Figure 18. Gemini Springs Reservoir littoral zone cross-section locations

Conclusions and Recommendations

The recommended minimum flow for Gemini Springs, equal to a mean flow of 9.3 cfs, corresponds to a 15% decline in spring flow from the no pumping condition. Based on the best available information, this recommended flow should protect water quality at Gemini Springs by ensuring no more than a 15% increase in water residence time in Gemini Springs' man-made reservoir when backwater from Lake Monroe and the St. Johns River is absent. Protecting water quality at Gemini Springs will help to maintain water clarity, thereby maintaining the aesthetic and scenic attributes. Maintaining water quality will also help to protect fish and wildlife habitats, including clear water for the potentially endemic Hydrobiid snails, and a healthy balanced phytoplankton community. Providing adequate flow from the spring pools to the weir helps to ensure protection of the environmental values at Gemini Springs given that the hydrology downstream of the weir is primarily a function of Lake Monroe and the St. Johns River.

Basing the minimum flow recommendation for Gemini Springs on a 15% increase in water residence time in Gemini Springs' reservoir is consistent with a common approach for Florida springs MFLs determinations, which allow for a 15% change in a resource or habitat value. This 15% change in a habitat or resource was used due to limited information regarding a critical environmental flow threshold for Gemini Springs.

Many factors, including the following, contributed to the rationale for this recommended MFL based on a 15% increase in water residence time in the springs' reservoir.

- The spring system has been highly altered through the construction of an impoundment/reservoir below the spring vents that is controlled by a fixed crest weir.
- According to the hydrodynamic model (Xiong and Zhang 2017), water residence time within the Gemini Springs Reservoir increased by approximately 1 hour and 23 minutes with a 15% decrease in spring discharge from average discharge, under free-flowing conditions at the weir. This is a small increase in water residence time and should not significantly increase algae abundance or decrease water clarity.
- The often large influence of backwater from Lake Monroe and the St. Johns River overwhelms the reservoir and springs pools hydrologic and ecologic characteristics;
- The man-made weir at Gemini Springs park provides extremely stable water levels in the reservoir, allowing large decreases in springs discharge to result in very small decreases in reservoir water stage and wetted perimeter.

Current pumping defined by 2010 conditions has resulted in a 1.0 cfs (9.5%) reduction in Gemini's spring flow from the no-pumping condition. Approximately 0.6 cfs (5.5%) of additional reduction in spring flow due to consumptive use can occur prior to the MFL being violated. Based on the current best available information, including the Volusia groundwater model (SJRWMD 2016c); the predicted flow reduction resulting from projected water use for the 20-year planning horizon is less than the flow reduction allowed by the recommended MFL. Therefore, the proposed MFL for Gemini Springs is achieved for the 20-year planning horizon, and neither a recovery nor a prevention strategy is required.

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Appendix A — Gemini Springs Land Use

The Gemini springshed or groundwater basin is relatively small in size, when delineated by the southern boundary of Volusia Blue Springs springshed and the northeast boundary of Wekiwa Springs springshed (Figures A1 and A2). Land use changes over the past few decades within the Gemini springshed were predominantly the shift in forestland from 59.7% to 3.0% and within urban/mining/transportation/recreation from 9% to 40.9%, between 1973 and 2009, respectively (Figures A1-1 and A1-2).

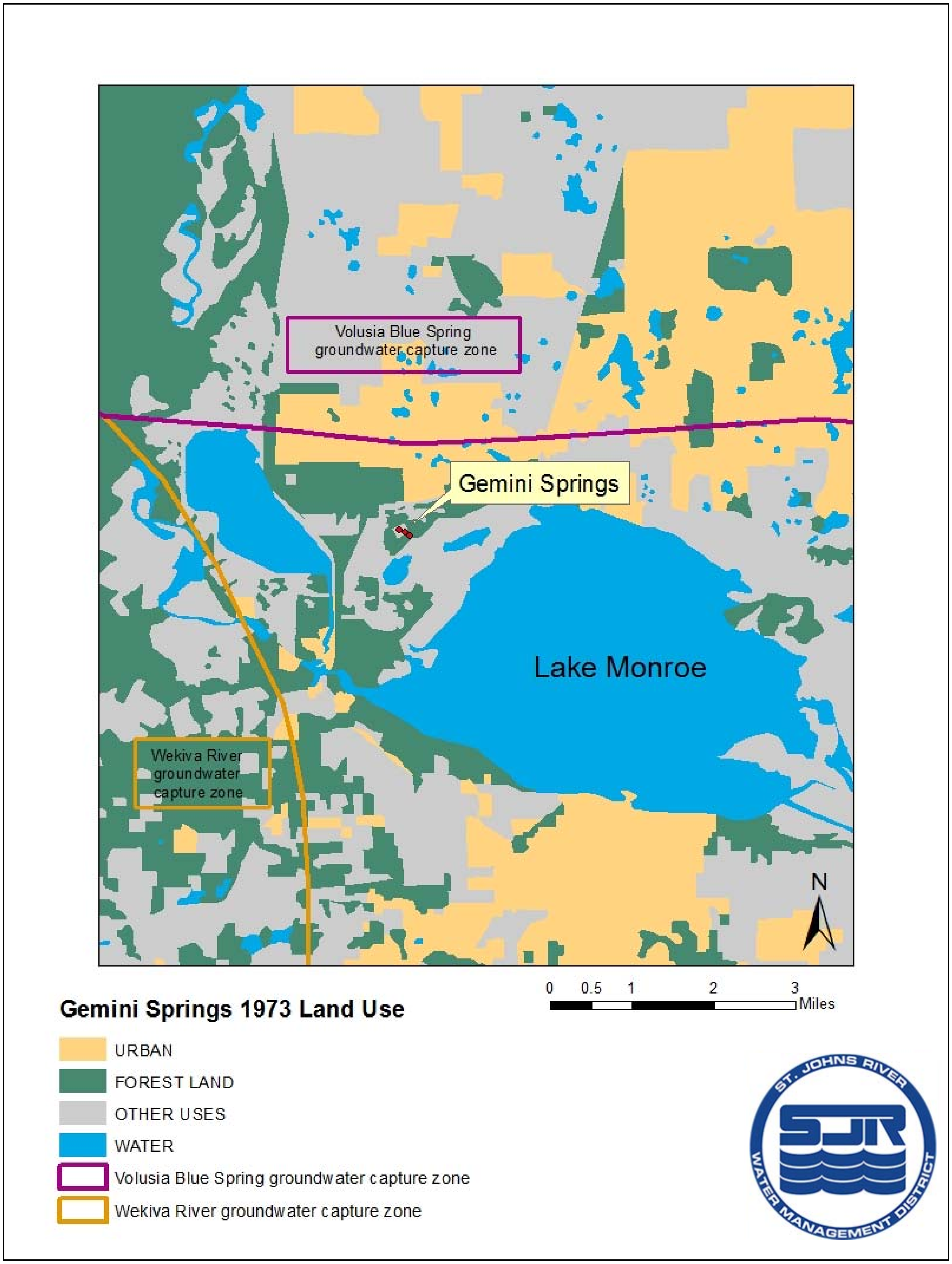

Figure A1-1. Gemini Springs 1973 land use (Groundwater capture zone sources : McGurk 2009 and Williams 2006)

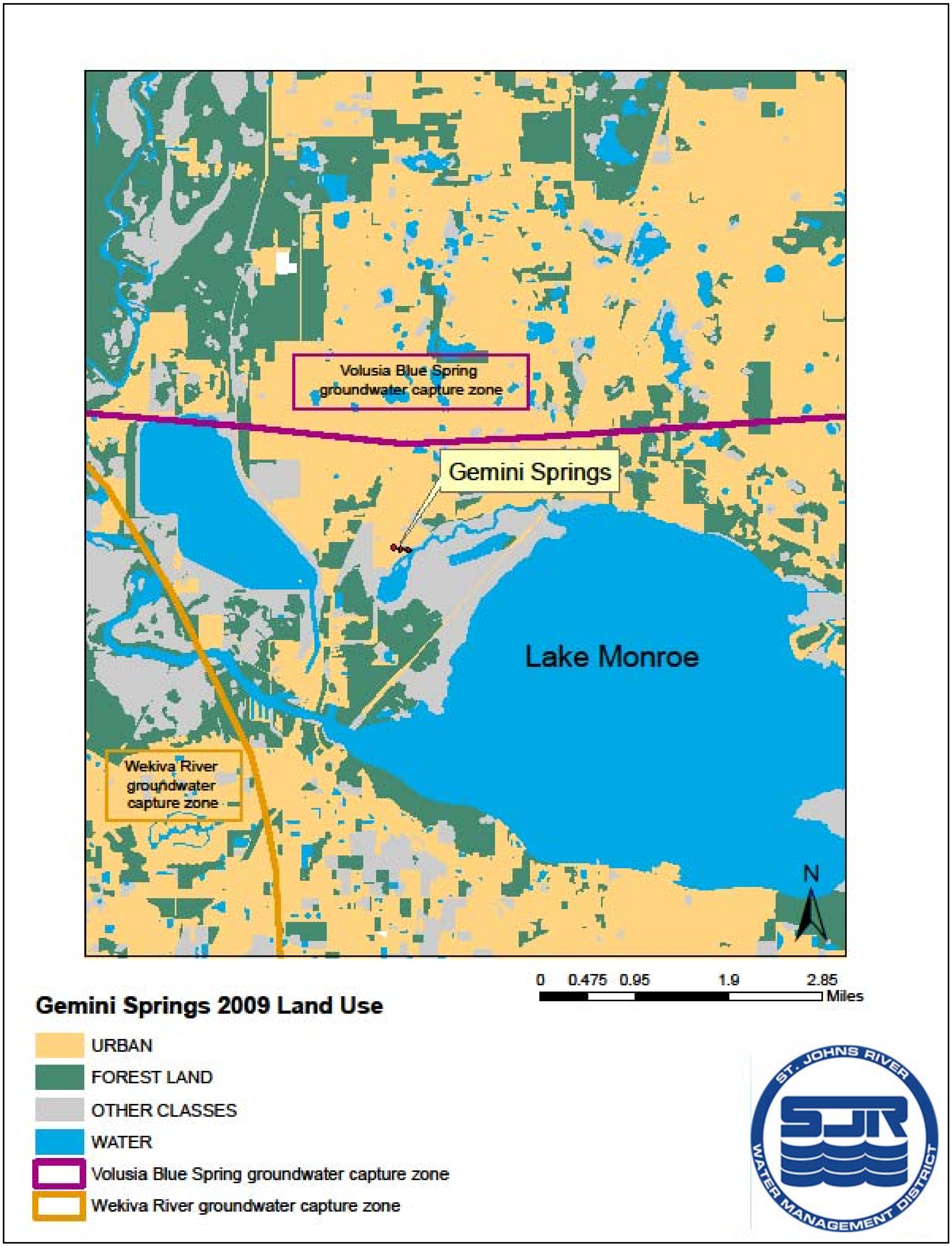

Figure A1-2. Gemini Springs 2009 land use (Capture zone sources : McGurk 2009 and Williams 2006)

Appendix B – Florida Springs Summary Table

Table B-1. Florida Springs reviewed with recommended or adopted MFLs as of January 2017

#	Springs / MFL	District	Criteria and Number of Springs Identified with the MFL	Recommended Flow Reduction
1	Blue Spring — Volusia County	SJRWMD	Thermal refugia for manatee — 1	0%
2	Wekiwa Springs Rock Springs Messant Spring Miami Springs Palm Springs Sanlando Springs Seminole Springs Starbuck Springs	SJRWMD	Based on flow necessary to meet MFLs for the Wekiva River at SR 46 — 8	**9%**
3	Blue Spring — Levy County	SRWMD	Maximum flow reduction to prevent significant reductions in the associated water resources — 1	**10%**
4	Manatee Springs	SRWMD	Thermal refugia for manatee — 1	**10%**
5	Fanning Spring	SRWMD	Maintenance of depth for manatee passage — 2	**10%**
6	ALA112971 (Treehouse) Santa Fe Rise Hornsby Columbia Poe COL101974 Rum Island	SRWMD	Based on the median percent MFL reduction in the streamflows for the Lower Santa Fe River — 9	**8%**

Table B-1. Florida Springs reviewed with recommended or adopted MFLs as of January 2017

#	Springs / MFL	District	Criteria and Number of Springs Identified with the MFL	Recommended Flow Reduction
	July Devil's Ear (Ginnie Group)			
7	Ichetucknee Head Blue Hole Mission Devil's Eye Grassy Hole Mill Pond	SRWMD	Based on the median percent MFL reduction in the streamflows for the Ichetucknee River — 6	**3%**
8	Aucilla River and Nutall Rise	SRWMD	Nutall Rise is a resurgence primarily of the Aucilla River — 1	6.5%, 8%, and 17%
9	Wacissa River and 12+ Springs	SRWMD	Flow reductions developed for Wacissa River gage is considered an index for the combined flows of the Wacissa Springs Group — 12	5.1% and 7.3%
10	Homosassa Springs	SWFWMD	Protection of low-salinity benthic habitats — 1	**3%**
11	Gum Slough Spring Run	SWFWMD	Aquatic habitat availability — 1	**6%**
12	Peace River at Zolfo Spring	SWFWMD	Officially this is a River MFL but since nearly all the baseflow at low flows is groundwater we included it — 1	**8%**
13	Rainbow Springs	SWFWMD	Inundated or available floodplain protection	**5%**
14	Chassahowitzka Spring (12 springs)	SWFWMD	Aquatic habitat availability — 12	**9%**

Table B-1. Florida Springs reviewed with recommended or adopted MFLs as of January 2017

#	Springs / MFL	District	Criteria and Number of Springs Identified with the MFL	Recommended Flow Reduction
15	Weeki Wachee Spring	SWFWMD	A 15% reduction of resource/habitat was adopted as representing significant harm — 1	**10%**

Appendix C — Gemini Springs Pool Hydrodynamic Analysis

GEMINI SPRINGS POOL HYDRODYNAMIC MODELING ANALYSIS

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St. Johns River Water Management District (SJRWMD)
Palatka, Florida

2017

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GEMINI SPRINGS POOL HYDRODYNAMIC MODELING ANALYSIS

1. INTRODUCTION

Within St. Johns River Water Management District (SJRWMD), Gemini Springs is a second-magnitude spring that consists of two spring vents (SJRWMD, 2016) located within the 210-acre Gemini Spring Park in the City of Debary, Volusia County, Florida. With continuous replenishment from the springs discharge, the approximately 1.3-acre Gemini Springs pool is a shallow semi-manmade Gemini Springs discharge water system formed and maintained by a dam and weir built in 1969 that impound water mainly for water supply and recreation. Discharge over the weir from the pool enters Padgett Creek, also known as Gemini Springs Run, and meanders east approximately 2 miles, passing under I-4 before entering Lake Monroe on the St. Johns River (SJR). Gemini Springs Park, purchased in 1994 by Volusia County from the Gray family, who owned the property since 1969 and gave Gemini Springs its name, opened to the public in 1996. In 2015, Florida Senate Bill 552 identified Gemini Springs as an Outstanding Florida Spring with the accompanying requirement for Minimum Flows and Levels (MFLs) adoption by July 1, 2017. In support of the development of Gemini Springs MFLs, a fresh modeling effort of Gemini Springs pool was conducted to understand the hydrology and hydrodynamics of the system and to quantify the impact of springs discharge reduction. Unlike previous Gemini Springs MFLs studies' emphasis on Padgett Creek, the Gemini Springs pool area inside the weir is the focus for this MFLs study.

A hydrodynamic model was developed for the Gemini Springs pool and the adjacent area downstream of the weir. The model was calibrated and validated to analyze water surface elevation, salinity and transport time characteristics of the pool. The model also provides a tool for evaluating the influence of downstream Padgett Creek stage (PCstage) on the upstream pool. The SJRWMD MFLs and modeling group conducted a stand-alone analysis of the springs discharge and PCstage time series over the period of record (POR) for the Baseline Conditions. Then, a certain percentage (e.g., 5%, 10%, and 15%) springs discharge reduction was applied to evaluate the impacts in water surface elevation, salinity and transport time.

2. GEMINI SPRINGS POOL STUDY AREA

Gemini Springs (Fig. 2.1), generally located at 28°51'45.66"N, 81°18'40.69"W in Volusia County, Florida (Stewart, 2015), is classified as 2nd magnitude spring (discharge: 10 – 100 cfs) that consists of two spring vents (North and South Vents). The springs is situated approximately 1 mile south of the city of

Weir

DeBary and about 2 miles northeast of the Interstate 4 (I-4) bridge where St. Johns River (SJR) enters the western end of Lake Monroe (Fig. 2.2) and is now operated as Gemini Springs Park by Volusia County.

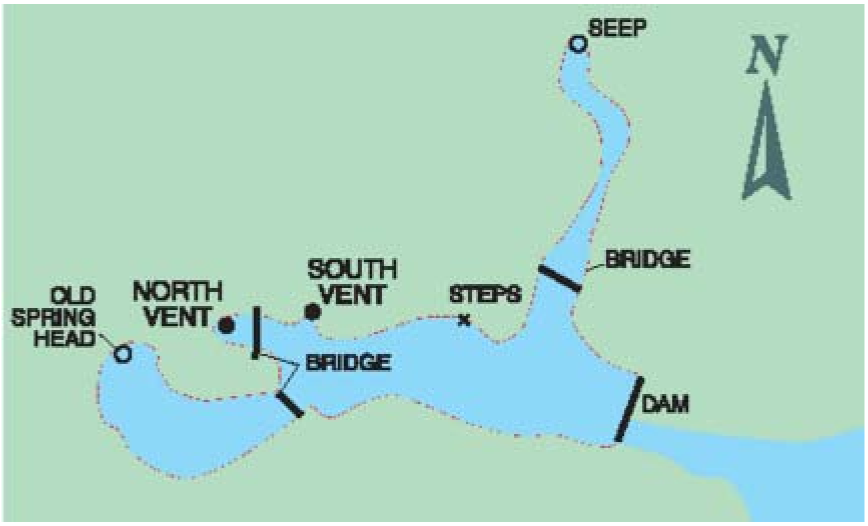

Figure 2.1. Gemini Springs Area (USGS, 2012)

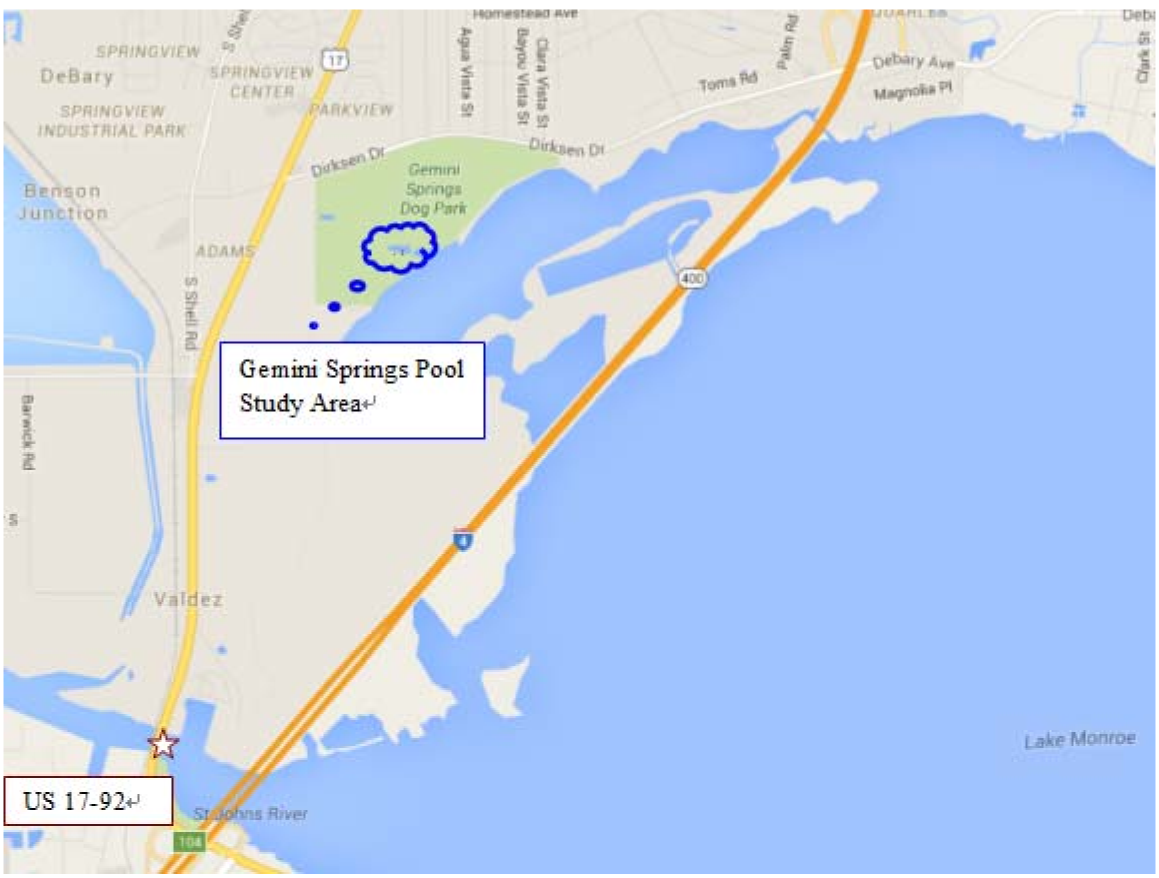

Figure 2.2. Locations of Gemini Springs

Figure 2.3. Gemini Springs Pool (Left: View from Dam to Gemini Springs; Right: View from Gemini Springs to Dam and Lake Monroe) (USGS, 2012)

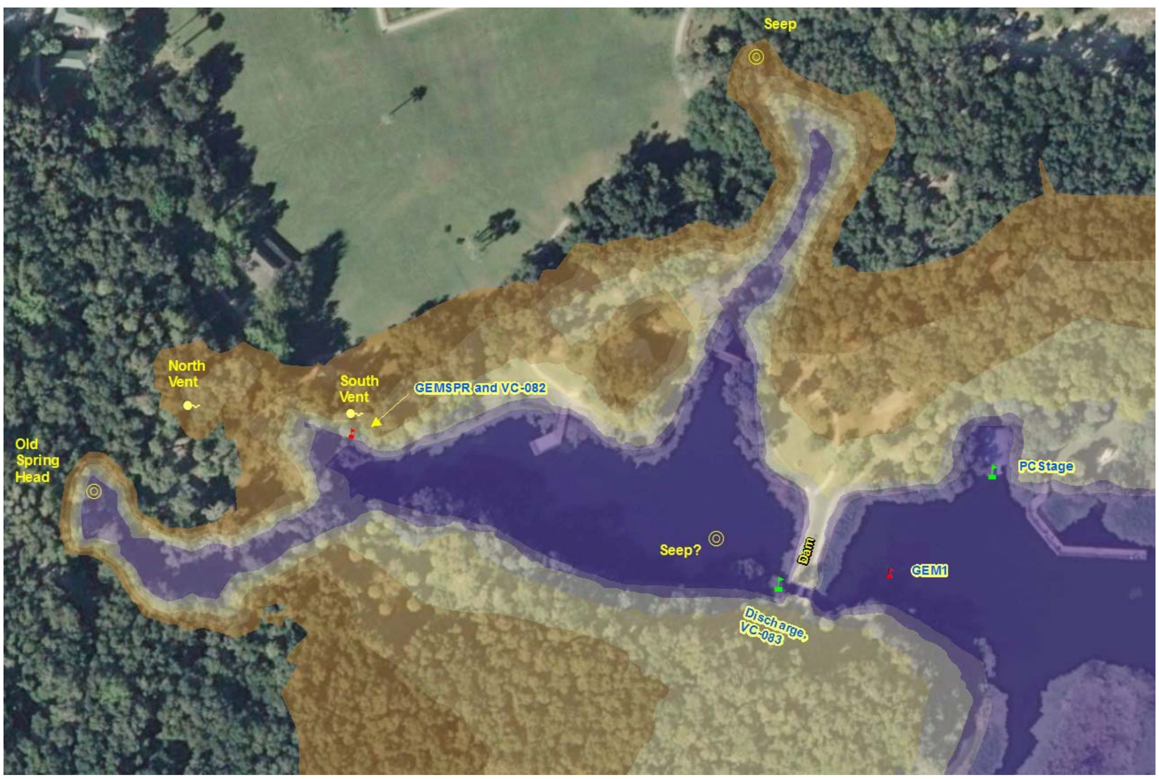

Figure 2.4. Gemini Springs Pool Study Area

The Gray family, the previous owner, built a dam in 1969 to create an impoundment for their cattle ranch; water from the springs flowing into the broader pool (Figures 2.3 and 2.4) discharges at a shallow broad crested weir opening into Gemini Springs Run or Padgett Creek, and eventually Lake Monroe. There may be an Old Spring Head (Fig. 2.4) at the far west end of the impoundment and a seep (North Seep, Fig. 2.4) is located north of the primary vents. Park personnel also reported that another spring (Pool Seep,

Fig. 2.4) is located in the center of the impoundment. However, there is little discharge out of the Old Spring Head and the two seeps.

To study the pool, the dam and weir that regulate the pool outflow are never an avoidable topic due to its significant influence on flow. According to the 2005 and 2016 survey from SJRWMD, the broad crested weir is around 10-foot wide, 14-foot long, and the averaged crest elevation is approximately 0.51 North American Vertical Datum of 1988 (ft-NAVD88), equivalent to 1.43 ft National Geodetic Vertical Datum of 1929 (ft-NGVD29). Until now, the pool bathymetry still roughly follows the pre-dam shape. The dam construction alters the original flow pattern, slows the velocity and certainly brings sedimentation problem, especially in the northern part of the pool. The dam also changes the turbulence eddy, dispersion coefficient distribution in the pool area. The location of the weir/outfall was considered to provide warm and clean surface water for Gemini Springs Run and to improve the water circulation for some downstream area and mullet lake (Table 2.1). However, this design increases the residence time at swimming dock and deep areas in the northern pool and then accordingly worsens the pool water self-cleaning capability, besides an obvious watershed runoff and wastewater from the picnic areas directly affect these areas. Despite a small pool with a short residence time, the flow is complicated if people take a closer look at the whole area. Besides the significant lateral (North-South direction; or direction parallel to the dam) flow variations mostly due to the weir/outfall location, Gemini Springs pool also exhibits longitudinal (from North and South Vents to the weir/outfall; or West-East direction) variations in hydrodynamic and water quality characteristics. Therefore, with two upstream inflow spring vents and a downstream weir outflow, plus occasionally high backwater driven by Lake Monroe, Gemini Springs pool has a great deal of spatial and temporal changes in hydrodynamic and water quality variables, similar to other reservoirs.

According to a previous investigation (ECT, 2012), an estimated 35 acres or 0.054688 square miles (mi^2) within the Gemini Springs Park that drains directly to the Gemini Springs pool predominantly by overland flow. Since the average runoff from watersheds near Sanford is approximately 0.93 cfs per mi^2 (ECT, 2012), the same runoff rate is considered from the park into Gemini Springs pool because of closeness. Based on the size of watershed, approximately 0.02 cfs flow was used in the model as storm water runoff.

For reference use, Table 2.1 (Stewart, 2015) provides general information and description of the features mentioned in this report.

Table 2.1. Description and Areal Extent of Surface Features (Stewart, 2015)

Feature	Description	Area (km^2)	Area (acre)
Gemini Springs	A set of springs generally located at 28°51'45.66"N, 81°18'40.69"W in Volusia County, Florida		
Gemini Springs Pool	A dam and weir create a pool that accumulates discharge from the two main Gemini Springs Vents and additional seepage	0.01	1.3
Gemini Springs Park	A 210-acre (85 ha) public nature park in DeBary,Florida, United States featuring two springs. The park, completed in 1996, is situated on bayou northwest of Lake Monroe (Florida).	0.85	210
Debary Bayou	Marsh / creek / lake system separated from Lake Monroe by the Interstate-4 causeway	2.52	622.5
Padgett Creek	Creek connecting Gemini Springs and Mullet Lake to Lake Monroe that runs through DeBary Bayou. The length is about 3.2 km from the mouth to the Gemini Springs pool weir, and about 3.8 km to the center of	0.1	23.6
Lake Monroe	Receiving water body for Padgett Creek, located above the Gemini Springs Pool	35.19	8696.3
Mullet Lake	Lake at the Upstream end of Padgett Creek and Interstate-4 causeway, downstream of Gemini Springs Pool	0.24	60.5
Interstate-4 causeway (I-4)	An earthen dike and road bed separating Lake Monroe and Debary Bayou		
US Highway 17-92 (US 17-92)	The downstream boundary for the study area along the St. Johns River		
City of Debary	The City of Debary encompasses the watershed to DeBary Bayou		

2.1. Previous Model Study

A couple of past modeling efforts were applied to Gemini Springs in the recent decade. An extensive CE-QUAL-W2 modeling of Gemini Springs Run downstream of the weir was involved to determine spring flows necessary to minimize negative water quality events in the spring run to Lake Monroe (ECT, 2012). An ensuing effort modeled Gemini Springs Run with proposals for improving the Debary Bayou by decreasing sedimentation in Gemini Springs Run (Stewart, 2015).

ECT (2012) indicated that the Gemini Springs flow is less than 0.50 percent of the St. Johns River flow; therefore, any flow reduction of Gemini Springs will have negligible hydrologic and water quality impacts on the St. Johns River system. It also revealed that the weir was frequently inundated by 51.5 percent of the time, which may cause the water in the spring run and marsh to be backwashed into the pool area (ECT, 2012). Stewart (2015) further verified that the Gemini Springs Run stages are dominated by Lake Monroe hydrology and Lake Monroe stage has significant effects on the spring run and the pool. Recently, a probability plot (Appendix C) based on recent 20-year SJRWMD hydrologic stage data at downstream of the weir also shows that around 48.0 percent of the time the weir could be inundated by downstream backwater. Appendix D, which illustrates the 20-year SJRWMD hydrodynamic stage probability in the pool, was adopted to show the water surface elevation difference between the pool and downstream of the weir.

2.2. Hydrology

Discharge at Gemini Springs was measured at random intervals by the U.S. Geological Survey (USGS) from 1966 to 1999 (SJRWMD, 2016). Discharge was measured seasonally by SJRWMD from 1996 to 2010 and then was measured daily since October 2010 (SJRWMD, 2016). The maximum measured discharge of 15.3 cfs occurred in November 2005, and the minimum discharge of 6.2 cfs occurred in June 1995 (SJRWMD, 2016). The mean and median discharges of the period from 1966 to 2010 are 10.15 cfs and 10.15 cfs, respectively (Table 2.2, SJRWMD, 2016).

The current flow measurements are made quarterly by SJRWMD at the downstream end of the dam (USGS, 2012). Total flow at the dam ranged from about 7.5 cfs during the drought of 2001 to about 13 cfs during the summer of 1996, which was a wet period (USGS, 2012). Individual measurements were made at each vent and at the dam to determine if additional springs were discharged into the Gemini Springs pool (USGS, 2012). On February 10, 2014, measured flow from the North Vent was 6.74 cfs and from the South Vent, 3.52 cfs. Flow at the dam was 10.2 cfs (USGS, 2012). On August 19, 2004, flow from the North Vent was 6.74 cfs and from the South Vent, 3.05 cfs. Flow at the dam was 10.1 cfs (USGS, 2012). The fact that flow at the dam is about equal to the total flow from both vents indicates that it is unlikely that other springs or Seeps are contributing flow to the pool (USGS, 2012). Flow measurements at the dam were 11.6 cfs on August 24, 2004, and 11.8 cfs on December 1, 2004. The mean daily flow at the weir for February 10, 2016 was 9.34 cfs and the measurement made under the bridge downstream of the North Vent was 5.94cfs on the same day. Therefore, approximately 65% of the total Gemini Springs discharge is from North Vent and the rest 35% from the South Vent, was assumed for the Gemini Springs pool modeling study.

2.3. Water Quality

Gemini Springs was sampled by USGS four times from 1972 to 1999. The district sampled Gemini Springs from 1986 to 2010 and currently samples the spring four times per year. Summary statistics of the water quality data for selected variables are shown in Table 2.2.

Table 2.2. Summary Statistics of Water Quality and Discharge at Gemini Springs (SJRWMD, 2016)

Gemini Springs	Min	Mean	Median	Max	Count	Period
Discharge, cfs	6.20	10.15	10.15	15.3	96	1966–2010
Alkalinity, total, mg/L as $CaCO_3$	125.0	137.8	138.3	158.0	55	1972–2010
Calcium, total, mg/L as Ca	86.0	100.1	100.8	110.0	54	1995–2010
Chloride, total, mg/L as Cl	525.0	622.4	621.5	760.0	56	1972–2010
Fluoride, total, mg/L as F	0.08	0.12	0.12	0.14	28	1995–2003
Magnesium, total, mg/L as Mg	31.0	38.0	38.0	46.0	53	1995–2010
Nitrate + nitrite, total, mg/L as N	0.50	1.04	0.98	2.20	55	1995–2010
Orthophosphate, total, mg/L as P	0.02	0.06	0.06	0.12	53	1995–2010
pH, field	6.67	7.37	7.39	8.46	55	1972–2010
Phosphorus, total, mg/L as P	0.06	0.08	0.08	0.13	29	1996–2010
Potassium, total, mg/L as K	6.8	8.1	8.1	9.4	53	1995–2010
Sodium, total, mg/L as Na	264.9	322.8	323.6	380.0	53	1995–2010
Specific conductance, field, µmhos/cm at 25°C	1650	2322	2374	2809	52	1995–2010
Specific conductance, lab, µmhos/cm at 25°C	1880	2272	2300	2540	32	1972–2010
Sulfate, total, mg/L as SO_4	85.0	116.6	118.0	141.0	58	1972–2010
Total dissolved solids, mg/L	1240	1408	1400	1900	54	1993–2010
Water temperature, °C	21.5	23.1	22.9	25.4	58	1972–2010

Units: µmhos/cm = micromhos per centimeter
mg/L = milligrams per liter
cfs = cubic feet per second

Water quality data have also been collected at the dam at Gemini Springs by SJRWMD since 1995 (USGS, 2012). During USGS's 2004 study, samples were collected from both spring vents and at the dam and the result shows that the water quality at both vents and at the dam was similar, except that dissolved oxygen (DO) was higher at the dam (USGS, 2012).

2.4. Gemini Springs Pool Transport Time

Water transport time scales measure how a water system responds to the introduction of dissolved and suspended materials, and how fast water masses are replaced within the system, and the basic time scales are commonly defined: flushing time, water age, residence time, and transit time (Li, 2010). Based on the ratio of the Gemini Spring pool average volume (V) to average outfall discharge (Q), the pool daily average residence time (T_r) can be simply calculated by

$$T_r = \frac{V}{Q} \qquad (2.1)$$

and has a typical range from 8 to 10 hours. Residence time and water age are commonly estimated to support water resources management. Both of them are local measures (i.e., spatially variable within the domain) (Monsen *et al.*, 2002), but provide different measures to estimate transport scales in aquatic environments (Shen *et al.*, 2011). Selection of the more appropriate transport time scale depends on the guiding question (Monsen *et al.*, 2002). Residence time is how long a parcel, starting from a specified location within a given area, will reach the outlet or exit the area. Water age, T_a, the complement to residence time, is the time required for a parcel to travel from a boundary to a specified location within the area (Li *et al.*, 2010). Water age is a water parcel specific quantity and is time dependent and spatially varying within a system (Li, 2010). By assuming that the water parcel moves from the boundary or entrance to exit following the path in Fig. 2.5 (Left), the same water parcel has a shorter age at locations near the entrance than those near the exit (Li, 2010). If two water parcels enter a system at the same time and move to Location A at the same speed following Path P1 and P2 respectively, as shown in Fig. 2.5 (Right), the water parcels have different ages in arriving at the same location A. Water age and residence time together measure the time interval that a water parcel travels from the entrance to the exit of the domain (Li, 2010). This transport time scale is the transit time, T_t, and $T_t = T_a + T_r$.

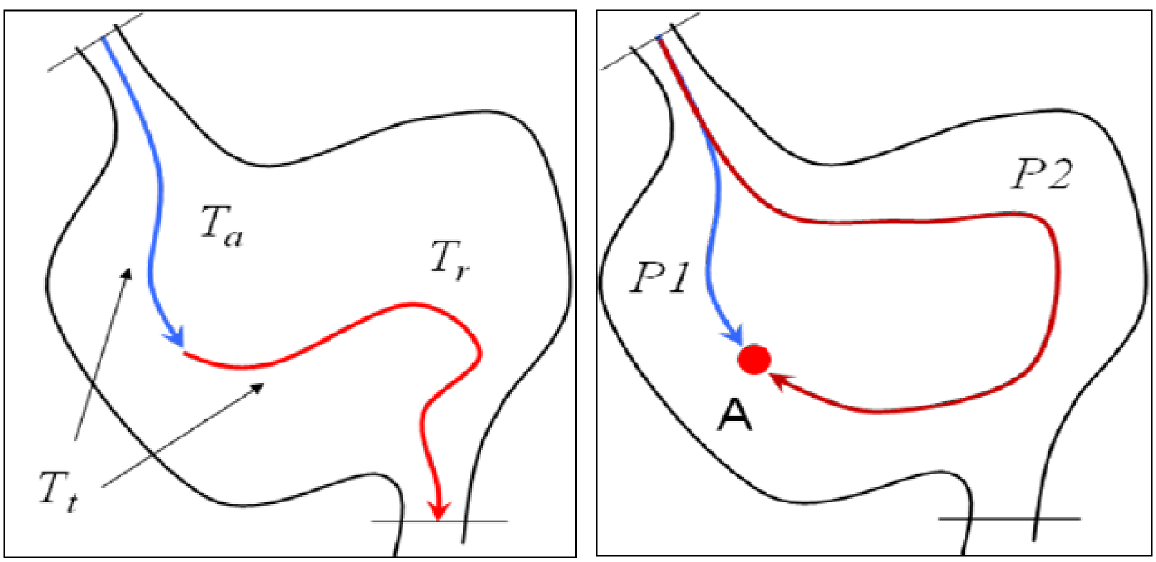

Figure 2.5. Water Age (Left: Water Age (T_a), Residence Time (T_r), and Transit Time (T_t) of a Water Parcel; Right: Two water parcels move from the entrance of the domain to Location A through Path P1 and Path P2, respectively) (Li, 2010)

Water age can be used as a reasonable indicator of the hydrodynamic processes and water quality issues. In view of the complex problem of investigating the internal hydrodynamic processes of Gemini Springs pool under these reductions, the concept of water age was investigated, in addition to average pool residence time. The water age varies with time and space deending on the variations of the dynamic conditions (e.g., wind-induced circulation and mixing, rainfall and evaporation, inflow discharge, outflow control) during the modeling period. According to previous Gemini Springs MFLs study, the pool pollution source was uncertain. The MFLs group is interested in knowing the elapsed time of a substance since it entered the system from multiple boundary locations under certain MFLs springs discharge reductions.

3. MODEL SETUP

An Environmental Fluid Dynamic Code (EFDC) Hydrodynamic model was setup to implement this modeling task for MFLs study. Table 3.1 shows the detailed steps to develop the model starting from the model setup as discussed in this Section. Model calibration, validation, and MFLs EFDC simulation will be described in the next a few Sections.

Table 3.1. Model Setup and Implementation Steps

MFLs EFDC Model	Model Implement	Model Parameter or Input	Model Run Period	Description
Model Setup	Grid Generation	Model Domain; Bathymetry		Gemini Springs Pool Mainly
	Model Input	Boundary Conditions; Initial Conditions	June, 1995 - December, 2014	20-year Model Input
Model Calibration	Model Calibration	Water Surface Elevation; Salinity	August, 2009 - December, 2010	High Springs Discharge Period
Model Validation	Model Validation	Water Surface Elevation; Salinity	March, 2012 - October, 2013	Low Spings Discharge Period
MFLs EFDC Modeling	MFLs Baseline Condition	Water Surface Elevation; Salinity; Water Age	SJRWMD MFLs Group Determined	Baseline Period and Springs Discharge (6 Cases)
	MFLs Scenario 1	Water Surface Elevation; Salinity; Water Age	Same as Above	5% Springs Discharge Reduction Only (6 Cases)
	MFLs Scenario 2	Water Surface Elevation; Salinity; Water Age	Same as Above	10% Springs Discharge Reduction Only (6 Cases)
	MFLs Scenario 3	Water Surface Elevation; Salinity; Water Age	Same as Above	15% Springs Discharge Reduction Only (6 Cases)

Determined by the MFLs group, temperature simulation was not considered. As mentioned earlier, salinity and temperature of springs discharge are very stable, and the pool is shallow and small, so vertical stratification is negligible in the hydrodynamic simulation. According to the discussion earlier in Section 2, vertical variation looks much less significant comparing with horizontal changes in the pool. Consequently, a vertical-averaged EFDC hydrodynamic model was recommended to focus on horizontal variations as well as to raise model implementation (Table 3.1) efficiency. Moreover, the drying and wetting option was activated to adapt to the decline and fluctuation of water levels.

3.1. EFDC Model Description

Environmental Fluid Dynamic Code (EFDC) is a public domain, open source, surface water quality modeling system, which includes hydrodynamic, sediment and contaminant, and water quality modules fully integrated in a single source code implementation (Tetra Tech, Inc., 2007a). EFDC originally developed at the Virginia Institute of Marine Science (VIMS) and School of Marine Science of The College of William and Mary, by Dr. John M. Hamrick beginning in 1988 (Tetra Tech, Inc., 2007a).

The physics of EFDC and many aspects of the computational scheme are equivalent to the widely used Princeton Ocean Model (POM) (Blumberg and Mellor, 1987) and U.S. Army Corps of Engineers' Chesapeake Bay model (Johnson *et al.*, 1993). However, EFDC has more features, such as wetting/drying in shallow areas. The EFDC model uses both standard sigma and generalized vertical coordinate (GVC). Horizontally, EFDC employs Cartesian or curvilinear and orthogonal horizontal coordinates. The numerical scheme employed in EFDC to solve the equations of motion uses second order accurate spatial finite differencing on a staggered or C grid (Tetra Tech, Inc., 2007a). In addition to two-time level integration option, the model's time integration employs a second order accurate three-time level, finite difference scheme with an internal-external mode splitting procedure to separate the internal shear or baroclinic mode from the external or barotropic mode (Ji *et al.*, 2002; Tetra Tech, Inc., 2007a). The turbulence closure scheme, Mellor-Yamada level 2.5, relates the vertical turbulent viscosity and diffusivity to the turbulent intensity, turbulent length scale and Richardson number (Luo and Li, 2009).

EFDC is capable of simulating cohesive and noncohesive sediment transport, near field and far field discharge dilution from multiple sources, eutrophication processes, the transport and fate of toxic contaminants in water and sediment phases, and the transport and fate of various life stages of finfish and shellfish (Liu and Huang, 2009). Specifically, EFDC model is capable of simulating the transport and fate of multiple size classes of cohesive and noncohesive sediment, (Liu and Huang, 2009), including sediment boundary layers, sediment bed mass conservation and geomechanics, bedload transport of noncohesive sediment, sediment settling, deposition and resuspension, contaminant fate and transport.

With fewer applications, EFDC water quality model is based on water quality kinetic from the Chesapeake Bay Water Quality model. The water quality model can be executed simultaneously with the hydrodynamic component of EFDC, or EFDC simulated hydrodynamic transport fields can be saved, allowing the EFDC code to be executed in a water quality only simulation mode (Luo and Li, 2009).

3.2. Model Grid

A vertical-averaged two-dimensional, orthogonal-curvilinear grid as described in Fig. 3.1 was generated for Gemini Springs pool and the adjacent area downstream of the weir using Tetra Tech's Visual EFDC (VEFDC 1.2) Grid Generator. Specifically, the domain includes the two spring vents, the swimming area, the old spring run, the weir downstream of the swimming area, and the adjacent spring run area right downstream of the weir. The model consists of 504 water cells in total. The available bathymetry data includes a 2-foot contours within springs pool, bottom elevation at creeks from two spring vents and transects at the weir, all provided by SJRWMD. These data were used to generate 504 model water cells using reverse distance interpolation technique (Fig. 3.1).

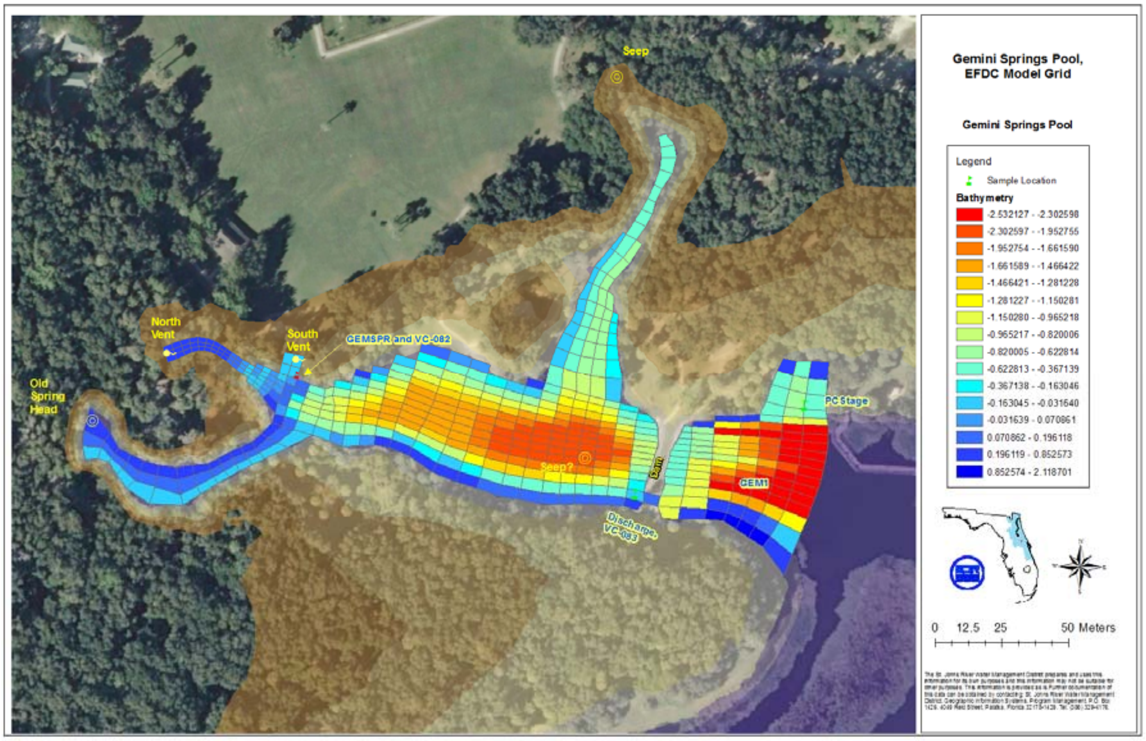

Figure 3.1. Gemini Springs Pool Model Grid

3.3. Boundary and Initial Conditions

To develop the hydrodynamic model, the Gemini Springs discharge and salinity, stage and salinity data of Gemini Springs pool and Padgett Creek near the pool were collected and compiled for model input. The detailed data collection information is described in Table 3.2. The data were obtained from various agencies, such as SJRWMD, Florida Department of Environmental Protection (FDEP), United States Geological Survey (USGS), Volusia County.

Table 3.2. Data Collection

Station	Parameter	Data Collection Site	Data Source	Latitude	Longitude
00410494	Gemini Springs Discharge, Pool Stage	Gemini Springs Pool	SJRWMD	28°51’45.98”N	81°18’46.06”W
VC-082	Salinity	Gemini Springs	FDEP	28°51’46”N	81°18’41”W
GEMSPRING1AND2	Salinity	Gemini Springs	SJRWMD		
Gemini Springs	Salinity	Gemini Springs	FDEP	28°51’45.98”N	81°18’46.06”W
VC-GEMSO	Salinity	Gemini Springs Pool	FDEP	28°51’45.03”N	81°18’39.57”W
GE01	Salinity	Gemini Springs	Volusia County	28°51’46”N	81°18’41”W
VC-083	Salinity	Gemini Springs Pool Outfall	FDEP	28°51’44.4239”N	81°18’34.74”W
GE02	Salinity	Gemini Springs Pool Outfall	Volusia County	28°51’44.4239”N	81°18’34.74”W
03710493 (PCstage)	Stage	Padgett Creek, Downstream of Pool	SJRWMD	28°51’45.64”N	81°18’32.5”W
GEM1	Salinity	GEMTR1CNT, Downstream of Pool	SJRWMD		
US 17-92	Stage	USGS 02234500 ST. JOHNS RIVER NEAR SANFORD, FL	USGS, SJRWMD	28°50’16”N	81°19’28”W

Based on the available data, inflow boundary conditions (North/South Vents inflows), runoff input, downstream open boundary conditions, meteorological conditions (atmospheric and wind), Rainfall (Figure 3.2) and initial conditions were obtained and incorporated into the model accordingly.

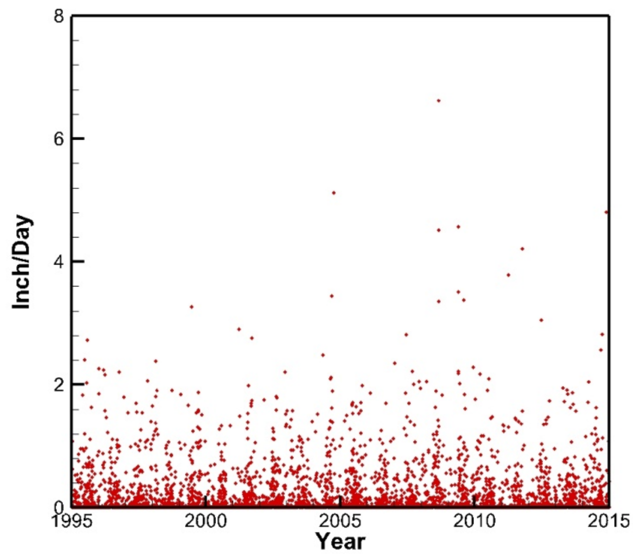

Figure 3.2. Gemini Springs Rainfall Data.

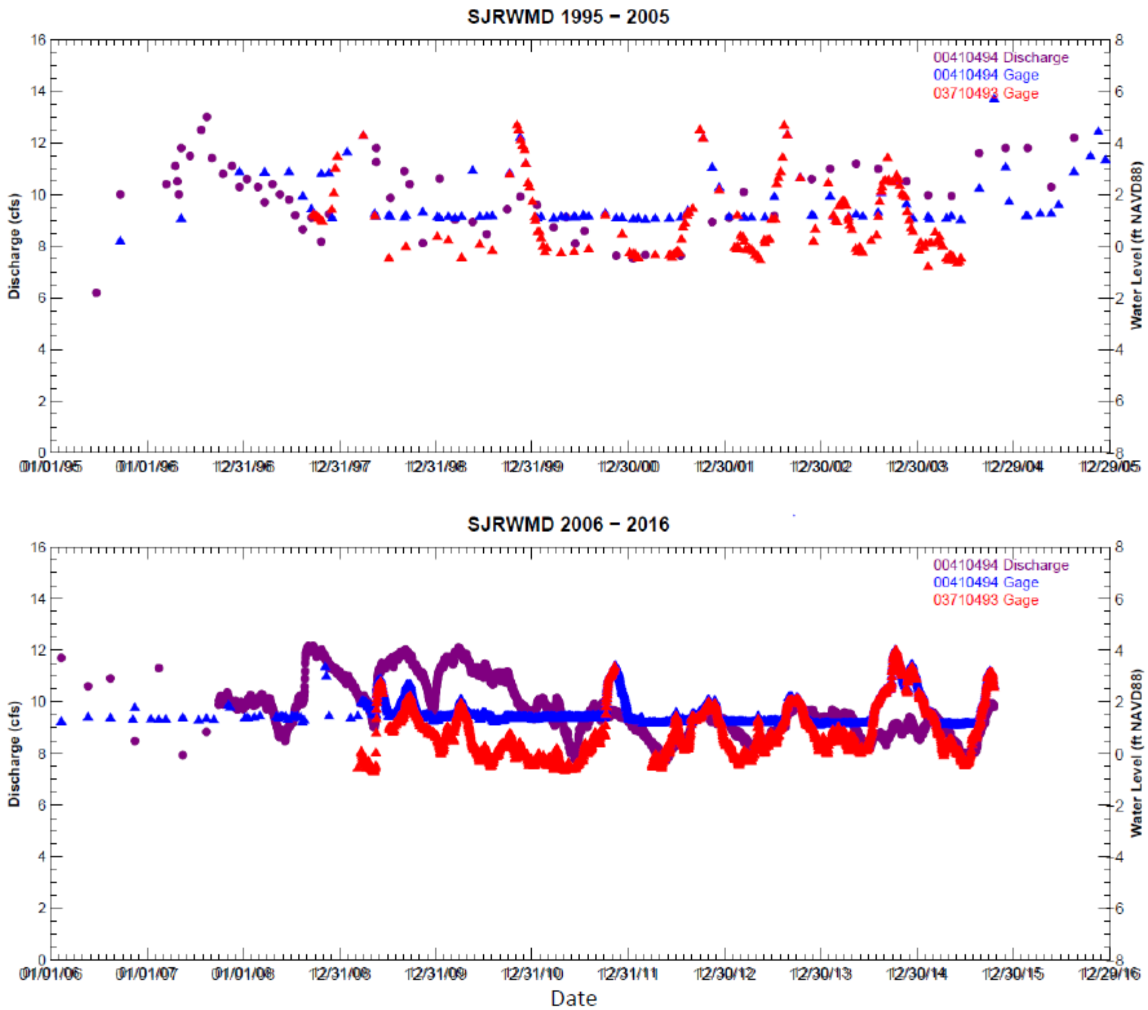

Figure 3.3. Gemini Springs Discharge and Gage Data

The 20-year Gemini Springs discharge, pool station 00410494 and the downstream station 03710493 (PCstage) time series stages from SJRWMD are displayed in Figure 3.3. In addition to the observed discharge measurements as discussed in Section 2, the Gemini Springs discharge data were fundamentally calculated based on the two ratings of nearby wells. The summary of the methodology is described in Appendix A and B. Rational method equation was used to approximately determine the time series peak overland runoff from Gemini Springs pool drainage area:

$$Q = CIA \tag{3.1}$$

Where Q, C, I, and A are the peak runoff (cfs), Rational method runoff coefficient (dimensionless), rainfall intensity (inch/hour) and drainage area (acre), respectively. The rational method runoff coefficient, C, was set to 0.20 in accordance with mostly forest and open space drainage area. The hourly time series rainfall intensity, I, was obtained using SJRWMD's Radar Rainfall Tool for ArcGIS 10.1.

The drainage area, A, was set to 35 acres (refer to Section 2). Regarding open boundary conditions, SJRWMD provides the daily water surface elevation since 2009 at the Padgett Creek (PC) Station, just outside the Gemini Springs pool (noted as PCstage). The existing daily measurement St. Johns River (SJR) at US 17-92 stage was compared with PC stage gage data to fill any open boundary stage data gap. Previous modeling studies (ECT, 2012; Stewart, 2015) realized and confirmed that Padgett Creek stages are dominated by Lake Monroe hydrology. The stage data indicates that during low water periods Padgett Creek behaves more like a tributary to Lake Monroe (Stewart, 2015). During high water periods and especially when water has started to inundate the marsh within the DeBary Bayou, Lake Monroe dominates stage (Stewart, 2015). Fig. 3.4 shows that Padgett Creek stage follows closely with the US 17-92 stage, and a regression relationship (Fig. 3.5, $r^2 > 0.90$) between PC stage and US 17-92 stages was then developed to extend the downstream open boundary water surface elevation to the whole model implementation period. Daily rainfall and evaporation data were obtained using SJRWMD's Radar Rainfall Tool and WHETS Tool 1.0 for ArcGIS 10.1, respectively. Wind hourly components (10 meters above the ground) were extracted from National Land Data Assimilation System (NLDAS) database using SJRWMD's "tsgettoolbox ldas" Unix Toolbox.

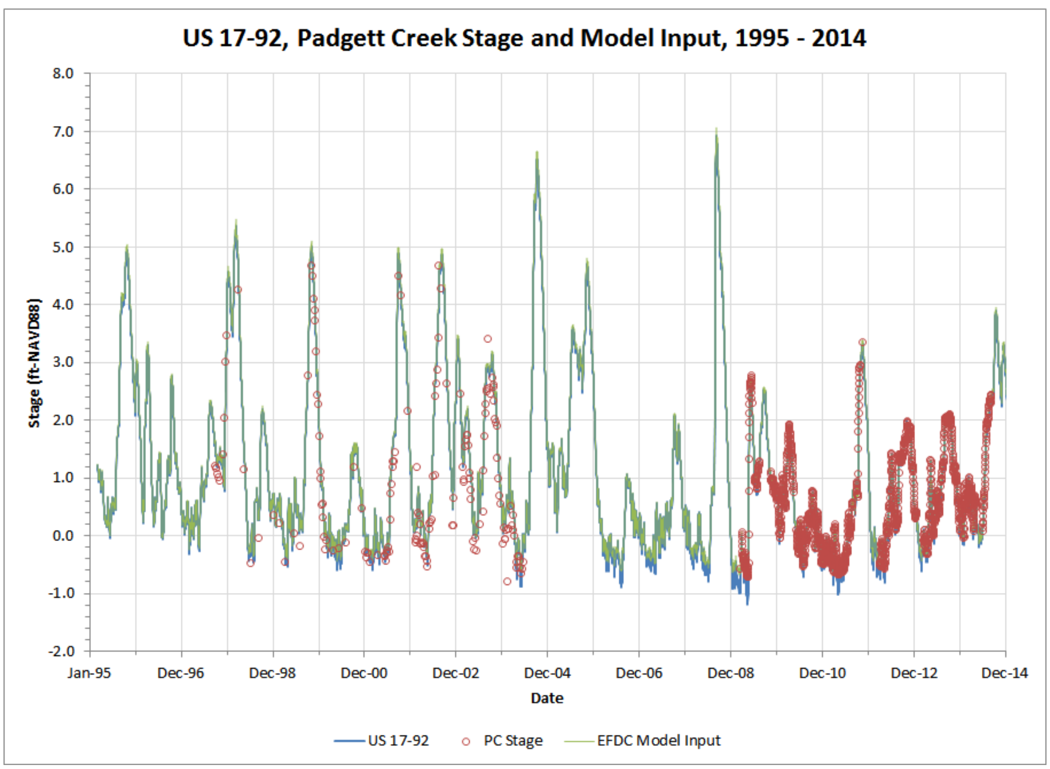

Figure 3.4. US 17-92, Padgett Creek Stages and Model Open Boundary Input

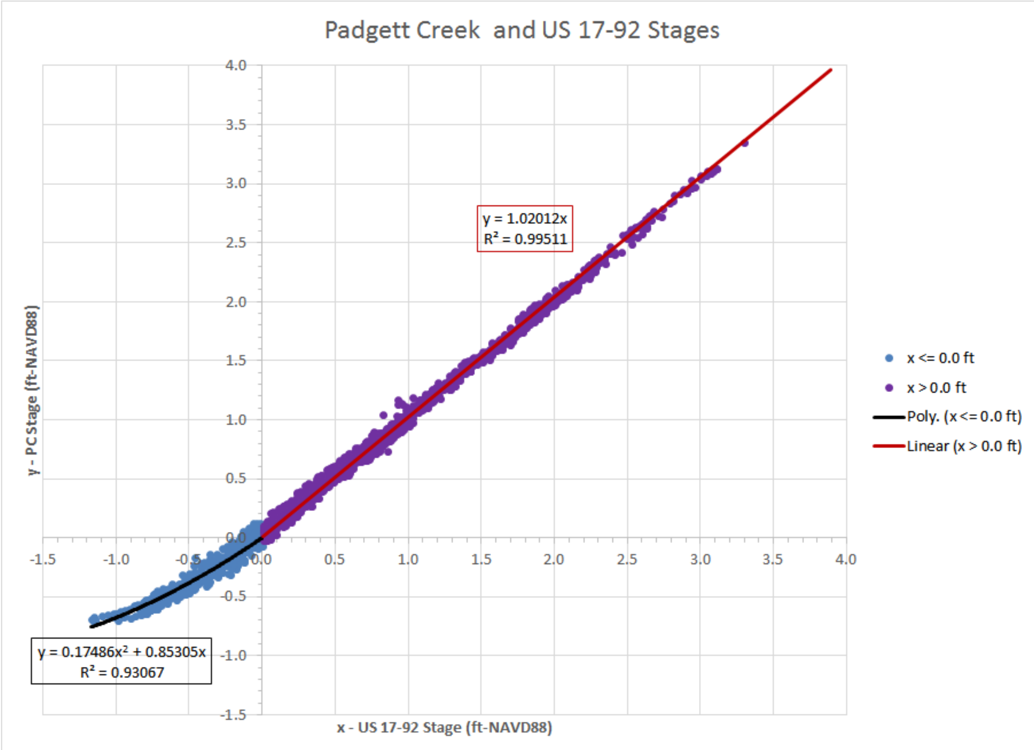

Figure 3.5. Correlationship between Padgett Creek and US 17-92 Stages

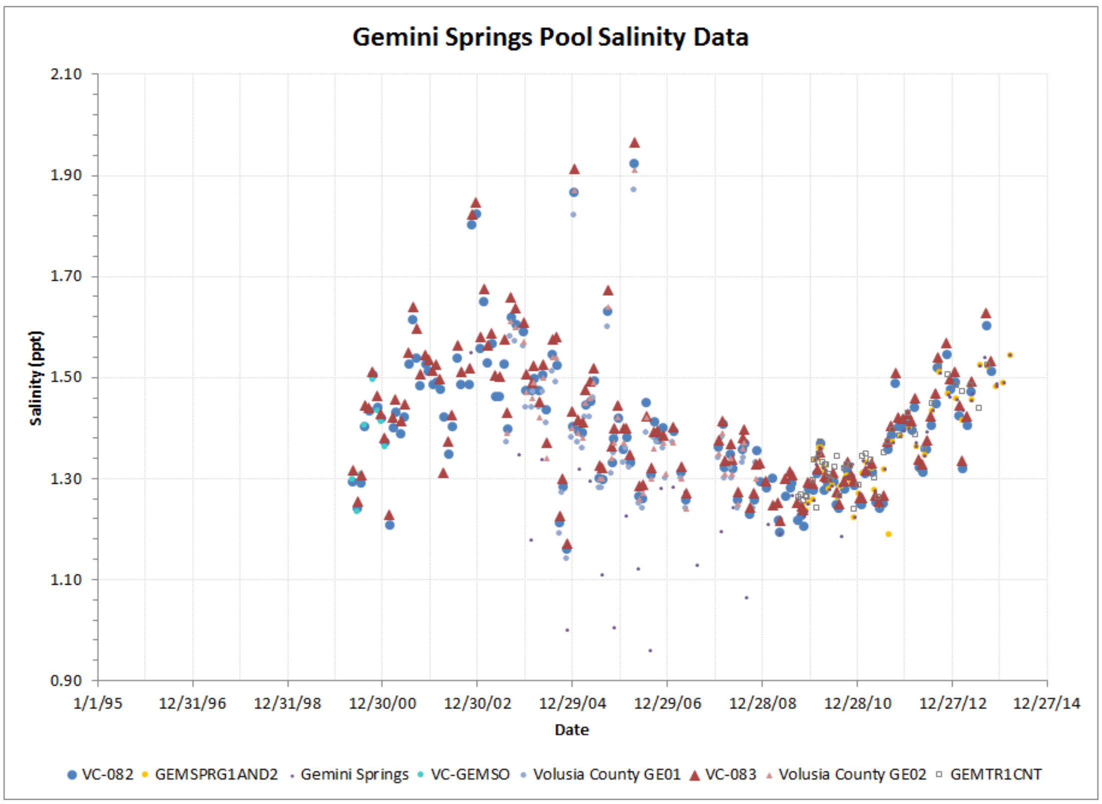

Figure 3.6. Salinity Data within Model Domain

Archived springs salinity data (Fig. 3.6) from a few sources were selected and compiled as the upstream inflow boundary conditions. The sampling frequency of all stations were one month or longer starting from year 1999. For model calibration and validation, monthly measurements at VC-082 were used as spring input. At downstream open boundary, station GEM1 was selected for its location. Since sampling frequency at the station was either one month or two months, linear interpolation was used to fill the data gap to generate monthly salinity boundary. For MFLs EFDC simulations, global average of stations within the pool were used as the long term salinity boundary from the vents and average of outfall stations were used as open boundary. Storm runoff salinity boundary was set to 0 ppt.

For initial conditions, water surface elevation was set to 3.3 ft and the salinity was set to 1 ppt for the entire domain.

4. MODEL CALIBRATION AND VALIDATION

The model was calibrated and validated using the observed pool stage at SJRWMD Hydrologic Station 00410494 and outfall salinity data at VC-83. Both the model calibration and validation were limited to a period with continuous Gemini Springs discharge (Station 00410494), open boundary stage (PCstage 03710493) and Gemini Springs pool stage (Station 00410494) measurements. SJRWMD daily Gemini Springs discharge data (based on the rating curve of a nearby well) at Station 00410494 was employed for both calibration and validation processes. Also, the bottom elevation of the shallow areas was adjusted to solve the numerical instability problem, reduce the computational cost and speed up the processes. Then it takes approximately 2.5 CPU hours per year of simulation on the given grid with a hydrodynamic time step of 2 seconds for the processes.

In this model calibration and validation processes, two distinct periods (a high and a low springs discharge periods) were selected to understand the pool hydrodynamics, evaluate and confirm the capabilities of the validated model for Gemini Spring Pool MFLs EFDC modeling. Based on the visual comparisons of simulated water surface elevation with the observed pool stage as described in the following Sections 4.1 and 4.2, a combination of statistical metrics (Table 4.1) were employed to quantify the errors and assess the model calibration and validation performances. The results suggested that simulations agreed well with the measurements.

Table 4.1. Comparison of Observed and Simulated Daily Pool Water Level over the Calibration and Validation Periods

Period	NRECS	R^2	MAE (ft)	MARE (%)	RMSE (ft)
Calibration	518	0.95	0.10	6.48	0.11
Validation	611	0.98	0.04	2.69	0.05
NRECS:	Number of paired values of simulated and observed water surface elevation				
R^2:	Coefficient of determination				
MAE:	Mean absolute error				
MARE:	Mean absolute relative error (%)				
RMSE:	Root-mean-square error				

4.1. Model Calibration

Based on period of record (POR), a 17-month calibration period was determined from August, 2009 to December, 2010, a high springs discharge period. The calibration process was subdivided into three steps due to the backwater impact and runoff uncertainty: 1) free flow period without considering overland runoff; 2) submerged flow period without runoff; 3) with estimated runoff.

The main calibrated parameters included horizontal eddy viscosities and diffusivities, bottom roughness height, broad weir discharge coefficient, and the wind sheltering coefficient. The most sensitive parameter, weir discharge coefficients, were adjusted in accordance with respective flow types and flow sections. The weir discharge coefficient was noted as the free flow weir discharge coefficient (C_f) when the outflow is totally upstream controlled, that is, the downstream water level is below the weir crest and has no effect on the flow from upstream pool at all. The free flow discharge above the weir equals:

$$Q_f = C_f \frac{2}{3}\sqrt{\frac{1}{3}}\sqrt{2g}H_1^{\frac{3}{2}}B \tag{4.1}$$

Where Q_f is the free flow discharge (m^3/s), g is the gravity acceleration (m/s^2), H_1 is the upstream height of water above the weir crest (m), B is the weir breadth (m), and C_f is the dimensionless free flow weir discharge coefficient. As the downstream water level is growing, above the crest, the weir is inundated by downstream water. When the submergence ratio is just high enough (≥ 0.80), the flow becomes submerged flow, which can then be split into two sections: 1) free portion discharge; and 2) submerged portion discharge, and each section was specified a weir discharge coefficient, C_{sf} and C_{ss}, respectively. The submerged weir discharge coefficient and formulation were incorporated and hardwired into EFDC code subroutine "*calqvs.for*". Specifically, the free portion discharge above the weir can be expressed as a function of upstream and downstream water height difference:

$$Q_{sf} = C_{sf} \frac{2}{3}\sqrt{\frac{1}{3}}\sqrt{2g}\left(H_1 - H_2\right)^{\frac{3}{2}} B \qquad (4.2)$$

Where Q_{sf} is the free portion discharge (m^3/s), H_2 is the downstream height of water above the weir crest (m), and C_{sf} is the dimensionless free portion weir discharge coefficient. The submerged portion discharge can be represented as:

$$Q_{ss} = C_{ss}\sqrt{\frac{1}{3}} H_2 \sqrt{2g\left(H_1 - H_2\right)} B \qquad (4.3)$$

Where Q_{ss} is the submerged portion discharge (m^3/s), and C_{ss} is the dimensionless submerged portion discharge coefficient. Therefore, the total submerged discharge equals:

$$Q_s = Q_{sf} + Q_{ss} \qquad (4.4)$$

Where Q_s is the total submerged discharge over the weir (m^3/s). The calibrated site specific weir coefficients, C_f, C_{sf}, and C_{ss}, usually ranging from 0.30 to 0.80, were set to 0.50. The bottom roughness height was set to 0.001 m. A uniform wind sheltering coefficient of 0.50 was employed to account for the pool wind-affected area or wind shear force reduction by tree canopy.

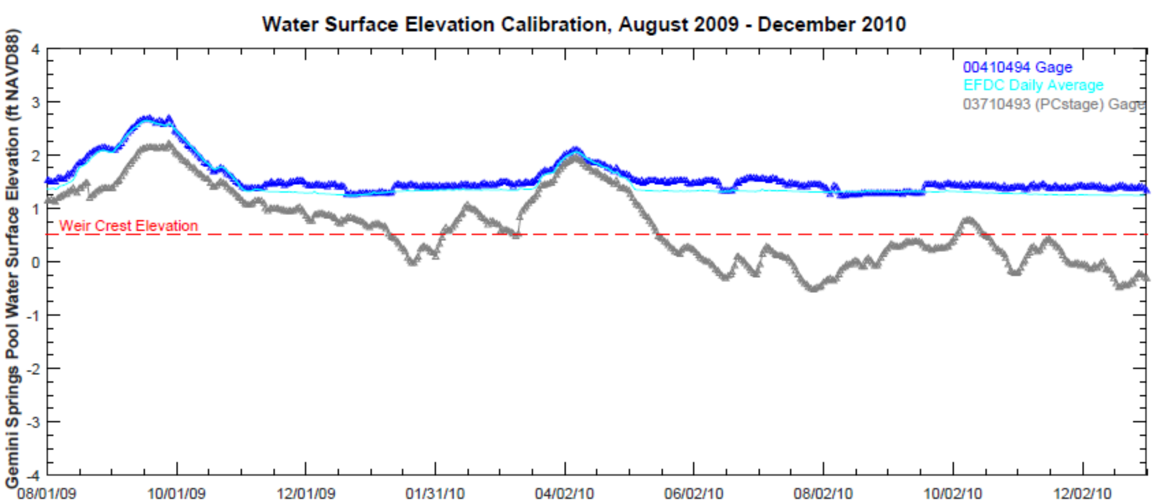

Figure 4.1. Water Surface Elevation Calibration Result

Fig. 4.1 shows the water surface elevation calibration result. Generally, the simulated result is reasonable and matches the data well. The simulated water level satisfactorily agrees the observed stage data at Station 00410494 in general trends. Taking a closer look at the water level comparison, we can find that the observed stage is slightly higher during free flow type period for some reason, and we believe a dynamic would result in a better fit instead of the given constant weir discharge coefficient. However, such prospective improvement is somewhat beyond our current understanding and could consequently exclude other unverified possibilities during this high springs discharge period. Furthermore, a subsequent model validation process during a different simulation period as described in Section 4.2 verified that excessive calibration is unnecessary and the current model calibration is acceptable. In addition, the simulated salinity has a good agreement with the observed data at the outfall (Fig. 4.2) which also indicated the success of model calibration.

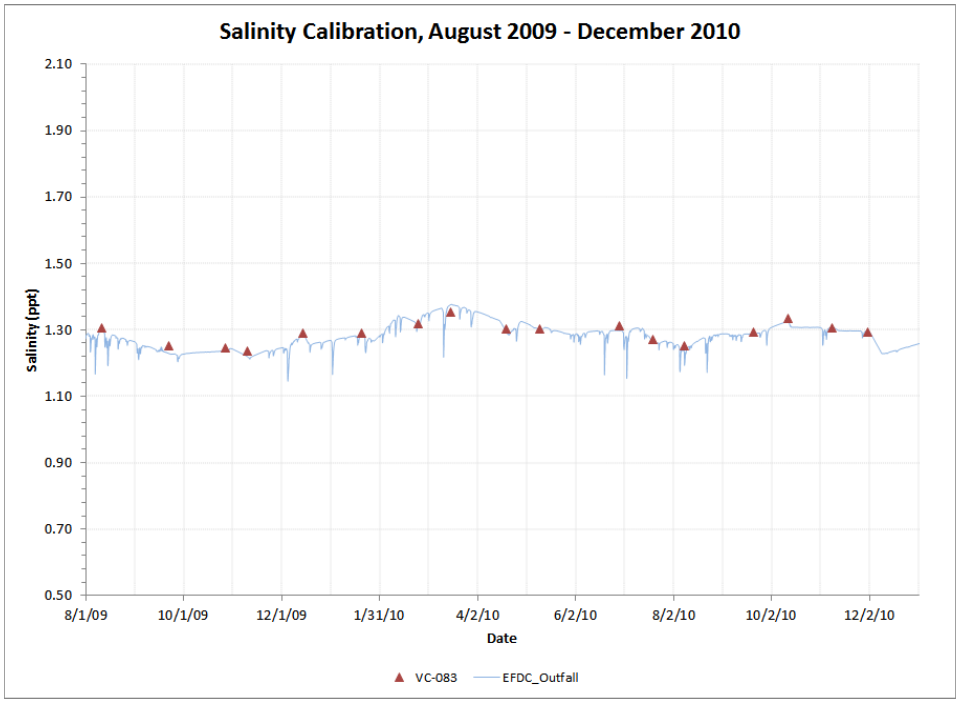

Figure 4.2. Salinity Calibration Result

4.2. Model Validation

After calibration, the model was validated with a different set of observed pool stage and outfall salinity data during a significantly different simulation period. Unlike the calibration period with a high springs discharge, a 20-month low springs discharge period, from March, 2012 to October, 2013, was selected for the model validation process.

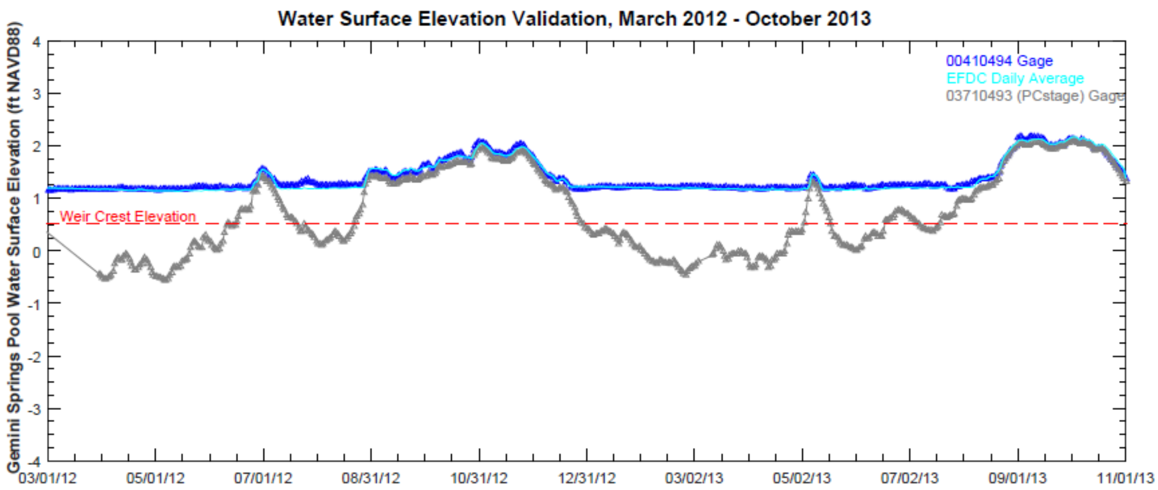

Figure 4.3. Water Surface Elevation Validation Result

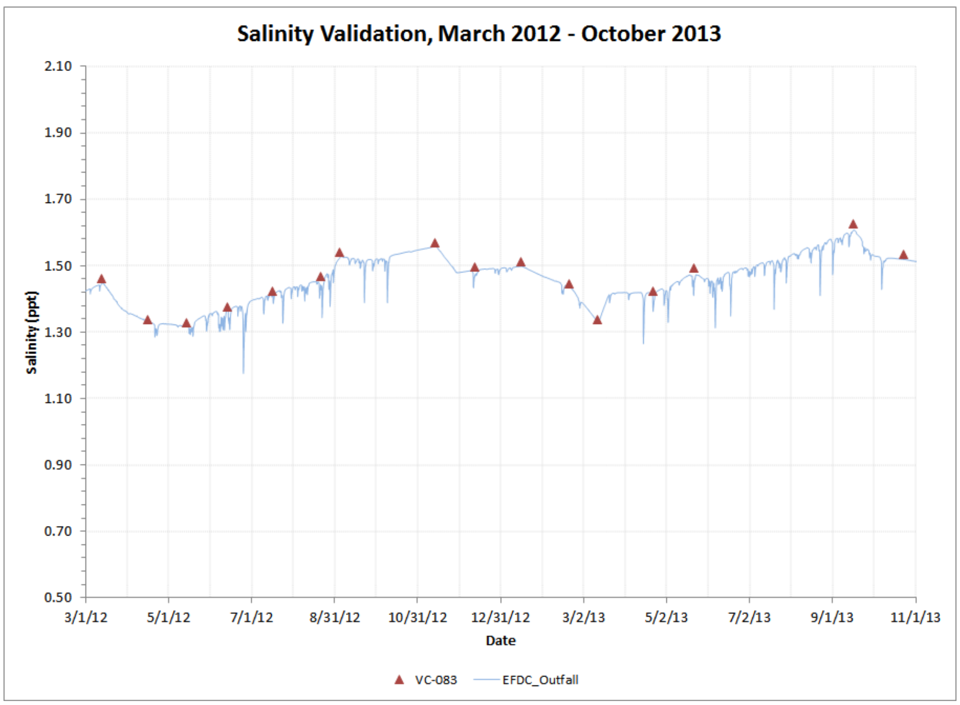

Figure 4.4. Salinity Validation Result

Figures 4.3 and 4.4 show the water surface elevation and salinity validation results, respectively. There were good agreements between the observed and simulated water surface elevations and salinities. Generally, the simulated result follows the observed data reasonably well. Therefore, the model was considered validated. To verify the dominant parameters ruling pool hydrodynamics, the validated model was subsequently used for a series of input sensitivity tests and the result indicates that wind, evaporation, rainfall and bathymetry have minor effect on the pool water surface elevation during calibration and validation periods. However, rainfall and runoff during episodic storm events definitely play an important role in pool salinity changes.

5. MFLs EFDC MODELING DESCRIPTIONS AND METHODS

The validated EFDC model sufficiently proved to be reliable for Gemini Springs pool MFLs simulations. Therefore, to assess the impact of possible springs discharge reduction on pool water surface elevation, salinity and water transport time, the modeling and MFLs groups worked together to design a few one-month EFDC steady state simulation cases as the Baseline Condition for reduction evaluation. The setup of the short-term simulation cases was based on the analysis of the springs discharge time series over the period of record (POR) and the outflow characteristics over the weir.

The mean, 90th percentile high, and 10th percentile low springs discharges were selected for the modeling cases, which are representatives of mean, wet and dry hydrologic conditions, respectively. Here is some quick Gemini Springs discharge information for the case design based on recent 20-year POR: the mean Gemini Springs discharge is 9.67 cfs (a little bit lower than the mean discharge reported for 1966-2010, 10.15 cfs, in Table 2.2); the 90th percentile discharge is 11.40 cfs and the 10th percentile discharge is around 8.40 cfs, based on the probability plot in Appendix E.

As stated in Section 2.1, it is around 50% percent of time that the weir was inundated by the downstream backwater driven by Lake Monroe in accordance with previous study (ECT, 2012) and the statistical analysis of POR at Padgett Creek station (PCstage or 03710493). The drown weir flow condition is never negligible. Therefore, the Baseline Condition for Gemini Springs MFLs modeling has to be separated into two groups of cases according to whether the weir is submerged or not: 1) free flow type: the downstream water surface elevation is below weir crest; and 2) submerged flow: the weir is inundated by the backwater coming from downstream open boundary.

Table 5.1. Baseline Free Flow and Submerged Flow Cases

Free Flow Cases	1-month Period	Dischage (cfs)	Open Boundary Stage (ft NAVD88)
1. Average Discharge Case	20-year average	9.67	0.00
2. High Discharge Case	20-year average	11.40	0.00
3. Low Discharge Case	20-year average	8.40	0.00
Submerged Flow Cases	**Steady State Boundary**	**Dischage (cfs)**	**Open Boundary Stage (ft NAVD88)**
4. Median Backwater Stage	20-year average	9.67	1.38
5. High Backwater Stage	20-year average	9.67	2.90
6. Low Backwater Stage	20-year average	9.67	0.66

Subsequently, a steady state condition was setup for each free flow dynamic case in the free flow group. The only difference among these three cases (Case 1-3, Table 5.1) is the constant springs discharge: 1) mean springs discharge; 2) 90th percentile high discharge; and 3) 10th percentile low discharge. During these three case periods, no backwater occurs or the flow is totally upstream controlled with a constant open boundary elevation of 0.00 ft-NAVD88, the median downstream water surface elevation based on the observed Stage data ≤ 0.51 ft-NAVD88 based on Appendix F or with about 20th percentile downstream water surface elevation based on Appendix C.

With a constant springs mean discharge of 9.67 cfs, another three Baseline steady state cases are all regarding to submerged flow type. The median, 90th percentile high, and 10th percentile low backwater surface elevations were selected from the POR at PCstage (with water level higher than weir crest) for the three submerged cases, which are representative of mean, high and low downstream hydrologic conditions. The sole difference among these three submerged cases (Case 4-6, Table 5.1) is the constant open boundary stage in accordance with Appendix C an G: 1) median downstream water surface elevation based on the observed Stage data > 0.51 ft-NAVD88 (or with about 70th percentile downstream water level); 2) 90th percentile downstream high water level based on the observed Stage data > 0.51 ft, that is, 95th percentile downstream high water level; and 3) 10th percentile low water level based on the observed Stage data > 0.51 ft, or 50th percentile downstream water level.

The above shows that the Baseline Condition has two groups and each group has three cases, totally six cases. Regarding springs discharge Reduction Scenarios (Scenario 1-3), as the MFLs group determined, a percentage of 5%, 10%, and 15% springs discharges reduction was applied to each Baseline case to evaluate the impact of the discharge changes, respectively. All other model boundary conditions remained the same for both Baseline Condition and Reduction Scenarios. Table 5.2 gives the representative springs discharge values for all cases from both Baseline Condition and the three Reduction Scenarios.

Table 5.2. Representation Springs Discharges for Baseline and Scenarios, in cfs

Free Flow Cases	Baseline	Scenario 1 (5%↓)	Scenario 2 (10%↓)	Scenario 3 (15%↓)
1. Average Discharge Case	9.67	9.19	8.70	8.22
2. High Discharge Case	11.40	10.83	10.26	9.69
3. Low Discharge Case	8.40	7.98	7.56	7.14
Submerged Flow Cases	**Baseline**	**Scenario 1 (5%↓)**	**Scenario 2 (10%↓)**	**Scenario 3 (15%↓)**
4. Median Backwater Stage	9.67	9.19	8.70	8.22
5. High Backwater Stage	9.67	9.19	8.70	8.22
6. Low Backwater Stage	9.67	9.19	8.70	8.22

As mentioned earlier in this report, this is the first hydrodynamic modeling attempt exclusively for Gemini Springs pool area. To enhance the overall understanding of the pool hydrodynamic system and support MFLs study, the modeling was expected to settle a variety of debates and obtain a general situation of the pool hydrodynamics and water quality. In this case, both water age and residence time in the pool are functions of springs discharge. Water age was considered as the main indicator of the transport timescale of conservative dissolved substances, and the pool average residence time was crudely calculated using Eq. (2.1) as the starting point to get an overview of the discharge reduction impact. Although the MFLs group proposed a few locations of their most concern, a water age distribution was generated to exhibit the spatial variation and identify possible environmentally susceptible areas.

Specifically, a passive conservative tracer was simulated to represent transport of a water parcel or dissolved substance. The model was initially run for one month of spin-up time without tracer releasing (or dye concentration of zero) for each case to warm up and obtain a dynamic equilibrium flow fields. Then, the water age calculations were hot started using the equilibrium flow fields as the initial condition. The incoming age tracer concentration was set to zero, that is, the water age was defined to be zero when it just exits the two spring vents and enters the system. The water ages of downstream open boundary and runoff input were also set to zero. In the model, the age of the water parcel within model domain is subject to a continuous increase over each simulation time step until it leaves the domain, and the mass weighted water age in a particular model cell is calculated based on the history of the water in that cell. In addition, hydrodynamic parameters, water surface elevation and salinity, were modeled simultaneously in each case for both Baseline and Reduction Scenarios.

6. MODELING RESULTS AND DISCUSSION

To address the complicated spatial water surface elevation difference in the Gemini Springs pool, the steady state water surface elevation, average pool residence time and water age distribution were obtained via extensive EFDC simulations. In addition to the whole Gemini Springs pool area (upstream of the dam/weir, area **a**), the MFLs group shows more interest in the following four areas or locations: the creeks from the two active vents (area **b**), south shore of the pool (area **c**), pool outfall (area **d**) and downstream of the weir (area **e**) as shown in Fig. 6.1. Therefore, averages were computed to quantify how springs discharge reduction affects water surface elevation, salinity and water age at these five areas based on the comparisons between Reduction Scenarios and Baseline Condition.

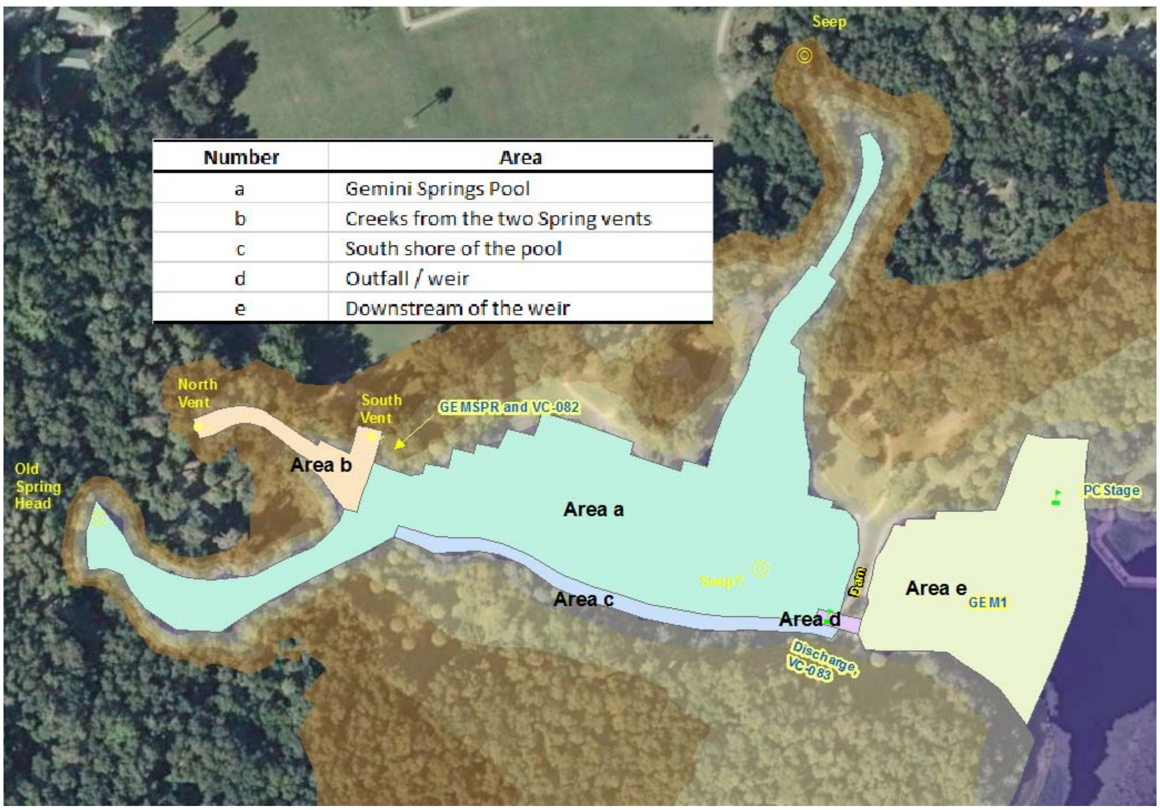

Figure 6.1. Five Modeling Investigation Areas

6.1. Water Surface Elevation

The water surface elevation in the pool normally exhibits a high spatial homogeneity (Fig. 6.2) except for the upper section (from the North Vent to north edge of the wood bridge) of the shallow creeks (area **b)** and the downstream of weir (area **e**). Moreover, the higher springs discharge, and the higher water level spatial homogeneity in the pool. Conveying the spring water from the North Vent to the pool and with a high bottom elevation, the upper steep section of area **b**, usually has a free gravity flow and less chance of being drown by the impounded pool water. Generally, the higher springs discharge, the higher pool water level has to be maintained to correspond the requested higher weir capacity, particularly according to free flow steady state simulation results in Table 6.1. The pool water level, which is not very sensitive to the discharge but definitely a function of the springs discharge, can be lifted to the wood bridge or even further all the way to the North Vent (in area **b**) under a medium or high backwater condition. Sometimes connecting with pool water and sometimes disconnecting, with unceasing flow from the pool, the downstream (area **e**) maintains its water level, which fluctuates in tune with the open boundary water level.

Certainly, the water level within the whole model domain is dominated by open boundary condition or Lake Monroe during high backwater period as described in Table 6.1 and Fig. 6.2. Otherwise, the EFDC simulation result (Table 6.1) clearly suggests a slight but consistent influence of springs discharge reductions on water surface elevation changes. The Baseline Condition has a little bit higher pool water level than the corresponding Reduction Scenarios, as springs discharge decreases every 5% until 15%, the water level drops accordingly with some regularity (0.01-0.03 ft) and the very shallow area is more likely to go dry. Such characteristic is more prominent under the circumstance that no backwater occurs (Table 6.1). For submerged weir flow cases (from Case 4 to 6), the springs discharge reductions have less influences on the water level changes (< 0.02 ft for each 5% reduction) than free flow cases. As the entire pool water level is gradually dominated by more vibrant backwater, the effect of springs discharge reduction on water level is put in secondary, and little change (< 0.01 ft) from Baseline to Reduction Scenarios in the pool area were perceived as described in Case 5 (Table 6.1), the whole domain tends to be spatially and temporally more uniform. To get a more comprehensive understanding of the discharge reduction’s impacts on water level, spatial distributions of calculated water surface elevation differences between each Reduction Scenario and Baseline were calculated in Figures 6.3, 6.4, and 6.5, respectively.

Table 6.1. Calculated Water Surface Elevation, in ft-NAVD88

Free Flow Cases	Area	Baseline	Scenario 1 (5%↓)	Scenario 2 (10%↓)	Scenario 3 (15%↓)
1. Average Discharge Case	a	1.26	1.23	1.21	1.18
	b	1.39	1.37	1.34	1.32
	c	1.24	1.22	1.19	1.17
	d	1.25	1.22	1.19	1.17
	e	0.01	0.01	0.01	0.01
2. High Discharge Case	a	1.34	1.31	1.28	1.26
	b	1.40	1.39	1.39	1.39
	c	1.33	1.30	1.27	1.25
	d	1.33	1.30	1.27	1.25
	e	0.01	0.01	0.01	0.01
3. Low Discharge Case	a	1.19	1.17	1.15	1.12
	b	1.33	1.31	1.29	1.27
	c	1.18	1.16	1.13	1.11
	d	1.18	1.16	1.13	1.11
	e	0.01	0.01	0.01	0.01
Submerged Flow Cases	**Area**	**Baseline**	**Scenario 1 (5%↓)**	**Scenario 2 (10%↓)**	**Scenario 3 (15%↓)**
4. Median Backwater Stage	a	1.57	1.55	1.54	1.52
	b	1.58	1.56	1.55	1.54
	c	1.56	1.55	1.53	1.52
	d	1.56	1.55	1.53	1.52
	e	1.38	1.38	1.38	1.38
5. High Backwater Stage	a	2.93	2.93	2.93	2.93
	b	2.93	2.93	2.93	2.93
	c	2.93	2.93	2.93	2.93
	d	2.93	2.93	2.93	2.93
	e	2.90	2.90	2.90	2.90
6. Low Backwater Stage	a	1.26	1.23	1.21	1.18
	b	1.39	1.37	1.34	1.32
	c	1.24	1.22	1.19	1.17
	d	1.25	1.22	1.19	1.17
	e	0.66	0.66	0.66	0.66

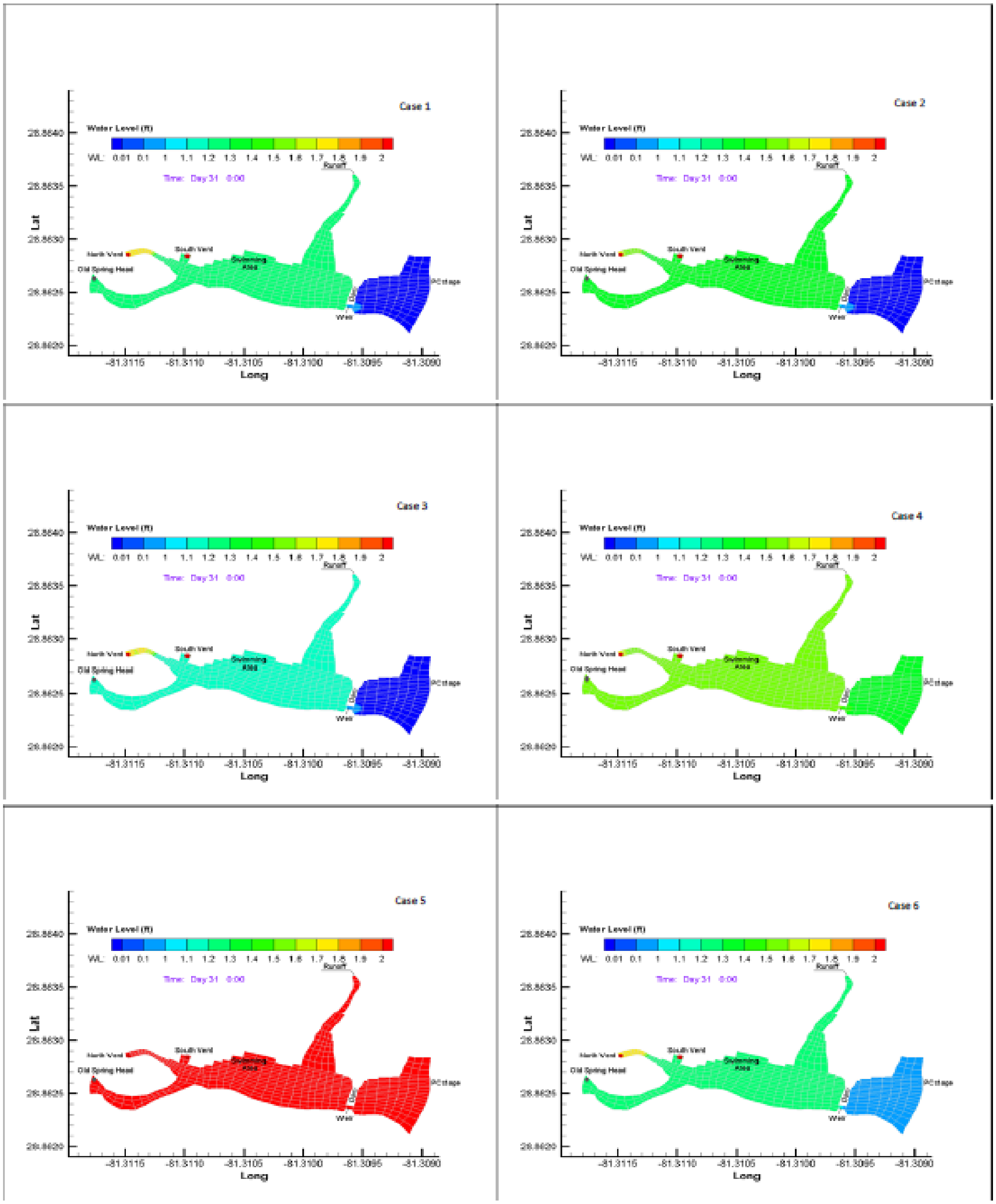

Figure 6.2. Water Surface Elevation Distribution, Baseline Cases, in ft-NAVD88

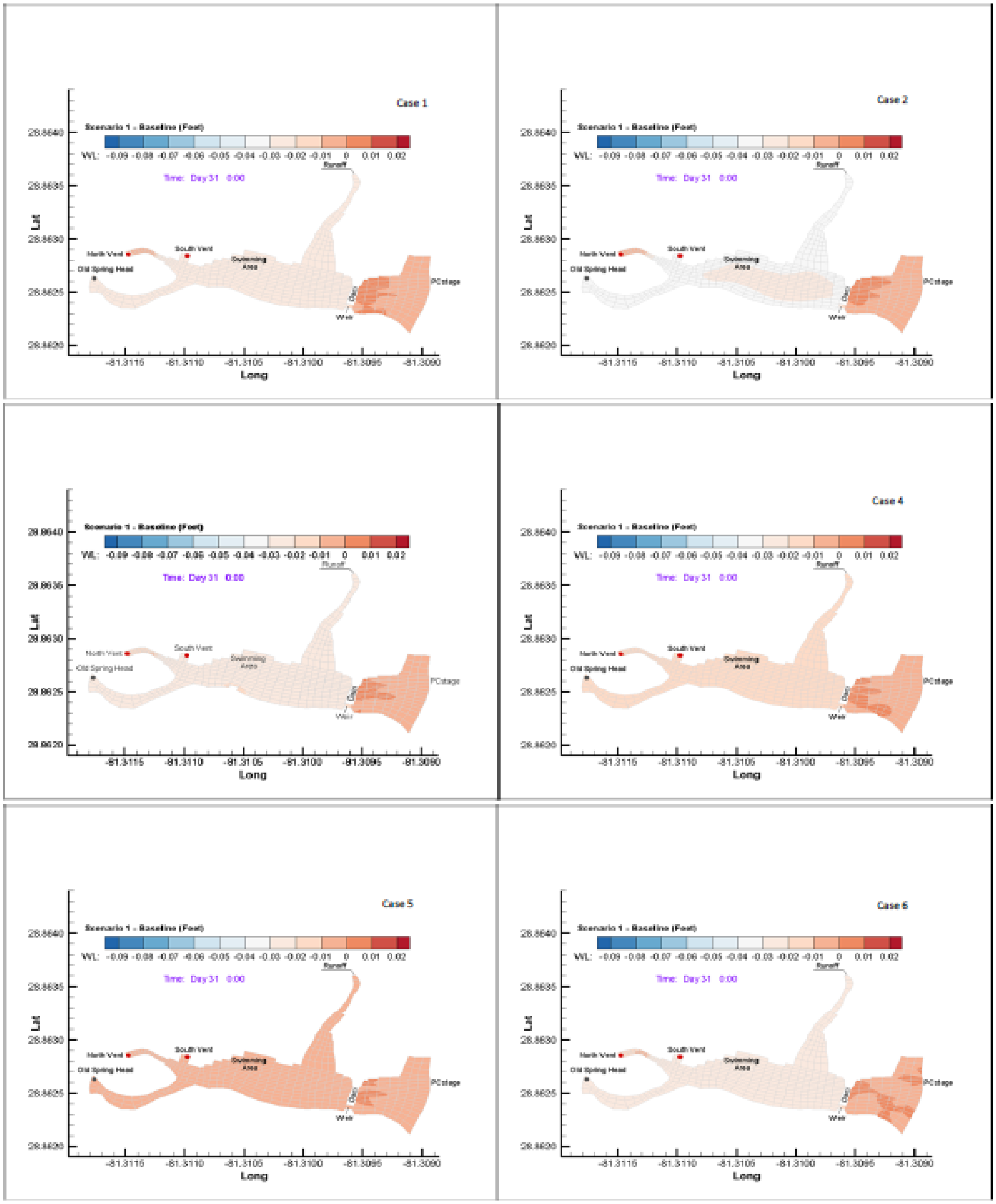

Figure 6.3. Water Surface Elevation Difference Distribution, Scenario 1 – Baseline, in feet

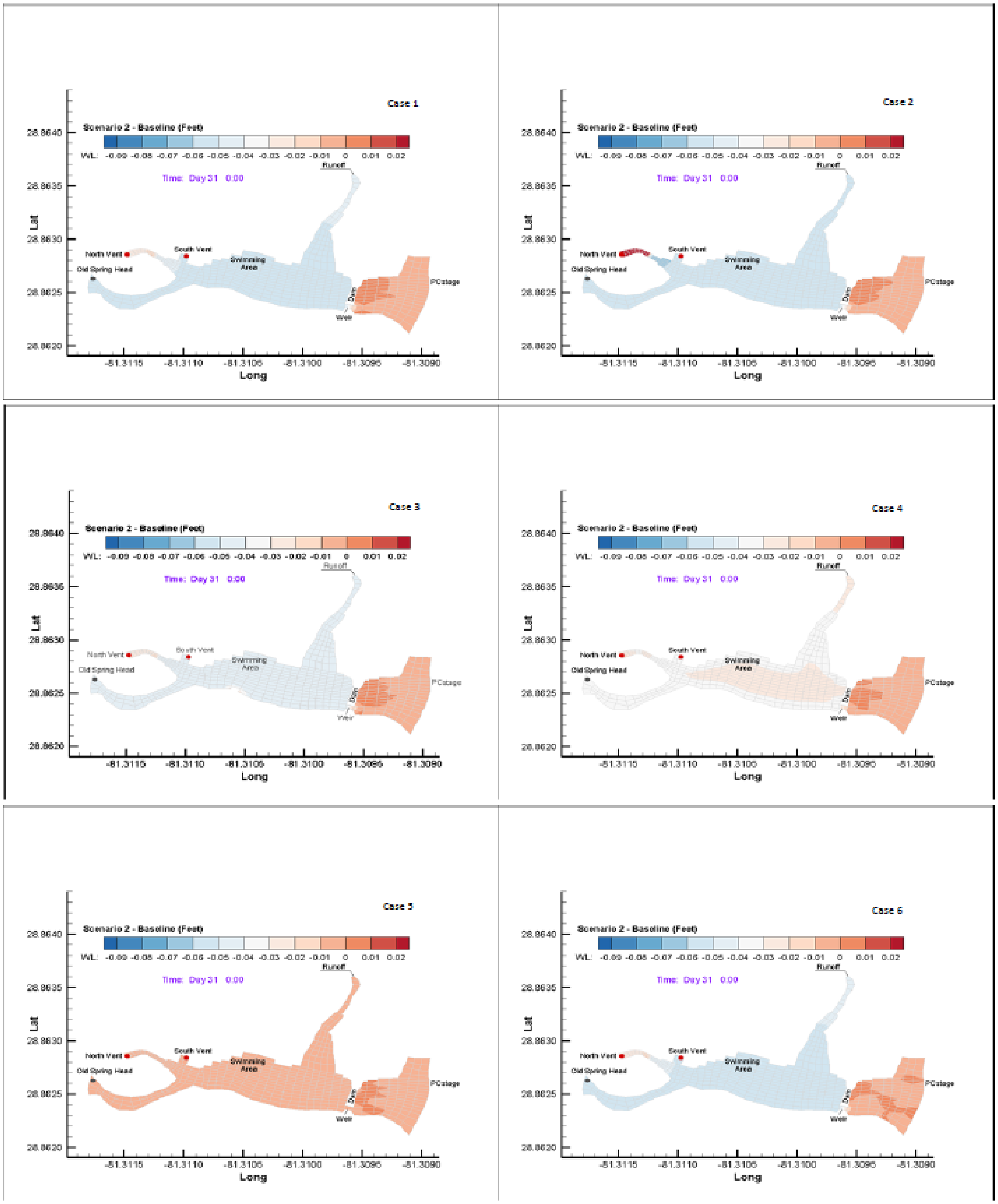

Figure 6.4. Water Surface Elevation Difference Distribution, Scenario 2 – Baseline, in feet

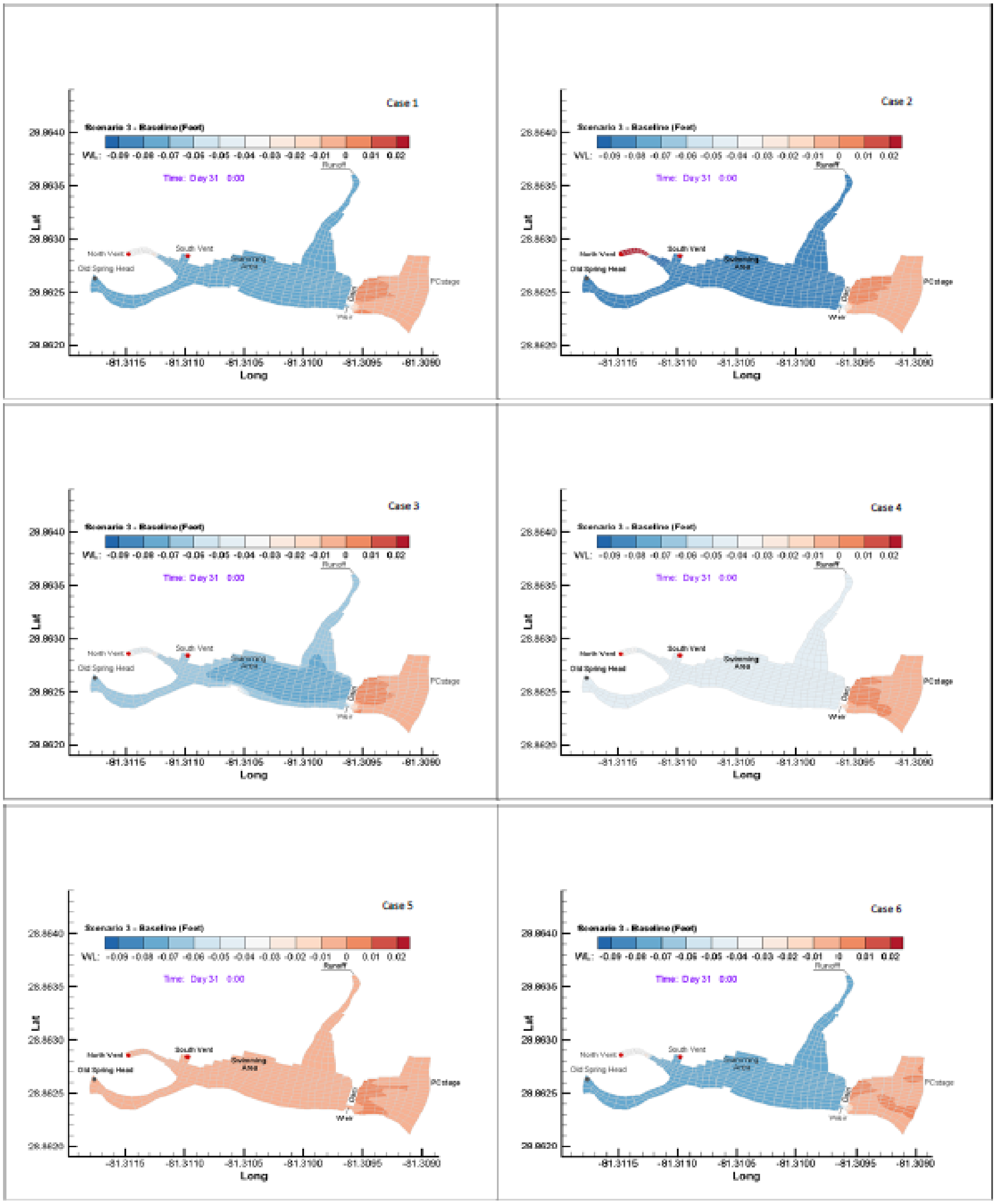

Figure 6.5. Water Surface Elevation Difference Distribution, Scenario 3 – Baseline, in feet

6.2. Salinity

The salinity in the pool (Fig. 6.6) exhibits an extremely high spatial and temporal homogeneity. The EFDC simulation results in Table 6.2 describe a series of nearly constant salinity values except for areas around overland runoff input and south shore (Fig. 6.6). Generally, as springs discharge decreases by 5%, 10% and 15%, slight lower pool salinity (< 0.01 ppt or < 1%) was shown in the Reduction Scenarios than the corresponding Baseline Condition, due to the relative increasing effect of overland freshwater runoff and rainfall with a salinity value of zero. Actually, the local salinity changes corresponding to the reduction are considerably affected by the residence time and pool circulation in the steady state simulations. The spatial salinity difference maps of Figures 6.7, 6.8, and 6.9 comprehensively illustrate a small positive or negative change in salinity. Lower springs discharge usually lengthens the time for spring water with a higher salinity to stay somewhere in the pool, and the salinity in that area could probably be decreased because of runoff or rainfall. However, in high discharge Case 2, the 10% and 15% discharge reductions apparently changed flow pattern slightly and increased mixing between springs water and fresh storm water. As the result, salinity concentration around the runoff input area was a little bit higher than base flow case. According to EFDC Case 3 simulations, as springs discharge reduces, several water cells, adjacent to the main flow path and with complex bathymetry in south shore discharge sensitive area (area **c**), are getting dry, which could be a factor that prevents the surrounding water cells from exchanging and mixing sufficiently with the actively moving flow. Therefore, rainfall turns into a dominant replenishment to the stagnant area within area **c** and the salinity decreases significantly (0.02 ppt or about 1.5% decrease from Scenario 2 to 3), which probably is the maximum salinity change. The simulation result clearly shows that discharge reduction has direct influence on low volume area **c**, which is more susceptible to discharge reduction. According to Figures 6.7, 6.8, and 6.9, the similar discharge sensitive areas are mostly located in south and north shore areas due to the specific bathymetry, relative shallowness and significant velocity gradient changes.

If backwater occurs (Table 6.2), the springs discharge reduction and all the other factors such as runoff and rainfall have minor effects on the salinity changes, and the pool water salinity makes insignificant changes from Baseline to Reduction Scenarios, due to copious backwater and great pool water volume, and the whole domain tends to be spatially and temporally more uniform.

Table 6.2. Calculated Salinity, in ppt

Free Flow Cases	Area	Baseline	Scenario 1 (5%↓)	Scenario 2 (10%↓)	Scenario 3 (15%↓)
1. Average Discharge Case	a	1.38	1.38	1.38	1.38
	b	1.39	1.39	1.39	1.39
	c	1.39	1.39	1.39	1.39
	d	1.39	1.39	1.39	1.39
	e	1.38	1.38	1.38	1.38
2. High Discharge Case	a	1.36	1.36	1.38	1.38
	b	1.39	1.39	1.38	1.39
	c	1.39	1.39	1.39	1.39
	d	1.39	1.39	1.39	1.39
	e	1.38	1.38	1.38	1.38
3. Low Discharge Case	a	1.38	1.37	1.37	1.37
	b	1.39	1.38	1.39	1.39
	c	1.39	1.38	1.38	1.36
	d	1.39	1.39	1.39	1.39
	e	1.38	1.38	1.38	1.38
Submerged Flow Cases	**Area**	**Baseline**	**Scenario 1 (5%↓)**	**Scenario 2 (10%↓)**	**Scenario 3 (15%↓)**
4. Median Backwater Stage	a	1.36	1.36	1.36	1.35
	b	1.39	1.39	1.39	1.39
	c	1.39	1.39	1.39	1.39
	d	1.39	1.39	1.39	1.39
	e	1.38	1.38	1.38	1.38
5. High Backwater Stage	a	1.36	1.36	1.35	1.35
	b	1.39	1.39	1.39	1.39
	c	1.39	1.39	1.39	1.39
	d	1.39	1.39	1.39	1.39
	e	1.38	1.38	1.38	1.38
6. Low Backwater Stage	a	1.38	1.38	1.38	1.38
	b	1.39	1.39	1.39	1.39
	c	1.39	1.39	1.39	1.39
	d	1.39	1.39	1.39	1.39
	e	1.38	1.38	1.38	1.38

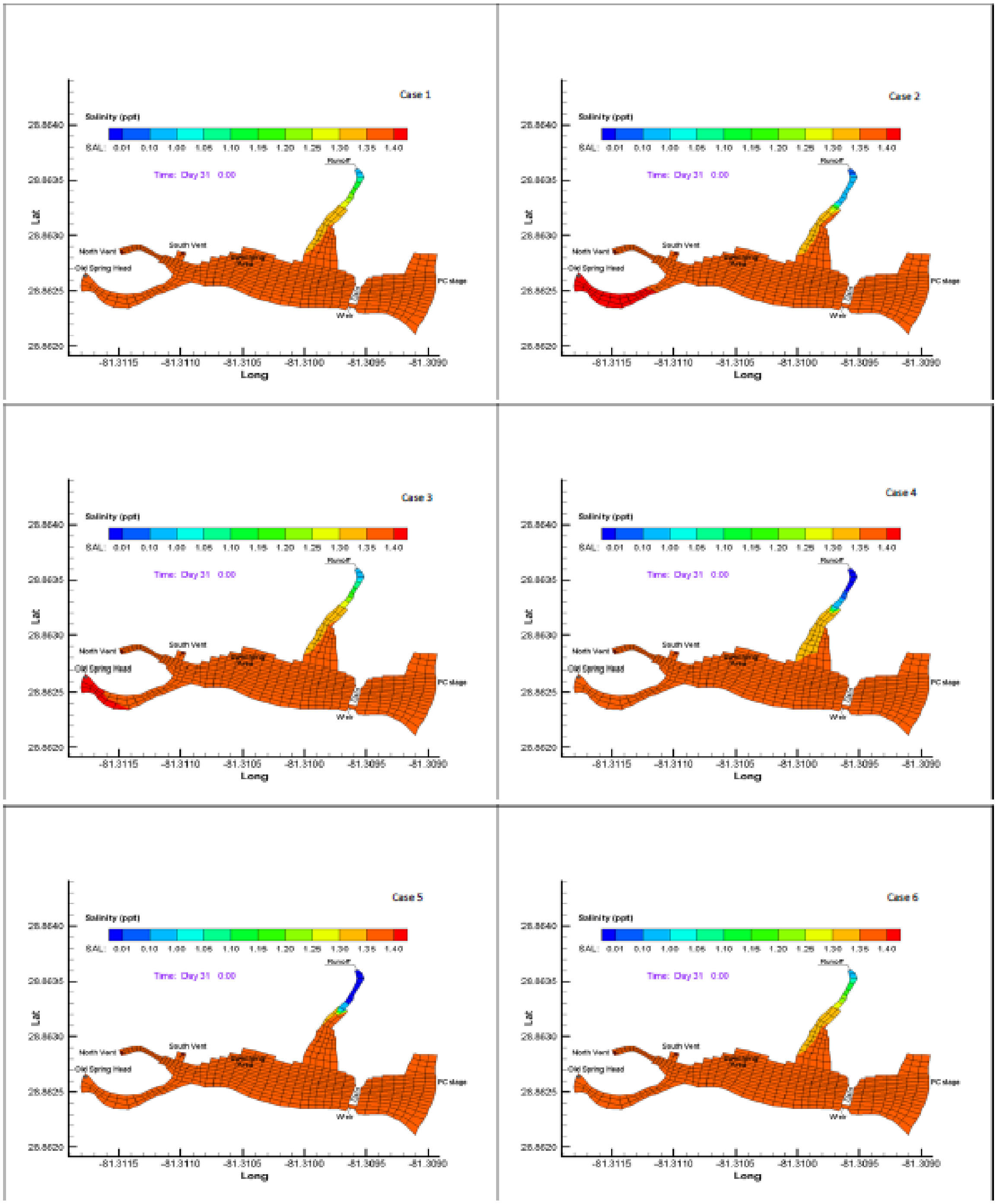

Figure 6.6. Salinity Distribution, Baseline Cases, in ppt

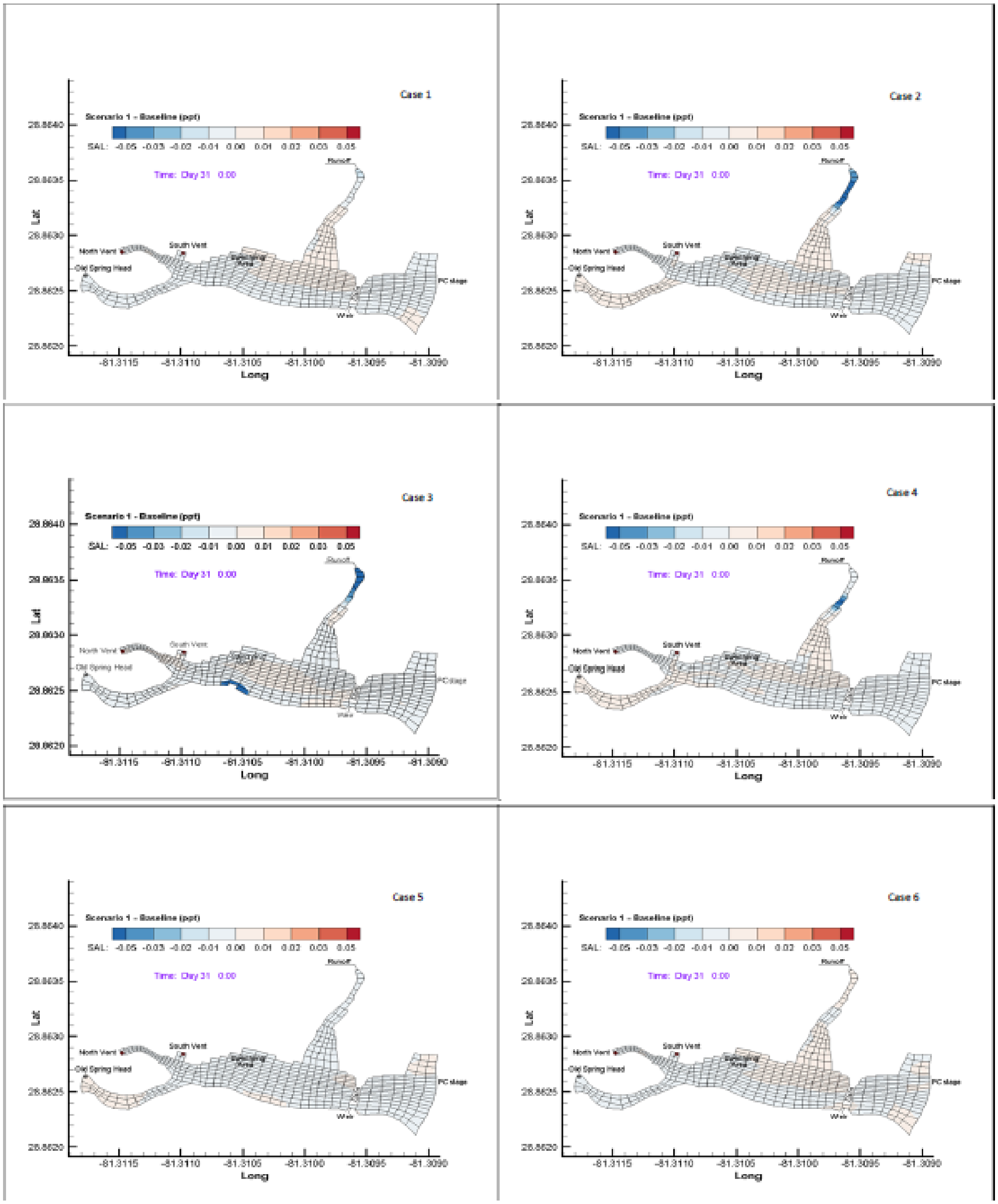

Figure 6.7. Salinity Difference Distribution, Scenario 1 – Baseline, in ppt

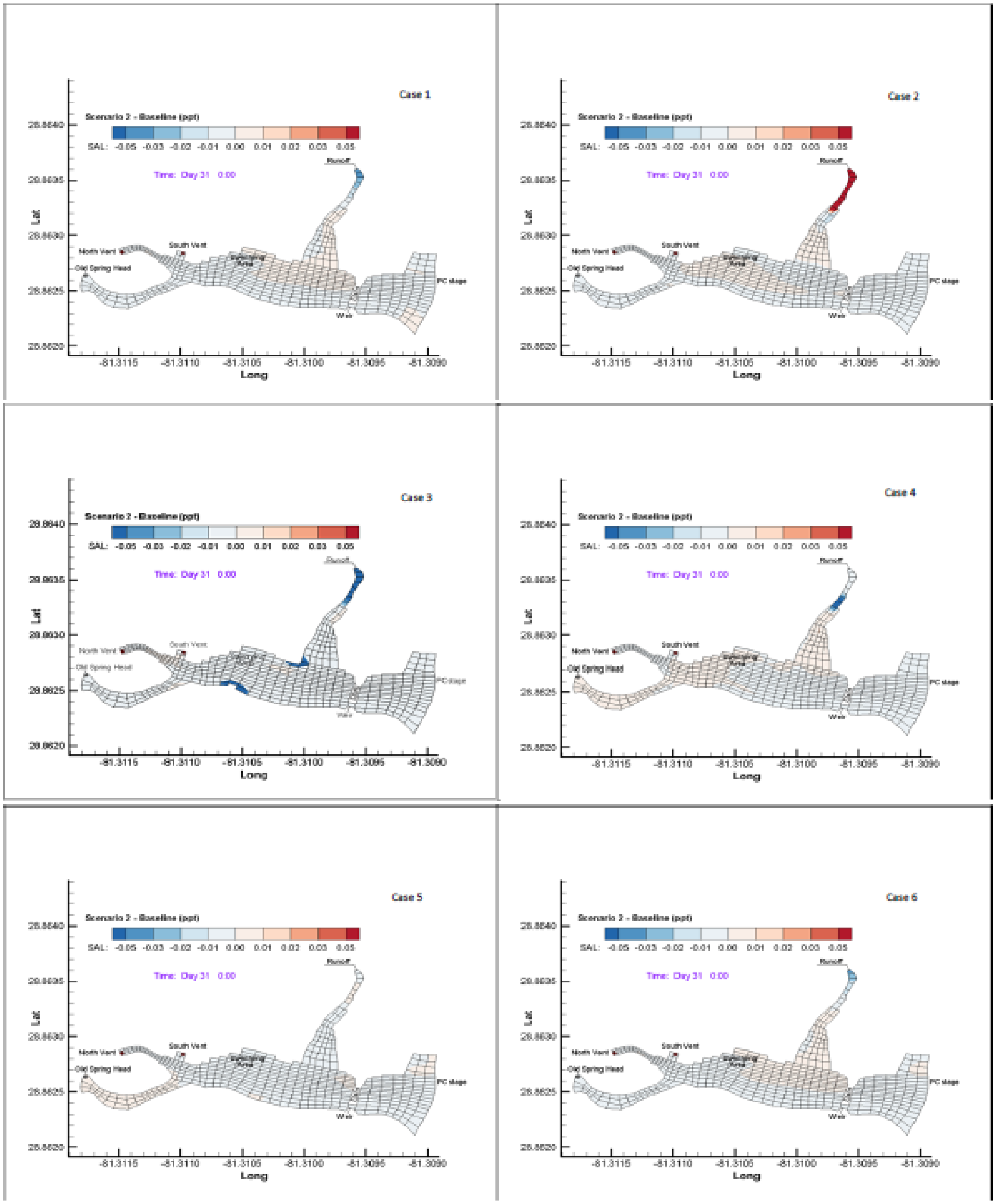

Figure 6.8. Salinity Difference Distribution, Scenario 2 – Baseline, in ppt

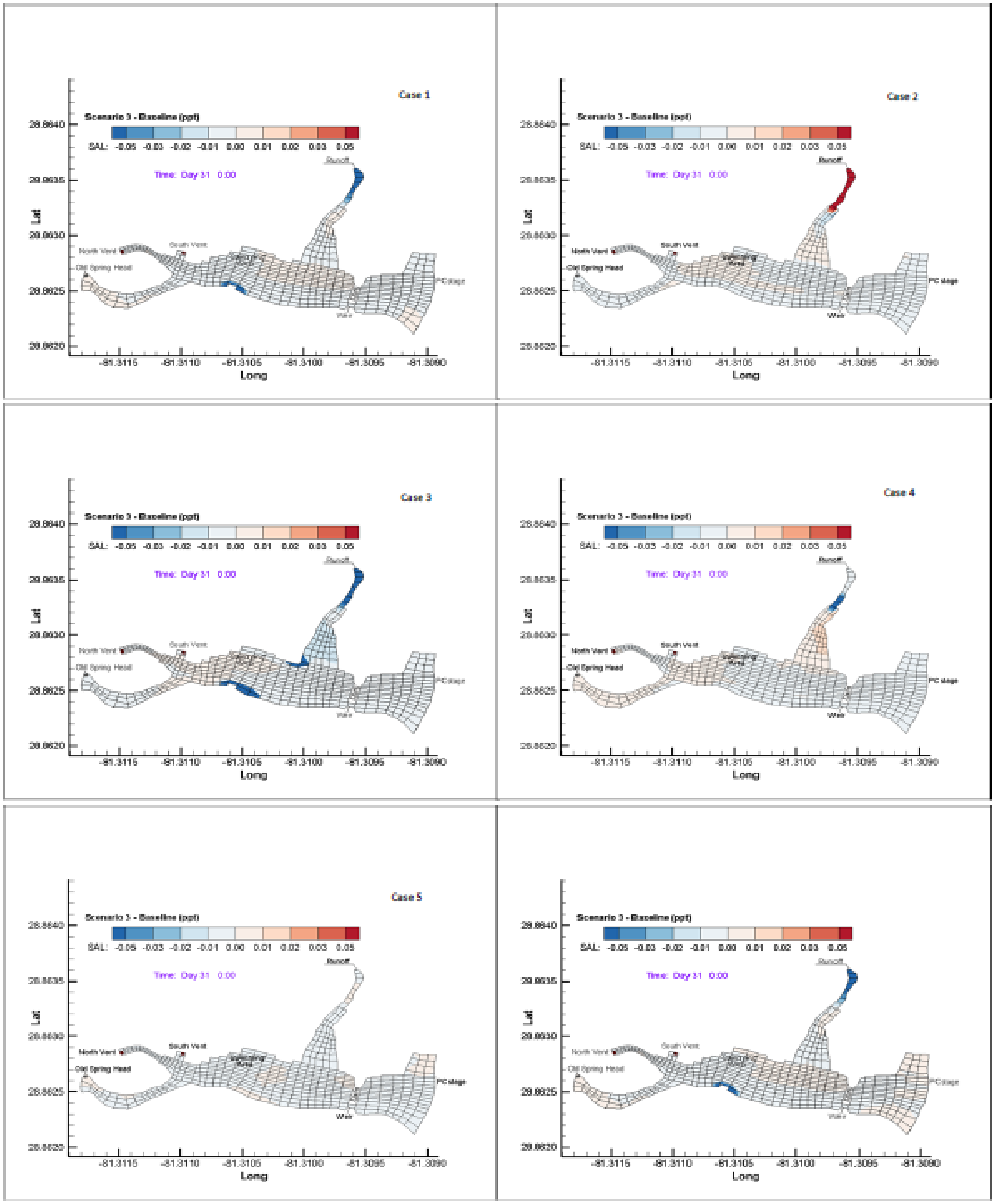

Figure 6.9. Salinity Difference Distribution, Scenario 3 – Baseline, in ppt

6.3. Water Age and Residence Time

To represent the overall pool transport time with springs reduction, an average pool residence time in area **a** (Table 6.3) for each case was roughly estimated. As expected, lower springs discharge results in consistently higher average pool residence time, and there is a significant inverse correlation between discharge and residence time. As springs discharge decreases every 5% until 15%, the residence time grows accordingly with an increment of one half hour or so, and this regularity is more notable under the circumstance that no high backwater occurs (Table 6.3). It is worth noting that the pool could experience unusual and unexpected environmental impacts from Gemini Springs Run and Lake Monroe during high backwater period thanks to the clear higher residence time in Case 5.

Table 6.3. Calculated Average Pool Residence Time, in hours

Free Flow Cases	Area	Baseline	Scenario 1 (5%↓)	Scenario 2 (10%↓)	Scenario 3 (15%↓)
1. Average Discharge Case	a	8.21	8.58	8.98	9.44
2. High Discharge Case	a	7.13	7.44	7.80	8.20
3. Low Discharge Case	a	9.27	9.69	10.15	10.68
Submerged Flow Cases	**Area**	**Baseline**	**Scenario 1 (5%↓)**	**Scenario 2 (10%↓)**	**Scenario 3 (15%↓)**
4. Median Backwater Stage	a	8.96	9.38	9.87	10.41
5. High Backwater Stage	a	12.23	12.87	13.58	14.37
6. Low Backwater Stage	a	8.21	8.58	8.98	9.44

Without significant loss of contact with reality, the EFDC simulation results in Table 6.4 suggest a much more complicated and profound influence of the springs discharge reductions on water age. To address the complicated spatial varying water quality issues in the Gemini Springs pool, steady state Baseline water age distribution (Fig. 6.10), a function of springs discharge, was illustrated for each case. Apparently, the water age within the pool area is controlled by spring discharge under free flow condition and Lake Monroe during high backwater period, respectively. Generally, an inverse relationship between age and discharge can be seen, the lower springs discharge, that is to say, the less incoming water mass with low water age, the higher water age and the more time the water parcel will take from the inflow boundaries to the outfall, especially for free flow condition. For a specific area, water age can be affected by unique bathymetry, flow condition, local water volume, storm runoff and rainfall, etc. The age distribution (Fig. 6.10) also shows a more prominent lateral gradient than longitudinal variation. Lower water age or residence time was observed along the clearly outlined flow path from springs vents to the outfall in most cases. Similar to residence time, Case 5 items have a generally higher water age than that in any other cases, including area **e**, downstream of the weir, and the flow pattern in the pool can be weakened or even disrupted by a mighty backwater with high resistance. Specifically, as shown in Baseline Case 5 of Fig. 6.10, the water age at outfall reaches a significantly high value, and water age in the pool is significantly higher than any other cases because less fresh water can easily slip out of the pool. Despite a much lower water age in submerged flow Case 4 than that in Case 5, lots of impounded springs water in the pool (area **a)** in Case 4 also shows a high water age due to the backwater effect. In most cases, as springs discharge decreases by every 5% until 15%, typically less than one-hour water age increment occurs. However, there do exist some environmental or discharge sensitive areas in the domain as stated in Section 6.2. Small stagnant area (within shore area **c)** is formed as discharge reduces, gradually, springs water with low water age is getting harder to get to that very small area with enough amount and then the water age can be significantly increased from Scenario 1 to 2 of Case 2 (> 30%) and from Scenario 2 to 3 of Case 3 (> 10%). In contrast to the considerable impact of backwater on pool area **a**, the growth and decline of springs discharge has insignificant effect on the downstream area **e** as indicated in Table 6.4. In order to understand the impact of the changes, the spatial distributions of calculated water age differences between each Reduction Scenario and Baseline were calculated as shown in Fig. 6.11, 6.12, and 6.13, respectively.

Table 6.4. Calculated Water Age, in hours

Free Flow Cases	Area	Baseline	Scenario 1 (5%↓)	Scenario 2 (10%↓)	Scenario 3 (15%↓)
1. Average Discharge Case	a	13.87	13.98	14.08	14.46
	b	0.93	1.03	1.08	1.14
	c	6.44	6.94	7.15	7.63
	d	8.09	8.50	8.93	9.36
	e	1.01	1.01	1.02	1.02
2. High Discharge Case	a	13.93	13.97	13.97	14.00
	b	0.20	0.20	0.66	0.93
	c	3.97	4.25	5.61	6.40
	d	6.90	7.22	7.73	8.09
	e	1.01	1.01	1.01	1.01
3. Low Discharge Case	a	14.14	14.71	15.46	15.97
	b	1.08	1.13	1.07	0.93
	c	7.35	8.04	8.38	9.55
	d	9.19	9.57	10.07	10.66
	e	1.02	1.02	1.02	1.04
Submerged Flow Cases	**Area**	**Baseline**	**Scenario 1 (5%↓)**	**Scenario 2 (10%↓)**	**Scenario 3 (15%↓)**
4. Median Backwater Stage	a	16.31	16.76	16.79	18.68
	b	0.26	0.27	0.28	0.29
	c	6.57	6.85	7.11	7.39
	d	8.67	9.09	9.53	10.17
	e	1.08	1.09	1.09	1.10
5. High Backwater Stage	a	25.08	26.01	26.76	27.70
	b	0.51	0.54	0.57	0.62
	c	11.95	13.22	13.99	14.34
	d	11.81	13.31	13.42	14.74
	e	1.30	1.40	1.38	1.44
6. Low Backwater Stage	a	13.75	13.93	14.01	14.32
	b	0.90	1.03	1.08	1.11
	c	6.43	6.86	7.22	7.56
	d	8.21	8.50	8.94	9.37
	e	0.95	0.95	0.95	0.95

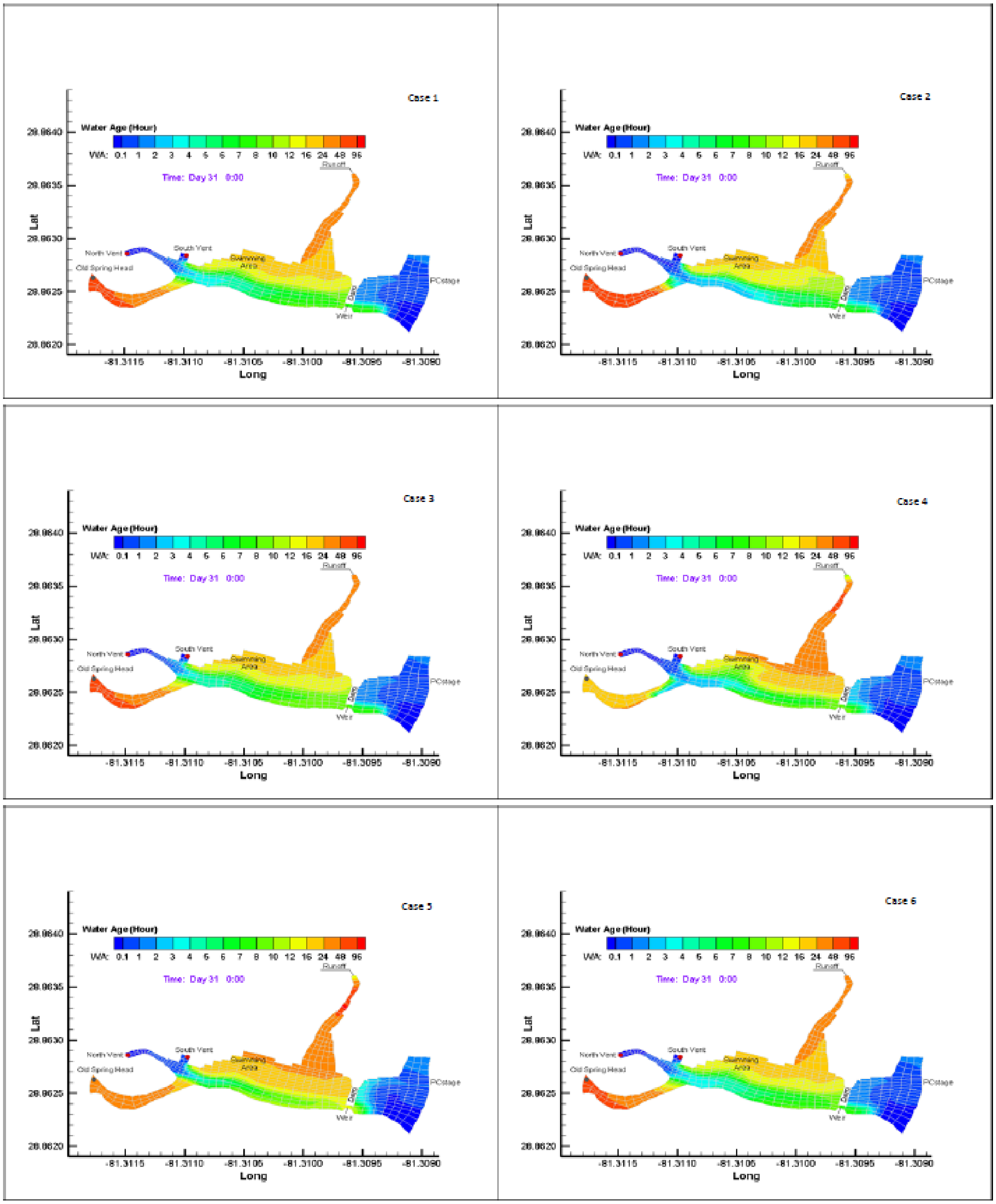

Figure 6.10. Water Age Distribution, Baseline Cases, in hours

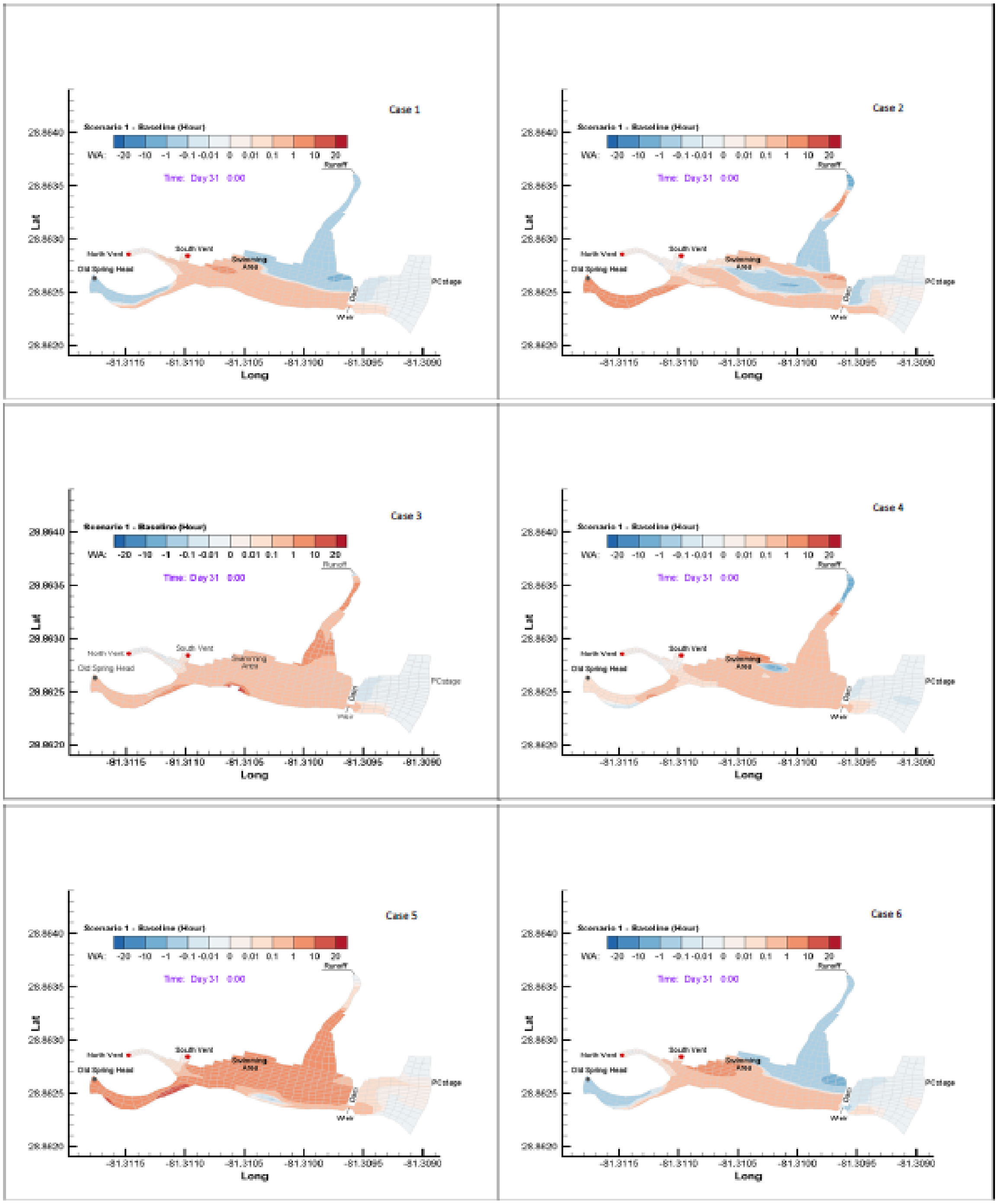

Figure 6.11. Water Age Difference Distribution, Scenario 1 – Baseline, in hours

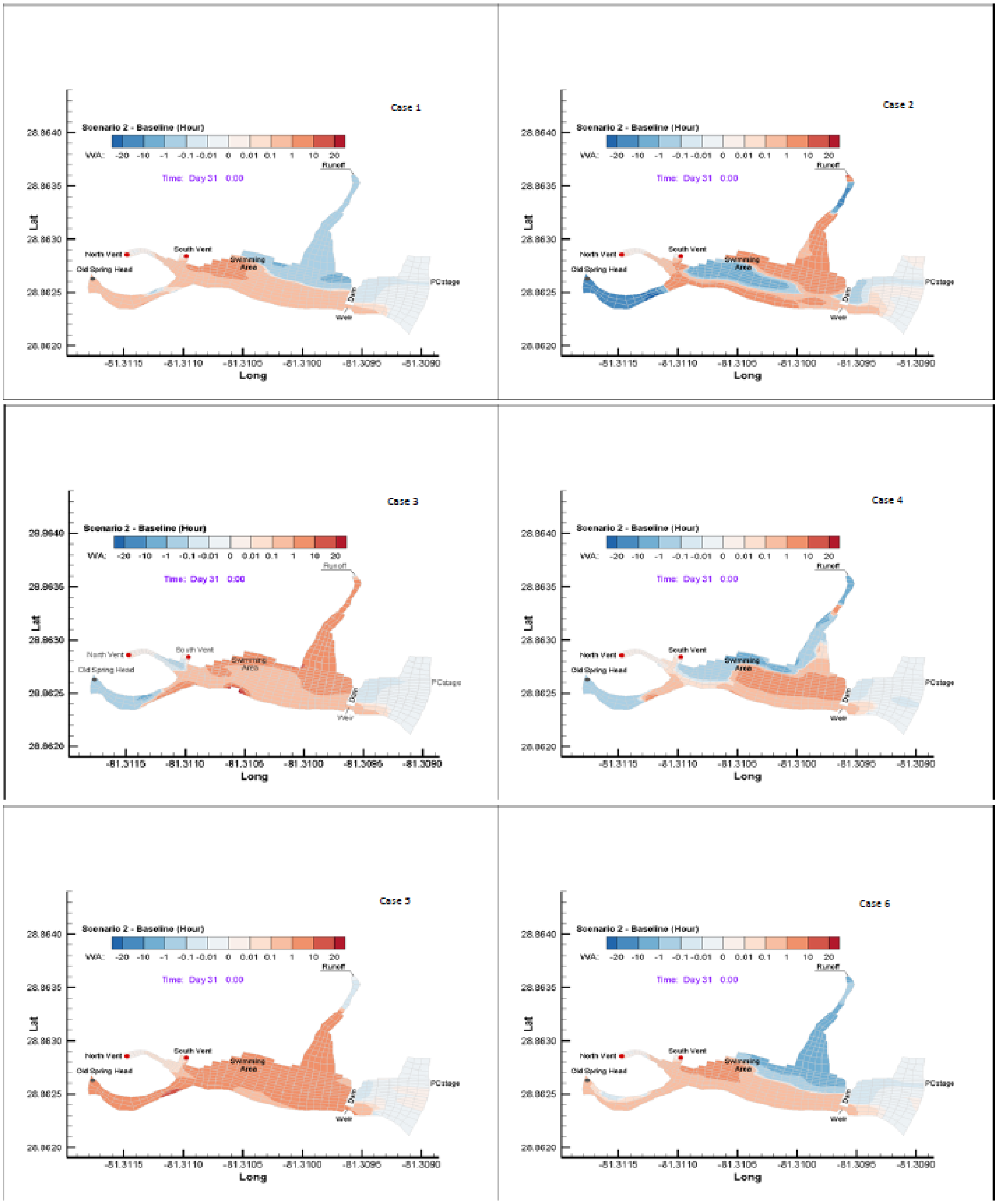

Figure 6.12. Water Age Difference Distribution, Scenario 2 – Baseline, in hours

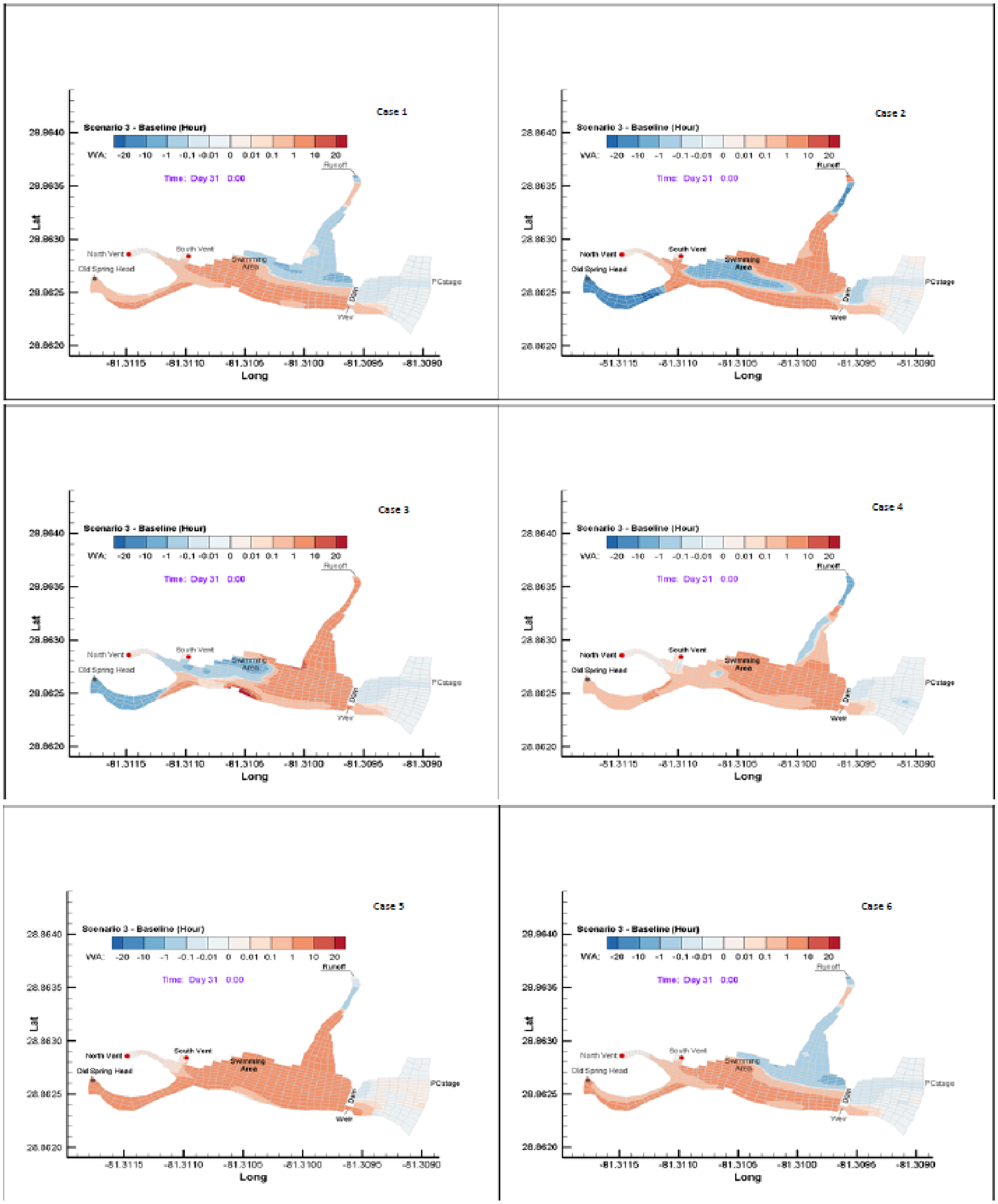

Figure 6.13. Water Age Difference Distribution, Scenario 3 – Baseline, in hours

7. SUMMARY

To understand Gemini Springs pool hydrodynamics and support Gemini Springs MFLs, a Gemini Springs pool EFDC hydrodynamic model was developed. Due to the satisfactory model calibration and validation results, the newly developed pool model was then applied to the Gemini Springs MFLs steady state simulations to assess the impacts of 5%, 10% and 15% springs discharge reductions on pool water surface elevation, salinity and water transport time. A few one-month EFDC steady state simulation cases for both the Baseline Condition and the corresponding three springs discharge Reduction Scenarios were setup based on the analysis of the springs discharge time series over the period of record (POR) and the outflow characteristics over the weir. The following summarizes the simulation results:

The water surface elevation in the pool exhibits a high spatial homogeneity. The impact of springs discharge reduction on the water level change is straightforward. Not surprisingly, the higher springs discharge, the slightly higher water surface elevation the pool can maintain, according to free flow cases simulation results. Certainly, as the whole model domain is gradually dominated by the coming backwater, the influence of discharge reduction on water level change could be negligible.

The salinity in the pool exhibits a very high spatial and temporal homogeneity as springs discharge decreases, especially during backwater period. As springs discharge reduces by 5%, 10% and 15%, the springs discharge Reduction Scenarios maintain slightly lower pool salinity than the corresponding Baseline Condition, due to the relatively increasing importance of freshwater runoff and rainfall with a salinity value of zero. For the springs discharge sensitive area or small stagnant area resulting from discharge reduction, the salinity change corresponding to a certain springs discharge reduction is elusive and highly related to the local residence time.

Water age is a good indicator for both pool hydrodynamics and water quality. Generally, the lower springs discharge, the higher water age, especially for free flow condition. The age distribution is a function of springs discharge. Although water age in certain pocket area considerably increases as springs discharge decreases, the EFDC simulation result confirms that the water age within the pool area is generally controlled by spring discharge under free flow condition and Lake Monroe during high backwater period. In a similar manner to salinity, the effect of discharge reduction on water age is significantly dependent on local bathymetry and velocity gradient variations.

The effect of the high backwater is overwhelming, and the modeling result shows that the whole pool hydrodynamic conditions and age distribution can be substantially interrupted by the high backwater. However, the influence of the discharge reduction on downstream of the weir is tiny in comparison.

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APPENDIX A

00410494 Gemini Springs at DeBary, FL

Documentation for computing discharge using Water Level Elevation of Well S-1225 vs. Discharge from Gemini Springs for Rating #1

Rating Analysis

Equipment.—Campbell CR206 datalogger in spring pool gage (upper), with broad-crested concrete weir and spillway at outlet. Metal-pipe trash grate at downstream end of weir since July 2, 2007. CR800 datalogger in tailwater gage, Hydstra No. 03710493 (lower).

Period of Record.—SJRWMD began collecting continuous gage-height record at both the upper and lower gages on March 25, 2009. Periodic discharge measurements made by USGS April, 1972 and May 1993 to September 1999 and by SJRWMD/HDS since May 1993.

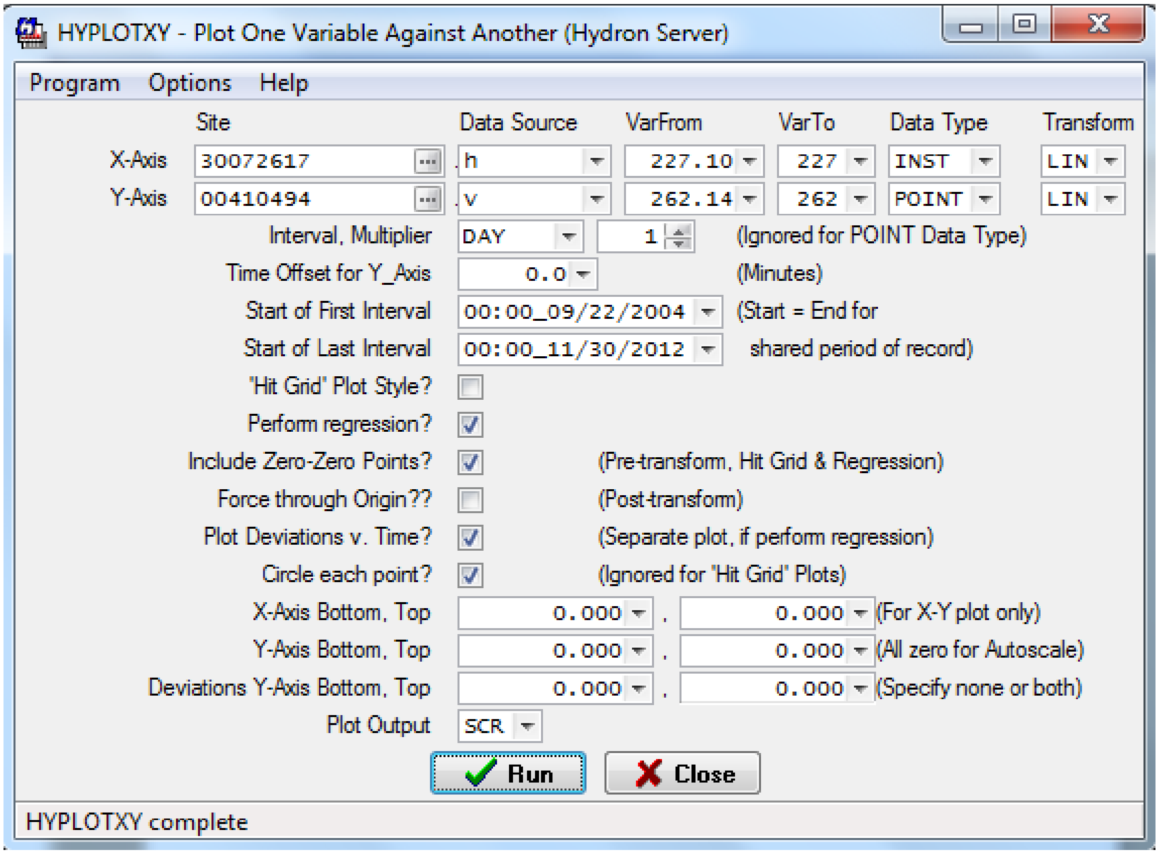
Rating.—Gemini Spring is tributary to Lake Monroe and at times the upper gage is subject to variable backwater from high stages on Lake Monroe., therefore, a normal stage-discharge rating cannot be used to compute discharge. An attempt was made to adjust for periods of variable backwater by the Fall Ratio/
Discharge Ratio method, however, a fall/Q rating could not be defined due to the availability of only two backwater affected discharge measurement since continuous record began. Due to these rating problems,
Mitch Wainwright, HDS, researched the possibility of defining a relationship between water-level in a nearby ground water well and discharge at Gemini Springs. A trial XY regression rating using differential head between the well, 30072617 S-1225 Yankee Lake STP at Sanford, and the spring pool could not be defined, again because the spring pool stage was affected by the variable backwater at times. Finally, it was found that a direct relationship between well water level and discharge at the spring was viable. On this basis, a regression rating was developed using random, periodic discharge measurements made since September 2004. The regression has a correlation coefficient of 0.837 and a standard error of estimate of 0.660. The resultant rating equation y= 0.587*x-4.241 was entered into Hydstra as Rating 1

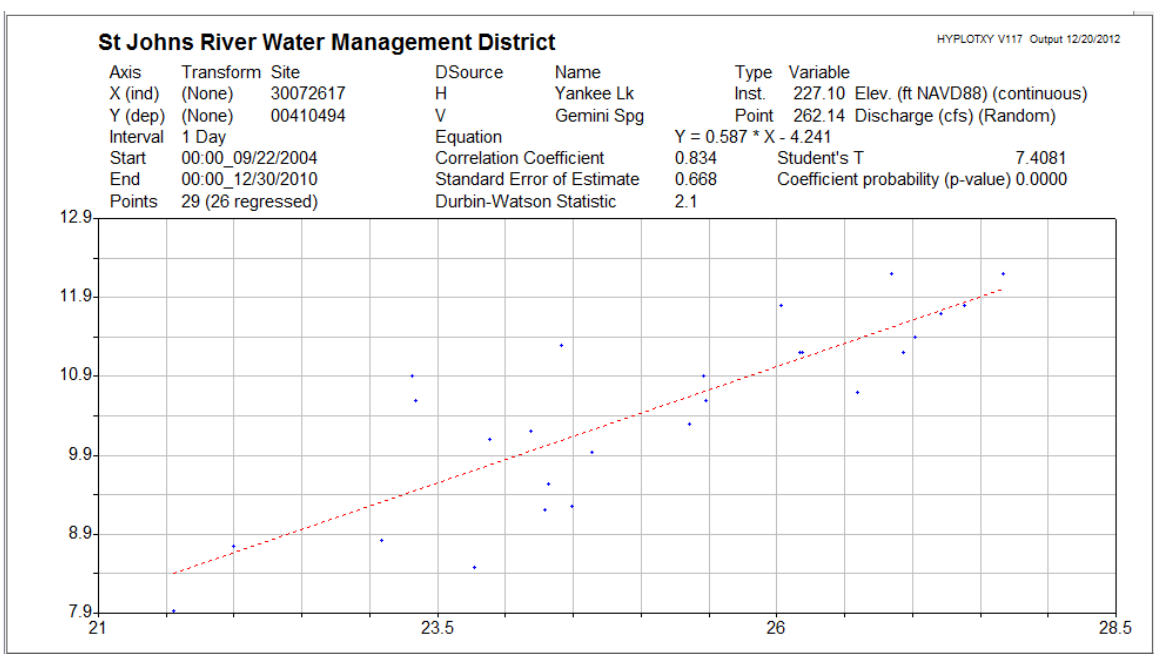
Discharge.—Rating No. 1 was used to compute the daily discharge record for the period October 1, 2007 to October 31, 2010. A reference trace of the random measurements on the daily discharge hydrograph for the period indicates that the discharge record is within 5% except for October 2007, where the measurement deviates by less than 10%. The only serious outlier occurred in December 2009 due to probable manual manipulation of the spring pool. Daily discharges for the period November 24, 2009 to January 11, 2010 were estimated based on the discharge measurement and appearance of the hydrograph.

Procedure.—See sequence of Hydstra screen prints below for computational steps used.

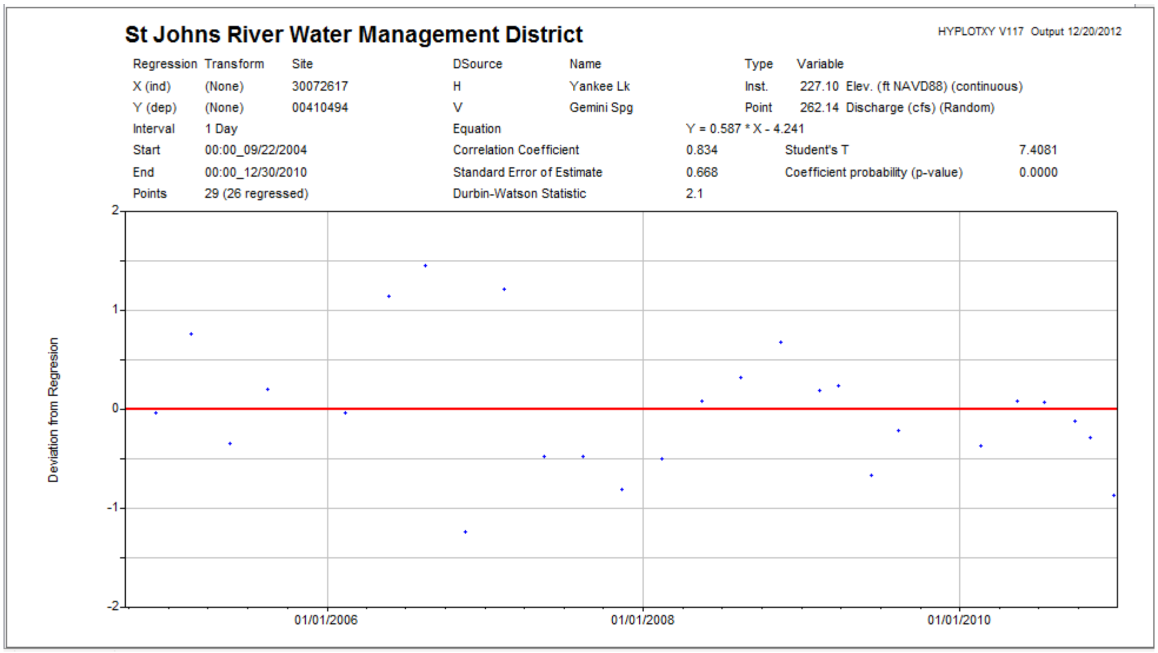
Prepared by: J. L. Oberg 09/25/2010
Revised by: J. L. Oberg 02/11/2011
Revised by: J. M. Wainwright 02/17/2011

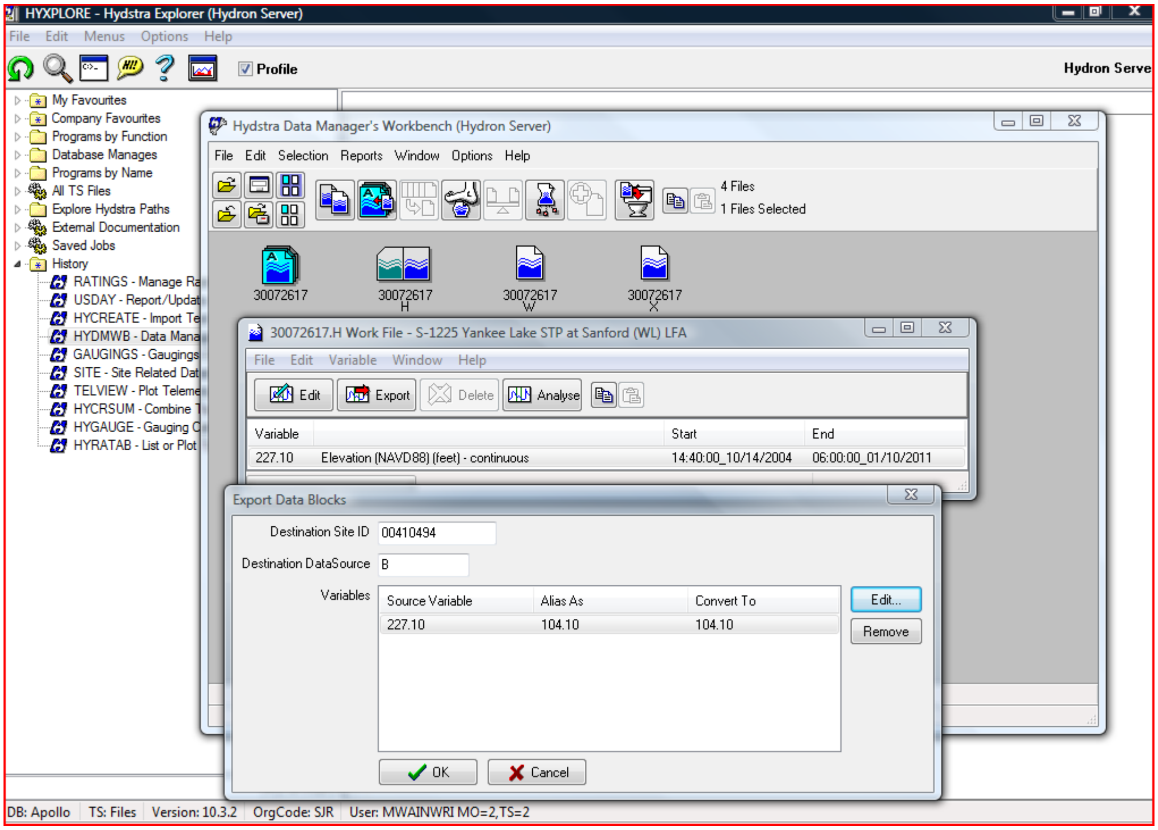
Reviewed by: R. Davis 12/20/2012





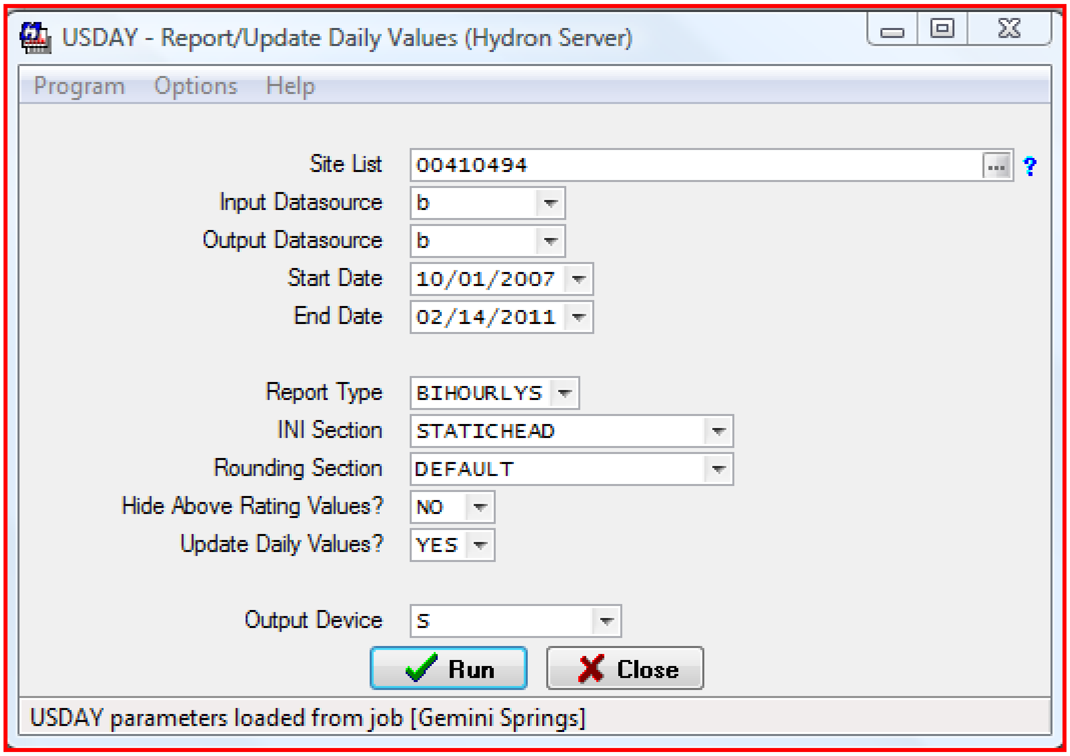
The above regression extends the date range to 12/30/2010, which improves the correlation coefficient.


St Johns River Water Management District
HYPLOTXY V117 Output 12/20/2012
Regression Transform Site DSource Name Type Variable
X (ind) (None) 30072617 H Yankee Lk Inst. 227.10 Elev. (ft NAVD88) (continuous)
Y (dep) (None) 00410494 V Gemini Spg Point 262.14 Discharge (cfs) (Random)
Interval 1 Day
Equation Y = 0.587 * X - 4.241
Start 00:00_09/22/2004
Correlation Coefficient 0.834
Student's T 7.4081
End 00:00_12/30/2010
Standard Error of Estimate 0.668
Coefficient probability (p-value) 0.0000
Points 29 (26 regressed)
Durbin-Watson Statistic 2.1
Deviation from Regresion
2
1
0
-1
-2
01/01/2006
01/01/2008
01/01/2010



The 227.10 water level at well S-1225 was converted to a 104.10 variable (static head) and exported to the Gemini Springs Hydstra work file. This is the well water level that will be used for computing daily discharge for Gemini Springs. Check for exact time period of 227.10 data, modification of data, start and end time in USDAY program for changes. If different time period used this could change the formula in the future, use caution. The computation is performed by running the USDAY program in Hydstra that will take the converted 104.10 data and compute daily computed discharge using the regression equation from the period you specify in USDAY for the 104.10 work file. Daily discharge record is then generated in the work file that was specified in USDAY. The converted 104.10 file should then be Archived so the process can be re-produced exactly if necessary.

The regression analysis should be checked on an annual basis to determine if the correlation between the differential well head and the spring discharge has changed.


USDAY - Report/Update Daily Values (Hydron Server)
Program Options Help
Site List 00410494
Input Datasource b
Output Datasource b
Start Date 10/01/2007
End Date 02/14/2011
Report Type BIHOURLYS
INI Section STATICHEAD
Rounding Section DEFAULT
Hide Above Rating Values? NO
Update Daily Values? YES
Output Device S
Run
Close
USDAY parameters loaded from job [Gemini Springs]

APPENDIX B
00410494 Gemini Springs at DeBary, FL

Documentation for computing discharge using Water Level Elevation of Well V-0810 vs. Discharge from Gemini Springs for Rating #2

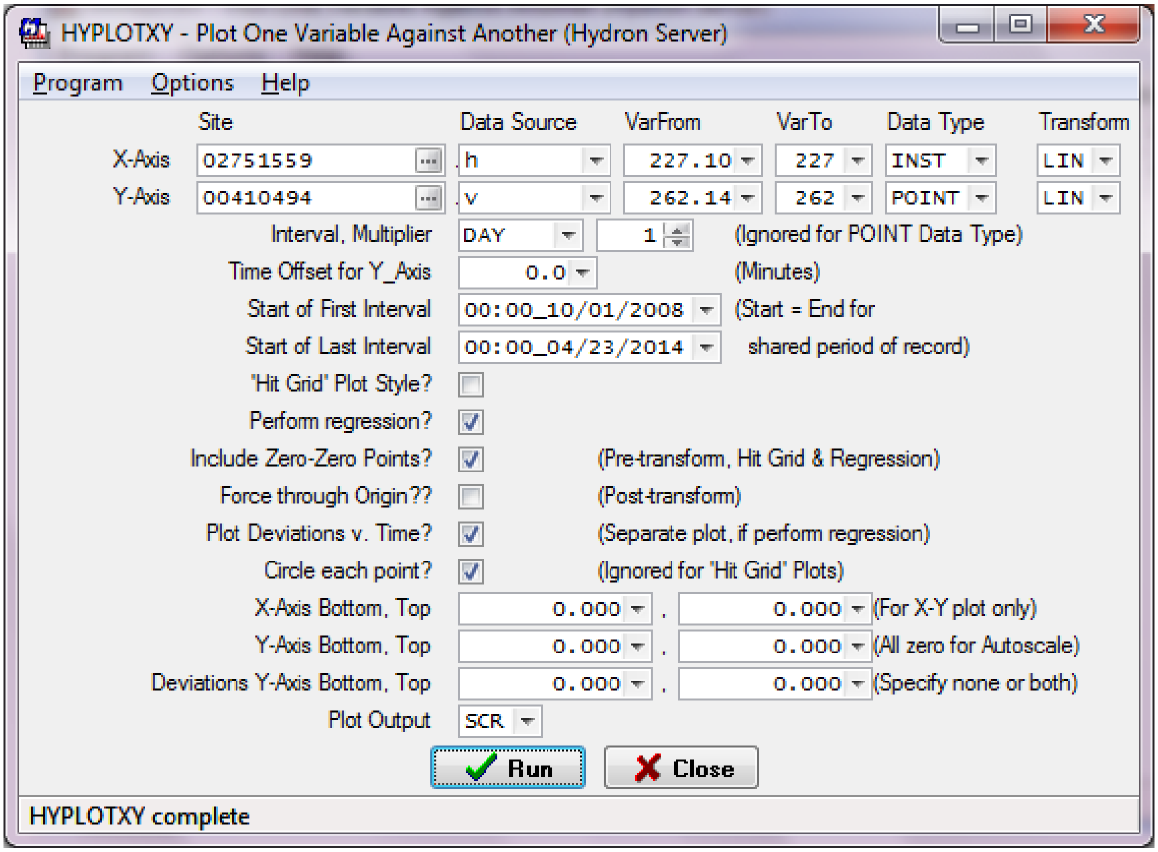
Rating Analysis

Equipment.—Campbell CR206 datalogger in spring pool gage (upper), with broad-crested concrete weir and spillway at outlet. Metal-pipe trash grate at downstream end of weir since July 2, 2007. CR800 datalogger in tailwater gage, Hydstra No. 03710493 (lower).

Period of Record.—SJRWMD began collecting continuous gage-height record at both the upper and lower gages on March 25, 2009. Periodic discharge measurements made by USGS April, 1972 and May 1993 to September 1999 and by SJRWMD/HDS since May 1993.

Rating.—Gemini Spring is tributary to Lake Monroe and at times the upper gage is subject to variable backwater from high stages on Lake Monroe., therefore, a normal stage-discharge rating cannot be used to compute discharge. An attempt was made to adjust for periods of variable backwater by the Fall Ratio/
Discharge Ratio method, however, a fall/Q rating could not be defined due to the availability of only two backwater affected discharge measurement since continuous record began. Due to these rating problems,
Mitch Wainwright, HDS, researched the possibility of defining a relationship between water-level in a nearby ground water well and discharge at Gemini Springs. A trial XY regression rating using differential head between the well, V-0810 Snook Rd, and the spring pool could not be defined, again because the spring pool stage was affected by the variable backwater at times. Finally, it was found that a direct relationship between well water level and discharge at the spring was viable. On this basis, a regression rating was developed using random, periodic discharge measurements made since October 2008. The regression has a correlation coefficient of 0.851 and a standard error of estimate of 0.595. The resultant rating equation y= 0.642*x+1.533 was entered into Hydstra as Rating 2

Discharge.—Rating No. 2 was used to compute the daily discharge record for the period October 1, 2011 to October 31, 2013. Rating 2 involved switching wells form S-1225 to V-0810 due to rating 1 deviating from the regression in a consistently negative manner. A reference trace of the random measurements on the daily discharge hydrograph for the period indicates that the discharge record is within 5-10% except for October 2013, where the measurement deviates by more than 10% due to storage from weeds on control. Daily discharges for the period Oct 01, 2011 to March 18, 2014 were estimated based on the discharge measurement and appearance of the hydrograph.



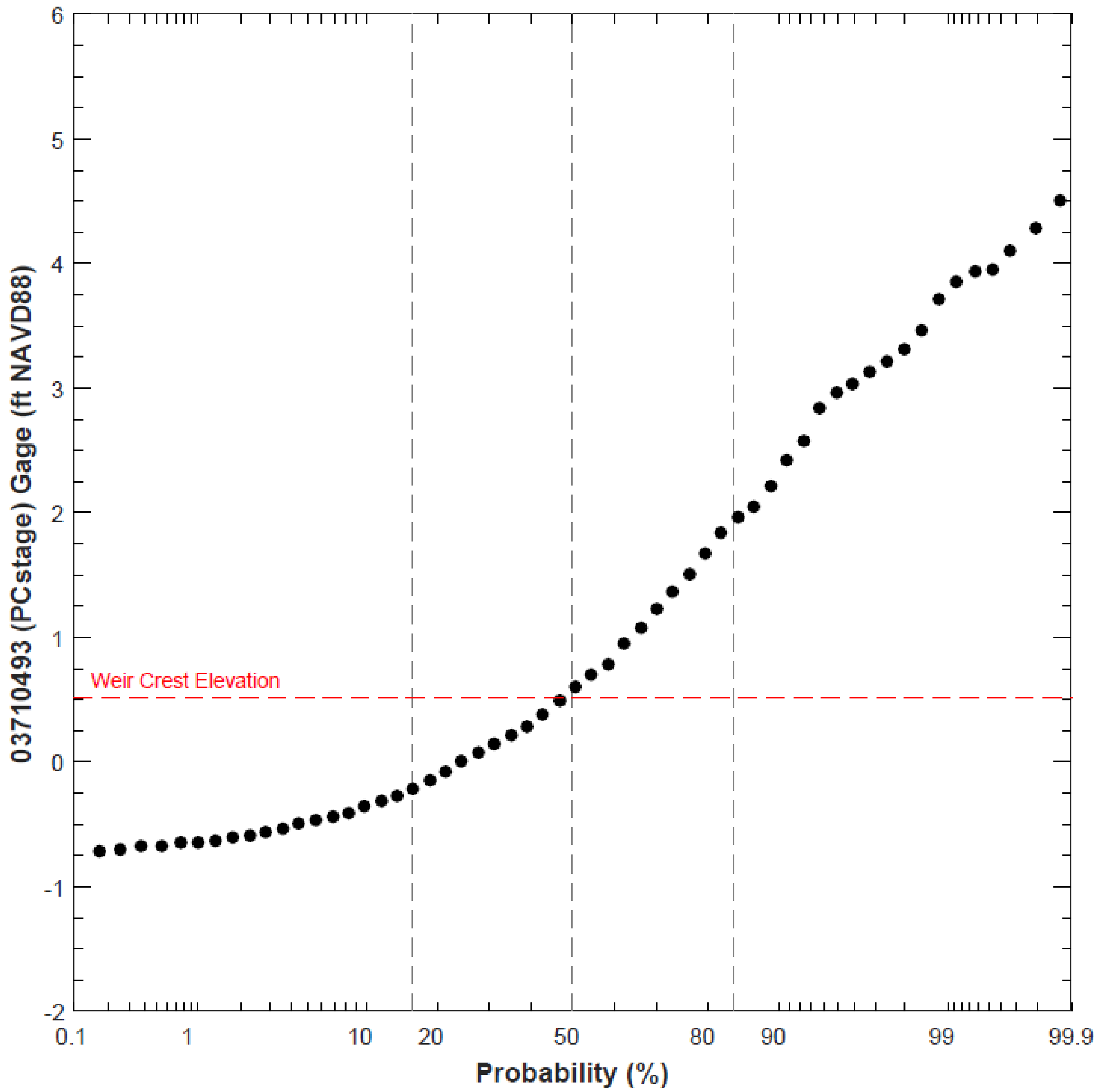
The 227.10 water level at well V-0810 was converted to a 104.10 variable (static head) and exported to the Gemini Springs Hydstra work file. This is the well water level that will be used for computing daily discharge for Gemini Springs. Check for exact time period of 227.10 data, modification of data, start and end time in USDAY program for changes. If different time period used this could change the formula in the future, use caution. The computation is performed by running the USDAY program in Hydstra that will take the converted 104.10 data and compute daily computed discharge using the regression equation from the period you specify in USDAY for the 104.10 work file. Daily discharge record is then generated in the work file that was specified in USDAY. The converted 104.10 file should then be Archived so the process can be re-produced exactly if necessary.

The regression analysis should be checked on an annual basis to determine if the correlation between the differential well head and the spring discharge has changed.

Prepared by: J. M. Wainwright 04/23/2014
Reviewed by: R. Davis 04/23/2014

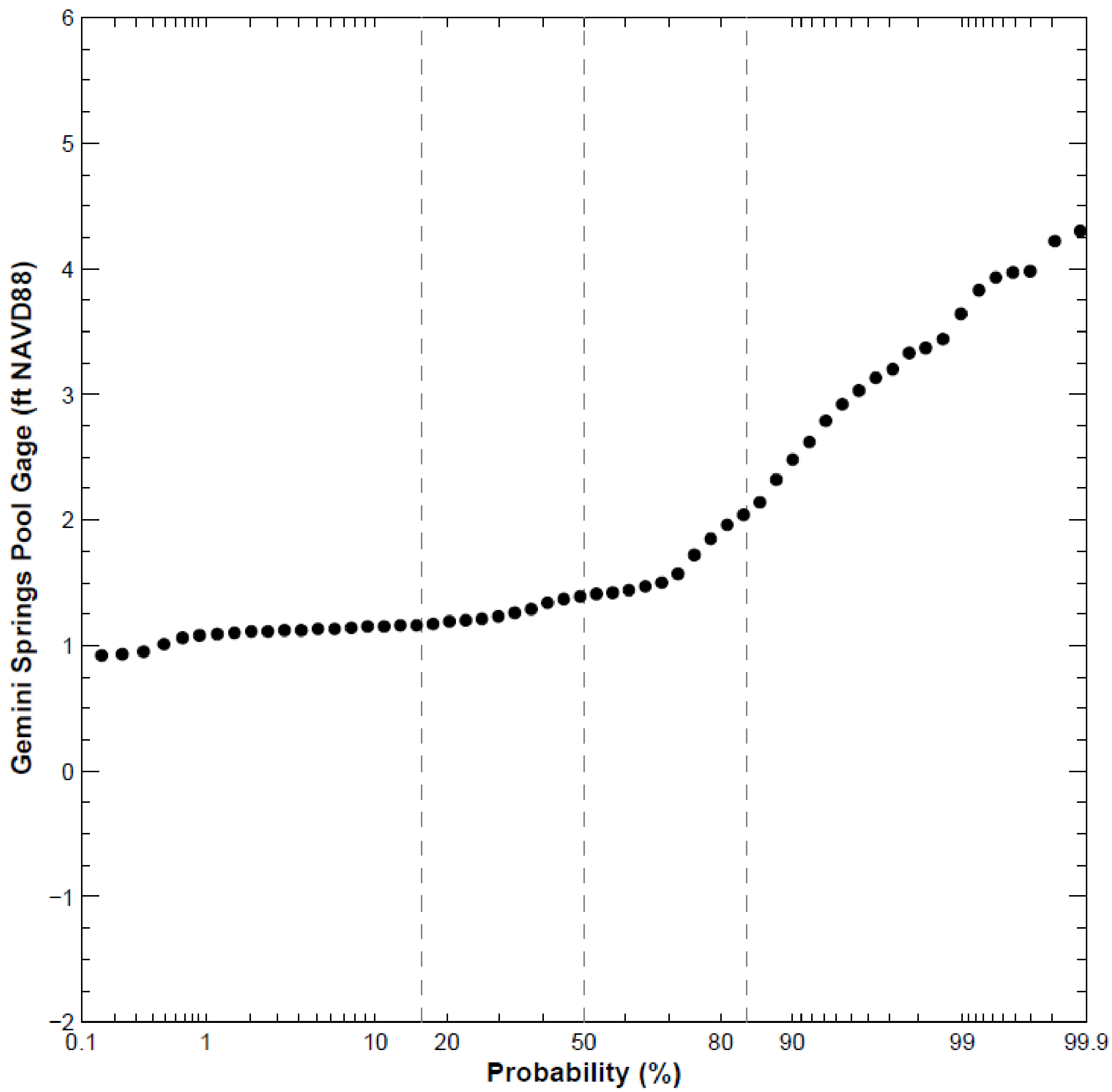
APPENDIX C

SJRWMD 03710493 (PCstage) Stage Probability Plot



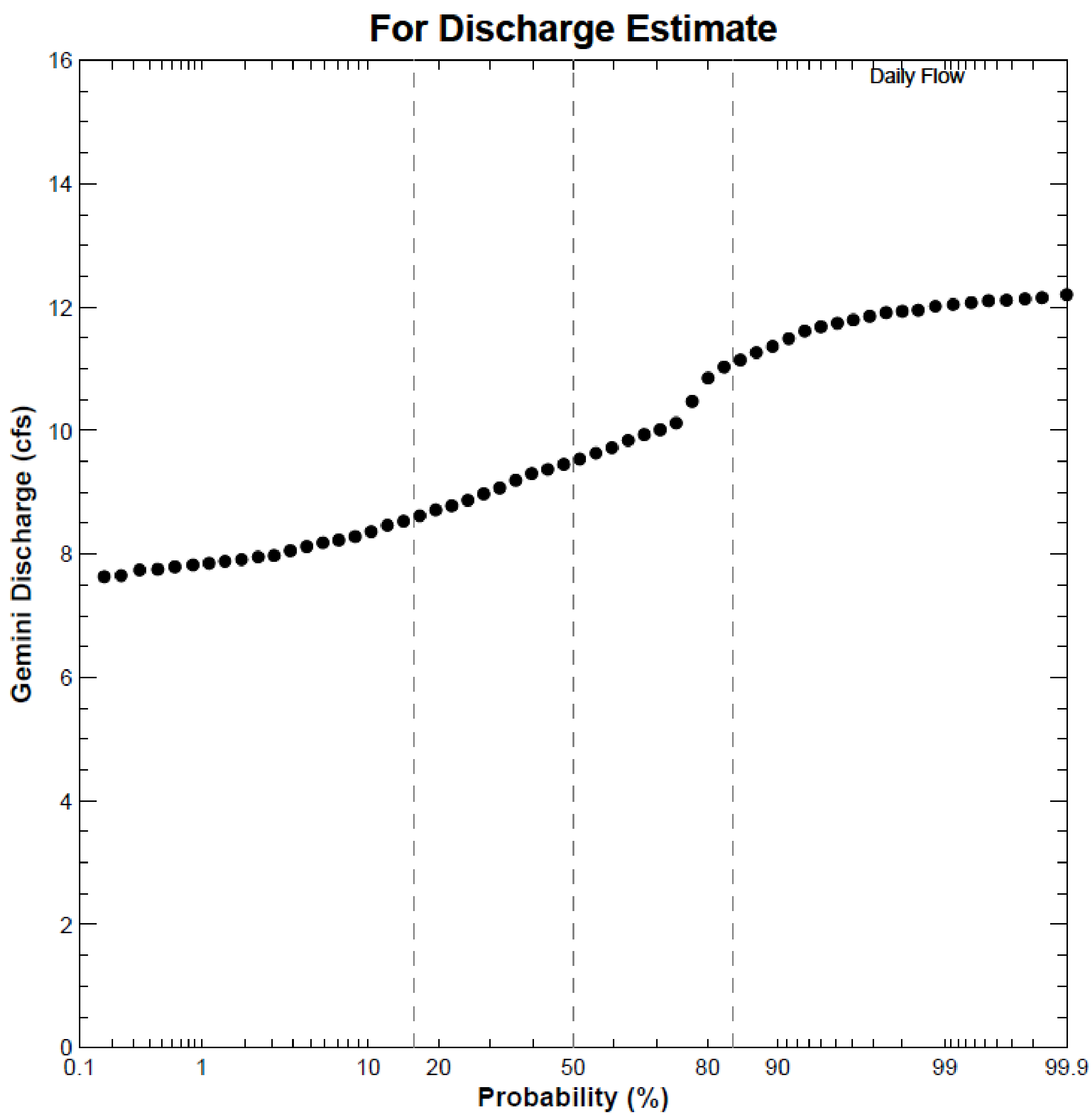
APPENDIX D

SJRWMD 00410494 Pool Stage Probability Plot



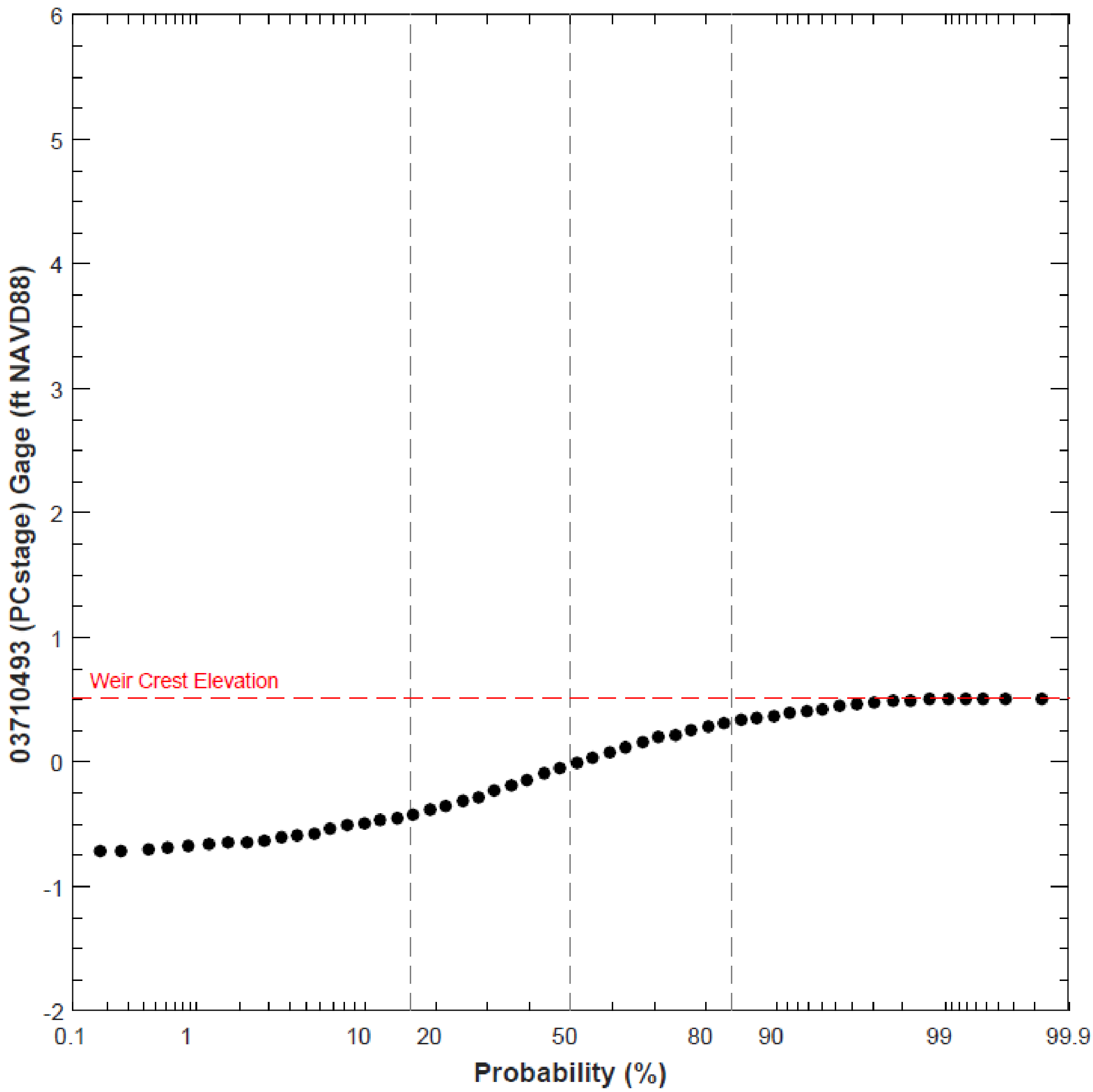
APPENDIX E

SJRWMD 00410494 Gemini Springs Discharge Probability Plot



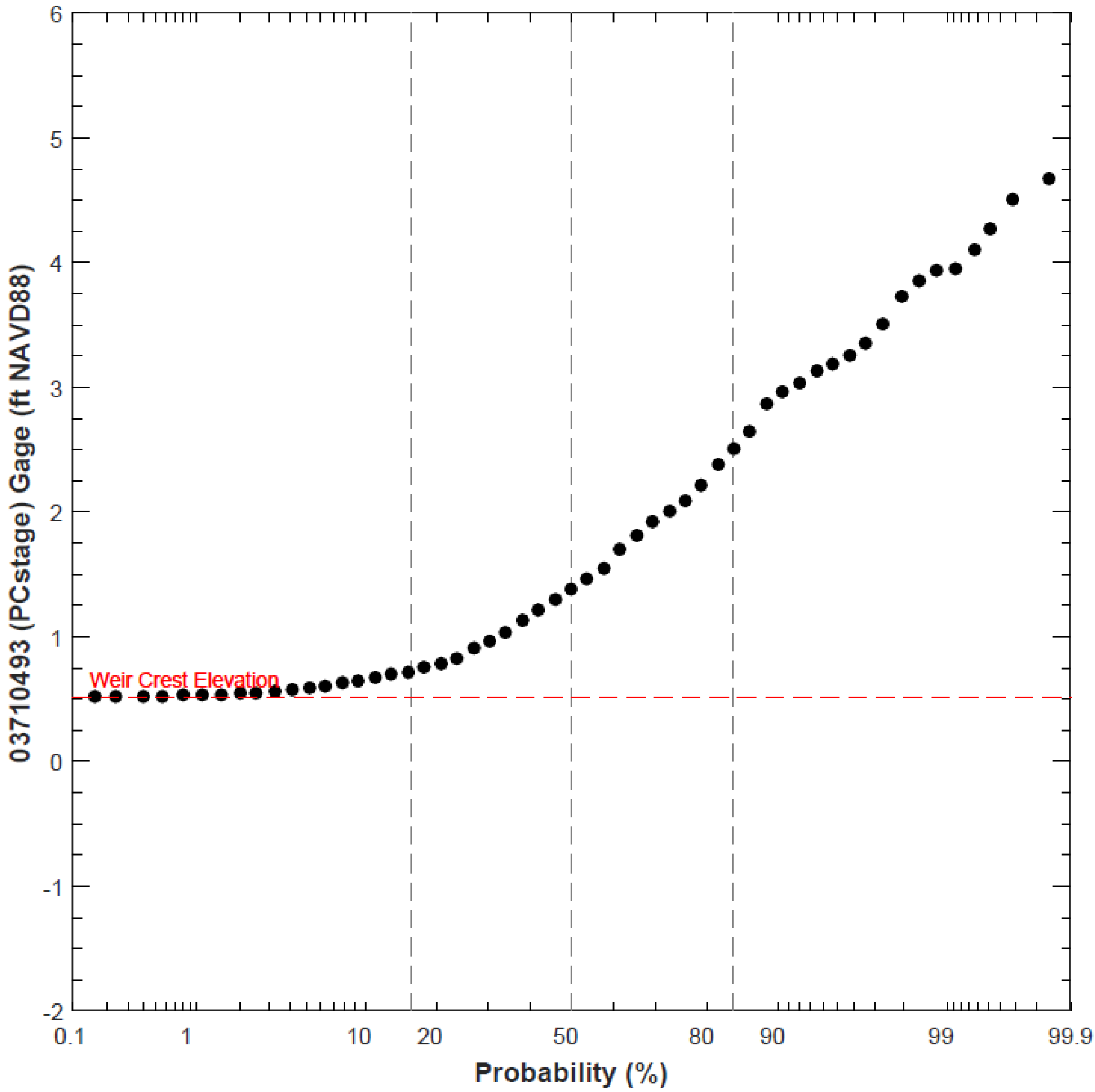
APPENDIX F

SJRWMD 03710493 (PCstage) Stage Probability Plot (based on Stage ≤ 0.51 ft-NAVD88)



APPENDIX G

SJRWMD 03710493 (PCstage) Stage Probability Plot (based on Stage > 0.51 ft-NAVD88)



APPENDIX H

Peer review resolution document for comments from Intera, "Review of Gemini Springs Pool Hydrodynamic Modeling Analysis" March 27, 2017, Resolution responses by Yanfeng Zhang

Peer Review Comments	Resolution
Pg. 2: A figure should be added to illustrate the rainfall over the period of record (POR) to strengthen the documentation.	A figure of rainfall over the period was added in the report
Pg2: Salinity data sources are listed in Table 3.2 and displayed in Figure 3.5 in Xiong (2016) however the sampling period and frequency are not discussed. Monthly averaged salinity data for the downstream open boundary condition (i.e. Padgett Creek) was taken from Station GEM1 however salinity data for the upstream flow boundary condition (i.e. Gemini springs) was compiled from several sources and the methodology used to derive monthly average values is not discussed.	Sampling period and frequency is shown in Figure 3.5 (Figure 3.5 in the updated report). As mentioned in the report, linear interpolation was used to fill in the gap based on available data.
Pg2: Xiong (2016) states that discharge data was also calculated based on rating curves for two wells but how this data was incorporated into the GSP model is not discussed. Figure 3.2 illustrates measurements that were taken more often than quarterly, this figure may include the discharge calculated from nearby wells, however further clarification is needed.	The discharge data was downloaded from district website and was used in the model without modification. The modeler just provided background information that discharge was calculated based on rating curve and well data.
Pg3: Stage data from Station US 17-92 was used to fill in gaps in stage data for PC Stage as shown in Figure 3.3 in Xiong (2016). The location of these stations is listed in Table 3.2 and displayed in Figure 3.2 and 3.3 in Xiong (2016) however the sampling frequency is unclear and needs further discussion.	Sampling frequency was added in the report.
Pg3: The source of the watershed delineation is the ECT (2012) report however no figure illustrating its location or connectivity to the GSP is provided. In order to strengthen the document, an additional figure illustrating the watershed area and location(s) where runoff contributes to the pool is recommended. This may further assist discussion of model results where salinity is lower on the south bank as illustrated in Figures 6.7–6.9 in Xiong(2016).	Detailed information on GSP watershed yield can be found in ECT (2012) report.
Pg3: More detail is needed in Section 3.2 that discusses the source(s) of this data and how the data was processed to obtain the bathymetry for each cell of the model. If the bathymetry data is not certain then a sensitivity analysis should be performed to test the impact of the poorly defined data.	The bathymetry data used to generate model grid was further elaborated in the report.
Pg3: Salinity data for the downstream open boundary condition (i.e. Padgett Creek) was taken from Station GEM1 however salinity data for the upstream flow boundary condition (i.e. Gemini springs) was compiled from several sources and the methodology used to derive monthly average values is not discussed. Further discussion on salinity data including the sampling period, frequency, and methodology used calculation of the upstream flow boundary condition would strengthen documentation.	Information on salinity at boundaries has been clarified in the report.
Pg4: Stage and rating curves for two wells were used to calculate discharge at Gemini springs as stated in Section 3.3 and 4. The data and methodology used to develop this relationship is discussed in Appendix A and B however, the discharge correlation should be expanded upon in the report.	The main focus of this report is to conduct hydrodynamic analysis of GSP. Rating analysis was included in Appendix A and B. The detailed discussion on discharge correlation with wells was not within scope of work for this modeling analysis.
Pg5: For the GSP model, stage was calibrated with observed data at the pool (Station 00410494) and salinity data at the outfall (Station VC-083). The pool stage data represents the best available data for this location however there is another station (Station GE02) at the outfall location with salinity measurements; as the sampling period and frequency are not discussed, it cannot be ascertained which represents the best available data for this location. Inclusion of two additional fields, sampling period and sampling frequency, into Table 3.2 may provide clarification as to why station VC-083 was preferred.	Station VC-083 has more salinity data than station GE02 and both stations are close to boundary. Thus data from station VC-083 was used for boundary condition.
Pg6: The rational method runoff coefficient, C, can be represented by 0.20 which is reflective of forest and open space in the watershed. A figure of the watershed confirming that the land cover is mostly forest	Arial photo of Figure 2.4 includes land coverage of Gemini Springs Park watershed. Detailed information regarding to watershed discharge can be found in ECT (2012) report listed in the reference.

Peer Review Comments	Resolution
and open space is needed to support this statement.	
Pg6: Gaps in daily salinity data can be filled with linearly interpolated values or monthly averaged between available data points. When each of these methods was used should be clarified in the documentation.	In the model, linearly interpolation was used for salinity boundary.
Pg7: The major limitation of the model is the calibration dataset that focuses on a period of high springs discharge. Whether or not this is a critical issue given the range of discharge from 6.2 cfs to 15.3 cfs (SJRWMD, 2016) should be discussed in the documentation.	The range of discharge during calibration and validation period is between 7.62 and 12.1 cfs, which covers 0.1% to 99.6% of the entire data collection period. So it should not be an issue.
Pg7: Propagation of bias from other models. Statistical models were used to determine the division of Gemini springs discharge between the North and South Vents, and calculate pool discharge based on well stage. Known bias for each of these models should be presented in the main body of the report, as this bias then propagates into the GSP model.	Flow measurement was made several times at each vent by USGS and they all concluded approximately 65% and 35% distribution between two vents. Considering their locations and closeness to each other, a few percent variation should have very limited effect on the entire GSP. As for calculation of pool discharge based on well stage, the correlation coefficient is 0.837 (Appendix A).
Pg7: Sensitivity analysis has not been conducted on the EFDC GSP model. Evaluating the sensitivity of the model to changes in calibrated parameters discussed in Section 4.1 of Xiong (2016) and to discharge (given the differences in discharge between the calibration and validation periods) is essential in order to have a more thorough understanding of model sensitivity. Of particular importance is the quantification of model sensitivity to the assumption of uniform bottom roughness height and to the uniform bottom roughness height of 0.001 meters, which is slightly outside the range of typical bottom roughness heights. Quantifying the model sensitivity will increase confidence in the predictive capability of the model.	There is no vegetation coverage within Gemini Spring Pool, so uniform bottom roughness is reasonable estimation for the model. The bottom roughness height used in the model was actually 0.002 meters, 0.001 m from grid input file DXDY.INP and 0.001 m from general EFDC input EFDC.INP. Sensitivity test was conducted by adjusting roughness from 0.002 m to 0.006 m for calibration period. The long-term absolute difference of water level and salinity at 00410494 station between the two runs were 0.0004 m and 0.002 ppt, respectively. The results implied that the model was not very sensitive to selection of bottom roughness.
Pg12: Errata The following errata noted in Xiong (2016b) should be addressed in the final model documentation: 1. The List of Figures is missing the plural. 2. The period of record (POR) is referred to for several data sources but the dates need to be clarified. 3. Figure 2.4 needs a legend to identify discharge sources and stations as well as labels to distinguish between pool seep and north seep. 4. It is unclear the purpose of including “The average flow yield of the small watersheds near Sanford…” in Section 2. 5. Clarification as to the sampling locations and frequency is needed in Section 2.2 to address the unknown District sampling frequency at Gemini springs from 2010 – present 6. Section 2.2 paragraph one should state “If two water parcels enter a system at the same time and move toward…” 7. Section 3 paragraph two should state “…focus on horizontal variations as well as to increase…” 8. Section 3.1 paragraph one should be “EFDC was originally… 9. Section 3.2 paragraph one; the sentence ending with “totally” should be changed to “in total.” 10. Figure 3.1. Show only 2-3 significant figures in Legend for bathymetry. 11. Section 3.3 paragraph one should state “United States Geological Survey (USGS), and…” 12. Resolution of figures and tables needs to be higher, in particular the x-axis legend in Figure 3.2 is difficult to read. 13. Legend in Figures 3.2, 4.1, and 4.3 should read “Stage” rather than “Gage”. 14. Section 3.3 last paragraph should use English units to be consistent with the rest of document: “The initial water surface elevation was set to 1m…” 15. Section 4.1 last paragraph, “…and then the model was considered calibrated.” should be reworded. 16. Section 6.1 last paragraph should state, “For submerged weir flow cases (from Case 4 to 6)…” 17. Section 6.1 paragraph one, “…leaving the pool quickly and allow saltier water to arrive certain unfrequented area...shorten the time...which could be the blockage prevents…” should be reworded.	The Errata had been addressed on the Peer Reviews in the updated final report.

Appendix D – Gemini Springs MFL Hydrologic Data Analysis

TECHNICAL MEMORANDUM

Date: March, 2017

By: Fatih Gordu. P.E and Jane Mace

Subject: Gemini Springs MFL 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 Gemini springs MFLs determination and assessment.

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
5. Estimating available water (freeboard or deficit)

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

Hydrologic Analysis

1 Data review

Gemini Springs is located within the St. Johns Offset sub-district of the Central Lakes District (Brooks 1982), an area characterized by sandhill karst with solution basins. The upper Floridan Aquifer is the source of discharge for most springs in this region, including Gemini Springs.

Gemini Springs is historically classified as a second magnitude spring (Rosenau et. al, 1977; http://www.sjrwmd.com/springs/gemini.html (SJRWMD 2016b). Minimum and maximum recorded discharges at Gemini Springs equal 6.2 and 13.0 cfs. Based on USGS and SJRWMD discharge data from 1993 to March 2016 with both random and daily discharge data the median discharge equals 9.5 cfs and the average discharge equals 9.7 cfs, identifying Gemini Springs as a third magnitude spring, just below the second magnitude spring minimum threshold of 10 cfs. Gemini Springs discharge, measured at the weir outlet, represents the combined flow from the two vents (Figure 1). Approximately 65% of the reported discharge occurs from the northwest vent, with 35% discharge from the east vent (Xiong and Zhang 2017).

Daily discharge measurements at Gemini Springs began in March 2009 and are based on the relationship between Gemini Springs discharge and the water level in nearby wells (S-1225, 2009-2011 and V-081, 2011 to present). Gemini Springs discharge is less than 0.5% of the St. Johns River flow immediately downstream from Lake Monroe at US Highway 17 (ECT 2012). Thus, changes in Gemini Springs discharge have little effect on the receiving water body, Lake Monroe and the St. Johns River. Additionally, because the Gemini Springs weir outfall and hydrologic control elevation equals only 0.51 ft NAVD88, Lake Monroe regularly (approximately 51% of the time; ECT 2012) backs into the Gemini Springs reservoir and spring vents, reducing the springs discharge (Figures 2- 4). Also, when Lake Monroe experiences average and low stages, resulting in small and zero backwater affect, surface water levels in the Gemini Springs reservoir remain very stable with a median stage of 1.4 ft NAVD88 under a relatively wide range of spring discharges, indicating that the weir provides considerable stability to water levels in the reservoir over a range of discharge rates. Figure 2 illustrates the poor stage-discharge relationship for Gemini Springs based upon Gemini reservoir stage and Gemini Springs discharge.

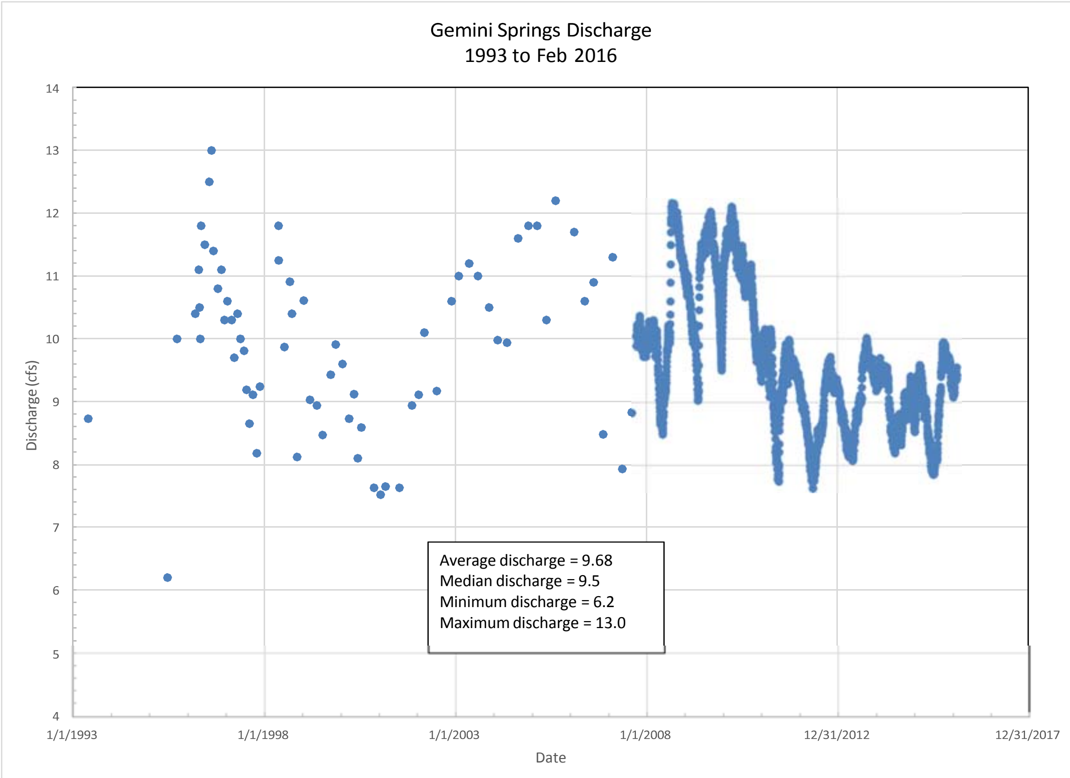


Figure 1. Gemini Springs period of record discharge

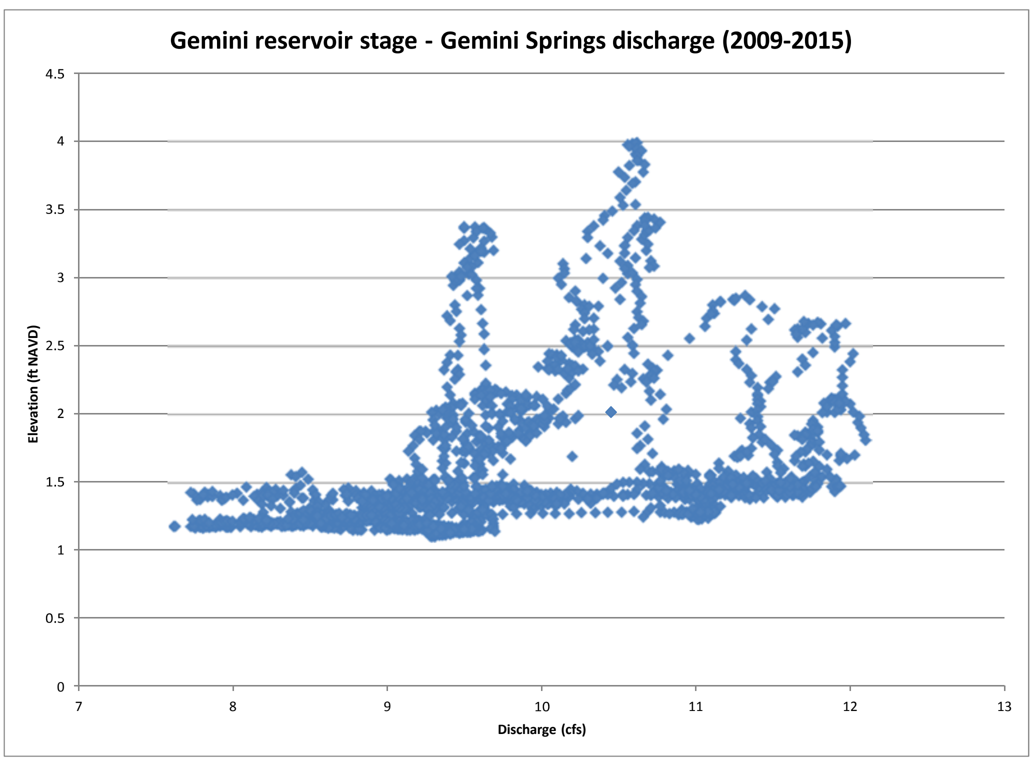


Figure 2. Gemini Springs discharge and reservoir stage

Figure 3. High water floods into Gemini Springs reservoir (photo T. Richardson)

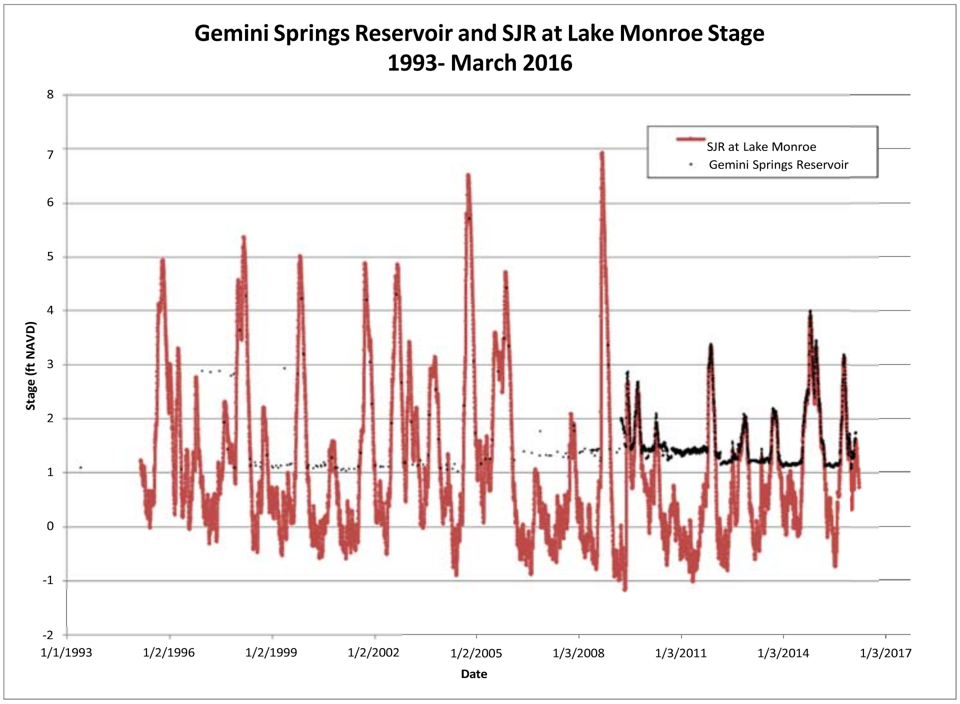


Figure 4. Gemini Springs reservoir stage and the St. Johns River at Highway 17/92 stage

2 Period of Record

As discussed in Section 1, Gemini Springs discharge data are not continuous daily data until 2008. They were generally random measurements and for some years, monthly data was available. There were only two records available until 1995. Table 9 shows the number of records available for spring discharge per year. The review of available data indicated that there was not sufficient data available before 1995 to be used for the MFL analysis. Therefore, only the data collected after 1995 were used in the MFL analysis.

Table 1. Number of spring flow records

Year	Number of flow records
1972	1
1993	1
1995	2
1996	12
1997	11
1998	6
1999	6
2000	6
2001	4
2002	4
2003	4
2004	4
2005	3
2006	4
2007	95
2008	356
2009	353
2010	365
2011	365
2012	366
2013	365
2014	365
2015	365

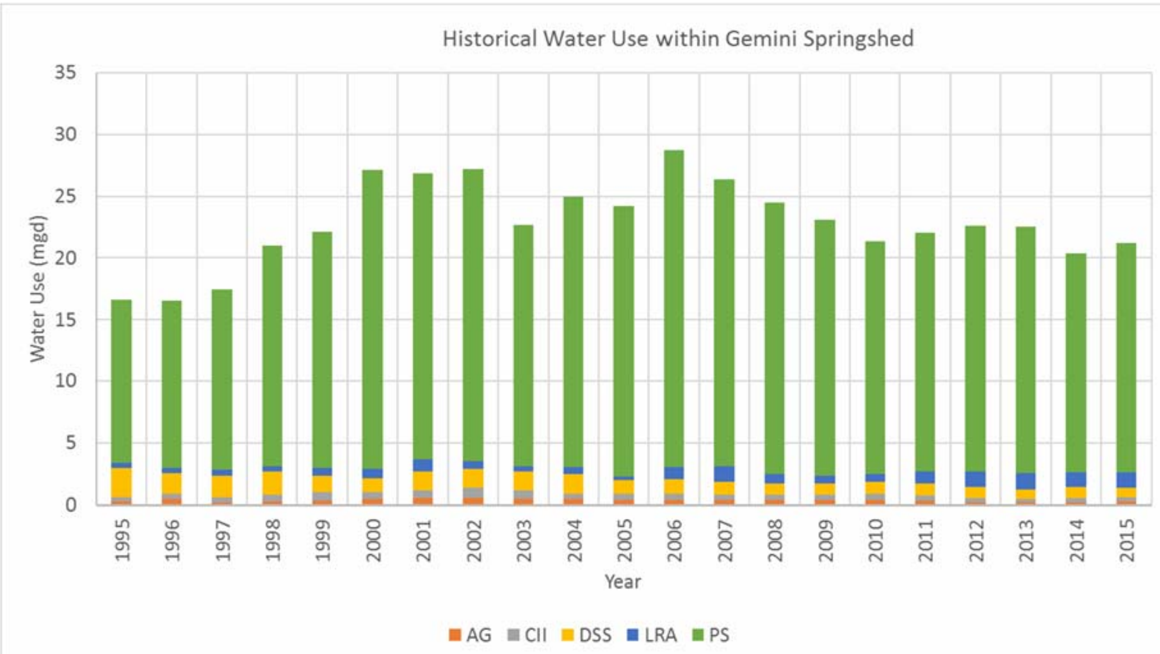
3 Groundwater pumping impact assessment

3.1 Groundwater use

To estimate the potential impact on spring flows from pumping, annual groundwater use from 1995 to present was estimated within the Gemini springshed plus a one-mile buffer (Figure 5). The springshed (groundwater contributing area) was developed using the Upper Floridan Aquifer potentiometric surfaces and a 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 5. Gemini 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 within the springshed plus one-mile buffer. Groundwater pumping totals include estimates for uses exempt from permitting requirements (e.g., domestic self-supply) and uses that fall below permitting thresholds (e.g., small agricultural operations). Figure 6 shows the estimated groundwater use within the springshed plus one-mile buffer.



PS: Public Supply; AG: Agricultural; CII: Commercial/Industrial/Institutional; LRA: Landscape/Recreational/Aesthetic; DSS: Domestic Self-supply

Figure 6. Estimated groundwater use within Gemini springshed plus one-mile buffer

3.2 Estimated impact on spring flows

The latest version of the SJRWMD Volusia County steady-state groundwater model was used (SJRWMD, 2016) in the assessment of potential impacts of groundwater pumping on spring flows. Because the latest version of the Volusia model was developed for 2010, the assessment was estimated under the 2010 groundwater pumping condition and resulted in an estimated impact of about 1 cfs.

Next, the relationship between the groundwater pumping and the reduction in spring flow due to pumping was developed using the Volusia County steady-state groundwater flow model. Figure 7 shows the relationship between the pumping in the model within springshed plus one mile buffer and the reduction in flow.

Using the estimated groundwater pumping from 1995 to present and the relationship between pumping and the reduction in spring flow (polynomial function shown in Figure 7), annual impact to the spring flow from historical pumping was estimated (see Figure 8).

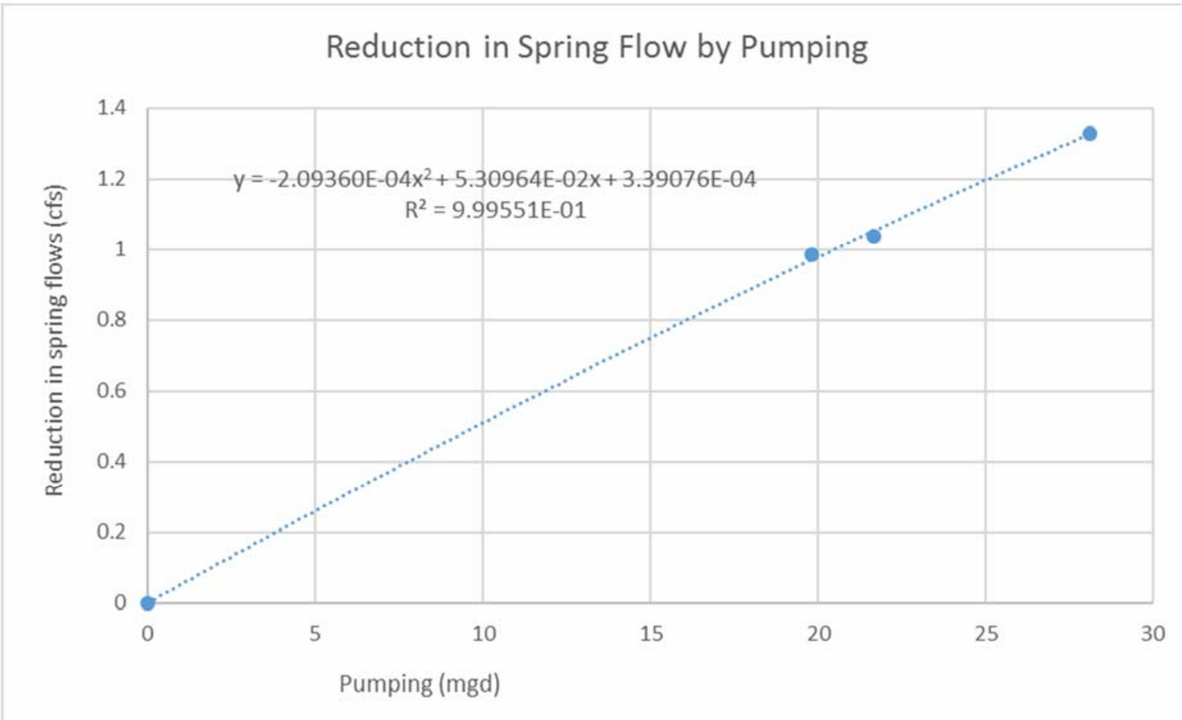


Figure 7. Relationship between pumping and change in spring flow

There are many springs (more than 45 springs) including Blue springs (a first magnitude spring) and river system such as Wekiva river in the close vicinity of Gemini spring (see Figure 9). It should be noted that the springshed shown in Figure 5 is our best estimate of possible maximum extent of the groundwater contributiong area. Because of existence of many other springs and water bodies in close proximity of Gemini spring as shown in Figure 9, delineating a springshed that encompasses a groundwater contributing area only for Gemini springs is not possible. All the other springs and water bodies in the area most likely interacts each other and have overlapping groundwater contributing areas. Because of this, the groundwater wells within the estimated Gemini springshed shown in Figure 9 withdraws water not only from the Gemini springshed but also from the groundwater contributing areas of the other springs and water bodies in the area. So, their impact spreads over many springs and water bodies. Since the Volusia county groundwater model takes into account all the interaction among springs and other water bodies in the area, it is the best available tool to estimate most likely impact of groundwater pumping on Gemini springs.

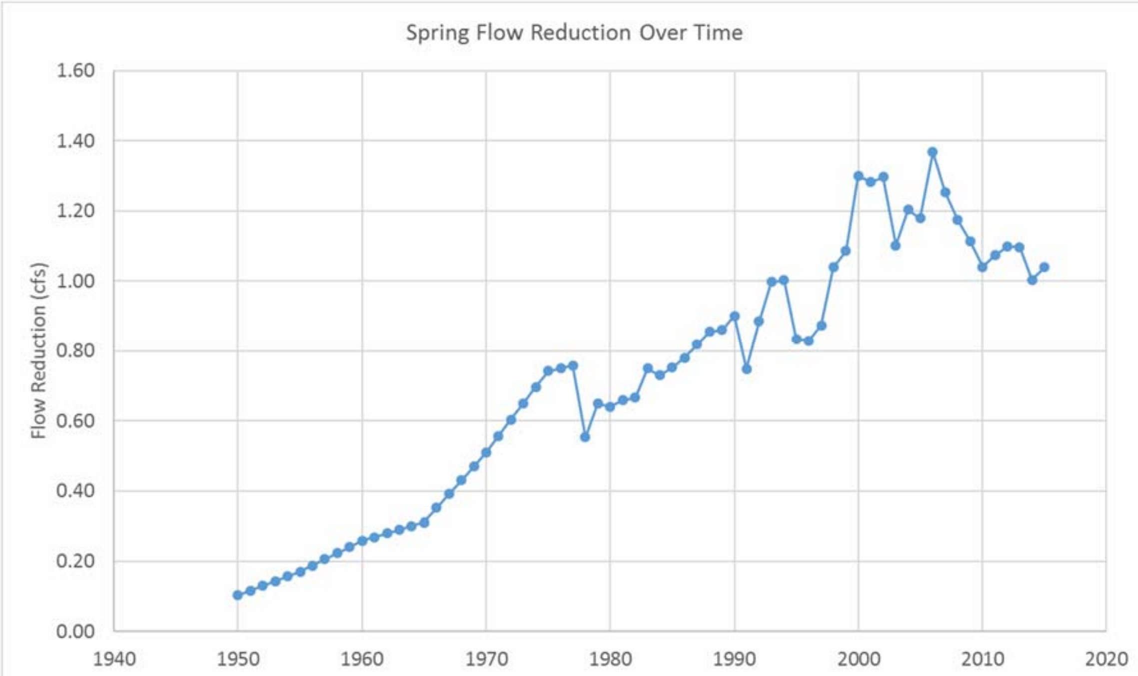


Figure 8. Estimated impact of pumping on spring flow over time

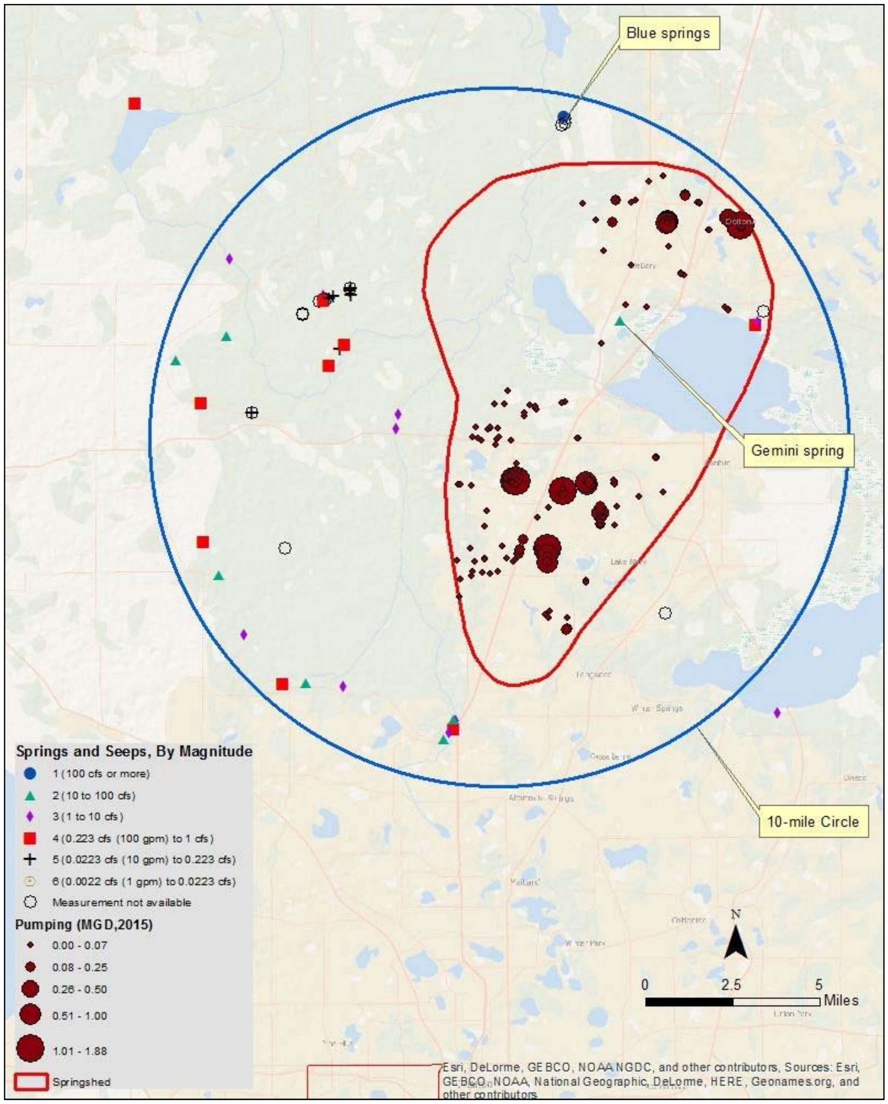


Figure 9. Other Springs and pumping wells near Gemini spring

4 Development of Synthetic Flow Time Series

Gemini spring MFL determinations and assessment are based on flow datasets representative of baseline and no-pumping conditions. 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. Because the latest groundwater model available for MFL analysis simulates the 2010-pumping condition, the 2010-pumping condition was assumed to represent the current pumping condition. As shown in Figure 6, the pumping in 2010 is not siginificantly different than current pumping, it should be considered a reasonable assumption. 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.

4.1 "No-pumping condition" flow time series

The impacts of pumping as shown in Figure 8 were added to the annual means of the monthly means of observed spring flow data to create a "no pumping condition" flow time series. This synthetic flow time series constitutes a reference hydrologic condition of the spring system in which the impact from groundwater pumping is assumed to be minimal.

4.2 "Baseline condition" flow time series

The Volusia groundwater model estimated a reduction of spring flow of 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 flow time series dataset for Gemini Spring. The synthetic baseline condition flow time series dataset represents a reference hydrologic condition of the spring system in which the impact from groundwater pumping on spring flows is constant over time at a rate of 1.04 cfs. Assuming climatic, rainfall, and other conditions present from 1995 – 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 Gemini Springs. Figure 10 shows the observed, no-pumping and baseline condition flows.

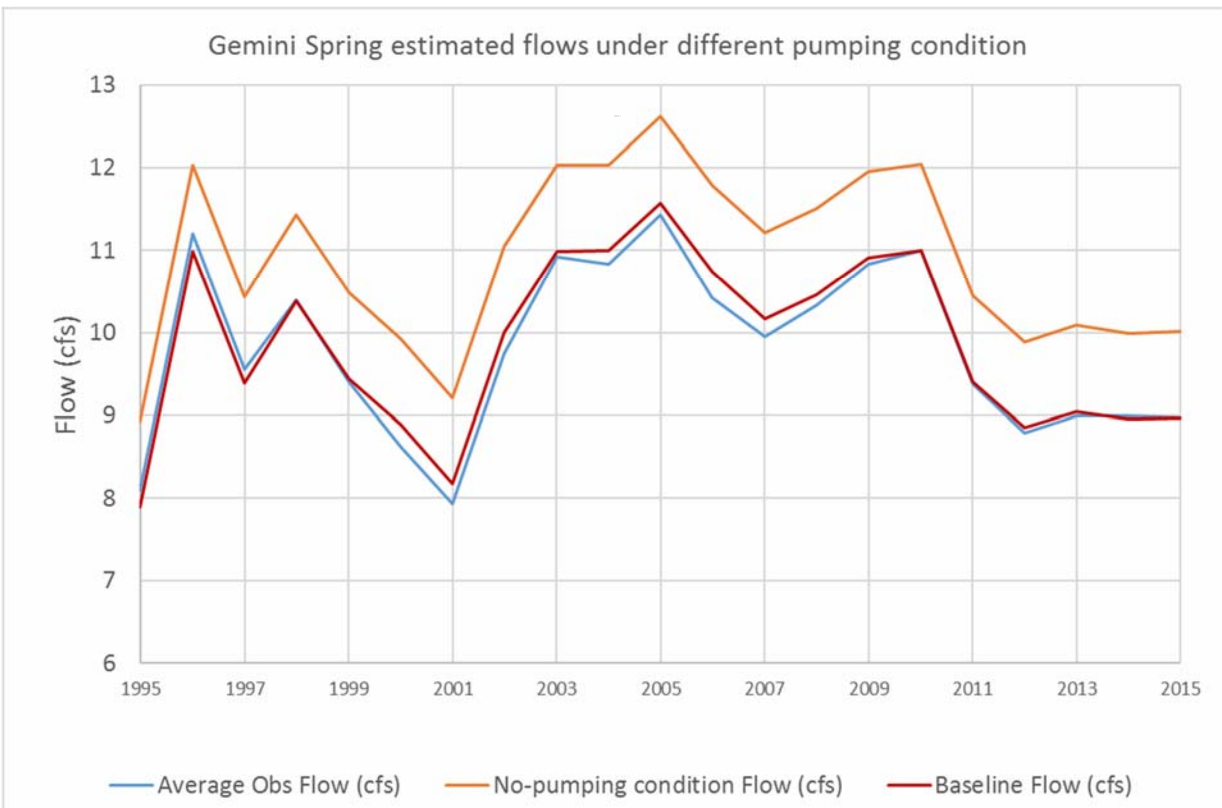


Figure 10. Observed and Estimated spring flow datasets

5 Estimating Available Water (Freeboard/Deficit)

5.1 Determination of MFLs

The recommended minimum flow is based on a 15% flow reduction from 10.91 cfs which is the average no-pumping condition flow for the period from 1995 to 2015 described in section 4.1. This results in a recommended minimum flow of 9.3 cfs. The basis of 15% flow reduction is described in detail in the report.

The average annual rainfall (Sanford station) for the same time period is 51.8 inches whereas the long-term (1957-2015) average annual rainfall is 48.3 inches. Therefore, the time period used to determine the MFL represents a slightly higher than long-term average rainfall condition.

5.2 Freeboard/Deficit

If the average baseline condition is higher than the recommended minimum flows, the difference would be the freeboard which would be the available water. If the average baseline condition is lower than the recommended minimum flows, the difference would be the deficit. The average baseline condition flow is 9.9 cfs and is higher than the established minimum flow of 9.3 cfs. Therefore, the freeboard is 0.6 cfs.

References

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