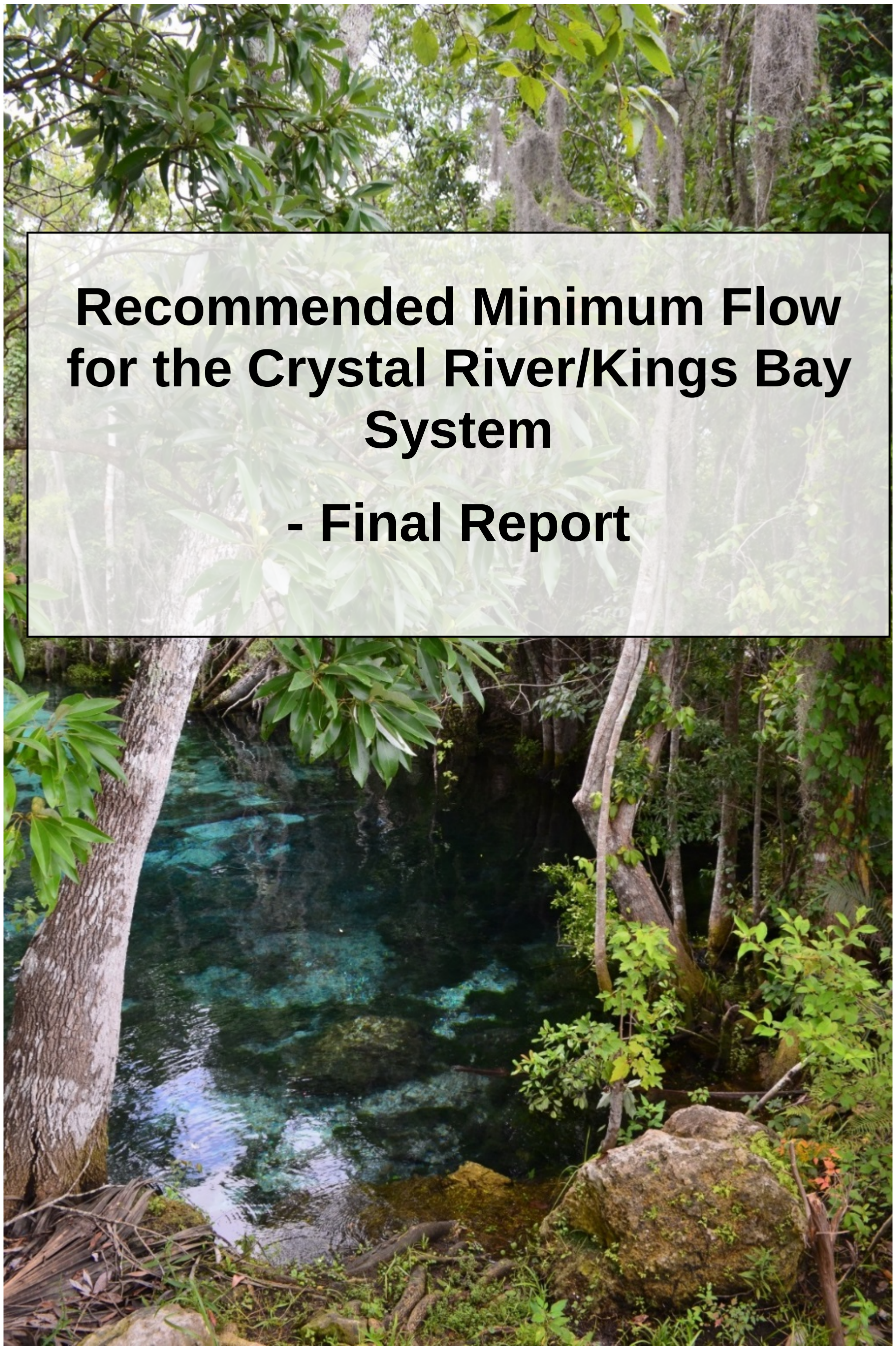
Recommended Minimum Flow for the Crystal River/Kings Bay System

- Final Report



May 1, 2017

Southwest Florida
Water Management District

Recommended

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Southwest Florida Water Management District

Brooksville, Florida 34604-6899

Gabe Herrick, XinJian Chen, Ron Basso, Mike Heyl and Doug Leeper

Recommended Minimum Flow for the Crystal River/King's Bay System

May 2017

The geological evaluation and interpretation contained in the report entitled *Recommended Minimum Flow for the Crystal River/King's Bay System* has been prepared by or approved by a Certified Professional Geologist in the State of Florida, in accordance with Chapter 492, Florida Statutes.

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ACKNOWLEDGEMENTS

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We are also indebted to several individuals and companies not directly affiliated with the District who helped with our work. We thank: the staff at Avineon for their vegetation assessments; Jim Culter with the Mote Marine Laboratory for his survey of barnacles within the system; Ping Wang with the University of South Florida for collecting bathymetric data; David Evans and others at Water & Air Research, Inc., for their assessment of benthic macroinvertebrates; Tom Frazer and Chuck Jacoby at the University of Florida for their data compilation and vegetation sampling efforts; Keith Hackett and Tony Janicki with Janicki Environmental, Inc., for their assessment of system salinities; Scott Burghart and Ernst Peebles with the University of South Florida for the analyses of zooplankton and ichthyoplankton; Cameron Gunther, Tim MacDonald, Robert McMichael and J. Davis with the Florida Fish and Wildlife Conservation Commission for their evaluations of nekton; Gary Serviss, Ronnie Van Fleet and others at Vanasse Hangen Brustlin, Inc. for their characterization of springs within the bay; and Dann Yobbi for his constructive review and insights concerning flow measurements. Finally, we thank Steve Peene, Ken Watson and Adam Munson for the constructive, independent scientific review of the originally proposed minimum flow.

EXECUTIVE SUMMARY

The Southwest Florida Water Management District (District) is directed by the Florida Legislature to establish minimum flows for all surface watercourses, i.e., for flowing surface waters within its jurisdiction. Minimum flows are defined in Section 373.042(1) Florida Statutes as “the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area.” Once adopted into District rules, minimum flows can be used for water supply planning, water use permitting and environmental resource regulation.

This report identifies proposed minimum flows for the Crystal River/Kings Bay system. The system includes a group of 70 springs that discharge approximately 215 million gallons per day of freshwater into the 600 acre Kings Bay. Water flows from Kings Bay into the Crystal River, which flows roughly 10 km / 6 mi into the Gulf of Mexico. The entire system is influenced by tides and salt water from the Gulf of Mexico.

The Crystal River/Kings Bay system is habitat for numerous plants, fish, invertebrates, birds, and other freshwater, marine, and estuarine species. This system is an Outstanding Florida Water, is the subject of a District Surface Water Improvement and Management (SWIM) plan, and is valued by residents as a tourist attraction, recreational site, and area of natural beauty. The springs discharging to Kings Bay are collectively classified as an Outstanding Florida Spring.

Discharge from spring vents is affected by groundwater levels within the aquifer and by surface water level in the bay above each vent. Rising groundwater levels increase discharge, while rising surface water levels decrease discharge. The springshed for these spring vents is in an unconfined region of the aquifer, which means that groundwater levels are directly influenced by rainfall and consumptive water use within the area, while factors outside the springshed have little effect on discharge. As such, discharge varies seasonally in correspondence with rainfall patterns for west-peninsular Florida, and on tidal cycles with the Gulf.

Spring discharge and its effect on water salinity and temperature within the system were modeled using tools that are the peer-reviewed, published, innovative products of District scientists. These models allowed evaluation of salinity-based habitats and manatee thermal refuge as potential indicators of significant harm. Salinity is particularly important as a factor determining the distribution and abundance of estuarine life. All 10 environmental values put forth in the State Water Resource Implementation Rule for minimum flow development were considered.

Water quality measurements were compared with established limits, and trends with time and flow were investigated. However, a full determination of the potential impacts of changes to flow on water quality is not feasible at this time. The District recommends that future work focus on quantification of potential relationships between flow reductions and water quality parameters - particularly chlorophyll a and other parameters tied to water clarity. Because of the lack of available data and analyses, water quality measures other than salinity and temperature were not available for use as criteria for setting the minimum flow for this system.

A draft minimum flow recommendation (Herrick et al. 2016) was reviewed by a Peer Review Panel of independent experts (SWFWMD 2016). This draft report recommended a minimum flow of 88 percent of the baseline, natural flow, based on determination of significant harm as a loss of 15 percent of low-salinity habitat defined by the volume of water less than or equal to 2 parts-per-thousand salinity. Overall, the Panel supported the conclusions and methodology in the report. The Panel generated 94 numbered comments among other unnumbered responses to the report. Among their comments, the Panel recommended further analysis of shoreline salinity-based habitats by distinguishing between altered shorelines (e.g., riprap and sea wall) and shorelines that are natural or vegetated. This recommended shoreline analysis resulted in a revised minimum flow recommendation of 89 percent of the baseline, natural flow to prevent a reduction of more than 15 percent of natural and vegetated shoreline exposed to average salinities less than or equal to 0.5 parts-per-thousand salinity. The proposed minimum flow for the Crystal River/Kings Bay system is protective of all relevant environmental values identified in the State Water Resource Implementation Rule for consideration when establishing minimum flows and levels.

Current withdrawal impacts springflow to the Crystal River/Kings Bay system and projected impacts for a 20-year planning horizon are on the order of 1 to 2%, respectively, indicating that development of a recovery strategy or specific prevention strategies for recovering flows or preventing flows from falling below the proposed minimum flow are not currently necessary. The District will continue to monitor flows in the system and complete periodic status assessments to ensure that the established minimum flow continues to be met. In addition, staff recommend reevaluation of the minimum flow for this system within ten years of its adoption into District rules.

CHAPTER 1 - INTRODUCTION

1.1 Overview

Our purpose is to find the minimum amount of groundwater discharge from submarine spring vents in Kings Bay necessary to prevent significant harm to the water resources or ecology of the Crystal River/Kings Bay system. In order to measure harm to water resources and ecology, we identified criteria that support the ten environmental values listed in the Water Resource Implementation Rule. Thus, we can establish a mechanistic, causative chain from reduced groundwater levels caused by water withdrawals (well pumping) through reduced spring discharge, reductions in measured criteria, and ultimately to environmental values held by the State of Florida and its citizens.

1.2 Legislative Direction

Our purpose is to establish the minimum spring discharge necessary to prevent significant harm to the water resources and ecology supported by the Crystal River/Kings Bay system. We are primarily guided in our purpose by legal directives which mandate setting minimum flows for surface water courses and prescribe methods for implementation:

1. Sections 373.042 and 373.0421 of The Florida Water Resources Act of 1972 (Chapter 373, Florida Statutes or F.S.) direct the Department of Environmental Protection (DEP) or the Southwest Florida Water Management District (SWFWMD or “District”) to establish minimum flows for all surface watercourses in the area.
2. Section 62-40.473 of The Florida Water Resource Implementation Rule (Chapter 62-40, Florida Administrative Code or F.A.C.), provides goals, objectives and guidance regarding the establishment of minimum flows and levels.

The District’s Minimum Flows and Levels Program addresses all relevant requirements expressed in the Water Resource Implementation Rule as well as those included in the Water Resources Act of 1972. The Crystal River/Kings Bay system is a flowing surface water course, and as such its volume of flowing water must be protected from significant harm. Establishing minimum flows that address all relevant requirements expressed in the Florida Water Resources Act of 1972 and the Water Resource Implementation Rule will support water-use permitting, water-supply planning and other water management activities that can provide this protection.

1.3 Minimum Flow Development

1.3.1 Fundamental Reasoning

The development of Minimum Flows proceeds from the following premises:

1. Alterations to hydrology will have consequences for the environmental values listed in Rule 62.40.473, F.A.C., and section 1.3.3 of this report.

2. We can measure criteria linked to these environmental values. We can also quantify links between flow alterations and measured criteria.

3. Flows may be reduced from non-withdrawal impacted conditions, yet be of sufficient magnitude to protect the water resources and ecology associated with identified environmental values.

An established body of scientific work supports all three of these premises by relating hydrology, ecology, and human-use values associated with water resources (Poff and Zimmerman 2010, Postel and Richter 2012). For example, consider a pristine, unaltered river with no local groundwater or surface water withdrawal impacts. We expect this hydrologic regime to respond in proportion to the magnitude of any new water withdrawals. Small withdrawals may produce a new hydrologic regime that is indistinguishable from the historical, natural regime, while large withdrawals could produce substantially altered regimes. An intermediate hydrologic regime will protect the water resources and ecology from significant harm while allowing for deviation from the historical hydrological habitat. Our objective is to define such an intermediate hydrologic regime that prevents significant harm, yet allows for withdrawals that may shift the regime away from historical or theoretically optimal conditions.

1.3.2 Flow Definitions

To address all relevant requirements of the legal mandates described above and aid in the understanding of information presented in this report, we find it helpful to elaborate on several flow-related definitions and concepts found herein.

1. Flow refers to streamflow or discharge – the volume of water flowing past a point for a given unit of time. Flow may be reported as in cubic feet per second (cfs), as has been done at U.S. Geological Survey (USGS) gages in Crystal River. In Kings Bay, discharge has been measured for individual vents and for groups of vents. Total spring discharge into the bay is a modeled value based on the difference between aquifer and sea levels (detail provided in the methods section of this report).

2. Long-term is defined in Rule 40D-8.021, F.A.C., as an evaluation period for establishing minimum flows and levels that spans the range of hydrologic conditions which can be expected to occur based upon historical records.

3. Reported, measured, gaged, and observed flows can be directly measured, however, in practice, flows are derived from relationships to directly-measured stage (elevation) and velocity data. One can measure water velocity (ft s^{-1}) and multiply this with cross-sectional area (ft^2) to get discharge (ft^3 s^{-1} or cfs). Further, discharge is commonly measured at USGS stations using stage measurement along with a rating curve based on repeated measurements of discharge and channel geometry (Buchanan and Somers 1969). For spring vents, discharge can be calculated as the product of velocity and vent mouth area.

4. Tidally filtered flow is calculated to remove tidal aliasing. Tidal aliasing is an apparent oscillation in the daily value of discharge which results from mismatch between the 24.84 hour lunar tidal cycle and the 24 hour solar day. The application of a low-pass digital filter is one way to eliminate the effects of tidal aliasing in time series data.

5. Modeled flows are flows that are derived using a variety of modeling approaches. Examples include flows predicted using numerical groundwater flow models, flows

predicted with statistical models derived from either observed or other modeled hydrologic data, and impacted flows adjusted for withdrawal-related flow increases or decreases.

6. Impacted flows are flows that include withdrawal-related impacts. Impacted flows can be *reported flows*, and they can also be *modeled flows*.
7. Baseline, natural, unimpacted, or historic(al) flows occurred in the absence of withdrawal impacts. Baseline flows may be *observed flows* if data exists prior to any withdrawal impacts. More typically, baseline flows are *modeled flows* based on our best knowledge of prior conditions. Rule 40D-8.021, F.A.C., defines "historic" as "a Long-term period when there are no measurable impacts due to withdrawals and Structural Alterations are similar to current conditions."
8. Minimum flow is defined by the Florida Water Resources Act of 1972 as "the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area."
9. A flow regime is a hydrologic regime characterized by the quantity, timing and variation of flows in a river. Rule 62-40.473, F.A.C., dictates 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 as provided in Section 373.042(1), F.S." The emphasis on a flow regime, rather than a single minimum flow value, reflects the natural variation present in flowing water systems (Poff et al. 1997). Expressing a minimum flow as an allowable percentage of a flow addresses the intent of protecting the flow regime as allowable flow changes are proportionally-scaled to the magnitude of flow.

1.3.3 Environmental Values

As part of its intention to provide goals, objectives, and guidance, Rule 62.40.473, F.A.C., within the Water Resource Implementation Rule, states 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, including:

(a) Recreation in and on the water;
(b) Fish and wildlife habitats and the passage of fish;
(c) Estuarine resources;
(d) Transfer of detrital material;
(e) Maintenance of freshwater storage and supply;
(f) Aesthetic and scenic attributes;
(g) Filtration and absorption of nutrients and other pollutants;
(h) Sediment loads;
(i) Water quality; and
(j) Navigation.

The District's Minimum Flows and Levels Program addresses all relevant requirements expressed in the Water Resource Implementation Rule as well as those included in the Water Resources

Act of 1972. We describe links between these environmental values and impacts to critical resources predicted as a consequence of flow reductions in section 1-7 of this report.

1.3.4 Significant Harm

Minimum flows must be established to prevent significant harm to the water resources and ecology of the Crystal River/Kings Bay system (Section 373.042, F.S.). However, no definition of significant harm is given in the statute. This makes the District responsible for determining the conditions that constitute significant harm in each system.

The District has successfully employed a 15% resource reduction criterion in the past, starting with the suggestion of the peer review panel for the upper Peace River (Gore et al. 2002). This 15% resource criterion states that the minimum flow is that below which >15% of a critical environmental resource would be lost or become unavailable. We typically express this flow as a fraction of baseline, unimpacted flows. Suppose a 5% reduction from the baseline flow resulted in a 10% loss of critical fish habitat, and a 10% reduction in flow resulted in a 20% loss of habitat. We might surmise, by linear interpolation, that a 7.5% reduction from baseline flow results in a 15% loss of this critical resource. In such a case, our minimum flow would be set at 92.5% (100% – 7.5%) of baseline, to prevent loss of more than 15% of the resource. This percent-of-flow approach has been used to manage stream flows by the District in several systems and has been supported by multiple independent peer reviews (Flannery et al. 2002, Heyl 2008, Heyl et al. 2010, 2012, Leeper et al. 2012).

What critical resources or factors might serve as measures of significant harm? The health of a river depends upon diverse factors including physical sediment transport, chemical water quality, and provision of habitat for fish and other taxa (Karr 1999, Norris and Thoms 1999, Boulton 1999). The 15% criterion has been used to identify significant harm as the loss or reduction of: habitat associated with invertebrates and fish in freshwater and estuarine systems; days of inundation of floodplains; population size or abundance of fish and invertebrates; volume of thermal refugia for manatee; and salinity-based habitat in estuaries. The determination of significant harm as the loss of 15% of these and other ecological variables has been incorporated into numerous minimum flows included in the District's Water Levels and Rates of Flow Rule (Chapter 40D-8, F.A.C.).

Environmental flows, of which minimum flows may be considered a subset, have been studied worldwide. Many systems that have received attention are much more heavily altered than those within the District. For example, the published research on environmental flows includes systems that have withdrawals in excess of 50 percent, impoundments or both, e.g., Murray-Darling in Australia (Overton et al. 2009), San Francisco Bay (Kimmerer 2002), and many more reviewed by Poff and Zimmerman (Poff and Zimmerman 2010). Two independent reviews of existing literature both concluded that although the majority of studies (86% - 92%) recorded ecological changes in response to reduced flow, there are no universal responses that can be used to generalize across systems (Lloyd et al. 2004, Poff and Zimmerman 2010). Thus, it is necessary to consider the unique details of the Crystal River/Kings Bay system in order to determine how it will respond to reductions in flow.

Potential loss of habitats and resources in other systems has been managed using methods other than our 15% resource reduction criterion. In some cases, resources have been protected less conservatively than through our use of 15% change criteria, e.g., habitat loss > 30% compared with historical flows (Jowett 1993) and preventing >20% reduction to historical commercial fisheries harvests (Powell et al. 2002). Dunbar et al. (1998) note, "…*an alternative approach is to select the flow giving the 80 percent habitat exceedance percentile*," which is equivalent to an allowable 20 percent decrease from baseline conditions. More recently, the Nature Conservancy proposed that in cases where harm to habitat and resources is not quantified, presumptive standards of 10% to 20% reduction in natural flows will provide high to moderate levels of protection, respectively (Richter et al. 2011). Presumptive limitations on flow assume that resources are protected when more detailed relationships between flow and resources of interest are not available. It is preferable, when possible, to explicitly link reductions in flow to critical resources; this is the approach we use with our 15% resource reduction standard.

1.3.5 Vertical Datum

The District is in the process of converting from use of the National Geodetic Vertical Datum of 1929 (NGVD 29) to use of the North American Vertical Datum of 1988 (NAVD 88) for measuring and reporting vertical elevations. While the NGVD 29 datum is used for most elevation values included within this report, in some circumstances elevation data that were collected or reported relative to mean sea level or relative to NAVD 88. As necessary, elevations relative to the differing datums were converted to alternate datums in accordance with the District's internal operating procedure for minimum flows and levels data collection, summarization, reporting and rule development (Leeper 2016).

1.4 System Description

1.4.1 Hydrologic Setting

The Crystal River/Kings Bay system is located in Citrus County within the Southwest Florida Water Management District, on Florida's Springs Coast, approximately 60 miles north of Tampa, Florida (Figure 1-1). The bay extends over approximately 600 acres and includes more than 70 spring vents (Wang 2008 [included as appendix], VHB 2009 [included as appendix]), (Figure 1-2, Figure 1-3). These springs provide over 99% of the freshwater inflow to Kings Bay (Romie 1990). Collectively, the springs group is one of the largest in the state, with a first-magnitude designation denoting discharge of more than 100 cubic feet per second, equal to more than 65 million gallons of water per day. The Crystal River begins at the northwest edge of Kings Bay and flows northwest approximately six river miles to the Gulf of Mexico. The Crystal River/Kings Bay system is designated by the state as a Class III surface water body, an Outstanding Florida Water (OFW), and a Surface Water Improvement and Management (SWIM) Priority Water Body. The Crystal River Springs group is also classified as an Outstanding Florida Spring.

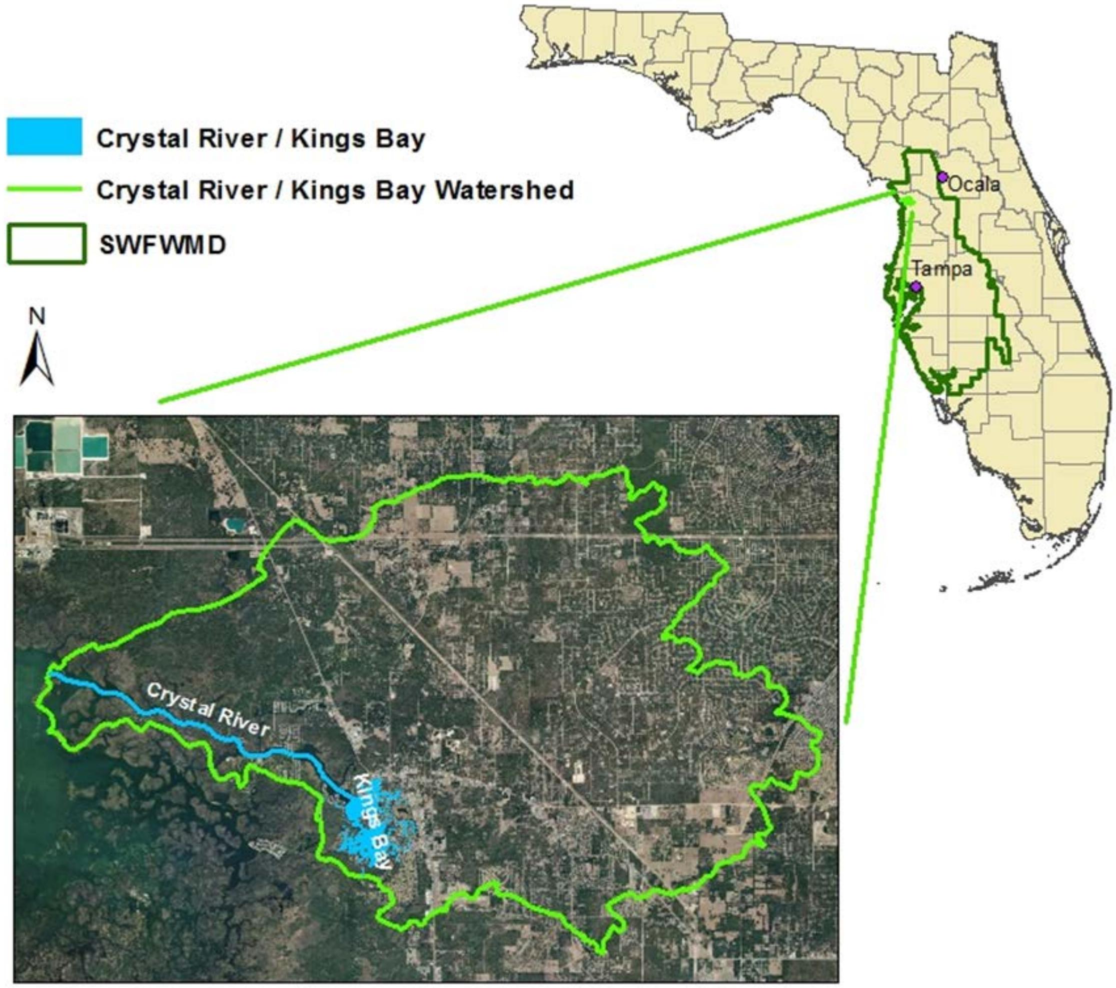


Figure 1-1 Location of Crystal River/Kings Bay system and watershed in Citrus County within the Southwest Florida water Management District (SWFWMD), Florida.

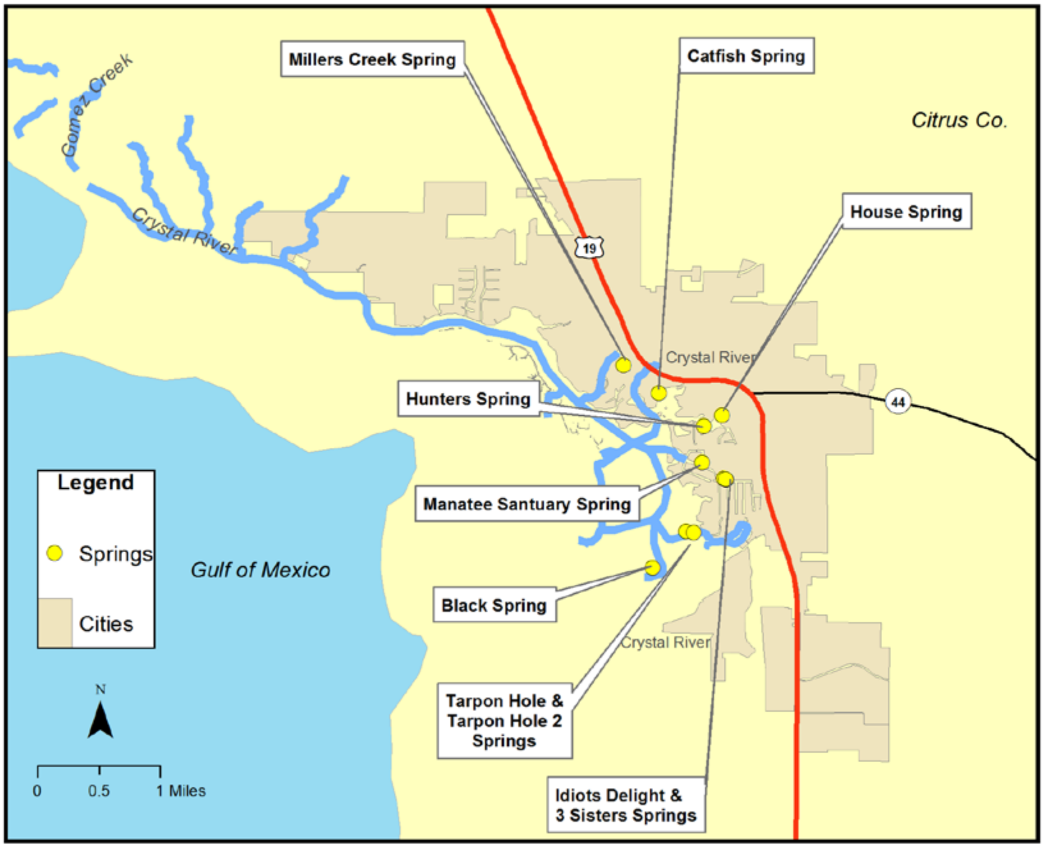


Figure 1-2. Location of Crystal River and selected springs.

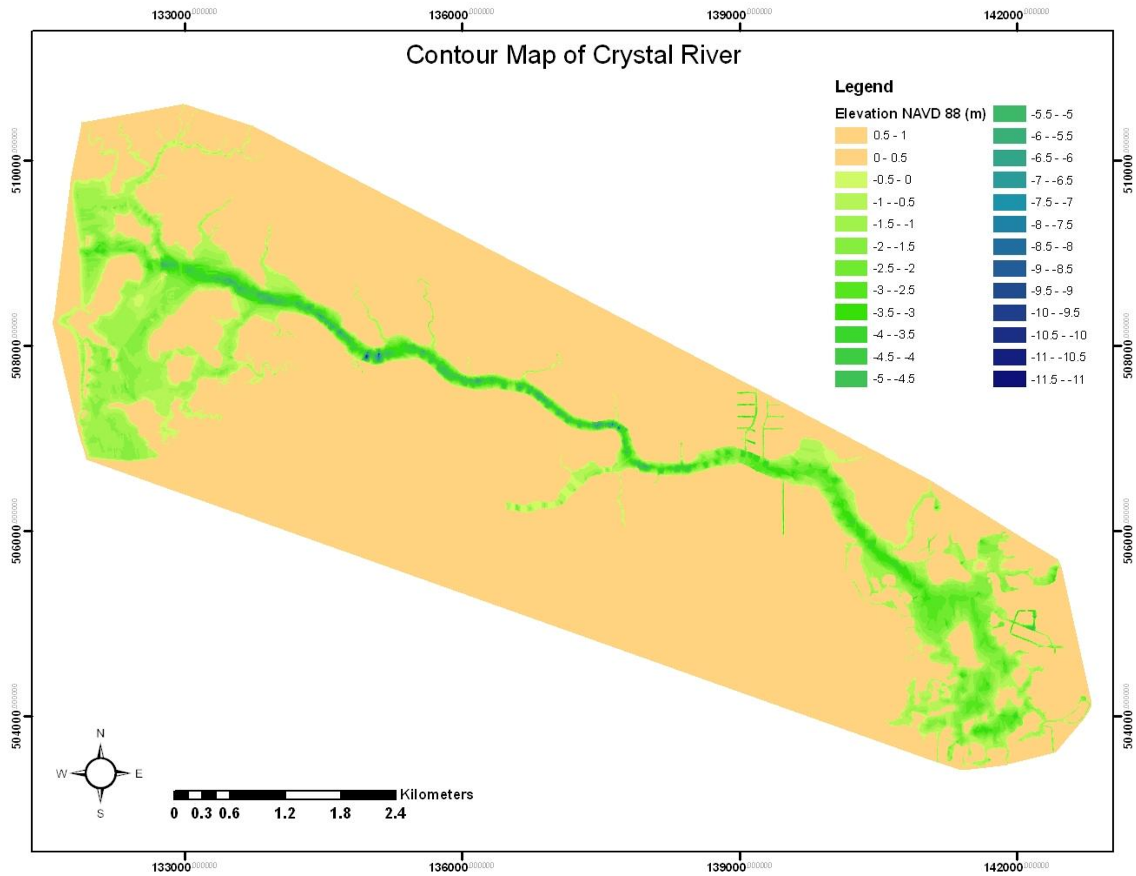


Figure 1-3. Bathymetry of the Crystal River/Kings Bay system.

Freshwater discharged from springs comes from groundwater within a springshed. The springshed for the Crystal River Springs group spans approximately 310 square miles in northern Citrus County (Figure 1-4). The potentiometric surface of the Upper Floridan aquifer (UFA) and groundwater flow field are used to delineate the springshed boundary. This boundary may shift slightly from year to year based on the measured elevation of the water levels within the UFA. However, the overall shape, size, and location of the springshed is expected to be relatively constant on a multi-decadal time scale.

The hydrogeologic framework in the vicinity of the Crystal River Springs group includes a surficial aquifer system, a discontinuous intermediate confining unit (ICU), and the thick carbonate Upper Floridan aquifer (UFA). Generally fine-grained sands occur at the land surface and extend several tens of feet deep before grading into clayey sand just above the contact with limestone. A thin, sometimes absent, sandy clay layer forms the intermediate confining unit (ICU) and overlies the limestone units of the UFA. In general, a regionally extensive surficial aquifer system is not present because the clay confining unit is thin, discontinuous, and breeched by numerous karst features. Because of this geology, the UFA is unconfined over most of the west-central Citrus County area.

The geologic units, in descending order, that form the freshwater portion of the UFA include the Oligocene age Suwannee Limestone, the upper Eocene age Ocala Limestone, and the middle Eocene age Avon Park Formation (Table 1-1). In northern Pasco and Hernando counties, the Suwannee Limestone is the uppermost unit. Further north in Citrus County, the Ocala Limestone forms the top of the UFA, while in extreme southern Levy County where the Avon Park Formation is exposed near land surface this formation is the top of the UFA. The entire carbonate sequence of the UFA thickens and dips toward the south and southwest. Average thickness of the UFA ranges from 500 feet in southern Levy County to 1,000 feet in central Pasco County (Miller 1986). The base of the UFA generally occurs at the first persistent sequence of evaporitic minerals such as gypsum or anhydrite that occur as nodules or discontinuous thin layers in the carbonate matrix. This low permeability unit is regionally extensive and is generally referred to as middle confining unit II (Miller 1986).

The springshed contributing flow to Crystal River Springs Group is located within the 4,600 square mile Northern West-Central Florida Groundwater Basin (SWFWMD 1987), which is one of seven regional groundwater basins located on the Florida peninsula (Figure 1-5). Similar to topographic divides that separate surface water drainage basins, groundwater basins are delineated by divides formed by high and low elevations in groundwater levels. Groundwater does not flow laterally between basins. Each basin also generally contains similar geology regarding the confinement of the UFA.

Water level declines due to pumping are greatest and most widespread in well-confined basins. In leaky or unconfined basins, pumping impacts are localized near major pumping centers with limited regional influence. Water level changes in the springshed for the Crystal River Springs group typifies the localized changes in water level found in unconfined regions (Figure 1-6). The greatest lowering of water levels in the UFA occurs in well-confined areas of Southeast Georgia, Northeast Florida, and Southwest Florida, where there is large groundwater extraction (Williams et al. 2011). In the unconfined regions, water level changes respond more to rainfall variation and pumping impacts are more localized.

In west Citrus County, the UFA is regionally unconfined and is located within a highly karst-dominated region. Dissolution of limestone is an active process via infiltration of rainwater because the limestone units of the UFA are close to land surface and poorly confined. Numerous sinkholes, internal drainage, and undulating topography that are typical of karst geology are frequent throughout the landscape. These active karst processes lead to enhanced permeabilities within the Floridan aquifer. The median transmissivity value of the UFA based on five aquifer performance tests in western Hernando and Citrus Counties is 210,000 ft^2 d^{-1} (Figure 1-4). The highest recharge rates to the UFA occur in west-central Hernando and Citrus Counties with values ranging between 10 and 30 inches per year (Sepulveda 2002, Hydrogeologic, Inc. 2013). There are two first-magnitude springs (flow greater than 100 cubic feet per second (cfs) discharge) found within this region: Weeki Wachee Spring and the Crystal River group. The spring groups discharging to the Homosassa River and the Chassahowitzka River also exceed the 100 cfs first magnitude spring threshold.

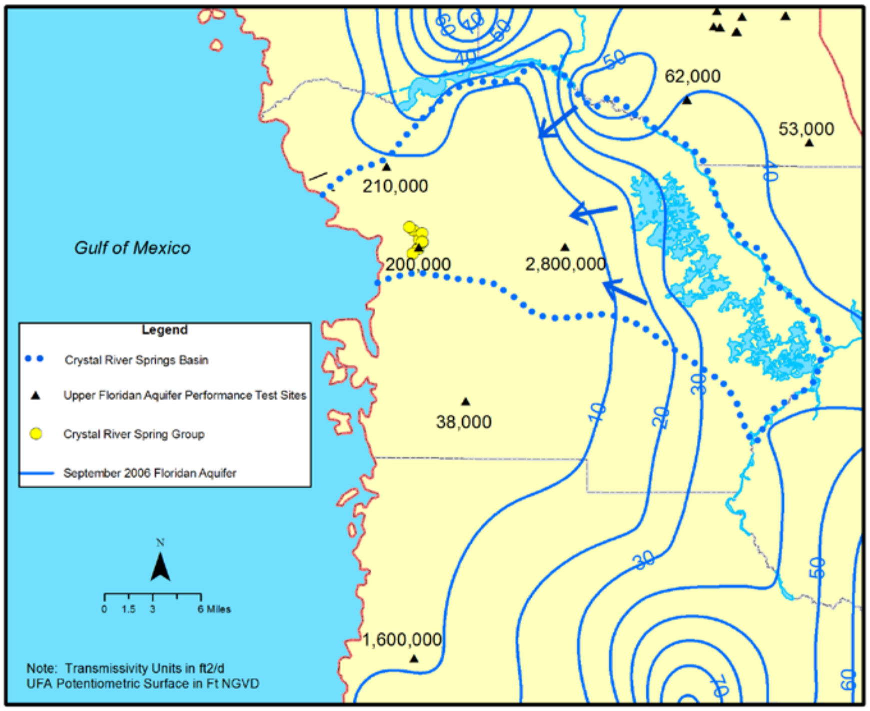


Figure 1-4. Delineation of the springshed (Crystal River Springs Basin) based on the September 2006 potentiometric surface (blue lines with elevations) of the Upper Floridan aquifer (UFA). Also includes transmissivity from aquifer performance tests. Arrows show general direction of ground-water flow.

Table 1-1. Hydrogeology of the Crystal River Spring Group area (modified from Miller 1986, Sacks and Tihansky 1996).

<table>
<tr><th>Series</th><th>Stratigraphic Unit</th><th colspan="2">Hydrogeologic Unit</th><th>Lithology</th></tr>
<tr><td>Holocene to

Pliocene</td><td>Undifferentiated Surficial Deposits</td><td colspan="2">Unsaturated Zone, Surficial Aquifer or locally perched Surficial Aquifer</td><td>Sand, silty sand, clayey sand, sandy clay, peat, and shell</td></tr>
<tr><td rowspan="4">Eocene</td><td>Ocala Limestone</td><td rowspan="2">Upper Permeable Zone</td><td rowspan="2">Upper

Floridan Aquifer</td><td rowspan="2">Limestone, white to tan, friable to micritic, fine-grained, soft, abundant foraminifera</td></tr>
<tr><td rowspan="3">Avon Park Formation</td></tr>
<tr><td colspan="2">Middle Confining Unit 2</td><td>Dolomite is brown, fractured, sucrosic, hard. Interstitial gypsum in Middle Confining Unit 2</td></tr>
<tr><td rowspan="2">Lower Permeable Zone</td><td rowspan="2">Lower

Floridan Aquifer</td><td rowspan="2">Limestone and dolomite. Limestone is tan, recrystallized.

Anhydrite and gypsum inclusions.</td></tr>
<tr><td></td><td>Oldsmar Formation</td></tr>
<tr><td>Paleocene</td><td>Cedar Keys Formation</td><td colspan="2">Basal Confining Unit</td><td>Massive anhydrites</td></tr>
</table>

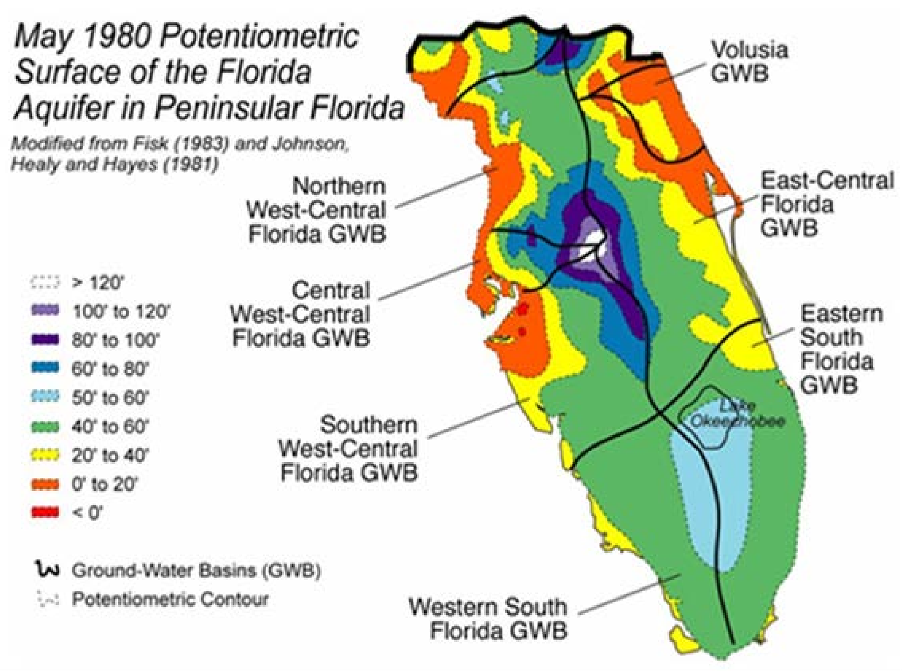
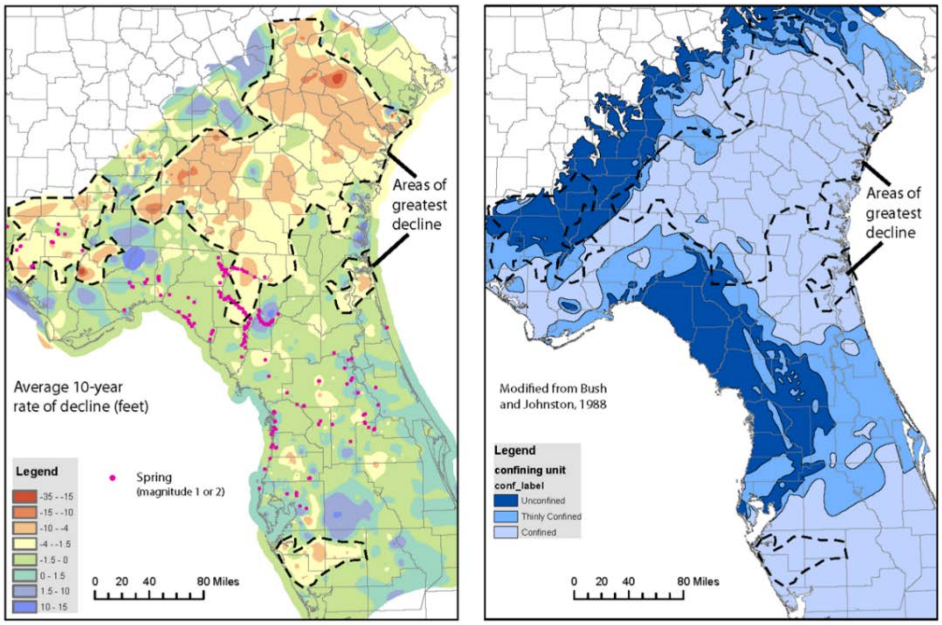


Figure 1-5 Location of regional groundwater basins in the Upper Floridan aquifer. The Crystal River/Kings Bay system is within the Northern West-Central Florida Groundwater Basin.



A. Composite 10-year rate of decline map for 1970 to 2010. Reds and yellows indicate declining trends; blues indicate increasing trends; greens indicates slightly increasing or decreasing trends in water levels.

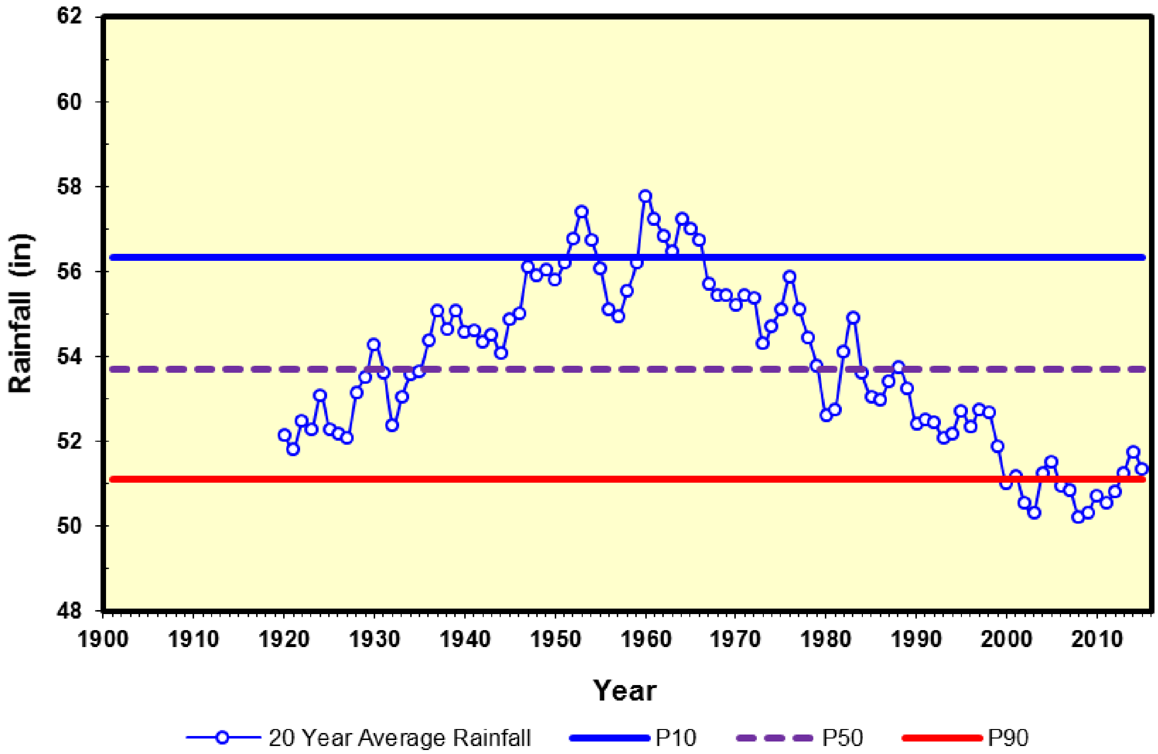
B. Relative confinment of the Floridan Aquifer System Light blue indicates confined areas and darker blues indicate thinly confined and unconfined areas respectively.

Figure 1-6. Water level change from 1970 through 2010 and the degree of confinement for the Upper Floridan aquifer (Williams et al. 2011).

1.4.2 Climate and Rainfall

The major climatological factor affecting the Crystal River/Kings Bays system, which lies within the subtropical climatic zone, is its low latitude and its proximity to the Gulf of Mexico. The temperature of the Gulf waters moderates the air temperatures in the area. The average mean daily temperature is approximately 70^{o} F (21^{o} C). Mean summer daily temperatures are in the low 80s (^{o}F) and the mean daily winter temperatures are in the upper 50s (^{o}F).

Average rainfall is approximately 54 inches per year and varies seasonally and annually. About 60 percent of annual rainfall occurs in the summer rainy season months of June through September when convective thunderstorms are common due to daytime heating and afternoon sea breezes. In addition, summer and fall rainfall can be enhanced by tropical cyclone activity from June through November. An analysis of 20-year moving average rainfall accumulated from the Ocala, Inverness, and Brooksville National Weather Service stations from 1901 through 2015 shows an increasing trend up until the mid-1960s and then a declining trend thereafter (Figure 1-7). This is consistent with multi-decadal cycles associated with the Atlantic Multidecadal Oscillation (Kelly and Gore 2008). The 20-year average was below the bottom 10th percentile (P90) for most of the averages post-2000. Recent 20-year moving averages (e.g., 1995-2014 and 1996-2015) have increased and lie between the P90 and P50 percentiles.

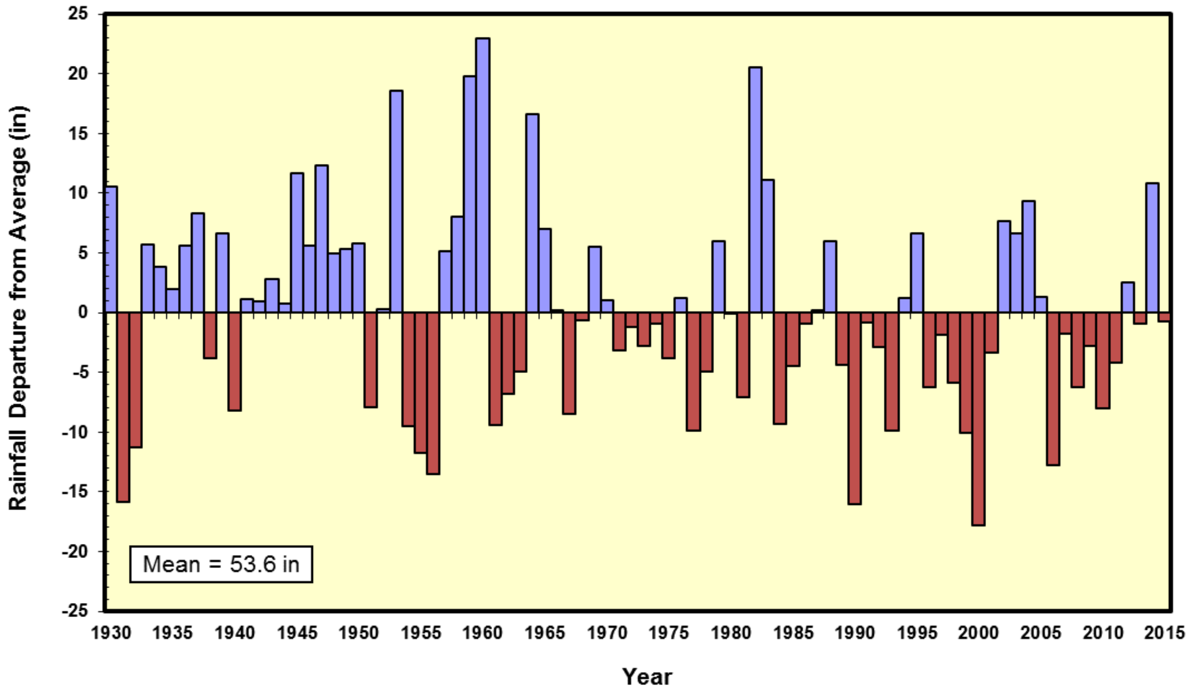


Note: 2012-15 data from SWFWMD Headquarters, Inverness Pool, and Ocala Airport

Figure 1-7. Twenty-year moving average rainfall from the Brooksville, Inverness, and Ocala NWS stations from 1901 through 2015.

The departure in annual rainfall from the long-term mean shows that below average rainfall has occurred in 19 of the 27 years since 1989 (Figure 1-8). Therefore, the recent quarter century has been extremely dry, in fact the driest in 115 years of recorded rainfall history. Since 2012, however, rainfall has been near average to above average.

In addition to the rainfall recorded at Brooksville, Inverness, and Ocala NWS stations, radar-estimated rainfall became available to the District in 1995 at a 2-kilometer (km) grid scale. Radar-estimated rainfall was averaged for the entire springshed each year from 1995 through 2015 using the September 2006 boundary of the springshed (Figure 1-9). Similar to the NWS station data, 12 out of 21 years of radar-estimated rainfall were below average. The cumulative departure for the 21-year period was -23.4 inches.



Note: 2012-15 data from SWFWMD Headquarters, Inverness Pool, and Ocala Airport

Figure 1-8. Departure in annual rainfall from the long-term mean for the Brooksville, Inverness, and Ocala NWS stations from 1930 through 2015.

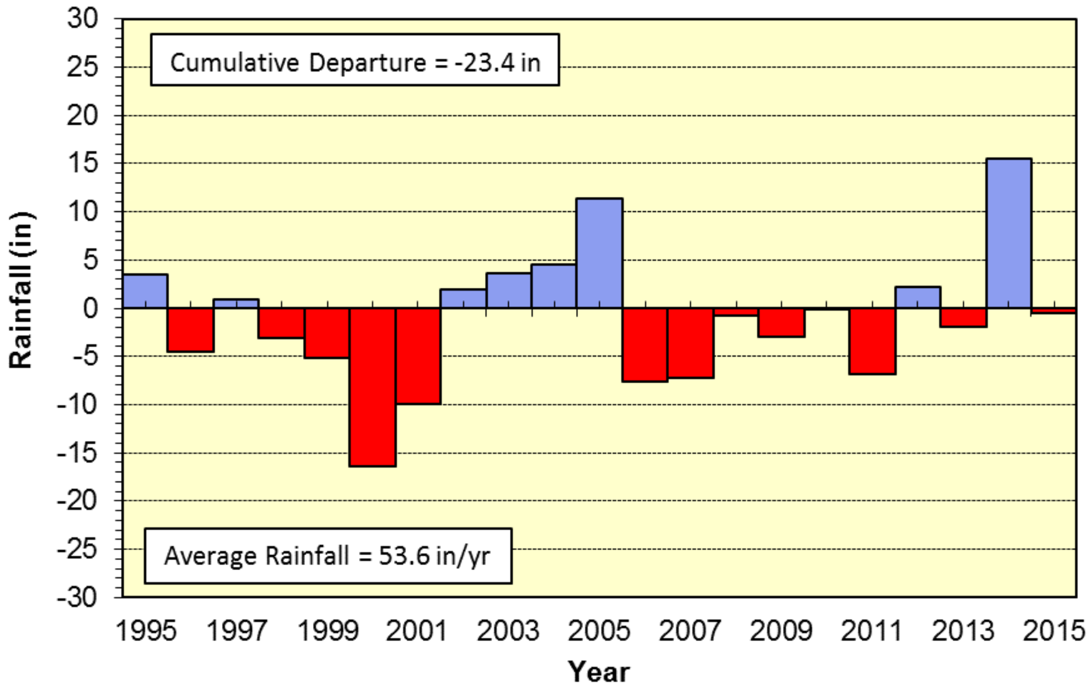


Figure 1-9. Annual departure from the long-term, radar-estimated rainfall in the Crystal River Spring Group Springshed from 1995 through 2015.

1.4.3 Discharge

Discharge in Crystal River and for the Crystal River Springs Group has been estimated using various methods at different sites. There is uncertainty associated with all measurements of flow in this system. Flow in the river was measured by the USGS at the Crystal River near Crystal River, FL gage #02310750 located approximately 2.3 miles downstream from the origin of the river at Kings Bay (Figure 1-10). Daily discharge for this site (Figure 1-11) averaged 971 cfs (628 mgd) (st. dev. = 630 cfs or 407 mgd) and the median was 927 cfs (599 mgd), for the period of record from March 1964 through September 1977. Yobbi and Knochenmus (1989) report a similar, mean discharge of 975 cfs (630 mgd) for the site, while Rosenau et al. (1977) and Fretwell (1983) report the average flow at the site was 916 cfs (592 mgd). In a review of the discharge record for the “Near Crystal River” site, Yobbi (2014 [included as appendix]) notes the difficulties in separating groundwater flow from tidal flow and measuring discharge at the site, citing issues with instrument errors and rating difficulties associated with site conditions. He indicates that reported river flow for the period from 1965 to 1977 may be overestimated, based on a subsequent, lower estimate of flow at the “Near Crystal River” site (534 cfs) derived from 65 instantaneous sampling events conducted from 1983 through 1985 using more precise instruments than were used for the earlier flow measurements. It is worth noting that the discharge estimate (of 534 cfs) from the 1980s is 437 cfs lower (or 45% lower) than the mean flow of 971 cfs calculated for the 1965-1977 period. Also noteworthy is the similarity between the discharge estimate from the 1980s (534 cfs) and the tidally-filtered mean flow estimate from 2002-2015 for the current, Bagley Cove site (447 cfs).

Starting in August 2002, tidally-filtered discharge has been reported as daily values by the USGS at the Crystal River at Bagley Cove near Crystal River, FL gage #02310747 located approximately 0.8 miles upstream from the historic site and approximately 2 miles downstream of the main collection of springs near the eastern shore of Kings Bay (Figure 1-12). Flows at this gage are calculated using an index velocity method (USGS 2017a). Mean daily discharge for the Bagley Cove site was 447 cfs (289 mgd) (st. dev. = 345 cfs or 223 mgd) and the median discharge was 437 cfs (282 mgd) between August 16, 2002 and October 7, 2015. Flows currently reported for the Bagley Cove site differ from those reported previously as a result of revisions made to the record by the USGS in 2011 following updates to rating curves used for discharge estimates (JEI 2012 [included as appendix]). This may account for some higher, previously reported flows at the site. The occurrence of numerous negative values in the discharge records at the Crystal River near Crystal River and Bagley Cove sites is indicative of a reversal in flow direction with the Crystal River, presumably due to tidal flux, storm surges and prevailing wind conditions. There are ongoing methodological advancements being implemented at the Bagley Cove gage including the installation of new equipment for measuring channel velocities. There is also an ongoing installation of two new gage sites at the Saragassa Canal (USGS 2017b) and Hunter Spring (USGS 2017c).

Another approach for estimating discharge for the Crystal River Springs group involves examining the water budget for the springshed. Hydrogeologic, Inc. (2008) developed a water budget for the Crystal River springshed and determined that flow from the Crystal River Springs varies between 300 and 400 cfs (194 to 259 mgd). Their estimated average flow in 1995 for the Crystal River Springs was 350 cfs with an additional 100 cfs coming from the Manatee Sanctuary Spring, and 5 cfs from House Spring. Based on an analytical water budget for the Crystal River springshed (310 square miles), recharge to the UFA is expected to be approximately 20 inches per year. This amount of groundwater recharge will result in a mean Crystal River Springs group (Crystal River, Manatee Sanctuary, and House) discharge of 455 cfs (294 mgd), assuming no change in storage and no other discharges from the groundwater system (Hydrogeologic, Inc. 2008). This recharge value is at the high end of reasonable flux to the UFA, and matches the USGS recharge value of 20 in yr^{-1} for the adjacent Homosassa Spring group basin in their estimation of the 1997-98 water budget (Knochenmus and Yobbi 2001). Larger estimates of discharge, such as the mean 916 cfs estimated for the 1960s and 1970s by Fretwell (1983) for Crystal River spring group (based on the Crystal River near Crystal River gage data) flow would require recharge in excess of 40 in yr^{-1} which is an unrealistically high number for a 310 square mile area if it is assumed all of it results in spring discharge.

In an effort to better characterize spring discharge, the District contracted a survey of spring vents and field measurements of discharge (VHB 2010, Serviss and Van Fleet 2017) [included as appendices]). Using these empirical, direct measurements of discharge, the District calibrated a linear model of discharge based on surface water level in the bay and the observed water level in the Upper Floridan aquifer at the nearby ROMP TR21-3 monitoring well. Details of this process are provided in the methods section of this report (see sections 2-1 and 2-2).

There is some uncertainty associated with any method of flow determination. In response to Peer Panel Comments, District staff conducted a thorough analysis of uncertainty in methods of flow determination and its effects on predicted ecosystem responses to alterations in flow (Herrick

2017) [included as appendix]. The conclusion of this uncertainty analysis is that the District empirical formula is the best method for determination of springflow Records are poor at the Crystal River near Crystal River gage (USGS 1972), and there are several problems in the estimation of discharge at this site (Yobbi 2014). into this system. According to USGS remarks for the Bagley Cove gage #02310747, “discharges are not a total of ‘freshwater flow’ but are a combination of freshwater flow and water storage” (USGS 2017a). Furthermore, the hydrodynamic model requires a continuous record of discharge which is not available from the Bagley Cove gage due to frequent missing dates as well as negative flows during rising tides. Discharges at Bagley Cove are a useful measure of water movement at the location of the Bagley Cove gage, but are not intended to nor do they substitute for continuous measurement of springflow from the 70 identified vents and numerous smaller seeps at the bottom of Kings Bay.

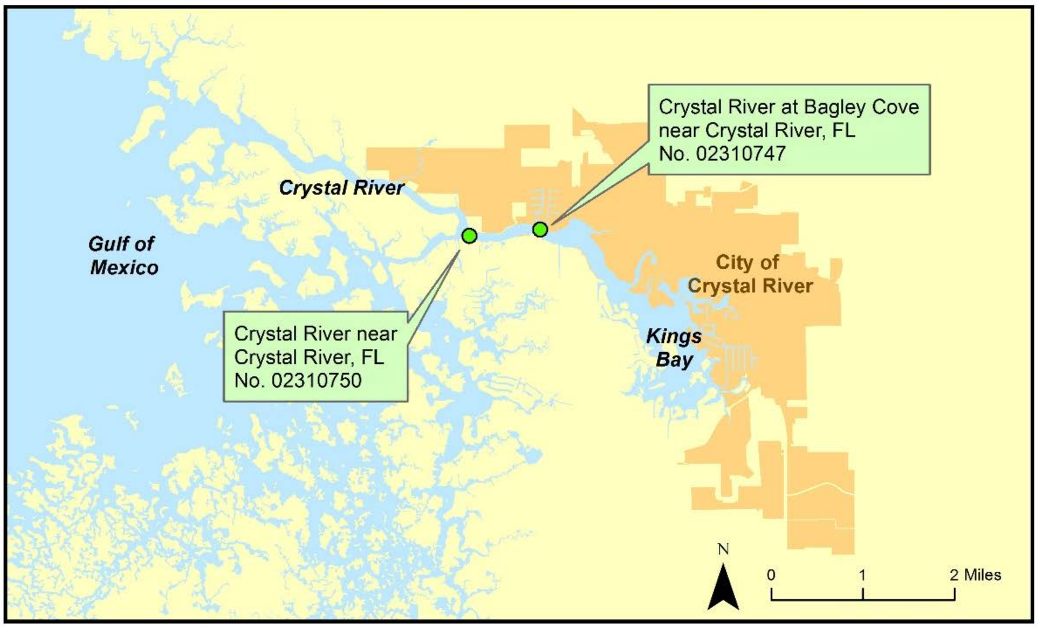


Figure 1-10. Location of historic USGS Crystal River near Crystal River, FL and existing Crystal River at Bagley Cove near Crystal River, FL gage sites on the Crystal River.

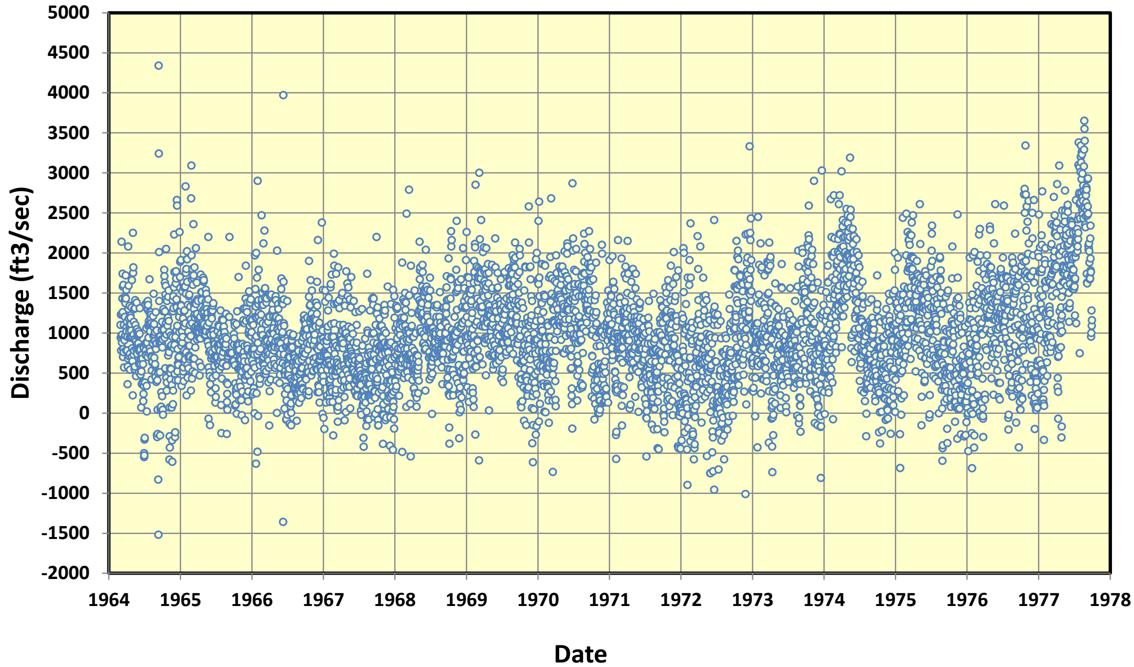


Figure 1-11. Flow (mean daily "approved" discharge) estimated by the USGS at Crystal River near Crystal River, FL (Site 02310750) on the Crystal River (March 1964 - September 1977).

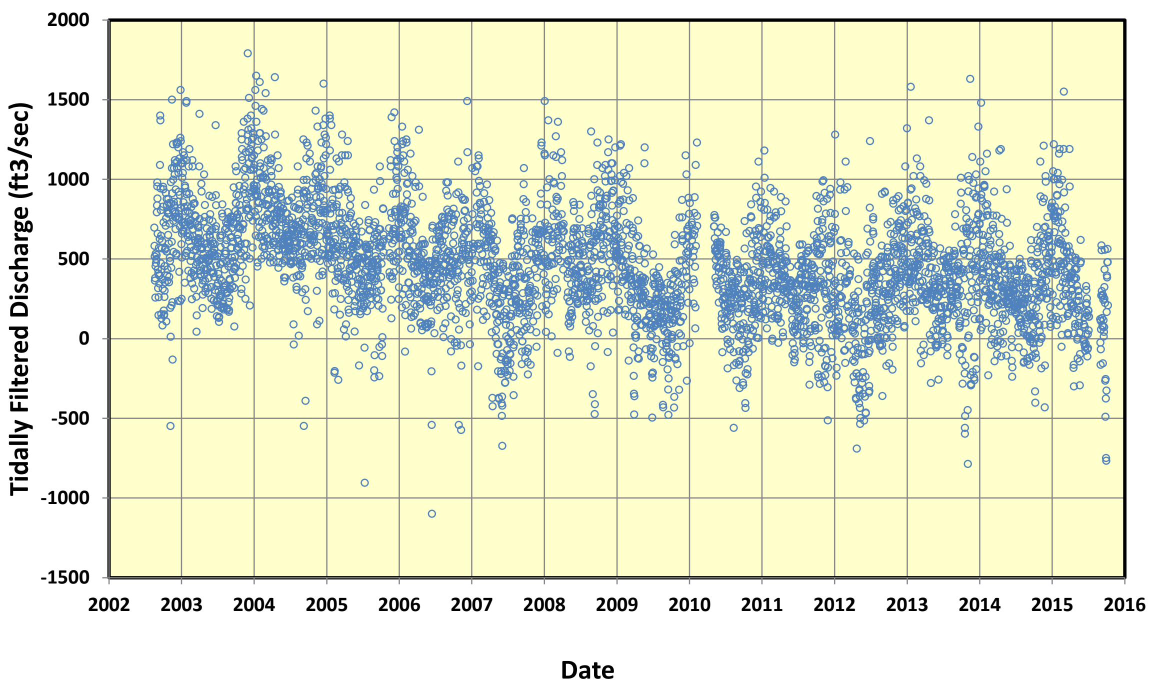


Figure 1-12. Flow (tidally filtered, mean daily "approved" discharge) estimated by the USGS at Bagley Cove on the Crystal River (August 2002- July 2015).

1.4.4 Groundwater Levels and Withdrawals

Water levels in the Upper Floridan aquifer are monitored at three wells within or near the Crystal River Spring group springshed: TR21-2, TR21-3, and Lecanto 7 (Figure 1-13). These are the three closest wells with relatively long periods of continuous measurements. Aquifer water levels have generally fluctuated between 3 and 7 Ft NGVD29 over the last 50 years due to short-term variations in rainfall (Figure 1-14). Analyses of long-term changes in groundwater levels in these wells can be used as an indicator of groundwater withdrawal impacts and/or multi-decadal rainfall variation in the region. Long-term declining aquifer water levels may be caused by lower than average rainfall or increases in groundwater withdrawals. Conversely, long term water level trends that are not statistically significant or are rising indicate that groundwater withdrawals have not had a significant impact on the region.

The District maintains a database of metered and estimated water use from 1992 through 2014 (Figure 1-15). Groundwater withdrawals have declined in the Crystal River Spring Group springshed since reaching their peak of 18.1 mgd in 2006. In 2014, groundwater withdrawals based on estimated and metered use were 15.3 mgd. Since 2005, groundwater use has essentially remained flat with a slightly negative change rate of -0.02 mgd per year. The quantity of groundwater withdrawn within a five-mile radius of the springs is relatively small and was 2.6 mgd in 2014. The trend in springshed groundwater use is similar to the overall trend of the SWFWMD Northern Planning region which includes Citrus, Hernando, Lake, Levy, Marion, and Sumter Counties. Groundwater use in this region in 2015 was 114.2 mgd, down from its peak in 2006 of 161.4 mgd (Figure 1-16).

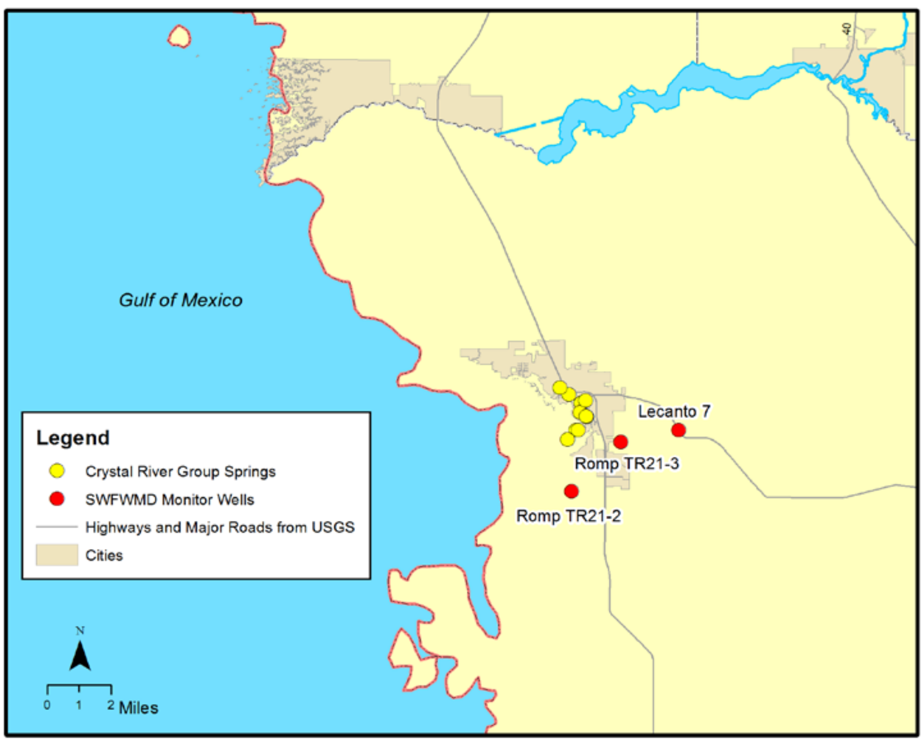


Figure 1-13. Location of Upper Floridan aquifer monitor wells near Crystal River Springs group.

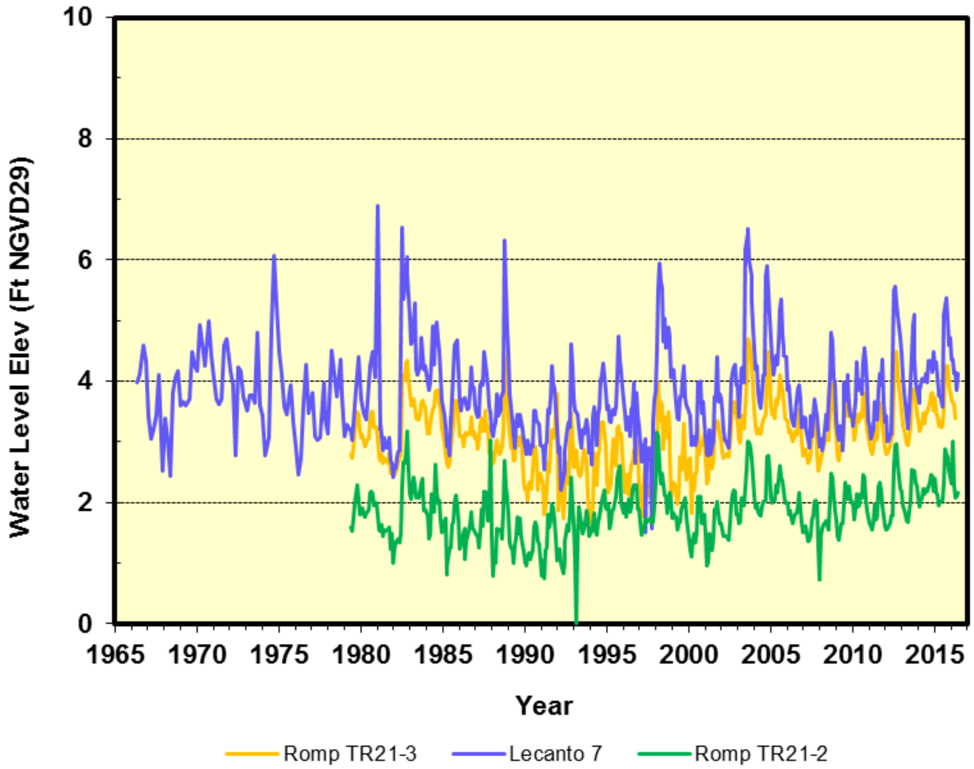


Figure 1-14. Average monthly water level history of the TR21-2, TR21-3, and Lecanto 7 wells.

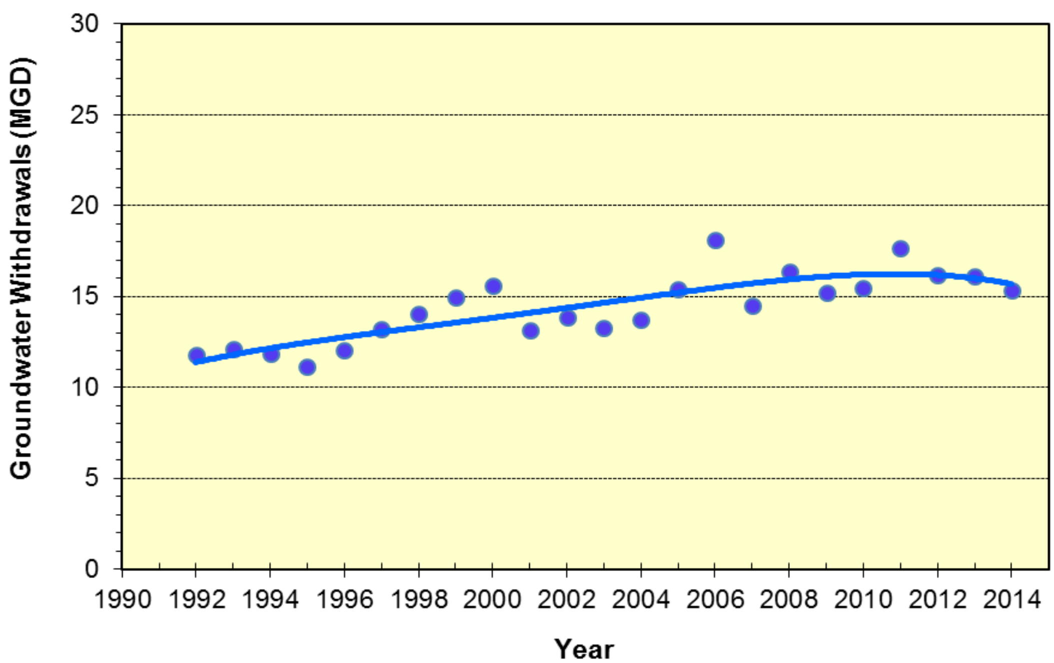


Figure 1-15. Estimated and metered water use history within the Crystal River Group Springshed from 1992 through 2014.

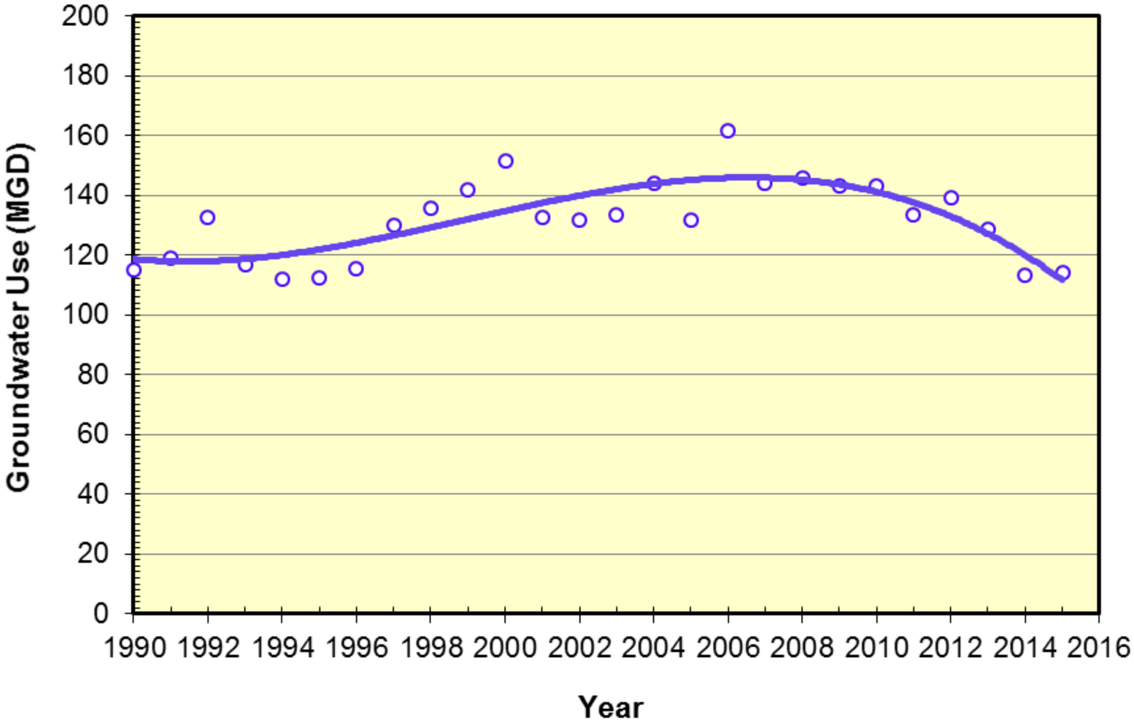


Figure 1-16. Estimated and metered water use history within the SWFWMD Northern Planning Area from 1990 through 2016.

1.4.4.1 Northern District Groundwater Flow Model

The Northern District Model (NDM) is a three-dimensional regional flow model. This model is unique for west-central Florida in that it is the first regional flow model that represents the groundwater system as fully three dimensional. Prior modeling efforts, notably Ryder (1982), Sepulveda (2002), Knowles et al. (2002), and Motz and Dogan (2004), represented the groundwater system as quasi-three dimensional. The NDM was originally developed in 2008 by HydroGeoLogic, Inc. (2008). Since that time, there have been several refinements to the original model, with subsequent Version 2 in 2010 and Version 3 in 2011 (Hydrogeologic, Inc. 2011). In 2013, Version 4.0 was completed by expanding the model grid slightly northward and east to the St. Johns River (Hydrogeologic, Inc. 2013). Version 5 (NDM5) was recently completed in August 2016 (Hydrogeologic, Inc. and Dynamic Solutions 2016). Versions 4.0 and 5.0 were peer reviewed by Dr. Pete Anderson, P.E. and Dr. Mark Stewart, P.G. (2016) in a cooperatively-funded project for SWFWMD and the St. Johns River Water Management District (SJRWMD). Dr. Stewart indicated in his most recent peer review that the Northern District Model version 5 “is the best numerical groundwater flow model currently available for assessing the effects of withdrawals in the central springs region.”

The domain of the NDM5 includes portions of the SWFWMD, the SJRWMD, and the Suwannee River Water Management District (SRWMD). The flow model encompasses the entire extent of the Central West-Central Florida Groundwater Basin (CWCFGWB), the Northern West-Central Florida Groundwater Basin (NWCFGWB), and portions of the Northern East-Central Florida

Groundwater Basin. The eastern boundary of the regional groundwater flow model extends to the St. Johns River, while the western boundary of the model domain extends approximately five miles offshore of the Gulf of Mexico (Figure 1-17).

The regional model grid consists of 212 columns and 275 rows with uniform grid spacing of 2,500 ft. The active model grid covers about 8,000 square miles in north-central Florida. Seven active layers in the model represent the primary geologic and hydrogeologic units including: 1) Surficial Sands, 2) ICU, 3) Suwannee Limestone, 4) Ocala Limestone, 5) Upper Avon Park Formation, 6) Middle Confining Units I and II, and 7) Lower Avon Park Formation or Oldsmar Formation. The UFA is composed mainly of the Suwannee Limestone, Ocala Limestone, and Upper Avon Park Formation (3, 4, and 5 above). The Lower Floridan Aquifer is composed of the permeable parts of both the Lower Avon Park and the Oldsmar Formations (7 above). Because of the permeability contrast between the units, the NDM simulates each unit as a discrete layer. This is superior to modeling a single layer to represent a thick sequence of permeable formations within the UFA.

The NDM5 was calibrated to steady-state 1995 calendar year conditions and transient conditions from 1996 through 2006 using monthly stress periods. The model was also verified for 2010 steady-state conditions. In the NDM5, mean water level error (simulated minus observed) in the UFA for 1995 and the 1996-2006 average transient period were +0.17 ft and +0.41 ft, respectively (Hydrogeologic, Inc. and Dynamic Solutions 2016). Mean absolute error varied from 3.77 to 3.61 ft for the two periods, respectively, based on 137 wells in 1995 and 157 wells from 1996-2006 within the 4,600 square mile NWCFGWB. Mean error for estimated Crystal River Spring group flows (simulated minus observed) for 1995 was -2 percent and for the 1996-2006 period was +3 percent.

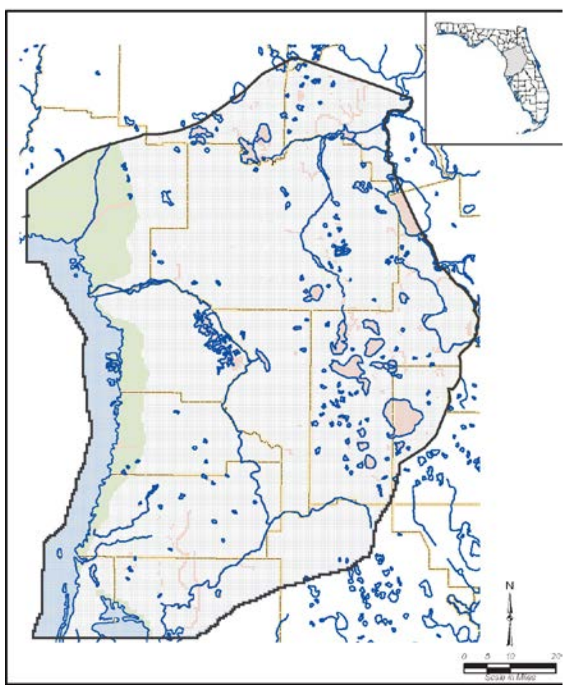


Figure 1-17. Northern District groundwater flow Model Version 5.0 model grid

1.4.5 Groundwater Level Trend

The District conducted a linear regression analysis of water levels in the Lecanto 7 well, which has the longest period of record (extending back to 1966), to look for evidence of declining water levels that could be the result of withdrawals in the area. A linear regression of monthly water levels in the Lecanto 7 monitor well from May 1966 to June 2016 revealed that long-term water levels have exhibited little change, although there appears to be a slight increase in water levels that is not statistically significant ($p = 0.11$) (Figure 1-18). This suggests that groundwater withdrawals have not significantly impacted groundwater levels near the Crystal River/Kings Bay system.

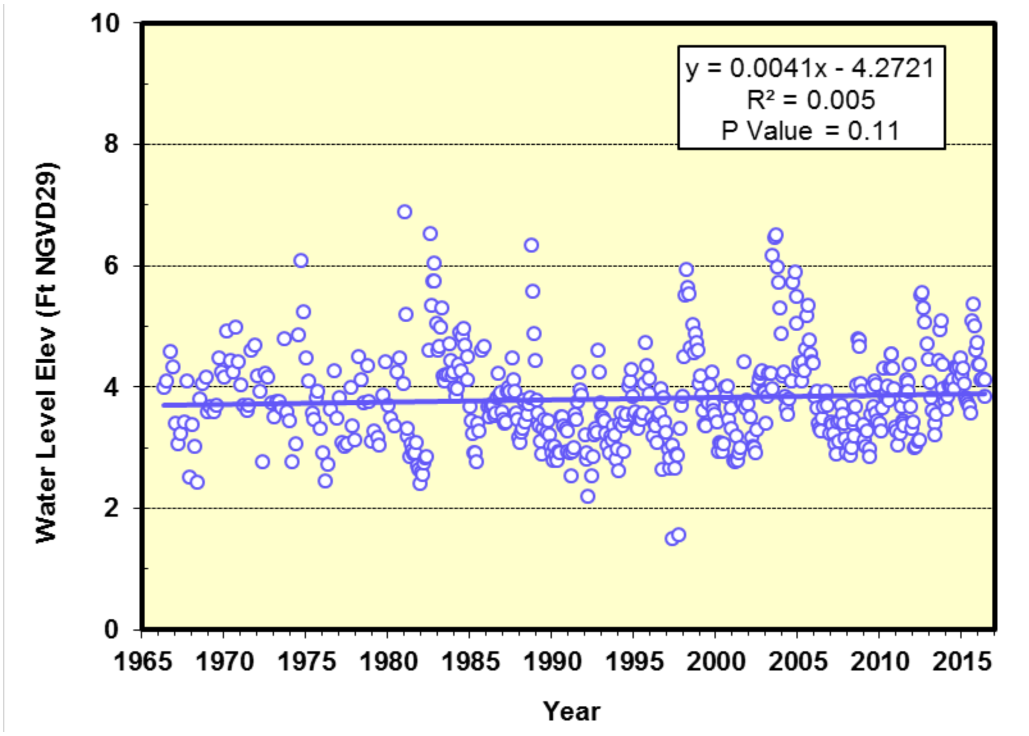


Figure 1-18. Linear regression of average monthly water levels at the Lecanto 7 monitor well (May 1966 - June 2016).

1.4.6 Predicted change in springflow due to Groundwater Withdrawals

Hydrogeologic, Inc. and Dynamic Solutions (2016) investigated the impacts of groundwater withdrawals on aquifer water levels and spring discharge by comparing NDM 5 simulations of the region with zero withdrawals (pumps off) to impacted conditions (pumps on) with groundwater withdrawals under current conditions in 2010 and 2014, and projected 2035 conditions. Pumping simulations were run under long-term transient conditions for five years. Baseline (pumps off) conditions were simulated by running the model for one year under transient conditions. Conditions in 2035 were simulated with and without conservation/reuse factors applied to withdrawal projections. The UFA heads and springflows generated at the end of each pumping scenario were subtracted from UFA heads and springflows at the end of the non-pumping (i.e., zero withdrawals) simulation to determine aquifer water level drawdown and flow changes.

The Northern District Model version 5 (NDM5) predicts UFA drawdown of approximately 0.1 feet from non-pumping to 2010 conditions at Crystal River Spring Group. The model individually simulates flows for the Crystal River group, Manatee Sanctuary Spring, and House Spring. These combined make up the Crystal River group of spring discharge in the model. The predicted reduction in Crystal River Spring Group flow from pumping in each period is shown in Table 1-2.

Table 1-2. Predicted flow changes for the Crystal River Spring Group from the NDM 5 model due to groundwater withdrawals in 2010, 2014, and 2035. Note: cfs = cubic feet per second.

Year	Non-pumping Flow (cfs)	Pumping Flow (cfs)	Difference (cfs)	Difference (percent)
2010	448.99	442.07	6.92	-1.5
2014	448.99	443.83	5.16	-1.1
2035	448.99	438.14	10.85	-2.4
2035 with Conservation & Reuse	448.99	439.42	9.57	-2.1

Estimated effects of groundwater withdrawals ranged from 1.1 to 1.5% under current groundwater withdrawal conditions. Predicted flow changes due to pumping are smaller in 2014 than 2010, and correspond to a 16% decline in domain-wide groundwater withdrawals associated with wetter conditions in 2014 and increased water conservation measures. Predicted decline in springflow ranges from 2.1% to 2.4% under 2035 pumping estimates.

Impacts to springflow can also be estimated through a water budget approach and used for verification of numerical model results. The recharge to the Upper Floridan Aquifer in 2014 was 298 mgd or 20 inches per year. Groundwater withdrawals in 2014 were estimated at 15.3 mgd or 1.04 inches per year. Groundwater withdrawals in 2014 within the springshed therefore constituted about 5.2 percent of average recharge, which can be considered equivalent to spring discharge. The USGS, however, estimates that on average only 45% of water withdrawn is consumptively-used (Marella 2008). Applying this factor to the total groundwater withdrawn in the springshed, and conservatively assuming every gallon of consumptively-used water results in a gallon decline in springflow, this would equate to a flow decline of 2.3 percent due to withdrawals within the springshed. This is a high impact estimate, however, since water from the aquifer can come from changes in storage (water level decline), induced leakage from the surficial aquifer, lakes, and wetlands, reductions in evapotranspiration, runoff, coastal groundwater seepage, and groundwater seepage to lakes and rivers. To put this in perspective, the quantity of water withdrawn from the springshed is equivalent to just three percent of annual evapotranspiration in the same area. So, using this water budget approach and the results of a groundwater flow model, groundwater withdrawal impacts to springflow in the Crystal River/Kings Bays system are small – on the order of one to two percent under current pumping conditions.

1.4.7 Ecology

The Crystal River/Kings Bay system consists of an approximately 600 acre bay connected to the Gulf of Mexico through the roughly six-mile long Crystal River. This system is home to both freshwater and salt-tolerant vegetation as well as fresh and saltwater species of fish. Kings Bay is relatively shallow, with an average depth of three to ten feet and mean water temperatures of 66° F to 76° F. Submerged aquatic vegetation (SAV) are the foundation of the Bay's ecology and have historically grown throughout the Bay. Offshore of the mouth of Crystal River, in Crystal Bay, extensive seagrass meadows mixed together with beneficial attached algae, sponges, and coral, are part of the approximately 400,000 mapped acres of habitat called the Springs Coast Seagrass Area. Like other spring-fed river systems on the west coast of Florida, the Crystal River/Kings Bay system harbors a unique assemblage of fish, distinguishable from surface fed rivers, which underlines the importance of conserving these spring-fed systems as unique habitat (Guenther et al. 2011 [included as appendix]). Other coastal habitats within the bay and river include oyster bars, mangroves, salt marshes, and hydric hammock wetlands. The Crystal River watershed provides habitat for 191 species of birds, 22 species of mammals, and 47 species of reptiles documented by extensive surveys in 1991 (Joiner et al. 1992). Kings Bay forms the largest natural warm-water refuge for the Florida Manatee in the United States. Over the past 15-20 years, manatee populations have expanded to record numbers increasing the grazing pressure on SAV growing in Kings Bay and potentially offshore in the Gulf of Mexico.

1.4.7.1 Vegetation

As early as the 1950s, there were concerns regarding water quality and the proliferation of undesirable plant and algal species in the Crystal River/Kings Bay system. By the 1980s, declining water clarity represented a widespread and high priority concern, although it was supported only by anecdotal evidence. In 2014, eleven types of submerged aquatic vegetation were found in a survey of Kings Bay: native coontail (*Ceratophyllum demersum)*, native muskgrass (*Chara spp.)*, exotic hydrilla (*Hydrilla verticillata)*, native filamentous algae including nuisance *Lyngbya wolleii*, exotic Eurasian watermilfoil (*Myriophyllum spicatum)*, native southern water nymph (*Najas guadalupensis)*, native pondweeds (*Potamogeton pectinatus and P. pusillus)*, native widgeon grass (*Ruppia maritima),* Vallisneria (*Vallisneria americana)*, and native horned pondweed (*Zannichellia palustris)* (Jacoby et al. 2014). A survey of the Crystal River/Kings system in 2010 found shoalgrass (*Halodule wrightii)*, *Myriophyllum spicatum*, and *Vallisneria americana*, but did not identify any of the other submerged species found before and after (Avineon 2010 [included as appendix]).

The assemblage of aquatic vegetation in Kings Bay has changed over time (Frazer et al. 2011 [included as appendix]). Anecdotal evidence suggest that historically, Kings Bay was dominated by the native, *Vallisneria americana*. Although native *Vallisneria americana*, *Najas guadalupensis* and *Potamogeton pusillus* have declined, cessation of wastewater effluent input to Kings Bay has had little to no impact on altering community composition of vegetation (Terrell and Canfield Jr 1996). Improving the natural SAV community is one of the goals of the SWIM plan for the Crystal River/Kings Bay system (SWFWMD 2015).

Submerged aquatic vegetation is sensitive to nutrient levels and competition for light. Increased nutrient loading reduces viability of large bottom-dwelling plants in favor of suspended phytoplankton, reducing water clarity (Sand-Jensen and Borum 1991, Duarte 1995). The decline in native *Vallisneria americana* and increases in abundance of exotic *Myiphyllum spicatuma* and *Lynbya* spp. are consistent with this pattern. Moreover, within Kings Bay, Eurasian watermilfoil *Myriophyllum spicatum* has been observed to competitively reduce abundance of native *Vallisneria americana* within experimental plots (Hauxwell et al. 2004b).

1.4.7.2 Manatee

Manatees are a high profile species in the Crystal River/Kings Bay system, with manatee viewing documented as one of the primary tourism draws to Kings Bay (Buckingham et al. 1999). The Florida manatee (*Trichechus manatus latirostris*), a subspecies of the West Indian manatee, is found primarily in the waters of Florida. Manatees are protected in the Florida Manatee Sanctuary Act (as implemented in Rule 68C-22, F.A.C.), which protects manatee habitat, sets restrictions on boating to prevent collisions, and limits interference and harassment by people. The U.S. Fish & Wildlife Service (USFWS) recently proposed reclassification of the Florida West Indian Manatee (including all subspecies) from endangered to threatened status under the Endangered Species Act, after finding the total estimated population throughout the species range at 13,142 (USFWS 2016). The USFWS proposal to reclassify the West Indian Manatee refers to Martin et al. (2015), who, based on surveys completed in 2011 and 2012, estimated a population of 6,350 (95% CI: 5,310 – 7,390) manatees along the Florida coast, with 2,790 (95% CI: 2,160 – 3,540) animals occurring on the west coast. Furthermore, the USFWS proposal cites the establishment of minimum flows by the District in their reasoning for down-listing the species.

The most recent synoptic aerial survey of manatees conducted by the Florida Fish and Wildlife Conservation Commission (FWC 2017a) estimates 6,620 manatees in the state of Florida in 2017, with 3,488 on the west (Gulf) coast. The winter population in Kings Bay averaged 129 individuals from 1983 to 2012, and ranged from a low of 5 to a high of 566 individuals in 2010 (Kleen and Breland 2014). Etheridge et al. (1985) provide additional historical information, noting 116 manatee were observed in Kings Bay in the winter of 1980-1981. More recent surveys show a peak of 758 individuals within the bay in January 2016 (USFWS Unpublished Data). Future population projections are favorable, with the expectation for continued growth and low chances for extinction going forward, in part due to the conservation efforts of concerned citizens, scientists, and state and federal agencies (USFWS 2016, Runge et al. 2017).

Manatees in Kings Bay are capable of eating large quantities of *Hydrilla verticillata*, though not enough to act as an effective control agent for this invasive species, as well as *Myriophyllum spicatum* and *Vallisneria americana* (Etheridge et al. 1985, Marshall et al. 2000). Manatees will also consume a variety of vegetative species common to freshwater, estuarine, and marine habitats (Ames et al. 1996) and will even eat red mangroves (*Rhizophora mangle*) (Castelblanco-Martínez et al. 2009).

1.4.7.3 Fish

The bay is unique among most other spring systems in the state and important as estuarine nursery habitat for many commercially and recreationally important species of fish such as tarpon (*Megalops atlanticus*), gag grouper (*Mycteroperca microlepis*), snook (*Centropomus undecimalis*), and redfish (*Sciaenops ocellatus*), all commonly found within bay. The fish community of Kings Bay is being characterized by FWCC as part of a multi-year survey of first magnitude springs systems in the SWFWMD (Simcox et al. 2015). As part of this sampling effort, the FWCC is conducting a series of fish sampling events to document fish abundance, diversity, richness, and fish species composition in portions of Kings Bay. To date, a total of 34 species have been collected from Kings Bay, including both freshwater and saltwater species. Common freshwater species include largemouth bass (*Micropterus salmoides*), bluegill sunfish (*Lepomis macrochirus*), and inland silversides (*Menidia beryllina*). Common saltwater species include mojarra (*Eucinostomus* sp.), striped mullet (*Mugil cephalus*), and pinfish (*Lagodon rhomboids*). As with other coastal spring systems, marine species utilize Kings Bay year-round, and especially during the winter as a thermal refuge. Sampling during the winter season revealed that 90% of the fish were of saltwater or estuarine species, while in the summer only 64% of the sampled fish were saltwater or estuarine in origin.

1.4.8 Human Use

As a result of its diverse habitats and wildlife species, the Crystal River/Kings Bay system is a popular ecotourism destination where manatee and wildlife viewing, diving, snorkeling, fishing, and recreational boating are popular activities. The direct economic impact of spending by visitors to four Florida springs averaged $17.13 million in 2002 (Bonn and Bell 2003).

Citrus County has experienced rapid population growth, with an increase from approximately 9,000 to over 140,000 residents between 1960 and 2010 (U.S. Census Bureau 2010). To meet the demand for waterfront residential property and boat access, extensive dredging and filling occurred between 1950 and 1980, and over 16 miles of seawalls were built along man-made canals in the bay, permanently altering much of the Crystal River/Kings Bay system (SWFWMD 2015).

Numerous, wide-scale land use changes have occurred within the Crystal River/Kings Bay watershed between 1944 and 2010 (Figure 1-19). Presently, urbanized areas are the predominant land use category in the springshed (45%), followed by “forestry/rural open” (26%). Agricultural land uses comprise only about 10% of the contributing area. Urbanized areas increased from 95 square miles in 1989 to 118 square miles in 2009. Conversely, agricultural areas decreased from 35 square miles in 1989 to 25 square miles in 2009. In this same period, forest/rural open areas also decreased from 80 to 67 square miles in 1989 and 2009, respectively. Both of these decreases were a result of agricultural and forest/rural open areas converting to urbanized areas.

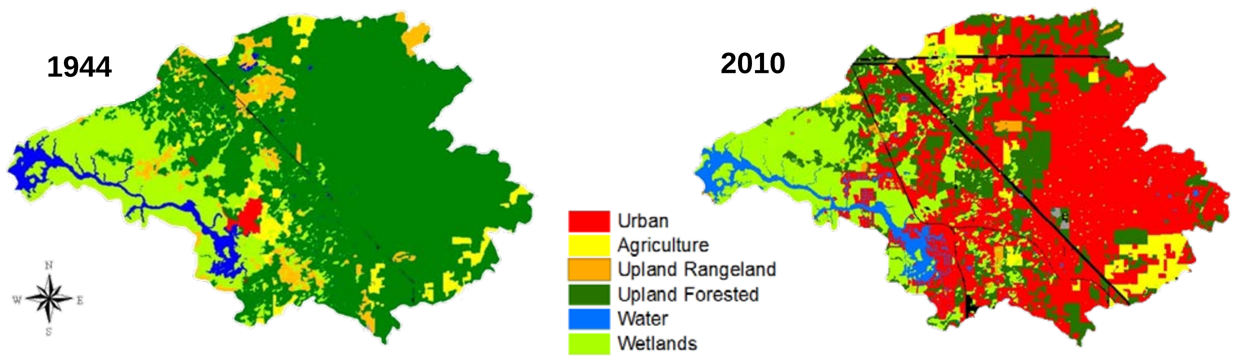


Figure 1-19. Land use changes in the Crystal River / Kings Bay springshed.

One of the primary concerns with this increased urbanization is the accompanying increase in nitrate concentrations in the springshed. Nitrate concentrations in ground water and springs have increased as land use has transitioned from natural land to agricultural and urban development. Anthropogenic sources of nitrate in the contributing area include atmospheric deposition, agricultural and residential fertilizers, and human and animal wastes.

1.5 Measured Criteria Linked to Significant Harm

In order to predict and prevent significant harm, we must identify criteria that will be measurably altered by reductions in flow. We focused our investigation of the impacts of reduced spring vent discharge on salinity habitats and manatee thermal refuge.

Salinity-based habitats have been used to set minimum flows for several estuarine systems within the District (Table 1-3). Proposed minimum flows for these systems were all subjected to independent, scientific peer-review.

Table 1-3. Systems for which determination of minimum flows was accomplished using salinity-based habitats.

System	Salinity Habitat	Reference
Anclote River	2 ppt bottom area	(Heyl et al. 2010)
Homosassa River	3 ppt bottom area	(Leeper et al. 2012)
Lower Myakka River	2 ppt and 5 ppt water volume	(Flannery et al. 2011)
Lower Peace River / Shell Creek	2 ppt and 5 ppt bottom area, water volume, and shoreline length	(SWFWMD 2010)

Manatee thermal refuge has also been assessed for setting minimum flows in the District and in other areas of the state (Table 1-4). Thermal refuge is the critical habitat most sensitive to reductions in flow in three of the five assessed systems. Other resources or environmental values were found to be more sensitive in the other systems.

Table 1-4. Systems that considered manatee thermal refuge for setting minimum flows in FL spring-fed systems.

System	Used?	Manatee Criteria	Reference
Blue Spring	Yes	Flow set to preserve 100% of anticipated manatee refuge.	(Rouhani et al. 2007)
Chassahowitzka River	Yes	Baseline flow produced no chronic stress habitat; 91% of baseline produced 15% loss of acute habitat, which was more than enough for every manatee in FL.	(Heyl et al. 2012)
Homosassa River	No	70% of baseline flow left enough chronic habitat for 9968 manatees, enough acute for 23,833 manatees. Less conservative than salinity.	(Leeper et al. 2012)
Suwannee River	Yes	Water surface elevation of 2.71 ft NGVD to allow manatee access to Fanning Spring, 130 cfs for manatee thermal refuge in Manatee Spring.	(Farrell et al. 2005)
Weeki Wachee River	No	75% of baseline flow sufficient for entire northwest FL population	(Heyl 2008)

1.5.1 Salinity Habitats

Salinity limits the distribution and abundance of plants, fish, mammals and algae, and affects water quality within estuaries worldwide (Day 1989, McLusky and Elliott 2004). We find that, based on observational and experimental studies cited below, protecting salinity-based habitat is an effective method for protecting a diverse array of species and preventing significant harm to environmental values.

1.5.1.1 Effects of Salinity on Vegetation

Shoreline and emergent vegetation

Shoreline and emergent vegetation are affected by estuarine salinity gradients (Crain et al. 2004). In seven Florida river estuaries, distribution of shoreline vegetation is linked to salinity, without any consistent breaks in vegetative communities that can be generalized across systems (Clewell et al. 2002). This suggests that each system has a unique assemblage of vegetative species. A survey of shoreline and emergent vegetation in the Crystal River/Kings Bay system revealed distributions of sawgrass (*Cladium jamaicense)*, *cattail (Typha domingensis)*, *smooth cordgrass (Spartina alterniflora)*, *black needlerush (Juncus roemerianus)*, *umbrella papyrus (Cyperus alternifolius)*, sabal palm (*Sabal palmetto)*, and southern redcedar (*Juniperus silicicola)* consistent with their known salinity tolerances (Avineon 2010 [included as appendix]). Thus, it is important to manage salinity habitat for emergent and shoreline species as shifts in salinity habitat are predicted to result in salt stress at the individual level and alter shoreline habitats at the community level.

Submerged aquatic vegetation (SAV)

Alterations to SAV species composition, distribution and abundance has widespread effects on water quality and other biota including grazers and fish (Carpenter and Lodge 1986). Globally, submerged SAV primary productivity acts as a sink for atmospheric CO_2 and forms the structural foundation for shallow, coastal communities, making them a target for conservation around the world (Orth et al. 2006). Moreover, Vallisneria in Kings Bay has even higher rates of productivity than reported in other geographical locations (Hauxwell et al. 2007). In addition, it supports a diverse community of epiphytic algae and invertebrates (Strayer et al. 2003, Dunn et al. 2008). On the Florida Gulf Coast, SAV serves as important forage for manatees (Bonde et al. 2004). Within Kings Bay, manatees consume Vallisneria with such alacrity, they must be excluded from plots planted for restoration or they will consume every plant (Hauxwell et al. 2004a). Because of the numerous positive impacts of SAV on the Crystal River/Kings Bay system, we are particularly interested in managing salinity habitats to encourage growth of beneficial vegetation.

Submerged aquatic vegetation is subject to a variety of stresses, and is impacted by natural and human-induced events that limit its distribution and abundance (Short and Wyllie-Echeverria 1996, Koch 2001). There is ample evidence in support of the hypothesis that salinity is a driving factor in determining distribution, abundance, and community composition of SAV in the Crystal River/Kings Bay system. In the Crystal River and two other Florida Gulf coast rivers, sites with long-term, annual salinity greater than 3.5ppt have very little SAV biomass compared with less saline sites (Hoyer et al. 2004). Furthermore, increased salinity can increase the epiphyte load on leaves, reducing incident light that reaches the leaf surface (Twilley et al. 1985, Twilley and Barko 1990). Moreover, storm events, which elevate sea level and increase salinity, have historically preceded decreases in vegetation in Kings Bay (Terrell and Canfield Jr 1996, Mataraza et al. 1999). Experimental salinity pulses comparable to those experienced during storm events within the Kings Bay system reduced growth and survival of *Hydrilla verticillata*, *Myriophyllum spicatum*, and *Vallisneria americana* (Frazer et al. 2006b). This suggests that salinity pulses associated with storm events are responsible for rapidly restructuring communities. However, disturbances are hypothesized to promote diversity in biotic communities (Huston 1979). Consequently, although salinity is not the only abiotic factor likely to affect the distribution of submerged aquatic vegetation in the Crystal River/Kings Bay system, it is likely an important determinant of the vegetative community.

There is no single number that corresponds to the salinity tolerance of a species due to the fact that biological complexity of response; length of time of exposure, life history stage, and recovery time all play a role in growth rate, loss of biomass, and mortality of estuarine species. Adding to the complexity of biological responses to salinity is the physiochemical variation within an estuary; salinity varies with freshwater inflow, tide, and storm events on time scales ranging from hourly through seasonal and even multidecadal patterns caused by oscillating ocean currents (Enfield et al. 2001). Furthermore, variation in salinity (rather than high or low salinity) was the best predictor of low plant biomass and benthic animal density in Florida Bay, on the south Florida Gulf coast (Montague and Ley 1993). Thus, while it is clear that salinity is affected by changes to freshwater inflow and produces changes to the biotic community, there is no simple, single salinity that must be maintained to manage an estuarine system in support of our environmental values.

Restoration efforts in Kings Bay have focused on *V. americana*, therefore it is worthwhile to explore the effects of salinity on the distribution and abundance of this species (SWFWMD 2015). *Vallisneria americana* has demonstrated variable tolerance to oligohaline (< 0.5 ppt), mesohaline (< 5 ppt) and polyhaline (< 18 ppt) estuarine waters. A microcosm experiment showed *V. americana* survives at salinities up to 12 ppt (Twilley and Barko 1990). In the Caloosahatchee estuary FL, *V. americana* mortality was observed at salinities >15 ppt in a transplant experiment, and was otherwise tolerant of salinities < 15 ppt (Kraemer et al. 1999). Mesocosm experiments on *V. americana* from the Caloosahatchee estuary showed tolerance of salinity up to 18 ppt, with no loss of leaves at exposures < 20 days, and survival following 70 days of exposure (Doering et al. 2001). In contrast, mesocosm experiments with *V. americana* from the St. Johns River, FL demonstrated reduced growth at 8 ppt and heavy losses in biomass at 18ppt, but also showed recovery following 10 weeks of exposure to 18ppt (Boustany et al. 2010, 2015). Seeds of *V. americana* are resistant to polyhaline salinities > 10 ppt, but germinate best with salinity under 1 ppt (Jarvis and Moore 2008). Using the best information available, Doering et al. (2002) set the minimum freshwater inflow to the Caloosahatchee River estuary on the Gulf Coast of Florida to protect habitat under 10 ppt based on a breakpoint in experimental, laboratory growth response and observed distribution of *V. americana*. Synthesis of the research above suggests that there is no single salinity target for ensuring the growth and ecological dominance of *V. americana.* As a result, we intend to look at broad patterns in changing salinity with flow, and focus on those salinity habitats most sensitive to reductions in flow.

1.5.1.2 Effects of Salinity on Fauna

There are diverse fish and invertebrate communities in the Crystal River/Kings Bay system (see section 1.4.7). Evans et al. (2010 [included as appendix]) found that compared with temperature, pH, depth, and dissolved oxygen, salinity has the greatest impact on driving benthic community structure throughout the system. Further, they concluded that decline in river flow could result in reductions in chironomids, oligochaetes, amphipods, gastropods, and other taxa characteristic of the oligohaline and freshwater zones of the system. Burghart and Peebles (2011) found that zooplankton, ichthyoplankton, and hyperbenthos communities in spring-fed estuaries of the Florida gulf coast experience more abrupt changes with salinity than in surface-fed estuaries. Furthermore, they showed that the Crystal River/Kings Bay system has a unique assemblage of species which is spatially structured based on consistent freshwater inflow typical of spring-fed rivers. Barnacles were identified as a nuisance by residents prompting research funded by the District which showed that salinity less than 2 ppt appears to inhibit barnacle settlement in the Crystal River/Kings Bay system, and barnacles were found in all but the freshest waters of the bay (Culter 2010 [included as appendix]). From this evidence, we conclude that conservation of natural community structure depends upon managing salinity habitats throughout the system.

1.5.2 Manatee Thermal Refuge

The northern range of the Florida subspecies of the West Indian Manatee is limited by cold water temperatures (Laist and Reynolds 2005, Laist et al. 2013). Florida manatees are vulnerable to death from cold stress when water temperatures fall below 20°C for several days or more, and even more quickly when temperatures drop to between 10° - 12°C (Laist et al. 2013). Death from cold stress syndrome following prolonged exposure to cold water is preceded by nutritional, metabolic, and immunologic disturbances culminating in opportunistic infectious disease (Bossart et al. 2004). Thus, we find that thermal manatee habitat is an appropriate criterion for consideration when setting minimum flows.

Florida manatee deaths have been monitored since in 1974, and are commonly attributable to collisions with watercraft, water control structures, marine debris, cold stress, red tide, and other causes (Runge et al. 2017). Statewide, cold stress has caused 12.8% of the 5,377 total deaths in the past 12 years in Florida (FWC 2017a) (Table 1-5). In Citrus County, 6.1% of 164 total deaths over the same time period are attributed to cold stress; less than half the statewide rate. This pattern held true in the unusually cold winter of 2009-2010, when only 2 of 338 statewide deaths due to cold stress occurred in the county. This indicates that manatees in Citrus County are less likely to die of cold stress than in other locations in Florida. Confirming this inference, Laist et al. (2013) concluded that springs offer better protection against cold stress than power plants and passive thermal basins. Moreover, the manatee is known to use the spring vents in Kings Bay as a thermal refuge during cold months (Kochman et al. 1985, Hauxwell et al. 2004b, SWFWMD 2015). This suggests that the unusually low death rate from cold stress is kept low by the springs feeding the Crystal River/Kings Bay, Homosassa River, and Chassahowitzka River systems, all of which are located in Citrus County. Furthermore the importance of springs is expected to increase as thermal refuge provided by power plants is expected to decrease with their retirement (Laist and Reynolds 2005, FWC 2007).

Table 1-5. Manatee deaths caused by cold stress for the past 12 years, statewide totals compared with Citrus County (FWC 2017a).

	Statewide			**Citrus Co.**		
Year	Cold Stress	All causes	Proportion (%)	Cold Stress	All causes	Proportion (%)
2016*	23	520	4.4	1	16	6.3
2015	18	149	12.1	2	7	28.6
2014	26	371	7.0	1	12	8.3
2013	40	830	4.8	0	17	0.0
2012	30	392	7.7	0	16	0.0
2011	114	453	25.2	3	14	21.4
2010	282	766	36.8	2	14	14.3
2009	56	429	13.1	0	6	0.0
2008	27	337	8.0	0	22	0.0
2007	18	317	5.7	0	12	0.0
2006	22	417	5.3	1	10	10.0
2005	31	396	7.8	0	18	0.0
All Years	687	5,377	12.8	10	164	6.1
Average	57	448	11.5	1	14	7.4

* Preliminary data

1.6 <u>Supplemental Analyses</u>

In addition to salinity habitats and manatee thermal refuge, which are the measured criteria linked to significant harm to environmental values, the District conducted analyses of sea level rise, estuary residence time, and water quality parameters in support of our development and assessment of minimum flows for the Crystal River/Kings Bay system. Sea level rise and estuary residence time were considered for their potential impacts once a proposed minimum flow was identified based on the measured criteria discussed in Section 1.5. Water quality parameters were investigated for trends with time and spring discharge to assess potential effects of minimum flow implementation. These supplemental analyses were not used as criteria for setting the minimum flow, but instead were used to prioritize the need for minimum flow reevaluation and further analyses.

1.6.1 Water Quality

Clear, numerical, cause-and-effect relationships are needed for setting minimum flows so that one can predict ecosystem responses to hypothetical reductions in flow. Data exist for various water quality parameters such as nitrogen, phosphorus, chlorophyll a and dissolved oxygen in the Crystal River/Kings Bay system. However, at present, there are no well-established relationships between flow and water quality parameters other than salinity and temperature. Water quality parameters were analyzed using methods developed for a technical report investigating the effects of springflow on nitrate/nitrite levels in seven Florida Springs (Heyl 2012). A full report on water quality analyses done for Kings Bay is included as an appendix.

The Peer Review Panel recommended future work be focused on quantification of relationships between flow and water quality (SWFWMD 2016). The Panel also advised the District to “acknowledge in the MFL report that a full evaluation of the potential impacts on water quality are not feasible at this time.” The District acknowledges that the water quality analyses presented here do not constitute a full evaluation of the potential impacts of changes in flow to water quality. However, the results shown indicate that future analyses may be fruitful. In this minimum flow report, the District reviews water quality standards that apply to the system, and presents results of an investigation into relationships between flow and water quality parameters over time.

1.6.1.1 Water Quality Standards

The Florida Department of Environmental Protection (DEP) set the Total Maximum Daily Load (TMDL) for nitrogen and phosphorus in Kings Bay and for a subset of spring vents within Kings Bay (Bridger 2014) (Table 1-6). Target nitrogen and phosphorus levels for Kings Bay are defined in Rule 62-304.645(17), F.A.C.; for individual vents in Rule 62-304.645(18), F.A.C.; and for Crystal River Estuary (which was not included in the TMDL report for Kings Bay) in Rule 62-302.532(w)8, F.A.C. Note that the DEP defines Kings Bay (WBID 1341) and Crystal River (WBID 1341I) using water body identifications that distinguish Kings Bay from Crystal River at a point downstream from the mouth of Kings Bay (Figure 1-20). Within Kings Bay, Hunter Spring, House Spring, Idiot’s Delight Spring, Tarpon Spring, and Black Spring share criteria for inorganic nitrate and orthophosphate, rather than total nitrogen and phosphorus. Note there are no chlorophyll-a criteria in the TMDL, nor is there any criteria for the Crystal River Estuary (WBID 1341I).

Chlorophyll-a criteria are not included in the TMDL, but there are limits identified in Rule 62-302.532, F.A.C. The chlorophyll-a criterion for the Crystal River Estuary is 4.4 µg l^{-1}. The limit for Kings Bay is 5.7 µg l^{-1}. Both limits are annual geometric means not to be exceeded more than once in a three-year period. The Crystal River Estuary criteria are slightly less restrictive for nitrogen and phosphorus, but more restrictive for chlorophyll a, reflecting ecological differences between the more saline, downstream estuary and the fresher, upstream bay.

Dissolved oxygen standards are defined in Rule 62-302.533(1), F.A.C. for Class III predominantly fresh waters and in Rule 62-302.533(2), F.A.C. for Class III predominantly marine waters. No more than 10% of daily average dissolved oxygen values are allowed to drop below 42% saturation in marine and 38% saturation in fresh waters. Most of Crystal River and Kings Bay are considered Class III marine waters. However, small areas around Cedar Cove (WBID 1341B), Crystal Spring (WBID 1341E), Hunter Spring (WBID 1341C) and Idiot's Delight Spring (WBID 1341F) are considered Class III fresh waters (DEP 2016).

Table 1-6. Water quality criteria for Kings Bay (Water Body ID numbers in parentheses) as set forth by TMDL, modified from Bridger (2014) tables 5.4 and 5.5; see this reference for detailed methods and results pertaining to establishment of TMDLs.

Water Body	Nitrogen Parameter	Nitrogen Target (mg l^{-1})	Nitrogen Existing (mg l^{-1})	Phosphorus Parameter	Phosphorus Target (mg l^{-1})	Phosphorus Existing (mg l^{-1})
Kings Bay (1341)	TN	0.28	0.36	TP	0.032	0.037
Hunter Spring (1341C)	Nitrate	0.23	0.64	PO_4^{3-}	0.028	0.027
House Spring (1341D)	Nitrate	0.23	0.49	PO_4^{3-}	0.028	0.025
Idiot's Delight (1341F)	Nitrate	0.23	0.31	PO_4^{3-}	0.028	0.030
Tarpon Springs (1341G)	Nitrate	0.23	0.29	PO_4^{3-}	0.028	0.031
Black Springs (1341H)	Nitrate	0.23	0.31	PO_4^{3-}	0.028	0.026

1.6.1.2 Comparison of Water Quality Measurements

Data analyzed in this report were collected for various purposes, but were not intended for determining compliance with water quality regulations. Water quality parameters investigated here are compared with current regulations to put quantitative values into perspective and to compare with other analyses. Nitrogen and phosphorus levels were analyzed by the DEP when establishing TMDLs for Kings Bay (Bridger 2014). According to the TMDL report, water quality standards for nitrogen and phosphorus are not being met within Kings Bay and the five individual spring vents for which criteria exist (Table 1-6). At present, levels of nitrogen and phosphorus in Kings Bay correspond to maximum growth rates for *Lyngbya wollei*, and TMDLs were set to limit growth of these nuisance cyanobacteria (Cowell and Dawes 2004, Stevenson et al. 2007, Albertin 2009, Bridger 2014).

1.6.1.3 Temporal Water Quality Trends

The DEP analyzed temporal trends in nitrogen and phosphorus as part of the methodology for establishing TMDLs in Kings Bay (Bridger 2014). We present results of a separate analysis using an expanded data set to compare with the trends noted by the DEP.

1.6.1.4 Effect of Flow on Water Quality

An investigation conducted by the District in 1998 determined that 94% of the total nitrogen in the bay comes from spring discharge (Jones et al. 1998). This is consistent with data from 2004-2012 included in establishment of TMDLs for the system, which show high concentrations of nitrate in water discharged from vents (Table 1-6) (Bridger 2014). Nutrient-rich water discharged from spring vents traces its origins to groundwater that is contaminated within the springshed area. An estimated 830,633 pounds of nitrogen per year enter groundwater within the springshed (Eller and Katz 2016). Thus, the existing SWIM plan and upcoming Basin Management Action Plan (BMAP) in development by the DEP focus on addressing nutrient inputs to the groundwater. We conducted an analysis to correlate rate of discharge from spring vents with water quality of that discharge.

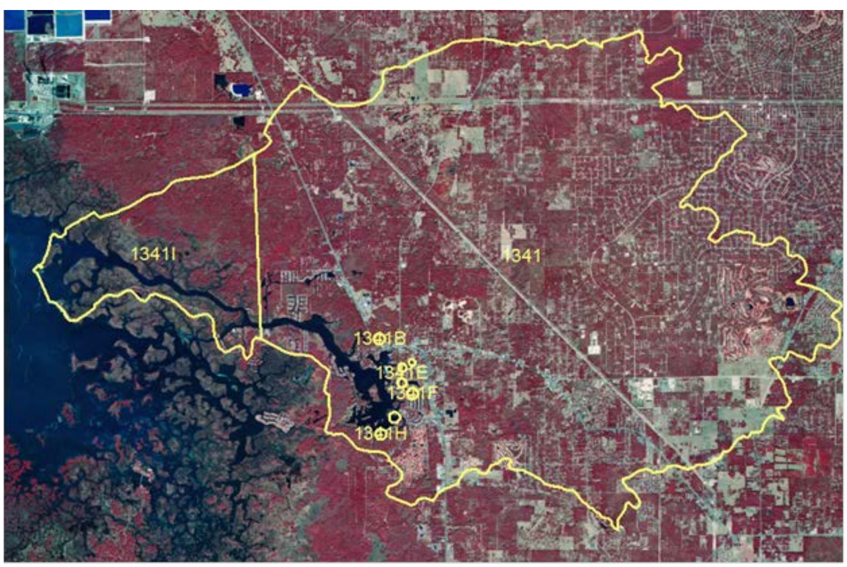


Figure 1-20. Water Body Identification numbers according to the Florida Department of Environmental Protection: Kings Bay (1341) Hunter Spring (1341C) House Spring (1341D) Idiot's Delight (1341F) Tarpon Springs (1341G) Black Springs (1341H) Crystal River (1341I).

1.6.1.5 Management Plans

The District has an existing SWIM plan for the Crystal River/Kings Bay system which includes management actions directed toward lowering nutrients through addressing the following issues: monitoring and research, agricultural operations, septic tanks, fertilizer (including golf courses), wastewater treatment facilities, stormwater, septic/sewage solids disposal, and atmospheric deposition (SWFWMD 2015). The DEP is currently developing a BMAP that compliments the District SWIM plan as a means of addressing impairment in TMDLs (Bridger 2014, SWFWMD 2015).

1.6.2 Sea Level Rise

Sea level rise is affecting coastal river and springs systems. Further rises in sea level will continue to increase the frequency and severity of high water events along the coast. This in turn will force higher-salinity gulf water into historically fresher areas of the Crystal River/Kings Bay system. Spring discharge is also affected by surface water levels in Kings Bay, with higher bay levels impeding or decreasing spring discharge. However, as sea levels rise, aquifer levels may rise as well due to pressure from rising sea levels and to some degree offset, or reduce effects of higher Gulf and bay water levels.

Sea level is monitored by the National Oceanic and Atmospheric Administration at Cedar Key and St. Petersburg stations. At Cedar Key, the mean sea level trend is 1.97 millimeters/year with a 95% confidence interval of +/- 0.18 mm/yr based on monthly mean sea level data from 1914 to 2015 which is equivalent to a change of 0.65 feet in 100 years (NOAA 2017a). At St. Petersburg, The mean sea level trend is 2.66 millimeters/year with a 95% confidence interval of +/- 0.25 mm/yr based on monthly mean sea level data from 1947 to 2015 which is equivalent to a change of 0.87 feet in 100 years (NOAA 2017b). Any historical data, insofar as they are affected by sea level, will necessarily reflect these historical changes in sea level.

We used U.S. Army Corps of Engineers (USACE 2016) recommendations concerning potential sea level change for evaluating coastal projects to assess the need for specific minimum flow prevention strategies for the Crystal River/Kings Bay system over the approximate 20-year planning horizon through 2035. We also assessed potential sea level change to help identify the potential need for reevaluation of minimum flows that are expected to be adopted for the system.

1.6.3 Estuary Residence Time

There are no data or analyses that establish a link between residence time and phytoplankton blooms in Kings Bay. However, there is good reason to suspect such a link may play a role in driving measured chlorophyll-a levels in the Bay. Model analysis shows that estuary residence times may be associated with lower rates of nitrogen removal (Dettmann 2001). Valiela et al (1997) show that phytoplankton respond to nitrogen loading and hypothesize links to residence time in shallow estuaries. Wan et al (2013) showed a link between freshwater inflow, residence time, and chlorophyll-a measurements in the Caloosahatchee River estuary. In an analysis of zooplankton in spring-fed and surface-fed estuaries in the District, Burghart and Peebles (2011) hypothesize that residence time be managed to limit phytoplankton blooms in Kings Bay, yet this report did not present data linking residence times to phytoplankton. Frazer et al. (2001a) also suggest that residence time influences phytoplankton biomass, but there is no analysis of that potential relationship in Kings Bay in their report. Thus, there is evidence to suggest that residence time may be important for driving phytoplankton dynamics in Kings Bay, but there is no direct evidence from data in this system to conclude that this is the case. Therefore, the hypothesis that residence time controls phytoplankton in Kings Bay is reasonable, but it has not been tested.

Residence time is included as an output of the District hydrodynamic model of the Crystal River/Kings Bay system. However, establishing a minimum flow based on residence time is not feasible at this time because there is no analysis linking residence time to measurements of water quality parameters of concern in the system. Setting a minimum flow based on residence time would depend upon establishing a firm link between residence time and some other ecological factor such as phytoplankton density. There is currently no such analysis for the Crystal River/Kings Bay system. The District agrees with the Peer Review Panel recommendation to investigate potential links between discharge, residence time, and chlorophyll-a levels for future reevaluation of the system.

1.7 Addressing Environmental Values

Environmental values listed in section 1.3.3 are identified in the Water Resource Implementation Rule. Here, we explain how these values are linked to salinity-based habitats and manatee thermal refugia that are, in turn, linked to flow (Table 1-7).

Table 1-7. Links between environmental values and resources evaluated for significant harm. Ecological and human use values are listed in F.A.C. Applicability to the system includes the presence of available information and expectation that reduced groundwater discharge to the system will significantly impact the value.

Ecological and Human Use Value	Is Value Applicable to the System?	Factors Evaluated for Significant Harm	Was the Value Considered?
Recreation in and on the water	Yes	Protection of salinity habitats to promote: water clarity, reduced algal blooms, native SAV. Manatee thermal refuge.	Yes
Fish and wildlife habitats and the passage of fish	Yes	Protection of salinity habitats and manatee thermal refuge	Yes
Estuarine resources	Yes	Protection of salinity habitats to protect community structure	Yes
Transfer of detrital material	No	Transfer of detrital material is not a relevant factor in this system	Yes
Maintenance of freshwater storage and supply	Yes	Groundwater withdrawals allowed above levels necessary to prevent significant harm	Yes
Aesthetic and scenic attributes	Yes	Protection of salinity habitats to promote water clarity, reduced algal blooms, native SAV, and natural shoreline vegetation	Yes
Filtration and absorption of nutrients and other pollutants	Yes	Protection of salinity habitats to promote water clarity, reduced algal blooms, native SAV	Yes
Sediment loads	Yes	Protection of salinity habitat to promote aquatic macrophyte growth and stability of bottom sediment	Yes
Water quality	Yes	Protection of salinity habitats to promote water clarity, reduced algal blooms, native SAV	Yes
Navigation	Yes	Protection of salinity habitats to promote water clarity, reduced algal blooms, native SAV	Yes

1.7.1 Recreation in and on the Water

Recreation in Crystal River and Kings Bay includes boating, fishing, kayaking, and nature viewing including manatee tours and birding. These activities are all linked to maintaining water quality and salinity, as they depend on healthy ecosystem functioning. Recreation associated with manatee is protected through preservation of thermal refuge. Surveys of residents revealed that they are interested in water clarity and reductions in algal blooms, both of which are identified in the District's SWIM plan, and which will be addressed, in part, through minimum flow development and implementation by maintaining salinity habitats supportive of native plant establishment and persistence (Evans et al. 2007, SWFWMD 2015).

1.7.2 Fish and Wildlife Habitats and the Passage of fish

Salinity-based habitats and manatee thermal refuge are measurable critical resources that are directly linked to fish and wildlife in the Crystal River/Kings Bay system (see Section 1.5). Several surveys funded by the district found diverse communities of fish and invertebrates in the system (Evans et al. 2010 [included as appendix], Burghart and Peebles 2011 [included as appendix], MacDonald et al. 2011 [included as appendix]). Maintaining salinity-based habitats and thermal refuge for manatees will address habitat concerns associated with these fish and wildlife resources. Because the bay and river are tidally influenced, system water levels are driven by tides, not by freshwater inflow. Thus, the passage of fish is not expected to be affected by implementation of minimum flows.

1.7.3 Estuarine Resources

Estuaries are defined by the confluence of freshwater with marine waters (Day 1989, McLusky and Elliott 2004). As such, estuarine waters exhibit a range of salinities that limit the distribution and abundance of organisms. Our focus on salinity-based habitats will have wide-ranging protective effects on estuarine resources within the Crystal River/Kings Bay system.

1.7.4 Transfer of Detrital Material

Our mandate is to use the "best information available" and there is no current information available on detrital material transfer for this system. As such, we did not explicitly assess the transfer of detrital material in our modeling of the effects of groundwater discharge to the system. However, we note that transfer of detrital material within the system is expected to be in large part a function of tidal dynamics and add that implementation of minimum flows sufficient to promote maintenance of salinity-based habitats in the system is expected to support natural detrital transfer paths and mechanisms.

1.7.5 Maintenance of Freshwater Storage and Supply

By setting the minimum flows for the Crystal River/Kings Bay system at the *minimum* level necessary to prevent *significant* harm, we balance the need to conservatively protect the resources and ecology of the region with the need for fresh water supply. We expect some acceptable loss of habitat due to groundwater withdrawals, thus allowing for water supply to the residents of the region. However, we also limit groundwater withdrawals before significant harm is done, thereby protecting the ecology and natural wonder of this Outstanding Florida Water and Outstanding Florida Spring. This protection will be afforded through inclusion of conditions in water use permits that stipulate permitted withdrawals will not lead to violation of minimum flows that are adopted for the system.

1.7.6 Aesthetic and Scenic Attributes

Residents and users of Kings Bay and Crystal River are concerned with water clarity and preventing / reducing algal blooms (Evans et al. 2007, SWFWMD 2015). However, there are no conclusive links established at this time between flow and water clarity or chlorophyll-a levels - future work should focus on establishing these links. In addition, the tourism industry depends upon manatee thermal refuge during cold months. The effects of flow on salinity and temperature are well established in this report. Both of these concerns are addressed in our analysis of salinity habitats and volume of warm water, which should have wide-ranging effects on maintaining natural aesthetic and scenic attributes, as well as manatee habitat.

1.7.7 Filtration and Absorption of Nutrients and Other Pollutants

The physical presence of submerged aquatic macrophytes prevents resuspension of sediments and associated nutrients by wave action (Barko and James 2012). It is thought that *Vallisneria americana* will have this effect in Kings Bay, resulting in a decrease in algal phytoplankton in the water column and increasing water clarity (Hoyer et al. 2001). Reducing the percent coverage of filamentous algae is an important component of managing Kings Bay. Submerged aquatic vegetation plays a significant role in controlling the growth of filamentous algae (Evans et al. 2007). The reintroduction of *V. americana* is a major component of the SWIM plan for the Crystal River/Kings Bay system as a means to help restore the benthic habitat and thereby reduce the coverage of filamentous algae and improve water clarity (SWFWMD 2015). Managing salinity habitats through minimum flow implementation is expected to have far-reaching positive effects on beneficial aquatic vegetation and their associated filtration and absorption of nutrients and other pollutants.

1.7.8 Sediment Loads

Submarine groundwater discharge into Kings Bay is free of sediment. A natural community of submerged aquatic vegetation functions to uptake nutrients and prevent resuspension of sediments and associated nutrients by wave action (Hoyer et al. 2001, Barko and James 2012). Therefore, focusing on preservation of low-salinity habitats and flows associated with their persistence should prevent significant harm to bottom sediment stability.

1.7.9 Water Quality

Salinity and temperature can be verified at permanent USGS gaging stations, show clear trends with flow, and have both been used as criteria for setting minimum flows for estuarine systems. Other water quality parameters such as nutrients, dissolved oxygen, and chlorophyll a do not show clear trends with flow in any complete analysis of this system. While there are no conclusive links established at this time between flow and water clarity or chlorophyll-a levels, future work should focus on establishing these links. An analysis of water quality parameters is included here, with more details in an appendix, but this analysis is inconclusive and insufficient for establishing minimum flow levels on criteria other than salinity and temperature. The District agrees with the recommendation of the peer review panel that future effort focus on analysis of potential links between flow and water quality parameters (SWFWMD 2016).

1.7.10 Navigation

Navigation has been impeded in the past by invasive vegetation (Evans et al. 2007). Water levels in the system are largely dependent upon tide and not on freshwater inflow, thus changes to springflow are not expected to have impacts on navigation of the system.

1.8 Summary

Florida statutes require that the District establish minimum flows for the Crystal River/Kings Bay system located on the Springs Coast of Florida (Section 1.2). Minimum flow development proceeds from a focus on protecting environmental values from significant harm which is determined on a case-by-case basis, but often taking the form of a 15 percent loss criterion (Section 1.3). The establishment of the minimum flow regime described herein follows extensive background data collection and analysis on the system. The District identified salinity habitats and manatee thermal refuge as measured criteria that are directly affected by changes in spring discharge to the system (Section 1.5). Furthermore, supplemental analyses of water quality (Section 1.6.1), sea level rise (Section 1.6.2), and residence time (Section 1.6.3) were conducted. All of the relevant environmental values listed in the Water Resource Implementation Rule were addressed by the measured criteria (salinity and temperature) for which we established cause-and-effect relationships to spring discharge (Section 1.7), and which we considered for the development of proposed minimum flows.

CHAPTER 2 - METHODS

2.1 Groundwater Levels and Discharge Measurement

A comprehensive inventory of spring vents commissioned by the District found a total of 70 springs, more than double the previously documented number (VHB 2009 [included as appendix]). For every spring vent identified, location, aperture area, and orientation were documented (Figure 2-1). Following on the initial survey work, discharge was measured at individual vents or groups of vents as the product of vent area or downstream channel area and flow velocity under various tidal conditions on multiple days (USFWS 2016). Measurements of specific conductance and temperature were taken concurrently with discharge using a multi-parameter water quality monitoring sonde.

The effect of surface water levels and tidal variation on spring discharge was based on deployment of two multi-beam Acoustic Doppler Current Profilers (ADCPs) to measure real-time cross-sectional flux in two groups of springs (G1 and G2) which discharge through narrow channels (Figure 2-2). These ADCP measurements were taken every 15 minutes for 25 days from July 27, 2009 and August 20, 2009. Water levels, salinity, and temperature monitored at various sites also contributed to our predictions of discharge and other variables. Groundwater levels used for estimating discharge were measured at ROMP TR21-3 located approximately 2.5 km southeast of the center of Kings Bay (Figure 2-1). Surface water levels, salinity, and temperature were measured at four USGS gage stations shown in Figure 2-1.

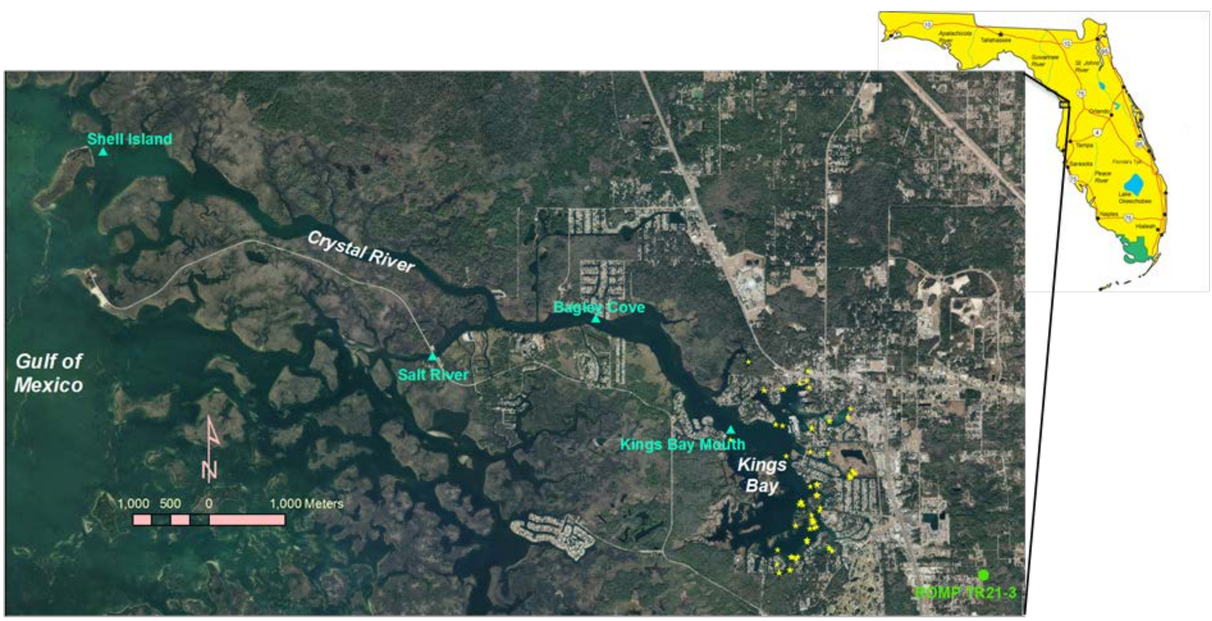


Figure 2-1. Location of individual spring vents and long term data collection (USGS gage) locations.

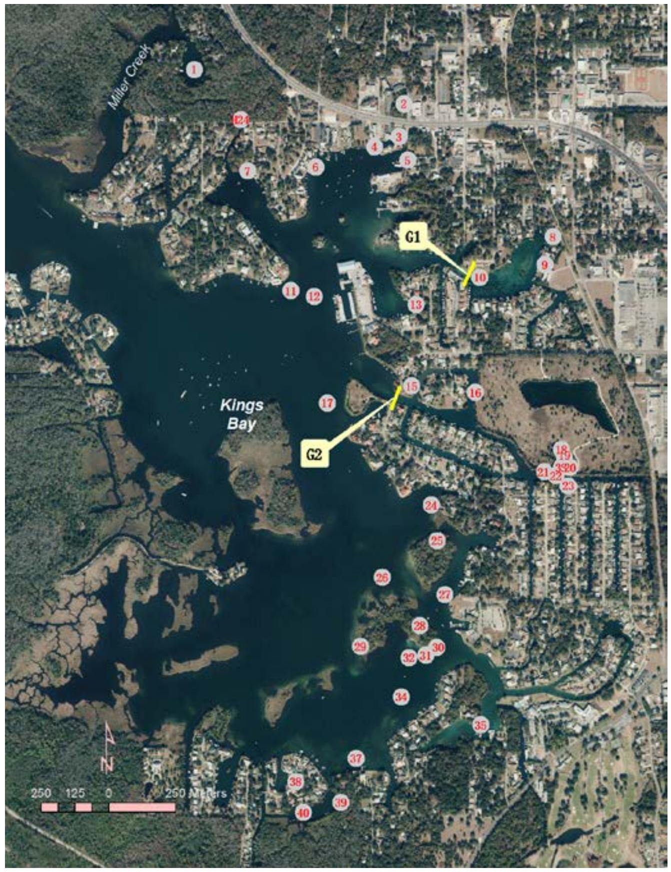


Figure 2-2. Location of springs groups where discharge was measured by multi-cell ADCP (G1 and G2) and individual springs where instantaneous measurements were taken (numbered).

2.2 <u>Predicting Freshwater Inflow</u>

The rate of instantaneous spring discharge was modeled as a linear function of head difference between groundwater and surface water levels (Equation 1). Development of this model is detailed in Chen (2014, 2016 [included as appendix]) and was reviewed by Yobbi (2015 [included in appendix]). The underlying theory is that flow will be proportional to head difference between groundwater levels and the potentiometric surface at the spring vent, an inference derived from Darcy's law, which states that groundwater flow is proportional to the gradient of the hydraulic head (Figure 2-3). Thus, spring discharge varies with changing levels of groundwater and surface water in the bay.

Selection of a record of spring discharge for this system is detailed in an analysis of uncertainty in flow and habitat [included as appendix] (Herrick 2017). This analysis was conducted in response to comments made by the Peer Review Panel [included as appendix] (SWFWMD 2016). The conclusion of this analysis is that the empirical formula provides the best estimate of discharge because it is updated continuously, is able to be hindcasted back to 1969, and represents springflow on a short-term basis.

$$q = q_0\left[1 + C_1(G - \Delta G - \eta) + C_2\frac{\partial \eta}{\partial t}\right]$$

Equation 1. Flow depends upon the rate of change in water levels in the bay as well as on head difference. Variables: q denotes estimated springflow, q0 is the long-term mean springflow, G represents the groundwater level in ROMP TR21-3. There are three parameters: C1 links head difference to discharge; C2 links the rate of surface water level change ($\partial\eta/\partial t$) to discharge and ΔG is the long-term average difference between G and G', the potentiometric surface at the vent site.

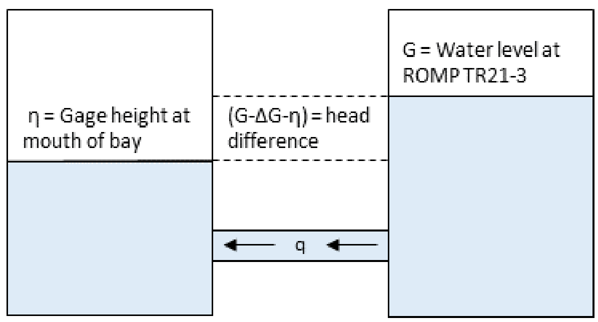


Figure 2-3. Schematic illustration of water levels and pressure differences that result in springflow. Water level is measured at two points: the groundwater well ROMP TR 21-3, and at the surface of the Crystal River at the mouth of King's Bay (USGS #02310742). The positive spring head difference between the ground water level (G) and the surface water in the bay (η) that drives discharge (q) out of the spring.

Mean springflow from field measurements of all 70 vents was used as the long-term mean springflow (q_0) (Equation 1). Flows from two subsets of springs, G1 with 3 springs and G2 with 8 springs, were evaluated to determine parameters C_1 and C_2 from the nearest spring subset (Figure 2-4). Long-term mean springflow q_0 was calculated from field vent measurements, and ΔG was calculated as a linear function of distance from G1 or G2 to account for variation in potentiometric surface among vents.

Flows estimated using Equation (1) are able to account for 72% and 94% of the variation in measured flow in the two groups (G1 and G2) of springs (Figure 2-4). (Chen 2014; Chen 2016 [included as appendix]). Equation (1) was used in the hydrodynamic model (see the next section) to estimate springflows at each time step. Model parameters determined through the model calibration process produced model estimates that agreed well with measured water level (R^2 = 0.98), salinity (R^2 = 0.75), and temperature (R^2 = 0.90) during a 34-month period from April 2007 through February 2010. Based on the time series of the total springflow estimated in the hydrodynamic model, an empirical formula was developed that links the lunar-cycle running average of springflow with the lunar-cycle running average of the head difference between the groundwater level in ROMP TR21-3 and surface water level in Kings Bay. This empirical formula was used to hindcast the springflow back to November 1969, resulting in a long-term average of 374 cfs for the 46-year period between November 1969 and October 2015 (Table 2-1, Figure 2-5) (Chen 2016 [included as appendix]).

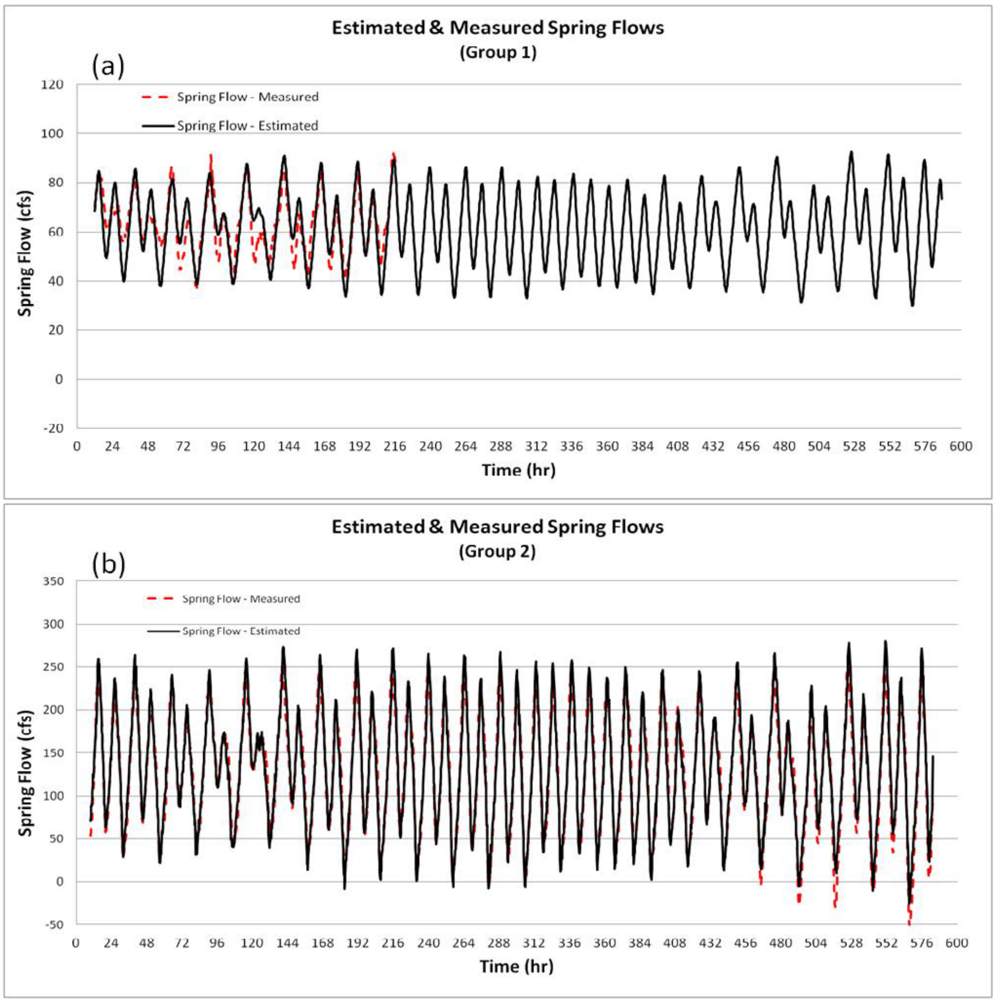


Figure 2-4. Estimated springflows and measured springflows for two groups of springs during a 25-day period from July 27, 2009 to August 20, 2009.

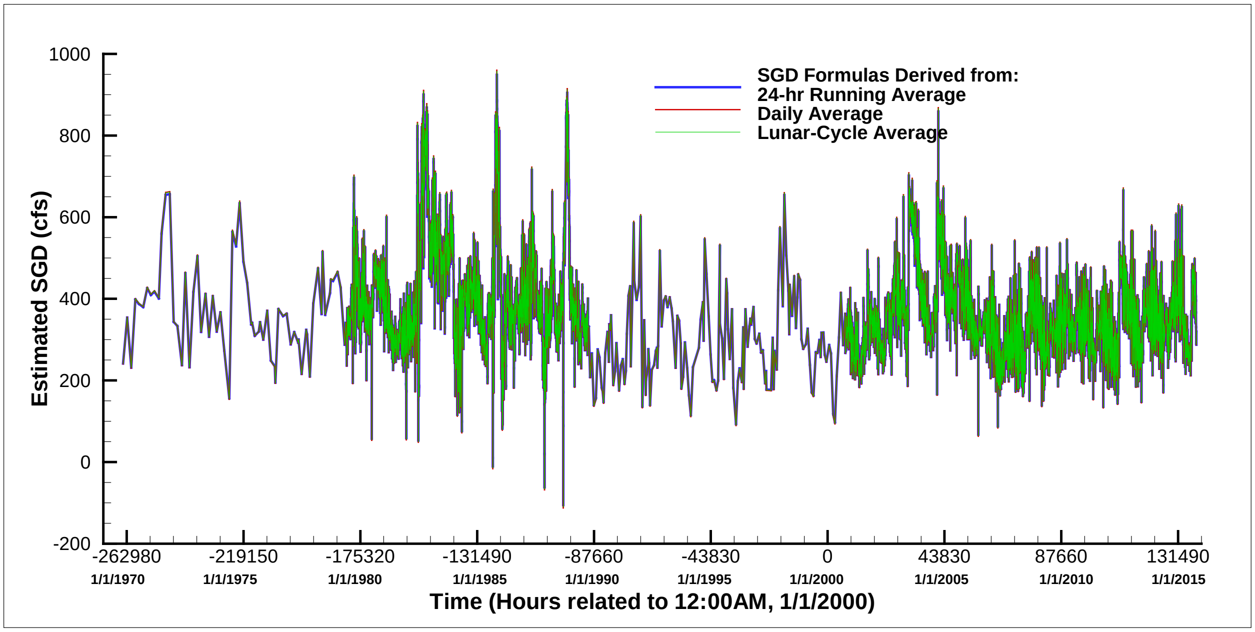


Figure 2-5. Submarine groundwater discharge (SGD) hindcasted from November 1969 through October 2015 (Chen 2016 [included as appendix]). The Daily Average line is plotted but overlaid by other lines for most of the depicted time.

Table 2-1. Statistics of daily submarine groundwater discharge values (SDGs) hindcasted using formulas derived from 24-hour running averages, daily averages, and Lunar-cycle running averages of the total SGD and head difference between the groundwater level in the ROMP TR21-3 well and the surface water level in Kings Bay from November 1969 through October 2015.

	Hindcasted Daily SGDs (cfs) Using Formulas Derived From:		
	24-hr Running Averages	Daily Averages	Lunar-cycle Running Averages
Minimum	-105.20	-112.32	-110.13
5th percentile	232.72	231.45	232.20
10th percentile	260.24	259.44	260.08
25th percentile	304.34	304.31	304.75
50th percentile	354.99	355.83	356.06
75th percentile	418.54	420.48	420.44
90th percentile	506.11	509.56	509.15
95th percentile	583.23	588.02	587.28
Maximum	948.83	959.94	957.64
Average	372.65	373.79	373.94

2.3 Hydrodynamic Modeling

Once we developed a model that estimates instantaneous spring discharge from regularly recorded data on groundwater and surface water levels (Equation 1), we could predict the effects of changes in groundwater level on the system (Figure 2-6), with the implicit assumption that groundwater withdrawals are directly associated with change in groundwater levels. We used UnLESS3D, an unstructured Cartesian grid model to simulate hydrodynamics of the system. This model sections the bay and river into discrete, three-dimensional cells of varying size and shape (Figure 2-7). Within each cell, the model solves the continuity equation, momentum equations, and transport equations for temperature, salinity, and conservative tracer concentration at every time step. The model is driven by measured water elevations, salinities, and temperatures at open boundaries (USGS stations near Shell Island and in Salt River) and wind shear stresses and heat flux at the water surface, which were calculated based on measured wind, solar radiation, air temperature, and relative air humidity at a weather station about 10 miles north of Kings Bay. The UnLESS3D model was also driven by the springflows at the bottom of Kings Bay. Further details of this model and its application to the Crystal River/Kings Bay system are thoroughly explored in Chen (2010, 2011, 2012, 2017a [included as appendix]).

Model predictions were calibrated and verified with values measured within the system at the USGS gage stations at the mouth of Kings Bay and at Bagley Cove. The calibration process of the UnLESS3D model for the Crystal River/Kings Bay system involved adjustment of mainly the following four parameters: bottom roughness, background eddy viscosity/diffusivity, attenuation of short wave radiation, and flow adjustment factor for flows through hairline fractures and diffuse flow. These parameters were set by matching model output to measured values of gage height, salinity and temperature from Dec 28, 2007 to May 26, 2008. They were then verified against measured values from Apr 24, 2007 to Dec 28, 2007 and from May 26, 2008 to Feb 23, 2010. Model results of water level, temperature, and cross-sectional flux agree very well with real-time field data with their skill assessment parameters being 0.97 or higher and their R^2 values being 0.89 or higher. Simulated salinities by the UnLESS3D model match well with real-time field data with an overall skill of 0.75 and an overall R^2 of 0.70, despite the fact that there are some unidentified uncertainties associated with springflows and the salinity values in these springflows.

A survey of the system identified and located 70 spring vents (VHB 2009 [included as appendix]). Instantaneous spring discharge for each vent was measured under various tidal conditions. Salinity measurements were taken at the same time (VHB 2010 [included as appendix]). Thus, we are able to model spatially explicit springflow with corresponding salinity values to accurately predict effects of springflow on salinity habitats. Discharge was modeled at every spring site using parameters in Equation 1 corresponding to the nearest group (G1 or G2). In addition to these 70 identified spring vents, diffuse flow and flow from hairline fractures were modeled by randomly placing 40 small vents throughout the system, each of which discharging between 0 and 1 cfs based on a parameter set during the calibration period. Diffuse flow accounts for less than approximately 6% of flow. Runoff and direct rainfall account for less than 1% of the total hydrologic loading to the estuary. Collectively the estimated rate of instantaneous spring discharge and the estimated diffuse flow were considered appropriate estimates of submarine groundwater discharge to the system.

Seventeen, nine-year scenarios were run: baseline flow; existing flow (98% baseline); baseline with three sea level rise estimates; and 12 incremental, 2.5% reductions in flow from 97.5% baseline to 70% baseline. Salinity and temperature values in all cells were written-out by the model in 30-minute time steps. The model run for the existing flow recreated conditions from October 6, 2006 to October 13, 2015 and all other scenario runs were based on the same time period. For the 9-year simulation, the spin-up period is 26 days, from October 6, 2016 to October 31, 2016 (Chen 2012).

Existing conditions were based on the historical record of groundwater, surface water levels, boundary conditions at Salt River and Shell Island, and calibrated and verified parameters as described above. Baseline and reductions in flow were simulated based on the district's estimated impacts to groundwater levels from withdrawals (Table 1-2). Measures used to drive the UnLESS3D model for the scenario runs and model output are listed in Table 2-2.

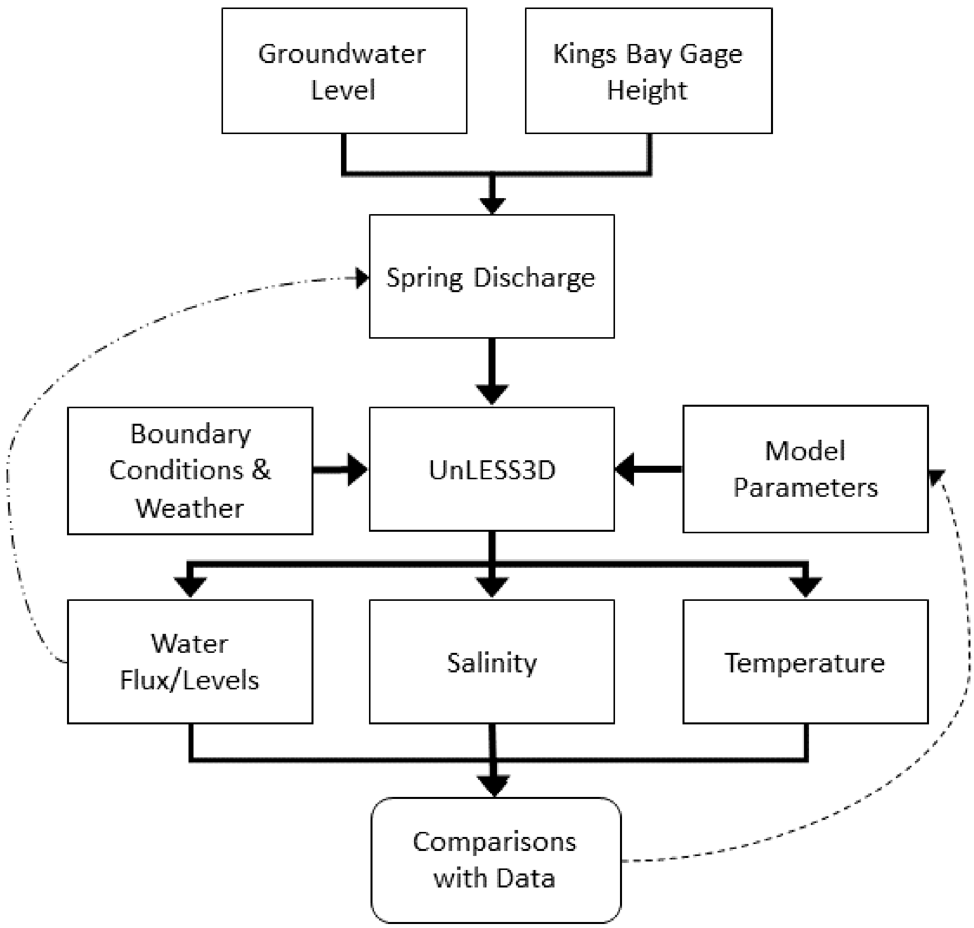


Figure 2-6. Conceptual model of inputs and outputs from UnLESS3D model. Measured water levels, salinity, and temperature were used to obtain model parameter values (dashed lines) through a model calibration process. The model computes water flux and levels, salinity, and temperature using these parameter values. At every time step (in the order of 60 – 120 seconds), spring discharge is calculated as a function of surface (dot-dash line) and groundwater levels, and then becomes one of the drivers of salinity, water levels, and temperature in the next time step. Spring discharge can also be estimated based on measured gage height. Changes in groundwater level inputs were implicitly assumed to be associated with groundwater withdrawals but were not included directly in the UNLess3d model analyses.

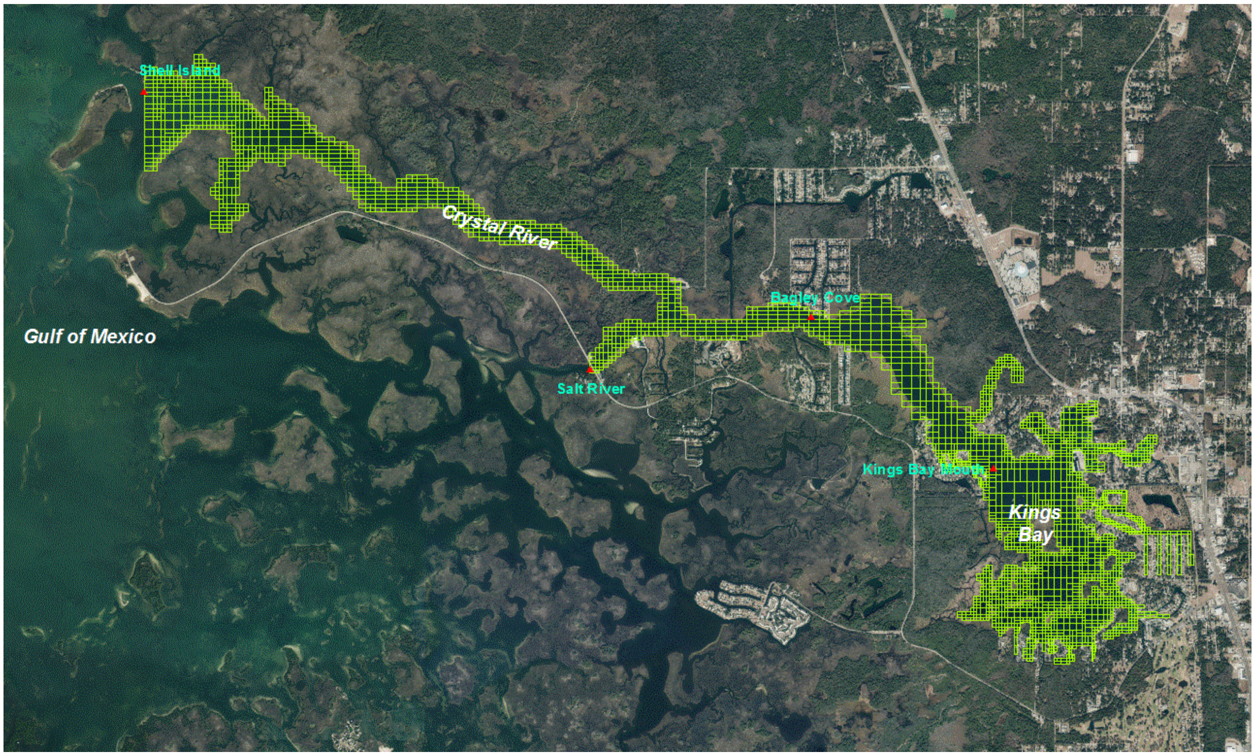


Figure 2-7. UnLESS3D model grid consisting of 3,030 horizontal cells and 14 vertical layers.

Table 2-2. UnLESS3D model data inputs and outputs.

Variable/parameter	Data Type	Period	Notes
Groundwater at ROMP TR 21-3	District monitoring well with hourly data	Daily 1979 – present	SGD formula input
Tide height at mouth of Kings Bay	USGS gage reports 15 min data	Nov 30, 2006 – present	SGD formula input, UnLESS3D input/output
Location and discharge of 70 spring vents	Locations and instantaneous discharge	Mapping: Oct 2008, Jan 2009 Discharge: July-Oct 2009	SGD at each vent modeled based on average measured discharge and location
Discharge at channel sites G1 and G2	Continuous measurement with ADP	July 27-August 20, 2009	SGD formula was calibrated to match these data
Submarine Groundwater Discharge (SGD)	Function of head difference	Oct 6, 2006 –Oct 13, 2015	Drives UnLESS3D model, updated every time step
Water level, salinity, temperature	Observed values at USGS Bagley Cove, Mouth of Kings Bay	Calibration: Dec 28, 2007 –May 26, 2008	UnLESS3D parameter values were calibrated to fit these reported values
		Verification: Apr 24, 2007 –Feb 23, 2010	UnLESS3D parameter values were verified against these reported values
Water level/flux, salinity, temperature	Model output	Oct 6, 2006 –Oct 13, 2015	These are the primary predictions of the model
Water level, salinity, temperature	15-minute data reported at Salt River, Shell Island	Oct 6, 2006 –Oct 13, 2015	Boundary conditions driving model at every time step
Meteorological Data	Model input	Oct 6, 2006 –Oct 13, 2015	Drives UnLESS3D model. Rainfall included as adjustable parameter, not as meteorological input.

2.4 Salinity-Based Habitat

Salinity-based habitats are defined as totals for shoreline length, water volume, and bottom area up to and including a given cutoff salinity value. UnLESS3D model cell values were summed across space to produce instantaneous total habitats in 30 minute intervals. These instantaneous estimates were averaged across the entire 9-year simulation period to produce estimates of shoreline length, total water volume, and bottom area for the entire system at salinity concentrations ranging from ≤0.5 ppt to ≤20 ppt. The model does not assume salinity to be well-mixed. Water volume is calculated across all model layers. The bottom area calculation used bottom-layer salinity. Vegetation along the shoreline was surveyed, and shoreline GIS layers were developed which distinguish between vegetated, natural (beach and ancient reef outcrop), and altered (seawall and rip-rap) shorelines (Avineon 2010). Shoreline was calculated based on bottom elevations at the four corners of a model grid and the simulated water surface elevation. This is more thoroughly explained in Figure 2 on page 10 of the hydrodynamic model report (Chen 2017a).

2.5 Manatee Thermal Refuge

Water volume and area were summed for all UnLESS3D model cells to produce instantaneous estimates of total water volume and area ≤ 15°C, >15°C, and ≥20°C in 30 minute increments as thermal refuge for manatee.

For the Crystal River/Kings Bay system, we define manatee thermal refuge as water that does not fall to 20°C or lower for longer than 3 days and does not fall to 15°C or below for longer than 4 hours (Table 2-3). Further, we estimate that each manatee requires an area of 28.5 ft^2 and a volume of 108 ft^3 with a minimum depth of 3.8 feet. These temperature and space requirements were used to set the minimum flow for the Chassahowitzka River in southern Citrus County (Heyl et al. 2012). These space requirements were originally developed for Blue Spring within the St. Johns Water Management District, where they used a minimum depth of 5 ft (Rouhani et al. 2007). Our minimum depth of 3.8 feet follows analyses used for the Chassahowitzka River minimum flows, which recognizes that manatees will bask in shallow waters to obtain warmth from sunlight.

We use instantaneous measurements of water temperature in 30 minute increments to find the three-day (or 72-hour) time periods with the smallest total volume and area of water >20°C and at least 3.8 ft deep as the time with the greatest risk of chronic exposure stress. We then compared this quantity of thermal refuge from chronic stress at baseline flow vs. reduced flow scenarios. We repeated the process for the 4-hour time period with the least amount of thermal refuge above 15°C to assess thermal habitat availability under conditions of acute thermal stress.

Table 2-3. Minimum habitat requirements for manatee thermal refuge in the Crystal River/Kings Bay system. Area and volume are space requirements for individual manatees.

Parameter (minimum)	Chronic Thermal Refuge	Acute Thermal Refuge
Area	28.5 ft^2	28.5 ft^2
Volume	108 ft^3	108 ft^3
Depth	3.8 ft	3.8 ft
Temperature	>20°C	>15°C

2.6 Water Quality

An analysis of water quality in the Crystal River/Kings Bay system was completed in October, 2016 and revised as a stand-alone report in April 2017 concurrent with revision of the minimum flow report (SWFWMD 2017a) [included as appendix]. The methods used in this analysis were designed to investigate links between amount of flow from spring vents and the quality of water discharged from those vents. In particular, nitrogen, phosphorus, and dissolved oxygen were hypothesized to vary with rate of discharge. This analysis used a database of complied water quality data collected within the system. However, these data were not collected for the purpose of determining compliance with any water quality criteria. The analysis and presentation of data herein is intended to broadly characterize historical data in terms of current regulations, not to determine compliance.

District staff added recent results to a water quality data set compiled by Frazer et al. (2010) [included as appendix] to create a final data set with 9,104 entries from 535 stations in 13 zones within the Crystal River/Kings Bay Springs system spanning January 5, 1984 to December 22, 2014 (Table 2-4). The District's water quality stations were divided into thirteen zones in order to gain a fine-scale picture of water quality and minimize confounding between the dilution with Gulf water (salinity gradient) and other water quality parameters (Figure 2-8). Zones 1-6 are in Kings Bay, zones 7 to 11 are in the Crystal River, and zones 12 and 13 extend off shore (Table 2-5). The Crystal River Estuary WBID (1341I), which extends from approximately Rkm 0 to 6.8, includes zones 9 – 10 but excludes all of zone 7 and part of zones 8 and 11 (Figure 1-20). River kilometer was defined with precision of 0.1 km with Rkm zero at 28.927 N, 82.694 W. Distance offshore was represented by negative river kilometer (Rkm). In order to compare measured values to water quality criteria for dissolved oxygen, we categorized each individual measurement as marine or fresh in accordance with DEP definitions (Rules 62-302.200(29) and 62-303.200(30), F.A.C.).

Trends were analyzed using the Kendall rank correlation coefficient to measure the association between water quality parameters and both time and flow. Trends associated with varying discharge used estimates of historical discharge rates by hindcasting with the submarine groundwater discharge model described in section 2.2 using historical records of groundwater and sea levels (Chen 2014, 2016 [included as appendix]). A minority (16%) of water quality samples were taken on dates for which historical groundwater levels are in monthly increments. As a result, we used linear interpolation to estimate daily discharge for these dates. The remaining 84% of water quality samples occurred on dates for which there exists daily gage height measurements. Trends in water quality parameters with discharge were analyzed using daily average discharge on the date of water quality parameter collection.

Table 2-4. Data sources for district water quality analyses.

Data source	Project Name	Source Report
DEP	Data sonde monitoring	(DEP 2010)
USF and FFWCC	Fish and Invertebrate Project	(USF and FFWCC 2010)
Mote Marine	Crystal Profiles 80s	(Dixon 1986)
SWFWMD	Crystal River Minimum flows stations	n/a
SWFWMD	Kings Bay and Crystal River WMIS Data	n/a
SWFWMD radar rainfall data	n/a	n/a
SWFWMD rainfall data	A0020061	n/a
SWFWMD rainfall data	A0020973	n/a
SWFWMD rainfall data	A0022955	n/a
SWFWMD rainfall data	A0023445	n/a
UF	Florida Lakewatch	n/a
UF	Frazer Kings Bay salinity project	Frazer et al. (2001)
UF	Frazer Project Coast	(Frazer et al. 2006a)
UF	Frazer River Project	(Frazer et al. 2001a)
USFWS	Kings Bay SAV monitoring	n/a

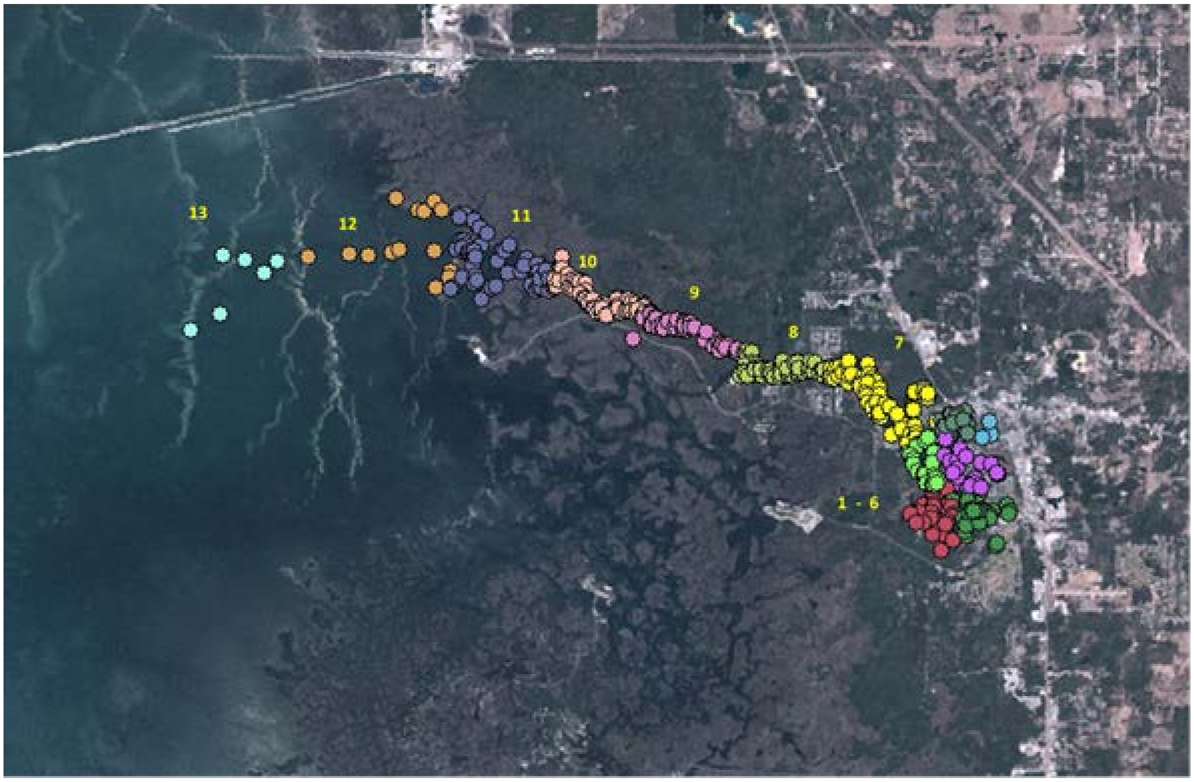


Figure 2-8. Location of SWFWMD water quality measurements within 13 zones spanning Kings Bay and the Crystal River and extending into the Gulf of Mexico.

Table 2-5. Location of water quality zones expressed in river kilometer (Rkm).

Zone	**1-6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Rkm	>10.1	8.0 – 10.1	6.0 – 7.9	4.0 - 5.9	2.0 – 3.9	0.0 – 1.9	-3.0 - -0.1	-6.0 - -3.1

2.7 Sea Level Rise

The District has made the decision to use sea level rise predictions to aid in identification of the need for and the scheduled reevaluation of coastal flowing-water systems for which minimum flows are developed. To do this, we first had to conduct the other analyses described here, finding the minimum fraction of flow necessary to prevent significant harm to the critical factors associated with environmental values. Once we obtained that minimum flow value, we generated a new baseline flow record that depends on predictions of sea level rise. This new baseline under sea level rise allowed us to predict the effects of sea level rise on salinity and thermal refuge. There are three updated scenarios associated with the effects of sea level rise: 1) the effect of sea level rise on baseline, natural flows, 2) the effect of sea level rise given existing impacts on groundwater levels, and 3) the effect of sea level rise in combination with additional reductions in flow. We looked at the combined effects of sea level rise and reduced flows near or at the minimum value established by our previous analysis to establish the need for re-evaluation. This approach recognizes the possibility that sea level rise could alter the sensitivity of the system to reductions in springflow.

Sea level rise was estimated for low, intermediate, and high scenarios following the Army Corps of Engineers recommendations (USACE n.d.). Sea level rise estimates at the mouth of the Crystal River were based on those at National Oceanic and Atmospheric Administration stations 8726520 (St. Petersburg FL) and 8727520 (Cedar Key FL). Inverse distance weighting was used for interpolation, given that Cedar Key is 40 km and St. Petersburg is 128 km from Crystal River. This resulted in sea level rise estimates for low, intermediate, and high projections of 0.162 feet (1.94 inches), 0.287 feet (3.4 inches), and 0.707 feet (8.5 inches), respectively, for an assessed 20 year horizon. The low projection is simply a continuation of the historical, linear rate of sea level change, which means that sea level in this system has risen 0.162 feet (1.94 inches) over the past 20 years and 0.324 feet (3.9 inches) over the past 40 years. The continuation of this linear trend is the lowest estimate of continued sea level rise.

These additions to sea level were added to water level at open boundaries in three model runs: a baseline flow scenario, and two runs corresponding to reduced flow scenarios. Each run produced their own values of discharge, salinity, and temperature. We did not include any other effects of sea level rise or climate change in our models. For example, although there is a possibility that rising sea levels will cause coastal groundwater levels to rise, we did not include any effects of sea level rise on groundwater levels. Similarly, we did not attempt to model potential sea level rise effects on water quality of spring discharge.

2.8 Estuary Residence Time

Estuary residence time (ERT) was modeled as the time needed for 95% of conservative tracer mass to be removed from Kings Bay in hydrodynamic model runs. In a chemostat with constant volume, residence time is inversely proportional to rates of inflow and outflow. However, because the volume, tidal flows, and spring discharge into Kings Bay are all variable, a number of simulation periods were selected to include the range of residence times experienced by the system (Table 2-6).

Table 2-6. Estuary residence time periods spanning range of tides, spring discharge rates, and bay volumes. MMSL = Mean monthly sea level. Spring tides are tides during new or full moon, while neap tides refer tides when the sun and moon are at right angles to each other. Average tides are those between spring and neap tides. The spring discharge percentiles presented in Table 2-6 are percent non-exceedance values.

Period	Tides	Discharge Rate	Kings Bay Volume
1	Spring	Low	Average
2	Neap	Low	Average
3	Average	High	High MMSL
4	Average	Average	Low MMSL
5	Neap	Average	Average
6	Average	5th percentile	Average
7	Neap	10th percentile	Above Average
8	Neap	50th percentile	High MMSL
9	Spring	90th percentile	High MMSL

CHAPTER 3 - RESULTS

3.1 Modeled Salinity habitats

The volume of water with salinity ≤ 2 ppt is the most restrictive salinity-based factor (Table 3-1). If the spring discharge falls to 88 percent of baseline (a 12 percent reduction in flow), the average volume of water with salinity at 2 ppt or less falls from 2.45 million cubic meters to 2.08 million cubic meters (Table 3-2). Larger fractions of salinity-based habitats include smaller fractions, e.g., the volume with salinity ≤ 2 ppt includes the volume with salinity ≤ 1 ppt, and so on. It can be seen (as critical flow reductions decrease, then increase with increasing salinity) that the effects of flow reduction on salinity-based habitats are not necessarily monotonic.

Table 3-1. Relative flow reductions (expressed as percent) corresponding to preserving 85% of baseline habitats. The lower the proportional reduction in flow allowed, the more restrictive the criterion. The most restrictive criterion marked with asterisk.

Salinity (≤ ppt)	Bottom Area	Water Volume	Shoreline Length
1	23	21	>30
2	13	12*	28
3	25	22	>30
5	>30	>30	>30
10	>30	>30	>30
15	>30	>30	>30

Table 3-2. Absolute reductions in salinity based habitats corresponding to baseline and minimum flow conditions defined as 85% of baseline habitats.

Salinity (≤ ppt)	Bottom Area ($m^2 \times 10^6$)		Water Volume ($m^3 \times 10^6$)		Shoreline Length (km)	
	Baseline	Minimum	Baseline	Minimum	Baseline	Minimum
1	0.332	0.282	0.437	0.371	8.29	7.04
2	1.42	1.20	2.45	2.08*	13.42	11.41
3	2.67	2.27	4.47	3.80	19.85	16.87
5	3.25	2.76	5.66	4.81	21.88	18.59
10	4.18	3.56	7.77	6.60	25.95	22.05
15	4.86	4.13	9.19	7.81	29.28	24.89

3.2 Modeled Manatee Thermal Refuge

The UnLESS3D model was able to predict volume and area of water in different temperature fractions throughout the bay. During the coldest 72 hours of the time period modeled, 85% of baseline flow is required to preserve 85% of the volume of water >20°C and deeper than 3.8 ft (Table-3-2, Figure 3-2). During time period with the smallest overall volume of thermal refuge from acute cold stress the volume of refuge was less sensitive to reductions in flow than at other times, however this is the most critical time period corresponding to the unusually cold winter of 2009 - 2010 (Table 3-4, Figure 3-2). At their smallest values, the total volume and area of water warm enough for manatee thermal refuge is sufficient to allow for several hundred thousand manatees.

Table 3-3. Maximum percent reduction in flow required to preserve 85% manatee thermal refuge. The lower the proportional reduction in flow allowed, the more restrictive the criterion. The most restrictive criterion is highlighted.

Parameter	Chronic Stress (72 h @ <20°C)	Acute Stress (4 h @ < 15°C)
Area	15	11
Volume	15	9

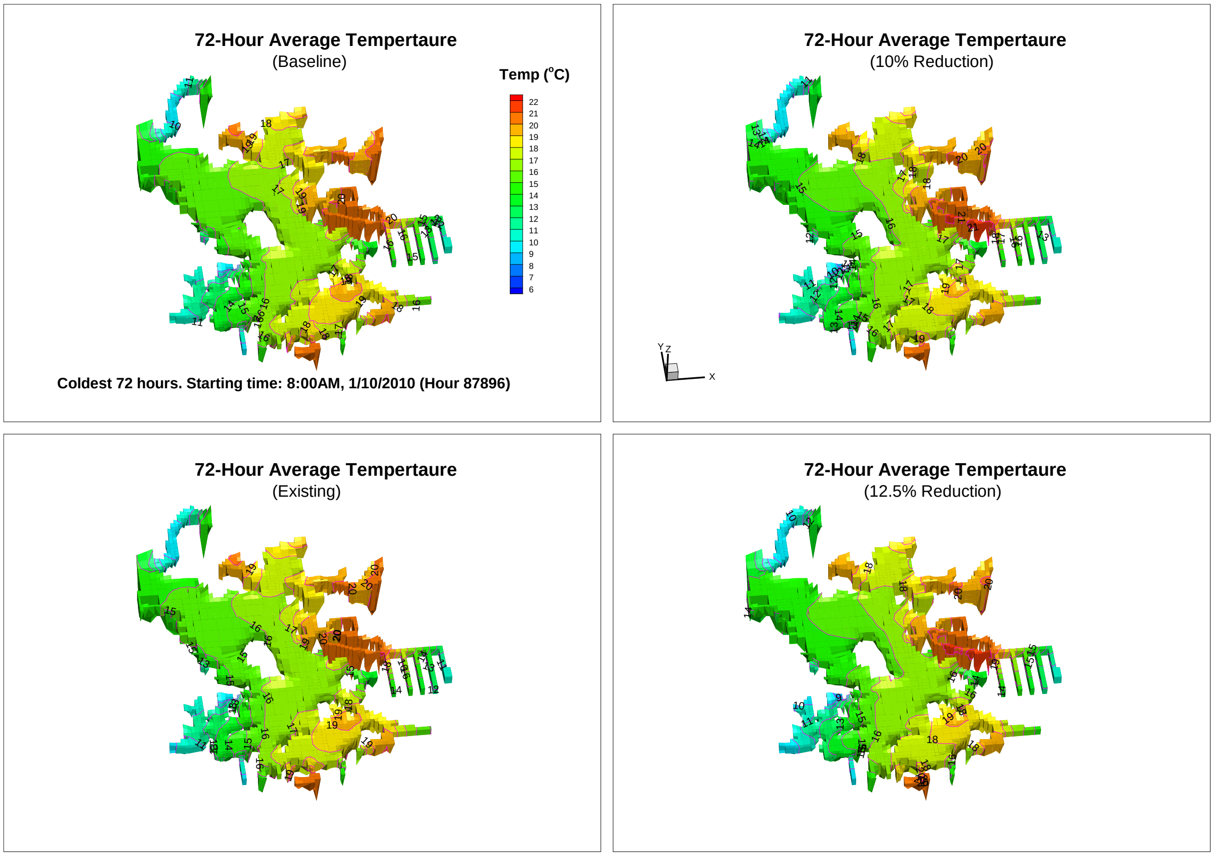


Figure 3-1. Volumes of warm water during coldest 72 hour window. These are three dimensional plots -see the x, y, and z axis in the upper-right plot.

Table 3-4. Amount of water >15°C and number of manatees that could be supported given space requirements of 108 ft^3 and 28.5 ft^2 from Rouhani et al. (2007). Values are for the four-hour period with smallest amount of refuge under baseline conditions. Shaded cells bracket 15% percent changes in volume and area.

% of Baseline Flow	Volume (ft^3)	% Volume	Area (ft^2)	% Area	Manatee Capacity by Volume*	Manatee Capacity by Area*
100	3.29E+07	100.0	7.40E+06	100.0	3.05E+05	2.60E+05
97.5	3.13E+07	95.1	7.08E+06	95.7	2.90E+05	2.48E+05
95	2.95E+07	89.7	6.74E+06	91.1	2.73E+05	2.37E+05
92.5	2.86E+07	87.0	6.56E+06	88.6	2.65E+05	2.30E+05
90	2.75E+07	83.5	6.38E+06	86.2	2.55E+05	2.24E+05
87.5	2.67E+07	81.1	6.22E+06	84.1	2.47E+05	2.18E+05
85	2.54E+07	77.3	5.95E+06	80.4	2.36E+05	2.09E+05
82.5	2.48E+07	75.2	5.81E+06	78.5	2.29E+05	2.04E+05
80	2.36E+07	71.6	5.65E+06	76.3	2.18E+05	1.98E+05
77.5	2.23E+07	67.9	5.41E+06	73.2	2.07E+05	1.90E+05
75	2.11E+07	64.0	5.21E+06	70.4	1.95E+05	1.83E+05
72.5	1.89E+07	57.4	4.79E+06	64.7	1.75E+05	1.68E+05
70	1.60E+07	48.7	4.18E+06	56.4	1.49E+05	1.47E+05

* Capacity values represent theoretical maxima based on thermally-favorable criteria and may be moderated by manatee behavior and environmental factors, including food availability

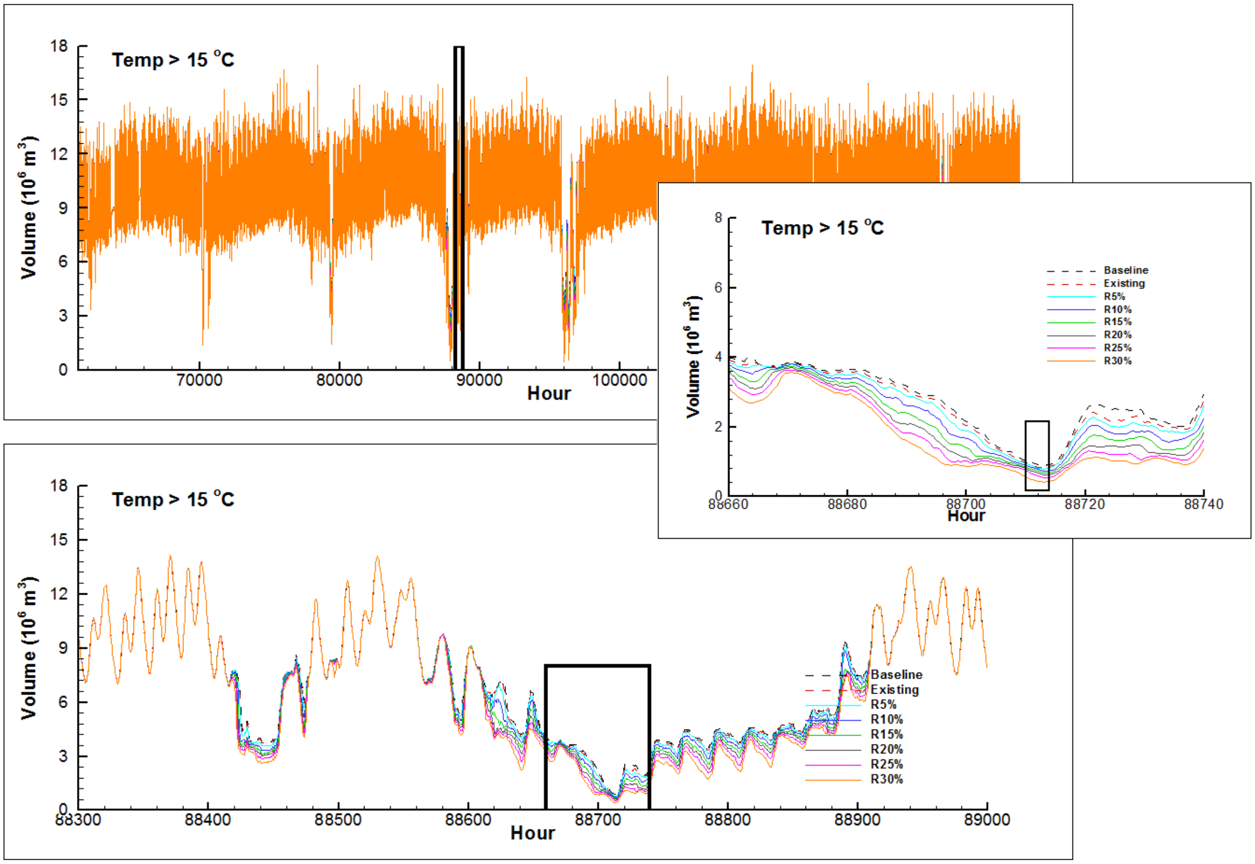


Figure 3-2. Time window with the lowest average volume of water > 15°C within Kings Bay.

3.3 Modeled Sea Level Rise

Sea level rise will impact the system even under baseline spring discharge rates (Table 3-5). These losses in habitat caused by sea level rise will be further compounded by reductions in flow. Care should be taken when interpreting these results. Reductions in habitat are relative to baseline flow conditions for the same sea level scenario. Sea level rise is anticipated to reduce low-salinity habitat. Reductions in flow will further reduce habitat. These effects are multiplicative rather than additive. For example, under the low sea level rise projection, sea level rise alone will reduce habitat by 14 percent to 86 percent of baseline. A 12 percent flow reduction will reduce habitat a further 18 percent, leaving 82 percent of the remaining 86 percent (1 - 0.86 x 0.82 = 0.29) which amounts to a 29 percent reduction to 71 percent of natural habitat.

Sea level rise is ongoing. Impacts to baseline flows are assessed as a percent-of-flow using a regional groundwater model. Model input includes water level in Kings Bay which has increased due to sea level rise. These sea level rises would have impacted baseline flows as well, so the percent-of-flow method we used for assessing flow-related changes in salinity habitat accounts for this.

Table 3-5. Comparison of habitat loss due to sea level rise under baseline flow conditions and with 12% reduction in flow. Values shown are percent loss of ≤ 2 ppt salinity-based habitat volume. These losses in habitat are relative to baseline (unimpacted) springflows under the same sea level conditions. For example, under 2011 sea level, a 12% reduction in flow will result in a 15% loss in ≤ 2 ppt salinity habitat; if sea level rises to the "low" projection, sea level rise alone will account for a 14 percent loss in habitat, 12 percent flow reduction will add an extra 18 percent loss, which compounds to a 29% total loss to the system.

Sea Level Rise Projection	Baseline Flow	12% Loss of Flow	Combined
High	65	28	75
Mid	36	20	51
Low	14	18	29
2011	0	15	15

3.4 Modeled Estuary Residence Time

Estuary residence time for the Crystal River/Kings Bay system varies with tides, discharge, and the total volume of the bay (Table 3-6). As expected, residence time under reduced flow conditions was greater than that for baseline flow conditions for each of the 9 assessed periods. Among periods, the shortest baseline residence time, which occurred during period 4 when volume of the bay was smallest, was 144 hours (6 days). The longest residence time occurred when submarine groundwater discharge was at its 5th (non-exceedance) percentile during period 6. The average residence time for the 9 assessed periods was 271 hours (11.3 days) under baseline spring discharge. This increased to 301 hours (12.5 days) when flows were reduced 12% in accordance with the most sensitive criterion assessed for minimum flows development.

Table 3-6. Estuarine Residence Time (ERT) varies with tides, discharge, and the total volume of the bay. Shading identifies mean values for the 9 assessed periods. SGD percentiles are non-exceedance, such that the 10th percentile is low flow.

SGD = submarine groundwater discharge; KB = Kings Bay; MMSL = Mean monthly sea level

Period	Tides	SGD	KB Volume	Baseline ERT(h)	MFL ERT(h)	ERT Increase
1	Spring	Low	Average	331.6	369.3	11.4%
2	Neap	Low	Average	298.4	327.2	9.7%
3	Average	High	High MMSL	220.9	240.9	9.1%
4	Average	Average	Low MMSL	144.2	188.8	30.9%
5	Neap	Average	Average	307.6	325.1	5.7%
6	Average	5th percentile	Average	372.7	389.4	4.5%
7	Neap	10th percentile	Above Average	327.2	370.7	13.3%
8	Neap	50th percentile	High MMSL	263.4	300.9	14.2%
9	Spring	90th percentile	High MMSL	170.2	192.3	12.9%
Average	Average	Average	Average	270.7	300.5	11.0%

3.5 Measured Water Quality

3.5.1 Comparisons with Concentration Limits

Of 3,770 samples taken across the entire Crystal River/Kings Bay system, only 2% fell below minimum dissolved oxygen requirements for marine waters and 4% fell below requirements for fresh waters (Table 3-7). Two zones (numbers 5 and 6) fell below the 42% saturation minimum for marine waters, and only zone 6 fell below 38% saturation minimum for fresh waters in excess of the maximum 10% of samples allowed. Measured nitrogen and phosphorus levels commonly exceeded TMDLs in Crystal River and Kings Bay (Table 3-8). Chlorophyll-a concentrations frequently exceeded limits set forth in Rule 62-302.532, F.A.C., which define limits as annual geometric means not to be exceeded more than once in a three-year period (Table 3-9).

Table 3-7. Dissolved oxygen samples that exceed regulations for marine and freshwater. Marine waters must have <10% of samples under 42% saturation; fresh waters must have <10% of samples under 38% saturation. All waters must be below 110% saturation of total dissolved gasses. Shaded cells exceed maximum allowed 10% of samples under saturation limits.

Zone	N Observations Marine	Percent < 42% Saturation	N Observations Fresh	Percent < 38% Saturation
1	10	0%	317	2%
2	1	0%	204	0%
3	98	2%	299	1%
4	45	4%	413	2%
5	145	13%	398	2%
6	84	52%	336	19%
7	342	1%	495	3%
8	488	0%	195	0%
9	605	0%	114	0%
10	1053	2%	121	2%
11	870	0%	37	0%
12	264	0%	0	0%
13	433	3%	0	0%
Total	4,438	2%	2,929	4%

Table 3-8. Nitrogen and phosphorus above Total Maximum Daily Loads (TMDLs) in the Crystal River/Kings Bay system. Data here are compiled from multiple sources, which is why numbers of observations vary (see Table 2-4). Exceedance proportion is based on the number of observations in the District database that exceeded the TMDL limits.

Nutrient	Water Body (WBID)	Limit (mg l^{-1})	Exceedance Proportion
Phosphorus (TP)	Crystal River (1341I)	0.047	4% (24/549)
Phosphorus (TP)	Kings Bay (1341)	0.032	24% (656/2,740)
Nitrogen (TN)	Crystal River (1341I)	0.37	14% (69/494)
Nitrogen (TN)	Kings Bay (1341)	0.28	34% (852/2,477)
Nitrate	Spring vents (1341C, 1341D, 1341F, 1341G, 1341H)	0.23	51% (104/205)
Orthophosphate	Spring vents (1341C, 1341D, 1341F, 1341G, 1341H)	0.028	29% (128/438)

WBID = Water Basin Identification Number

Table 3-9. Chlorophyll-a concentrations compared with limits as annual geometric means not to be exceeded more than once in a three-year period. Values in excess of limits are in red text.

	Crystal River (limit = 4.4 µg/L)		Kings Bay (limit = 5.7 µg/L)	
Year	Chl-a (µg/L)	Samples (n)	Chl-a (µg/L)	Samples (n)
1988	3.437544	5	2.460436	30
1989	5.731771	12	4.502163	65
1990	3.932638	19	3.835674	88
1991	7.313917	13	5.632301	208
1992	3.89806	5	4.569637	157
1993	6.488526	10	6.067751	315
1994	6.664692	7	5.645896	113
1995	7.393496	13	4.241511	73
1996	7.211445	18	7.483977	66
1997	3.334693	23	6.082901	75
1998	5.714857	42	6.131532	71
1999	3.266997	54	5.449445	80
2000	3.074739	53	5.477485	89
2001	3.995786	12	6.210918	77
2002	3.44379	12	6.889453	65
2003	6.930694	11	5.147426	90
2004	4.572627	12	4.547677	112
2005	4.098	12	6.782987	82
2006	3.622566	12	5.303807	97
2007	3.988069	12	5.794217	101
2008	4.697056	20	5.552605	188
2009	3.529896	28	5.744703	269
2010	2.699585	11	7.138318	147
2011			8.638075	48
2012			11.85256	48
2013			7.540579	52
2014			8.031929	51

3.5.2 Temporal Trends

The DEP found a decrease in total nitrogen (TN) in Kings Bay (Table 3-10) (Bridger 2014). The District found inconsistent trends in total nitrogen, with increases in some zones, decreases in others, and no trends in the remainder. Our analysis was consistent with DEP findings for nitrate, with increases in some zones, and no trend in others. Both the DEP and the District found increases in TP concurrent with decreases in orthophosphate.

Temporal trends in dissolved oxygen, salinity, chlorophyll a, and temperature were not analyzed by the DEP for TMDL development (Bridger 2014), but are included in our analysis. We found decreases in dissolved oxygen over time in zones 8-13. Salinity increased in zones 1 and 3 through 11. Chlorophyll a increased in zones 1, 3-5, and 7, and decreased in zone 9. The District also found decreases in temperature in zones 6-9.

Table 3-10. Temporal trends in nutrient levels within the Kings Bay/Crystal River system. The DEP TMDL reports Mann-Kendall values which with significance at $p < 0.05$ for TN and TP in Kings Bay but not for individual springs (hence NA is shown for trends not seen); the TMDL also reports nitrate and orthophosphate for Kings Bay and for individual springs within Kings Bay (Bridger 2014). The district's analysis used a combined record of water quality samples divided into 13 zones. All thirteen zones were investigated for temporal trends in most water quality parameters. Orthophosphate was only measured in 10 of 13 zones. For district analysis, a Bonferroni correction was done to set the familywise error rate at $p = 0.05$, where all zones are considered a family and test-wise error $\alpha = 0.004$ with 13 zones (McDonald 2009).

Data source	Parameter	Increase	Decrease	Stay the Same / Not Significant	Dates
DEP TMDL (Bridger 2014)	TN	NA	Kings Bay	NA	1974-2012
	TP	Kings Bay	NA	NA	1974-2012
	nitrate	Kings Bay, Hunter, House, Tarpon	None	Black, Idiot's Delight	Kings Bay: 1980-2012 Springs: 1990-2012
	PO_4^{3-}	None	Kings Bay	Hunter, House, Black, Idiot's Delight, Tarpon	Kings Bay: 1974-2012 Springs: 1989-2012
District analysis presented here	TN	zones 1-2, 6-7, 10	zones 3, 12	zones 4-5, 8-9, 11, 13	1984-2014
	TP	zones 1, 3-7, 10	None	zones 2, 8-9, 11-13	1984-2014
	nitrate	zones 1-2, 7	None	zones 3-6, 8-13	1984-2014
	PO_4^{3-}	None	zones 1, 3-6	zones 2, 7-9, 11	1984-2014
	DO	None	zones 8-13	zones 1-7	1984-2014
	salinity	zones 1, 3-11	None	zones 2, 12-13	1984-2014
	chlorophyll a	zones 1, 3-5, 7	zone 9	zones 2, 6, 8, 10-13	1984-2014
	Temp	None	zones 6-9	zones 1-5, 10-13	1984-2014

TN = total nitrogen; TP = total phosphorus, DO = dissolved oxygen; Temp = Temperature

3.5.3 Flow Trends

All six water quality parameters investigated showed at least one significant Kendall rank correlation coefficient (Table 3-11). These trends were not consistent among zones or water quality parameters: some were positive, others negative, and the remainder with no significant trends. Significance depends upon application of a Bonferroni correction for sample size. Phosphate increases with discharge in zones 1, 3, 5, and 6 (all within Kings Bay WBID -see Figure 2-8 for locations of zones). Total phosphorus decreases with discharge in zone 2 (in Kings Bay) and increases with discharge in zone 8 (at border between Kings Bay WBID and Crystal River Estuary WBID). Nitrate increases with discharge in zones 3, 5, 6, 8, 9 and 10. Total nitrogen decreases in zone 2, and increases in 8, 12, and 13. Dissolved oxygen decreases with discharge in 3, 4, 5, 6, and 7, and increases in zones 11 and 13. Chlorophyll a decreases with discharge in zones 1 and 2 (both within Kings Bay), and increases in 10, 12, and 13 (from estuary extending offshore). Trends stated above all use a critical alpha value of 0.05, yet a Bonferroni correction for multiple hypotheses will reduce this threshold for significance, depending upon how it is applied (Table 3-11).

An in-depth analysis of correlation between vent water quality and discharge can be found in the appendix (SWFWMD 2017a). Nitrate exhibited some significant correlations with varying discharge, but there were no consistent patterns. Likewise, there were no consistent or decisive patterns in phosphorus or dissolved oxygen correlations with flow.

Table 3-11. Trends in water quality parameters with varying springflow (discharge). Tau-b numbers are Kendall rank correlation coefficients. Key for p-values: * significant at alpha = 0.05, ** significant with Bonferroni correction for 13 zones (alpha = 0.0038), * significant with Bonferroni correction for 13 zones and 6 parameters (alpha = 0.00064).**

Zone	Ortho -P			TP			Nitrate		
	Tau-b	n	p	Tau-b	n	p	Tau-b	n	p
1	0.087	237	0.046*	0.017	402	0.611	0.025	186	0.613
2	-0.060	168	0.249	-0.109	168	0.036*	-0.079	120	0.202
3	0.164	158	0.002**	0.009	335	0.806	0.122	158	0.023*
4	-0.010	221	0.826	-0.028	302	0.468	0.078	171	0.130
5	0.183	228	0.000***	-0.019	412	0.565	0.173	199	0.000***
6	0.096	262	0.021*	-0.005	758	0.837	0.059	194	0.222
7	0.008	41	0.950	0.025	233	0.571	0.299	62	0.001***
8	0.053	37	0.654	0.136	271	0.001**	0.295	59	0.001**
9	0.258	18	0.145	-0.081	57	0.377	0.381	58	0.000***
10				0.015	314	0.396	0.460	20	0.005*
11	0.340	18	0.053	0.052	37	0.660	0.171	38	0.134
12				-0.066	40	0.556	-0.164	40	0.139
13				0.066	153	0.227	-0.086	20	0.619
Zone	**DO saturation**			**Chl a**			**TN**		
	Tau-b	**n**	**p**	**Tau-b**	**n**	**p**	**Tau-b**	**n**	**p**
1	-0.022	290	0.577	0.015	304	0.697	0.060	352	0.093
2	-0.090	175	0.077	-0.137	95	0.050*	-0.132	127	0.028*
3	-0.107	365	0.002**	0.020	323	0.592	0.003	329	0.936
4	-0.125	409	0.000***	0.019	210	0.683	0.042	249	0.324
5	-0.079	482	0.010*	0.029	372	0.404	0.041	392	0.226
6	-0.096	374	0.006*	-0.065	649	0.013*	0.014	689	0.583
7	-0.098	705	0.000***	0.063	212	0.173	0.014	224	0.756
8	-0.053	549	0.063	0.059	221	0.192	0.098	239	0.024*
9	0.043	577	0.122	0.113	58	0.213	-0.012	56	0.902
10	0.082	985	0.000***	0.200	315	0.000***	0.072	278	0.074
11	0.046	664	0.076	0.085	38	0.460	0.007	36	0.963
12	0.096	156	0.076	0.363	40	0.001**	0.295	40	0.008*
13	0.079	381	0.021*	0.240	153	0.000***	0.144	117	0.022*

CHAPTER 4 - DISCUSSION: USING RESULTS TO SET MINIMUM FLOW

4.1 Crystal River Spring Group Discharge

A comprehensive analysis of the method for selecting a record of spring discharge is described in a separate report [included as appendix] (Herrick 2017). In summary, streamflow gages measure tidal flows into and out of the Bay, but do not represent short-term, continuous estimates of submarine groundwater discharge needed to predict changes to salinity and temperature as a result of groundwater withdrawals.

Our estimate of mean discharge from spring vents into Kings Bay is 374 cfs based on lunar cycle running averages from November 1969 through October 2015 (Chen 2014, 2016 [included as appendix]). Fretwell (1983) estimated the average total spring discharge during 1965–1977 to be about 916 cfs for Kings Bay. We obtained available historical flow records from the USGS for this time period and calculated mean and median discharge values of 971 and 927 cfs, respectively. In an effort to simulate circulation and flushing characteristics of Kings Bay, the United States Geological Survey (USGS) conducted a flow measurement during June 7-8, 1990 near Bagley Cove in the Crystal River, and estimated net flux through this cross section at 735 cfs (Hammett et al. 1996). Tidally filtered daily discharge at the Bagley Cove site, collected with modern instrumentation between 2002 and 2015 averaged 447 cfs with a median flow of 437 cfs.

These previous estimates lack the full spatial comprehensiveness of our study, which includes the set of 70 spring vents found in a 2008-2009 survey funded by the district (VHB 2009 [included as appendix], 2010 [included as appendix]). We estimated a long-term average springflow of 374 cfs for a 46-year period between November 1969 and October 2015 based on the head difference between the groundwater level in ROMP TR21-3 and surface water level in Kings Bay. Our estimate of total spring discharge into the bay is calibrated using measured discharge at two sets of vents and matches the total springshed water budget better than previous estimates. Past short term measurements of discharge and continuous discharge reported at the Crystal River at the USGS Bagley Cove gage #02310747 represent the flux through the cross section at Bagley Cove only and do not necessarily represent total springflow entering Kings Bay at the time of the measurement. In addition, flow at the gage provides limited information on flow at the numerous discharge points (e.g., vents) within the system. The cross-sectional flux through Bagley Cove is a combination of tidal fluxes, springflows entering Kings Bay during the preceding 6 – 20 days, stormwater runoff, wind action, and nonlinear interactions among factors affecting circulation and transport processes in the estuary. Furthermore, these previous estimates of discharge do not match the water budget for the springshed, which is able to account for 455 cfs of springflow from the Crystal River Springs group given 20 inches of recharge per year. The previously reported, high estimates of discharge are inexplicable in terms of the water budget for the springshed. In contrast, our estimate of discharge is consistent with the water budget for the springshed and has been verified against measured water levels, salinities, and temperatures using a hydrodynamic model. Therefore, because of our comprehensive field survey and measurements combined with hydrodynamic modeling of the Crystal River/Kings Bay system and the water budget for groundwater recharge, we are confident in our estimates of spring discharge presented here.

4.2 Modeled Salinity Habitats

The 2 ppt salinity water volume is the most sensitive salinity-based habitat within the Crystal River/Kings Bay system, in terms of flow-related change (Table 3-1). An impacted discharge at 88% of baseline (i.e., a 12% reduction in baseline or natural flow) results in a loss of 15% of the volume of water under 2 ppt salinity. This is the criterion we used to develop proposed the minimum flow for the Crystal River/Kings Bay system.

These low-salinity waters are important habitat for numerous species within the Crystal River/Kings Bay system (Evans et al. 2010 [included as appendix]). Burghart and Peebles (2011 [included as appendix]) found a rapid change in faunal community structure in spring-fed Florida Springs coast rivers (including the Crystal River) at low salinities. They also found that consistent springflow sets up more distinct zonation than in flashier surface-fed systems, a finding that emphasizes the importance of maintaining historical spring discharge patterns into the estuary. Low-salinity waters are also considered critical for limiting barnacle settling in Kings Bay (Culter 2010 [included as appendix]).

Salinity is recognized as an important physiochemical factor for structuring vegetative communities in the Crystal River/Kings Bay system (Hoyer et al. 2001, Clewell et al. 2002, Jacoby et al. 2014) and elsewhere (Haller et al. 1974, Hart et al. 1990, Boustany et al. 2010, 2015). Management of the Crystal River/Kings Bay system has focused on the growth and restoration of native submerged aquatic vegetation because of its importance on improving water quality and cascading effects throughout the ecosystem (SWFWMD 2015).

Reducing blooms of the filamentous algae is also a top priority for managing Kings Bay, and it is believed that submersed macrophytes play a role in reducing the dominance of these nuisance algae (Evans et al. 2007). Controlling *Lyngbya spp*. is particularly important because it produces Debromoaplysiatoxin (DAT), which has been linked to ulcerative dermatitis in the West Indian manatee (Harr et al. 2008). Moreover, harmful algal blooms have been linked to manatee deaths and constitute an ongoing threat to manatee conservation in the state of Florida (Bledsoe et al. 2006).

The physical presence of *Vallisneria americana* decreases resuspension of sediments and associated nutrients by wave action in Kings Bay, resulting in a decrease in algal phytoplankton in the water column and increasing water clarity (Hoyer et al. 2001). Moreover, it supports a diverse community of epiphytic algae and invertebrates (Strayer et al. 2003, Dunn et al. 2008). However, increased salinity can increase the epiphyte load on leaves, reducing incident light that reaches the leaf surface (Twilley et al. 1985, Twilley and Barko 1990). Our conclusion, based on the above studies, is that maintaining low-salinity habitats is critical to promoting restoration of native vegetation which will in turn have positive impacts on water quality throughout the system.

New model runs suggested by Peer Review Panel incorporated changes to boundary conditions as a result of reduced flows. These minor increases in salinity at downstream boundaries did not substantially alter model results. These new results are included as an appendix (Chen 2017b).

4.3 <u>Modeled Mantee Thermal Refuge</u>

Although a reduction to 91% of baseline discharge will result in a 15% decrease in acute thermal refuge volume, there will still be enough warm water present for current and future manatee populations (Table 3-4). Kleen and Breland (2014) report a peak of 566 manatee in Kings Bay observed in January, 2010. More recent surveys show a peak of 758 individuals within the bay in January 2016 (USFWS Unpublished Data). A total population estimate of 6,350 has been reported, based on surveys conducted in 2011 and 2012, with 2,790 manatees observed on the west coast of Florida (Martin et al. 2015). A 2017 synoptic survey estimated 3,488 animals along the west coast of the state (FWC 2017b). Population increases are expected; Runge et al. (2017) note the total state population may increase nearly 100% or more in the coming 50 years.

At their smallest values, the total, simulated volume and area of water warm enough for manatee thermal refuge that we identified is sufficient to allow for several hundred thousand manatees (Table 3-3). We acknowledge that these theoretical maximum car estimates are based solely on manatee thermal requirements during critical cold periods and do not account for behavioral factors and environmental factors, including food availability that can affect carrying capacity. Provancha et al. (2012) identified carrying capacities based on the extent of warm-water within Kings Bay that are approximately one-order of magnitude less than our estimates (median = 13,725 animals; maximum = 24,726 animals). These carrying capacity estimates assumed a single layer of animals, i.e., no vertical stacking of individuals within the water column, and did not account for behavioral effects. A more recent simulation study, Runge et al. (2017) estimates current median carrying capacity for medium- and high-quality sites at 16,363 animals state-wide.

Based on this information, we do not find it appropriate to set minimum flows for the Crystal River/Kings Bay system using manatee thermal refuge, as there appears to be more than enough to sustain the population given present rates of growth. This position is consistent with a report submitted to the U.S. Fish and Wildlife Service, which concluded that warm water is far more abundant than required to support Florida manatee populations, and that manatee protection should focus on forage as the factor limiting population size (Provancha et al. 2012).

There is precedent for setting minimum flows using manatee thermal refuge, and there is also precedent for finding more thermal refuge than necessary to support present population sizes (Table 1-4). Manatee thermal refuge has been used to develop recommended minimum flows in the Chassahowitzka River in Citrus County and for Blue Spring in the St. Johns River Water Management District. For the Chassahowitzka, there was zero available habitat for chronic stress conditions (i.e., >20°C) during the coldest period analyzed (January 4-6, 2002), but there was ample acute stress habitat (water > 15°C) for every manatee on both coasts of Florida, i.e., much more habitat than required. For Blue Spring, the minimum flow was set to preserve “the minimum length of useable warm water refuge needed to accommodate the anticipated increasing manatee populations under catastrophic conditions” (Rouhani et al. 2007). Thus, the minimum flows established for Blue Spring did not preserve 85% of baseline habitat, but rather preserved 100% of anticipated, needed habitat for the growing manatee population. Manatee thermal refuge has been considered in setting minimum flows for two other spring-fed estuaries: the Homosassa River system in Citrus County (Leeper et al. 2012) and the Weeki Wachee River system in Hernando County (Heyl 2008). For both the Homosassa and the Weeki Wachee systems, preserving 85% of baseline manatee thermal refuge was considered unnecessary because there was more than enough habitat for the expected number of manatees even with large reductions in flow. Our present results are in line with those of the Homosassa and Weeki Wachee rivers systems and with recent USFWS findings (Provancha et al. 2012): there will be more than enough manatee thermal refuge in the Crystal River/Kings Bay system even with potentially large flow reductions.

4.4 <u>Measured Water Quality</u>

District data collection and analyses discussed here are not intended to determine compliance with any water quality regulations. Comparisons with water quality regulations are made to put historical data into perspective by comparing with current standards. These comparisons can be used to determine if nutrients and chlorophyll-a levels are “high” relative to regulations.

Trends in water quality parameters are analyzed to determine direction and rates of change in the system. Temporal trends can show how water quality parameters have changed over time. Trends with flow can show how historical variation in flow correlates with variation in water quality parameters. All trends here were analyzed using Kendal rank correlation coefficients, which are suited to non-parametric data. This rank-correlation method can show if water quality parameters tend to consistently change with respect to time or flow. However, this rank correlation method cannot produce a regression equation from which one might infer levels of flow necessary to adjust water quality parameters to within prescribed boundaries. Further work needs to be done, both in data collection and analyses, to investigate the presence of mechanistic links between flow variation and water quality parameters in the Crystal River/Kings Bay system. As such, potential impacts of flow reductions on water quality are not feasible at this time, given current data and analyses. The District recommends, in accordance with Peer Review Panel recommendations, that future work focus on elucidating the impacts of flow reductions on water quality parameters, particularly chlorophyll-a levels.

Included as an appendix to this report is a water quality analysis that includes correlations with flow at individual spring vents. There are several methodological details which limit the inferential breadth of the analyses, which is why they have been placed in the appendix and not included here. First, water quality data collection sites within nine meters of vent locations were considered “vent” stations and correlated with flow. Sites nine meters away will not capture pure spring water, but will represent water that has been in the bay for an indeterminate period of time. Furthermore, Kendall and Spearman rank correlations were performed with water quality parameters and flow on the date of collection. This is appropriate to investigate links between rate of discharge and vent water quality, but not suitable for investigating water quality changes in the bay on longer time scales. For instance, chlorophyll-a levels on the date of sample collection will depend on environmental conditions in the preceding days and weeks, as populations of phytoplankton and epiphytic or benthic algae that may be sloughed into the water column take time to increase in response to more favorable conditions. Lastly, rank correlations can indicate that water quality parameters tend to change in connection with flow rates, but do not establish causal linkages or further quantify the potential relationship to flow. Thus, correlations deemed significant based on small p-values are insufficient for determining minimum flows. Further analyses will be needed to quantify potential relationships between flow and water quality parameters.

4.4.1 Dissolved Oxygen

Low dissolved oxygen has been linked to algal blooms in Florida springs, and suggested as a more important driver of eutrophication than nutrient levels (Heffernan et al. 2010). Thus, trends in dissolved oxygen levels are important for the ecology of the system.

The Dissolved Oxygen Criteria (Rule 62-302.533, F.A.C.) prescribes that no more than 10 percent of daily average dissolved oxygen values are allowed to be below 42% saturation for marine and 38% saturation for fresh waters. All samples, both marine and fresh, must stay below 110% saturation of total dissolved gasses (62-302.530(112) F.A.C.). Measured values for dissolved oxygen values were within saturation limits 98% of marine and 96% of freshwater samples collected (Table 3-7). However, individual zones within the Crystal River/Kings Bay system exceeded the allowable 10% of daily samples (Table 3-7).

Dissolved oxygen decreased over time in the Crystal River (zones 8-13), but had no trend in Kings Bay (Table 3-10). Dissolved oxygen also decreased with flow in zones 3, 4, 5, 6, and 7, but also increased with flow increases in zones 10 and 13 (Table 3-11). These correlations do no support the conclusion that increasing flow will increase dissolved oxygen levels.

4.4.2 Nitrogen

Total nitrogen exceeded the Crystal River Estuary limit of 0.37 mg L^{-1} in only 14% of samples, and exceeded the Kings Bay limit of 0.28 mg L^{-1} in 34% of samples in the database (Table 3-8). The TMDL sets limits for individual spring vents at 0.23 mg L^{-1} nitrate; this was exceeded in 51% of samples located within nine meters of vents. The TMDL report showed that total nitrogen in Kings Bay has decreased over time. The analysis here showed a decrease in zone 3 (in Kings Bay) and increases in zones 1, 2, and 6 (in Kings Bay) along with increases in zones 7 and 10 (in the Crystal River) (Table 3-10). As a result, there does not appear to be any system-wide trend in total nitrogen levels. District analyses also revealed increases of nitrate in zones 1, 2, and 7. The trends observed in individual zones indicate that further work is needed to characterize historical changes to this system.

There are no consistent correlations of total nitrogen or nitrate with flow (Table 3-11). Some zones show positive correlations (nitrate increases with flow in five zones), others show negative correlations (total nitrogen decreases with flow in zone 2). These correlations are between nitrogen levels and average discharge on the date of measurement. Thus, these correlations do not reflect any potential relationships between long-term changes in flow and nitrogen levels. There is no evidence in this data that alterations in springflow are driving nitrogen levels in this system. Further work is needed to establish potential relationships between nitrogen levels and discharge in this system.

4.4.3 Phosphorus

Temporal trends in both the District's analysis and the TMDL report (Bridger 2014) consistently showed increasing TP and decreasing orthophosphate, suggesting assimilation by primary producers (Table 3-10) (Correll 1998). Orthophosphate does not readily dissolve in the alkaline waters of the aquifer, suggesting anthropogenic origin (Upchurch and Lawrence 1984, Jones et al. 1998). The ratio of nitrogen to phosphorus determines which element will limit primary production in marine and freshwater systems. An analysis of 33 near shore coastal sites throughout Florida showed that phosphorus accounted for 81% and nitrogen for 44% of variance in chlorophyll-a concentrations suggesting that phosphorus is more limiting than nitrogen at levels found in Florida waters (Hoyer et al. 2002). In Florida lakes, phosphorus is typically the limiting nutrient until the TN:TP ratio falls below 10:1 (Canfield 1983, Brown et al. 2000). Worldwide, nutrient limitation of phytoplankton appears to be determined by the relative concentration of N:P with strong nitrogen limitation as N:P falls below a 20:1 molar ratio (approx. 9:1 mass ratio) (Smith 2006). Further work is needed to establish relationships between chlorophyll-a levels and N:P ratio in this system.

Orthophosphate increased with increasing flow, while total phosphorus increased in one zone and decreased in another (Table 3-11). These data indicate that phosphorus levels are driven by factors other than springflow. Further work is needed to establish potential relationships between quantity of spring discharge and phosphorus levels in this system.

4.4.4 Chlorophyll a

Links between residence time, flow and phytoplankton blooms (and corresponding chlorophyll-a measurements) have been found in other systems and are hypothesized for the Crystal River/Kings Bay system, but there is no direct evidence of such links in this system (Section 1.6.3). Development of a minimum flow recommendation based on chlorophyll-a levels is not feasible at this time. Further work is needed to establish relationships between chlorophyll-a levels and changes to spring discharge in this system. Improved field measurements of flow at spring vent sites, along with more comprehensive chlorophyll-a measurements may help to describe a relationship between these two variables.

Chlorophyll-a levels regularly exceeded limits over the water quality database period of record (Table 3-9). Historically, chlorophyll-a levels increased in five zones, decreased in one, and had no trend in the remaining seven (Table 3-10). Chlorophyll a decreased with flow in zones 2 and 6 in Kings Bay, and tended to increase with flow in zone 10 in the Crystal River Estuary (Table 3-11). Interestingly, in zone 2, chlorophyll a did not increase over time but decreased with increasing flow. However, this flow-related decrease is at the weakest p-value, and any Bonferroni correction will change the significance of this test. These flow correlations link chlorophyll-a levels to average daily discharge on the date of water quality parameter collection. However, chlorophyll-a levels are measures of population dynamics of phytoplankton blooms. These blooms can vary in spatial extent; data collection at a few sites may not characterize the patchy spatial pattern of phytoplankton blooms that describes the bay as a whole. Furthermore, phytoplankton populations are expected to respond to environmental conditions as they develop over periods of days and weeks. Correlations to daily discharge values on the date of data collection will not capture the biological time scale of changing chlorophyll-a levels (Frazer et al. 2001b, Saindon 2005).

4.5 Supplemental Analyses

Sea level rise and residence time were considered as supplemental to minimum flow development. This means they were not considered as measured criteria for establishing significant harm to environmental values, as was the case for salinity and manatee thermal refuge. However, once we identified the most sensitive criterion for establishing a proposed minimum flow, we determined the potential effects of implementation of the proposed minimum flow on residence time and as part of an analysis of sea level rise. Because a 15 percent decrease in the 2 ppt water volume was associated with a 12 percent reduction in flow, we investigated how that 12 percent reduction in flow will affect estuary residence time as well as salinity-based habitats and manatee thermal refuge under projected sea level rise conditions.

4.5.1 Modeled Sea Level Rise

There are two types of comparisons to make when investigating the effects of sea level rise on the Crystal River/Kings Bay system. The first comparison shows the effect of sea level rise on the system in the absence of groundwater withdrawal impacts. This comparison was presented in Table 3-5, which shows proportion of habitat loss when spring discharge is unimpacted by groundwater withdrawals and sea level increases from current conditions. The second comparison shows the effect of reduced spring discharge due to groundwater withdrawals under present and predicted future sea level estimates.

4.5.1.1 Effects Under Baseline Flows

The United States Army Corps of Engineers (USACE) identifies reasons for using low, intermediate, and high projections of sea level rise when assessing coastal projects (USACE n.d.). The range of predicted decreases in the ≤ 2 ppt salinity habitat vary from low (14%), to intermediate (36%), to high (65%) proportions of habitat loss by 2035 due to the effects of sea level rise on the system when spring discharge is unimpacted by groundwater withdrawals (see Table 3-5). This range implies a large degree of uncertainty surrounding the consequences that sea level rise may effect on this system.

4.5.1.2 Effects of Reduced Flow Under Sea Level Rise

We looked at the effects of reduced flow under two flow scenarios: a 9% reduction in flow corresponding to the critical flow reduction to preserve 85% of acute thermal refuge volume of >15 °C water, and a 12% reduction in flow corresponding to the critical flow reduction necessary to preserve 85% of ≤ 2ppt salinity volume habitat (see Table 3-5). All scenarios showed double-digit losses in habitat attributable to flow reductions in addition to losses already incurred due to sea level rise. These losses in habitat can be compared to losses under present sea levels. For instance, a 12% reduction in flow under current sea level conditions corresponds to a 15% decrease the volume of ≤ 2 ppt salinity habitat. The amount of habitat reduction increases to between 18% and 28% depending on the degree of sea level rise (Table 3-5).

4.5.1.3 Summary of Sea Level Rise Analysis

The effect of sea level rise on groundwater levels in the aquifer is not included in our model because there is no clear agreement on what these effects will be. Sea level rise may also alter saltwater intrusion and alter the salinity of spring discharge. Thus, changing sea levels will likely alter groundwater levels and salinity of spring vent discharge. However, there is little conclusive data or research on which to base accurate predictions of what these effects will be, so we limited our sea level rise analysis to direct impacts on sea level at the boundary of our modeled hydrodynamic system.

We recognize that our model treatment of sea level rise is incomplete, yet we can use the projections we produced to get a sense for the severity of potential impacts on the system. Our analysis of increased sea level shows that projections of sea level change over the next 20 years can have strong effects on the system. This agrees with our findings for other springs coast systems in Florida (Heyl 2008, Heyl et al. 2012, Leeper et al. 2012). As a result, we suggest ongoing monitoring of the system and re-evaluation of minimum flows that are required to be adopted for the system in 2017.

4.5.2 Modeled Residence Time

Links between residence time and phytoplankton blooms (and corresponding chlorophyll-a measurements) have been found in other systems and are hypothesized for the Crystal River/Kings Bay system, but there is no direct evidence of such a link in this system (Section 1.6.3).

Residence time varies for the Crystal River/Kings Bay system based on spring discharge, volume of the bay, and tide stage. The system is most likely to experience adverse effects of residence time when residence times are the longest, not when reductions in flow will have the greatest proportional increase in residence time. The volume of Kings Bay varies on a monthly cycle. Residence time is longer when the volume of water in Kings Bay is at its high point in this cycle. An increase in residence time during this natural high point when residence times are already at their longest will likely have a greater effect on promoting phytoplankton growth than an equivalent proportional increase during points in the cycle when residence times are shorter.

We found the greatest baseline residence time of 373 hours when spring discharge into the system was at its 5^{th} percentile (95% exceedance probability) during time period 6 (Table 3-6). During this critical time period, a 20% reduction of flow will increase residence time by 15 percent from 373 to 432 hours. In contrast, during period 4, when the volume of Kings Bay is at its lowest point in the monthly cycle, residence time is at its lowest (144 hours during baseline flows), yet reducing flow only 6 percent will increase residence time 15% to 166 hours (see Table 3-5). However, these 166 hours are relatively short (45 percent as long) compared to the 373 hours the system experiences during baseline flows in period 6 when discharge is at the low end of its natural range. Because of the variability in residence time throughout the tidal cycle and variations in spring discharge due to seasonal rainfall and groundwater levels, we conclude that the average residence time across simulated periods is the most appropriate single measure for quantifying the effects of reduced flow on residence time within the river and bay. With a 12 percent reduction in flow (corresponding to a 15 percent reduction in 2 ppt water volume) there will be an 11 percent increase in residence time from 271 h to 301 h (Table 3-6).

4.6 <u>Initial Minimum Flow Recommendation</u>

The District produced an initial minimum flow recommendation (described in this section) which was reviewed by a panel of independent experts. This panel recommended additional analyses which resulted in a revised minimum flow recommendation (described in Section 4.7).

Based on our initial analyses, we found that the total volume of water ≤ 2 ppt salinity was the factor most appropriate for setting minimum allowable submarine groundwater discharge, i.e., for identifying proposed minimum flows to the Crystal River/Kings Bay system (Table 4-1). Based on preservation of 85% of this 2 ppt salinity habitat, we recommended the minimum flow be set to an allowable 12% reduction from the baseline condition. The baseline condition is the natural flow condition which represents the flows expected in the absence of withdrawal impacts.

There is precedent for setting minimum flows in estuarine systems using salinity habitats (Table 1-3). This use of salinity-based habitat to set the minimum flow was developed taking into account the unique features of this system and based on years of study on water quality, vegetation, fauna, and stakeholder input as to the resources that must be protected in this system.

At first glance, thermal refuge from acute thermal stress seems to be more conservative indicator of significant harm to the system: a 9% reduction in flow will result in a 15% decrease in thermally favorable habitat when this habitat is at its minimum value. However, when we look at the amount of habitat available, we see that there is more than enough for the population using Kings Bay even when flow to the bay is reduced by 30% (see Table 3-3). Thus, there is no foreseeable impact on thermal habitat within the Crystal River/Kings Bay system necessary to support wintering populations on the Springs Coast of Florida.

In contrast to thermal refuge, which has a maximum useable volume based on the manatee population, low salinity habitat (≤ 2 ppt) is both sensitive to reductions in flow and likely to support restoration efforts to improve the native submerged aquatic vegetation community and improve water clarity. Nitrogen, phosphorus, and dissolved oxygen concentrations in spring effluent do not correlate with rate of discharge, and thus are not candidates for use as criteria for setting minimum flows. Therefore, the initial staff recommendation was to set minimum flow from submarine groundwater discharge into the Crystal River/Kings Bay system at 88% of baseline (i.e., natural) flow.

Table 4-1. Criteria modeled as sensitive to reductions in freshwater inflow to the Crystal River/Kings Bay system.

Criteria	Allowable Percent Reduction in Flow	Comments
Volume ≤ 2ppt salinity	12	This is our recommended criterion for developing the proposed minimum flow. The criterion is the most sensitive of all assessed salinity-based habitats.
Acute thermal refuge (water not <15° for > 4h)	9	Not considered an appropriate criterion, as there is more than enough thermally favorable habitat in Kings Bay for state-wide manatee population at 70% of baseline flow.

4.7 Stakeholder Input, Peer Review and Revised Minimum Flow Recommendation

The District solicits public comment on proposed minimum flows and levels and the methods used for their development and also subjects this information to independent, scientific peer review. These efforts are undertaken to inform stakeholders about and to solicit feedback on the minimum flow recommendations. These processes ensure that the best possible minimum flows and levels are adopted and used for District permitting and planning programs.

4.7.1 Stakeholder Review and Public Outreach

The District has engaged a number of stakeholders to obtain input on the development of a minimum flow for the Crystal River/Kings Bay system. Early in the process, the District took advantage of various opportunities to inform stakeholders about relevant, ongoing and planned activities. For example, the development of minimum flows for the system was first identified on the 1996 Priority List and Schedule for the Establishment of Minimum Flows and Levels. Public outreach for the minimum flow effort has continued through facilitation of numerous public meetings and staff presentations to various groups and organizations, including the following (with presentation or meeting dates in parentheses):

- Citrus County Board of County Commissioners (April 2011)
- Citrus County Chronicle Editorial Board (March 2017, April 2017)
- Citrus County Task Force of the Citrus/Hernando Waterways Council (March 2008, May 2008, August 2010)
- Citrus County Utility Infrastructure Advisory Group (December 2010)
- Crystal River Management Group (September 2007)
- Crystal River Rotary Club (in Jun 2007)
- Crystal River Waterfront Board (in March or April 2008)
- Florida Fish and Wildlife Conservation Commission (April 2017)
- Florida Springs Council (April 2017)
- Kings Bay Association (May 2008)
- Kings Bay Working Group (May 2012)
- Save Crystal River (April 2017)
- Springs Coast Minimum Flows and Levels Public Workshops (June 2011, July 2011, September 2011, October 2011)
- U.S. Fish and Wildlife Service (January 2011, February 2013, April 2017)
- Withlacoochee Aquatic Restoration, Inc. (April 2017)
- Withlacoochee Regional Water Supply Authority Board (January 2017)

In addition to organizing numerous meetings, the District has engaged in a vigorous outreach effort involving exchange of written communications and other information to facilitate public understanding of the minimum flow development process and to provide opportunities for stakeholder input [included as appendix]. A draft minimum flow report for the Crystal River/Kings Bay system was posted to the District web site in October 2016 and made available to all interested stakeholders.

Staff has carefully considered all issues identified by stakeholders regarding minimum flow development for the Crystal River/Kings Bay system. Review of this input resulted in identification of the need to further investigate potential flow-related changes in thermally-favorable manatee habitat; results from these analyses are described in Section 4.7.3.

4.7.2 Peer Review

A draft minimum flow report for the Crystal River/Kings Bay system that included a recommended minimum flow which would allow up to a 12 percent reduction in natural flow was reviewed by an independent panel of experts (SWFWMD 2016) [included as an appendix]. Overall, the Peer

Review Panel supported the conclusions presented within the report. In addition, the Panel identified key comments and recommendations to improve the report. The District produced a response to the peer review which addresses each of 94 numbered comments in addition to other unnumbered comments throughout the Panel report [included as an appendix] (SWFWMD 2017b). Key comments and responses are summarized below.

First, the Panel recommended the District elaborate on uncertainty in methods of flow determination and limitations this uncertainty creates for predicting changes to flow. The District conducted an analysis of uncertainty (Herrick 2017) [included as an appendix] which describes alternative methods of flow determination and selection of a flow record for hydrodynamic model input. The conclusion of this uncertainty analysis supports the decision to use the empirical formula for submarine groundwater discharge as an input to the hydrodynamic model (Section 2.2).

Second, the Panel recommended the District consider salinity habitats by parsing between hardened vertical shoreline (i.e., seawall) and more natural shoreline types. The District followed through with this recommended analysis which resulted in a revised minimum flow recommendation described in Section 4.7.3 .

Third, the Panel recommended the District consider changes to salinity at model boundaries and more complete documentation of seepage. These are addressed in the District response to peer review (SWFWMD 2017b) and in the response to hydrodynamic model comments [included as an appendix] (Chen 2017b). In summary, changes to salinity at model boundaries does not significantly change predictions. Furthermore, seepage is included in flow estimates in Table 2-1 as described in the hydrodynamic model report [included as appendix] (Chen 2017a).

4.7.3 Additional Analyses and Revised Minimum Flow Recommendation

The original analysis of flow-related changes to thermally-favorable manatee habitat extended throughout the Crystal River/Kings Bay system and was reasonably focused on the total area of warm-water during critically cold periods. The U.S. Fish and Wildlife Service has established seven Federal sanctuaries (USFWS 2012) within Kings Bay that encompass some warm-water areas that are heavily used by manatees during cold periods and which also include foraging areas (Figure 4-1). Human waterborne activities, such as swimming and boating are not permitted within the sanctuary boundaries from November 15 through March 31.

Because our original analyses indicated that acute manatee thermal habitat was most sensitive to flow reductions, we focused on potential changes in acute habitat that is available in the seven Federally-designated sanctuaries. Simulations run with the UNLESS3D model indicated that a 13% reduction in baseline flow would be associated with a 15 percent reduction in thermally-favorable acute habitat (by area) within the designated sanctuaries for the coldest four-hour period (Table 4-2). This response indicates acute thermal habit within the sanctuaries is less sensitive than the full extent of acute thermal habitat (by volume) within the system, which was reduced by 15 percent with a 9 percent flow reduction (Table 3-3).

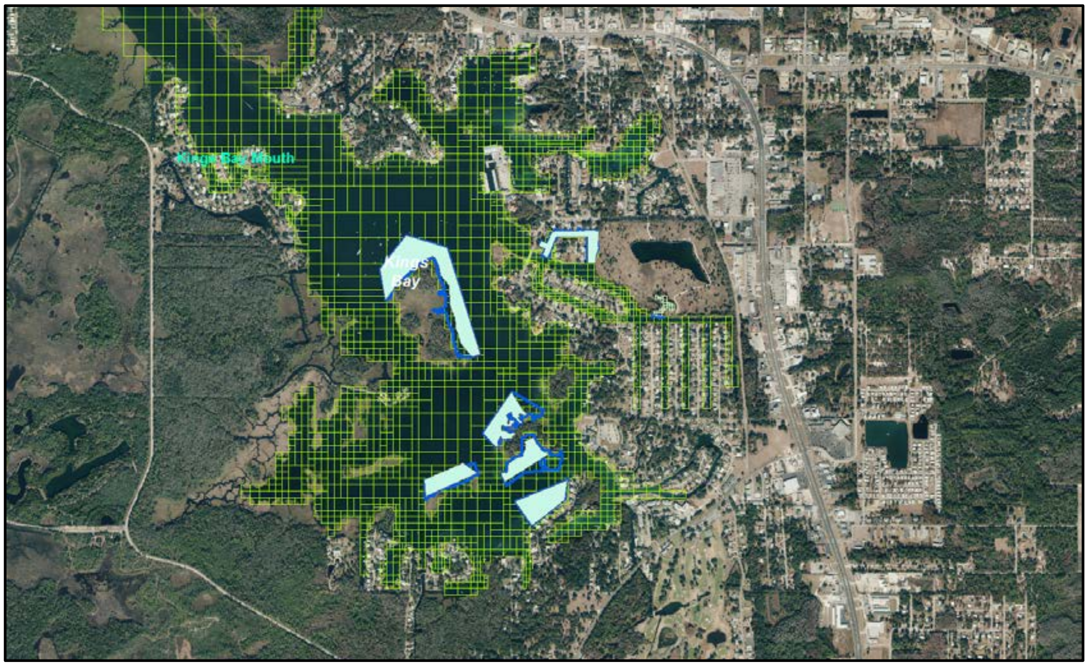


Figure 4-1. Federal manatee sanctuary areas (blue polygons imbedded within the green UNLESS 3D hydrodynamic model mesh) used for additional assessment of potential changes in thermally-favorable manatee habitat.

Table 4-2. Amount of water ≥ 15°C and number of manatees that could be supported in seven Federal manatee sanctuary areas given space requirements of 108 ft^3 and 28.5 ft^2 from Rouhani et al. (2007). Values are for the four-hour period with smallest amount of refuge under baseline conditions. Shaded cells bracket 15% percent changes in volume and area.

% of Baseline Flow	Volume (ft^3)	% Volume	Area (ft^2)	% Area	Manatee Capacity by Volume*	Manatee Capacity by Area*
100	7.91E+04	100.0	1.06E+04	100.0	7.32E+02	3.72E+02
97.5	7.58E+04	95.8	1.02E+04	96.3	7.02E+02	3.58E+02
95	7.55E+04	95.5	9.88E+03	93.4	6.99E+02	3.47E+02
92.5	7.52E+04	95.1	9.42E+03	89.0	6.96E+02	3.30E+02
90	7.48E+04	94.6	9.26E+03	87.5	6.93E+02	3.25E+02
87.5	7.45E+04	94.2	9.03E+03	85.3	6.90E+02	3.17E+02
85	7.43E+04	93.9	8.69E+03	82.1	6.88E+02	3.05E+02
82.5	7.18E+04	90.7	7.89E+03	74.5	6.65E+02	2.77E+02
80	7.17E+04	90.7	7.83E+03	73.9	6.64E+02	2.75E+02
77.5	7.09E+04	89.7	7.47E+03	70.6	6.57E+02	2.62E+02
75	7.01E+04	88.7	7.24E+03	68.4	6.50E+02	2.54E+02
72.5	7.01E+04	88.6	6.54E+03	61.8	6.49E+02	2.29E+02
70	6.89E+04	87.1	6.01E+03	56.8	6.38E+02	2.11E+02

* Capacity values represent theoretical maxima based on thermally-favorable criteria and may be moderated by manatee behavior and environmental factors, including food availability; in addition, Federal manatee sanctuaries do not encompass the full extent of thermally-favorable manatee habitat within the system

Thermal habitat within Federal manatee sanctuaries is less sensitive to flow reductions relative to the full extent of thermally-favorable habitat occurring within the Crystal River/Kings Bay system. This sensitivity analysis supports our original conclusion that salinity-habitat responses are the most appropriate criteria for establishing a minimum flow. Interestingly, our estimates of the acute thermal habitat within the sanctuaries indicate that under baseline conditions there would be sufficient warm-water volume and area for 732 and 372 individuals, respectively (Table 4-2). The observation of 758 manatee within the bay in January 2016 (USFWS Unpublished Data), our hydrodynamic modeling results for thermal habitat within the entire Crystal Rier/Kings Bay system, and carrying capacity estimates on the order of 10,000 animals reported for the bay (Provancha et al. 2012), confirm our understanding that the Federal manatee sanctuaries do not include the full extent of thermal refuge habitat within the system.

The peer review panel convened to evaluate the initial minimum flow recommendation for the Crystal River/Kings Bay system recommended parsing flow-related changes to shoreline salinity-based habitat by making a distinction between natural and altered shoreline. The original analysis of changes to shoreline salinity habitat did not distinguish between shoreline type (i.e., altered vs. natural or vegetated). The District used GIS layers created by Avineon (2010) to determine that natural and vegetated shoreline is more sensitive to changes in flow than total shoreline. This led to the conclusion that the habitat consisting of natural and vegetated shoreline with average salinity of less than 0.5 parts-per-thousand salinity is the most sensitive habitat (Table 4-3). This low-salinity natural and vegetated shoreline length will be reduced by 15% from 1,571 meters to 1,335 meters with an 11% loss of flow. This is a loss of 236 meters of natural and vegetated shoreline habitat.

Based on potential flow-related changes to natural and vegetated shoreline, the recommended minimum flow for the Crystal River/Kings Bay system was revised from an allowable 12 percent reduction in natural flow based on water volume with salinities ≤ 2 ppt to an allowable 11 percent reduction based on changes in shoreline length associated with salinities ≤ 0.5 ppt. The revised, recommend minimum flow is, therefore, 89% of the baseline (i.e., natural) flow.

Table 4-3. Revised sensitivity of salinity based habitats with analysis of natural and vegetated shoreline. Values are percent flow reductions that result in more than a 15 percent reduction of habitat. The most sensitive habitat is the natural and vegetated shoreline with an average salinity less than or equal to 0.5 parts per thousand. The lowest reduction in flow to trigger a 15 percent change in habitat is 11 percent, indicated with an asterisk.

Salinity (≤ ppt)	Bottom Area	Water Volume	Total Shoreline Length	Natural and vegetated shoreline
0.5	23	22	>30	11
1	23	21	>30	19
2	13	12	28	14
3	25	22	>30	27
5	>30	>30	>30	>30
10	>30	>30	>30	>30
15	>30	>30	>30	>30

4.8 Status Assessment and Reevaluation

The Florida Water Resources Act of 1972 stipulates that if the existing flow or level in a water body is currently or projected to fall below an applicable minimum flow or level within twenty years, the DEP or the District governing board as part of the regional water supply plan shall adopt or modify and implement a recovery strategy to either achieve recovery to the established minimum flow or level as soon as practical or prevent the existing flow or level from falling below the established minimum flow or level.

The recommended minimum flow for the Crystal River/Kings Bay system is 89 percent of the natural flow, allowing up to a 11 percent reduction from baseline, unimpacted discharge, and is based on preservation of 85% of ≤ 0.5 ppt salinity shoreline habitat. Current (2014) groundwater pumping impacts are estimated to reduce flow by 1.1% of the baseline, unimpacted flow (Table 1-2). Projected impacts at the planning horizon of 2035 estimate flow to be reduced by 2.4 percent, or 2.1 percent with implementation of conservation and reuse measures and projects. Thus, District Staff conclude that recovery is not needed at this time, because current and projected impacts are much less than then the proposed allowable reduction of up to 11%. A specific prevention strategy is similarly not warranted, although the District will continue to implement its general, three-pronged prevention strategy that includes monitoring, protective water-use permitting, and regional water supply planning to ensure that the adopted minimum flow for the system continues to be met.

The District is committed to periodic reevaluation and if necessary, revision of minimum flows for the Crystal River/Kings Bay system. Minimum flow status assessments will be completed on an annual basis, on a five-year basis as part of the regional water supply planning process, and on an as-needed basis in association with permit and project activities. In addition, staff recommend reevaluation of the minimum flow for this system within ten years of its adoption into District rules.

CHAPTER 5 - LITERATURE CITED

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CHAPTER 6 - APPENDICES (BOUND SEPARATELY)