The Determination of Minimum Flows for Sulphur Springs, Tampa, Florida

September 28, 2004
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Southwest Florida Water Management District

The Determination of Minimum Flows for Sulphur Springs, Tampa, Florida

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Acronyms and Definitions

AMO	Atlantic Multidecadal Oscillation
BOD	Biochemical Oxygen Demand
CDF	Cumulative Distribution Function
cfs	Cubic feet per second
COB	Center of Abundance
DO	Dissolved oxygen
EPCHC	Environmental Protection Commission of Hillsborough County
F	Fluoride
F.A.C.	Florida Administrative Code
F.S.	Florida Statutes
FDEP	Florida Department of Environmental Protection
FMRI	Florida Marine Research Institute
FWC	Florida Fish and Wildlife Conservation Commission
GIS	Geographic Information Service
HBMP	Hydro-Biological Monitoring Plan
HILLSULPH	Hillsborough River at Nebraska; USGS site "Hillsulph"
HIMP	Hillsborough Independent Monitoring Program
K	Potassium
Km	Kilometer
LHR	Lower Hillsborough River (Reach below reservoir)
LOESS	Locally Estimated Scatter plot Smoothing
MFLs	Minimum Flows and Levels
mg/l	Milligrams per liter
mgd	Million gallons per day
MOUTH	Confluence of Sulphur Springs Run and Hillsborough River
N	Nitrogen
n	Sample size
NGVD	National Geodetic Vertical Datum
NO2-N	Nitrite Nitrogen
NO3-N	Nitrate Nitrogen
NWI	National Wetlands Inventory
P	Phosphorus
ppt	parts per thousand
PSU	Pracatical Salinity Units
RUN	Sulphur Springs run between pool and Hillsborough River
SAS	Statistical Analysis System
SCS	Soil Conservation Service
SJRWMD	St. Johns River Water Management District
SS	Sulphur Springs (Pool)
SWFWMD	Southwest Florida Water Management District
SWUCA	Southern Water Use Caution Area
TBC	Tampa Bypass Canal
TBEP	Tampa Bay Estuary Program
TDS	Total Dissolved Solids

TKN	Total Kjehldal Nitrogen
TN	Total Nitrogen
TOC	Total Organic Carbon
TOC	Total Organic Carbon
TSS	Total Suspended Solids
UF	University of Florida
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

Executive Summary

The Southwest Florida Water Management District (the District) is directed by Florida Statutes to establish minimum flows and levels for water resources within its jurisdiction. Minimum flows are defined as "the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area". By identifying the hydrologic requirements of natural systems associated with a water body, minimum flows serve as standards by which permitting or planning decisions can be made concerning withdrawals from either surface or groundwater sources.

Sulphur Springs is an artesian spring that lies within a small park in a highly urbanized setting in Tampa, Florida. The average flow of Sulphur Springs for the last twenty years is 34 cubic feet per second (cfs) or 22 million gallons per day (mgd). For many years, Sulphur Springs was a popular recreational resource that was used for swimming, but problems with high bacteria counts closed the spring to swimming in the 1980s. Since the 1960s, Sulphur Springs has been used as a back-up water supply source by the City of Tampa to augment water supplies in the Hillsborough River Reservoir. The mineral content of Sulphur Springs has been increasing since the 1970s and the spring currently exceeds potable water standards for a number of constituents. However, by blending the spring water with the supplies in the reservoir, the City can divert water from the spring for limited periods of time. The spring, however, is only used during impending water shortages, and withdrawals from the spring have occurred on only 11 percent of the days since 1991.

Sulphur Springs provides flows of low-salinity water that supports downstream biological communities in the spring run and the Lower Hillsborough River. Until recently, periodic withdrawals have had a major effect on flows from the spring pool. The pump for the City's diversion facility operates at a rate (19.7 mgd) that is nearly as great as the average flow of the spring. Consequently, during periods of withdrawal, flows from the spring to the spring run and lower river were reduced to zero or very low rates of flow. In 2001 the City modified the diversion facilities at Sulphur Springs so that variable amounts of water can be diverted from the spring pool. These modifications were done in part to meet the minimum flow rule for the Lower Hillsborough River, which stipulates that 10 cfs (6.5 mgd) of water from Sulphur Springs can be diverted to the base of the dam to meet minimum flows. The City now has the capability to simultaneously divert variable amounts of spring water into the reservoir, to the base of the dam, and to the spring run.

In 1999 the District began a series of studies to establish minimum flows for Sulphur Springs with the understanding that the modified diversion facilities would be used to manage springflow within a range that protects the biological communities in the spring run and lower river from significant harm. Using the modified diversion facilities, experimental flow tests were conducted to examine the downstream effects of a range of flows from the spring pool. Data collection for these studies included the operation of a series of continuous recorders in the spring run and lower river, water quality and biological sampling in the spring run, and hydrodynamic salt transport and thermal model simulations of the lower river. Data from previous and ongoing hydrobiolgical studies of the Lower Hillsborough River conducted by other agencies were also evaluated.

Based on observed relationships between flows from the spring and the ecological characteristics of the spring run and the lower river, the District established three management goals for the determination of minimum flows for Sulphur Springs. These are:

1. Minimize the incursion of brackish water from the lower Hillsborough River into the upper spring run.

2. Maintain low salinity habitats in the Lower Hillsborough River

3. Maintain a thermal refuge for manatees in the Lower Hillsborough River during cold winter periods.

Goal number 1 was developed to protect the abundance and diversity of the benthic macroinvertebrates in the upper spring run, which can be impacted by the incursion of high salinity water from the lower river at flow rates of springflow. The flow tests indicated a flow of 18 cfs (11.6 mgd) largely prevents the incursion of water from the lower river, except during very high tides. During times of water shortage flows could be reduced to 13 cfs (8.4 mgd), which will result in brief incursions of water from the river on high tides. Water levels of 19 feet in the Hillsborough River Reservoir should be used to identify times of impending water shortage. It was concluded that the invertebrate community would recover from these periodic incursions with the resumption of higher flows when water shortages end. Since the incursions of river water are related to tides, flow from the spring can be reduced to 10 cfs (6.5 mgd) at low tide stages in the river, if it does not result in the incursion of water from the river into the upper spring run.

The minimum flows for goal number 1 were evaluated further to determine their effects on the salinity and thermal characteristics of lower river (goals 2 and 3) Modeling results indicate that the river benefits from higher flows, but the 18 cfs minimum flow combined with periodic use of 13 and 10 cfs minimum flows would be within acceptable limits for the prevention of significant harm. These minimum flows also meet the requirements of a thermal refuge for manatees in the lower river, provided that the minimum flow remain at 18 cfs if water temperatures in either surface or bottom waters in the lower river near the mouth of the spring drop below 15 degrees Celsius, equal to 59 degrees Fahrenheit. Based on these findings, the proposed minimum flow for Sulphur Springs is as follows:

The proposed minimum flow for Sulphur Springs is 18 cfs. This minimum flow may be reduced to 10 cfs during low tide stages in the Lower Hillsborough River if it does not result in salinity incursions from the lower river into the upper spring run. Salinity incursions shall be defined as when salinity values in the upper spring run are more than 1 ppt greater than the concurrent salinity value in the spring pool. A minimum flow of 13 cfs can be implemented when water levels in the Hillsborough River reservoir fall *below 19 feet NGVD of 1929. This minimum flow can be reduced to 10 cfs at low tide stages in the lower river if it does not result in salinity incursions into the upper spring run. A minimum flow of 18 cfs will be maintained if the temperature of either surface or bottom waters in the Lower Hillsborough River near the mouth of the spring are below 15 degrees Celsius.*

The adoption of a minimum flows for Sulphur Springs will require more intensive management flows from the spring pool. Water level and salinity recorders will be maintained to allow real-time management of springflow based on tides and salinity levels in the spring pool, spring run, and lower river. The adequacy of the minimum flows for the Sulphur Springs will be checked by ongoing data collection programs in the spring run and lower river. The minimum flows for Sulphur Springs will also be considered as they factor into the re-evaluation of minimum flows for the Lower Hillsborough River which is scheduled for 2005.

This report, and the data relied upon for its analysis, are based on the existing configuration of the structure that separates the upper and lower spring run. However, there is a possibility that modification of this structure could provide additional protection from salinity incursions into the upper spring run, while providing for low salinity habitats and a thermal refuge in the Lower Hillsborough River. Further analysis of potential modifications to the existing structure on Sulphur Springs Run may provide an alternative to the minimum flows recommended in this report.

Acknowledgments

This report incorporates data and analyses prepared by a number of professionals who have been involved with research on Sulphur Springs and the Lower Hillsborough River in cooperation with the Southwest Florida Water Management District. Keith Hackett and Ray Pribble of Janicki Environmental, Inc. performed the thermal modeling simulations presented in this report. David Wade of Janicki Environmental generated graphics associated with the evaluation of flow experiments presented in Chapter Five. Gary Warren of the Florida Fish and Wildlife Conservation Commission supervised the collection and identification of benthic macroinvertebrates in the spring run and provided those data to the District. Mike Allen and Debra Murie of the University of Florida Department of Fisheries and Aquatic Sciences provided the fish data from Sulphur Springs discussed in Chapter Three. Bob Woithe of PBS&J, Inc. provided data for the Lower Hillsborough River collected as part of the Hydrobiological Monitoring Program for Tampa Bay Water. Richard Boler of the Environmental Protection Commission of Hillsborough County provided data for the lower river collected by that agency. The timely participation of all these individuals is gratefully acknowledged.

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CHAPTER 1

PURPOSE AND BACKGROUND OF MINIMUM FLOWS AND LEVELS

1.1 Overview

The Southwest Florida Water Management District (District) is responsible for permitting the consumptive use of water within the District's boundaries. Within this context, the Florida Statutes (Section 373.042) mandate that the District protect water resources from “significant harm” through the establishment of minimum flows and levels for streams and rivers within its boundaries. The purpose of minimum flows and levels (MFLs) is to create hydrologic and ecological standards against which permitting or planning decisions can be made concerning withdrawals from either surface or ground waters.

Sulphur Springs is an artesian spring that is periodically used as a water supply source by the City of Tampa during times of impending water shortage. Sulphur Springs also serves important ecological functions by providing flows that sustain downstream biological communities in the spring run and Lower Hillsborough River. In establishing MFLs for Sulphur Springs, the District evaluated to what extent flows from the spring can be reduced by withdrawals without causing significant harm to these downstream ecosystems. The determination of minimum flows is a rigorous technical process in which extensive physical, hydrologic, and ecological data are analyzed for the water body in question.

This chapter provides an overview of how the District applied legislative and water management directives in the determination of minimum flows for Sulphur Springs. The rationale and basic components of the District approach are also summarized. Greater details regarding the District's technical approach, including data collection efforts and analyses to determine minimum flows, are provided in subsequent chapters culminating with the proposed minimum flows for Sulphur Springs.

1.2 Legislative Directives

As part of the Water Resources Act of 1972, the Florida Legislature mandated that the five water management districts establish MFLs for surface waters and aquifers in their jurisdictions (Section 373.042, F.S.). Although that Section has been revised in subsequent years, the definitions of MFLs that were established in 1972 have remained the same. Minimum flows are defined as “*the minimum flow for a given watercourse shall be the limit* *at which further withdrawals would be significantly harmful to the water resources or ecology of the area.*" Minimum levels are defined as "*the minimum water levels shall be the level of groundwater in an aquifer and the level of surface water at which further withdrawals would be significantly harmful to the water resources of the area*." It is generally interpreted that ecological resources are included in the "water resources of the area mentioned" in the definition of minimum water level. The establishment of MFLs for flowing watercourses can incorporate both minimum flows and minimum levels. However, as described in Chapter 4, the establishment of MFLs for Sulphur Springs involved only a flow component, and the term minimum flows is used in this report with specific reference to Sulphur Springs.

Section 373.042 F.S. further states that MFLs shall be calculated "*using the best information available. When appropriate, minimum flows and levels may be calculated to reflect seasonal variations. The Department [of Environmental Protection] and the governing board [of the relevant water management district] shall also consider, and at their discretion may also provide for, the protection of non-consumptive uses in the establishment of minimum flows and levels*."

Guidance regarding non-consumptive uses of the water resource to be considered in the establishment of MFLs is provided in the State Water Resources Implementation Rule (Chapter 62-40.473, Florida Administrative Code), which states that "*consideration shall be given to the protection of water resources, natural seasonal fluctuations in water flows or levels, and environmental values associated with coastal, estuarine, aquatic and wetlands ecology, including:*

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

Identification of severe water resource problems in the Northern Tampa Bay area in the mid-1990s (*e.g.*, see SWFWMD 1996) precipitated renewed interest by the Florida Legislature concerning the establishment of MFLs. In 1997, Section 373.042 F.S. was revised to provide additional guidance on factors to be considered when establishing MFLs. According to Section 373.0421(1a), F.S., when establishing MFLs the governing board "*shall consider changes and structural alterations have had, and the constraints such changes or alterations have placed, on the hydrology of the affected watershed, surface* *water, or aquifer, provided that nothing in this paragraph shall allow significant harm as provided by s. 373.042(1) caused by withdrawals*" (Section 373.0421, F.S.). In essence, the District is to evaluate and account for the effects of previous structural alterations on a watercourse when assessing the potential for withdrawals to cause significant harm.

Given this suite of legislative directives, the basic function of MFLs remains to ensure that the hydrologic requirements of natural systems are met and not jeopardized by excessive withdrawals. In turn, establishment of MFLs are important for water supply planning and regulation since they affect how much water from a water body is available for withdrawal. Because of the central roles that MFLs play in both natural resource protection and water supply management, the methods, data, and analyses on which MFLs are based should be comprehensive and technically sound. For this reason, it is District practice for the technical information upon which a proposed minimum flow is based to be independently reviewed through a formal voluntary peer review process. This process commences upon the publication a draft technical report by District staff that provides the technical justification for the proposed MFLs. Pending the findings of this peer review, the Governing Board may choose to adopt the proposed minimum flows or pursue further analyses and possible revision of the minimum flows.

1.3 Application to MFLS for Sulphur Springs

Recent assessments of MFLs for flowing water courses by the state's water management districts have emphasized the maintenance of natural flow regimes, which include seasonal variations of low, medium and high flows that reflect the climatic and watershed characteristics of particular stream or river system (SJRWMD 1994, SWFWMD 2002, SRWMD 2003,). As described in the District's MFL report for the Upper Peace River, this approach endorses the concept that the biotic makeup, structure, and function of an aquatic ecosystem depends largely on the hydrologic regime that shaped its development (Poff et al. 1997 as cited in SWFWMD 2002). District assessments of freshwater inflows to estuaries have similarly emphasized maintaining the patterns of variability associated with natural flow regimes by limiting withdrawals to a percentage of streamflow at the time of withdrawal (Flannery et al. 2002).

As described in greater detail in Chapter 4, the District did not employ a flow regime approach to Sulphur Springs for a number of reasons. First, like many artesian springs, the flow regime of Sulphur Springs is relatively stable as seasonal fluctuations of springflow are much less than variations in streamflow in creeks and rivers that receive surface runoff. Secondly, both Sulphur Springs and Lower Hillsborough River are extensively altered by seawalls and water control structures that affect the physical and biological characteristics of these resources. In keeping with the directives of the Florida Statutes described above, the District took these alterations into account in determining minimum flows for the spring.

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Lastly, the effects of flow from Sulphur Springs on both the spring run and lower river are strongly related to the rate of flow to the lower river from the Hillsborough River reservoir. In recent decades there have been no flows to the lower river from the Hillsborough River reservoir for about half the days each year on average. In the year 2000, the District established a minimum flow of 10 cubic feet per second (cfs) for the Lower Hillsborough River. The District also stipulated that alternate sources of water, including diversions from Sulphur Springs, could be used to provide that flow.

As described in Chapter 3, the ecological benefits of flows from the spring to the river are most critical when there would otherwise be no flow from the reservoir and minimum flows to the lower river are in effect. Also, because water flowing from Sulphur Springs exceeds potable water standards for certain constituents, it was assumed there would be little desire to withdraw water from the spring when the reservoir is full and discharging. In consideration of these factors, the District's analysis of minimum flows for Sulphur Springs focused on periods of when there minimum flows to the lower river are in effect, rather than on the historical seasonal characteristics of flow from the spring.

The District evaluated rates of flow from Sulphur Springs that would meet management goals in the spring run and lower river during periods of minimum flow from the Hillsborough River reservoir. Relying on data from a variety of sources, these goals were based on analyses of the relationships of springflow to the ecological characteristics of the spring run and lower river. As described in Chapter 4, these management goals are to:

1. Minimize the incursion of water from the Lower Hillsborough River into the upper spring run

2. Maintain low salinity habitats in the Lower Hillsborough River

3. Maintain a thermal refuge for manatees near the mouth of the spring run during winter months

These goals were developed to address the needs of biological communities in the spring run and lower river that are sensitive to the effects of reduced flows. The purpose of goal number one is to protect benthic macroinvertebrate populations in the upper spring run from adverse effects resulting from the incursion of high salinity water from the lower Hillsborough River during periods of low springflow. The purpose of goal number two is to provide a salinity gradient in the lower river that includes low salinity habitats in order to support the diversity of plant, invertebrate and fish populations that inhabit the lower river. Goal number three provides for the thermal requirements of the Florida manatee, an endangered marine mammal, that can be stressed or killed by cold water temperatures.

Within the context of these goals, the District used ecological indicators as parameters to determine how well a minimum flow would meet each management goal. For goal number one the indicators were the frequency and duration of salinity incursions in the upper spring run. For goal number two the indicators were the volumes of water in the lower river less than 4 ppt and less than 11 ppt salinity. For goal number three the indicator was maintaining temperature changes within a thermal refuge region in the river to less than two degrees Celsius.

These indicators were used to evaluate the potential for significant harm to the ecology of the spring run and the lower river that could result from reductions in springflow due to withdrawals. The responses of the spring run and river to various rates of flow were evaluated. The final determination of what constitutes significant harm and minimum flows for Sulphur Springs rests with the Governing Board of the District. That determination will be largely based on the approach and technical information presented in this report and the resulting peer review.

1.4 Content of Remaining Chapters

The remainder of this report presents the results of the District's analyses of minimum flows for Sulphur Springs. Chapter Two describes the physical and hydrologic characteristics of the spring pool and the response of springflow to historic rates of water use. Chapter Three describes the relationships of flows from the spring pool to the ecological characteristics of the spring run and Lower Hillsborough River. Based on these relationships, Chapter Four presents the District's approach for determining minimum flows for Sulphur Springs, including the identification of management goals and ecological indicators on which the minimum flows are based. Chapter Five presents the results of the District's minimum flow analysis and the proposed minimum flows. The report concludes with the Literature Cited and Appendices.

CHAPTER 2

PHYSICAL AND HYDROLOGIC CHARACTERISTICS OF SULPHUR SPRINGS

2.1 Introduction

Sulphur Springs is a second magnitude artesian spring which discharges to the Hillsborough River within the city limits of Tampa, Florida. The reach of the Hillsborough River that extends downstream from the City of Tampa's reservoir is referred to as the Lower Hillsborough River. Sulphur Springs discharges via a short spring run to the lower river 2.2 miles (3.5 km) below the reservoir spillway, or 8 miles (12.9 km) upstream of the river mouth (Figure 2-1).

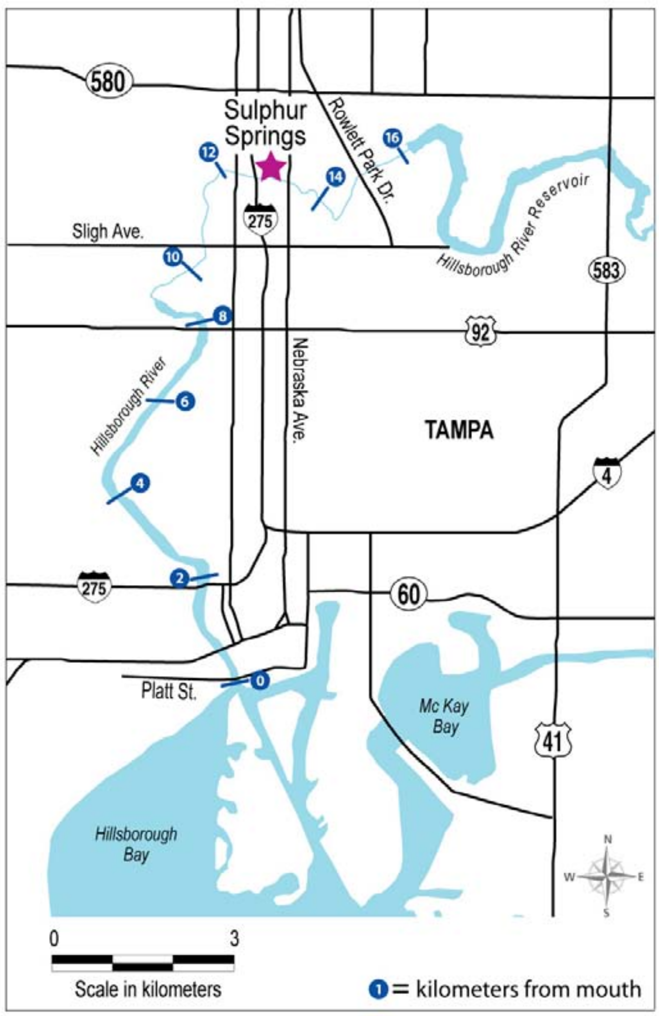

Figure 2-1. Location map of Sulphur Springs and the Lower Hillsborough River in Tampa, Florida.

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The spring and its run lie in a small city park in a highly urbanized setting. For many years Sulphur Springs was a major recreational resource that was used for swimming and bathing by the citizens of Tampa. The current configuration of retaining walls and water control structures at Sulphur Springs reflect the historic use of the spring for recreation, and in later years, for water supply. Historic photos show that the spring pool was enclosed by a circular concrete rim by the early 1900s (Figure 2-2A). Water flowed from this pool through a water control structure to the spring run, which had a weir near its mouth that was built to maintain suitable water levels for swimming and wading. Over various periods, facilities were maintained at the spring system that included pavilions, a water slide, diving boards and sand beaches, and Sulphur Springs was a major attraction for bathing and social gatherings (Figure 2-2B).

Figure 2-2A. Photograph from1908 showing the concrete rim enclosing the Sulphur Springs Pool.

Figure 2-2B. Public swimming and recreation at Sulphur Springs during the early 1900s.

Problems with high coliform bacteria counts caused the City to close Sulphur Springs to swimming and bathing in the 1980s. Remediation of this problem was determined to be infeasible, and in the 1999 a swimming pool was constructed within the Sulphur Springs Park for public use. Since the 1960s, the City of Tampa has periodically made withdrawals from the spring pool to augment water supplies in the Hillsborough River Reservoir during times of water shortages. Over the years, modifications were made to the facilities and water control structures at Sulphur Springs to support its dual use for recreation and water supply. The determination of minimum flows for Sulphur Springs is based on the current configurations of the spring pool and run, which are described below.

2.2 Current physical setting of the spring pool and run

The spring is enclosed by a circular concrete wall, which creates a pool approximately 40 feet (ft.) in diameter (Figure 2-3). When the pool is full under normal flow conditions (no withdrawals), water surface elevations in the spring pool generally fluctuate about 7.1 ft above the National Geodetic Vertical Datum 1929 (NGVD). Water depths in the spring pool range from about 5 to 22 ft at normal operating levels, as elevations of the bottom of the pool range from about +2 to –15 ft. NGVD. Ground water discharges to the spring pool via a single vent that is located near the center of the pool

Water discharges from the pool to the spring run through an operable water control structure (Figure 2-4). When this structure is closed, water flows over the top of this structure or flows through two flumes that are located on either side of an operable lift gate. When the gate is opened, water discharges through the bottom of the gate to the spring run. When the structure is closed, water levels in the spring pool are unaffected by tides. When the structure is fully opened, water levels in the spring pool may be affected by tidal water level fluctuations in the Lower Hillsborough River.

The spring run extends from the water control structure about 500 ft. to the mouth of the run at the Lower Hillsborough River (Figure 2-5). The width of the run varies from about 50 to 100 ft., with the widest portions occurring in the upper half of the run near the spring pool. Two footbridges cross the spring run; one at the mouth of the run and another approximately 170 ft. upstream (Figure 2-6A). Midway between these two bridges there is a weir across the spring run that has a rectangular opening near the middle (Figure 2-6B). The top of the weir extends about 1½ to 2½ feet above the water surface in the run during high tides. The opening is approximately 10½ ft. wide, with a bottom elevation of approximately -0.7 ft. NGVD. All water discharging from the spring run to the Lower Hillsborough River flows through this opening. The spring run above this wall is referred to as the upper spring run, while the run below this wall is referred to as the lower spring run (Figure 2-5).

The banks of the upper spring run are hardened by a seawall. Emergent vegetation is present in front of the seawall over much of the north bank of the upper run (Figure 2-6C). The entire southern shoreline of the upper run is un-vegetated, with the seawall extending to the waters edge (Figure 2-6D). The shoreline of the lower run is not hardened, although it is quite steep and rocky with emergent vegetation growing on much of the banks. Greater details about the vegetation and other biological communities of the spring run are described in Section 3.7 of this report.

Figure 2-3. Recent photograph of Sulphur Springs Pool.

Figure 2-4. Discharge structure at Sulphur Springs Pool.

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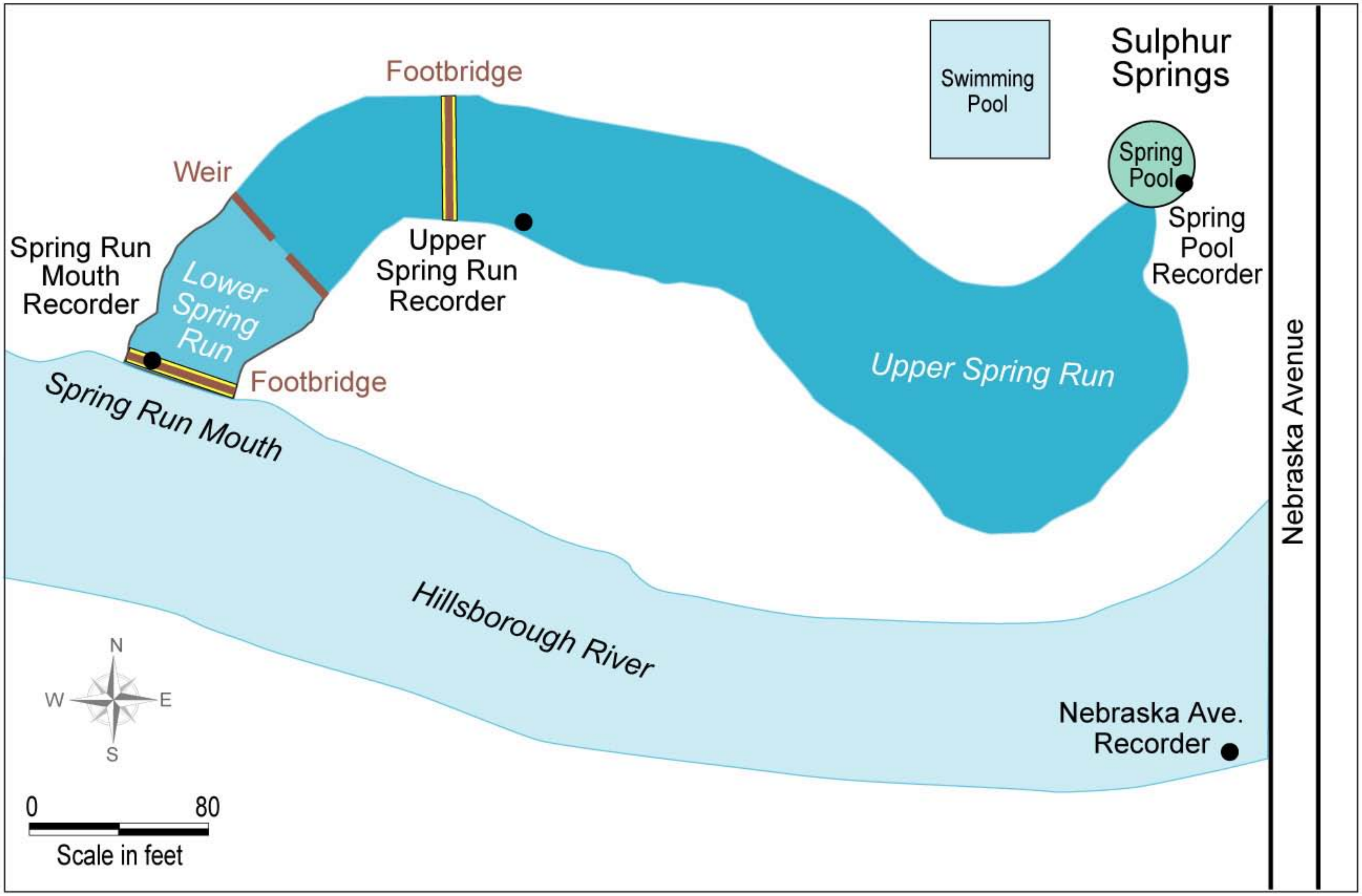

Figure 2-5. Diagram of Sulphur Springs showing the shoreline and structural features associated with the spring pool, spring run, and Lower Hillsborough River. Also shown are the locations of four recording gages operated by the U.S. Geological Survey.

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Figure 2-6A. Upper footbridge over Sulphur Springs Run viewed from north bank just below pool.

Figure 2-6B. Weir with opening extending across Sulphur Springs Run, showing the footbridge at the mouth of the spring run in the background.

Figure 2-6C. Shoreline of Sulphur Springs Run, looking upstream along North Bank.

Figure 2-6D. Shoreline of Sulphur Springs Run looking upstream along the south bank, showing USGS data recorder in the upper spring run.

A bathymetric map of Sulphur Springs Run is shown in Figure 2-7. Water levels in the spring run fluctuate with tide, and the depths that are shown correspond to NGVD 1929, which what is about 0.7 ft. below a mean tide level in the spring run. Most of the spring run is less than two ft. deep at mean tide. Shallow zones are widespread along much of the shoreline, with deep areas restricted to near the mouth of the spring run and in the plunge pool just below the discharge point from the spring outlet structure.

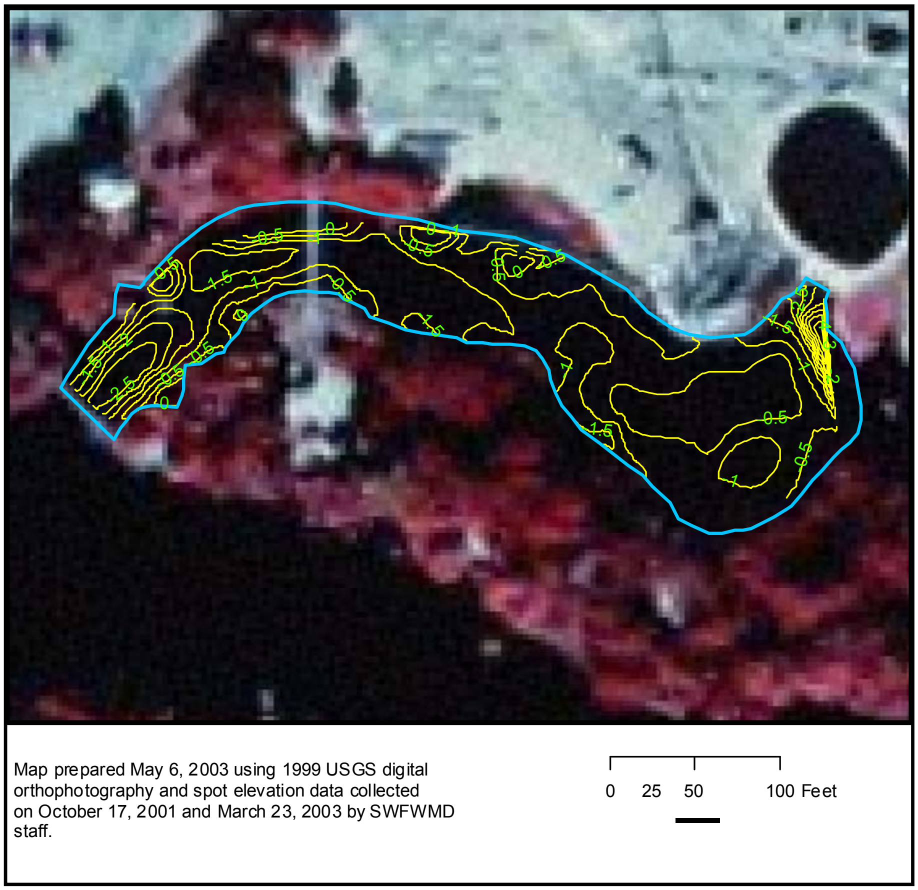

Figure 2-7. **Bathymetric map of Sulphur Springs Run. Yellow lines are one-half foot contours relative to NGVD, 1929.**

The surface area and volume of the spring run are plotted as a function of elevation in Figure 2-8. This graphic can be used to evaluate how the area and volume of the run change as water levels in the run rise and fall. The surface area of the spring run when water levels are greater than about 0.7 feet NGVD is 3.1 hectares (0.75 acres). Surface area shows no increase at higher elevations, as water levels rise up the retaining wall around the run with no increase in surface area. The water volume of the spring run continues to increase with rising water levels. High tide water levels typically range between 1.0 and 3.0 ft. NGVD in the run. The volume of water in the run corresponding to this range of levels is about 1,500 to 3,800 cubic meters (m^3), equal to about 53,000 to 134,000 cubic feet ($ft.^3$).

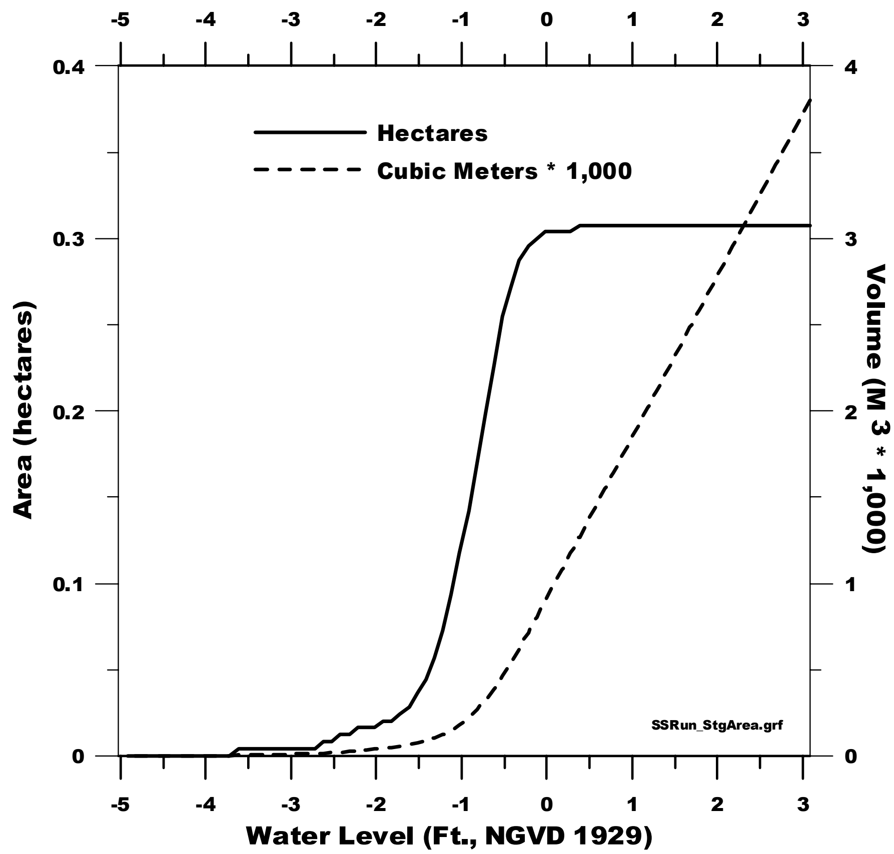

Figure 2-8. Surface area and volume of Sulphur Springs Run as a function of water level in the spring run.

2.3 Water Supply Use of Sulphur Springs

In describing the hydrologic characteristics of Sulphur Springs, it is first helpful to understand how the spring is used for water supply. Since 1965, the City of Tampa has periodically diverted water from Sulphur Springs to the City's reservoir to augment water supplies. Waters are diverted from the spring pool through an intake pipe to a pump house that encloses a centrifugal pump that runs at a constant rate of 30.5 cubic ft per second (cfs) or 19.7 million gallons per day (mgd) when in operation. An underground pipe extends approximately two miles from this pump house to the western shore of the reservoir just upstream of the dam. The City's withdrawal rate of 19.7 mgd is rounded to a value of 20 mgd (31 cfs) for further discussion in this report.

Diversions from Sulphur Springs are used as supplemental water supplies during prolonged dry periods when water levels in the City's reservoir become low. The City has been issued a Water Use Permit from the Southwest Florida Water Management District to withdraw water from Sulphur Springs. That permit specifies that maximum daily withdrawals cannot exceed a rate of 20 mgd, equal to the capacity of the pump. The average daily withdrawal rate calculated for any twelve-month period cannot exceed a rate of 5 mgd (7.7 cfs), and the average withdrawal rate for any single month cannot exceed a rate of 10 mgd (15.5 cfs) and be in compliance with the permit conditions.

As described in more detail in Section 2.5.3, waters discharging from Sulphur Springs are fairly mineralized, exceeding Class I potable water standards for several constituents. Blending the spring water with the large volume of river water in the reservoir allows Sulphur Springs to be periodically used to supplement the City's water supplies. However, if diversions from the spring are prolonged, concentrations of some water quality constituents (e.g. chloride) rise to problematic levels. For this reason, the City tries to minimize its withdrawals from Sulphur Springs and use the spring only during times of impending water shortage.

Records of withdrawals from Sulphur Springs begin in 1984. Total monthly withdrawals were recorded from May 1984 to April 1990, while total daily withdrawals have been recorded from May 1990 to present. Using these combined records, Figure 2-9 shows average yearly withdrawal rates from the spring for 1984–2002. Yearly withdrawals rates were highest during the drought years of 1985, 2000, and 2001, averaging 8.3, 9.1 and 5.5 mgd (12.8, 14.0, and 8.5 cfs), respectively, during these years. There were six years between 1984 and 2002 when there were no withdrawals from the spring.

Withdrawals from the spring are not distributed evenly through the year, but are concentrated during what are typically the drier months. Figure 2-10 shows average withdrawals for 1984 – 2002 plotted on a monthly basis. It is again apparent that the most prolonged withdrawals from the spring occurred during the 1985 and 2000-2001 droughts. Conversely, pumping occurred during only five months in a 7½-year period from mid-1991 through 1998. For nearly five years within this period (1994 –1998), pumping was limited to eight days during April of 1997. These graphics demonstrate that Sulphur Springs is an important water supply source for the City of Tampa during dry years. However, during normal or wet periods, the spring is generally not used for water supply.

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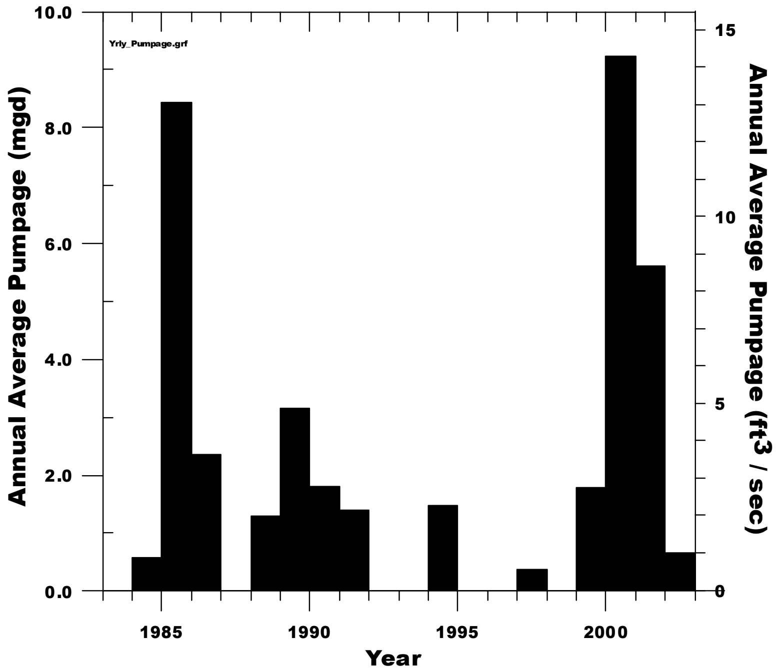

Figure 2-9. Average annual pumpage rates from Sulphur Spring by the City of Tampa for 1984-2002.

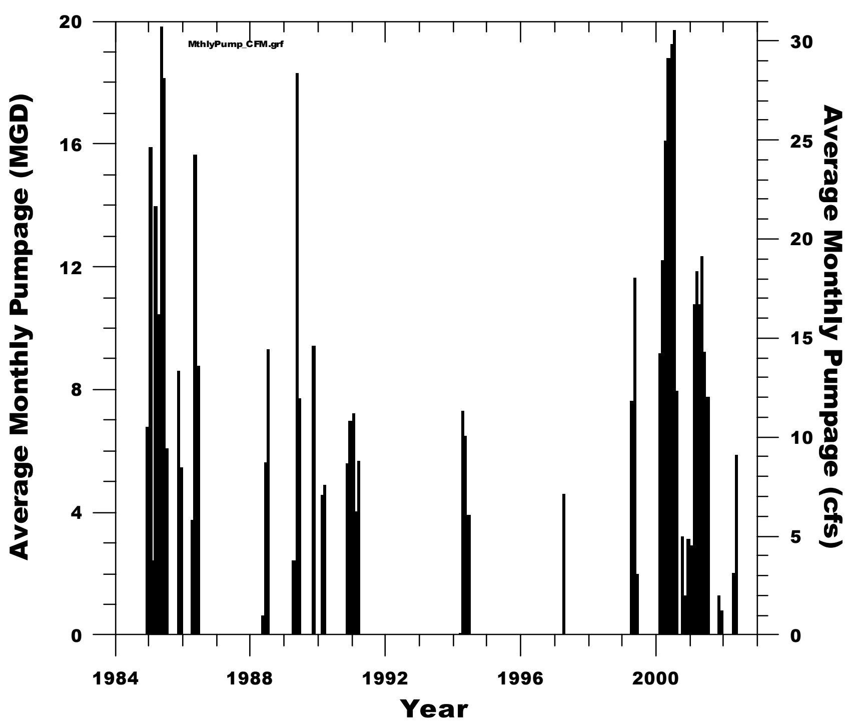

Figure 2-10. Average monthly pumpage rates from Sulphur Springs for 1984-2002.

For the evaluation of minimum flows, it is important to view the effects of withdrawals from Sulphur Springs on a short-term basis. To illustrate patterns of daily withdrawals from the spring during very dry periods, average daily pumpage values are plotted for 1999 - 2002 in Figure 2-11. The flat shape of the top of the pumpage hydrograph reflects series of consecutive days when the withdrawals were taken continuously at the pump capacity of 20 mgd (31 cfs). The most prolonged period of pumping from the spring occurred during May though July 2000, with frequent but less consistent pumping occurring during the first part of 2001.

When they have occurred, withdrawals by the City of Tampa have had a major effect on flows from the spring pool to the spring run. The capacity of the pump (20 mgd) is almost as great as the average flow of Sulphur Springs (22 mgd or 34 cfs), and until recently, pumpage by the City of Tampa often caused flow to the spring run to fall to zero or very low rates of flow. Average daily flows from spring to the run are shown for the 1999-2002 period in Figure 2-12. Comparison to Figure 2-11 shows that when withdrawals were in effect, discharges from the pool fell to very low values. When withdrawals ceased, there was a rapid increase in discharge from the spring pool.

The period of high flow (> 50 cfs) that occurred primarily in 1999 was due to opening of the gate at the spring outlet. During this period, the City opened the structure to lower water levels in the pool so that work on the swimming pool in the Sulphur Springs Park could be undertaken without damaging the structure of the swimming pool. Raising the gate and lowering water levels in the spring pool induces greater ground-water discharge due to less head pressure over the spring vent. In the spring of 1999, the City closed the structure and began withdrawals for water supply, as shown by the drop in flows seen in April though June of that year (Figure 2-12). Additional information on the ground-water relations and flow characteristics of Sulphur Springs are presented in later sections of this report.

2.3.1 Recent improvements to the diversion facilities at Sulphur Springs

Modifications were made to the water diversion facilities associated with Sulphur Springs during 2001 to allow for better management of flows from the spring pool. As part of the minimum flow rule for the Lower Hillsborough River that was adopted in the year 2000, it was established that diversions from Sulphur Springs could be used to provide the 10 cfs minimum flow at the base of the Hillsborough River dam. To accomplish this objective, a junction was put in the pipe that leads from Sulphur Springs to the reservoir so that spring waters can be released to the lower river near the base of the dam. A valve and flow meter were installed at this junction so that varying amounts of spring water could be diverted either into the reservoir or to the base of the dam. A 100 ft. long flume was constructed that extends from this junction to the river below the dam (Figure 2-13). The turbulence created by this flume aerates the spring water before it is released to the lower river.

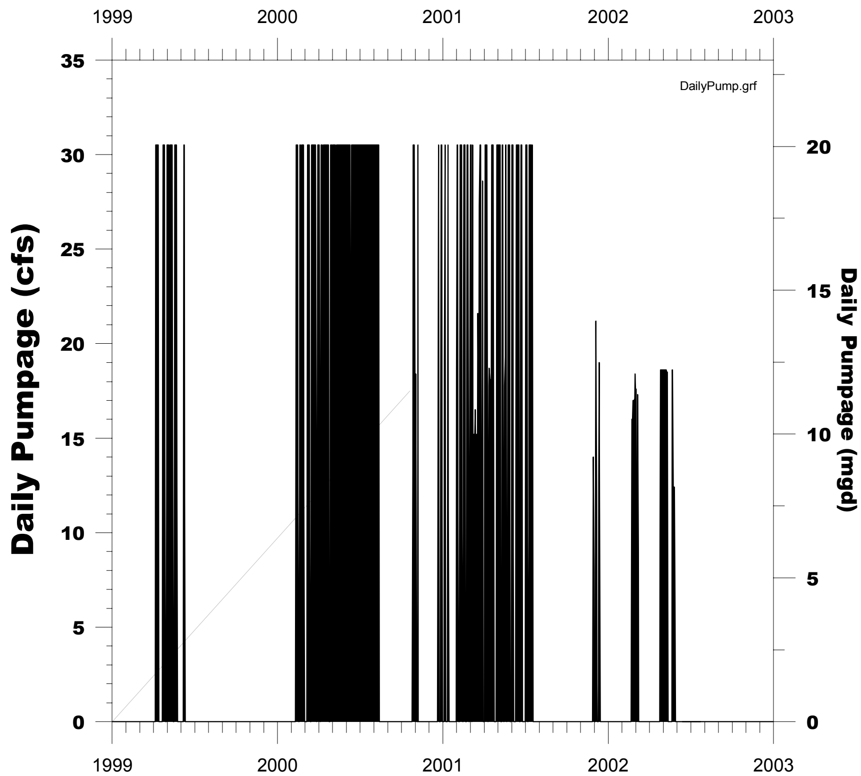

Figure 2-11. Average daily pumpage from Sulphur Springs 1999-2002.

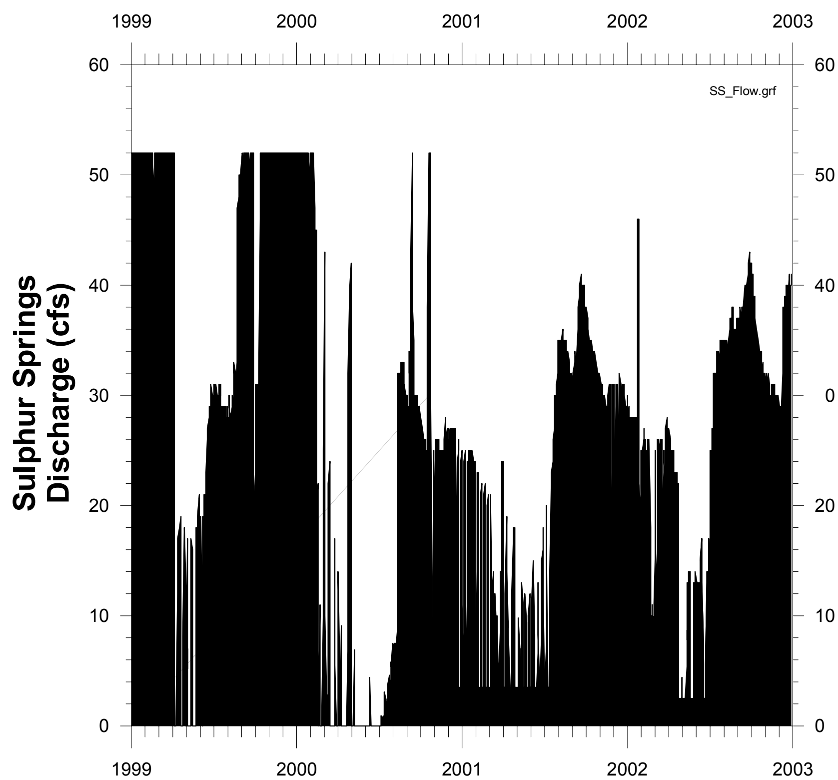

Figure 2-12. Daily discharge from Sulphur Springs 1999 – 2002.

The minimum flow rule for the Lower Hillsborough River also specified that the minimum flow would be re-evaluated by 2005, including tests of minimum flow releases up to and above 30 cfs. The study design document for this re-evaluation (Janicki Environmental 2002) listed a series of minimum flow tests that involve varying combinations of flow to the lower river water released from the reservoir or diverted from Sulphur Springs.

Figure 2-13. Flume discharge structure at base of reservoir dam.

The diversion facilities at the spring pool were modified so that varying amounts of springflow could be diverted to the reservoir and the base of the dam, while allowing the remaining springflow to discharge to the spring run. To accomplish this, a return pipe and junction were put in the intake that leads from the spring pool to the pump house. This return pipe was fitted with a valve and flow meter so that variable amounts of water can be sent to the reservoir and/or the base of the dam, with the remaining flows returned to the spring pool. The return pipe terminates above the concrete wall forming the spring pool (Figure 2-14).

Figure 2-14. Return flow structure at Sulphur Springs Pool.

The modification of these diversion facilities allows for the improved management of flows from Sulphur Springs. Before these modifications were in place, diversions of spring water to the reservoir at a rate of 20 mgd often caused flows to the spring run to cease. Now, varying amounts of springflow can be divided between the spring run, the reservoir, and releases to the lower Hillsborough River below the dam. Beginning in November 2001, a series of flow experiments were undertaken in which various quantities of water were diverted from the spring pool to the reservoir or to the base of the dam. Flow quantities and the response of salinity in the river during these tests are discussed in later chapters of this report.

2.4 Hydrogeologic and Flow characteristics of Sulphur Springs

2.4.1 Geologic Setting

The hydrogeology of the Sulphur Springs area was described in a United States Geological Survey Water Resource Investigation report by Stewart and Mills (1984). The springs are located in an urban area overlain by 30 to 40 ft. (9.1 to 12.2 m) of surficial sediment composed of sand and clay. Beneath the surficial sediments are a series of layers of clay, sandy clay, and clayey sand with a combined thickness of approximately 20 ft. (6.1 m). These sediments are remnants of the Miocene Hawthorn

Formation and act as a hydrologic confinement layer separating the surficial water table from the underlying Upper Floridan aquifer.

Beneath the confining layer is the weathered surface of the Miocene Tampa Limestone, underlain by the Oligocene Suwannee Limestone, Eocene Ocala Limestone, Avon Park Limestone and the Oldsmar Limestone. Together these carbonate sequences comprise the Upper Floridan aquifer. The Tampa Limestone is a white, gray, and tan sandy limestone with a great number of fractures, solution channels and numerous sinkholes. It is also an important source of water supply. The underlying Suwannee Limestone is a yellow-white to light brown fossiliferous limestone and is the source of most domestic water in the area (Knutilla and Corral, Jr. 1984).

Although the Avon Park Limestone is an important source of water, particularly from the highly fractured zone, it is separated from the overlying formations by the Ocala Limestone, a yellow-gray, chalky, fossiliferous limestone that is not a very good producer of water. The Ocala acts as a semi-permeable confining unit separating the Avon Park from the overlying units. The consequence is that the portions of the aquifer below the Suwannee Limestone are not likely to be important contributors to the flow at Sulphur Spring.

2.4.2 Springflow characteristics

Sulphur Springs is an artesian spring from which ground waters discharge due to hydrostatic pressure in the underlying aquifers. The average flow for Sulphur Springs is 31.4 cfs for the period 1991 through 2002. Correcting this value for withdrawals by the City of Tampa (adding withdrawals to flow) yields an average flow of 34.3 cfs. Flows from Sulphur Springs exhibit slight seasonal variation in response to the progression of dry and wet seasons in west-central Florida. Average monthly withdrawal-corrected flows range from 28.9 cfs in June, just after the spring dry season, to 39.4 cfs in September (Figure 2-15). Duration curves for flows at Sulphur Springs are presented in Figure 2-16 for days when there were no withdrawals and the complete daily record (including withdrawals). The curves are relatively similar but diverge at low flows, showing the effect of the periodic withdrawals by the City. As with most other springs, flows from Sulphur Springs are much more stable than flows in freshwater streams that receive surface runoff. Eighty percent of the daily flow values with no withdrawals range between 26 and 48 cfs (Figure 2-16).

Water flowing from the spring has two sources. The primary source is from the Tampa and Suwannee limestones of the Upper Floridan Aquifer. Much, if not all, of the ground water component flows along fractures and solution channels. Some of the solution channels connect with sinkholes in the area, which are extremely numerous (Figure 2-17). To a lesser degree some stormwater runoff, which has been captured by the sinks, flows along the same conduits to Sulphur Springs, although that contribution has

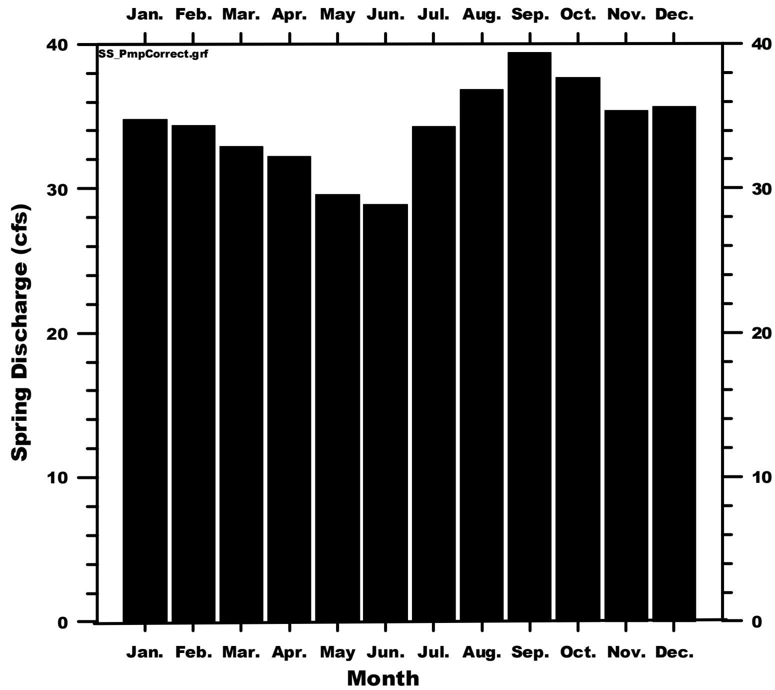

Figure 2-15. Average monthly flows from Sulphur Springs corrected for withdrawals for 1991 – 2002.

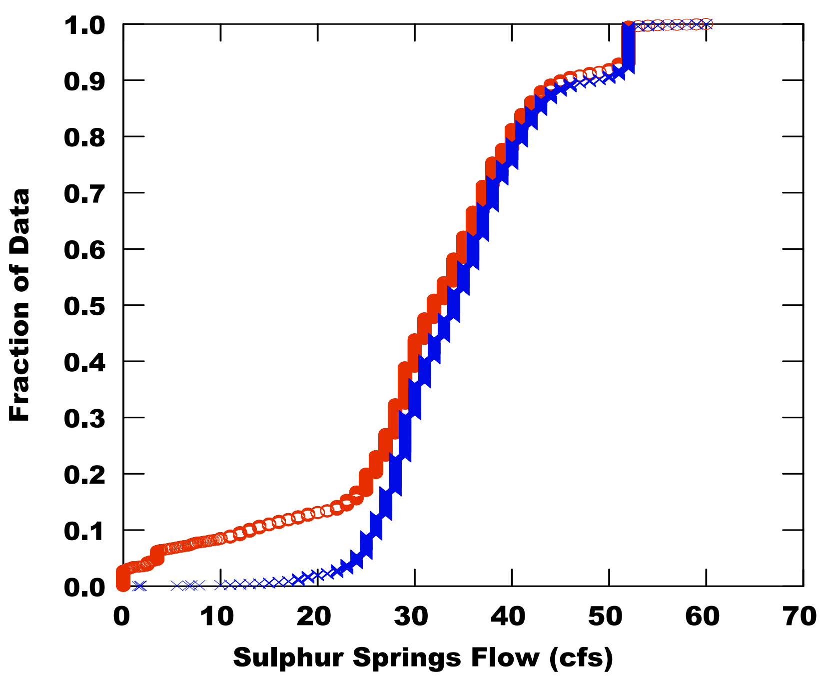

Figure 2-16. Flow duration curves for daily flow values from Sulphur Springs for days with no withdrawals (blue) and complete daily records (red) for 1991 – 2002.

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apparently declined over time. Studies performed by the City of Tampa in 1958 confirmed a connection between Sulphur Springs and Curiosity Sink and also Blue Sink, which are located approximately 2.5 miles (4 km) northwest of Sulphur Springs. Tracer dyes indicated flow rates in the range of 4,200 to 9,200 ft per day (1,280 to 2,800 meters per day). Stewart and Mills (1984) visited the Blue Sink complex in 1963-64 and noted that the sinks were approximately 20 to 30 feet (6.1 to 9.1 m) deep with water visibly flowing at the bottom. However, by 1981 the sinks were only about 6 feet (1.8 m) deep and dry. The connection between Sulphur Springs and the Blue Sink complex had been lost due to the build up of trash and sediment, which effectively plugged the sinks. A dye test was conducted by the City of Tampa in 1987 to determine if the connection still remained between Blue Sink and Sulphur Springs. The dye never arrived at the spring indicating that the connection was sealed.

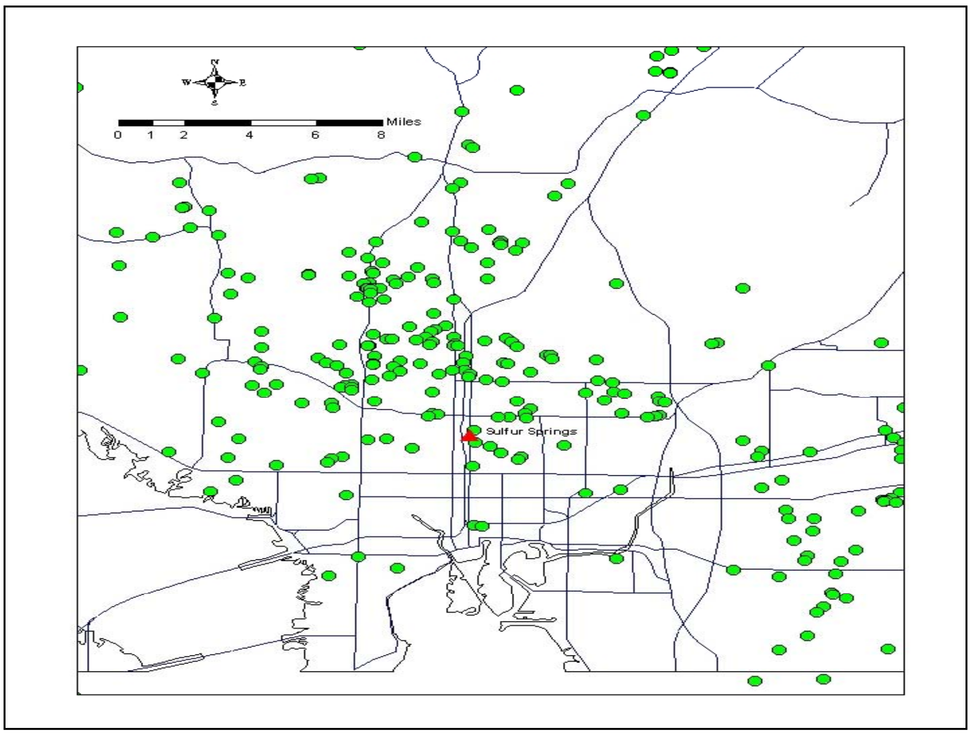


Figure 2-17. Known sinkholes locations near Tampa, Florida.

In 1989, Environmental Engineering Consultants, Inc. conducted additional dye tracer tests to verify the hydraulic connection between Alaska and Poinsettia (also called Jasmine or Trinity) sinks to Sulphur Springs. Alaska sink is approximately 549 m (1,800 ft) northwest of Sulphur Springs and Jasmine is 7,500 feet (2,286 m) north of Sulphur Springs. The calculated flow rate for the flow between Alaska sink and Sulphur Springs was 12,900 ft per day (3,932 meters per day). The results for the Poinsettia sink indicated a flow rate of approximately 8,200 ft per day (2,499 meters per day). The test derived flow rates are, of course, head dependent. The greater the hydraulic gradient the more pronounced the flow. Consequently, if levels are reduced at Sulphur Springs due to withdrawals for public water supply, there will be a tendency to have stronger flows along the hydraulic gradient and from any surface water being collected by the sinks.

Because of flooding problems in the vicinity of Blue Sink and the nearby Curiosity Creek, Schreuder Inc., an environmental consultant firm, has been engaged by the City of Tampa to investigate the Blue Sink complex. The purpose of their investigation is to determine the feasibility of re-opening Blue Sink to improve drainage from the Curiosity Creek drainage basin to Sulphur Springs. Their investigations, conducted in 1997, 1999, and 2000, have found that the connection between Blue Sink and Sulphur Springs is blocked somewhere between Poinsettia Sink and Blue Sink (Schreuder Inc. 1999, 2001). Additional work in 2003 located the blockage, but concluded that because of its size and location under private property, it is not feasible to remove it (Schreuder Inc. 2004). The firm proposed that a berm and pump station be constructed in Blue Sink and excess water be pumped through a series ponds and pumping stations to a new 40-acre urban wetland/upland park area.

Examination of the May 2002 Upper Floridan potentiometric surface shows the presence of a ground-water divide approximately 3-4 miles (4.8 to 6.4 km) west of Sulphur Springs (Figure 2-18). Ground water further west of that line would flow away from the spring. The primary direction of ground water flow in the vicinity of the spring would be from north to south. Other springs, such as the Lettuce Lake spring complex, located east of Sulphur Springs, would have a significant ground water flow from the northeast and east.

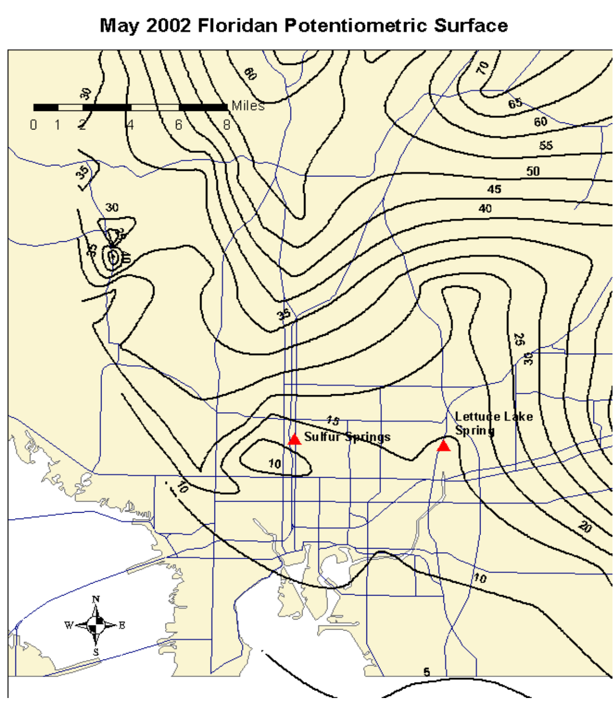


Figure 2-18. **Potentiometric surface of the Upper Florida aquifer near Sulphur Springs for May, 2002**.

There is evidence that flows have been gradually decreasing over time from Sulphur Springs. Daily flow records recorded by the United States Geological Survey (USGS) begin in 1956. Withdrawals from the spring pool began in the mid-1960s, but records for the withdrawals are unavailable for the period prior to 1984. For the period of 1984 to present, it is possible to correct the recorded flows on a monthly basis by adding back the quantities withdrawn. Consequently, the flow data prior to 1984 flow show much more scatter due to occasional low flows that are not corrected for withdrawals.

Figure 2-19 shows time series plots of flows for both uncorrected pre-1984 data and 1984 to present data that are corrected for withdrawals. In both cases a Kendall-Theil regression line has been fitted to the data to illustrate the overall average trend. The Kendall-Theil method is a non-parametric form of regression that is independent of the data distribution and more robust in the presence of extreme values. The results of the regression for the two time periods are fairly similar and indicate a statistically significant ($\alpha = 0.05$) slight decrease in flow over time. The slopes of the regression lines are –0.60 cfs/yr for the pre-1984 period and -0.36 cfs/yr for 1984 to present.

2.5 Water Quality of Sulphur Springs

The water quality characteristics of the Sulphur Springs pool are described below. Seasonal and long-term trends in specific conductance are described first, since this parameter is a good indicator of the overall mineralization of the spring water and changes in the spring's ground-water sources. Periodic long-term specific conductance data from the USGS and the City of Tampa are evaluated with recent data from a continuous specific conductance recorder located in the spring pool. This is followed by a discussion of other water quality characteristics of the spring (e.g., nutrients, color), which are related to the ecological characteristics of the spring run and the adjoining reaches of the Lower Hillsborough River.

2.5.1 Data sources

Water quality data for the Sulphur Springs pool examined in this report are taken from two sources. Since 1990, the City of Tampa has taken samples from Sulphur Springs pool for water quality analysis on a monthly basis. These data are submitted to the SWFWMD as part of the City’s water use permit for withdrawals from the spring.

The USGS has also collected periodic water quality samples from the Sulphur Springs pool, with records dating back to the 1945 for some parameters. The frequency of sampling has varied considerably, ranging from a few measurements every several years prior to 1966 to roughly bi-monthly sampling during much of the 1970s and 1980s. Temperature, pH, specific conductance and dissolved oxygen have been the most frequently measured parameters. Water quality sampling by the USGS has decreased since the early 1990s, largely because regular water quality sampling was instituted by the City of Tampa. Selected variables in the USGS database are described as they compare to more recent data collected by the City.

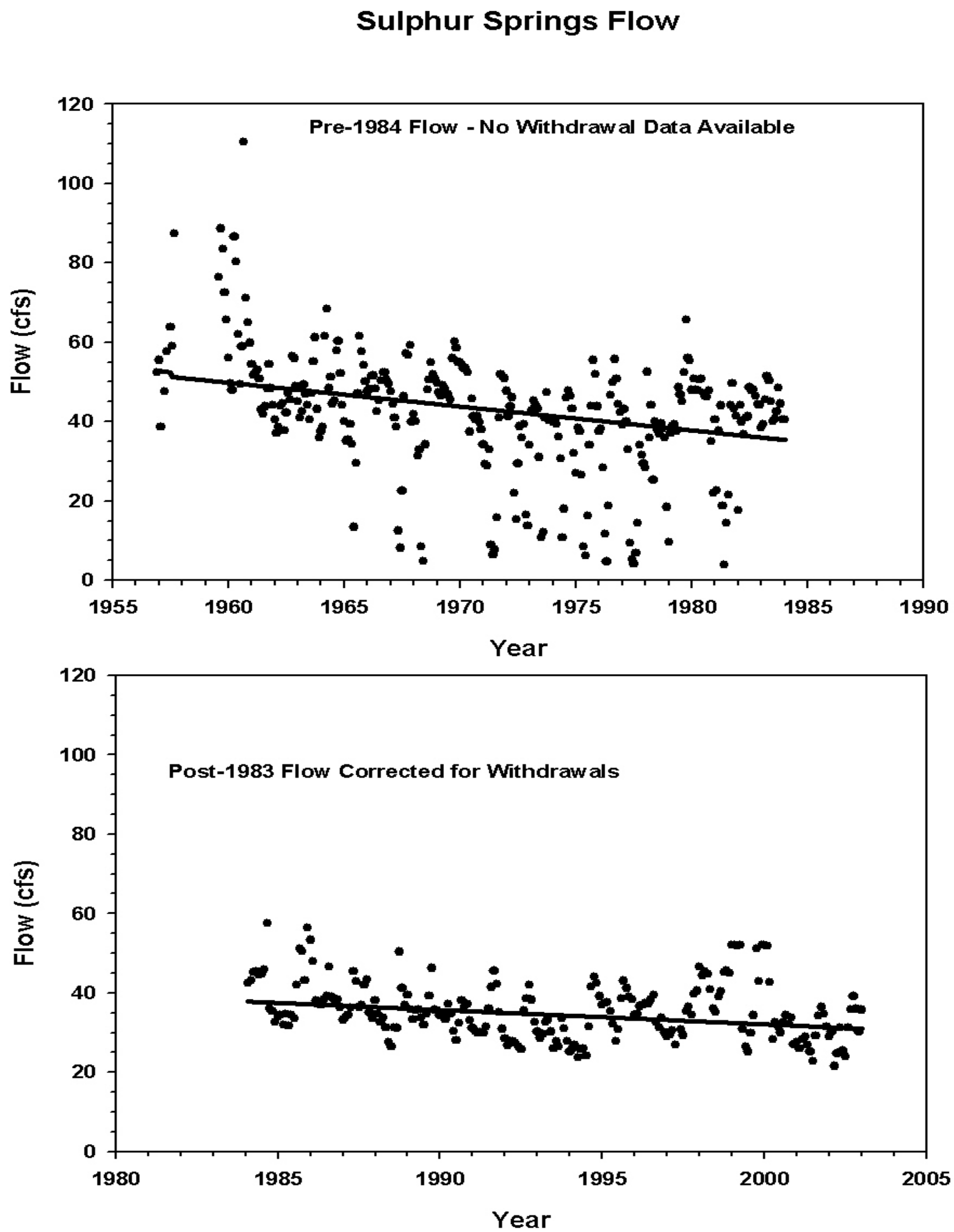


Figure 2-19 . Temporal trend of monthly Sulphur Springs flows: corrected and uncorrected for withdrawals. Kendall-Theil slope shown.

Since April 1999, the USGS has also collected water temperature and specific conductance data in the spring pool every 15 minutes using a continuous recording device. Water level records at this site (# 02306000) go back to 1959, with periodic measurements extending back further. Fifteen-minute data for temperature and specific conductance at this recorder began in April 1999 as part of the District-funded minimum flow study for Sulphur Springs.

2.5.2 Trends in specific conductance

Specific conductance, or the capability of water to conduct an electrical current, is a measure of the total dissolved inorganic ions in water. The specific conductance of most freshwater streams and springs in Florida is less than 500 µmhos/cm. Friedman and Hand (1986) reported a median value of 366 µmhos/cm for Florida springs, and state that values over 1,500 µmhos/cm reflect the effects of salt water at some sites.

Based on recent data from the spring pool, Sulphur Springs can be considered a slightly brackish, mineralized spring. The mean specific conductance value for the monthly data from the City of Tampa during 2001-2002 was 3,093 µmhos/cm, with a range of 1,971 to 4,040 µmhos/cm. Similarly, the mean specific conductance value for the USGS recorder for 2001-2002 was 3,218 µmhos/cm, with average daily values ranging from 1,821 to 6,558 µmhos/cm. The mineralization of the spring is also reflected in high total dissolved solids concentrations (TDS). In the monthly samples for 2001-2002, TDS ranged between 1,128 and 3,177 mg/l with an average 1,834 mg/l. These concentrations are well over the Florida potable water standard of 250 mg/l for total dissolved solids.

Data from the spring pool and a nearby well indicate that ground-water quality in the immediate vicinity of Sulphur Springs is becoming increasingly mineralized. Specific conductance values in the spring outflow and the underlying Upper Floridan Aquifer have been steadily increasing since approximately 1973 to present. The Tourist Club Floridan monitor well is located approximately 260 feet (79 m) from Sulphur Springs. It is cased to 80 feet (24 m) and is 318 feet (67 m) deep. Specific conductance measured in the well has increased from around 5,000 to over 15,000 µmhos/cm at an average rate of 331 µmhos/cm/yr (Figure 2-20). Salinity, as calculated from the specific conductance using the equations of Jaeger (1973), has shown an increase of 0.20 ppt/year for the same period.

Specific conductance in the discharge from Sulphur Springs has also shown a pronounced increase, but at a lesser rate (Figure 2-21). Prior to about 1973, the spring's specific conductance was fairly constant at about 1,000 µmhos/cm. However, beginning in 1973, specific conductance values began climbing at an estimated rate of 65 µmhos/cm/yr to the present level of approximately 3,000 µmhos/cm. Some readings have been as high as 6,000 µmhos/cm. Salinity values have shown an increase of 0.036 ppt/year after 1973.

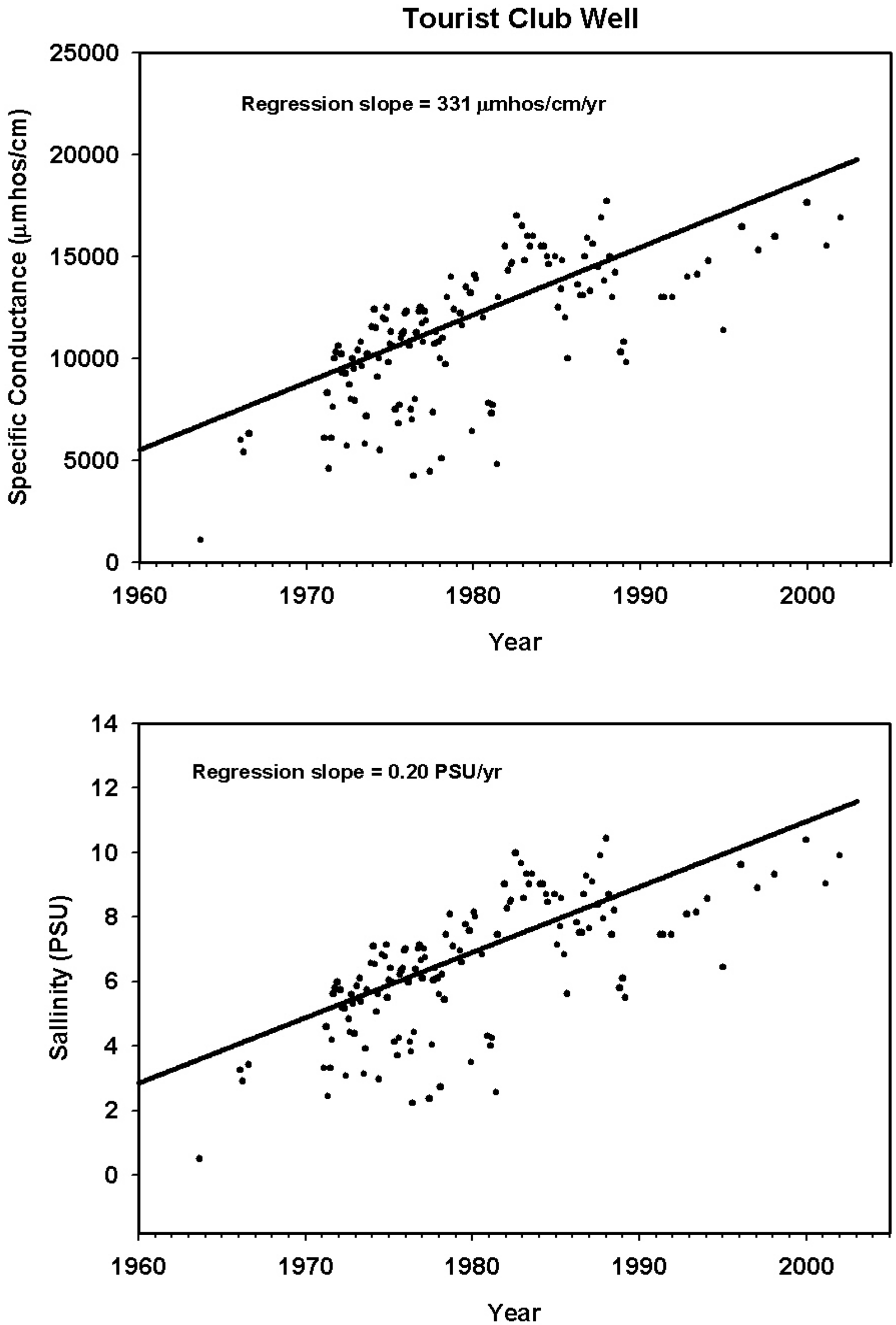


Figure 2-20. Temporal trends of specific conductance and salinity in the Tourist Club well. Kendall-Theil slope shown.

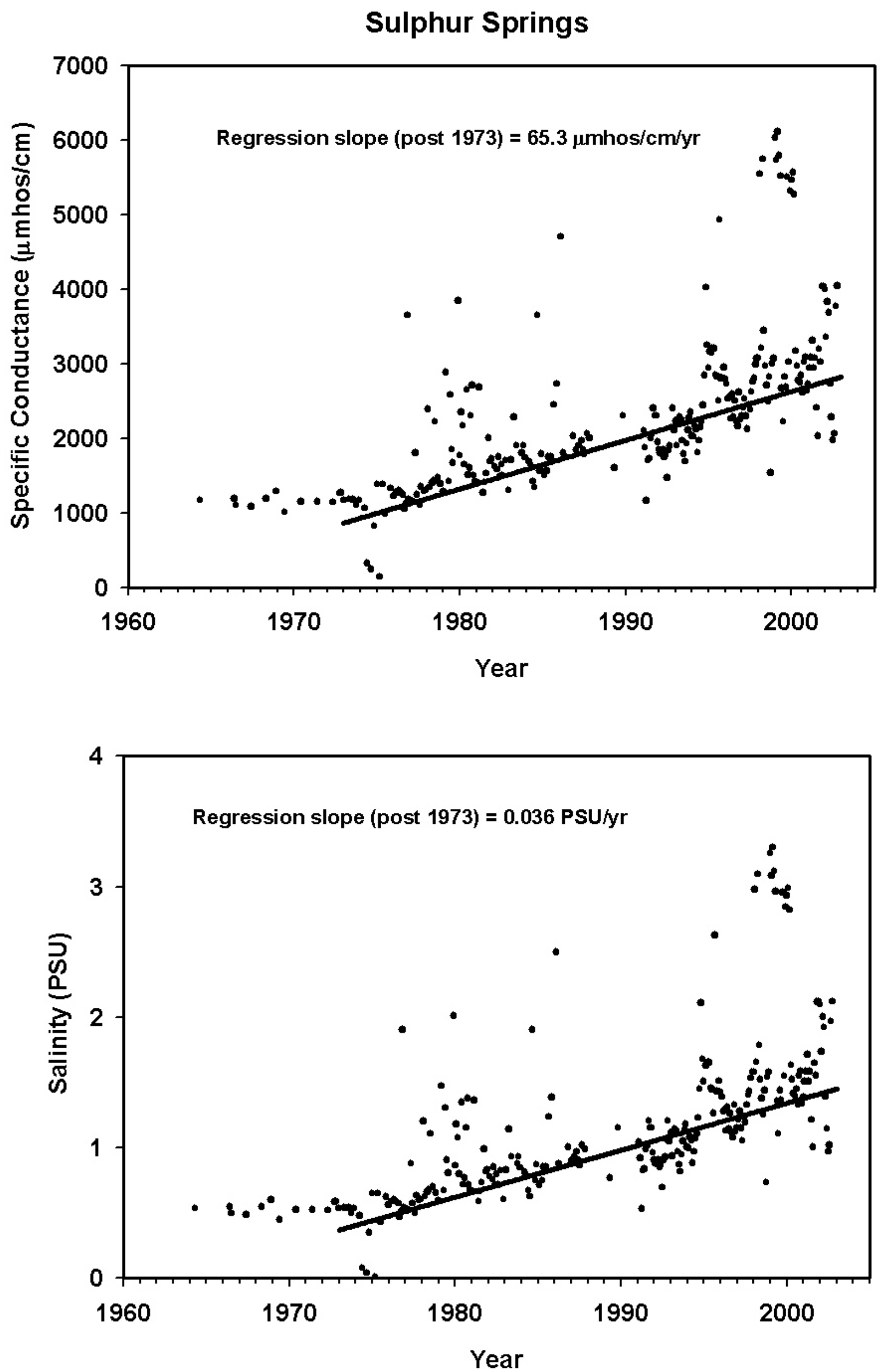


Figure 2-21. Temporal trend of specific conductance and salinity in the Sulphur Springs Pool. Kendall-Theil slope shown.

In comparison to specific conductance values of other Floridan aquifer wells in the area, the observed values at Sulphur Springs and the Tourist Club well are anomalously high. Data are somewhat limited in recent years, but for the year 2000, specific conductance is on the order of 15,000 µmhos/cm for the Tourist Club well and around 3,000 µmhos/cm for the spring. Three monitor wells located within 3 miles (4.8 km) or less of the spring had specific conductance values of 390, 550, and 993 µmhos/cm. This evidence points to local upconing at the spring of more mineralized water, presumably flowing along preferential fractures. The City of Tampa has sponsored diver explorations of the cave system that contributes flow to Sulphur Springs (Figure 22-B on the following page). These investigations have found that the passage that flow from the Alaska tunnel has much higher specific conductance than flow from the Orchid tunnel (Figure 2-22A). The specific conductance seen at Sulphur Springs is the result of the mixing of both water sources (Schreuder Inc. 2004).

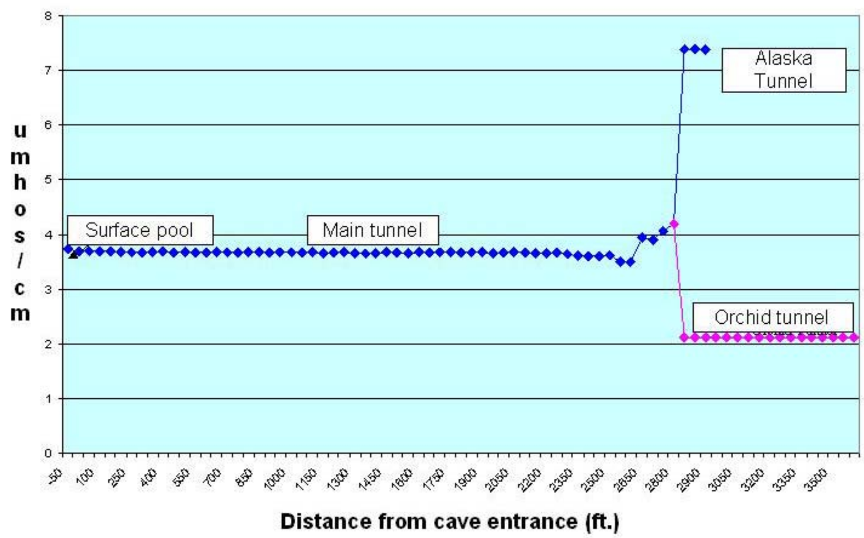
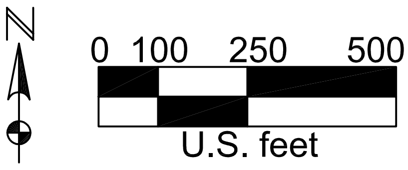


Figure 2-22A. Specific conductance in the Sulphur Springs cave system on November 15, 1998. Adapted from Schrueder, Inc. Used with permission of the City of Tampa.

2.5.2.1 Effects of gate operations and withdrawals on specific conductance

The manipulation of water levels in the spring pool can affect the water quality of the spring discharge. When water levels in the pool are lowered by opening the gate at the outlet structure, specific conductance values in the pool typically increase. **Figure 2-23** is a plot of average daily values for gage height and specific conductance in the spring pool for the period of 1999 through 2002. Those days when the gage heights are below approximately 2 ft. represent times when the pool was manually lowered for maintenance purposes. Prolonged periods of gate openings and corresponding low water levels occurred during 1999 – 2000 and much shorter intervals in 2000 and 2002.

Figure 2-22B. Known extent of Sulphur Springs cave system accessible to divers. Printed with permission of Schrueder, Inc. and the City of Tampa.



SCHREUDER, INC. 110 West Country Club Drive Tampa, FL 33612 PH: 813-932-8844, FAX: 813-932-2991	Know Extent of Sulphur Springs Cave System Accessible to Divers SUBSURFACE EVALUATIONS, INC. Engineering Geology & Geophysics	Date- 4/5/2004	Drawn By- NS
		Scale- See Scale Bar	Approved By- HCH
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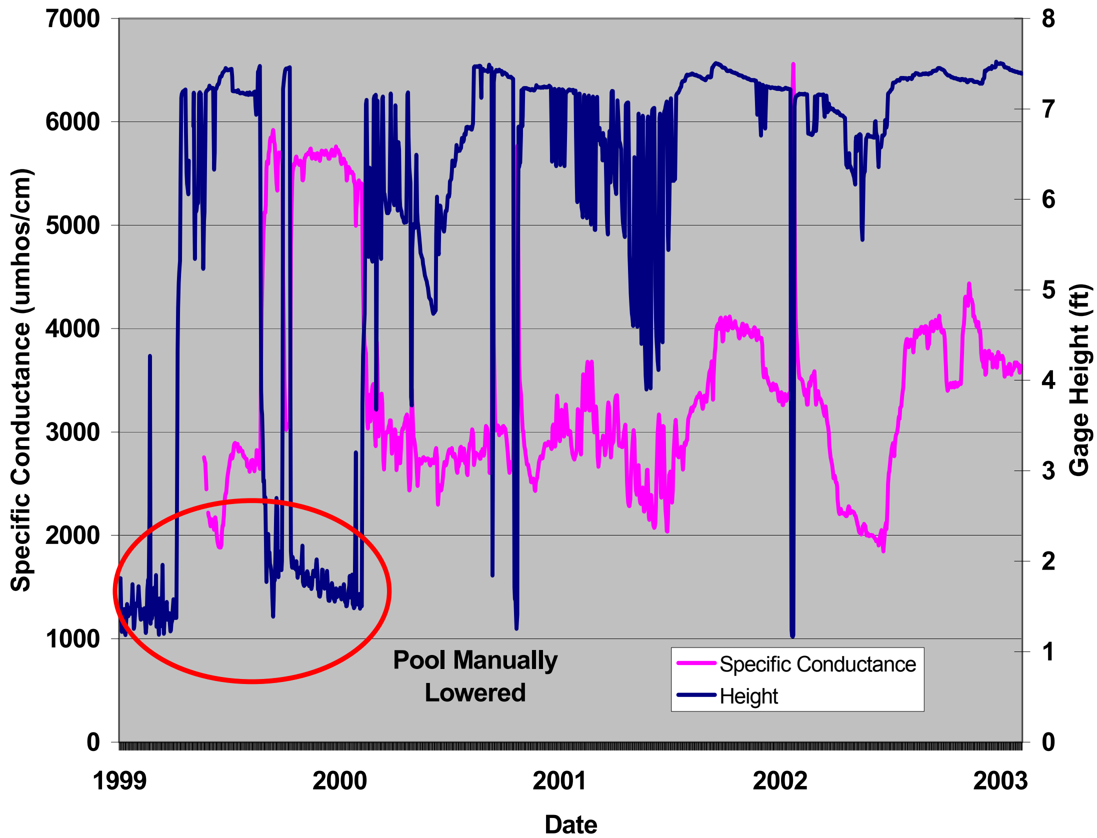


Figure 2-23. Average daily values of water levels and specific conductance for Sulphur Springs Pool for 1999 through 2002.

The collection of specific conductance data at the recorder in the spring pool began spring of 1999. Data collected since that time show that gate openings resulted in pronounced spikes in specific conductance. As described earlier, these gate openings also result in increased discharge from the spring due to less head pressure over the spring vent. Apparently, these increases in total springflow are accompanied by increased flows from those conduits in the groundwater system that contribute mineralized, high conductance water to Sulphur Springs. Since the net specific conductance of the discharge from the spring pool increases during these periods, the proportion of flow contributed by these conduits must increase as well.

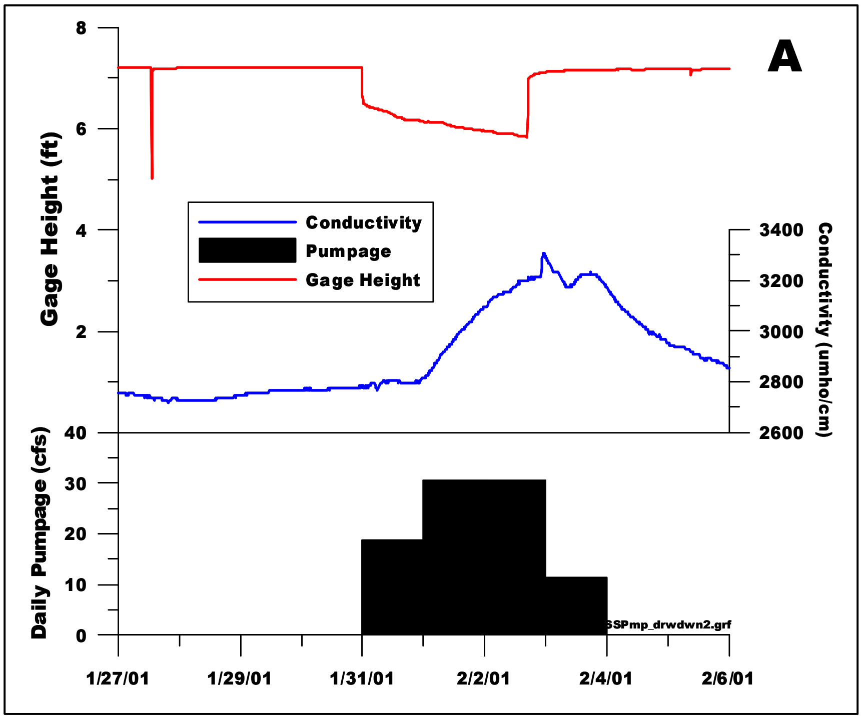
The withdrawal of water from Sulphur Springs pool for water supply can also affect water levels in the pool and the quality of the spring discharge. Plots of 15-minute values of water level and specific conductance in the spring pool are shown along with average daily withdrawals for two series of dates in Figure 2-24 A and B. The first pumping episode involved pumping over a four-day period during January and February 2001 (Figure 2-24A). Initiation of pumping on January 31 resulted in an almost immediate drop in water levels, with the rate of decline slowing after the initial fall. The response of specific conductance was not so immediate, as a steady rate of increase that totaled about 400 μmhos/cm began approximately one day after pumping began. Cessation of pumping on February 3 resulted in a quick rebound in water levels and a slower decline in specific conductance.

The time series shown in Figure 2-24B is for an 8-day pumping episode during June 2001. Again, water levels showed an immediate drop in response to pumping, followed by a slower, but continued, decline. Compared to the four-day winter pumping episode, in which water levels fell to 5.9 ft, (Figure 2-24A), water levels fell to 3.9 ft. after eight days of pumping in June (Figure 2-24B). Specific conductance again showed about a one-day lag, with a steady increase that totaled about 1,100 μmhos/cm over the following seven-day period. Again, cessation of pumping resulted in a rebound in water levels and a decline in specific conductance.

In order to gain some insight into the effects of withdrawals from the spring, it is helpful to filter out the seasonal changes that occur in both the flow and specific conductance values for the spring. Plots of daily specific conductance values vs. day of the year are overlain for the years 2001 and 2002 in Figure 2-25. The curves for these years are very similar, reflecting the periodicity of a seasonal component. Some of the unusually large spikes in specific conductance correspond to those times that the spring pool was manually lowered.

In addition to the plots for the two individual years, there is also shown a LOESS (Locally Estimated Scatter plot Smoothing) regression line of the data for the year 2001. This year was chosen simply because there were no significant manual pool lowerings during that year, although there were a noticeable number of withdrawals. The LOESS regression line bears a similarity to the seasonal pattern of average monthly values shown in Figure 2-15. It is reasonable to assume that this regression model can represent the seasonal component of specific conductance. If this assumption is valid, then by examining the residuals, or the difference between the actual data and the values predicted by the model, one could examine how other factors may influence conductance in addition to the seasonal component.

The residual conductance values for 2001 are plotted in Figure 2-26 along with daily pumpage records from the springs. The pumping events have been shifted by one day. That is, today's specific conductance is plotted against the previous day’s withdrawal event. This takes into account the slight lag time of the response of the water quality to the withdrawal event. During the first half of the year when most of the withdrawal events occurred, the number of spikes in specific conductance is noticeably higher when compared to the latter half of the year. Equally obvious is the direct correspondence between the pumping events and the specific conductance spikes.



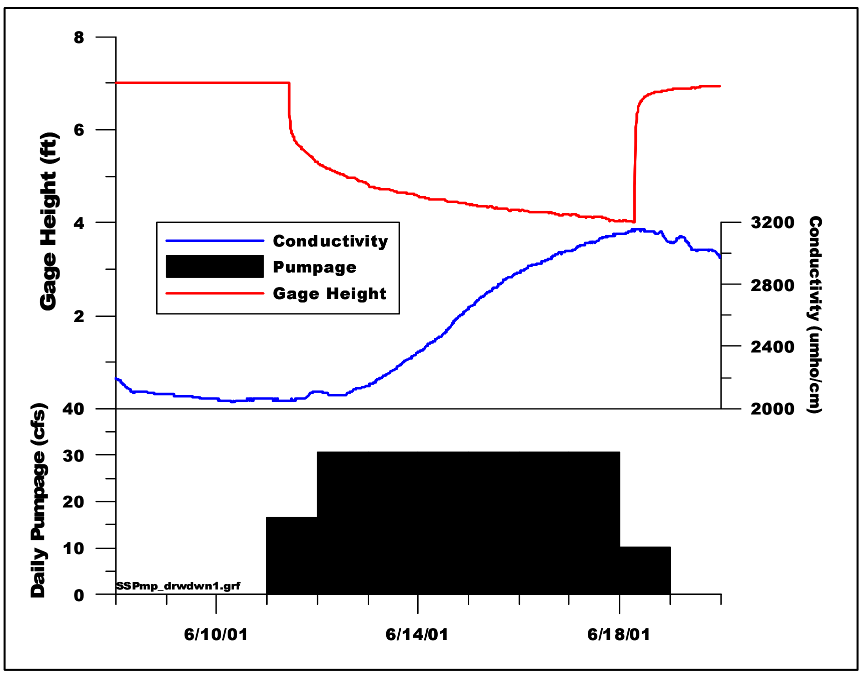


Figure 2-24. Water level and specific conductance response to withdrawals from the Sulphur Springs Pool for two periods during 2001.

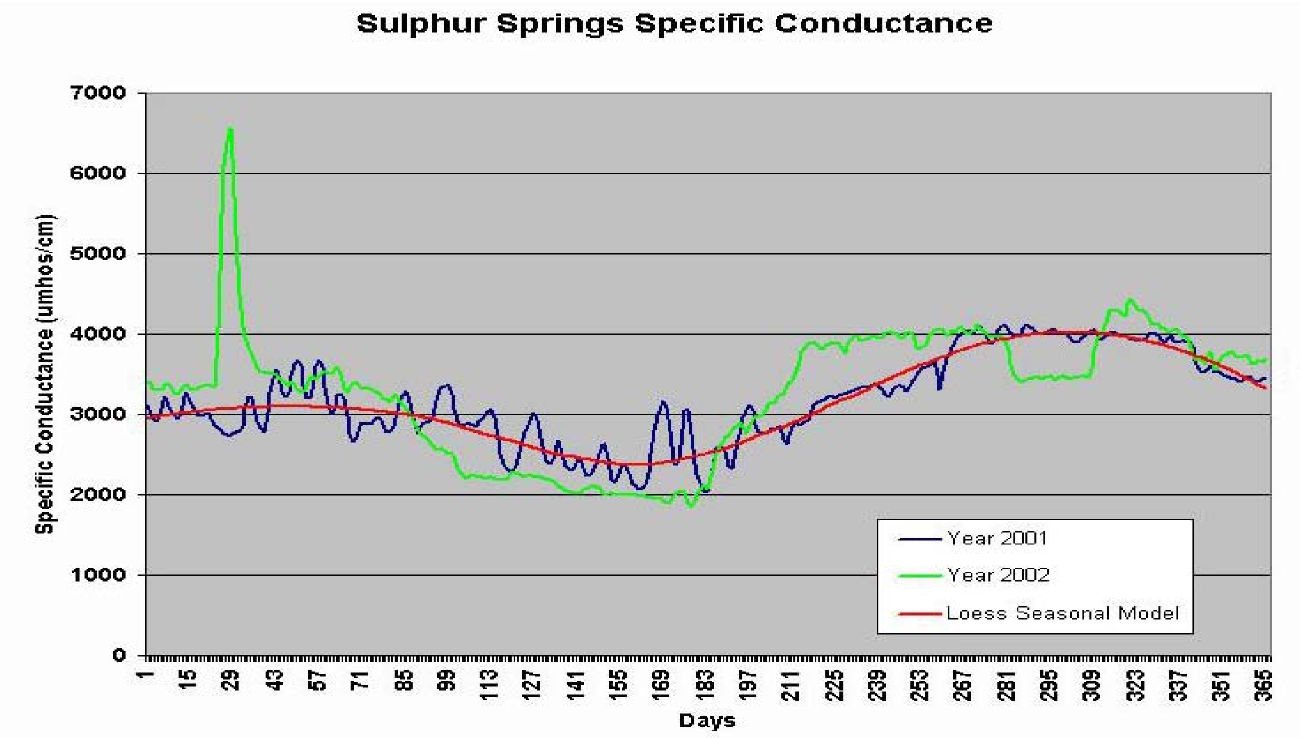


Figure 2-25. Average specific conductance values for each day of the year for 2001 and 2002 with a LOESS line fitted to the 2001 data.

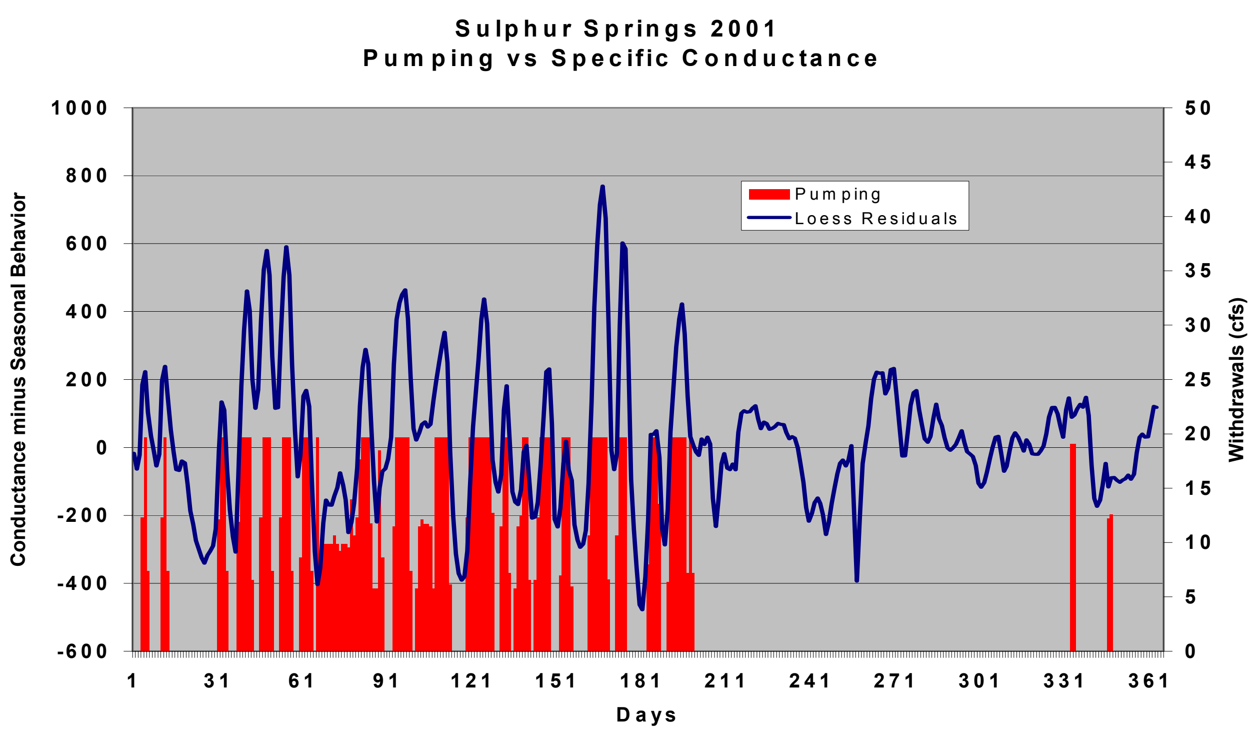


Figure 2-26. Residual values for conductance vs. day of the year and pumpage from Sulphur Springs for 2001.

While visually compelling, there are methods of testing the correspondence between the withdrawal events and spikes in the specific conductance. Inspection of Figure 2-26 would indicate that many of the withdrawal events are associated with spikes that exceed 150 µmhos/cm. By counting the number of times that the seasonally corrected conductance equaled or exceeded 150 µmhos/cm and counting the number of withdrawal events, a cross tabulation table was constructed as seen in Table 2.1.

The Pearson Chi-square test for this table has a value of 16.70 and a p-value of <0.0001. This indicates that there is a strong, statistically significant relationship between withdrawals and the spikes in the specific conductance. The row percentages in the Table 2-1 show that withdrawals are associated with specific conductance spikes 34% of the time while non-withdrawals are associated with spikes 16% of the time. In other words, a spike in the specific conductance is twice as likely to be associated with a withdrawal event as a non-withdrawal event.

Table 2-1 Cross Tabulation table of conductance vs. withdrawal.

	Conductance Spike	No Conductance Spike
Withdrawal Events		
Frequency	47	90
Percent	13%	25%
Row Percent	34%	66%
Column Percent	57%	32%
No Withdrawal Events		
Frequency	36	192
Percent	10%	53%
Row Percent	16%	84%
Column Percent	43%	68%

2.5.2.2 Effects of recent smaller withdrawal rates

It should be noted that the spikes discussed above largely occurred when withdrawals from the spring were conducted at a rate of 20 mgd (31 cfs). As described in Section 2.3.1, the ability to withdraw spring water at smaller rates was not possible until November 2001, when the return pipe and valve were installed at the spring diversion point. Using these modified facilities, a series of withdrawal experiments were conducted in the spring of 2002, during which smaller amounts of spring water were diverted from the pool to either the reservoir or the flume at the base of the dam.

Water levels and specific conductance values in the spring pool and average daily withdrawals from the spring are plotted for the period from March 9 to July 20, 2002 in Figure 2-27**.** The withdrawal rate from the spring was slightly below the historic withdrawal rate of 31 cfs during April 26 to May 11 and two days in late May. The effects of these higher pumping rates on lowering water levels are apparent. For most of this experimental period, however, withdrawals were considerably smaller. Withdrawal rates near 10 cfs were maintained for a total of 38 days between mid-April and mid-June. The effect of the 10 cfs diversion rate on water levels in the pool were considerably less than withdrawals near the historic rate. In addition, a two-week period of pumping at a rate of 17 cfs began on June 20th. Pumping at this rate lowered water levels in the pool to about 6.7 to 6.9 feet. A brief change to a pumping rate of 11 cfs on June 30th resulted in a quick rebound in water levels.

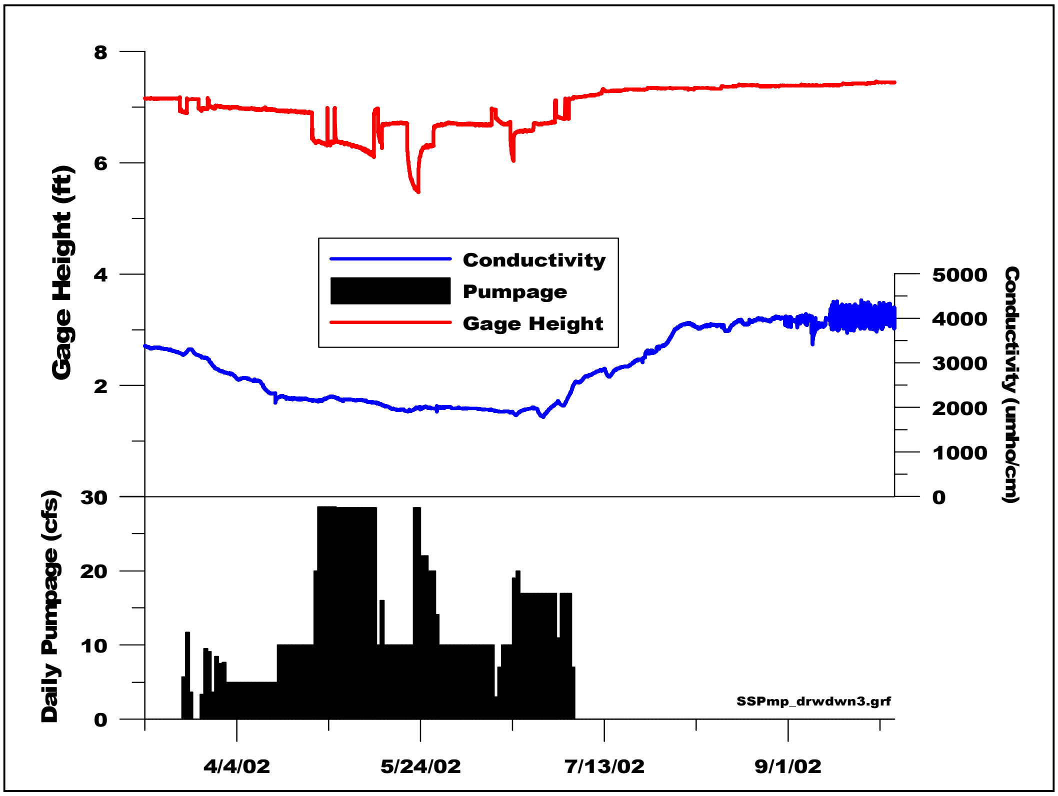


Figure 2-27. Response of water levels and conductance to withdrawals after modification of water diversion facilities at Sulphur Springs, March - September, 2002.

Specific conductance values did not show a clear response to any of the withdrawal rates implemented during the experimental period. Similar to the seasonal trend shown in Figure 2-20, conductance values declined during April to reach minimum values in May and then rebounded in June. Changes in withdrawals rates showed very little effect on this seasonal pattern. This lack of response may have been related to the brief duration of the high pumping events, or that much of the pumping was done at lesser withdrawal rates.

The experimental withdrawals ended on July 5, 2002 when high river flows returned to the spillway at the Hillsborough River dam. Due to an unusually wet year, there was nearly continuous river flow at the Hillsborough River through the remainder of 2002 and all of 2003. Consequently, diversions of spring water to the base of the dam were not necessary to meet minimum flows at the dam. Additional experimental withdrawals to evaluate minimum flows for Sulfur Springs were also not conducted because the river was usually fresh near the spring mouth. Experiments that involved diverting various amounts of water to the base of the dam were conducted during the spring of 2004, during a two-month period when there was no flow from the reservoir. The findings of these flow experiments will be included in the re-evaluation of the minimum flow for the Lower Hillsborough River scheduled for 2005.

2.5.3 Concentrations and trends of other constituents

Summary statistics for water quality parameters measured monthly in the spring pool by the City of Tampa are presented in Table 2-2 for the years 2001-2002. As is characteristic of Florida springs, the water in the spring pool typically has very low levels of color, turbidity, and total suspended solids. Total organic carbon and biochemical oxygen demand (BOD) concentrations are also low. Although water clarity is not measured in the pool, the water generally appears to be very clear, again typical of spring discharge.

The average temperature of the spring water is 25.1 degrees Celsius (77.2 degrees Fahrenheit), with only minor seasonal variation. There are typically low levels of dissolved oxygen in the spring pool; with a median concentration of 1.78 mg/l. Ground water discharges are frequently low in dissolved oxygen, and the occurrence of dissolved oxygen in Sulphur Springs may be partly due to circulation and aeration that occurs within the spring pool. Photosynthesis by attached algae, which can become dense on the sides and bottom of the pool, may also contribute to high dissolved oxygen concentrations that are periodically observed.

Nutrients in the spring pool are generally low, but do indicate some nutrient enrichment. The median nitrate nitrogen concentrations in the pool were 0.25 mg/l during 2001-2002, with an inter-quartile range (25^{th} to 75^{th} percentile) of 0.19 to 0.73 mg/l. The median total nitrogen concentration was 0.72 mg/l, with inter-quartile range of 0.53 to 1.45 mg/l. By comparison, Friedman and Hand (1989) reported a median concentration of 1.2 for total nitrogen in Florida streams, with values of 0.70 and 1.9 mg/l for the 20^{th} and 80^{th} percentiles, respectively. The median total phosphorus concentration for Sulphur Springs (0.1 mg/l) was very similar to the median values reported for Florida streams (0.11 mg/l).

Table 2-2. Sulphur Springs summary statistics for monthly water quality values reported by the City of Tampa for 2001 – 2002 (Uncensored).

Parameter	Units	Minimum	Mean	Maximum	25th Percentile	Median	75th Percentile
Temperature	° C	23.1	25.1	26.3	24.5	25.2	26.2
pH	SU	6.98	7.24	7.78	7.03	7.22	7.7
Dissolved Oxygen	mg/l	0.9	2.6	9.4	1.3	1.8	7.09
Turbidity	NTU	0.2	0.6	3.4	0.3	0.4	2.2
Color	PCU	7	16	40	9	12	37
Total Organic Carbon	mg/l	0.50	2.52	4.40	1.95	2.53	4.33
BOD	mg/l	0.0	2.5	9.7	2.0	2.0	9.4
Total Suspended Solids	mg/l	1	2	16	1	1	7
Specific Conductance	µmhos/cm	1,971	3,093	4,040	2,680	3,079	4,039
Salinity	psu	0.74	1.56	4.42	1.32	1.44	2.67
Total Dissolved Solids	mg/l	1,128	1,834	3,177	1,525	1,849	2,684
Sulfate	mg/l	149	237	293	222	237	293
Chloride	mg/l	412	795	1,060	727	791	1,044
Ammonia-N	mg/l N	0.10	0.17	1.00	0.10	0.10	0.87
NO_3-N	mg/l N	0.05	0.29	0.88	0.19	0.25	0.73
NO_2-N	mg/l N	0.01	0.02	0.06	0.01	0.01	0.05
Kjeldahl-N	mg/l N	0.10	0.36	0.60	0.28	0.40	0.60
Total Nitrogen	mg/l N	0.39	0.73	1.81	0.53	0.72	1.45
Ortho Phosphorus	mg/l P	0.05	0.10	0.50	0.05	0.09	0.26
Total Phosphorus	mg/l P	0.10	0.16	0.50	0.10	0.10	0.40

In the absence of pollution, nutrient levels in the Upper Floridan Aquifer are generally very low (SWFWMD 2001). Since their flows are dominated by groundwater discharge, springs in largely pristine regions would be expected to have lower nutrient concentrations than streams that receive overland runoff. The nutrient concentrations in Sulphur Springs indicate nutrient enrichment of the groundwater sources that contribute to the spring, which is not surprising given the location of the spring in a heavily urbanized/industrialized setting.

Since monthly data collection began in 1991, Sulphur Springs has frequently exceeded drinking water standards for chloride, sulfate, color and TDS. This had been particularly the case for chloride and TDS, reflecting the brackish influence on the spring water chemistry. Violations of potable water standards have been less frequent for sulfate (33% of observations). Receiving water body standards for Class I (potable waters) are listed in Table 2-3. Sulphur Springs periodically exceeds these standards for chloride, TDS, and dissolved oxygen. However, as discussed later in this report, fall of the water over the outlet structure at the spring effectively aerates the spring discharge.

As previously discussed, long-term data for specific conductance indicate the discharge of Sulphur Springs has become increasingly mineralized over the last thirty years. Other water quality parameters in the City of Tampa's monitoring program have shown changes since 1991. Time series plots of parameters measured monthly by the City are included in Appendix A, along with LOESS lines to indicate general trends in changes over time. All parameters were plotted on a linear scale using the entire dataset. In order to accommodate the range of values, some parameters were also plotted on a $\log_{10}$ axis, resulting in the censoring of zero concentration values. In addition, in a few cases the upper limit of data was censured in the log scale portrayal in order to better illustrate the temporal changes in the bulk of data.

Table 2-3. Comparison of monthly water quality data from spring pool (1991-2002) with water quality standards.

	Drinking Water Standard	Water Quality Criteria – Class I	Number Exceedances	Percent of Exceedance
pH	6.5 – 8.5	6.0 – 8.5	0	0%
NO_2-N	1 mg/l		1	1%
NO_3-N	10 mg/l	10 mg/l	0	
Dissolved Oxygen		5.0 mg/l minimum	138	96%
Chloride	250 mg/l	250 mg/l	135	99%
SO_4	250 mg/l		45	33%
Color	15 pcu		59	41%
TDS	250 mg/l	1,000 mg/l	131(1)	97%

(1) Drinking Water Exceedances

These plots indicate that historically color, pH, nutrients and suspended solids were higher and dissolved oxygen concentrations were lower than at present. For several of the parameters, an apparent change in water quality occurred during 1995-1997. For example, Figure 2-28 illustrates the temporal change in nitrate nitrogen and that is typical of several parameters. Nitrate (NO_3-N), nitrite (NO_2-N), total Kjeldahl nitrogen (TKN), total nitrogen (TN), and total suspended solids (TSS) exhibit apparent concentration maxima during this period. By contrast, concentration minima appear in the BOD and turbidity time series. A non-parametric (Kruskal-Wallis) comparison of 1996 or earlier concentrations with 1997 or newer concentrations was completed to determine if the apparent differences before and after was statistically significant at the $p < 0.05$ level. Table 2-4 provides these results and indicates that for most parameters the apparent visual difference is also statistically significant.

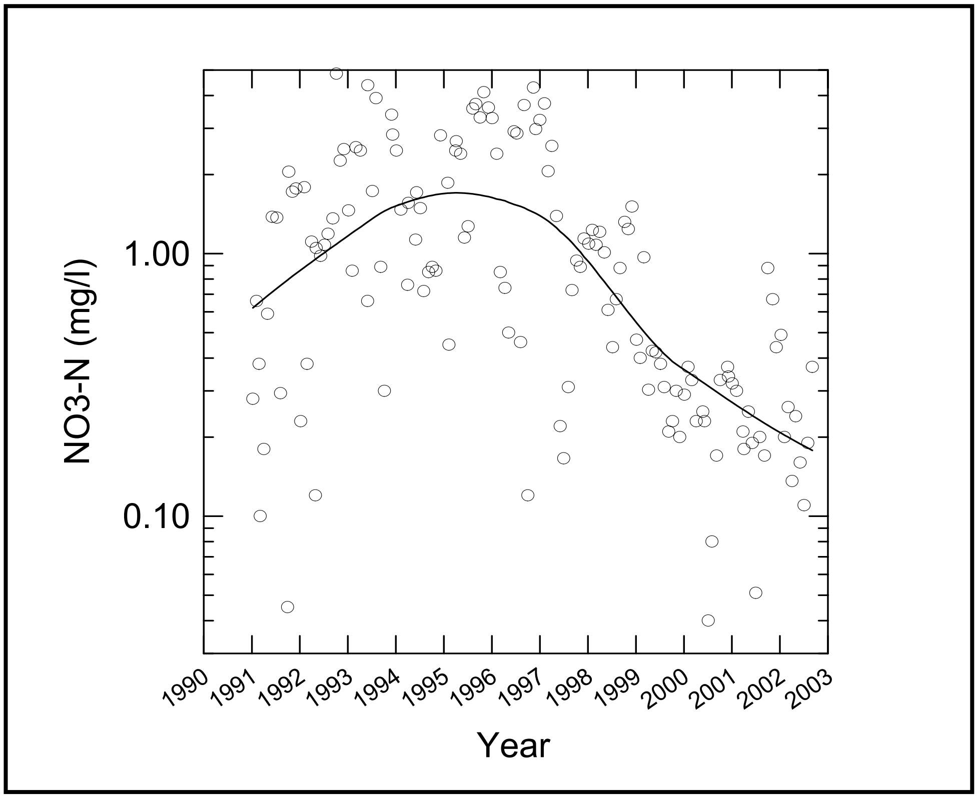


Figure 2-28. Temporal trend in nitrate nitrogen in the Sulphur Springs Pool for 1991-2003 (three values not shown).

A second inflection period appears to have occurred in 1999-2000. This period represents concentration minima for total organic carbon (TOC), color, dissolved oxygen, nitrite and potentially ortho-phosphate phosphorus, although the latter may be an artifact of a lower analytical detection limit. During the same period, turbidity and possibly BOD reached period of record maxima, although the BOD results may also be a detection limit artifact.

Table 2-4. Results of Kruskal-Wallis test of differences between pre-1997 and recent concentrations reported by the City of Tampa for the period 1991-2002. Plus or minus sign indicates the concentration being higher (+) or lower (-) in the more recent period.

Parameter	+/-	Probability	Parameter	+/-	Probability
Ammonia- N	+	$\leq$0.000	Specific Conductance	+	$\leq$0.000
Nitrite-N	-	$\leq$0.000	Chloride	+	$\leq$0.000
Nitrate-N	-	$\leq$0.000	Sulfate	+	0.014
Total Kjeldahl N	ns	0.433	TDS	+	$\leq$0.000
Total N	-	$\leq$0.000	PH	-	$\leq$0.000
Total organic C	-	$\leq$0.000	Color	-	0.001
BOD	+	$\leq$0.000	Diss. Oxygen	ns	0.160
TSS	-	$\leq$0.000	Total P	ns	0.143
Turbidity	-	0.001	OPO_4-P	-	$\leq$0.000
Temperature	+	$\leq$0.000			

It is unclear what may be causing these changes in water quality in the spring. Although the increasing mineralization of the spring is problematic, some of the changes seen in recent years, particularly the decrease in nitrate nitrogen, are beneficial. The groundwater system(s) that contributes to Sulphur Springs is complex, with connected sinks and vents in the region. The periodic closing and opening of sinks in the region may affect not only the quantity of flow from the spring, but also the quality. Investigations to determine strategies to improve the quantity and quality of springflow are now underway by the City of Tampa.

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CHAPTER 3

ECOLOGICAL RESOURCES OF SULPHUR SPRINGS AND THE LOWER HILLSBOROUGH RIVER

3.1 Introduction

Sulphur Springs functions ecologically as a distinct spring run and as an important component of the Lower Hillsborough River system. The plants and animals that inhabit the spring run and the nearby areas of the river are closely related to the flow and water quality of the spring discharge. In that regard, the hydrologic and water quality characteristics of the spring run are described first below, followed by a discussion of the ecological characteristics of the spring run and how the spring influences the water quality and ecology of the Lower Hillsborough River.

3.2 Salinity and water level records in the spring and river system

Historical physical and water quality data for the spring run are scarce. Data collected over the last several years, however, demonstrate how water levels, salinity, and water temperatures in the spring run respond to changes in flow from the spring pool. As part of these studies, a series of continuous recorders were installed by the USGS in the spring and lower river system in the late 1990s. Two recorders that measure temperature and specific conductance every fifteen minutes were installed in the upper spring run and at the spring mouth in May 1999. The recorder in the upper run, which also measures water levels, is located on the channel bottom near the south shore of the run about 100 ft (30 m) upstream of the weir (Figures 2-4 and 2-5.D). The other recorder is located on the channel bottom at the footbridge at the mouth of the run. Specific conductance data from these recorders can be used to calculate approximate salinity values, although actual salinity will be dependent on the ionic composition of the water. For better comparison to the lower river, calculated salinity values in the spring run are discussed below rather than specific conductance.

Recorders were also installed by the USGS at five locations in the Lower Hillsborough River: at the bridge at Rowlett Park Drive (km 15.6); near Hanna's Whirl (km 14.5); Nebraska Avenue (km 13.0); Interstate 275 (km 12.6); and at the mouth of the river at Platt St (Figure 2.1). The recorder with the longest period of record is at Rowlett Park Drive, where the current series of records began in 1996. Data collection at the remaining sites began between 1999 and 2002. Water level, salinity (calculated from specific conductance) and water temperature data from these recorders are discussed in various sections of this report.

3.3 Tidal water level fluctuations in the spring run

Water levels in Sulphur Springs Run show fluctuations in response to tides in the Lower Hillsborough River. The river near the spring is strongly tidal, with a mean daily amplitude in water levels of about 1.0 meters at the recorder near Nebraska Ave. (USGS station Hillsborough River at Sulphur Springs). Stage duration curves of water levels at this site and the recorder in the spring run are presented in Figure 3-1. The curves are very similar above the median water level for the spring run, which is approximately 0.7 ft. NGVD. Below that level, however, the curves diverge and greater fractions of values in the river are below 0.0 feet, extending to a minimum value of –2.7 ft. These curves reflect that at higher tide stages water levels in the spring run closely track water levels in the river, but at low tide stages water levels in the river fall to lower levels than in the run.

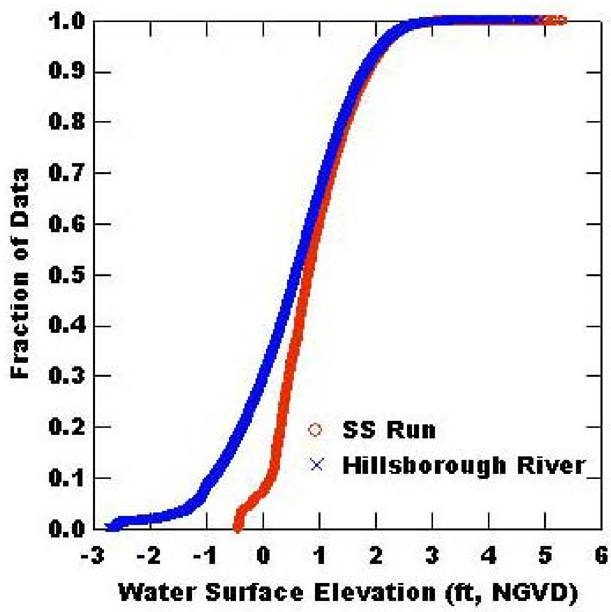

Figure 3-1. Stage duration curves of water levels in the upper spring run and the Hillsborough River near the mouth of the spring.

This relationship is also shown in a time series plot of water levels for the spring run and river for one week in January 2001 (Figure 3-2). Springflow rates during this period were at 23 to 25 cfs and not altered by withdrawals from the spring pool (normal flows). At higher tides, water levels in the spring run and river were nearly the same, as water levels in the river created a backwater condition that controlled water levels in the run. On falling tides, however, water levels in the spring run stabilized around 0.25 feet while levels in the river fell to near – 1 feet. These differences are due to the effect of the weir, which tends to retain water in the upper spring run due to the hydraulic constriction of the weir opening.

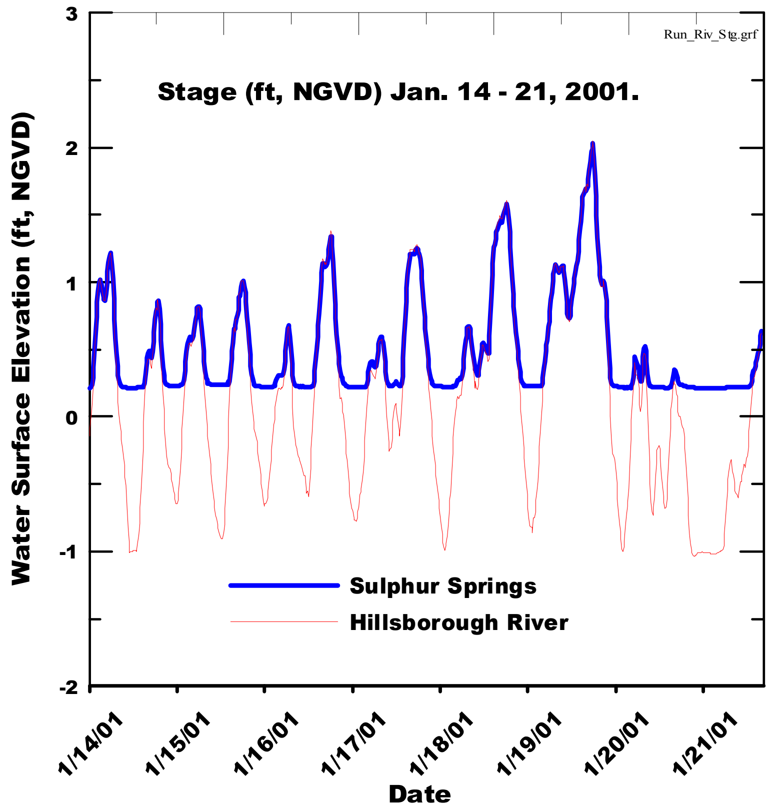

Figure 3-2. Time series graph of water levels in upper spring run and river near the moth of the spring during a period of normal flow from the spring pool (January 14 – 21, 2001).

By reducing flow from the spring, withdrawals can affect the elevation of water in the spring run at low tides. The stage duration curve for the spring run in Figure 3-1 was based on all flows recorded from the spring pool since May 1999. Two stage duration curves for the spring run are overlain in Figure 3-3 for periods when there are very low flows (<5 cfs) and normal flows (>20 cfs) from the spring pool. The curves are similar above 0.6 feet, but diverge at lower water surface elevations. During normal flows, water levels in the spring rarely go below 0.3 feet; whereas during low flows, approximately 25 percent of water levels drop are less than 0.0 feet. The opening in the weir restricts discharge from the upper spring run, and at low tide, acts to holds water levels higher as flows from the spring pool increase. Compared to normal flows (Figure 3-2), Figure 3-4 shows that low-tide water levels in the run fall to lower values during of periods of low flow (3.5 cfs) from the spring pool. The plots presented in Figures 3-2 and 3-4 were generated for periods when there were no flows from the Hillsborough River Reservoir to remove the confounding effect of high flows in the river on water levels in the spring run.

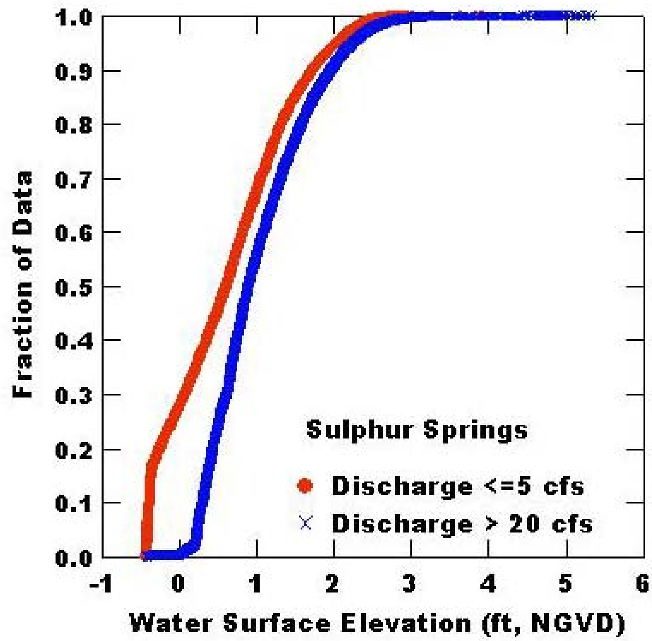

Figure 3-3. Stage duration curves for water levels in the upper spring run for periods of normal flow (> 20 cfs) and low flow (<5 cfs).

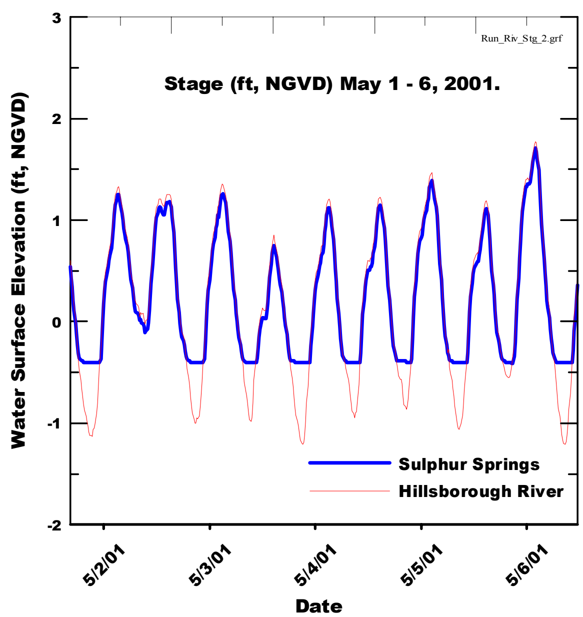

Figure 3-4. Time series graph of water levels in upper spring run and river near the mouth of the spring during a period of low flow (3.5 cfs) from spring pool (May 1- May 6, 2001).

3.4 Salinity in the spring run and response to withdrawals from the spring pool.

Average daily salinity values for the recorders in the upper spring run and the spring mouth are plotted over daily withdrawals from the spring pool for 1999 – 2002 in Figures 3-5 and 3-6. When there were prolonged periods of no pumping from the spring, salinity values in the spring run were similar to values in the spring pool, generally fluctuating in a range of 1 to 3 ppt (Figure 3-5). The higher values in this range (2-3 ppt) occurred during the latter part of 1999 and January 2000, when the pool elevation was lowered by gate operation. As described in Section 2.2, lowering the pool elevation increased the specific conductance of the spring discharge.

Withdrawals from the spring pool resulted in large increases in salinity in the spring run. During a six-month period of extensive withdrawals in the year 2000, average daily salinity values in the run frequently exceeded 10 ppt, reaching a maximum value near 17 ppt. Salinity values also showed a close relationship with pumpage in 2001, but the spikes in salinity were not as great as in 2000, typically ranging from 4 to 8 ppt.

These increases in salinity represent the movement of high salinity water from the Hillsborough River into the spring run. As previously discussed, all withdrawals from the spring prior to November 2001 were at a rate of 31 cfs (20 mgd), a rate that reduces flow from the pool to zero or very low values. When this occurs, high salinity waters from the Hillsborough River migrate upstream of the weir into the upper spring run.

The recorder at the spring mouth showed a similar relationship with pumpage (Figure 3-6). During periods of no pumpage, salinity values at the spring mouth were similar to the spring pool, indicating that normal flow from the spring keeps this site flushed by spring water most of the time. However, large increases in salinity were observed at the spring mouth during periods of withdrawals. The peaks in salinity at the mouth were higher than in the spring run, especially in 2001. Also, salinity at the mouth did not drop as rapidly as in the run when flow from the spring resumed to normal rates of flow.

The results from these two recorders are supported by series of vertical salinity profiles taken in the spring run. Biologists from the University of Florida (UF) took vertical profiles of salinity in the spring run on seven dates between May 2000 and November 3003 (Allen et al. 2001, Allen, unpublished data). Two of these dates (May 26 and July 14, 2000) were during periods of prolonged withdrawals that resulted in zero or very low flows (1 cfs) from the spring pool. The mean salinity values for all stations in the run on these two dates were 13.2 and 11.6 ppt, respectively. Salinity was high throughout the spring run during these events, as mean salinity values for stations near the mouth were only about 1.5 to 2.5 ppt higher than upstream areas (Table 7 in Allen et al. 2001). Overall, mean surface salinity values were about 4 to 5 ppt lower than mean bottom salinity values on these dates, indicating there was density stratification in the spring run (Table 3-1). During the period of no flow (May 26, 2000), this may have resulted from low rates of springflow seeping through the outlet structure, which layered over more saline water that entered the run from the lower Hillsborough River.

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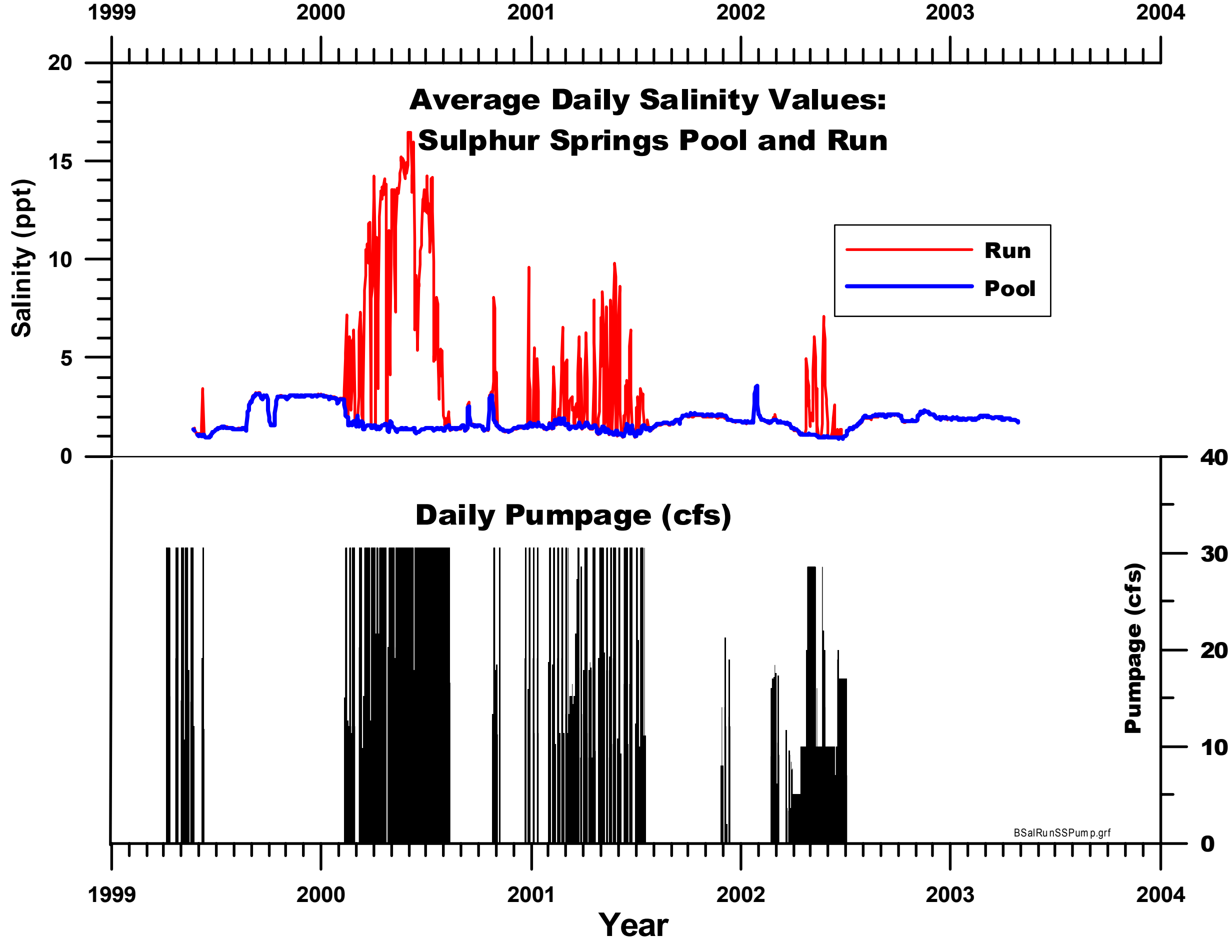

Figure 3-5. Average daily salinity values for the spring pool and the data recorder in the upper spring run over pumpage from the pool for 1999 – 2002.

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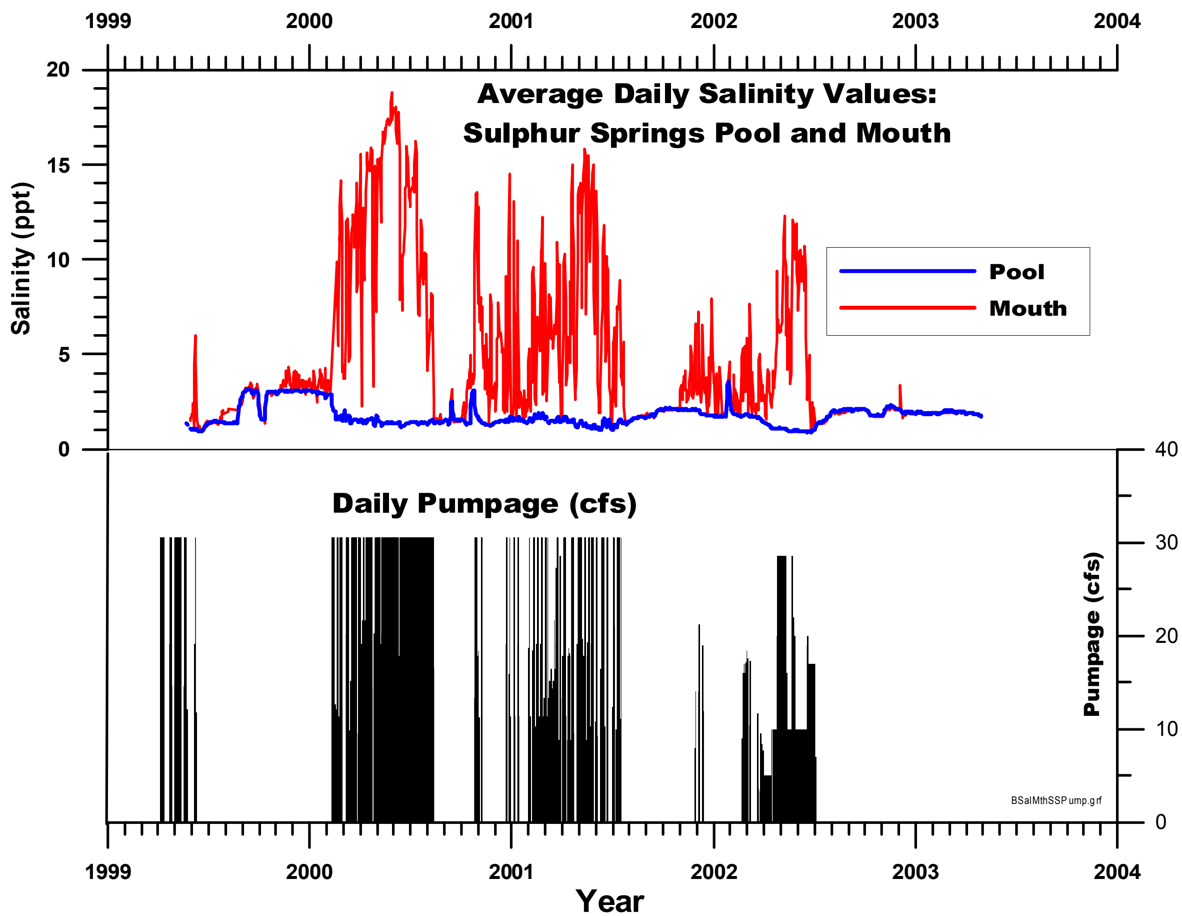

Figure 3-6. Average daily salinity values for the spring pool and the data recorder at the spring mouth over pumpage from the pool for 1999 – 2002.

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Table 3-1 Summary statistics of vertical profile measurements taken in the upper spring run by the University of Florida and the SWFWMD.

Date	Spring Flow (cfs)	n all depths	Mean salinty + 1 s.d. (all depths)	Mean surface salinity	Mean bottom salinity	Mean DO + 1 s.d. (all depths)	Mean surface DO	Mean bottom DO	% DO values <2 mg/L	% DO values 2 - 4 mg/L
UF										
26-May-00	0	46	13.1 + 1.6	10.7	14.8	4.0 + 1.0	4.3	3.6	0	63
14-Jul-00	1	62	11.6 + 2.0	9	14	1.5 + 0.3	2	0.9	81	19
29-Sep-00	29	52	1.5 + 0.2	1.4	1.6	5.1 + 0.6	5.2	4.9	0	4
09-Jul-01	15	45	1.6 + 0.3	1.6	1.7	4.5 + 0.4	4.7	4.4	0	2
01-Nov-01	32	54	2.1 + 0.0	2.1	2.1	4.7 + 0.2	4.8	4.7	0	0
22-Nov-02	31	50	2.3 + 0.0	2.3	2.3	5.9 + 0.6	6.1	5.7	0	0
11-Nov-03	34	53	2.1 + 0.0	1.9	2.1	4.4 + 0.3	5.2	3.8	0	8
SWFWMD										
26-Nov-01	31	32	2.3 + 0.3	2.3	2.3	5.3 + 0.2	5.3	5.3	0	0
30-Nov-01	23	51	2.5 + 0.8	2.4	2.6	7.0 + 0.6	7.4	6.5	0	0
03-Dec-01	31	25	2.1 + 0.0	2.1	2.1	6.5 + 0.9	6.5	6.4	0	0
06-Dec-01	19	28	2.1 + 0.0	2.1	2.1	9.3 + 0.9	9.4	9.2	0	0
10-Dec-01	31	43	1.9 + 0.0	1.9	1.9	6.5 + 0.5	6.8	6.3	0	0
13-Dec-01	19	47	2.6 + 1.7	2.4	2.8	8.8 + 0.8	9.3	8.3	0	0
17-Dec-01	32	38	1.9 + 0.0	1.9	1.9	5.5 + 0.3	5.6	5.4	0	0
05-Mar-02	25	6	1.9 + 0.0	1.9	1.9	5.8 + 0.7	5.8	5.8	0	0
08-Mar-02	16	40	3.2 + 3.8	3	3.5	7.8 + 1.1	7.8	7.7	0	0
12-Jun-02	13	22	10.3 + 3.2	4.5	14.7	7.1+ 2.3	8.4	5.9	0	9
20-Jun-02	2.5	49	1.5 + 1.1	1.1	1.9	7.4 + 2.1	8.4	6.4	6	2

In contrast, mean salinity values from profiles taken during periods of normal flow (no withdrawal) ranged from 1.5 to 2.3 ppt, and there was very little, if any, difference between surface and bottom salinity values (Allen et al. 2001). The UF sample on July 9, 2001, when average daily spring flow value was 15 cfs, was an unusual case. Extensive withdrawals occurred from the spring 3 to 8 days prior, but flows of 18 to 20 cfs resumed on July 7. Records show that withdrawals began again on July 9, but after the vertical profiles had been measured on that day.

The salinity increases observed by UF all occurred when withdrawals from the spring were at a rate of 20 mgd (31 cfs). Starting in late November 2001, the District began a series of tests that involved lesser rates of withdrawal from the spring. These intermediate withdrawal tests are represented by dates after November, 2001 with springflow rates between 13 and 19 cfs (Table 3-1). These tests were made possible by the changes to the diversion systems that were completed at that time. Figure 3-5 shows that many of these lesser pumping events did not result in an apparent increase in average daily salinity at the USGS recorder in the upper spring run, while other pumping events resulted in salinity increases of 4 to 5 ppt. Vertical profile measurements in the spring run conducted as part of these tests also showed that some pumping events caused salinity increases while others did not (Table 3-1). The findings of these intermediate flow tests are discussed in more detail in Chapter 5 (Results of the Minimum Flow Analysis).

3.5 Dissolved oxygen concentrations in the spring run and response to withdrawals from the spring pool.

Dissolved Oxygen (DO) data for the spring run are limited to the vertical profile measurements taken by UF and District staff. As described in Section 2.5.3, the ground-water discharge to the spring pool is typically not well oxygenated. The median DO value for grab samples from the pool is 1.78 mg/l (Table 2-2). During periods of normal flow, however, waters in the spring run are well oxygenated, indicating that the fall over the outlet structure and turbulence in the plunge pool is effective at aerating the spring water. Summary statistics for DO profiles measured by UF are included in Table 3-1. During periods of normal spring flow, mean DO values for surface and bottom waters ranged between 4.4 and 6.1 mg/l. Out of a combined total of 240 salinity readings on these dates, only 6 values were slightly below 4 mg/l.

Low DO values were observed by UF during withdrawal events in May and July 2000, when discharge from the pool was reduced to zero or very low rates of flow (1 cfs). Sixty-three percent of the DO values were below 4 mg/l during the May 26 sampling, but none were below 2 mg/l. DO values were considerably lower during the July 14 sampling, as 81% of the DO values were less than 2 mg/l, with a mean bottom DO value of 0.9 mg/l. These bottom DO values may have been related to density stratification in the run, as evidenced by the difference between mean surface and bottom salinity values (Table 3-1).

DO concentrations in vertical profiles measured by the District in 2001 and 2002 are also summarized in Table 3-1. For the first nine sampling dates, when flows ranged between 16 and 32 cfs, average DO values for all depths ranged between 5.3 and 9.2 mg/l and there were no DO readings below 4 mg/l. On June 12, 2002, when flows were 13 cfs, nine percent of the DO readings were below 4 mg/l. There was significant density stratification on this date, as mean surface and bottom water salinity values differed by 10.2 ppt at the time of sampling. Vertical profiles were also taken by the District when withdrawals were taken from the spring at a rate of 31 cfs (June 20, 2002). Six percent of the DO values were below 2 mg/l, while two percent were between 2 and 4 mg/l.

In general, these data indicate the DO concentrations in the spring run are well oxygenated during times of normal flow from the spring pool. The occurrence of hypoxia (low oxygen concentrations) differed between periods when withdrawals reduced the rate of flow to zero or very low values. The occurrence of hypoxia may be related to the duration of low flows and the degree that the water column in the spring run becomes stratified due to differences in surface and bottom salinity. The quantities of flow needed to maintain well-mixed, low salinity water in the spring run are discussed in Chapter 5. In all likelihood, achieving this goal would prevent hypoxia from occurring in the spring run.

3.6 Other water quality characteristics of the spring run

Water column averages for pH in the profiles measured by the District ranged between 6.9 and 7.6, reflecting the well buffered, groundwater origin of the spring flow. There was however, a negative correlation (r = -0.57, p <0.001) between pH and flow from the spring. Average pH values from the stations measured by the District are plotted against flow in Figure 3-7. The pH values were generally higher and displayed more scatter at low flows. This may be partly due to the influence of river water in the spring at very low flows, or the effects of photosynthesis in the spring run that becomes more apparent as the residence time of the water in the run increases.

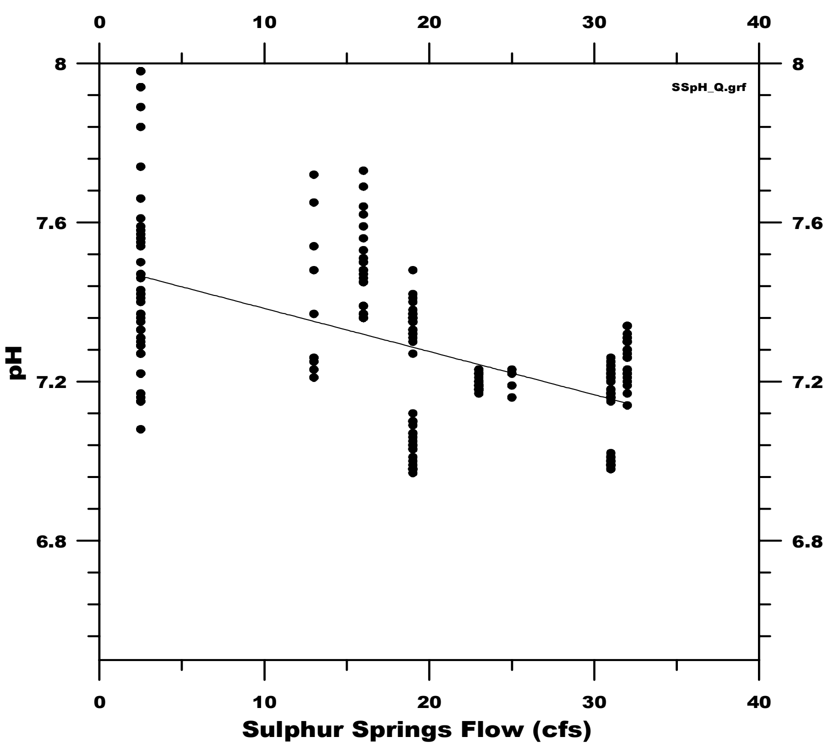

Figure 3-7. Average water column pH values for stations in the spring run sampled by the SWFWMD between November 21, 2001 and June 20, 2002.

As discussed in Section 2.5.3, the temperature of discharge from Sulphur Spring pool shows only minor seasonal variations. Data from the vertical profiles showed some seasonal variation, with average temperature values for all stations in the run ranging from 24.4^{o} C on March 4, to 28.5^{o} C on June 12, 2002. These results also were likely affected by periodic incursion of river water into the run at low flows. Greater elaboration concerning temperature is provided at the end of this chapter with regard to use of the spring run and river by the Florida Manatees.

Other than vertical profile measurements, no other water quality data were collected in the spring run. However, it is probably reasonable to conclude that under conditions of normal flow (no withdrawals), the concentrations of most parameters in the spring run (e.g. nutrients, BOD and suspended solids) are similar to the spring pool. The volume of the spring run is relatively small, and under conditions of even intermediate rates of flow, the water in the run is replaced by spring water many times a day. Under conditions of no flow or very low rates of flow, it is likely that the concentrations of water chemistry constituents are affected by incursions of water from the Lower Hillsborough River, although no data were collected to support this hypothesis.

3.7 Biological habitats and communities in the spring run

3.7.1 Benthic habitats

As discussed in Section 2.1, the spring run is fairly shallow, with most water depths less than two feet deep at mean tide. There are virtually no snags or aquatic macrophytes in the run. Bottom habitats reported by the University of Florida during 2000 consisted of bare sediments and sediments covered by filamentous algae (Allen et al. 2001). Sediments were classified to a macro-level scale using the Wentworth classification scheme (McMahon et al. 1996). The sediments were predominantly sand, with much lesser fractions of slit, shell, pebble and rock.

The algae that were common on the sediments were comprised of the genera *Melosira*, a diatom that can form filamentous aggregations, and filamentous green algae of the genus *Cladorphoa*. Attached and floating mats of filamentous algae were widely distributed in the spring run during the no flow periods of 2000 and 2001. The return of high flows in 2002 and 2003 reduced the abundance of these algal mats, as evidenced by percent coverage values of less than 6 percent at stations as measured by UF biologists in 2003 (SWFWMD, unpublished data).

3.7.2 Shoreline vegetation

The shoreline of Sulphur Springs is hardened by a retaining wall, but shoreline plants have become established waterward of the wall over approximately three-fourths of the northern shore of the upper spring run (Figure 2-5C). Plants that are common along this reach include leatherfern (*Acrostichum danaeifolium*), cattail (*Typha domingensis*), elderberry (*Sambucus canadensis*), and brazilian pepper (*Schinus terebinthefolius*). Other species that occur along the northern shore of the upper run include groundsel tree (*Baccharis halimifolia*), string lily (*Crinum americanum*), peppervine (*Ampelopsis arborea*), rosary pea (*Arbrus precatorius*), softstem bulrush (*Scirpus tabernaemontani*) and giant bulrush (*Scripus californicus*). There are no shoreline plants established along the southern bank of the upper spring run, as a retaining wall reaches to the water's edge.

The banks of the lower spring run (below the weir) are steep with scattered concrete rubble**.** Vegetation along this reach of the run is dominated by leatherfern, brazilian pepper, with some string-lilly, Ceaser weed (Urena lobata) and climbing aster (*Aster caroliniana*). With the exception of brazilian pepper, the plants along both the upper and lower spring run are native wetland species that are common along the tidal freshwater and oligohaline reaches of southwest Florida rivers (Clewell et al. 2000).

3.7.3 Benthic macroinvertebrates

3.7.3.1 1997 Macroinvertebrate survey

Historic data for macroinvertebrates in the Sulphur Springs system are limited, but informative. On November 19, 1997, staff from SWFWMD and FDEP did a qualitative sampling of the benthic macroinvertebrates in Sulphur Springs run. Macroinvertebrates were sampled by sweeps of a D-frame dip net (600 micron mesh) from unvegetated portions of the channel bottom, shoreline plant communities, and small woody snags in the spring run. Flow from the spring pool was at a rate of 41 cfs, and as described in Section 2.3, this collection occurred during a several-year period when withdrawals were limited to only a few days in April of 1997. On the day of sampling, dissolved oxygen concentrations measured at one profile in the middle of the spring run were 5.2 mg/l; pH was 6.94; and surface and bottom salinity values were near 1.6 ppt. The collection occurred during a high flow event from the Hillsborough River Reservoir and the lower Hillsborough River was fresh near the mouth of the spring run.

Taxonomic identifications were performed by staff from the FDEP. A list of macroinvertebrate taxa collected from the spring run is provided in Appendix B, along with species that were collected in later years by the Florida Fish and Wildlife Conservation Commission. The invertebrate species collected in 1997 included freshwater taxa and a number of euryhaline species common to tidal creeks and coastal springs. The crustacean fauna was characterized by amphipods, isopods, decapods, a cumacean and a mysid species that are common to tidal creeks and other low salinity habitats. Though not quantified, the amphipods and isopods seemed particularly abundant. Although these species are most common in low salinity waters, most can tolerate and are frequently found in tidal fresh waters (e.g. *Taphromysis bowmani*, *Rhithropanopeus harrisii*, *Almyracuma* sp). One euryhaline polychaete (*Laeonereisculveri culveri*) was found. It is assumed that brackish water species enter the spring run from the river during the dry season.

A number of freshwater species were found in the spring run. For the most part, these are species that are tolerant of a wide array of environmental conditions (e.g. the collected dipteran and oligochaete species). The mayfly that was collected (*Callibaetis floridanus*) is common in slightly brackish coastal springs and a wide array of fresh waters (Berner and Pescador 1988). Similarly, the damselflies (Zygoptera) that were collected are widely distributed, including documented occurrences in brackish waters for *Enallagma civile,* and *Ischnura ramburii* (Dunkel 1990, Westfall and May 1996).

Five species of gastropods (snails) were collected in the spring run, including a widely distributed exotic species (*Melanoides tuberculata*) and three predominantly freshwater native species (*Amnicola dalli johnsoni, Elimia floridensis, and Planorbella scalaris*). Another collected snail (*Pyrogophorus platytrachis*) is common in fresh and brackish waters (Thompson, 1984). In sum, the macroinvertebrate community of Sulphur Springs Run in 1997 appeared comprised of a mixture of species that are common to fresh waters and brackish water species that are common in oligohaline tidal creeks.

3.7.3.2 Invertebrate collections from 2000 to 2003

In 2000, the District contracted UF and Florida Fish and Wildlife Conservation Commission (FWC) in a joint study to make quantitative collections of fishes (by UF) and macroinvertebrates (by FWC) in the Sulphur Springs Run. The results of collections during year are described in a combined report by those investigators (Allen et al. 2001). Benthic macroinvertebrates also were collected from the spring run on three dates between 2001 and 2003 by the FWC, but these data have not yet been summarized in a final report by that agency. However, results from those collections have been made available to the District and are briefly summarized in this report.

Data collection from the spring run by the FWC has included both qualitative and quantitative samples. Quantitative samples were collected on three dates (May 25, 2000; November 8, 2001; and December 9, 2003). Qualitative collections were also made on these dates and July 8, 2001, for a total of five qualitative collections counting the 1997 SWFWMD/FDEP survey. The results of these qualitative collections are described first, followed by a discussion of the quantitative samples.

3.7.3.3 Results of FWC qualitative samples

The qualitative sampling program was stratified by habitat type. All habitats that were subjectively judged to account for greater than five percent of the total area of the spring run were sampled. Those habitats sampled included open sand sediments, benthic filamentous algae mats, overhanging vegetation (primarily *Acrostichum daneafolium*), emergent vegetation (*Typha* and *Panicum*), wood debris (snags), organic debris packs, and concrete sea walls. Samples were obtained from all habitats sampled using 900 micron mesh dip nets. A sample was obtained by vigorously deploying the net in approximately one square meter of the sampled habitat. In addition to the dip net technique, hand picking was also employed in the sampling of wood debris and concrete structure. One sample from each areally dominant habitat was obtained in each of the three study segments in the spring run during each sampling event.

Samples were rinsed with water and preserved in the field with 95 percent ethanol. Small sample portions were placed in a white photo-processing pan and examined using a cyclops lamp. Aquatic invertebrates were removed and placed in labeled vials. After inspection using the cyclops lamp, one-fourth of each sample (by weight) was examined under a stereo-dissecting microscope (magnifications from 6.3 to 40.0 x) in order to ensure removal of smaller organisms. Removed organisms were identified to the lowest taxonomic level possible, given the maturity and condition of the specimen. Separate species lists were compiled for each qualitative collection. Organisms from the July 2001 and December 2003 qualitative samples were enumerated, allowing for compilation of percent composition tables for these two collections.

Taxonomic presence/absence data from the FWC collections are listed in Appendix B along with the taxa recorded in the 1997 SWFWMD/DEP survey. Taxa were identified to the lowest practical taxonomic level, which was to species in most cases. Also listed is a general characterization of the flow conditions from the spring preceding the each sampling event. As previously discussed, the 1997 collection by SWFWMD/FDEP was after a prolonged period of normal flow from the spring. The next two collections (by FWC) corresponded to brackish conditions in the spring run that resulted from the extensive withdrawals and very low flows from the spring pool that occurred during 2000-2001 drought. The May 2000 collection was during a no-flow period when salinity in the spring run fluctuated between 10 and 16 ppt. (Figure 3-5). Withdrawals from the spring pool continued into 2001, and flows prior to the July 2001 collection were very low (3-10 cfs), with average daily salinity values in the run fluctuating as high as 5 – 8 ppt. The remaining two samples were collected during normal flow conditions when there had been no withdrawals from the spring pool. The November 2001 collection occurred after four months of normal flow. The December 2003 collection occurred after eighteen months of normal flow.

There were distinct shifts in the taxonomic composition of the macroinvertebrate community that coincided with changes in the spring flow. Presence/absence records in

Appendix B are color coded to denote combinations of dates when various taxa were recorded. Twelve taxa shown in orange were recorded by SWFWMD/DEP in 1997 but not recorded again in subsequent collections. Notable in this group are three species of freshwater snails (Gastropoda – *Amnicola dalli johnsonii*, *Planobella scalaris*, and *Elimia floridensis*). A bivalve mollusk found in 1997 that is more euryhaline (*Modiolus modiolus squamosus*) was also not recorded in subsequent collections from the spring run.

All collections by the FWC beginning in 2000 have found dense populations of the exotic snail *Tarebia granifera. Tarebia* is native to southeast Asia and was introduced to Florida in the 1930s via the aquarium industry. It can thrive in both fresh and brackish waters, and is abundant in some streams and springs in Florida. In many cases it can outcompete native snail species and achieve high densities. FDEP and SWFWMD staff do not recall observing an overabundant snail in the spring run during 1997, and it is believed the reported absence of this snail in 1997 was not the result of a misidentification. It is not certain when *Tarebia* colonized Sulphur Springs Run, but it appeared to thrive in the high salinity conditions observed during the 2000 drought. The disappearance of freshwater snails recorded in 1997 could have resulted from the high salinity that occurred during the 2000 drought. However, the proliferation of *Tarebia* may have contributed to their disappearance, and the inability of these species and the euryhaline *Modiolus modiolus squamosus* to recolonize the spring with the return of prolonged normal flows in 2002 and 2003.

Other species that were limited to the 1997 sample included an oligochaete *(Dero obtusa*), an amphipod (*Gammarus tigrinus*), a cumacean (*Alymyracuma sp*), a mysid (*Taphromysis bomanii*), and a tanaid (*Tanais sp*.). These are euryhaline species that are common in tidal creeks. Three insects that were restricted to the 1997 collection (*Endotribelos hesperium, Polypedilium scalaenum*, and *Engalla civille*) are common in fresh water, but are also tolerant of low salinity.

The ten taxa shown in yellow showed an interesting pattern; in that they were present in 1997, absent during the high salinity collections of May 2000 and July 2001, and reoccurred in the last two samples that corresponded to the return of normal flows. These species are also common in fresh and low salinity waters. Given the level of effort by the FWC, this observed pattern of disappearance and reoccurrence in the spring run is probably real and not a sampling artifact. Furthermore, it is likely that the high salinity values that occurred during the drought and the return to low salinity values in the final two samples, were a factor in this pattern. It is unclear why some species have been able to recolonize the spring while other taxa have not.

Sixteen taxa highlighted in red first appeared in the high salinity samples of May 2000 and July 2001, but were not recorded in the final two collections. Two polychaetes in this group (*Neanthes succinea* and *Stenoneries martini*) are common in west-central Florida estuaries, and salinity increases during the drought probably played a role in their occurrence in the spring run. This contrasts with the polychaete *Laeonereis culveri*, which was present in 1997. *Laeonereis* is also euryhaline, but often found in low salinity waters. Other species that occurred only during the drought are species that are tolerant of low salinity (*Chaetogaster diastrophus*, *Dero pectinata*, *Tropisternus blatchleyi*, *Thienemanniella* sp., and members of the dipteran families Dolichopodidae, Ephydridae and Stratimyidae). Some of these taxa are common in non-flowing waters and can be associated with vegetation, such as mats of filamentous algae. Reductions in current velocities and the proliferation of algal mats in the spring run during the drought may have been a factor contributing to the presence of these taxa. Factors related to current velocity and physical habitat may also have been factors in their disappearance with return of normal flow and reduction of algal mats in the last two collections.

Possibly the most striking finding in the presence/absence data are the large number of taxa which colonized the spring upon the return to normal flows. A total of thirty-one taxa were first recorded in the final two collections by the FWC. Eight taxa highlighted in blue were first recorded in November 2001 after four months or normal flow, while another twenty-three taxa highlighted in green were first recorded in December 2003 after eighteen months of normal flow. The qualitative sampling effort and methods employed by FWC were more rigorous than the methods employed during brief SWFWMD/FDEP survey, so it is possible that some of the taxa recorded in the final two collections were also present in 1997. However, given the consistency of the FWC methods, it is more certain that these species were truly absent from the high salinity collections during the 2000-2001 drought. The total number of taxa recorded in the final drought collection (July 2001) was 37, compared to 60 taxa recorded on December 2003, demonstrating a strong rebound in species richness with the return to normal flows from the spring pool.

A number of the taxa that first appeared in the final two collections are commonly abundant in fresh water, but also are found in low salinity tidal creeks. These taxa include *Hydra sp*., *Prostoma sp*., *Apedilium* sp., *Microvelia* sp., *Pachydiplax longipennis,* members of the annelid family Naididae and members of the Zygoptera (damselflies) genera *Enallagma* and *Ischnura*. The pelycpod *Cyrenoididae floridana* is the most estuarine taxon first collected in the last two samples, as it is common in Tampa Bay, but almost never found in true fresh water (<0.5 ppt).

A number of other taxa that were first collected in final two collections are primarily freshwater species. These include two snail species in the family Ancylidae, the dragonfly (Anisoptera) *Epitheca princeps regina*, the damselfly (Zygoptera) *Argia sedula,* the hemipteran species *Pelicoris femoratus*, and a number of species in the dipteran families Chironomidae and Chironominae. The freshwater grass shrimp *Palaemonetes paludosus* first appeared in December 2003, after prolonged normal flow from the spring pool and flow from the Hillsborough River dam.

Periodic flows from the dam and the expansion of freshwater habitat in the lower Hillsborough River aids the colonization of Sulphur Springs Run by freshwater organisms. Although species that have aerial stages, such as flying aquatic insects, do not require contiguous fresh water for colonization, the close proximity of freshwater habitat in the lower river probably affects the rate of colonization by these species. Although colonization by organisms that are aquatic throughout their life cycle can occur through various means (e.g. bird droppings), the availability of freshwater habitat in the river near the mouth of the spring during seasonal high flows from the reservoir allows the colonization of the spring run by these taxa.

The final group of taxa recorded during the qualitative collections were those that occurred during both normal flow and drought conditions. This group included 31 taxa, which are denoted by not being shaded in Appendix B. This group is comprised of widely distributed euryhaline species that generally do not have narrow habitat or salinity requirements. These species were able to survive in the spring run during times of normal flow, when there was stable low salinity and strong downstream currents on outgoing tides, and also during the drought when there was high salinity in the spring run and slower current velocities.

This general category contained taxa that were identified only to higher taxonomic levels (e.g. Nematoda, Hirundenea) and others that were identified to species . The criterion for inclusion in this group was broad - a taxon had only to be collected in at least one drought collection and one normal flow collection. Some of these taxa appeared in only two or three collections and may no longer be in the spring run, as they were not collected in 2003. Other taxa were present during all or nearly all of the collections in the study. These common taxa included nematodes, the amphipod *Grandidierella bonnieroides*, the brackish water grass shrimp *Palemonetes pugio*, the isopod *Munna reyonoldsi*, the pelcypod *Mytilopsis leucophaeata*, and three snails *Pygrophorus platyachis*, *Melanoides* sp., and *Tarebia granifera*. As previously discussed, the exotic snail *Tarebia grainifera* is the most abundant organism in the spring run, and likely invaded the spring run between the 1997 and 2000 collections. *Melaoides* sp. are also exotic snails that are tolerant of a wide range of environmental conditions, including fresh and brackish salinities. *Pyrogophorus platyrachis* is also common in both fresh and brackish waters. The taxa in this final group are probably the least sensitive to the flow management of the spring.

3.7.3.4 Percent composition in various habitats

For two of the qualitative collections the FWC enumerated the catch and estimated percent composition of all taxa in four habitats in the spring run. These two collection dates corresponded to one sample from the drought (July 16, 2001) and one after prolonged normal flows (December 09, 2003). Habitats in the spring run for which percent composition was estimated in the November 2001 collection were open sand, filamentous algae, shoreline vegetation, and concrete structure. The habitats for which percent composition was reported were somewhat different for the 2003 sample, comprised of open sand, filamentous algae, shoreline vegetation, cattails, organic debris packs, and snags. Although percent composition values do not provide abundance estimates in number per square meter, they do give perspective on the relative dominance of different taxa in the sampled habitats.

Percent composition values for the two dates are included as Appendices C and D. Shoreline vegetation supported the most taxa of any habitat: 27 taxa in the 2001 collection and 33 taxa in the 2003 collection. Cattail habitat had 27 taxa in the 2003 collection, 13 of which were not recorded in the shoreline vegetation category. Since cattails are shoreline plants, a total of 46 taxa were recorded in combined shoreline vegetation in the 2003 collection. Cattails were also sampled in 2001 but not listed as a separate category. Thus, the shoreline vegetation category exhibited a large increase in species richness with the return to normal flows. In 2001 the percent composition of the shoreline vegetation was dominated by *Tarebia granifera* (41.5%), snails of the family Hydrobiidae (34.8%) and oligochaetes (13.6%), primarily of the family Naididae. In 2003 the shoreline vegetation community had much less *Tarebia* (6.4%) and oligochaetes (0.4%), but a higher percent compositions of isopods (38%), Zygoptera (5.4%) and Tricoptera (16.7%) compared to 2001.

Bare sand and filamentous algae had 8 and 10 taxa, respectively, in the 2001 collection. The number of taxa in these habitats increased markedly in the 2003 collection, with 25 taxa reported for bare sand and 27 taxa for filamentous algae. Qualitative sweeps from concrete structures were made in 2001 with 10 taxa reported. This habitat was not sampled in 2003. Snags (submersed wood) and organic debris packs in the channel were sampled in 2003, although the snag habitat was very limited. *Tarebia* continued to be a dominant species in these habitats with 30% and 41.7% compostion in snags and organic debris. Both of these habitats had significant percentages of amphipods and isopods, the latter being particulary dominat in snags (43.3%). Aquatic insects were common in organic debris packs, which contributed to a fairly high count of total taxa (30) in this habitat. No aquatic insects were reported from snags in 2003, but this may have been due to the very limited amount of snag habitat available for sampling.

3.7.3.5 Quantitative samples from May 2000, November 2001, and December 2003

The FWC collected quantitative samples of macroinvertebrates from benthic habitats in the channel of the spring run on three of the collection dates: May 25, 2000, November 8, 2001, and December 9, 2003. Samples were collected using a petite ponar dredge with an sampling area of 232 cm^2. Samples were sieved in the field using 300 micron sieve buckets and preserved in 95% ethanol. A full description of the field and laboratory methods for site selection, sample processing, taxonomic identification and enumeration can be found in Allen et al. (2001).

The findings of the May 2000 sampling, including discussions or species abundance, evenness and diversity, are presented in the report Allen et al. (2001). The results of the latter two collections will be discussed by the FWC in a final report to be published in 2005. The results from these samples, however, were made available to the District and are presented below.

The FWC using a modified stratified sampling design to allocate samples in the two dominant benthic habitats in the spring run; bare sediments and filamentous algae. Although historic quantitative data are not available, it appeared that filamentous algal mats first became common in the spring run during the winter and spring of 2000, when withdrawals reduced spring flow to zero or low rates of flow for successive months in the dry season. These withdrawals greatly reduced current velocities and allowed water from the Hillsborough River to back into the spring run. Algae coverage averaged 38 percent bottom coverage at sites visited in 2000 by Allen et al., with no bare sediments reported in the most downstream sampling zone. However, the return of normal flows has reduced the abundance of filamentous algae in the spring. Benthic algal coverage during December 2003 reported by the University of Florida averaged 6 percent, with coverage exceeding 20 percent at only two of the twenty sites sampled.

Abundance values from the three quantitative collections are summarized in Appendix E. *Tarebia granifera* was by far the most abundant species in all habitats sampled in the 2000 collection, accounting for 84.4 percent of all organisms in the quantitative samples. Nematodes and the crownsnail *Pyrgophorus platyrachis* were the second and third most abundant taxa. Aside from T. *granifera*, Nematoda, and *P*. p*latyrachis*, no other invertebrate taxon accounted for more than two percent of the total organisms in any sample. *Pyrgophorus platyrachis* was the only taxon that had a statistically significant difference in abundance between habitats, being abundant in algal mats than on bare sediment.

Based on evenness (Pielou 1969) and diversity (Krebs 1999) values calculated for the combined habitats, the FWC concluded that the invertebrate community in 2000 was characterized by low species richness and extreme dominance by one species. Even when the qualitative collections were included, the FWC noted (in Allen et al. 2001) that the species composition in 2000 was very different from that reported by the District and FDEP in 1997. The FWC also reported that that invertebrate community evaluations of other coastal spring runs on Florida's west coast (Homosassa and Weeki Wachee) were indicative of more evenly distributed populations and the presence of many more euryhaline species (Sloan 1954; 1956). Data from low salinity zones of the Weeki Wachee and Crystal Rivers sampled by Mote Marine Laboratory (Culter 1996) also support this statement.

Compared to the 2000 collection, quantitative sampling in November 2001 found marked changes in the abundance of a number of taxa (Appendix E). Although differences in abundance between these collections have not been statistically tested, some changes seem apparent. The mean density of oligochaetes in combined habitats increased by over a factor of eight between the two periods, from 1,172 to 9,779 number per square meter (/m^2), with large increases for members of both the families Naididae and Tubificidae. The total number of mollusks decreased between 2000 and 2001, due largely to decreases in *Tarebia granifera*. *Tarebia* decreased from 47,839 to 8,766 numbers/m^2 in the combined habitats. In contrast, the crownsnail *Pyrgophorus platyachis* increased by over a factor of six, from 3,058 to 19,458 number/m^2.

Crustaceans also increased greatly between the two periods. Amphipods and isopods were virtually absent in the 2000 collection, but averaged 12,014 and 3,430 number/m^2 in the combined habitats for 2003. The abundance of aquatic insects also increased substantially between the two periods.

The data from the December 2003 collection also indicated further shifts in the species composition of the macroinvertebrate community and changes in the abundance of a number of taxa. The numbers of *Tarebia* per square meter were greater in combined habitats in 2003 (17,884) than in the 2001 (8,766), but still less than half the value recorded during the 2000 drought conditions. December 2003 represented the longest period of normal flow among these three sampling dates, demonstrating that *Tarebia* can proliferate under a wide range of salinity in the spring run.

A number of taxa had much greater abundances reported for the bare sand habitat in 2003 compared to 2001, including the *Dero digita* complex, *Grandidierella bonnieroides*, *Munna reyonoldsi*, and a number of insects in the Orders Hemiptera and Diptera. Total numbers of the amphipods and isopods increased greatly on bare sand between the two periods. Some taxa, however, were more abundant in the filamentous algae habitat during 2001, including total Oligochaeta (including members of the family Naididae) and total numbers of gastropods and amphipods. The reductions in gastropods in filamentous algae between 2001 and 2003 was largely due to reduced numbers of *Tarebia* and *Pyrogophus platyrachis*; the latter being a euryhaline species that is widespread in fresh and low salinity waters. By contrast, total isopods (dominated by *Munna reynoldsi*) increased greatly in the filamentous algae habitat as well as on bare sand.

The mean value for total number of organisms combined habitats was greatest for 2003 (104,009 per sq. meter). Mean density values were similar between 2000 and the 2001 collections, but this was largely due to very high numbers of *Tarebia* in 2000. The abundance of many other important taxa increased substantially between these periods, and continued to increase by 2003. These changes are reflected in improved evenness and diversity index values calculated for the invertebrate community. The mean evenness values per sample in the combined habitats increased from 0.31 in 2000 to 0.59 in 2001, and remained at 0.59 in 2003. Mean diversity per sample progressively increased from 0.84, to 2.12, to 2.47 for the three dates between 2000 and 2003. Taxonomic richness in the combined quantitative samples increased markedly from 20 taxa in 2000 to 42 in 2001, then increased slightly to 45 in 2003.

The changes in the invertebrate community that accompanied a return to normal flows in 2001 and 2003 can be considered desirable. The qualitative sampling from five dates showed distinct changes in the species richness of the spring run with changes in flows. The quantitative samples showed that the diversity and eveness of the invertebrate community also improved, reflecting substantial increases in many taxa and less dominance by the exotic snail *Tarebia granifera*. Importantly, many of the taxa that increased with a return to normal flows are prey organisms widely used as food sources by fishes (amphipods, isopods, aquatic insects).

3.7.3.6 Possible factors affecting changes in the macroinvertebrate community

In the 2001 report, the FWC concluded that the absence of at least some species that were recorded in 1997 by the SWFWMD and FDEP was likely due to the prolonged diversions of spring flow to the City of Tampa's reservoir and the resulting high salinity levels in the spring run. The results presented for later collections demonstrate that the invertebrate community rebounded with the return of normal flows, and was recolonized by many groups that are characteristic of freshwater or low salinity conditions. It is reasonable to conclude that variations in salinity in the spring run over the period of study was a major factor affecting the species composition and abundance of many invertebrate taxa in the spring run.

These changes in the invertebrate community corresponded to pronounced alterations to the spring's flow regime. The collections for May 2000 and July 2001 occurred during periods of zero flow or very low rates of flow. The collections for the three normal flow cases corresponded to normal flow from the spring, with flows ranging from 31 to 41 cfs. These flow conditions represent the extremes in the flow regime of the spring. As described in Sections 2.3.1, the City now has the capability to manage flows from the spring pool to the spring run at intermediate rates. The results of tests using flows at such intermediate rates are presented in Chapter 5. The management of flows in a suitable intermediate range could possibly improve invertebrate populations compared to no-flow or low-flow conditions

Other factors associated with reduced spring flow may have been involved in the observed changes in the invertebrate community. As described in Section 3.5, hypoxia (low dissolved oxygen concentrations) can occur in the spring run during no-flow periods when high salinity waters from the lower Hillsborough River move into the spring run, resulting in density stratification. As also discussed on page 3-10, the occurrence of hypoxia in the run is probably related to degree and duration of salinity incursions. Although dissolved oxygen data for the spring run are limited to several dates, the data indicate the prolonged no-flow conditions that occurred during the dry months in the 2000-2001 drought may have resulted in hypoxia that affected the benthic community.

It has also been suggested that operation of the gates at the outlet structure at the pool could have impacted the invertebrate community in the spring run. As described in Section 2.5.2.1, the water control gates at the spring pool were raised for a total of 84 days in 1999 and 2000 to lower groundwater levels and allow work on the swimming pool at Sulphur Springs Park. When the gates are open, waters discharge from the spring pool without benefiting from the waterfall effect and turbulence that occurs when the gates are closed. This may have resulted in less aeration of the spring discharge, and possibly even high sulfide concentrations in waters discharging to the spring run. No dissolved oxygen measurements were made in the spring run when the gates were open, and it is not known to what extent that discharge from the pool became oxygenated in the spring run. Similarly, there are no sulfide data for the spring pool or run on which to make reasonable inferences. If the gates need to be opened in the future, there should be plans to mechanically aerate the spring discharge if this is shown to be a problem.

In sum, it is not possible to evaluate to what degree hypoxia during 1999 and 2000 may have been a factor in the change in invertebrate community composition of the spring run. It is reasonable to conclude, however, that the dramatic salinity changes that occurred would have affected at least some of the less euryhaline invertebrate species in the spring run. The potential effect of different minimum flows on the invertebrate community in the spring run is discussed in Chapter 5.

3.8 Fish populations in the spring run

The species composition of the fish community that inhabits Sulphur Springs Run is closely linked to fish populations in the Lower Hillsborough River. Fish populations in the river have been described in two reports related to the use of the Hillsborough River for water supply. The first study by Water and Air Research and SDI Environmental Services (WAR/SDI 1995) collected fish data in the lower river on a monthly basis for two years during 1991 -1993. Life stages that were collected included egg, larval and juvenile stages collected by 500 micron mesh plankton nets, and juvenile and adult stages collected by seines.

A second major investigation of the fish fauna of the lower river is currently ongoing as part of the Hydrobiological Monitoring Program (HBMP) for Tampa Bay Water, a regional Water Supply Authority. The HBMP is being conducted by the principal firm PBSJ, Inc., with participation by the University of South Florida College of Marine Science and the Florida Fish and Wildlife Conservation Commission's Florida Marine Research Institute. Data collection for this project began in May of 2000 and is scheduled for at least a few more years. Although the distribution of collection sites is different than the WAR/SDI study, this study similarly collects both ichthyoplankton and juvenile life stages throughout the lower Hillsborough River on a monthly basis. Results from this study for the years 2000 – 2002 were presented in a year three interpretive report by PBSJ (2003).

Both the WAR/SDI and PBSJ reports presented extensive information on other biological communities (e.g. vegetation, benthic invertebrates) in the Lower Hillsborough River, but included no sampling in Sulphur Springs Run. However, in 2000, the District funded a study of the fish fauna in Sulphur Springs Run by the University of Florida that was conducted in conjunction with the invertebrate studies described in Section 3.7.3.2. University staff have sampled fishes in the spring using seines seven times since May

2000. The results from three sampling events during the spring and summer of 2000 are presented in the report by Allen et al (2001), which includes information on the design and methods used in this project. Complete data for the other four sampling trips will be presented in report to be published in 2005. However, the number of individuals of each species collected during these sampling trips have been provided to the District and are presented in Table 3-2 of this report.

The fish fauna in Sulphur Springs Run is comprised of many of the same species that are common in the upper reaches of the lower Hillsborough River, and includes both freshwater and estuarine species. In general, the dominant fishes in the spring run are species that are commonly found in low salinity areas of tidal rivers or coastal marshes, such as the silversides (*Menidia spp*.), rainwater killifish (*Lucania parva*), sheephead minnow (*Cyprinodon varigaetus*), menhaden (*Brevortia* sp), sailfin molly (*Poecilia latipinna*), and hogchoker (*Trinectes maculatus*). The silversides and rainwater killifish were particulary abundant in the early collections. Two species of *Tilapia* that were collected in the spring have also been collected in the lower river. These are species that are native to South Africa that were unintentionally introduced to Florida waters. They are often seen in the spring run, building and guarding large nests that are visible from the shoreline. Estuarine/marine species that were less common in the spring run included the Atlantic needlefish (*Strongylura marina*), bay anchovy (*Anchoa mitchilli*), ladyfish *(Elops saurus*), and two species of mojarras.

A number of freshwater fish species were found in the spring run. The mosquitofish (*Gambusia holbrooki*) is a widely distributed fish in freshwater lakes and rivers, but also is frequently collected in low salinity areas of tidal creeks and rivers. Mosquitofish were abundant in the spring run during the first three sampling events, with 56 to 216 individuals reported. The sailfin molly (*Poecillia latipinna*) is also common to both fresh waters and tidal creeks, as has a fairly broad salinity tolerance. This species was mainly collected during the first three sampling events, including dry (May) and wet (September) conditions during the year 2000.

The remaining freshwater fishes collected in the spring run are species that are commonly most abundant and widespread in fresh water, including the bluegill (*Lepomis macrochirus*), bluefin killifish (*Lucania goodei*), Florida gar (*Lepososteus platyrinchus*), redear sunfish (*Lepomis microlophus*), and largemouth bass (*Micropterus salmoides*). None of these species were collected during the no-flow, high salinity conditions during the 2000 drought. Two species (bluefin killifish and Florid gar) were collected during low-flow conditions during July 2001, while the other species (bluegill, largemouth bass, redear sunfish, and Seminole killifish) were collected only during periods of normal flow in the fall of 2001 and 2002.

The total number of species that inhabited the spring run varied between 5 and 13 species on the different sampling dates. There was no apparent relationship between the number of species and the rate of springflow. Comparatively large numbers of

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Table 3-2. Number of individuals for fish species captured in Sulphur Springs Run on five dates by the University of Florida.

Common name	Species	26-May-00 Total	14-Jul-00 Total	29-Sep-00 Total	19-Jul-01 Total	01-Nov-01 Total	22-Nov-02 Total	09-Nov-03 Total
Atlantic needlefish	*Strongylura marina*	0	0	0	0	2	2	0
Bay anchovy	*Anchoa mitchilli*	2	0	0	20	0	0	0
Blackchin tilapia	*Tilapia melanotheron*	28	0	12	0	3	0	0
Blue tilapia	*Tilapia aurea*	14	3	153	4	6	32	0
Bluefin killifish	*Lucania goodei*	0	0	1	7	0	0	0
Bluegill	*Lepomis macrochirus*	0	0	0	0	5	8	0
Common snook	*Centropomus undecimalis*	2	0	0	0	0	0	0
Clown goby	*Microgobius gulosus*	0	0	0	1	0	0	0
Florida gar	*Lepososteus platyrinchus*	0	0	0	2	1	0	0
Eastern mosquitofish	*Gambusia holbrooki*	56	187	216	2	0	2	3
Gulf killifish	*Fundulus grandis*	0	0	1	0	0	1	0
Gulf menhaden	*Brevoorita* sp.	391	1	0	0	0	0	0
Hogchoker	*Trinectes maculatus*	0	1	1	1	4	50	46
Silversides	*Menidia* sp.	1129	1919	147	674	536	0	468
Ladyfish	*Elops saurus*	0	0	0	5	0	0	0
Largemouth bass	*Micropterus salmoides*	0	0	0	0	0	1	0
Rainwater killifish	*Lucania parva*	833	728	1068	422	102	2	4
Redear sunfish	*Lepomis microlophus*	0	0	0	0	3	3	0
Sailfin molly	*Poecilia latipinna*	49	6	216	0	2	0	0
Seminole killifish	*Fundulus seminolis*	0	0	0	0	0	2	0
Sheepshead minnow	*Cyprinodon variegatus*	1	2	5	1	2	29	6
Spotfin mojarra	*Eucinostomus argenteus*	0	0	0	0	0	2	0
Striped mojarra	*Diapterus plumieri*	0	0	0	0	0	10	0
Mojarra sp.	*Gerreidae*	0	0	1	0	8	0	0
Fat Sleeper	*Dormintator maculatus*	0	0	1	0	0	0	0

species (10 to 13) were collected during periods of no flow and normal flow; while low numbers of species (5 to 7) were also collected during periods of no flow and normal flow.

The presence of fishes in Sulphur Springs may be related to flow and water quality conditions in the Lower Hillsborough River, but such relationships are only speculative. During periods of no flow from the dam, salinity in the spring run is generally considerably lower than in the river. This may attract some species to the spring run, but factors such as the temperature, clarity and dissolved oxygen in the spring run might be equally as important. Conversely, it could be argued that during high flows, suitable habitat becomes more available in the lower river, thus not concentrating fish in the spring run.

It can be concluded that the spring run provides a valuable low salinity refuge for freshwater species during periods of no flow from the Hillsborough River dam. Freshwater species, such as largemouth bass and bluegill, are often collected in the low salinity areas of tidal creeks and rivers where they can feed on the food resources found there. A review of the effects of salinity on freshwater fishes in the coastal plain of the southeastern U.S. is provided by Peterson and Meador (1994). Elevated salinity can influence fish behavior, physiology, growth, or reproduction. However, the salinity values that are generally reported for these effects are well above the background salinity that occurs in Sulphur Springs under normal flows, and even during some periods of salinity incursion from the river. Acknowledging that salinity tolerances vary considerably between fish families, Peterson and Meador state that many freshwater species can withstand extended exposures up to 9 ppt salinity, and tolerate brief exposures at higher values. They furthermore state that some studies suggest that most freshwater fishes cannot reproduce in salinities greater than 3-4 ppt, but few studies have addressed this issue.

It is unlikely that salinity incursions in the spring run observed during this study jeopardized the survivability of the estuarine/marine fish that inhabit the spring run. However, the prolonged high salinity values (8-16 ppt) that resulted from the large withdrawals from Sulphur Springs during the 2000-2001 drought likely caused the spring run to be unsuitable habitat for most freshwater fishes found in the Lower Hillsborough River. However, salinity incursions of lesser magnitude or duration, such as occurred during the fall of 2001 and spring 2002 (Figure 3-5), may not have jeopardized the survivability of these species or possibly their reproduction.

The use of the spring run by fishes will be dependent not only on salinity, but also on food resources available in the run. Given the findings for invertebrates presented in Section 3.7, the species composition of the invertebrate community is likely more sensitive to changes in salinity in the low range than the fish fauna. It is unclear, however, if such a community shift in the invertebrates would result in less total prey for fishes. The potential biological effects of salinity incursions into the spring run resulting from different flow rates from the spring are considered in Chapter 5.

3.9 Relationships of Sulphur Springs discharge to the hydrology, water quality and ecology of the Lower Hillsborough River.

The flow from Sulphur Springs has important hydrologic and ecological functions in the Lower Hillsborough River system. During much of the year, Sulphur Springs provides much of the combined inflow of fresh or low salinity water to the lower river. This inflow is very important for establishing salinity distributions in the river, and during winter months, maintaining thermal refugia for manatees and cold sensitive fish species such as snook. The hydrology of the spring in relation to the river is described first below, followed by a discussion of the physical-chemical and biological effects of the springflow to the river system.

3.9.1 Hydrology of the Lower Hillsborough River

The watershed draining to the Lower Hillsborough River has an area of approximately 650 square miles. Approximately 90 percent of this area drains to the Hillsborough River Reservoir. The dam that creates the reservoir is located approximately 16.3 kilometers (10 miles) upstream of the river mouth. Downstream of the dam there is about twenty square miles of highly urbanized watershed that drains to the lower river via storm sewers and drains. During rains events, considerable freshwater inflow is contributed to the lower river from the sub-basin below the dam (HSW 1992). In the dry season, these events can be infrequent, with very little inflow contributed below the dam for prolonged periods of time.

The majority of the inflow to the lower river comes from discharges from the Hillsborough River Reservoir. Daily streamflow records for discharges from the reservoir date back to 1939. There has been a significant decreasing trend in stream flow for the reservoir, as evidenced by a time series of average flows shown in Figure 3-8. Increasing withdrawals from the reservoir by the City of Tampa has been a factor contributing to these decreasing flows. Average yearly withdrawals from the reservoir were less than 31 cfs in the late 1940s, increasing to an average of 105 cfs (68 mgd) over the last several years.

Other factors affecting the decline in average annual flows from the reservoir include the operation of the Tampa Bypass Canal (TBC). Since the mid-1980s, the Bypass Canal has been periodically used to divert high flows away from the reservoir to prevent flooding in the urban Tampa area. In addition, above the influence of the TBC, there appears to be a declining trend in inflows to the reservoir system (SWFWMD 1999). Long-term changes in rainfall and groundwater levels in the region may be contributing to these reductions in flow.

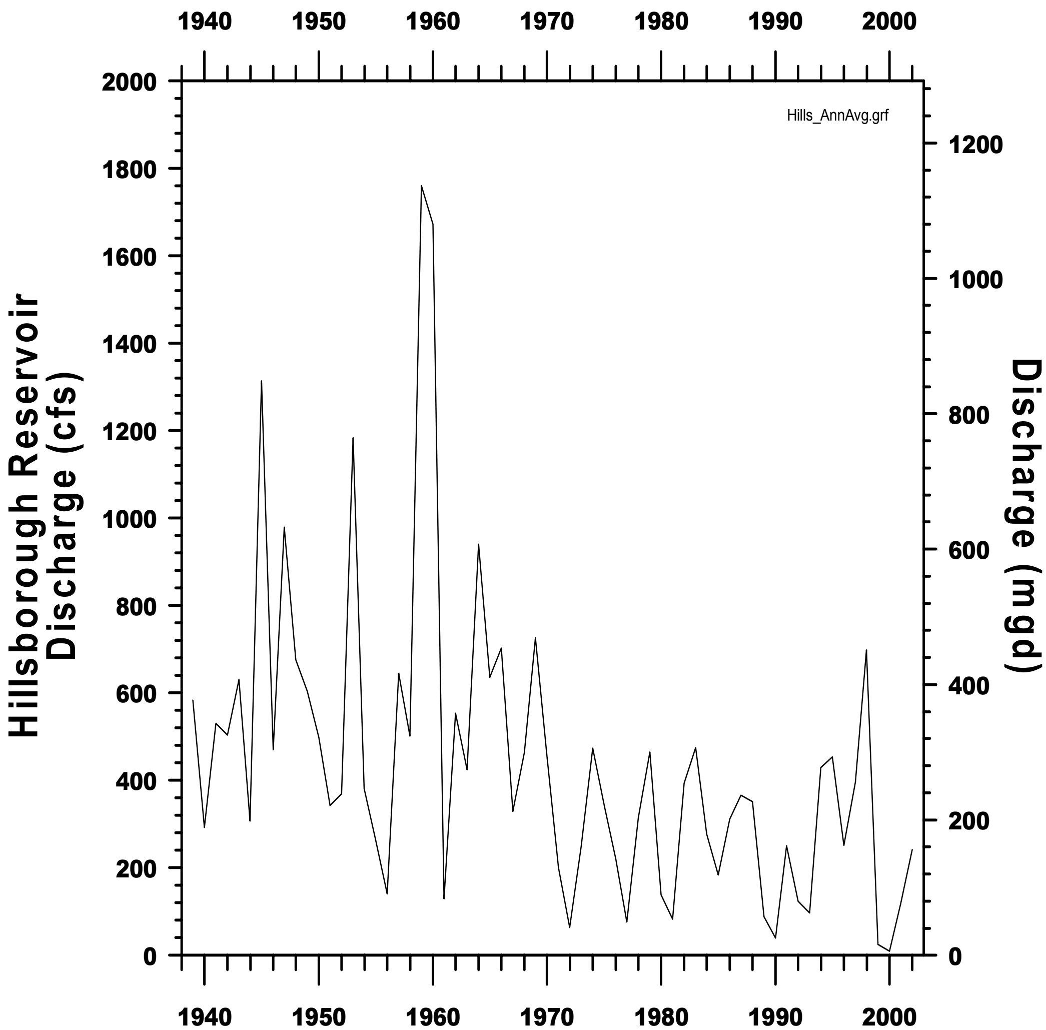

Figure 3-8. Average yearly flows to the lower river from the Hillsborough River Reservoir.

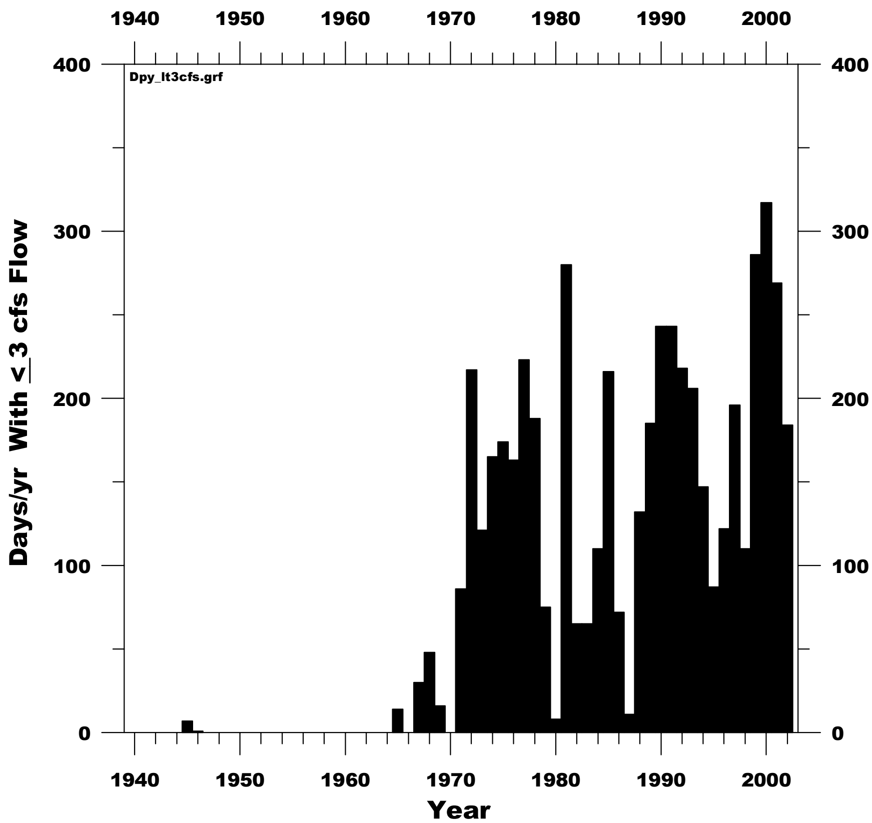

Figure 3-9. Number of no-flow days per year from the Hillsborough River Reservoir .

A principal effect of these flow reductions has been a dramatic increase in the occurrence of no-flow days at the reservoir spillway, or days when there is no discharge from the reservoir other than leakage and seepage near the dam. A value of 3 cfs is chosen to represent no-flow days since daily flows values up to 3 cfs appear in the USGS records to denote leakage from the dam. The occurrence of no flow days at the spillway began to first regularly appear in the late 1960s (Figure 3-9). The number of no-flow days per year increased rapidly in the 1970s, when water use from the reservoir first reached average yearly quantities of about 77 cfs (50 mgd). Since that time, it is not uncommon for no flow days to exceed 200 days in dry years, reaching a maximum quantity of 320 days in the year 2000 at the height of the recent drought.

A flow duration curve of discharges from the Hillsborough River dam for the period 1988 – 2002 is shown in Figure 3-10. This period was chosen as it represents a period when withdrawals by the City were near their present use. No flow conditions at the dam occurred on about half of the days during this period. However, when there is flow from the dam it can be substantial. For example, flows of 303 cfs were exceeded 20% of the time during 1988-2002, while flows of 1,500 cfs were exceeded 5% of the days.

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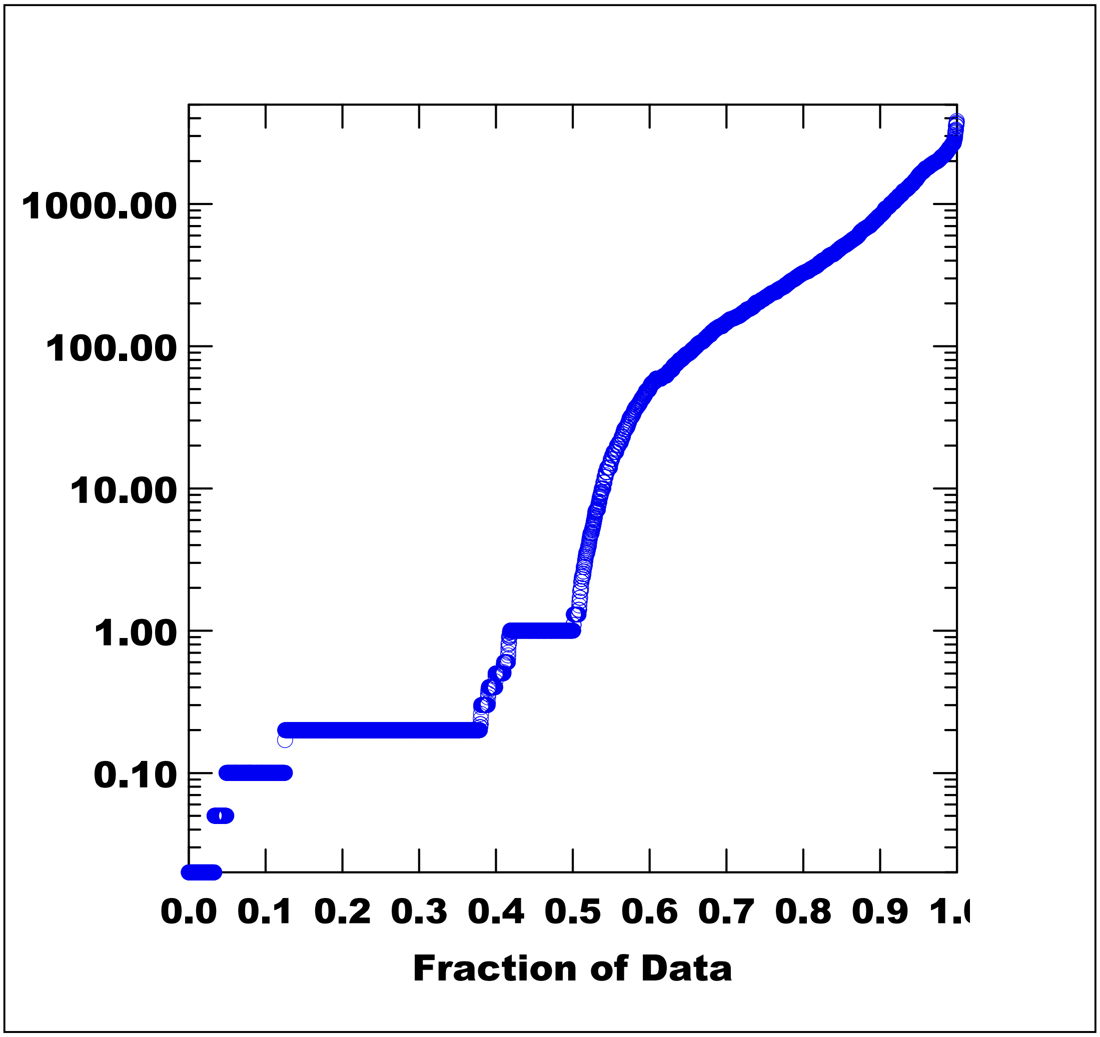

Figure 3-10. Flow Duration curve for daily flow values from the Hillsborough River Reservoir.

When there is no flow from the reservoir, Sulphur Springs provides nearly all of the inflow of low salinity inflow to the lower river. Figure 3-11 is time series graph of the proportion of total gaged inflow to the Lower Hillsborough River represented by Sulphur Springs. During prolonged periods, the spring provides in excess of 80% of the gaged inflow to the lower river. Table 3-3 lists percent exceedance values for the proportion of total gaged flow to the lower river that is comprised by Sulphur Springs. For fifty percent of the time, flow from Sulphur Springs comprises at least 89% of the gaged inflow to the Lower Hillsborough River. However, periodic ungaged flows of stormwater runoff from the urbanized catchment below the dam are not included in Figure 3-11 or Table 3-3.

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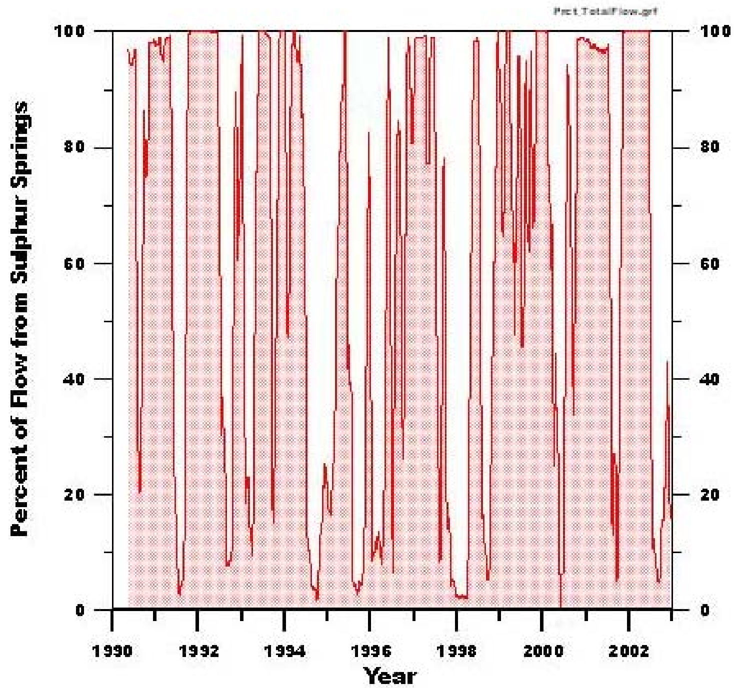

Figure 3-11. Time series of percent of daily gaged inflow to the lower river comprised by flow from Sulphur Springs.

Table 3-4. Percent of days that proportions of total gaged flow to the lower river are exceeded by flows from Sulphur Springs. Example: for 60 percent of the time, flow from Sulphur Springs exceeds 39.2 percent of the total gaged flow to the Lower Hillsborough River.	
Percent of time exceeded	% of total gaged flow
99	0
90	3.7
80	9.1
70	18.6
60	39.2
50	89.4
40	97.3
30	99.3
20	99.6
10	99.7
1	100

3.9.2 The effects of flows from Sulphur Springs on salinity distributions in the Lower Hillsborough River

The relationships of freshwater inflows from the reservoir and Sulphur Springs to the water quality and ecology of the Lower Hillsborough River has been the subject of considerable study, including previously published reports and ongoing data collection efforts. A study of the relationships of freshwater flows to the Hillsborough River was published in 1995 as a condition of the renewal of the City of Tampa's Water User Permit for withdrawals from the reservoir and Sulphur Springs (WAR/SDI 1995). In the late 1990s, the District conducted data analyses to support the establishment of minimum flows for the Lower Hillsborough River at the base of the dam (SWFWMD1999). As part of this process, the Tampa Bay Estuary Program (TBEP) facilitated a minimum flows technical advisory group to recommended to the District water resource and ecological criteria necessary to establish minimum flows at that location. The advisory group concluded that salinity and dissolved oxygen concentrations were key water quality parameters on which the determination of minimum flows should focus. The TBEP also managed a contract with Coastal Environmental to consolidate previously collected data for the river and develop statistical models to predict salinity distributions and dissolved oxygen concentrations as a function of inflow from the dam and Sulphur Springs (Coastal Environmental 1997).

In January 2000, the District established a minimum flow of 10 cfs for the Lower Hillsborough River near the base of the dam. As described in Section 2.3.1, this rule stipulated that alternate sources, including water diverted from Sulphur Springs, could be used to provide this minimum flow. The minimum flow for the Lower Hillsborough River was reviewed by a scientific review panel, which recommended that additional studies be undertaken to improve the understanding of the response of the river to freshwater inflows (Montagna et al. 1999). Accordingly, the adopted rule also stipulated that the minimum flow would be re-evaluated by 2005, with new studies conducted to evaluate the effects freshwater flows up to and above 35 cfs have on the lower river. Those studies are now underway.

Ongoing data collection on the river is also being conducted as part of monitoring programs conducted by the Environmental Protection Commission of Hillsborough County (EPCHC) and Tampa Bay Water, a Regional Water Supply Authority. The water quality data collection by the EPCHC is longstanding, with records at three fixed location sites in the river dating back to the 1970s. Vertical profiles of salinity, dissolved oxygen, and other in situ parameters are also taken by the County at a much large number of stations as part of their Hillsborough Independent Monitoring Program (HIMP). The effort by Tampa Bay Water is part of an extensive Hydrobiological Monitoring Program (HBMP) that is required by their Water Use Permit to withdraw water from the Hillsborough River when flows at the dam exceed 100 cfs. Using a stratified random design, the HBMP has involved extensive water quality and biological data collection since the spring of 2000. The first interpretive report for this program was published in April 2003 (PBSJ 2003).

The characterization of the effects of Sulphur Springs on the water quality and the river relies largely on data collected by these various programs. Figure 3-12 summarizes the length of salinity data at various fixed stations in the river, including sites monitored by the EPCHC and continuous recorders operated by the USGS. A full suite of water quality parameters is measured at the EPCHC sites, while the USGS sites are limited to water level, temperature, specific conductance (converted to salinity), and for some limited periods, dissolved oxygen readings.

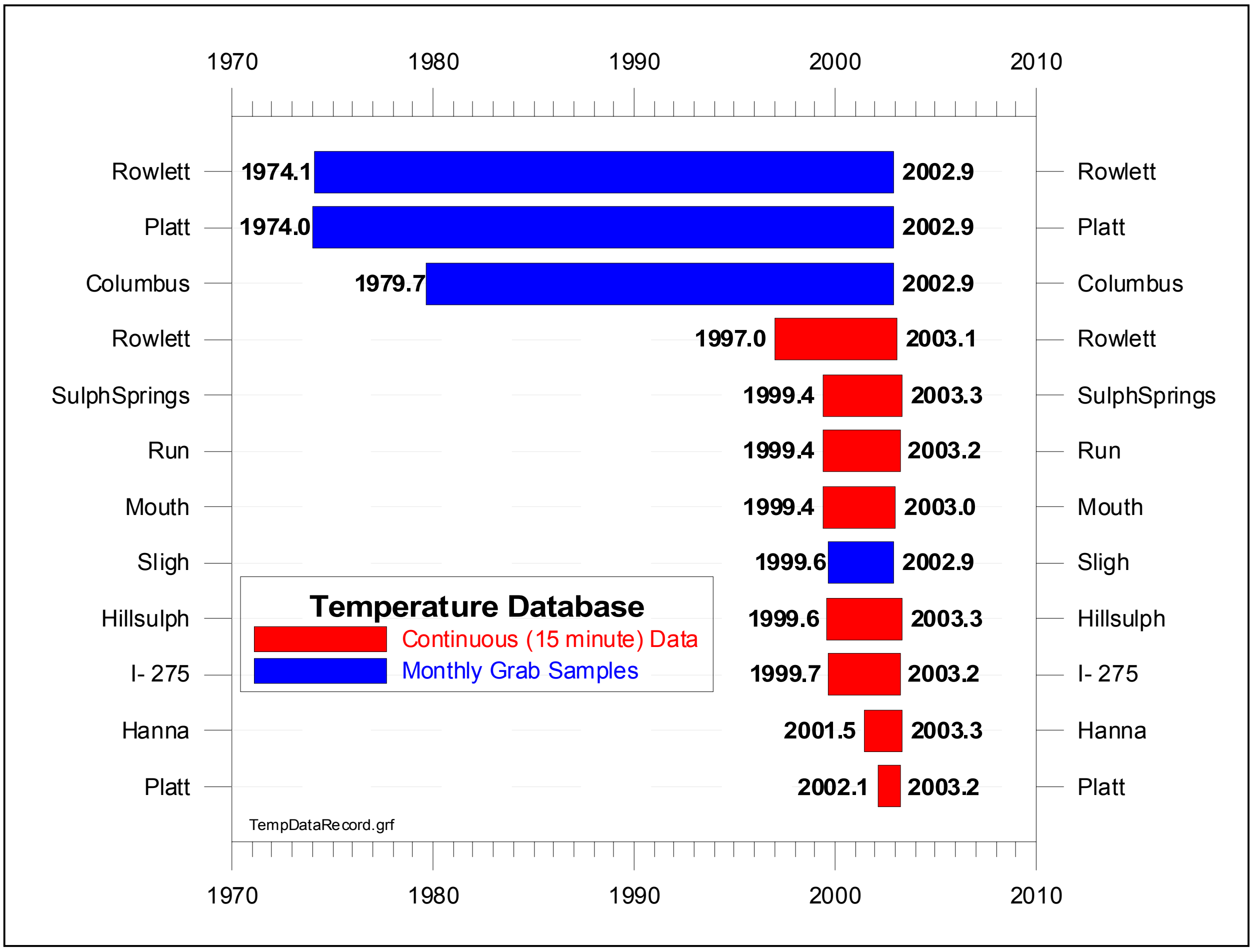

Figure 3-12. Periods of record for salinity, temperature, and dissolved oxygen measurements at fixed location water quality sites sampled by the EPCHC ambient monitoring program and data recorders operated by the USGS.

Data from the Tampa Bay Water HBMP, which are not included in Figure 3-9, are available for salinity, temperature, pH, and dissolved oxygen at a large number of sites, and for chlorophyll a, color, total suspended solids, and total and dissolved organic carbon at a subset of these. Because salinity and dissolved oxygen concentrations are most closely affected by Sulphur Springs flow, the discussion on the effects of Sulphur Springs on the water quality of the Hillsborough River is limited to those parameters.

3.9.2.1 Empirical salinity data plots

Flows from Sulphur Springs have their greatest effect on the water quality of the Lower Hillsborough River during times when there is no flow at the dam. Box and whisker plots of salinity in 2-kilometer intervals along the lower river are presented in Figure 3-13 using data from the Tampa Bay Water HBMP and the EPHC/HIMP programs during 2000-2002. This period is chosen for analysis as it represents the most spacially extensive data for the lower river. Statistical distributions of surface and bottom water salinity values are graphed separately for flow and no-flow conditions from the Hillsborough River reservoir. Since the USGS frequently reports flow values up to 3 cfs to represent leakage from the dam, no-flow conditions were classified as less than 3 cfs to denote no flow from the reservoir spillway.

Brackish waters can extend to the base of the Hillsborough River dam during times of no flow. The median salinity values for surface and bottom waters near the base of the dam (km 16) were approximately 10 ppt for no flow conditions (Figure 3-13). Compared to other long-term data for the river, these values are particularly high, as the HBMP/HIMP data are heavily influenced by the prolonged 2000-2001 drought when salinity in the lower river reached record levels. Surface salinity values do not show a strong gradient between kilometers 10 and 16 during no-flow conditions. In fact, the median surface salinity value near the dam (km 16) is greater than the median value near Sulphur Springs (km 12). This reverse salinity gradient, in which salinity increases upstream, is due to the effect of Sulphur Springs, which reduces surface salinity in the river near the spring outfall. Salinity values in the lower river are substantially lower for flow conditions. Median salinity values at or near fresh water extend downstream to km 10 for surface waters and to km 12 for bottom waters. Under many flow conditions, fresh waters extend from the dam downstream past Sulphur Springs.

Box and whisker plots of salinity data from the four EPCHC fixed location sites show similar relationships (Figure 3-14), but reflect a longer period of record. The median surface salinity value at Rowlett Park (km 15.6) under no-flow conditions is 6 ppt, which is substantially lower than the median value in the HBMP/HIMP data set. Surface salinity values are typically fresh down to km 10.6 for flow conditions, but the median bottom salinity at this location during flows is near 8 ppt. It should be noted the period of record at this site (Sligh Avenue) is much shorter than for the other EPCHC stations (Figure 3-12.). In general, the box and whisker plots show there are marked differences in the salinity characteristics of the lower river between flow and no-flow conditions, particularly upstream of Sulphur Springs.

Figure 3-13

HBMP & EPCHC 2000 - 2002

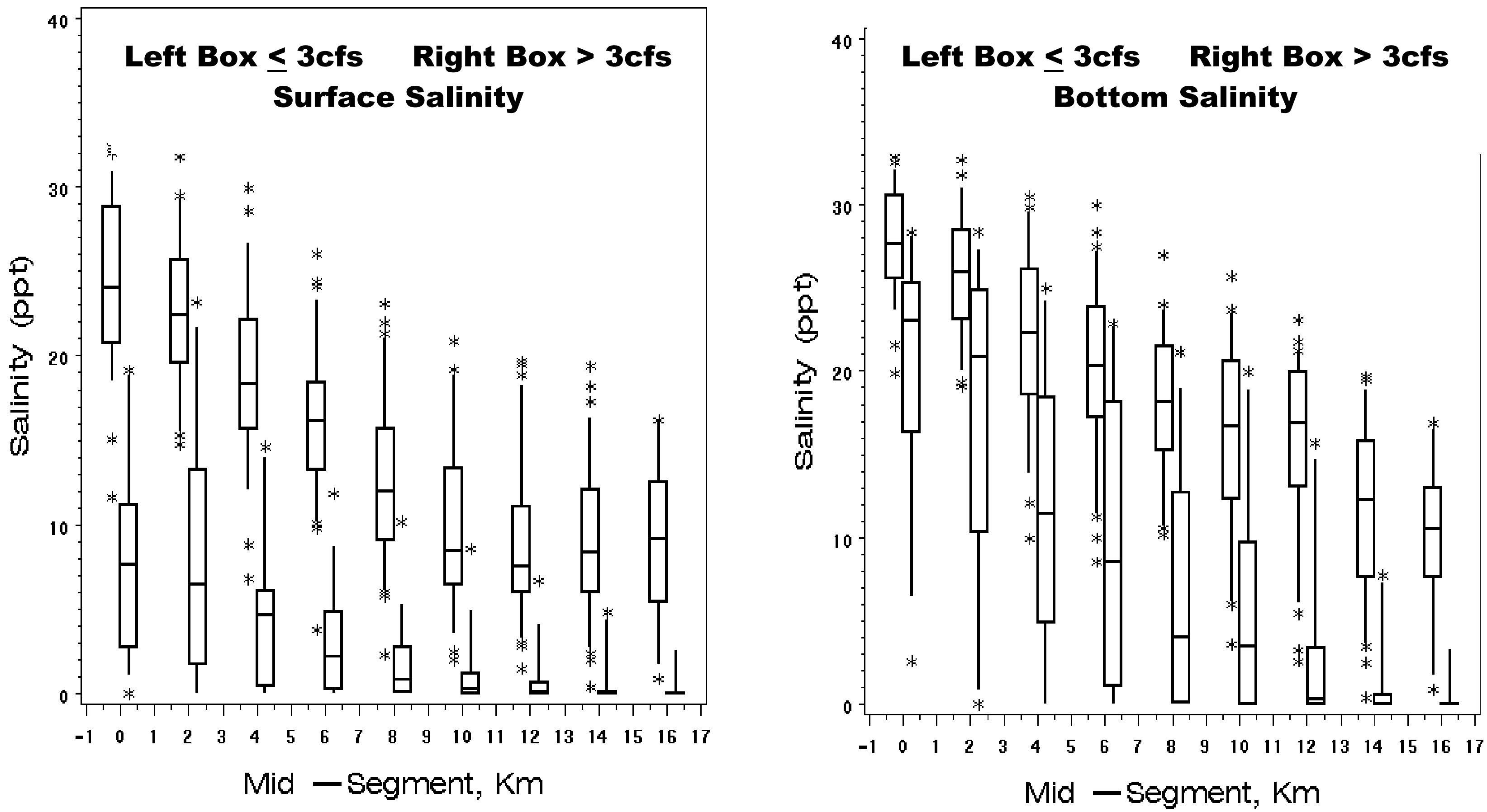

Figure 3-13. Box and whisker plots of surface and bottom salinity values in two kilometer segments in the Lower Hillsborough River for flow and no flow conditions. Data taken from the HBMP and the EPCHC HIMP programs for 2000 – 2002.

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EPCHC Period of Record Data

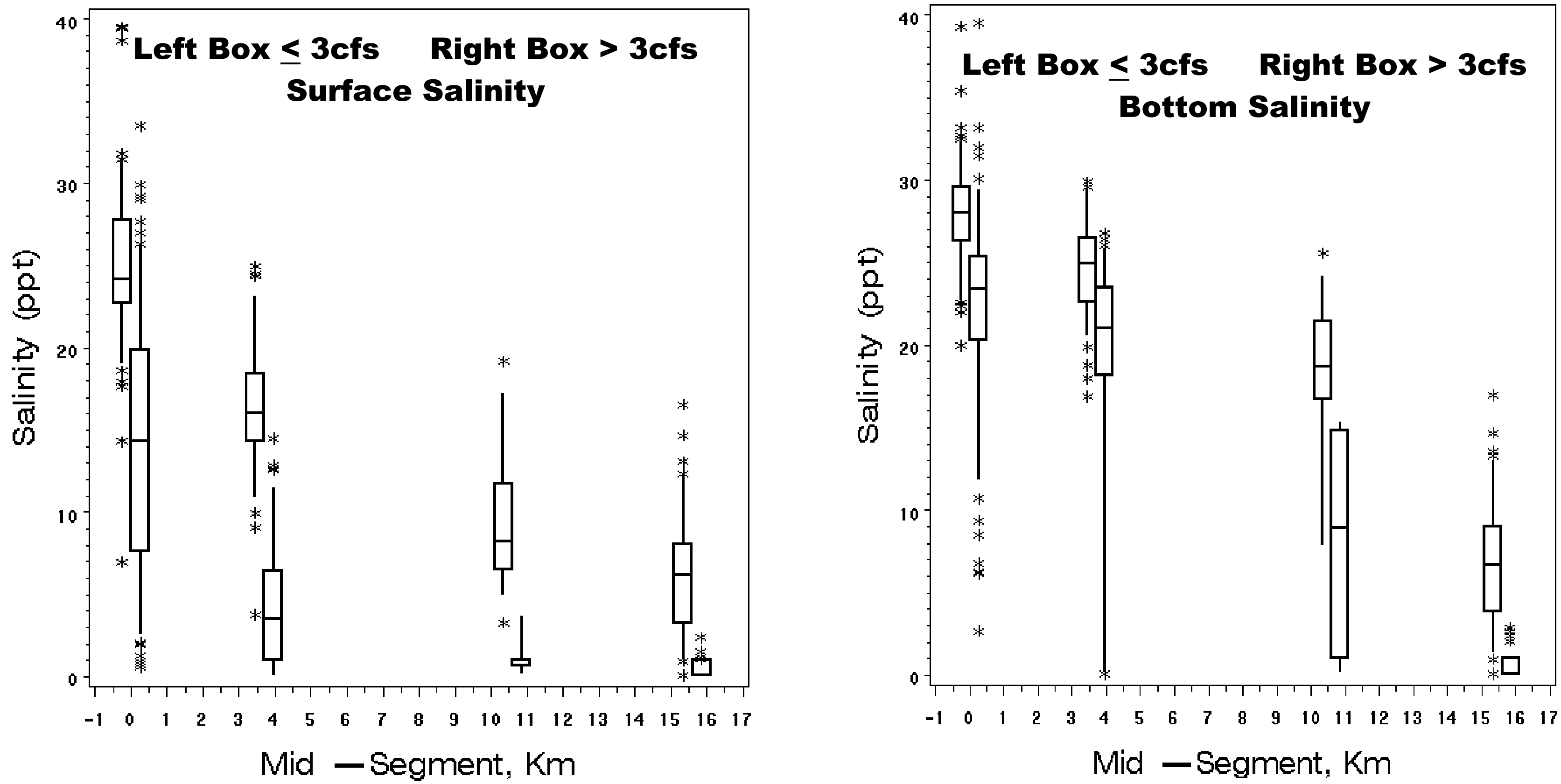

Figure 3-14. Box and whisker plots of surface and bottom salinity values at the EPCHC ambient monitoring stations on the Lower Hillsborough River for flow and no flow conditions. Data taken from the period of record at each station.

Figure 3-14

The 15-minute data from the USGS recorders are also useful for examining the salinity characteristics of the lower river. Time series plots of surface and bottom salinity values for four recorders in the river are presented in Figure 3-15**.** Salinity is averaged over the preceding 29-day period to aid visual interpretation of the plots. The longest period of record is for the Rowlett Park recorder, which dates back to 1997. The unusually high values that occurred during the 2000 –2001 drought are apparent from this plot. It is also notable there is very little vertical stratification at this site, as evidence by the similarity of surface and bottom values. The period of record at Hanna's Whirl is much shorter, as it started in the spring of 2001 as part of the re-evaluation of the minimum flow for the Lower Hillsborough River. This station has remained fresh since the summer of 2002, when an extended period of flow began at the Hillsborough River dam. During the dry season of 2001-2002, salinity at this site varied between 5 and 12 ppt.

The site at Hillsborough River near Sulphur Springs (HILLSULPH) is especially informative for it is located only about 100 meters upstream from the mouth of the spring run. Both surface and bottom waters can go fresh during the wet season, but bottom salinity at this site fluctuates above 15 ppt during no-flow conditions. An important characteristic of this site is the large difference between surface and bottom salinity values in the dry season. This is largely due to the effect of Sulphur Springs, as the low salinity water from the spring run layers over the higher salinity water in the river. This results in pronounced density stratification, which as will be discussed later, contributes to frequent hypoxia in this reach of the river.

3.9.2.2 Hydrodynamic salt transport model of the river

An effective tool for examining the effect of freshwater inflows on the salinity regime of the Lower Hillsborough River is a laterally averaged two-dimensional hydrodynamic model of the Lower River developed by District staff (Chen et al. 2001). This model was used in the establishment of 10 cfs minimum flow (SWFWMD 1999), and its further use was recommended by the scientific review panel (Montagna et al. 1999). Since the model's initial use in the late 1990s, the model has been recalibrated using new data from the expanded array of continuous recorders in the river.

Graphs of salinity distributions in the river for a series of different inflows from the dam and Sulphur Springs are presented in Figures 3-16 through 3-21. The results were generated by assigning inflow values to initial conditions as measured on January 16, 2002 and running the model for 20 days. This no-flow period was chosen because it is more representative of the long-term no-flow conditions in the river than the much saltier conditions that occurred during the 2000-2001 drought.

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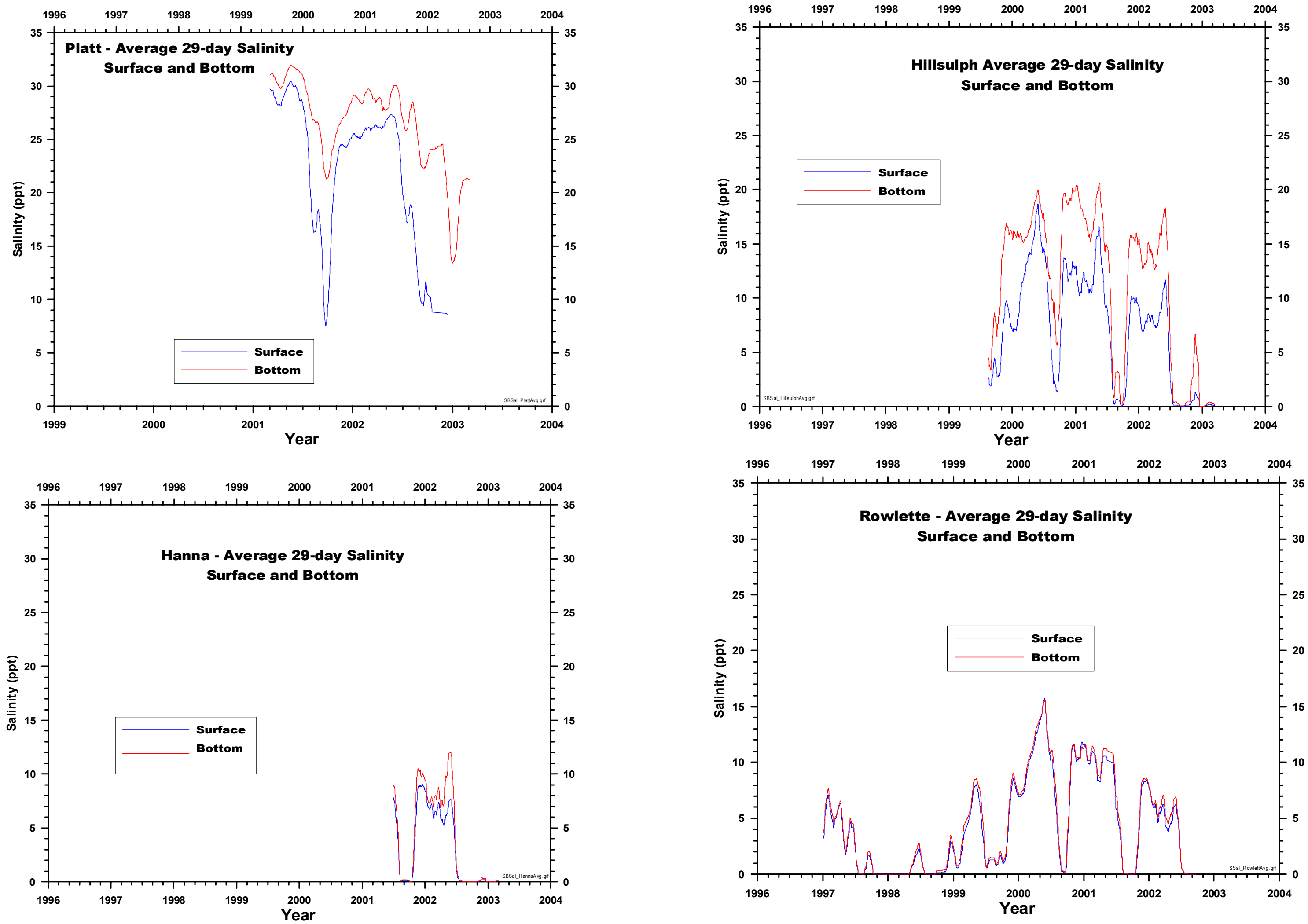

Figure 3-15. Time series plots of surface and bottom salinity values at four data recorders in the Lower Hillsborough River.

Figure 3-16 illustrates salinity in the river with no flow at the dam and average flow from Sulphur Springs uncorrected for withdrawals (31 cfs). Salinity near Rowlett Park Bridge (km 16) is between 6 and 7 ppt, which is similar to the long-term median value for that site in the EPCHC data set (Figure 3-14). This figure also shows a shallow lens of low salinity water at the surface near Sulphur Springs. Similar to the empirical box and whisker plot (Figure 3-13), modeled surface salinity values there (4-5 ppt) are lower than at Rowlett Park. The river near Sulphur Springs is highly stratified, as bottom salinity values at 10 to 11 ppt. The reverse salinity gradient in surface waters and pronounced salinity stratification in the vicinity of Sulphur Springs is a distinct characteristic of the river during no-flow conditions.

The next three figures show the effects of different flows of fresh water from the reservoir spillway on salinity in the river. A flow of 10 cfs of river water creates a zone of water less than 1 ppt and pushes the 7 ppt isohaline (line of equal salinity) on the river bottom to kilometer 13.4 near the dam (Figure 3-17). A flow of 60 cfs creates a freshwater zone of <1 ppt all the way to the Sulphur Springs (Figure 3-18) and breaks the steep stratification observed there at lower flows. A flow of 120 pushes the 1 ppt isohaline about one km below Sulphur Springs on the river bottom (Figure 3-19). Under high flow conditions, the waters from Sulphur Springs mix with the fresh river water and to not result in salinity stratification near the spring outfall.

The model outputs are also useful for evaluating the effects of routing spring water to the base of the dam**.** Figure 3-20 shows the effect of routing 10 cfs of spring water to the base of the dam with the remaining spring flow (21 cfs) discharging to the river at the mouth of the spring run. This flow scenario results in waters of less than 3 ppt below the dam and pushes the 7 ppt isohaline to km 14.6 on the river bottom. Routing a total of 15 cfs of spring water to the base of the dam pushes the isohalines further downstream, resulting in more low salinity water below the dam (Figure 3-21). Steep vertical salinity gradients remain near the Sulphur Springs outfall. However, since the establishment of low salinity habitats below the dam is a criterion for establishing minimum flows for the Lower Hillsborough River, moving a portion of the flow of Sulphur Springs to the base of the dam can be considered a net benefit to the river, as long as the minimum flow requirements of the spring run are met. The determination of the minimum flow for the spring run is presented in Chapter 5.

3.9.3 Relationships of freshwater inflows to dissolved oxygen concentrations in the lower Hillsborough River

Dissolved oxygen data for the river are available from the sources described above for salinity; which are EPCHC long term monitoring, EPCHC HIMP monitoring, the Tampa Bay Water HBMP, and District data collection associated with re-evaluation of the Lower Hillsborough River minimum flow. Dissolved oxygen measurements at the USGS continuous recorders are limited to brief periods at the Rowlett Park and Hanna's Whirl sites. Although collection of DO data at these recorders will be an important part of the re-evaluation of the minimum flow for the lower river, those data are limited and are not

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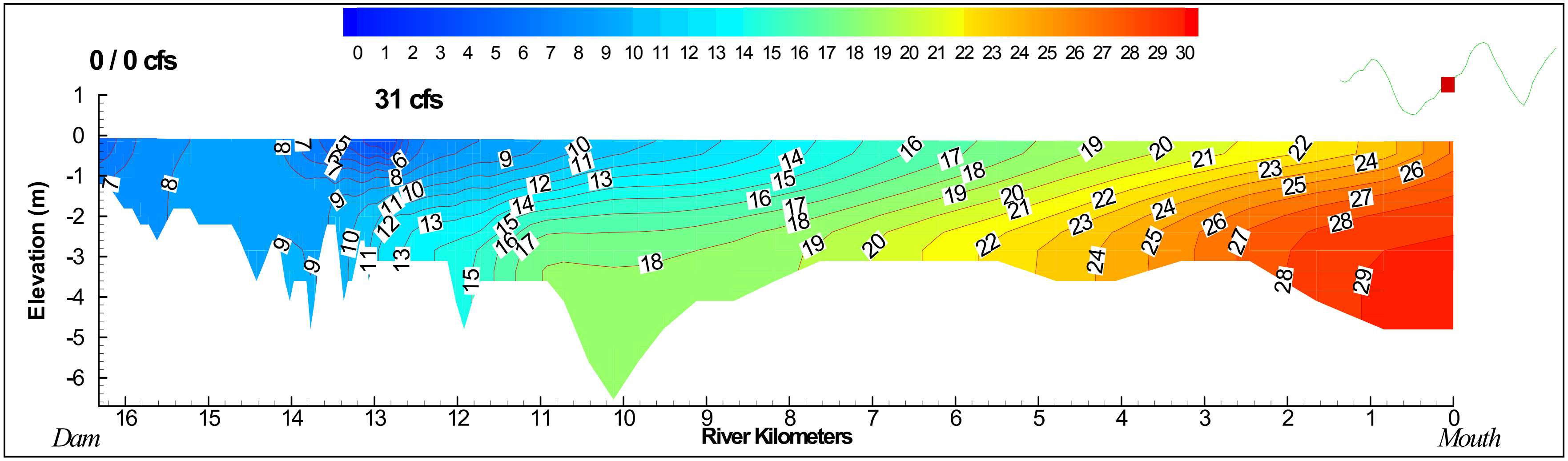

Figure 3-16. Two-dimensional plot of salinity distributions for inflows of 0 cfs at the dam and 31 cfs of springflow at Sulphur Springs.

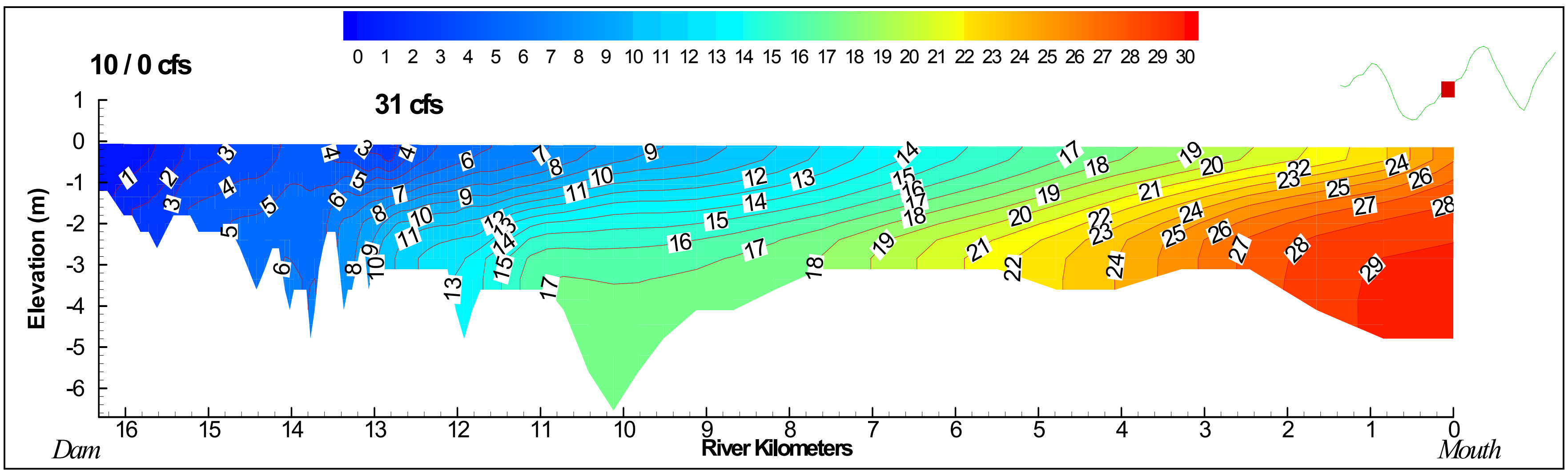

Figure 3-17. Two-dimensional plot of salinity distributions for inflows of 10 cfs of river water at the dam and 31 cfs of spring water at Sulphur Springs.

Figure 3-18, 3-19

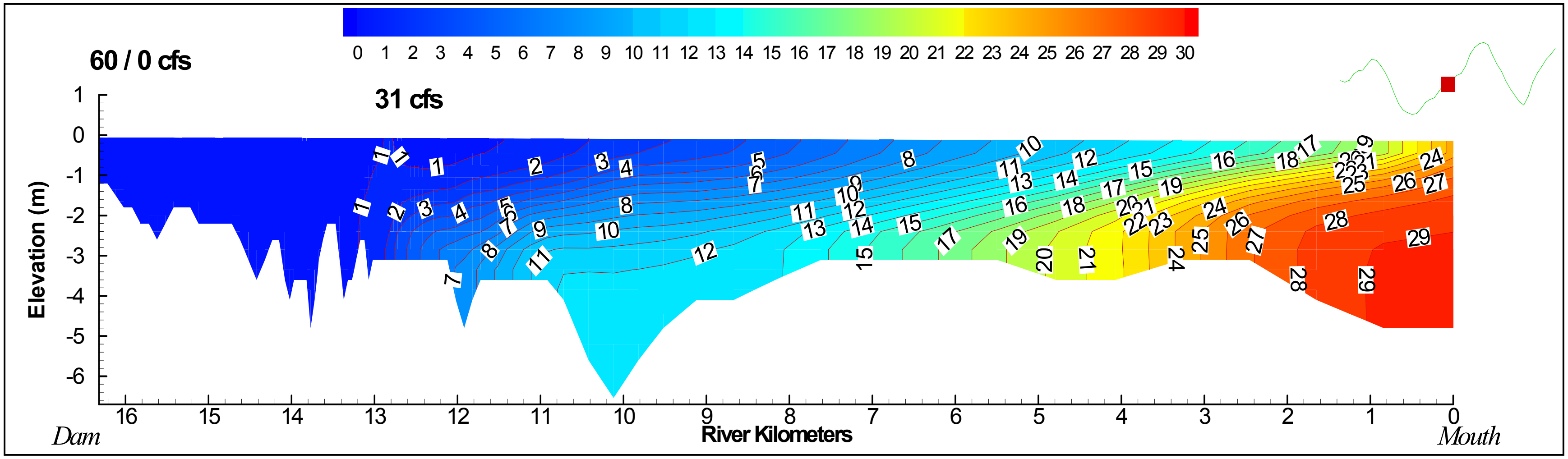

Figure 3-18. Two-dimensional plot of salinity distributions for inflows of 60 cfs of river water at the dam and 31 cfs of spring water at Sulphur Springs.

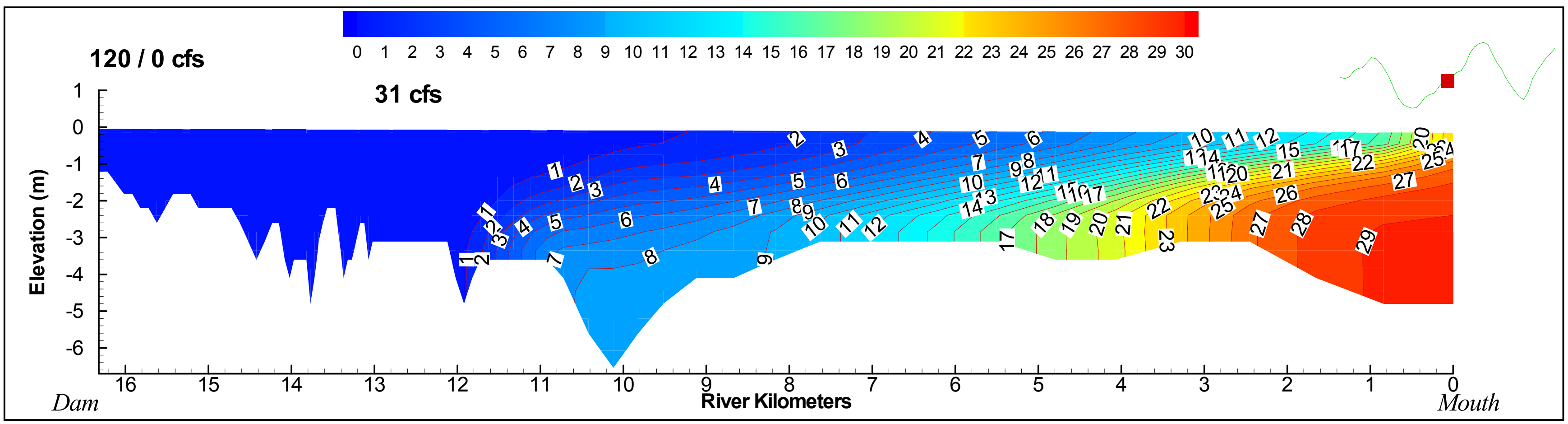

Figure 3.19. Two-dimensional plot of salinity distributions for inflows of 120 cfs of river water at the dam and 31 cfs of spring water at Sulphur Springs.

Figure 3-20, 3-21

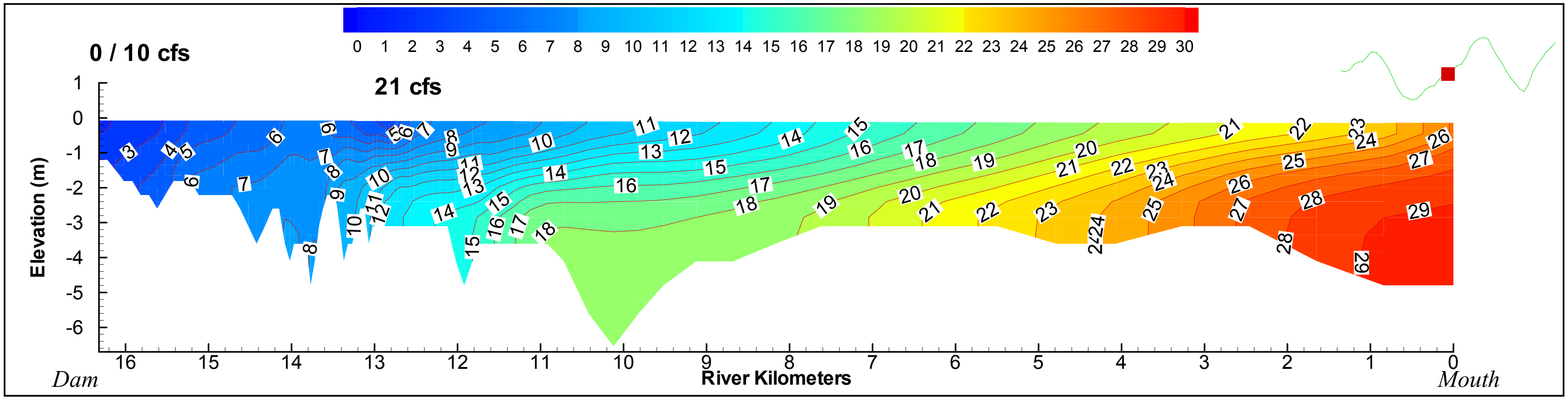

Figure 3-20. Two-dimensional plot of salinity distributions for inflows of 0 cfs of river water and 10 cfs of spring water at the dam and 21 cfs of springflow at Sulphur Springs.

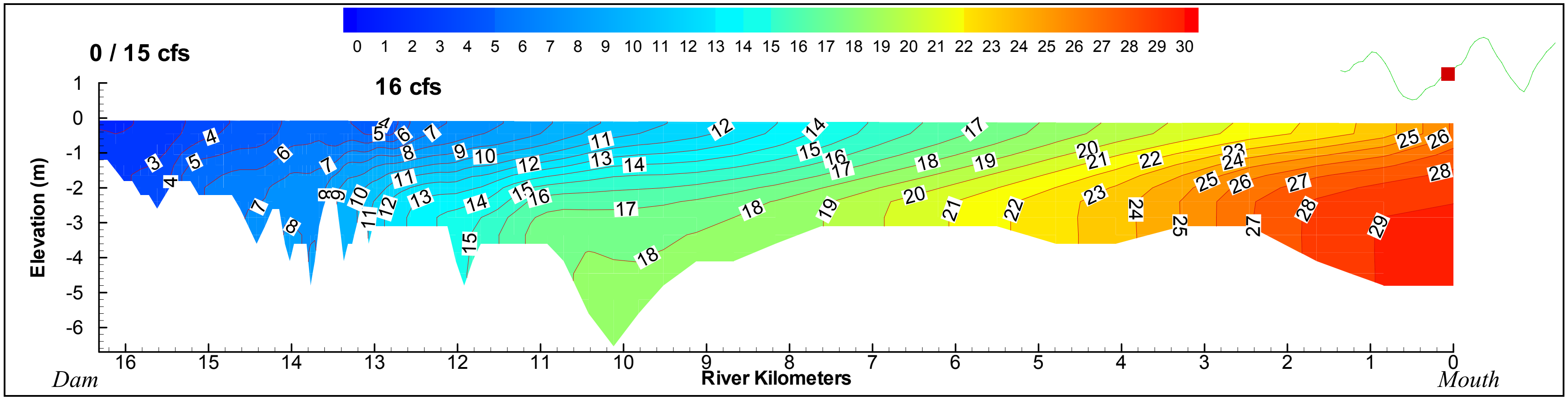

Figure 3-21. Two-dimensional plot of salinity distributions for inflows of 0 cfs of river water and 15 cfs of spring water at the dam and 16 cfs of springflow at Sulphur Springs.

presented in this report. Dissolved oxygen is also measured at three continuous recorders operated by Tampa Bay Water at Sligh Avenue, Columbus Avenue and the Crosstown Expressway (kilometers 10.6, 3.7, and 0.2 respectively). However, the DO data presented below are limited to vertical profile measurements included in the three data sets first described, due to their large number of observations and good spatial coverage in the area between the dam and Sulphur Springs.

DO concentrations in the Lower Hillsborough River are related to the amount of freshwater inflow, particularly in the reach of the river above Sulphur Springs. Box and whisker plots of surface and bottom DO data in segments of the river taken from the combined Tampa Bay Water HBMP/HIMP data are presented in Figure 3-22 for flow and no-flow conditions at the Hillsborough River dam. Different patterns are observed between the upstream and downstream reaches of the lower river. Downstream of km 7, the distribution of surface DO values is generally higher for no-flow conditions. Conversely, upstream of Sulphur Springs (km 12.9), surface DO values are higher for flow conditions at the dam. A similar pattern holds for bottom DO values in the HBMP/HIMP data - values for no-flow conditions are higher below km 7 and values for flow conditions are higher above km 13. It should be noted that bottom DO concentrations are lowest in the segment nearest to Sulphur Springs (km 12), which is probably related to the steep density gradients that occur there during no-flow conditions (Figures 3-13 and 3-16).

Only some of these patterns are apparent in the box and whisker plots for the EPCHC stations (Figure 3-23), which for three of the stations represent a much longer period of record (Figure 3-12). In contrast to the HBMP/HIMP data, distributions of surface and bottom DO concentrations in the EPCHC data appear similar between flow and no-flow conditions at the two downstream stations (km 0.0 and km 3.5). An important similarity in the two data sets is they both show that surface and bottom DO concentrations improve with flow in the reach of the river above Sulphur Springs (upstream of km 13).

At Sligh Avenue (km 10.6) the EPCHC data show a pattern similar to the HBMP in that surface DO values are similar between flow and no-flow conditions, while bottom DO concentrations are somewhat higher during flow conditions. These results reflect that the water column is highly stratified in this reach of the river during no-flow conditions, partly due to the effect of Sulphur Springs, which lowers salinity in the surface layers (Figure 3-16). The improvement in DO during flow conditions is likely due to the inclusion of high flow values in those data, which diminish vertical stratification at that location (Figures 3-18 and 3-19).

3.9.4 Effects of low flows on salinity distributions and dissolved oxygen concentrations between the dam and Sligh Avenue

The effects of freshwater inflow will be examined throughout the river as part of the re-evaluation of minimum flows for the Lower Hillsborough River. For the evaluation of minimum flows for Sulphur Springs, special attention is given in this report to the reach

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Figure 3-22

HBMP & EPCHC 2000 - 2002

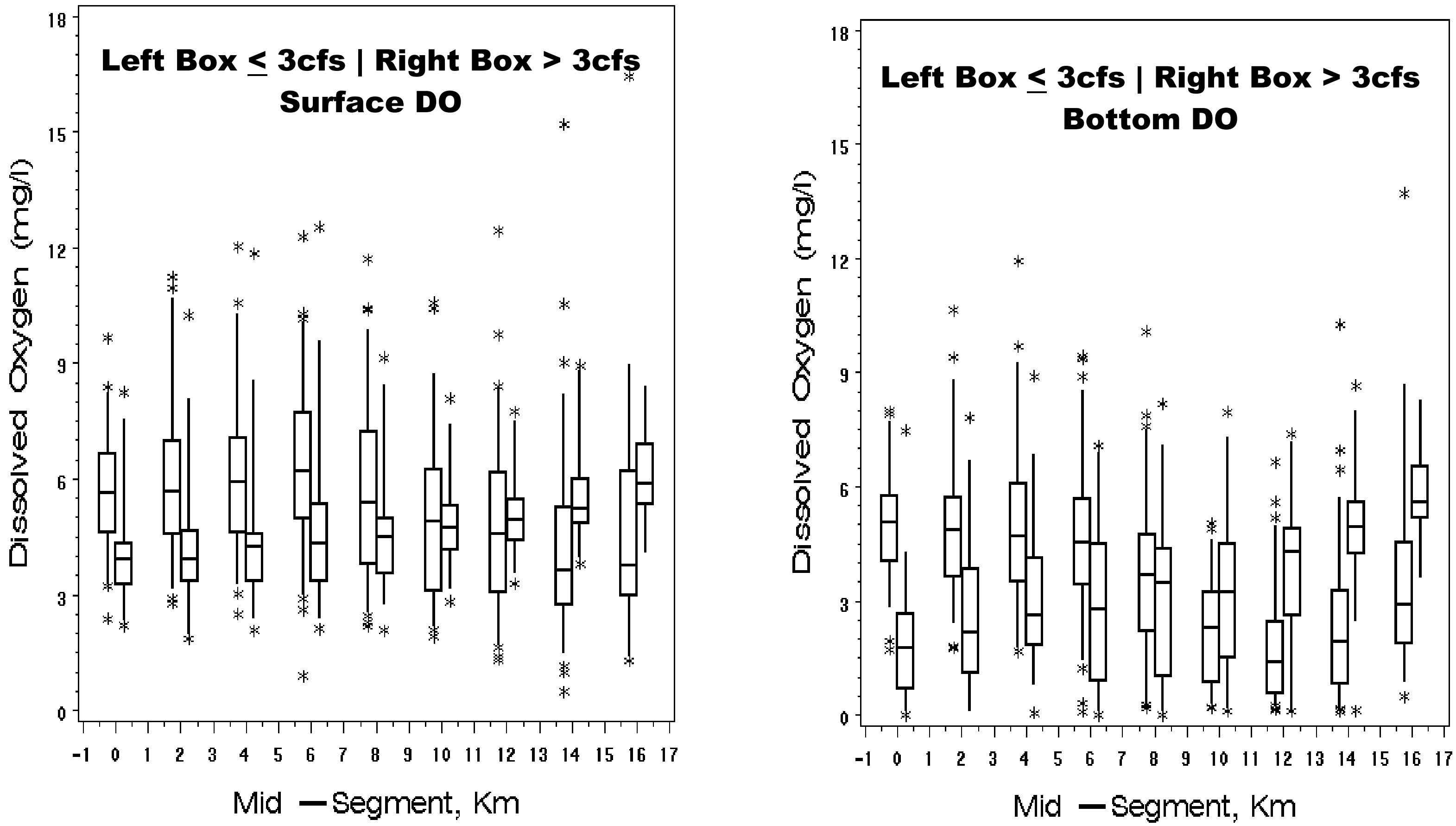

Figure 3-22. Box and whisker plots of surface and bottom dissolved oxygen concentrations in two-kilometer segments in the Lower Hillsborough River for flow and no flow conditions. Data taken from the HBMP and the EPCHC HIMP programs during 2000-2002.

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Figure 3-23

EPCHC Period of Record Data

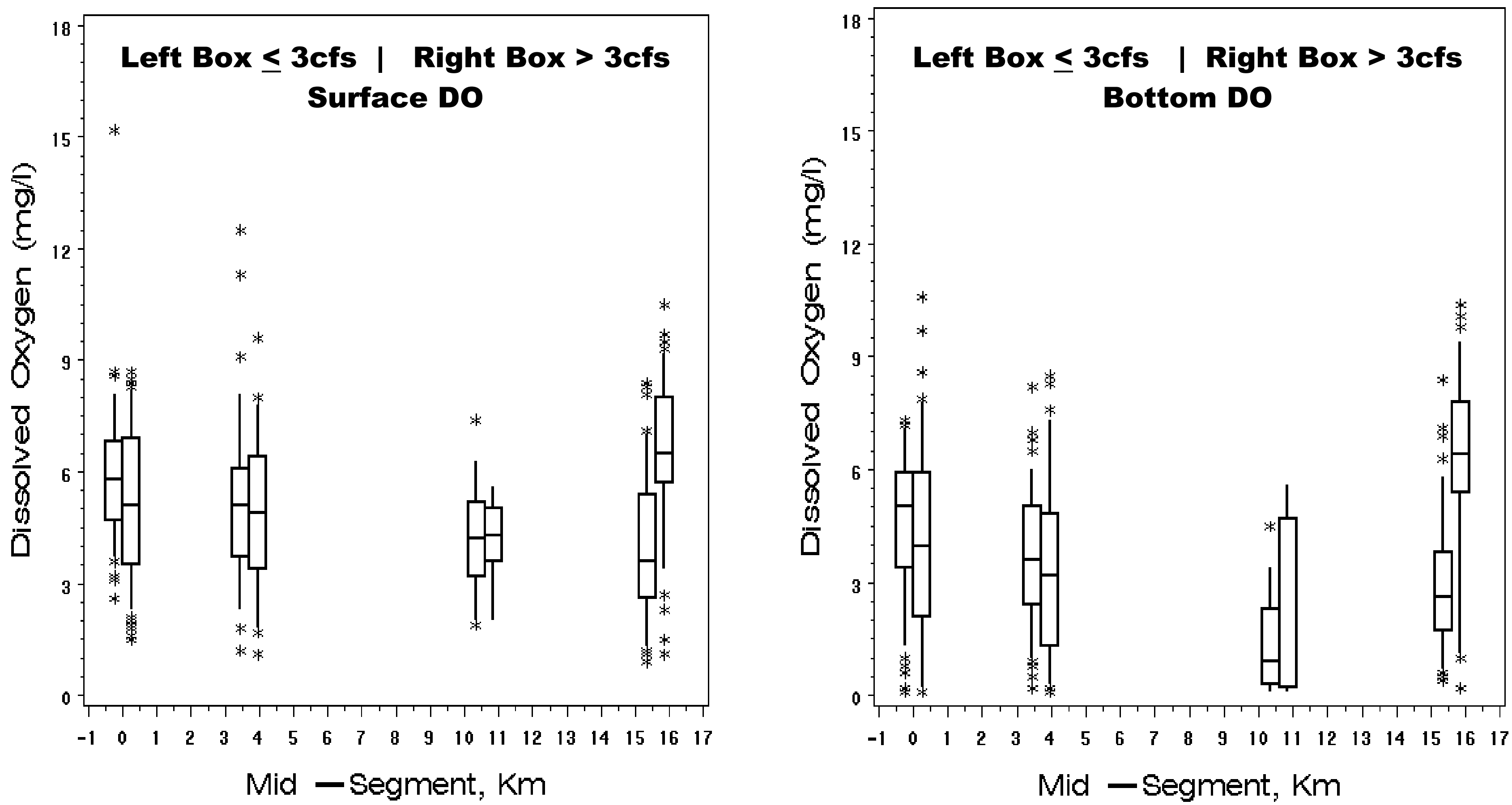

Figure 3-23. Box and whisker plots of surface and bottom dissolved oxygen concentrations for the periods of record at EPCHC ambient monitoring stations on the Lower Hillsborough River for flow and no flow conditions.

of the river between the dam and Sulphur Springs, as this is where flow from the spring has its greatest effect on salinity distributions, density gradients, and DO concentrations. The results presented below are taken from SWFWMD data collection at fixed location stations conducted for the re-evaluation of minimum flows for the Lower Hillsborough River.

The effect of four rates of freshwater flow on salinity and DO in the river above Sligh Avenue are shown in Figures 3-24 A though D. The plot for Nov 21, 1996 was recorded when there was no flow at the dam and flow from Sulphur Springs was 29 cfs (Figure 3-24A). Salinity values at stations just below the dam (above km 14.7) were near 9 ppt, with no difference between surface and bottom values. Further downstream surface salinity values were lower, reflecting the effect of Sulphur Springs on shallow layers. The salinity of bottom waters increases to values between 15 and 19 ppt, however, resulting in a highly stratified water column in this reach of the river. Dissolved oxygen concentrations show the effect of this density stratification, as bottom DO concentrations drop to hypoxic levels (<2 mg/l) below km 14.7.

Profiles from May 20, 2002 and May 30, 2003 represent low flow conditions at the base of the dam. On May 20, 2002, there was no discharge from the reservoir spillway, but 10 cfs of spring water was routed to the base of the dam (Figure 3-24 B). Salinity values were 1.2 ppt at most upstream station (km 15.8), slowing increasing downstream with a sharp rise in bottom salinity around km 14. Bottom dissolved oxygen concentrations declined rapidly in the first kilometer below the dam and were near anoxic (0 mg/l) in the highly stratified region below km 14.5. An unusual occurrence was DO values below 3 mg/l in surface waters between km 12.5 and km 15.

The plot of May 30, 2003 corresponds to a flow of 47 cfs from the reservoir (Figure 3-24C**)**. This rate of flow established well-mixed, freshwater conditions upstream of km 13.5, with a sharp increase in bottom salinity further downstream. Bottom dissolved oxygen concentrations followed this density pattern, being above 5 mg/l above 13 km and near anoxic at points downstream where the water column was stratified. The profile for February 19 represents the highest flow in the series, 350 cfs of flow from the reservoir spillway (Figure 3-21 D). This rate of flow created freshwater conditions and well oxygenated waters past km 10.5.

These results indicate that freshwater inflows provide an improvement in DO concentrations downstream of the dam as far as freshwater or low salinity conditions are achieved. Downstream of this limit, where density stratification becomes prevalent, bottom hypoxia may again appear. With regard to the management of flow from Sulphur Springs, normal flow from the spring creates a shallow lens of low salinity water and bottom hypoxia near the spring outfall. Moving some of this water to the base of the dam, as allowed by the District's minimum flow rule for the Lower Hillsborough River, provides a net benefit to the river by creating a small zone of low salinity water below the dam that has improved dissolved oxygen concentrations. Studies are currently

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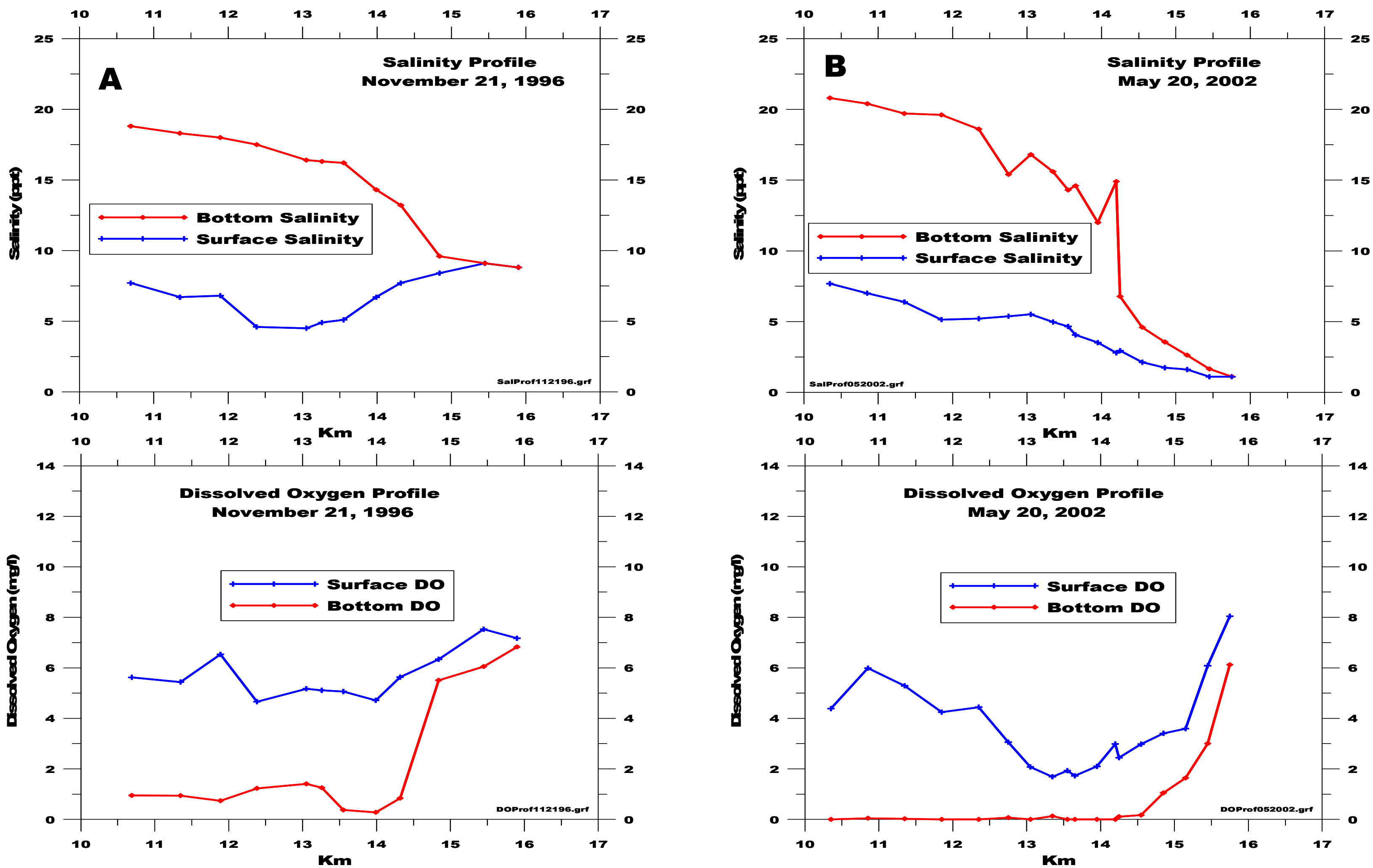

Figure 3-24 A and B. Longitudinal gradients of surface and bottom salinity and dissolved oxygen concentrations in the lower river between kilometer 10 and the dam for November 21, 1996 and May 20, 2002.

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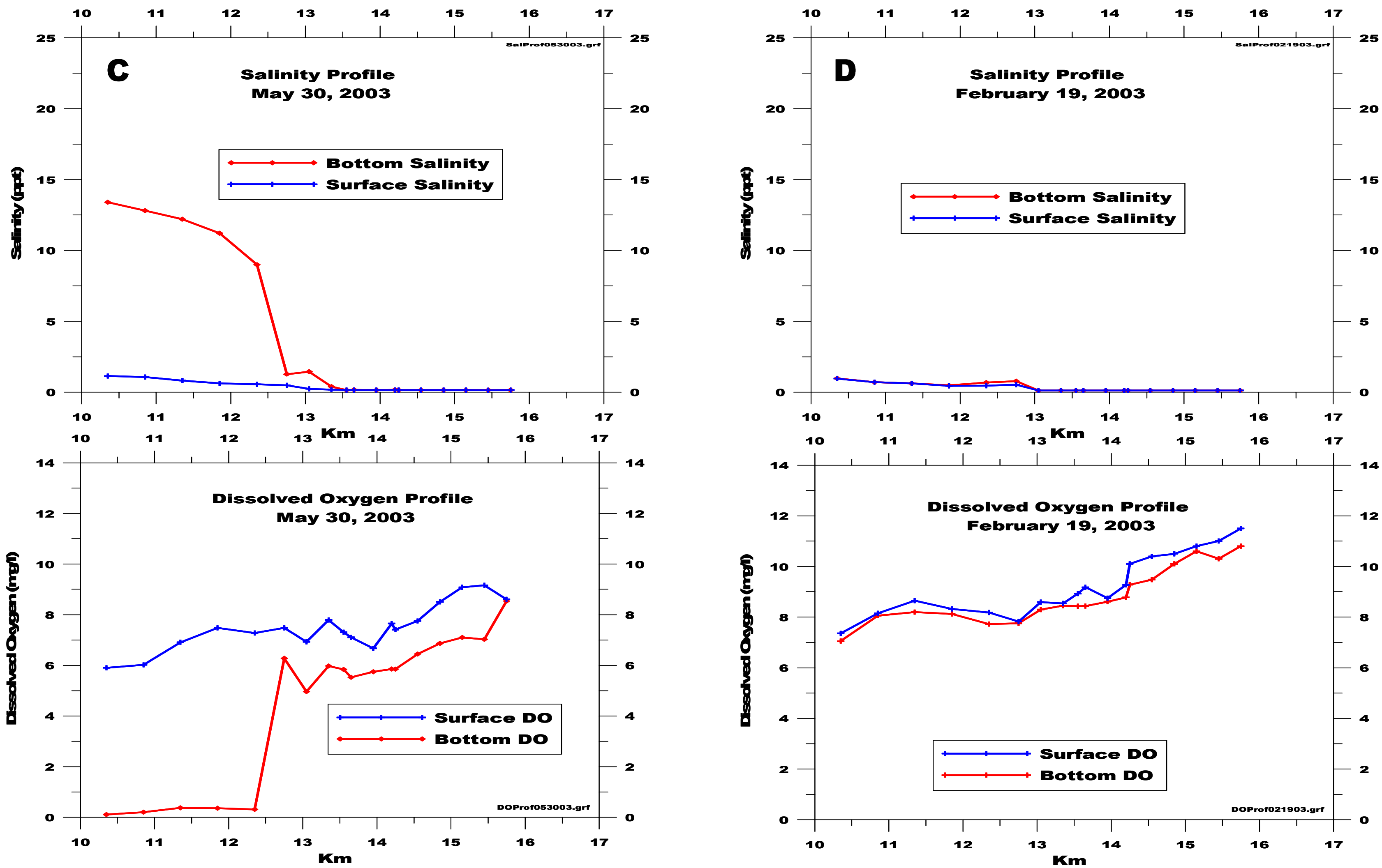

Figure 3-24 C and D. Longitudinal gradients of surface and bottom salinity and dissolved oxygen concentrations in the lower river between kilometer 10 and the dam for May 30, 2003 and February 19, 2003.

underway to test the effect of flows in excess of 30 cfs on the river reach below the dam. Various water sources are being considered to meet a possible revised minimum flow for the Lower Hillsborough River. Diversions from Sulphur Springs could be used to provide a portion of such a minimum flow, as long as the minimum flows for the spring run are met.

3.10 Biological characteristics of the Lower Hillsborough River and relation to the management of Sulphur Springs

The principal sources of biological information for the Lower Hillsborough River are WAR/SDI (1995) report and the interpretive report for the ongoing HBMP project (PBSJ 2003). The goals and time periods of these studies were described in previous sections of this report. General findings from these studies are discussed briefly below as they relate to the relationships of discharge from Sulphur Springs on the biota of the lower river. Vegetation, macroinvertebrate, and fish communities are discussed first, followed by a discussion of the use of the lower river by an endangered species, the Florida manatee (*Trichechus manatus latirostris*).

3.10.1 Intertidal vegetation

Both the WAR/SDI and HBMP projects described the distribution of shoreline vegetation along the length of the Lower Hillsborough River. The linear and areal extent of vegetation along the lower Hillsborough is limited compared to other tidal rivers in the region due to the urbanized character of the Lower Hillsborough. However, there are distinct gradients in the species composition of vegetation communities along the length of the lower river, and in many reaches, shoreline vegetation provides useful habitat and cover for fishes and macroinvertebrates.

The shoreline inventory conducted by WAR/SDI (1995) classfied shorelines as natural or altered, depending on the degree of modification and presence of vegetation. Approximately 24% of the river shoreline was characterized as natural. The majority of the natural shoreline was located upstream of Sulphur Springs, although patches of natural shoreline extended downstream to North Boulevard. There was no natural shoreline in the most downstream 8 km of the lower river. This study also identified various plant species in 13 contiguous reaches of the river as present or dominant. Upstream from Sulphur Springs, leatherferrn (*Acrostichum danaefolium*), bald cypress (*Taxodium distichum*), paragrass (*Brachiaria mutica*) and seaside paspalum (*Paspalum vaginatum*) were listed as dominant, with a number of other species listed as present. Further downstream, a number of species were found between Nebraska and Buffalo Avenues, with cattails (*Typha* sp.) being the most frequently occurring and dominant plant.

The HBMP project (PBSJ 2003) mapped the linear and areal extent of various vegetation communities along the lower river. The lower river contained approximately 2.03 hectares of emergent wetlands vegetation, with areas of the most wetlands occurring between kms 6 and 8.5 and upstream of Sulphur Springs. Nine vegetation associations were identified, which were aggregated to seven groups for purposes of analysis. Leatherfern and mixed herbaceous wetlands were the dominant groups immediately below the dam. Much or the area from km 12 to 15 has sharply incised banks that do not support much vegetation, although leatherfern was found there. Cattails spanned much of the river, comprising much of the emergent vegetation from km 4 to the region below the dam.

3.10.2 Benthic macroinvertebrates

Both the WAR/SDI and HBMP studies found spatial and temporal patterns in the species composition of macroinvertebrate communities that corresponded to salinity gradients in the lower river. Both studies found freshwater and estuarine species in the lower river. As expected, freshwater species were most abundant in the upper reaches of the river and increased their distribution after prolonged flow events. Using a fixed station design in which the same sites in the river were samples repeatedly, WAR/SDI (1995) reported that freshwater species were periodically found at stations 3 and 5, the latter of which is located about 3 km downstream of Sulphur Springs. During periods of no discharge from the dam, these sites were increasingly colonized by estuarine species.

WAR/SDI also pointed out that there were frequently low bottom dissolved oxygen concentrations at sites 3 and 5 during periods of no discharge from the dam, which contributed to low abundances of invertebrates in deep mid-channel areas. The pronounced density stratification that occurs in the upper river during periods of no flow from the dam is a major factor contributing to this hypoxia. Benthic macroinvertebrates were collected in shallow waters at sites 3 and 5 in the second year of the WAR/SDI study and much greater invertebrate abundances were found, apparently due to improved dissolved oxygen concentrations at the shallower depths.

Using a probabilistic design, PBSJ (2003) presented macroinvertebrate data for upper and lower sections of the river, including graphics for various parameters in one kilometer intervals. Several taxa showed gradients in their distribution in the river, either increasing in an upstream or downstream direction, or with peak abundances in the middle reaches of the river. There was a disproportionate number of species which showed either their first or last occurrence in the most downstream 3 kilometers in the river, indicative of a progression to a more saline, bay-like fauna in that reach of the river. Abundances of more freshwater organisms (e.g. chironomids) increased toward the dam. Like WAR/SDI, PBSJ found a zone of minimum organism abundance and diversity just downstream of Sulphur Springs near kilometers 10 and 11, with hypoxia being the likely causative factor.

In general, these studies demonstrate strong relationships between salinity gradients in the lower river and distribution of benthic macroinvertebrates. As discussed in Section 3.9, flows from Sulphur Springs provide a majority of the inflow of low salinity water to the river for much of the year and exert a strong influence on salinity gradients in the lower river during dry periods. Hypoxia that is related in part to density stratification in the river also exerts a strong influence on benthic populations, particularly downstream of Sulphur Springs. The potential effects of removing or diverting waters from Sulphur Springs on salinity distributions and dissolved oxygen concentrations are discussed further in Chapters 4 and 5 of this report.

3.10.3 Fishes

A range of life stages of fishes in the Lower Hillsborough River has been sampled as part of the WAR/SDI and HBMP studies using plankton nets, seines, and trawls (trawls in HBMP only). Thorough discussions of those results are presented in those reports. Some basic findings are presented below as they pertain to the management of flows from Sulphur Springs.

The fish fauna of the lower Hillsborough River contains both freshwater and estuarine/marine species. The WAR/SDI study found that true freshwater species were restricted to the most upstream stations (at kms 3 and 6). Native freshwater species that were collected included largemouth bass (*Micropterus salmoides*), the redear (*Lepomis microlophus*), bluegill (*Lepomis macrochirus*) and spotted (*Lepomis punctatus*) sunfishes; the bluefin *(Lucania goodei*), marsh (*Fundulus confluentus*) and least (*Heterandria formosa*) killifishes; the mosquito fish (*Gambusia holbrooki*), and the golden shiner (*Notmemgonus crysoleucas*). Three species of the family Cichladae, which are non-native species that have been introduced to the lower river, were also collected in the upriver areas. The HBMP study also recorded freshwater species, but generally in low abundance. It is likely that the very high salinities values that occurred in the river during the 2000 –2002 drought reduced the abundance of freshwater fishes in the lower river. By providing most of the inflow of low salinity water in the dry season, Sulphur Springs plays an important role in maintaining the viability of freshwater fish populations by acting to reduce salinity in the lower river.

The fish fauna of the lower river is dominated by saltwater species that are either estuarine residents of transients. Estuarine residents are those species that spend most of all of their life cycle in the tidal river, and include numerically dominant species such as silversides (*Mennidia* spp), hogchoker (*Trinectes macrulatus*) and members of the killifish families Cypridontidae, Fundulidae and Poecillidae. Estuarine transients are those species which are dependent upon and use the estuary during some part(s) of their life cycle, which for some species may have a strong seasonal component. Common estuarine transient species in the lower Hillsborough River include the yellow menhaden (*Brevortia smithii*), black drum (*Pogonias cromis*), spot *(Leiostomus* *xanthurus*) red drum (*Sciaenops ocellatus)*, sand seatrout (*Cynoscion arenarius*), snook (*Centropomus undecimalis*) and mullet (*Mugil cephalus*). The numerically dominant bay anchovy (*Anchoa mitchilli*) can be considered a transient in the lower river as adults are more abundant in the bay, but all life stages are found within the lower river.

Various resident and transient species show distributional patterns and areas of peak abundance in the tidal river. WAR/SDI reported that the numerically dominant *Menidia berrylina* and a number of other species were most abundant in mid-river areas. As previously described, freshwater species increased toward the dam, while a number of estuarine species (*Funduluds similes*, *Pogonias cromis*, *Sciaenops ocellatus*, *Mugil cephalus* and *Cynoscion arenarius)* increased toward the mouth of the river. PBSJ (2003) calculated center of abundance (COA) values to represent the kilometer location of peak density to describe distributional patterns for each species. Many species had COA values in the upper part of the river. For example, of the seven most abundant taxa collected, five had COA values above 9 kilometers. However, the COA for most abundant species in the river (*Anchoa mitchilli*) was further downstream at kilometer 5.4

Studies from other tributaries to Tampa Bay that are less altered than the Hillsborough River demonstrate that many estuarine transient fish species enter tidal rivers during larval and juvenile stages and concentrate in low and mid-salinity waters (Peebles and Flannery 1992, Peebles 2002). Freshwater inflows and the presence of low salinity waters influence the presence and distribution of fish species within the lower Hillsborough River. WAR/SDI pointed out that the Hillsborough River contained more freshwater and estuarine fish species compared to the Palm River, where salinity values were higher and the fauna was more marine.

It is the conclusion of this report, that by exerting a pronounced effect on salinity distributions, flows from Sulphur Springs are likely a significant factor affecting fish distributions in the lower river, particularly in the dry season. During a study period that was unusually dry, PBSJ (2003, page 4-31) remarked that fish density was significantly greater in the upper river, specifically near kilometer 14, just upstream of Sulphur Springs. They suggested that the location of peak density might have been related to the flow of water from the spring, as well as the availability of habitat that is suitable for sampling.

Low dissolved oxygen concentrations also affect fish distribution and abundance in the lower river. Based on an assessment of early life stages, WAR/SDI found that the Lower Hillsborough had poor recruitment into the larval and juvenile age classes compared to the Little Manatee River. These are stages during which many species become oriented to bottom substrates and benthic feeding. They suggested that hypoxia in bottom waters was a factor in this poor recruitment, either by its direct effects on the early life stages or by reducing the density of fish food organisms in bottom waters. By affecting density stratification in the river reaches near the spring, manipulation of flows from Sulphur Springs could have a localized effect on fish populations in the lower river through its interactions with dissolved oxygen.

3.11 Thermal characteristics of the spring run and the lower river and use by cold sensitive species

The list of estuarine species that utilize the lower Hillsborough River is linked to the populations that inhabit Tampa Bay. Although it is classified as a sub-tropcial estuary, Tampa Bay is in the northern limits of the geographic range for a number species that occur on the west coast of Florida. For example, hard freezes can kill or damage mangroves in upper regions of the bay (Lewis and Estevez 1988) and cause mortality of a number of cold-sensitive fishes, including the prized gamefish snook (Gilmore et al. 1978; Shafland and Foote, 1983).

By providing flow of water that is largely isothermal year round, Sulphur Springs provides a thermal refuge in the spring run for cold-sensitive species during winter fronts. The spring also mediates to some extent the effect on cold fronts on the water temperatures in the lower Hillsborough River. This is particularly important for the use of the river by the Florida manatee (*Trichechus manatus latirostris*), a marine mammal that is currently on the United States Department of the Interior endangered species list.

During summer months, manatees migrate freely between rivers, bays and other coastal waters on both Florida coasts, and have been reported as far north as Virginia, with frequent sitings in Georgia and North Carolina. During winter months the United States manatee population is largely restricted to peninsular Florida. During the coldest part of winter, manatees in coastal Florida waters seek areas of warmer water temperatures, such as near the discharges from artesian springs or electrical power generation plants. Manatees begin to seek thermal refuge when water temperatures fall below 20^{o} C., and are usually not present in an area when water temperatures fall below 15^{o} C. Manatees that are unable to leave an area with water temperatures of less than 10^{o} C will likely die within two days (B. Ackerman, personnel communication).

Manatees are periodically observed in the Lower Hillsborough River, especially in or near the Sulphur Springs Run. Data on use of the river/spring system are available from the Marine Mammals Program of the Florida Fish and Wildlife Conservation Commission (FWC). Information gathered from interviews with FMRI staff (B. Ackerman, personal communication) and data from the FWC photo-identification effort are summarized below.

Manatee use of lower river and spring run was documented as part of a six-year radio-telemetry project of manatees that over-wintered at the Apollo Beach power plant on Hillsborough Bay (FWC written communications). In 1991, forty-seven manatees were tagged with radio transmitters following their capture in Tampa Bay. The project was continued until February 1997 when the last radio transmitter was removed. Seven of the tagged animals, including five males and two females, utilized the Hillsborough River during the time they were tagged. Only one of the tagged animals was located in the Hillsborough River during the winter. The remaining animals occurred in the river during non-winter months. The use of the river is likely related to access to fresh water, as manatees seek fresh water to drink. Use of the river varied from quick trips to the spring run or dam spillway to extended stays in the river for two to three days. Manatees were observed feeding on cattails and floating vegetation.

In August 1992, one of the tagged manatees was observed with nine others upstream of the springs. One of the tagged females was observed in the river with her calf in the summer of 1995 and then with a second calf in the fall of 1996. Although there are no specific data for manatees giving birth in the Lower Hillsborough River, it may be a calving area, as are other rivers in the Tampa Bay area.

Other documentation is recorded by FWC as part of a recent photo-identification program, in which sites are visited and photographs are taken of manatee use. FWC staff visited the spring on two dates in January and December of 2002, and on six dates between January and March of 2003. Manatees were observed at Sulphur Springs on half of these eight dates, with two animals observed on two dates and four animals on one date. The staff report that the manatees generally congregate in the lower pool, but have been observed in the upper pool. FWC staff visits the spring run at high tide because manatees have trouble accessing the spring when tides are low due to shallow water depths.

In summary, Sulphur Springs is not a major over wintering site for manatees in Tampa Bay, as there are much larger and warmer thermal refuges available at the nearby Apollo Beach power plant. However, manatees are observed in the lower river and spring run during winter months and experience thermal benefits from the spring discharge.

The seasonal thermal characteristics of the spring run and lower river are described in the section below. Criteria that were used to evaluate the effects of removing or diverting flow from Sulphur Springs on a thermal refuge for manatees in the Lower Hillsborough River are described in Chapter Four. The results of thermal modeling simulations in which various quantities of springflow were removed from, or re-routed within, the river/spring system are presented in Chapter Five in support of the determination of minimum flows for Sulphur Springs.

3.11.1 Thermal characteristics of Sulphur Springs pool and run

Water temperature data for the Sulphur Springs complex are available as monthly values from the spring pool collected by the City of Tampa and 15 minute values measured at three continuous recorders in the spring pool, the upper spring run, and mouth of the spring operated by the USGS. The average water temperature for the spring pool was 25^{o} C for 1991-2003 based on the monthly City data. The pool temperature exhibited a slight seasonal pattern over this period (Figure 3-25), but the monthly variations were very small (standard deviation = 0.4^{o} C).

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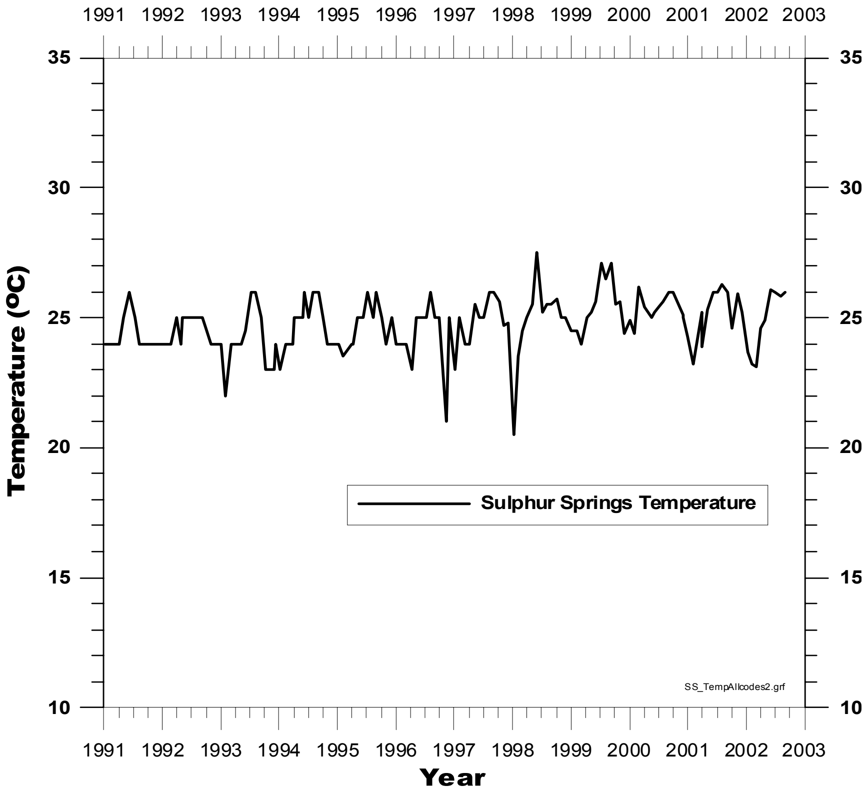

Figure 3-25. Seasonal temperature variations in Sulphur Springs pool taken from monthly data recorded by the City of Tampa

Average daily water temperatures at the continuous recorders in the spring pool and upper spring run are plotted in Figure 3-26 along with withdrawals from the spring pool. Similar to the monthly data, daily temperatures in the pool display a very minor seasonal variation, generally fluctuating within one degree of a mean temperature of 25^{o} C. When there are no withdrawals from the spring, water temperature in the run closely tracked the temperature of the pool. When withdrawals occurred, temperatures in the run varied from the pool temperature, being colder in the winter months and warmer in the summer months. These deviations represent the movement of water from the Hillsborough River into the run during withdrawals. Withdrawals during October or April do not cause such temperature changes in the run, as the river and spring are near the same temperature during these months.

A similar relationship is seen at the mouth of the spring (Figure 3-27). Like the results for salinity (Section 3.4), these data indicate the thermal characteristics of the upper and lower run are very similar to the spring pool in the absence of withdrawals. However, withdrawals can affect temperature in the run depending on the magnitude of the withdrawal and water temperatures in the river at the time of the withdrawal.

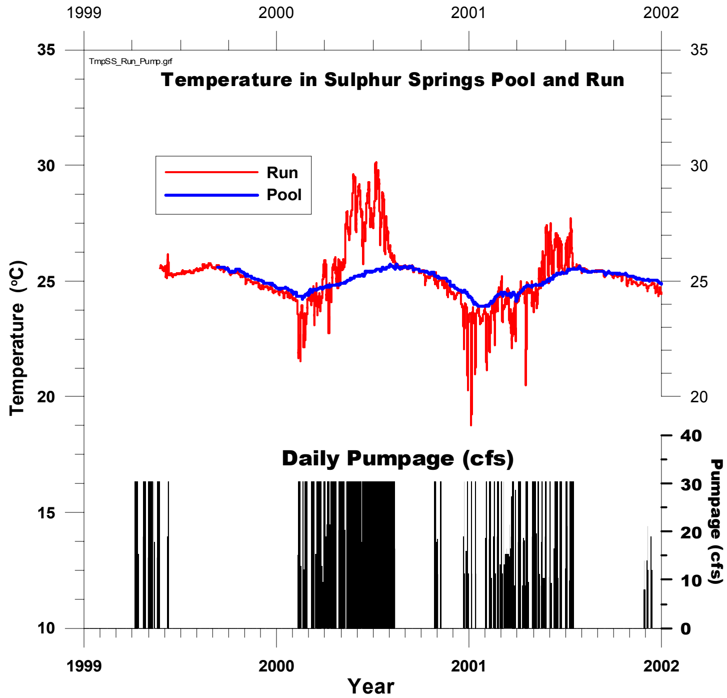

Figure 3-26. Comparison of water temperatures in Sulphur Springs pool and the data recorder in the upper spring run over withdrawals from the spring pool.

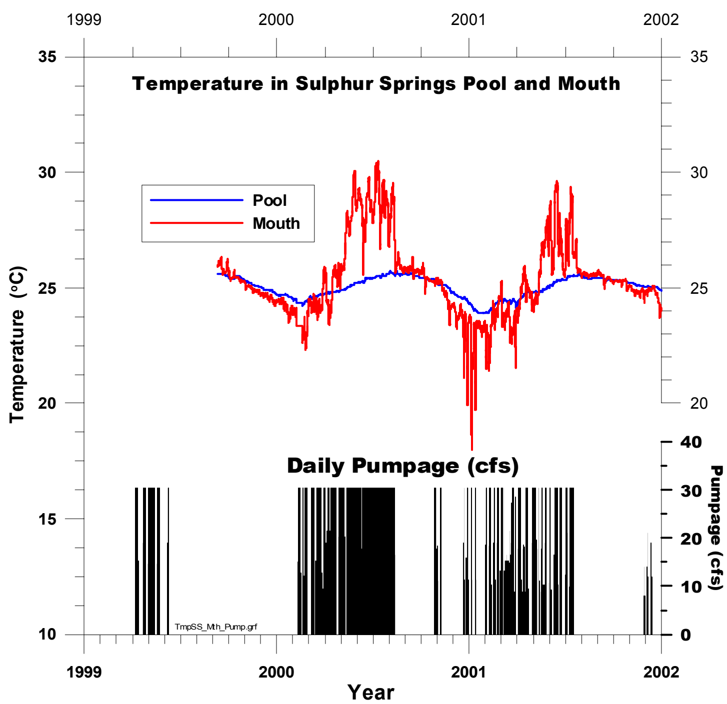

Figure 3-27. Comparison of water temperatures in Sulphur Springs pool and the data recorder at the mouth of the spring run over withdrawals from the spring pool.

3.11.2 Thermal characteristics of the Lower Hillsborough River

Average yearly water column temperatures for the period of record at four stations in the Lower Hillsborough River measured by the EPCHC range from 24.13 to 24.80^{o} C (Table 3-4), which are near the average temperature for Sulphur Springs. Mean water temperatures are similar among stations; the largest difference in annual means is for middle depths (0.94^{o} C), while surface means vary by only 0.31^{o} C.

Table 3-4 Mean water temperatures (^{0}C) for four stations monitored by the Environmental Protection Commission of Hillsborough County for 1999-2002.

Station	Kilometer	Surface	Middle	Bottom	Water column mean
Platt		24.5	24.6	24.5	24.5
Columbus		24.2	24.9	25.0	24.7
Sligh		24.2	25.0	25.2	24.8
Rowlett		24.2	24.1	24.1	24.1

Despite this similarity in mean values, spatial and seasonal temperature variations are more pronounced and show a consistent pattern among stations**.** Box and whisker plots of monthly water column temperatures for the period of record at the four EPCHC sites are shown in Figure 3-28. Median monthly temperatures (Appendix F) are at or below 20^{o} C for December, January and February of the year at the Platt, Columbus, and Rowlett stations. These represent months when there would be a frequent need for thermal refuge for manatees in the lower river.

Median water column temperatures at Sligh Avenue remain near or above 20^{o} C for these months, indicating the reach of the river below Sulphur Springs tends to stay warmer during the winter. The period for Sligh Ave shown in Figure 3-28 is considerably shorter than the other stations, which could affect these results. To correct for differences in period of record, monthly mean and minimum water temperatures for the 1999 – 2002 at these stations are plotted in Figures 3-29 A and B**.** Median and minimum temperatures at Sligh are again warmer than the other stations in the winter months, indicating this reach of the river may have thermal advantages for manatees and other cold sensitive species. During summer months, median water temperatures in the upper reaches (Rowlett and Sligh) remain cooler than the lower reaches, probably reflecting the flow of water from Sulphur Springs and also the Hillsborough River reservoir. Seasonal water temperature fluctuations were greatest at Platt station near the mouth of the river, which is more closely affected by water temperatures in Tampa Bay.

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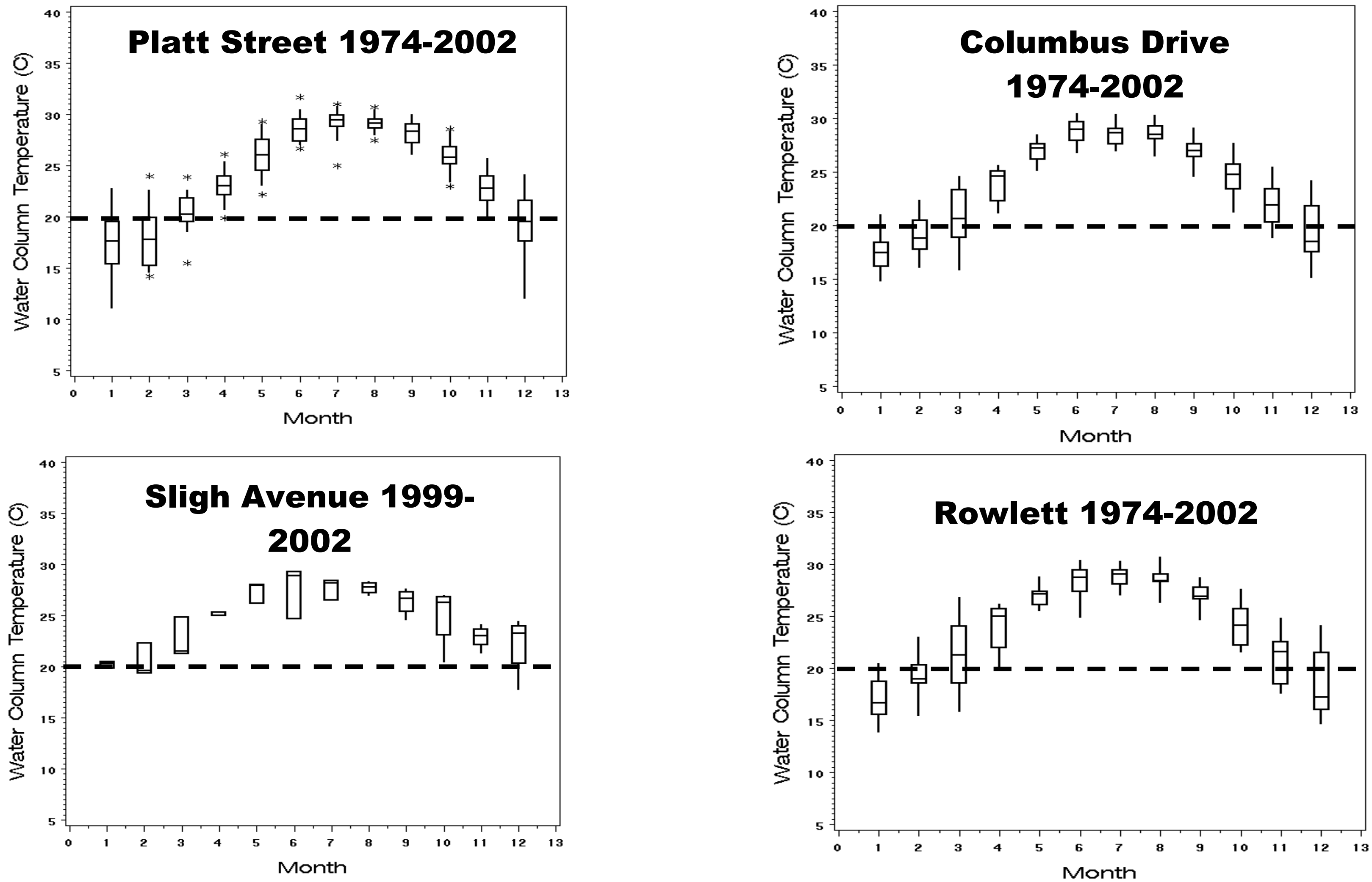
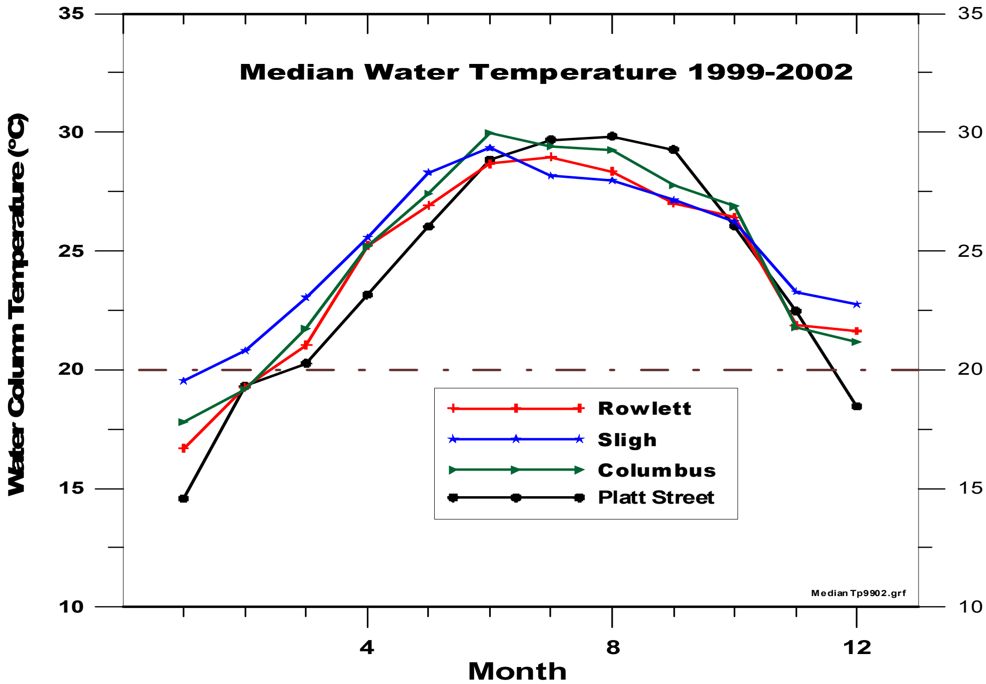


Figure 3-28. Box and whisker plots of monthly water temperatures for the periods of record at four sites monitored by the EPCHC ambient monitoring program (all depths combined).

Figure 3-28



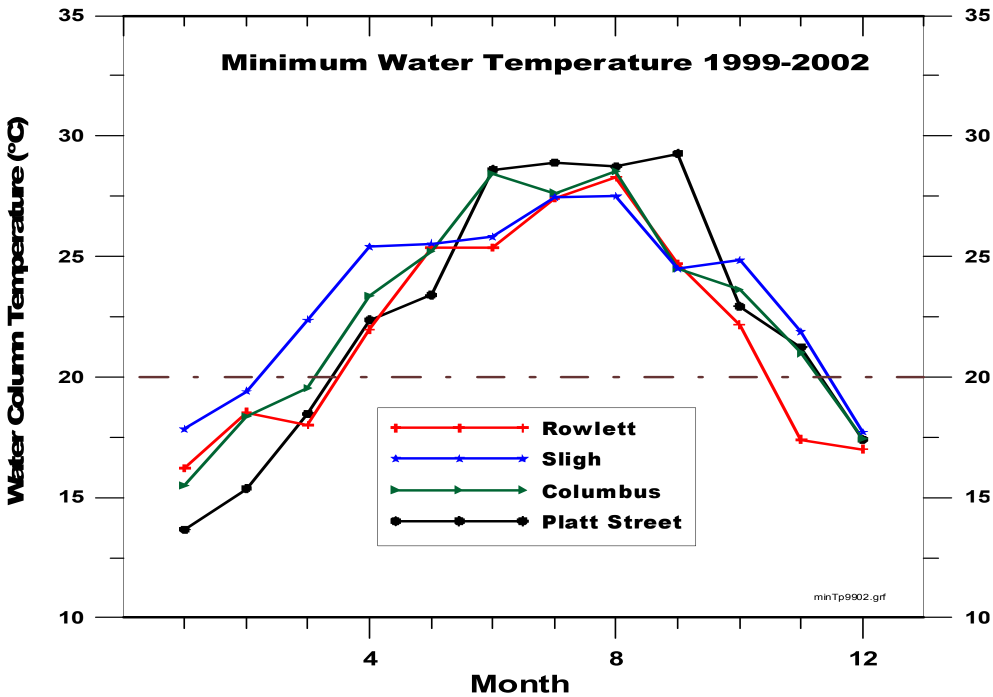


Figure 3-29. Monthly median and minimum water temperatures for four sites in the Lower Hillsborough River monitored by the EPCHC ambient monitoring program for 1999-2002 (all depths combined).

Figure 3-29 A, B

Median and minimum water temperatures calculated at four continuous recorders in the lower river operated by USGS are plotted in Figures 3-30 A and B for 2002. The recorder at I-275 is 100 meters downstream from Sulphur Springs, while the recorder at Hanna's Whirl is 1.7 km upstream of the spring. Again, median and minimum water temperatures are warmer near the spring at the I-275 recorder during January and

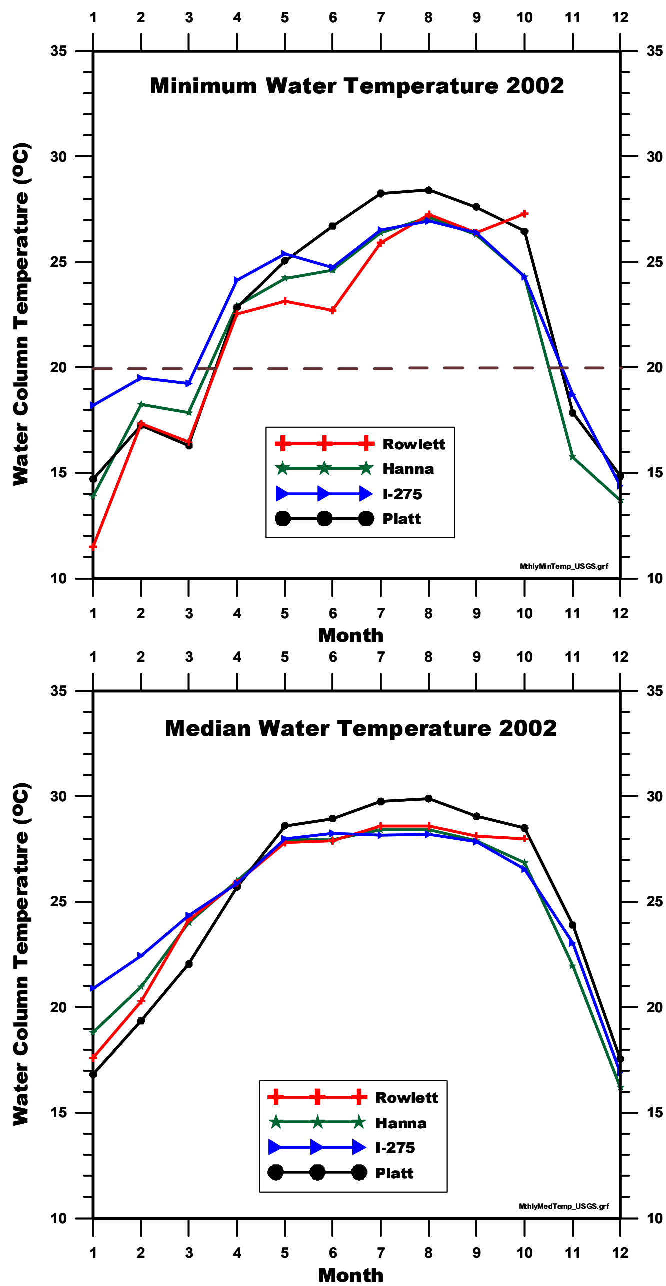


Figure 3-30. Monthly median (A) and minimum (B) water temperatures for four data recorders in the Lower Hillsborough River monitored by the USGS for 2002.

February 2002 when there was no flow from the dam. However, water temperatures at all the stations were similar in December 2002, when flow from the dam averaged 210 cfs. As with the EPCHC sites, water temperatures in the river during summer months are highest near at the mouth of the river at Platt Street.

Time series plots of average daily values for surface and bottom temperatures for the period 1990 - 2002 at the four USGS recorders are shown in Figure 3-31. The period of record is longest at the Rowlett and Nebraska Avenue stations, as data collection at the Platt and Hanna's stations began in the first part of 2001. Data were not available after September 2002 for Rowlett at the time of this report. Water temperatures went below 20^{o} C at all recorders in the river every year. With the exception of the Nebraska Avenue site, water temperature dipped below 15^{o} C every year. The winter of 2002-2003 appeared to be the coldest, as water temperatures at Platt and Hanna were below 15^{o} C for almost two months. Winter water temperatures were somewhat warmer at Nebraska Ave., as temperatures dipped to 15^{o} C only twice in the four years of record.

3.11.3 Vertical and diurnal variations in river water temperatures

Differences between surface and bottom temperatures for these same four recorders are plotted in Figures 3-32. The largest differences between surface and bottom temperatures appear to be near the spring at I-275, followed by Platt. At both stations, there are fluctuations when the surface is either warmer or cooler than the bottom, likely reflecting the effect of short-term meteorological conditions on surface waters. Surface to bottom differences were generally smaller at the Hanna's and Rowlett recorders, which are closer to the dam.

In addition to the spatial, seasonal, and vertical temperature variations, there are significant thermal differences that occur at shorter time scales. Figure 3-33 illustrates diurnal variations in water temperature, expressed as daily ranges in surface and bottom temperatures. Bottom temperatures are generally more stable than surface temperatures, where daily variations in air temperatures have a greater effect. Diurnal swings in surface water temperatures were often in the range of 2-3^{o} C and reached as high as 5-7^{o} C at I-275 on some days. Diurnal temperature variations appeared to be somewhat greater in the upper river, compared to the mouth of the river at Platt St.

3.11.4 Temperature variability and relation to biological use

The results presented above show there are both horizontal and vertical gradients in water temperature in the lower Hillsborough River and these gradients change temporally on short-term and seasonal time scales. Highly motile organisms such as fishes and manatees can migrate in the river to seek suitable temperature regimes in times of temperature extremes. Due to its discharge of relatively stable water throughout the year, Sulphur Springs exerts a clear effect on the thermal characteristics of the lower river, particularly in its upper reaches and during times of no flow from the dam.

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Figure 3-31

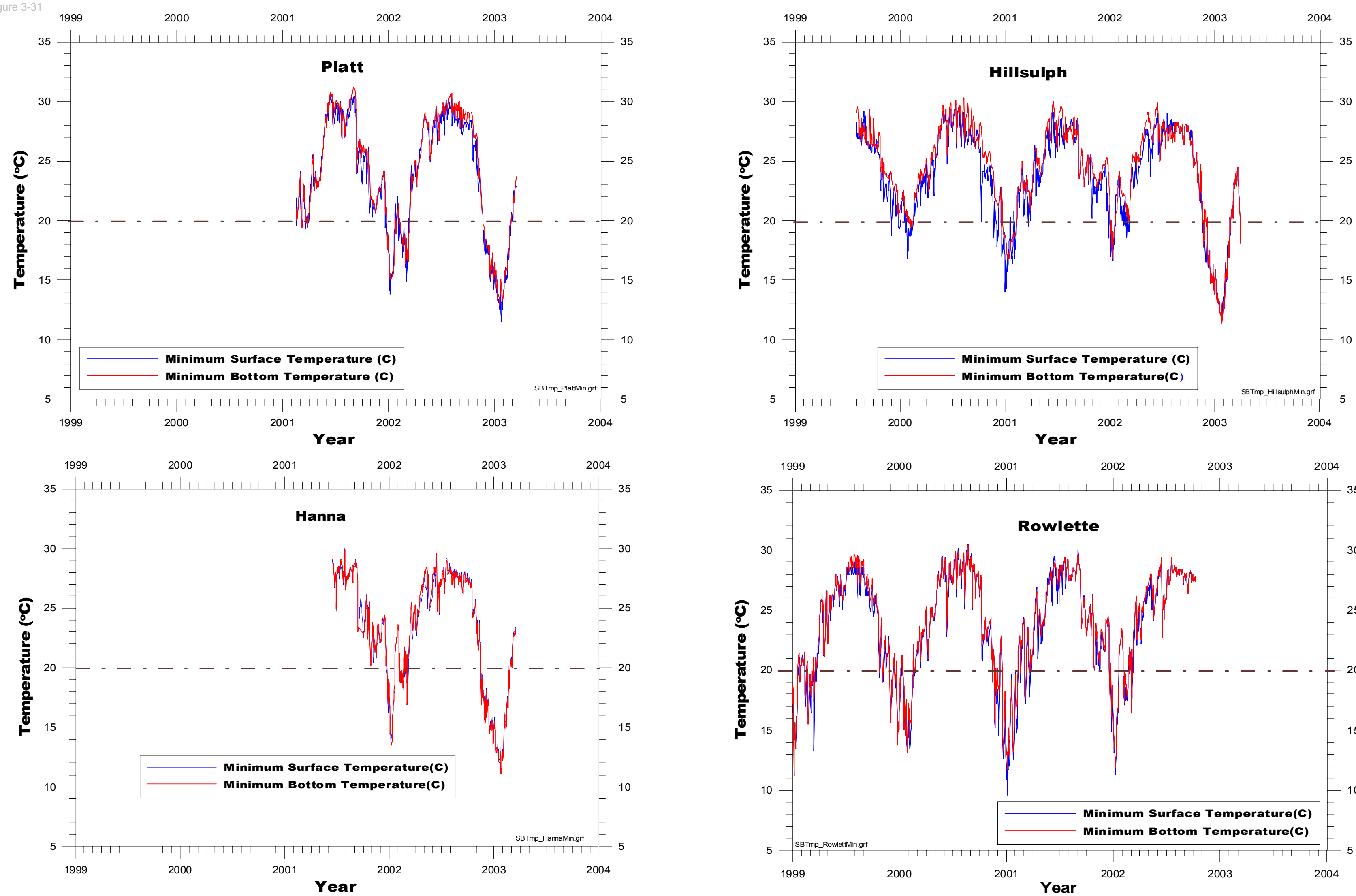

Figure 3-31. Time series of surface and bottom water temperatures at four data recorders in the Lower Hillsborough River operated by the USGS.

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Figure 3-32

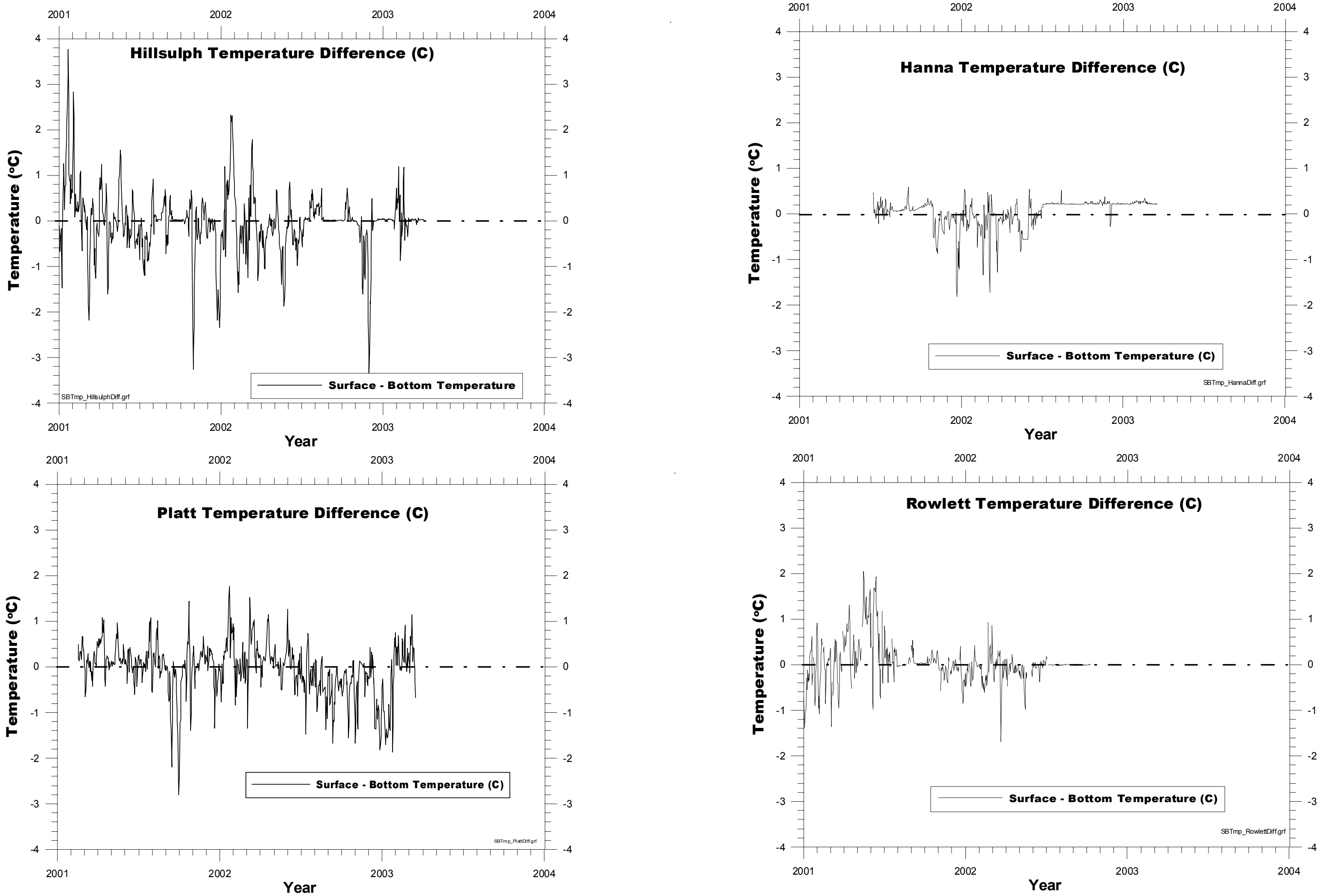

Figure 3-32. Vertical temperature differentials (surface minus bottom) at four data recorders in the Hillsborough River operated by the USGS.

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Figure 3-33

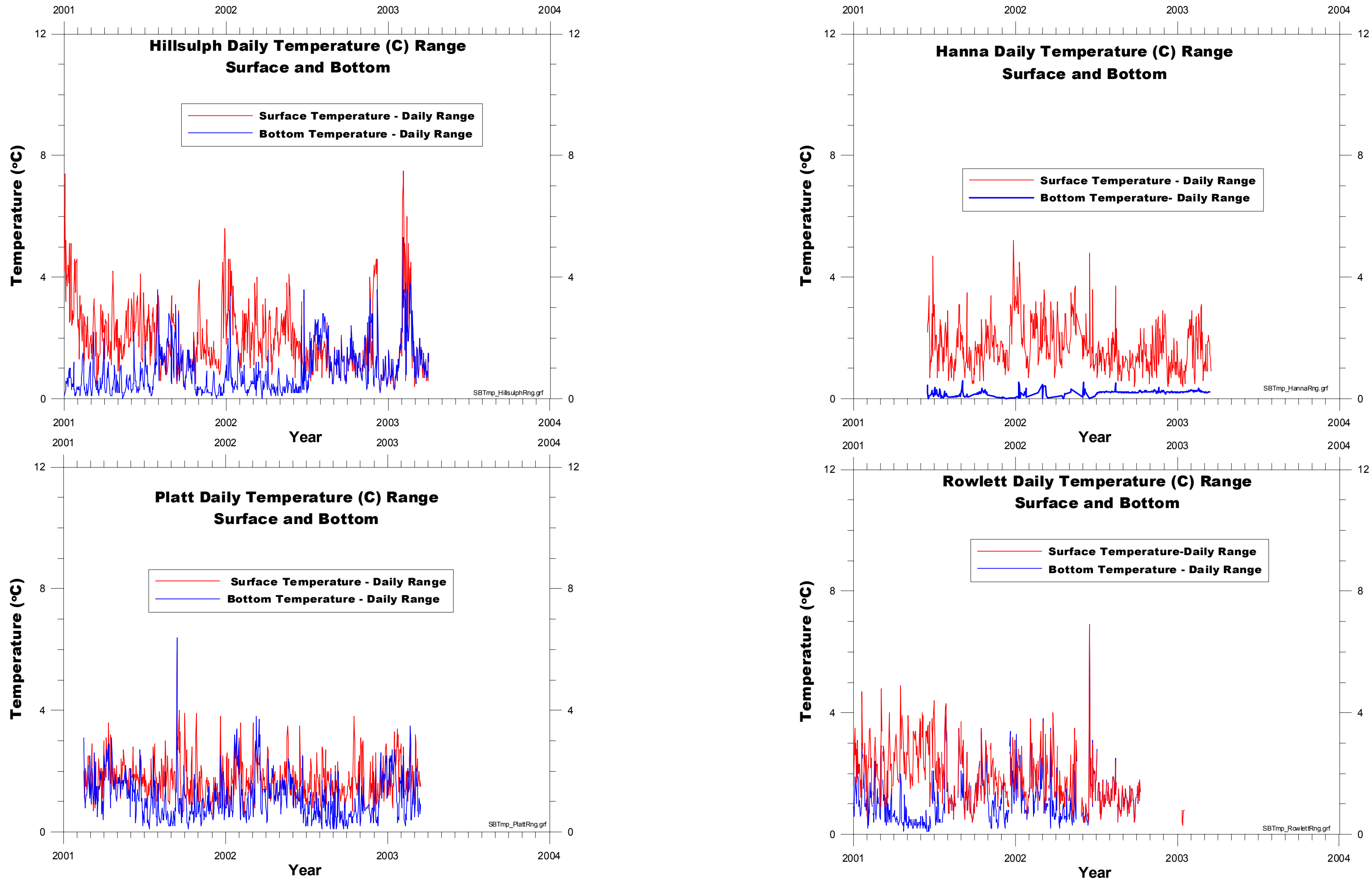

Figure 3-33. Daily ranges of water temperatures (maximum – minimum) for surface and bottom waters at four data recorders in the Hillsborough River operated by the USGS.

The effects of removing or rerouting water from Sulphur Springs on the thermal characteristics of the lower river during cold periods are examined in Chapter 5. A hydrodynamic thermal model of the river is used to evaluate the effects of removing different quantities of spring water from the river or moving it to the base of the dam. These results are used in conjunction with the findings of analyses of salinity distributions and the biological characteristics of the spring run and lower river to evaluate a recommended minimum flow for Sulphur Springs.

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CHAPTER 4

TECHNICAL APPROACH FOR DETERMINING MINIMUM FLOWS FOR SULPHUR SPRINGS

4.1 Overview

The chapter presents the District's approach for determining minimum flows for Sulphur Springs. As discussed in Chapter 3, flows from Sulphur Springs provide important ecological functions to both the spring run and the Lower Hillsborough River. The District's approach to establishing minimum flows for Sulphur Springs therefore considered potential impacts to natural systems in both the spring run and lower river. The resource characteristics and management goals upon which the minimum flows for Sulphur Springs are based are described below. The results of empirical data analyses and mechanistic modeling that were used to determine the minimum flow are described in Chapter Five, along with the proposed minimum flows.

4.2 Consideration of structural alterations to the determination of minimum flows

In keeping with directives provided by Florida Statutes (373.0421(1a) F.S., the District took into consideration structural alterations to the spring and river system in the determination of minimum flows. One of the most important alterations is that the spring pool is enclosed by a circular concrete wall that extends about three feet above the land surface. Under normal operations, the pool is hydraulically isolated from the spring run and is not used as habitat by aquatic biota in the spring run or lower river. As a result of this physical isolation, the determination of minimum flows for Sulphur Springs did not evaluate the ecology of the spring pool proper, but instead focused on the functions of flow from the pool on the downstream biological communities in the spring run and lower Hillsborough River. Other structural alterations, such as the presence of the weir in the run and the hardening of much of the shoreline, were accounted for as they affect the hydraulic and ecological characteristics of the spring run and river system.

The term "minimum flows and levels" is often used to identify regulations that address the hydrologic requirements of natural systems, as many biological communities respond to changes in water levels as well as flow. However, the determination of minimum flows and levels for Sulphur Springs only involved a flow component, as it was concluded that water level fluctuations in the spring pool are relevant only as they affect discharge from the spring pool. Therefore, the term "minimum flows" (without levels) is used throughout this report

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4.3 Consideration of seasonal variations of springflow and relationships to flows from the Hillsborough River reservoir

Other District efforts to establish minimum flows for flowing water bodies have emphasized the maintenance of complete flow regimes, which include natural seasonal variations of low, medium, and high flows that reflect the climatic and watershed characteristics of a particular river system (SWFWD, 2001). District assessments of freshwater inflows to estuaries have similarly emphasized maintaining natural flow regimes by limiting diversions to a percentage of streamflow at the time of withdrawal (Flannery et al. 2002).

The maintenance of a flow regime with natural seasonal variations was not applied to the determination of minimum flows for Sulphur Springs for a number of reasons. First, the flows from Sulphur Springs show subdued seasonal variations, generally fluctuating between 25 and 41 cfs under normal flow conditions. Due to this fairly constant rate of flow and the physical characteristics of the spring run, seasonal variations of physical and water quality variables in the upper spring run are small under normal flow conditions. However, the data collected for this project demonstrate that the ecology of the spring run can be strongly affected by withdrawals and corresponding flow reductions that allow the incursion of high salinity water from the Lower Hillsborough River into the spring run. Therefore, rather than focusing on the seasonal range of flows necessary to maintain the spring run, the District's analysis focused on flow rates that prevent or minimized salinity incursions.

The percentage of inflow to the Lower Hillsborough River comprised by Sulphur Springs typically has a strong seasonal component, but this is primarily due to the effects of withdrawals from the Hillsborough River reservoir on flows from the dam. On the average, there have been no flows from the reservoir to the lower river for about half of the days in recent decades. During these periods, Sulphur Springs is the principal source of inflow of low salinity water to the lower river. When there are flows from the reservoir, the percent of inflow contributed by Sulphur Springs declines greatly. In general, the ecological functions of flows from the spring to the lower river are most critical when there is no flow to the lower river from the reservoir.

As described in Section 2.5.3, the discharge from Sulphur Springs is fairly mineralized and exceeds potable water standards for some constituents. As a result, there has historically been little emphasis to withdraw water from the spring for water supply, except during water shortages when water levels in the Hillsborough River reservoir become low. Since 2001, a portion of the flow from Sulphur Springs has been routed to the base of the Hillsborough River dam to provide minimum flows to the lower river during periods of no flow from the reservoir. An important objective of this minimum flows report is to determine if such diversions can occur and still meet the minimum flow requirements of Sulphur Springs. If they cannot, then minimum flows to the spring will take precedence and other sources of water will have to be used to provide minimum flows at the base of the dam.

The sum of these considerations in that the establishment of minimum flows for Sulphur Springs is a management issue that primarily applies when there is no flow to the lower river from the Hillsborough River reservoir and minimum flows for the lower river are in effect. As a result, the District's minimum flows analysis for Sulphur Springs focused on conditions that occur in the spring run and river during periods of no flow from the Hillsborough River reservoir. It was concluded that these no-flow conditions represent times when the spring run and lower river are most susceptible to impacts that can result from reductions in springflow. Minimum flows adopted for such conditions will protect these resources during high flow conditions at the dam as well.

4.4 Selection of management goals and ecological indicators for evaluating the effects of reduced flows

An important component of a minimum flow evaluation is determining what ecological characteristics of the resource are to be protected from impacts that can result from withdrawals and reduced flows. This approach can be expressed as a series of resource management goals. Each goal can in turn include a group of ecological indicators, or characteristics of the resource for which hydrologic requirements can be identified and the effect of reduced flows evaluated. The selection of ecological indicators is an important step in a minimum flows determination, as it affects the overall evaluation of potential impacts to the ecosystem as flows are reduced due to withdrawals.

The nature of ecological indicators can vary. For example, the hydrologic requirements of a single species, such as a highly prized gamefish, can be quantified and utilized as a valuable indicator. Alternately, the hydrologic requirements of group of species with similar life histories can be used, such as the durations and depths of inundation suitable for wading birds. One approach is to identify the suitable habitat for a group of species and quantify changes in the amount of suitable habitat as a function of water levels or flow. In many cases, relationships between the amount of suitable habitat and flow can be quantified much better than the direct response of a species to a change in flow. By providing suitable habitats, it can be reasonably assumed that the hydrologic requirements of the species using those habitats will be met. The identification of habitats can vary, ranging from inundation of woody snags in a freshwater stream to areas within suitable salinity ranges in estuarine ecosystems.

On many water bodies it is desirable to employ a variety of ecological indicators to account for different components of the ecosystem. These indicators should be ecologically important, in that they account for major components or processes in the ecosystem in question. Collectively, they should be as comprehensive as possible and address the hydrologic requirements of several key resources. Since some components of the ecosystem may be more susceptible to flow reductions than others, it is important that sensitive indicators be selected if they are important to ecosystem processes.

Lastly, the relationship between the indicator and flow should be quantifiable, so that change in the indicator can be expressed and used in determining the minimum flow rates.

The District determined there are three management goals important to the establishment minimum flows for Sulphur Springs, which are: (1) minimize the incursion of high salinity water from the river into the upper spring run; (2) maintain low salinity habitats in the Lower Hillsborough River; and (3) provide a thermal refuge for manatees in the Lower Hillsborough River. The rationale and ecological indicators corresponding to for each of these goals are presented below. This discussion is based on the information presented in Chapter 3 concerning the relationships of flow from Sulphur Springs to the ecology of the spring run and Lower Hillsborough River.

4.5 Goal 1 – Minimize the incursion of high salinity river water into the upper spring run.

As discussed in Section 3.4, salinity data indicate that waters from the Lower Hillsborough River do not move into the upper spring run under normal flow conditions (no withdrawals). However, as flows are reduced by withdrawals, relatively high salinity water (up to 17 ppt) from the river can move into the upper spring run. Data collected by the FDEP and the FWC indicate that high salinity values that occurred in the upper spring run during the drought of 2000-2001 had a major impact on the macroinvertebrate community there, as a number of freshwater species were lost from the spring run. With the resumption of normal flows in late 2001, 2002 and 2003, a number of these species reappeared in the spring run, accompanied by increases in overall species richness, evenness, and diversity. A number of salt-tolerant species that persisted in the spring run during the drought also showed marked increases in abundance with the resumption of normal flows. Many of the species that rebounded with normal flows are important fish food organisms (isopods, amphipods, aquatic insects). Based on these findings, a goal of the District's minimum flow evaluation for Sulphur Springs is to minimize the incursion of high salinity river water into the upper spring run. This goal should provide suitable conditions for many of the freshwater taxa that have been found in the spring run, and maintain the high species richness and diversity that was observed during periods of normal flow.

When there are no incursions of river water, salinity values in the upper spring run typically vary between 1 and 3 ppt on a seasonal basis. Given this salinity range, the upper spring run would not be classified as fresh water (<0.5 ppt) based on the Venice estuarine classification system (Anonymous, 1959). However, many of the freshwater taxa in the spring run have some salt tolerance and can thrive in this salinity range. It is also reiterated that many other invertebrate taxa in the spring run are not true freshwater species, but are euryhaline species that are common in higher salinity conditions in tidal creeks. These species also appear to thrive under normal flows and the corresponding low salinity conditions in the spring run.

It is the conclusion of this report that a threshold salinity value for the upper spring run would not be practical and should not be established. The wide array of species that inhabit the spring run during normal flow have different salinity tolerances. What is well documented is that the likelihood of high salinity values in the run increases as flows from the spring pool decline. Since it is directly related to flow, the ecological indicator that should be managed is the potential for salinity incursions as at function of flow. As will be described in Chapter 5, the frequency and duration of salinity incursions in the upper spring run increase as flows decline. To be most conservative, flows from the spring could be maintained at a rate that prohibits the incursion of river water and this option is discussed in Chapter 5. However, at some lesser rates of flow, salinity incursions are limited to only several hours on the days they occur. It is possible that many of the freshwater invertebrate species in the spring run could tolerate brief salinity incursions. However, useful values for durations of acceptable salinity exposure are not available from the scientific literature for the species in the spring run. Therefore, breakpoints in the flow-salinity relationship are evaluated in Chapter 5 and used to determine the potential for significant harm to the invertebrate community of the upper spring run and minimum flows for Sulphur Springs,

It is concluded that macroinvertebrates represent a sensitive biological community in the upper spring run with regard to salinity. It is also concluded that minimum flows that prevent significant harm to the invertebrate community will also protect the shoreline plants and fishes as well. The plants that inhabit the spring run include species that are found in and along low-salinity reaches of tidal creeks and rivers (see discussion in following section). Sulphur Springs also provides a refuge for a number of freshwater fish species that inhabit the Lower Hillsborough River. As described in Section 3.8, the fish species documented by this study are among the more salt-tolerant freshwater taxa that are found in low salinity tidal creeks. However, the high salinity values that occurred during the 2000-2001 drought probably reduced the survivability of such species in the upper spring run. The frequency and duration of salinity incursions that are considered in the minimum flow analysis in Chapter 5 are well below the high salinity values that occurred during the drought.

4.6 Goal 2 - Maintain low salinity habitats in the Lower Hillsborough River

In contrast to Sulphur Springs, the flow regime of the Lower Hillsborough River is characterized by high seasonal variability, ranging from prolonged periods of no flow at the dam to flow rates in excess of 1,000 cfs in the wet season. Compared to the spring run, the river encompasses a much broader salinity gradient that covers a wide range of salinity values. When there is discharge from the reservoir, salinity values range from fresh water (<0.5 ppt) in the upper regions of the lower river to polyhaline conditions (18-30 ppt) near the river mouth. However, when flows from the dam cease, salinity values in the river can become considerably higher. As described in Section 3.9.2, brackish waters often extend to the base of the dam. The mean salinity value for no flow conditions for the long-term EPCHC sites at Rowlett Park is 5.2 ppt.

The current minimum flow for Lower Hillsborough River was adopted in 2000. As part of that process, the Tampa Bay National Estuary Program facilitated a minimum flows advisory group to the District, which formulated a series of recommendations regarding water resources and ecological criteria necessary to establish minimum flows for the Hillsborough River downstream of the dam. The advisory group formulated five recommendations, two of which dealt with the salinity regime of the lower river. The first was to maintain a salinity gradient ranging from fresh (<0.5 ppt) to polyhaline to optimize estuarine dependent fish utilization. The second recommendation pertained to the maintenance of a freshwater zone below the dam to serve as a refuge for freshwater biota. A general conclusion from both of these recommendations is that the ecology of the Lower Hillsborough River would benefit by having a complete salinity gradient that ranges from fresh water near the dam to higher salinity values near the mouth of the river.

As previously discussed, when there is no flow from the Hillsborough River reservoir, Sulphur Springs provides the majority of flow of low salinity water to the lower river. Since the salinity of the spring water typically fluctuates between 1 and 3 ppt, discharge from the spring does not create freshwater conditions in the lower Hillsborough River. Spring flows, however, do create low salinity zones in the river, and as discussed in Section 3.9, diverting 10 cfs of spring water to the base of the dam provides a net benefit to the lower river by reducing salinity in the upper regions. Improvement in the salinity regime of the river near the dam was a primary criterion for the 10 cfs minimum flow adopted for the Lower Hillsborough River (SWFWMD 1999). In keeping with this management strategy, reductions of springflow are of concern if they reduce the area and volume of low salinity habitats in the Lower Hillsborough River.

Given these considerations, a second goal in establishing minimum flows for Sulphur Springs is to maintain low salinity habitats in the lower Hillsborough River. Such low salinity zones help freshwater biota survive the dry season when salinity in the river becomes high. Low salinity zones also serve as nursery areas for an array of estuarine dependent fishes and invertebrates associated with Tampa Bay (Peebles and Flannery 1992, TBNEP 1997, WAR/SDI 1995, PBSJ 2003). Reductions in salinity that result from the inflow of spring water also benefit many brackish water shoreline plants (*Typha domingensis*, *Scirpus* sp.) that occur along the lower river.

4.6.1 Distribution and volume of <4 ppt and <11 ppt salinity zones as ecological indicators in the lower river

The distribution and volume of waters less than 4 ppt and less than11 ppt were selected as indicators to the evaluate changes in the amount of low salinity habitats as a function of springflow. The selections of both of these salinity zones were based on ecological criteria. The <4 ppt zone was selected to represent the low salinity region the estuary that typically occurs upstream of Sulphur Springs during periods of no flow from the dam. Based on principal component analysis of salinity data for a large number of fish and invertebrate species, Bulger et al. (1993) proposed five overlapping salinity zones that range from fresh to marine waters. The lowest of these zones was for waters from 0 to 4 ppt, equivalent to the <4 ppt indicator in this report. They stated that the primary basis for this upper boundary was salinity ranges of stenohaline (narrow salt tolerance) freshwater fishes. The boundary also is very close to the 5 ppt upper boundary for oligohaline waters (0.5 to 5. 0 ppt) established in the widely used Venice salinity classification system (Anonymous, 1959).

Eleven ppt was selected as the upper limit of the second salinity zone selected as an indicator. Hydrodynamic modeling indicates that waters of 11 ppt are typically found in surface waters downstream of Sulphur Springs. Thus, as opposed to the <4 ppt zone, the <11 ppt indicator can be used to evaluate the effect of reducing flows on the salinity regime of the river below the spring. The <11 ppt indicator was based on a combination of ecological factors that are relevant to the Lower Hillsborough River. The salinity zone classification scheme of Bulger et al. (1993) has two of overlapping zones at 2-14 ppt and 11-18 ppt. They stated that the upper limit of the 11-14 ppt zone represents an upper salinity limit for euryhaline freshwater fishes. As discussed in Section 3.8, Peterson and Meador (1994) suggested 9 ppt as a salinity limit for chronic exposure by euryhaline freshwater fishes. The <11 ppt indicator is an approximate mid-point for these ranges.

Data for estuarine dependent fish and zooplankton species in the Lower Hillsborough River indicate that a number or key species are abundant in the mid-salinity reaches of the lower river. PBS&J (2003) calculated the mean salinity of capture for a number of important fish and invertebrate species in the lower river. Although these taxa were captured over a wide range of salinity conditions, the mean salinity at capture provides some measure of which salinity zones they are most abundant. The mean salinity at capture for the indicator species ranged from 9.52 for the grass shrimp (*Paleomonetes pugio*) to 18.59 for the skilletfish (*Gobieson strumosus*). PBS&J stressed that factors such as food sources, habitat, and water quality (e.g. DO) can exert a strong effect on where various species are concentrated in the river. Therefore, mean salinity at capture values should be viewed as a statistic that may be related to other factors, and not viewed as physiological salinity optimum (Peebles 2002). Secondly, the mean salinity at capture is not a constant and may vary with time and freshwater inflow (PBS&J 2003). Regardless, the salinity at capture values demonstrate that middle salinity zones in the Lower Hillsborough River are characterized by relatively high abundances of a number of important species. In this regard, the distribution and volume <11 ppt salinity water provides a meaningful indicator of the availability of ecologically important mid-salinity zones in the lower river

Eleven ppt may also be an important indicator for the maintenance of brackish shoreline plants that occur along the lower river downstream of Sulphur Springs. A number of brackish marsh plants such as *Typha domingensis*, *Crinum americana*, *Acrostichum danefolium*, and *Scirpus* americanus are found along the river banks downstream of the spring. *Typha domingensis* (cattails) are particularly abundant and are concentrated between river kilometers 6 and 8, or about 5 to 7 km downstream of the spring. These species are freshwater plants that have some salt tolerance, and are generally restricted to low and medium salinity zones in tidal rivers. At higher salinities, they are generally replaced by saltmarsh plants (*Juncus romerianus*, *Spartina alterniflora*) or mangroves. In a survey of seven rivers on the coast of west central Florida, Clewell et al (2002) found that brackish marsh plants (including *Typha domingensis* and *Scirpus americana*), were most common where median surface salinity values were less than 4 ppt, which has relevance to the <4 ppt indicator zone that typically occurs above the spring. These plants also occurred in somewhat higher salinity waters, but were rarely found where median salinity values exceeded 12 ppt. Similarly, in a study of the Suwannee River estuary, Clewell et al. (2000) found that the transition from *Cladium jamaicense* (another brackish plant) to saltmarsh species (*Juncus roemerianus*) was where maximum salinities were near 10 ppt. These finding collectively indicate that the distribution of an <11 ppt zone may be a useful indicator for maintaining brackish marsh plants and existing vegetation gradients in the Lower Hillsborough River downstream of the spring.

In sum, the distribution and volume <4 and <11 ppt salinity zones were selected to serve as indicators of how reductions in flows from Sulphur Springs might affect salinity distributions in the Lower Hillsborough River. The <4 ppt zone is usually located upstream of the spring during the dry season, while the <11 ppt salinity zone typically extends downstream of the spring. The District's hydrodynamic model of the lower river was run to evaluate the effects of various rates of flow on the distribution and volumes of these salinity zones. These results are presented in Chapter 5.

4.7 Goal 3 – Maintain a thermal refuge for Manatees in the winter

As described in Section 3.11, the Sulphur Springs run and the Lower Hillsborough River are used as habitat by the Florida manatee (*Trichechus manatus latrirostris*), a marine mammal that is on the federal endangered species list. During winter cold periods manatees seek areas of warmer water, such as found near artesian springs or power plant discharges. Sulphur Springs provides thermal benefits to manatees by discharging water that fluctuates within one degree of 25^{o} C (77^{o} Fahrenheit). As a result of this discharge, waters in the spring run and river near the run remain warmer than other areas of the lower river during cold periods, and manatees have been frequently observed in the vicinity of Sulphur Springs during winter months.

Marine manatee specialists from the Florida Fish and Wildlife Conservation Commission (FWC) were consulted in order to establish criteria that could be used to evaluate the effects of removing or diverting springflow on a thermal refuge for manatees in the Lower Hillsborough River. The FMRI agreed that changes in water temperatures in a reach of the river 50 meters long near the mouth of the spring could serve as an indicator of the maintenance of a thermal refuge for manatees (B. Ackerman, personnel communication). FWC staff further suggested that the mean water temperature in this refuge should not be reduced by more than 2 degrees Celsius (^{0}C) as a result of springflow diversions when water temperatures in the refuge are in the range of 15 to 20 ^{0}C. This was considered to be a conservative approach, as it was assumed that water temperature changes in the spring run would be less than those observed in the river. Also, if the spring discharge can maintain water temperatures above 20^o C during cold periods, when other areas of the river are below 20^o C that is of benefit as well. Such thermal functions would benefit not only manatees, but also fishes that are susceptible to kills during very cold periods (e.g. snook). Thermal modeling simulations that predict the effects of removing or diverting various quantities of flow from Sulphur Springs on water temperatures in the lower river are evaluated in Chapter Five in relation to proposed minimum flows for Sulphur Springs.

CHAPTER 5

RESULTS OF THE MINIMUM FLOWS ANALYSES

5.1 Introduction

This chapter presents the technical findings that support the recommended minimum flow for Sulphur Springs. The determination of the minimum flow was based on the degree that it met the three management criteria that were described in the previous chapter, which are: (1) maintain low salinity habitats in the spring run; (2) maintain low salinity habitats in the lower Hillsborough River, and (3) maintain a thermal refuge for manatees. The findings related to these three criteria are presented sequentially below.

5.2 Criterion 1 – Maintain low salinity habitats in the upper spring run

As discussed in Section 3.4, the background salinity in the upper spring run in the absence of spring water withdrawals is determined primarily by the salinity of the discharge from Sulphur Springs pool. Under these normal flows, the background low salinity habitat of the upper spring typically ranges from 1 to 3 ppt (Figure 3-5). By reducing flow from the pool, withdrawals can raise salinity values in the spring run by allowing the movement of brackish water from the lower river into the upper spring run. Depending on the salinity tolerances of the species occurring in the spring run, such salinity incursions may, or may not, affect the species composition and ecology of the spring run.

The most conservative way to maintain the low salinity characteristics of the upper spring run would be to keep spring flow above a flow rate that hydraulically prevents salinity incursions. However, if salinity incursions were infrequent and of short duration, they may not result in adverse impacts to the biota of the spring run. The determination of the criterion 1 minimum flow thus focused on the probability that various rates of flow from the spring would result in salinity incursions and the level and duration of such incursions.

5.2.1 Criterion 1 data sources

Two types of measured data provided an empirical basis for identifying the Criterion 1 minimum flow. These were a set of controlled spring release experiments conducted by the District during 2001 and 2002, and the multi-year continuous recorder data measured in the spring and river system by the USGS. The time periods of the experiments and continuous recorder data represent conservative periods of unusually low rainfall and were thus ideally suited for these analyses.

5.2.2 Controlled release experiments

The District measured salinity at 21 stations in the upper spring run during a set of controlled spring release experiments conducted between November 2001 and June 2002. During these experiments, the City of Tampa diverted variable amounts of water from Sulphur Springs pool to either into the Hillsborough River Reservoir or to the base of the dam. The experiments were implemented soon after the City had completed modification of the diversion facilities at the spring pool. The diversions were performed by City personnel based on communications with District staff. Flow meters were not installed in the diversion pipes until the spring of 2002, so City personnel used estimation and adjustments during the early experiments to approximate the target flows. Consequently, the flows during some of the experiments were not held constant and varied from day to day. Regardless, the resulting flows from the Sulphur springs pool were accurately measured by the USGS, and these data represent a valuable set of experimental flow conditions.

A hydrograph of flows from Sulphur Springs for November 2001 – June 2002 in shown in Figure 5-1, along with reference lines for when each flow experiments was conducted. For each experiment, the District measured vertical salinity profiles in the spring run during two separate sampling events. The first sampling event was before the controlled release, while the second sampling event was after a few days of the controlled release. The samples collected on two dates during June 2002 were supplementary experiments during which sampling was conducted on only one day each.

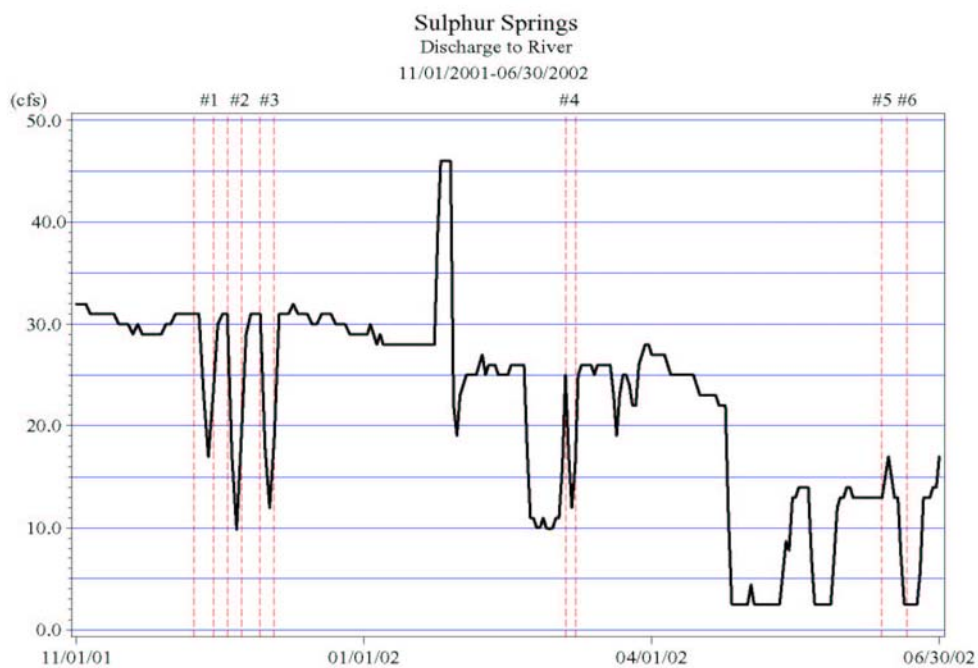

Figure 5-1. Average daily flows from Sulphur Springs Pool for November 2001 through June 2002 with reference lines denoting periods of experimental flow releases.

Table 5-1 includes dates and the rates of springflow on the days of field sampling for each experiment. The daily flow values from the spring pool during each experiment are listed in Appendix G, along with flows for several days preceding and following the experiment and the daily mean, minimum, and maximum salinity value at the spring run recorder for all days listed.

The design of the flow experiments involved monitoring the movement of brackish water into the upper spring run. The experiments were discontinued in the summer of 2002 when a period of high flows began at the Hillsborough River dam, causing the river to be fresh near the Sulphur Springs outfall. Due to unusually wet conditions during the remainder of 2002 and 2003, high flows continued at the dam, thus effectively ending the experimental period in June 2002.

Table 5-1 Rates of springflow and dates of salinity sampling for controlled release experiments from Sulphur Springs pool

Experiment	Rate of springflow on days when salinity profiles were made	Dates of salinity profiles
1	31 & 23 cfs	November 26 & 30, 2001
2	31 & 19 cfs	December 3 & 6, 2001
3	31 & 19 cfs	December 10 and 13, 2001
4	25 & 15 cfs	March 5 and 8, 2002
5	13 cfs	June 12, 2002
6	2.5 cfs	June 20, 2002

5.2.3 Salinity response during the controlled release experiments

Vertical profiles of specific conductance, salinity, temperature, pH, and dissolved oxygen were measured in the upper spring run and lower spring run for each sampling event. Salinity data were collected at a systematic series of 21 sites in the upper spring run and 3 sites in the lower spring run (Figure 5-2). The sites were numbered from upstream to downstream within the spring run in triplets. For example, sites 1, 2, and 3 were located laterally across the most upstream zone of the upper spring run; sites 19, 20, and 21 were located laterally across the most downstream zone in the upper spring run, and sites 22, 23 and 24 were located laterally across the lower run.

Box and whisker plots for salinity values measured at the 24 stations on the last sampling day for each experiment are shown in Figures 5-3 a through f. Salinity values from all depths at each station are included. With the exception of Experiment 2, salinity values at stations in the lower run were higher that stations in the upper run. These results indicate that salinity in the lower run is much more sensitive to the effects of reduced flows than the upper run, as the hydraulics of the lower run are more linked to the Lower Hillsborough River, while the upper run is more isolated from the river due to the presence of the weir.

Salinity incursions above the weir were not apparent at any of the stations in the upper run during experiments 1, 2 and 4 (Figures 5-3 a, b, and d). The daily flow values corresponding to the second sampling event for these experiments ranged from 15 cfs to 23 cfs (Table 5-1). Salinity in the spring run, however, can vary with tide stage during low flows, and the sampling event could have missed the time of salinity incursion. To check the representiveness of the experimental results, time series plots of 15-minute values for salinity and water levels at the continuous recorder in the spring run are presented in Appendix H for each experimental period.

Efforts were made to sample the spring run near slack high tide, when the potential for incursions of river water is the greatest. Plots of water levels at the continuous recorder in the upper run show that this was largely achieved for experiments 1 and 4, but sampling for experiment 2 occurred after high tide and was actually near the time of minimum low water. Salinity remained stable at the recorder throughout experiments 1, 2 and 4, however, indicating that salinity incursions did not occur over the tidal cycle. In contrast, salinity values did vary with tide at the recorder at the spring mouth (also shown in Appendix H). Elevated salinity was more prolonged during experiments 2 and 4 than during preceding or following days when higher flows occurred.

The box and whisker plots show that slight salinity incursions occurred during experiments 3 and 6 (Figures 5-3 c and g). Slightly higher salinity values were observed at station 20 near the opening of the weir during experiment 3, when the flow was 19 cfs. This sample was taken near the secondary high tide peak for the day. Salinity at the recorder in the upper run did not show evidence of any salinity incursion at that location. This recorder is located about 100 feet upstream of station 20, indicating that the salinity incursion in the upper run during experiment 3 was restricted to near the weir opening.

Experiment 6 (June 20, 2002) showed a similar result, in that sampling was conducted near high tide and comparison of the box and whisker plot with the recorder data indicates that salinity increases were restricted to the most downstream stations in the upper run. This test produced unusual results in that the flow from the spring was only 2.5 cfs. There was no flow from the Hillsborough River dam on this day, which generally results in high salinity in the river near the spring outfall. However, the summer rainy season had commenced by mid-June, and reductions in salinity were observed at the nearby continuous recorders in the river. The lack of a strong salinity incursion during experiment 6 may have been related to low salinity in the river and the effects of localized rainfall on salinity in and near the spring run.

The most striking result among the six test flows was the result for test 5 on June 12, 2002 (Figure 5-3e). Flow on this day was 13 cfs and was maintained at that rate for the previous 9 days (Appendix G). This represented the only successful attempt to maintain a constant, intermediate flow rate during the experimental period. Boat failure restricted sampling on that day to stations 16 through 24, but the data indicated a substantial salinity incursion. Mean water column values were between 6.7 and 10.6 ppt at stations 16 through 21 in the upper pool, with bottom values ranging from 11.5 to 15.9 ppt.

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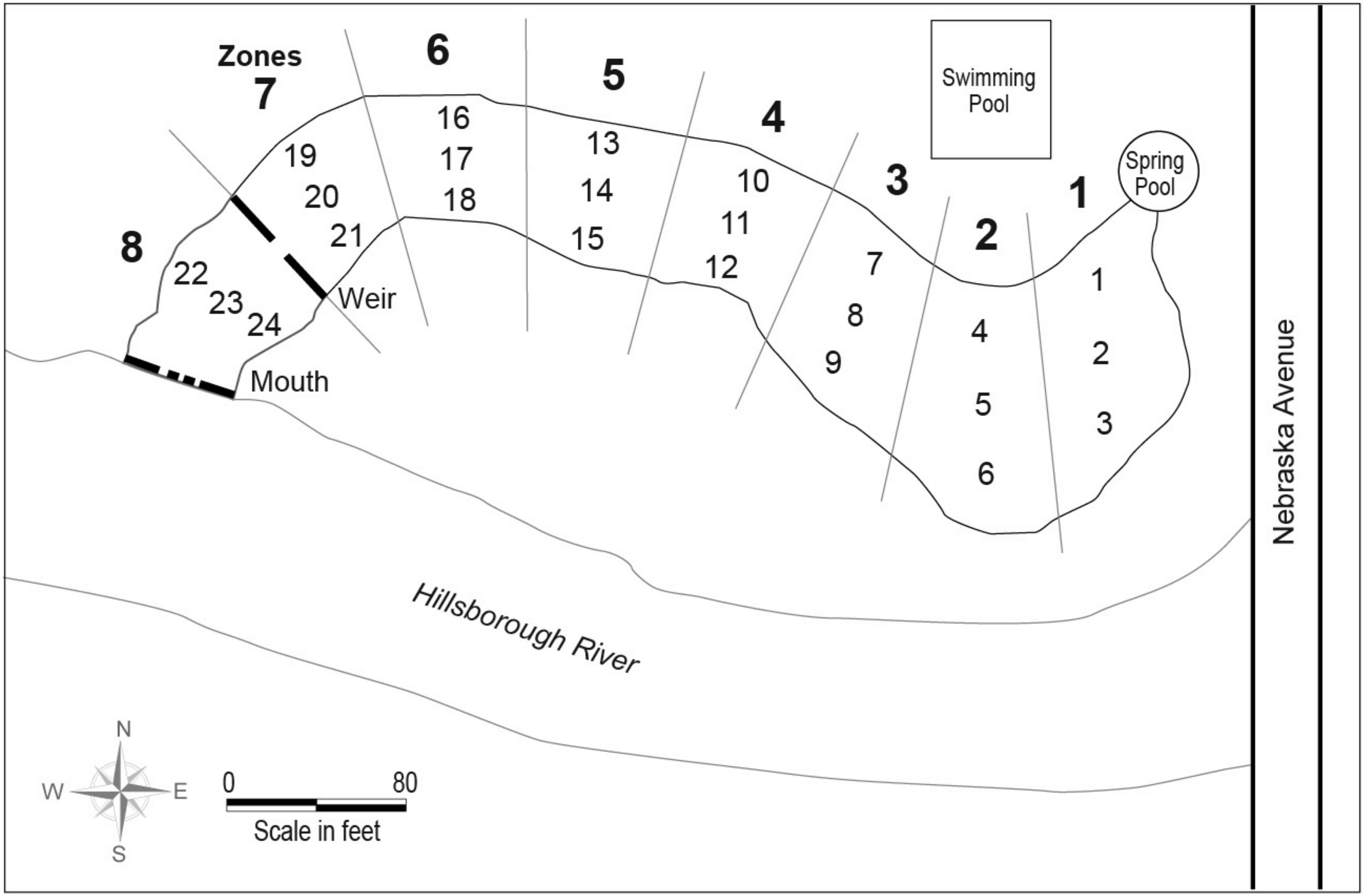

Figure 5-2. Location of vertical profile stations measured during experimental flow releases.

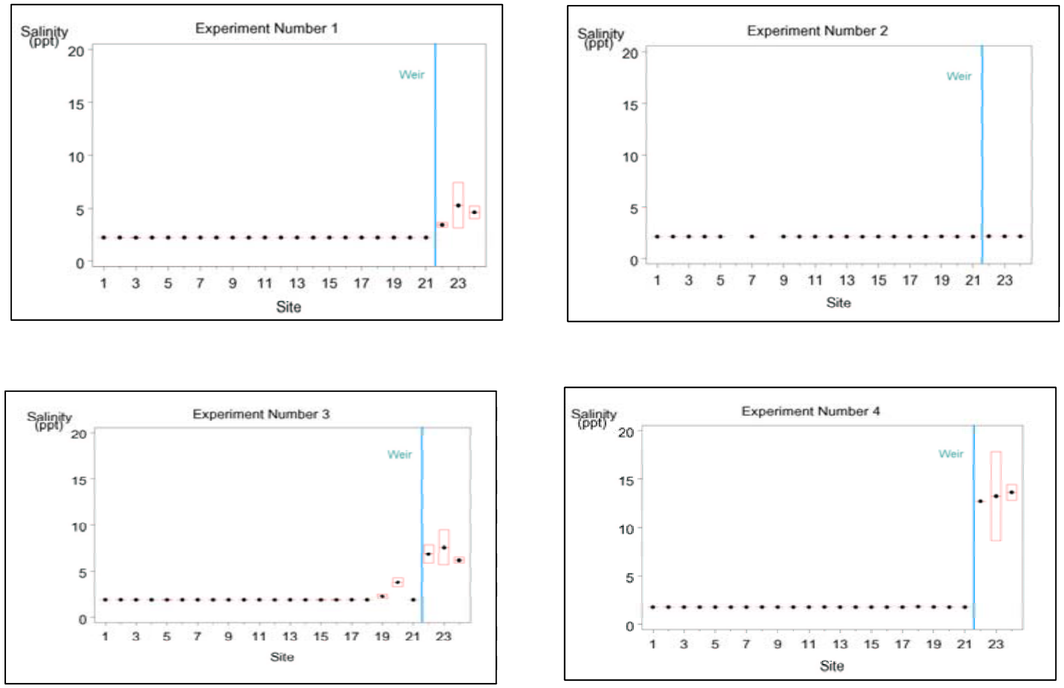

Figure 5-3. A – D. Box and whisker plots for salinity measurements at 23 stations in the upper and lower spring run for six flow experiments. Data include all salinity values from the water column (top to bottom) (2 pages).

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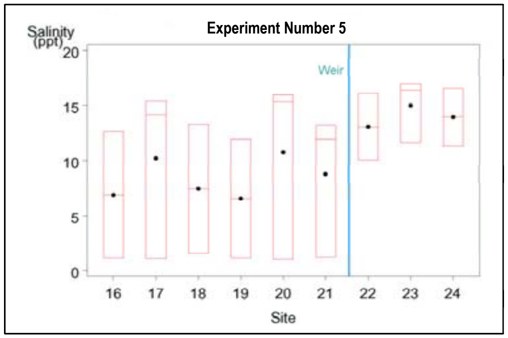

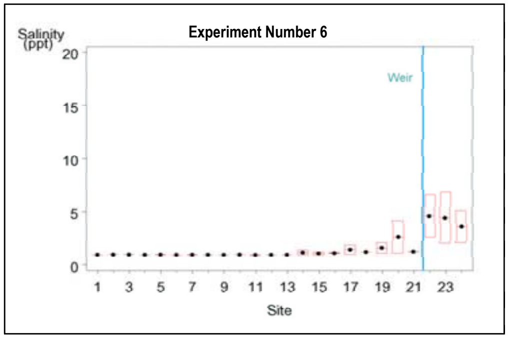

Figure 5-3. E– F. Box and whisker plots for salinity measurements at 23 stations in the upper and lower spring run for six flow experiments. Data include all salinity values from the water column (top to bottom).

The results of the vertical profile data for experiment 5 were supported by the results of the continuous recorder, which showed a peak salinity value of 12.6 ppt on the sampling day (Appendix H). There was considerable covariation of salinity with tide stage at the continuous recorder, however, as the incursion occurred primarily at higher tide stages. Daily salinity range values from the continuous recorder show that salinity incursions also occurred during the five days prior to June 12th, which also had flows of 13 cfs (Appendix I). However, no incursions were noted between June 3rd and 6th, when flows were at the same rate. Tide stage values in the Hillsborough River also listed in Appendix I show that salinity incursions during this controlled release typically occurred on days when maximum tide stages were over 2.0 feet. Particularly strong incursions occurred on June 10th and 12th, when tide stages in the river peaked at 2.4 feet and 2.7 feet, respectively.

In summary, the six experimental flow tests provide a limited data base for evaluating the effects of flow reductions on salinity in the spring run. These data indicate the response of salinity in the run can vary greatly within a narrow range of flows, or even for the same rate of flow. Salinity incursions did not occur on three dates with moderate flows (16 to 23 cfs), while another experiment at 19 cfs found a slight incursion that went only a short distance above the weir. However, only one experiment was conducted with a prolonged controlled release. The combined data from the vertical profiles and the continuous recorder during that release show that salinity incursions can vary greatly from day to day at a constant flow rate of 13 cfs. As will be discussed further, a principal factor affecting this variability is tide stage in the lower Hillsborough River.

5.2.4 Salinity response at the continuous recorder in the upper spring run to variable flows

The continuous recorder data that were collected in the spring pool, the spring run, and the nearby reaches of the Hillsborough River provide valuable data for evaluating the relationships of spring flow and tide stage with salinity incursions in the spring run. The recorder data for the upper spring run evaluated in this report extend from May 25, 1999 to December 31, 2002. During this period, there were 836 days when flows in Sulphur springs ranged from 0 cfs to the average flow rate of 31 cfs.

The number of days that flow rates from the spring occurred in 1 cfs intervals are plotted in Figure 5-4. The data are limited to periods when there was no flow from the Hillsborough River Dam, as this is when meaningful data can be collected regarding salinity incursions into the spring run. During the period of study, there were 107 days that flows were 1 cfs from the spring pool. There were also a large number of days at 2 and 3 cfs. Although these data are informative for examining the response of the spring at very low flows, they are likely below a minimum flow to be established for the spring.

The number of days of record range from 6 to 26 for flows between 4 and 21 cfs. There is a peak in the number of days for flows between 25 to 30 cfs, which corresponds to commonly occurring normal flows for the spring. The number of 15-minute observations of salinity for each flow class are also plotted in Figure 5-4.

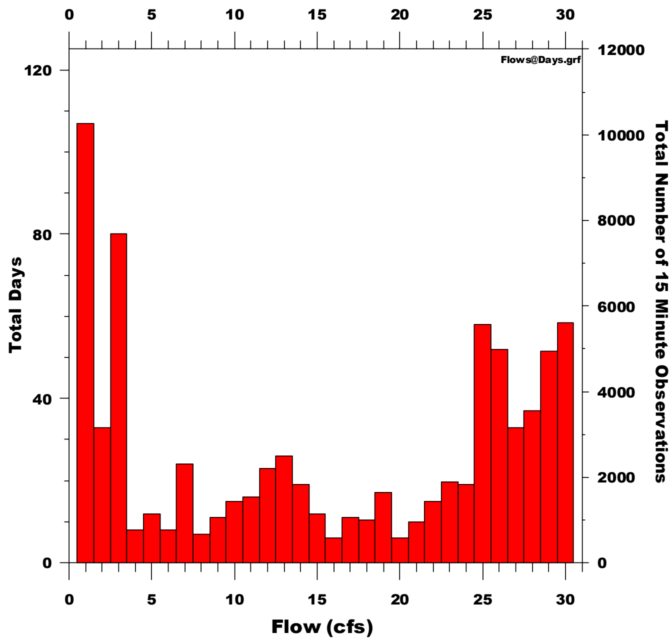

Figure 5-4. Number of days in 1 cfs flow classes for flows from Sulphur Springs pool. Data restricted to periods when there was no flow to the lower river from the Hillsborough River reservoir.

Percentile distributions of 15-minute salinity values at the spring run recorder in 1 cfs intervals up to 33 cfs are also shown in box and whisker plots in Figure 5-5. Thirty-three cfs was chosen as the upper limit for the plot as the number of observations are very limited above that amount. The median salinity value for each flow interval is shown as the lateral line across the interior of each box, while the top and bottom of the box represent the 25th and 75th percentile values respectively. The upper whisker extends between the 75th percentile to the 95th percentile, and the upper set of dots represent individual 15-minute data points that occur above the 95th percentile.

The data presented in Figure 5-5 and following figures were limited to periods when there was no flow from the Hillsborough River reservoir, as flow from the dam can result in fresh water in the river near the spring mouth and mask the effect of any incursions into the spring run. Also, as discussed in Chapter 4, the establishment of minimum flows for Sulphur Springs primarily applies to periods of no discharge from the dam. Values of less than 3 cfs were used to identify no-flow days, as the USGS sometimes reports values of 2 to 3 cfs to represent leakage through the dam.

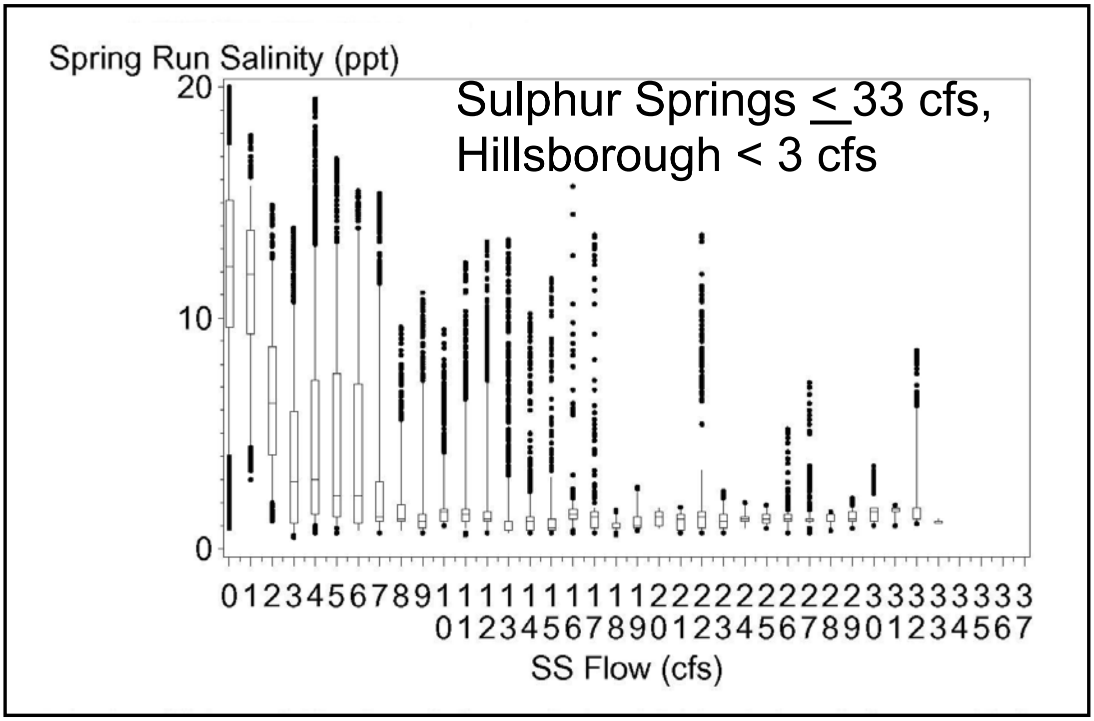

Figure 5-5. Box and whisker plot of 15 minute salinity measurements at the data recorder in the upper spring run. Data restricted to periods when there was no flow to the lower river from the Hillsborough River reservoir.

There is a conspicuous break in the median and 75th percentile values between 6 and 7 cfs, with a smaller secondary drop in the 75th percentile values between 7 and 9 cfs. Above 9 cfs, the median and 75th percentile values are relatively flat across the remaining higher flows. Similarly, there is a noticeable drop in the 95th percentile values between 7 and 8 cfs. There were a considerable number of days at 7 cfs (24 days), while there were 17 combined days at 8 and 9 cfs (Figure 5-4). Thus, these breaks in the data are supported by a reasonable number of observations. A secondary drop in the 95th percentile values occurs between 12 and 13 cfs, which respectively had 23 and 26 days of record. At 13 cfs, the 95th percentile value is 3.3 ppt. A second general drop in the 95th percentile values occurs near 16 or 17 cfs, above which most of the 95th percentile values are near or below 2 ppt.

A conspicuous drop in salinity values above the 95th percentile occurs between 17 and 18 cfs. Above 18 cfs, incursions of brackish water appear to be very infrequent. Assuming the salinity values presented in Figure 5-5 are representative of longer periods within those flow ranges, 18 cfs flow may represent a threshold flow to prevent brackish incursions into the spring run except for very high tides.

There were some flow rates above 18 cfs that showed salinity observations greater than 3 ppt. These are shown as the individual data points above the 95th percentile in Figure 5-5 (for flows less than 34 cfs). With the exception of the data for 26 and 30 cfs, these observations were recorded during one of two periods during the year 2000; which were February 12 through February 15 and April 27 through May 2. During these periods there were major manipulations of water levels in the spring pool due to operation of the outlet structure at the pool and withdrawals by the City. These manipulations typically occurred during the middle of the day, so the average daily flows reported for the spring included widely varying flows, which are not represented in the average daily flows presented in Figure 5-5. The data reported for 30 cfs are similar in that the structure was operated during that day and flows varied widely.

The high salinity observations for 26 cfs were a different situation, as there were no manipulations of water levels in the pool and flows had been relatively stable for the preceding seven days. Maximum salinity on the preceding days remained below 1.5 ppt, but on July 23, 2001, a peak tide stage of 4.95 feet was recorded in the Hillsborough River near the spring. This is an unusually high tide that may have been caused by prevailing southerly winds. The incursion of water over 2 ppt into the spring run began when water levels in the river first exceeded 4.35 feet, and lasted for approximately 7½ hours. There were 50 total days in which flows from the spring equaled 26 cfs, but this was the only day among those during which a salinity incursion occurred.

In summary, the data from the continuous recorder indicate the probability for salinity incursions into the spring run increases as flows decline. However, it is not a linear response and there appear to be breakpoints in this relationship. With the exception of very high tides, 18 cfs appears to preclude salinity incursions into the run. Summary statistics for salinity and tide stage from the continuous recorder are listed for all days with flows between 5 and 20 cfs in Appendix I. There was a total of 11 days when flows were 18 cfs. On each of these days, daily minimum and maximum values of salinity in the run were nearly identical, indicating no incursion occurred.

It is reiterated that the recorder in the run is located about 100 feet upstream of the weir, and small incursions could possibly occur that do not reach that far upstream or are limited to deeper depths. An example of such an event is the experiment of Dec 13, 2001, when vertical salinity profiles (Figure 5-3c) showed a small incursion above the weir that was not registered at the recorder. It is not known to what extent 18 cfs would allow such small incursions, but it is expected such small incursions would not affect low salinity zones in shallow and upstream areas, allowing sufficient refuge for salt-sensitive species. Given this assumption, the data from the continuous recorder can be used to evaluate the relationships of springflow with significant salinity incursions.

Other breakpoints in the data are apparent and could be used for the determination of minimum flows, depending on the management goals for the spring run. The 75th percentile salinity values showed a breakpoint between 6 and 7 cfs. At 6 cfs, the median value is 2.1 ppt. However, the 75th percentile value is 7.8 ppt, with a 90th percentile value of 13.5 ppt. The median value for 7 cfs was 1.5 ppt, which is equal to median salinity of the spring run under normal flows. At 7cfs the 75th percentile drops to 2.8 ppt, while the 90th percentile value drops to 6.7 ppt. There were three times as many days of record with flows of 7 cfs (24 days) than there was for 6 cfs (8 days), so inferences about salinity for 7 cfs are probably more valid.

The daily values listed in Appendix I can be used to determine on what days salinity incursions occurred for each flow rate. Differences in minimum and maximum salinity values in excess of 1.5 ppt can be used to indicate the movement of river water upstream of the weir on a sampling day. Using this criterion, salinity incursions occurred on 22 of the 26 days (85%) when flows were 7 cfs. Daily maximum salinity values in excess of 10 ppt occurred on six of the days that had incursions. As previously discussed, the 95th percentile salinity values show a breakpoint between 12 and 13 cfs, dropping from 7.3 to about 3.3 cfs. There were 26 total days of record with flows of 13 cfs. Salinity incursions occurred on nearly half (46%) of those days, with maximum salinity values in excess of 10 ppt occurring on four of the incursions.

The number of days there were salinity incursions equal to or greater than 5 or 10 ppt are summarized in Table 5-2 for flow classes greater than 5 cfs, along with statistics for the durations of these incursions. The percentage of the 15 minute observations that exceeded 5 or 10 ppt are also listed in Table 5-2 and illustrated in Figure 5-6. Similar to the results shown in the box and whisker plots, there are breakpoints in the percent of observations over 5 ppt at 7, 13, and 18 ppt. As discussed earlier, the occurrence of high salinity values at flows above 20 cfs are due to large changes in flows during those days that are masked by the average flow value, or are due to unusually high tides during a flow of 26 cfs. Excluding these outliers, the percent of observations above 5 ppt never exceeded 4% at flows above 13 cfs, and were zero at flows above 18 cfs.

Table 5-2 Number of days and durations of salinity incursions greater than or equal to 5 ppt and 10 ppt at the recorder in the upper spring run.

	Percent >=5ppt	Number of 'Days' of Incursions >= 5 ppt	Average Hrs per 'Day'	Longest Duration Hours >= 5ppt	Median Duration Hours >= 5ppt		Percent >=10 ppt	Number of 'Days' of Incursions >= 10 ppt	Average Hrs per 'Day'	Longest Duration Hours >= 10 ppt	Median Duration Hours >= 10 ppt
1	93.2						72.7				
2	32.4						8.7				
3	37.1						15.9				
4	45.4						19.8				
5	36.5						15.5				
6	32.7	7	9.0	18.5	4.0		20.1	6	6.4	15.8	2.0
7	14.2	14	5.9	19.0	1.3		6.3	6	6.0	13.0	3.8
8	9.2	5	3.1	5.3	2.0		0.0	0	0.0	0.0	0.0
9	11.8	7	4.5	8.5	2.3		1.8	2	2.4	4.3	2.4
10	4.4	4	3.9	4.8	1.6		0.0	0	0.0	0.0	0.0
11	7.4	6	4.8	7.8	2.0		1.5	2	2.9	4.8	2.8
12	8.0	10	4.4	5.8	4.0		1.6	5	1.8	3.0	1.4
13	3.9	7	3.5	7.0	2.5		1.4	4	2.2	4.5	1.6
14	1.5	2	3.5	4.5	3.5		0.1	1	0.5	0.8	0.8
15	3.4	3	3.3	5.0	2.1		1.2	3	1.2	1.5	0.9
16	3.0	1	4.3	4.3	4.3		0.9	1	1.3	1.3	1.3
17	2.7	2	3.6	6.8	0.3		1.7	1	4.5	4.5	4.5
18	0.0	0	0.0	0.0	0.0		0.0	0	0.0	0.0	0.0
19	0.0	0	0.0	0.0	0.0		0.0	0	0.0	0.0	0.0
20	0.0	0	0.0	0.0	0.0		0.0	0	0.0	0.0	0.0
21	0.0	0	0.0	0.0	0.0		0.0	0	0.0	0.0	0.0
22	4.1	1	14.8	14.8	14.8		1.4	1	5.0	3.3	2.5
23	0.0	0	0.0	0.0	0.0		0.0	0	0.0	0.0	0.0
24	0.0	0	0.0	0.0	0.0		0.0	0	0.0	0.0	0.0
25	0.0	0	0.0	0.0	0.0		0.0	0	0.0	0.0	0.0
26	0.1	1	1.3	1.3	1.3		0.0	0	0.0	0.0	0.0
27	0.3	1	2.8	2.8	2.8		0.0	0	0.0	0.0	0.0

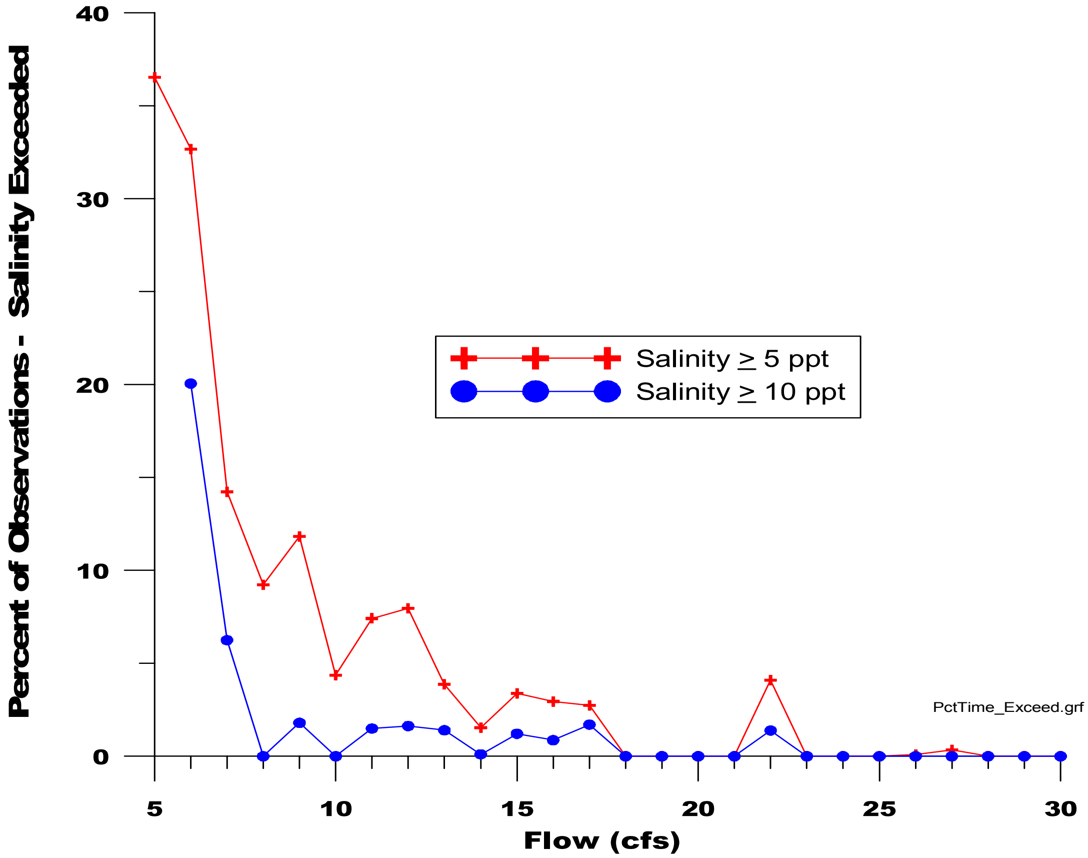

Figure 5-6. Percent of 15-minute observations greater than or equal to 5 or 10 ppt at the data recorder in the upper spring run for 1 cfs flow classes from Sulphur Springs.

The durations of the incursions that exceeded 5 or 10 ppt are plotted in Figure 5-7. At flows greater than 7 cfs, the > 5 ppt incursions typically lasted only a few hours. For example, at 13 cfs flow the average duration of an incursion greater than 5 ppt was 3.5 hours, with a maximum duration of 7 hours (Table 5-2). The longest duration in the flow range of 8 to 17 cfs was 8.5 hours at a flow of 9 cfs. Salinity incursions greater than 10 ppt were less frequent and of shorter duration. The longest duration of salinity greater than 10 ppt for flows greater that 7 cfs were 4.5 hours, recorded at flows of 13 and 17 cfs.

Using these results to establish a minimum flow will be dependent on the salinity tolerances of the biota in the spring run and the management goals for the run. It is the conclusion of this report that salinity incursions into the upper spring run should be minimized. In the absence of withdrawals, salinity values in the upper spring closely track the salinity of the spring pool. Under these conditions, the spring run functions like a tidal freshwater zone in that water levels fluctuate with tide but brackish waters from the river do not penetrate the upper spring run. The upper spring run is not a true freshwater zone in that salinity values generally fluctuate seasonally between 1 and 3 ppt, but salinity values do not experience any variation over the tidal cycle.

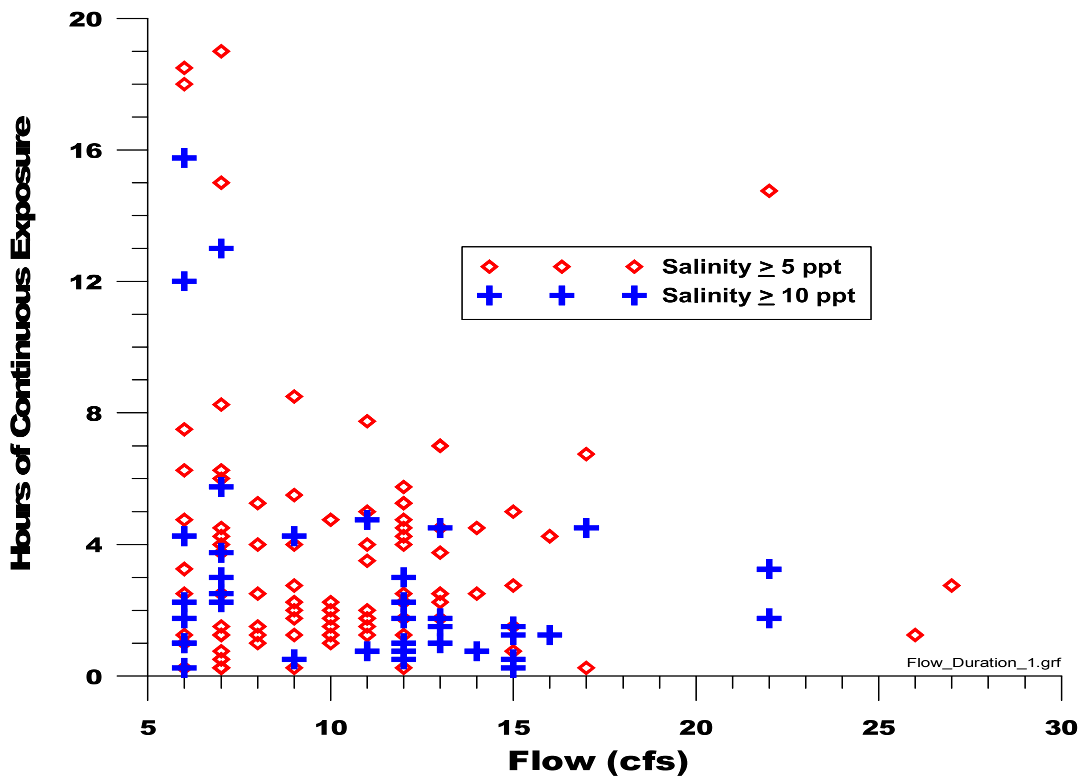

Figure 5-7. Duration of salinity incursions greater than or equal to 5 ppt or 10 ppt at the data recorder in upper spring run for 1 cfs flow classes from Sulphur Springs.

Many of the invertebrate taxa that inhabit the upper spring run are euryhaline, or able to tolerant of a range of salinity. These species can flourish in either the spring run or in nearby areas of the Lower Hillsborough River. Other invertebrate groups that have been found in the run, however, are comprised of species that are found predominantly in fresh water. The invertebrate community that was observed in the spring run in 1997 included many freshwater taxa that are tolerant of slightly elevated salinity. The high salinity values that occurred as a result of large springflow diversions during the 2000-2001 drought were a factor in the loss of these taxa from the spring run (Allen et al. 2001). As described in Section 3.3.7.3, some of these taxa reappeared in later samples that were collected after periods of normal flow. The collection of December 2003, which was preceded by sixteen months of normal flow from the spring, found that species richness and the abundances of a number of taxa improved greatly, with the appearance of many freshwater taxa that have some tolerance of low salinity. In likelihood, the resumption of low, stable salinity values contributed to recovery.

It is possible that infrequent or slight salinity incursions could occur without impacting the salt-sensitive species that have become reestablished in the spring run. It is difficult however, to evaluate the frequency, duration and magnitude of salinity incursions that such species could tolerate. Although there is a general knowledge of the ecological requirements of these species, there is not literature that gives specific threshold salinity values or durations of salinity that cause reductions in growth or reproduction. What is known is that as flow from the spring pool goes lower, the likelihood for greater salinity incursions will rise. Given this situation, breakpoints in the flow-salinity relationship can be used to evaluate flows that reduce the likelihood of salinity incursions.

The data presented in this report indicate a clear breakpoint in the data for the upper spring run at 18 cfs. This rate of flow, however, will not entirely preclude the possibility of salinity incursions, as very high tides could cause brief salinity incursions into the upper spring run. If a greater probability of salinity incursions could be tolerated, a breakpoint of 13 cfs could be used. However, the data indicate that salinity incursions into the upper river at 13 cfs could occur about half the days, with incursions occurring on several successive days depending on tides in the river. Although the duration of these incursions would be on the order of a few to several hours, there appears to be a marked difference in the probability and severity of salinity incursions between 13 and 18 cfs. Given the unique character of the habitat and fauna in the Sulphur Spring Run, the more conservative protection provided by an 18 cfs minimum flow is warranted for routine application. Circumstances under which a smaller minimum flow could be applied are described in the following sections.

5.2.4.1 Tide stage effects on salinity incursions

The height of tide stages in the Lower Hillsborough River can be important to the magnitude and length of salinity incursions, as higher tides tend to push more brackish water into the spring run during low flows. Water levels are recorded at continuous recorders in the spring run and approximately 100 yards upstream in the river at the Hillsborough River at Sulphur Springs gage. The stage records in the spring run date from May 25, 1999 to present, while stage records in the river began on October 1, 2000. Although the period of stage records for the river is somewhat shorter, those records are valuable for examining the effects of tide stage in the river on salinity incursions in the spring run, as concurrent data are available for many of the intermediate flows that occurred during 2001 and 2002.

As described in section 3.3, water levels in the river and spring run track each other closely at higher tide stages. However, water levels in the river drop below water levels in the spring run at low tide stages (Figures 3-2 and 3-4). This difference in low water levels is due to the effect of the weir, which acts to retain water in the upper spring run as water levels in the river fall. As water levels in the river rise, brackish water can be pushed upstream of the weir if there is not sufficient flow to keep the incursions from occurring. The data discussed above indicates that flows of greater than 18 cfs prevent the incursion of river water above the weir, except for very high tide stages.

The relationship of tide stage (water level) in the river to salinity values in the spring run is illustrated in Figure 5-8, in which 15-minute salinity values at the recorder in the upper run are plotted against simultaneous water level values in the river for days when flows from the spring were in the range of 10 to 18 cfs. Although there is considerable scatter in this plot, there a general positive relationship between salinity in the run and tide stage in the river. With the exception of one data point, salinity values above 3 ppt did not occur when water levels in the river were below –0.5 feet NGVD. The occurrence of high salinity values increases when water levels in the river rise between 0 and 1 foot NGVD, as this is when river levels exceed the elevation of the bottom of the opening in the weir. Higher water levels continue to push more brackish water into the run, as salinity values above 10 ppt were only recorded when water levels exceeded about 1 foot NGVD.

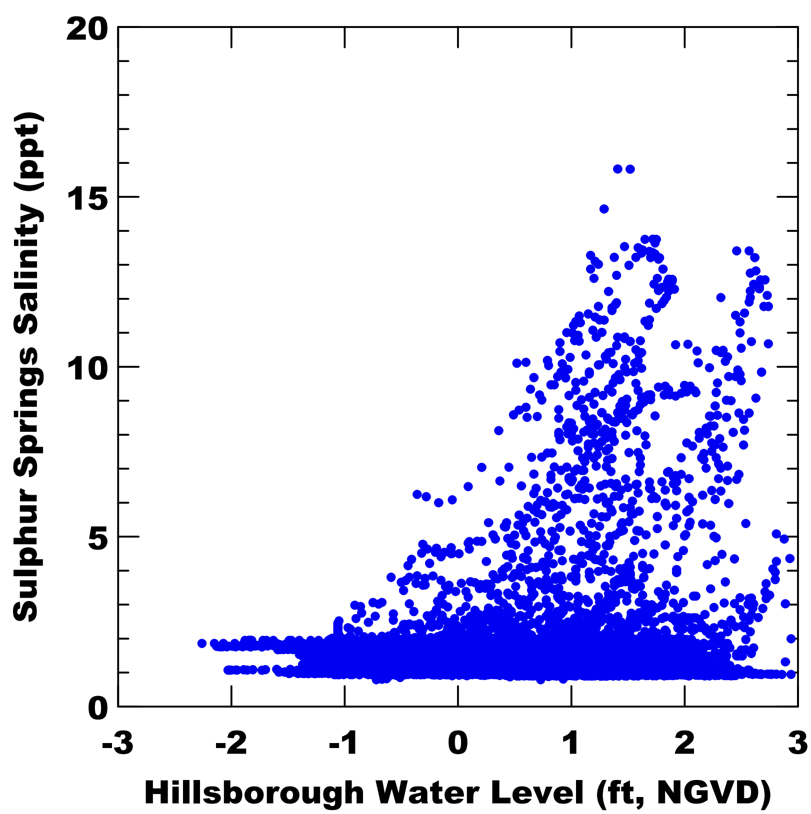

Figure 5-8. Relation between 15-minute values for water levels in the lower river and salinity at the recorder in the upper spring run for flows between 10 and 18 cfs from the spring pool.

The effects of tide stage on salinity could be used to minimize salinity incursions while allowing for diversions of water from the spring pool. For example, flows could be reduced from 18 cfs to 10 cfs during times of low river levels (< -0.5 feet) without causing the incursions into the spring run. In this regard, a plan to manage flow from the spring that accounted for tide stage in the river could make additional spring water available for use without causing significant salinity incursions. It is not known how quickly the hydraulic relationships at the weir would respond to such changes in flows, and the most effective manipulation of flows based on water levels would require further field testing.

5.2.5 Relations of springflow to water levels in the upper spring run

In addition to their effect on salinity, changes in flows could affect the water levels in the spring run and the depth and inundation characteristics of aquatic habitats. As previously discussed, water levels in the run largely track water levels in the river at high tide stages. As a result, the water levels in the run that occur at medium or high tides do not show a strong relationship with flow. Daily mean and maximum water levels are plotted versus same-day springflow in Figures 5.9 a and b. There is no apparent response of maximum daily stage with flow, and a simple linear regression between these variables was not significant ($p < 0.41$). There was a significant relationship between mean daily stage and flow ($p < 0.001$), but the slope of the regression (0.009) was very flat, indicating a change of 1 cfs would change mean daily water levels by less than one-hundredth of a foot.

The most pronounced relationship with flow was for minimum water levels (Figure 5-9 c). The lowest water level that can be measured by the recorder in the run is – 0.44 ft. Water levels lower than –0.44 ft. are recorded as that value, although the site may be dry or sitting in an isolated pool. Water levels recorded as –0.44 feet were most common when there was zero cfs flow from the pool, although values very close to – 0.44 were occasionally recorded at flows up to 14 cfs. As previously discussed, comparing 15-minute values to average daily flows involves some error because on some days flows changed greatly when the withdrawal pumps were turned on or off. Secondly, the number of days of record and tide stage conditions in the river varied considerably among the flow classes, which could influence the range of values observed for a flow class. Regardless, the data in Figure 5-9 indicate there is a relationship between flow from the pool and the minimum daily tide stage in the upper spring run.

Viewed another way, Figure 5-10 shows a box and whisker plot of the distribution of daily minimum stage values in the spring run in 1 cfs flow classes. At flows less than 5 cfs, the median values (of the daily minima) are all near –0.4 NGVD, demonstrating that the daily minimum stage at low tide reaches the bottom of the recorder during periods of very low flows. There appears to be a break in the median values near 10 cfs, as the

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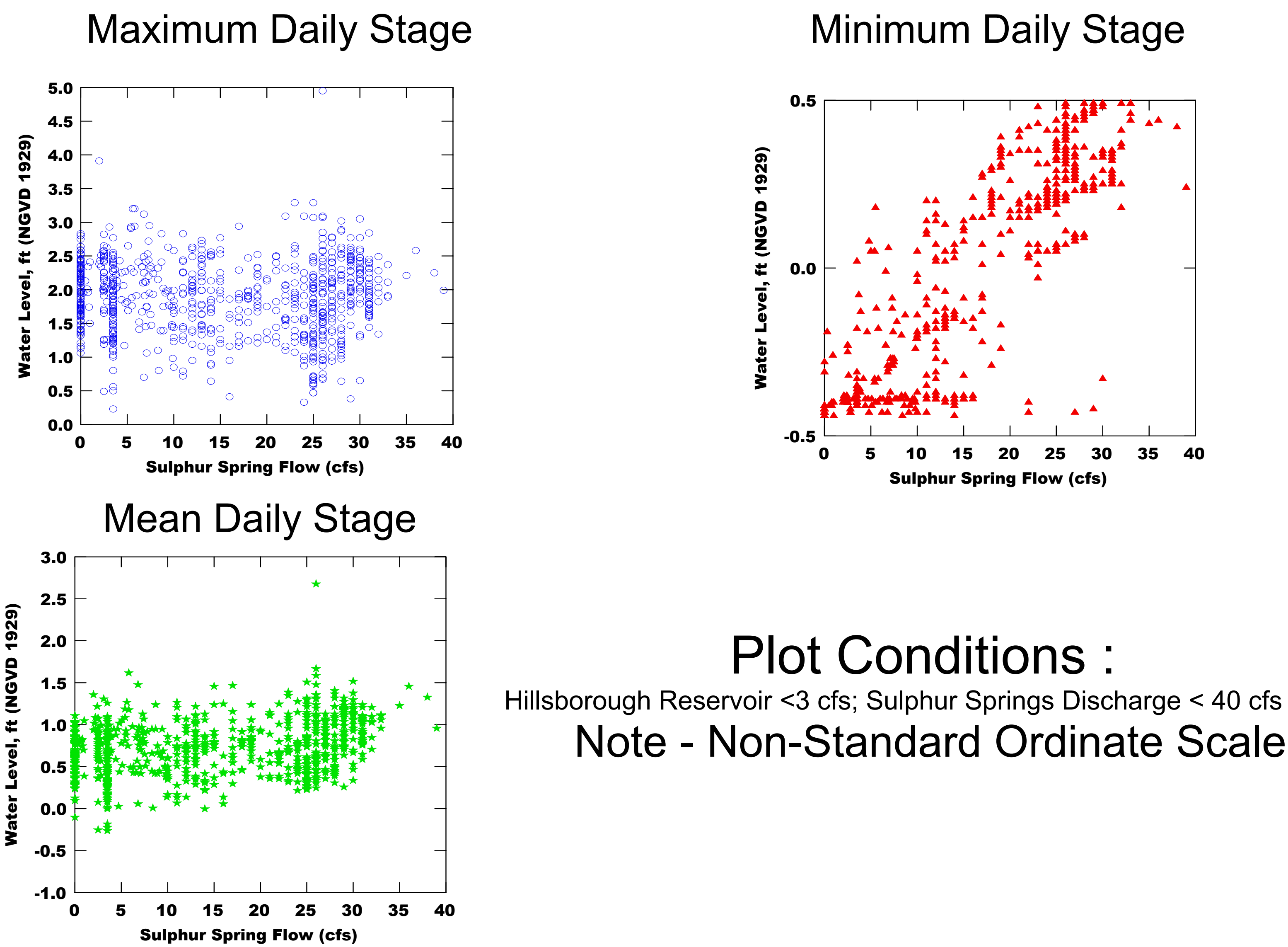

Figure 5-9. Relationships between daily mean, maximum, and minimum water levels in the upper spring run and flow from Sulphur Springs pool.

medians rise to near -0.2 feet. The largest break in the distribution of daily minimum stage values, however, occurs near 17-18 cfs, where the medians and the inter-quartile ranges all rise dramatically. Above 17 cfs, the median values daily minimum stage generally remain above 0.2 feet, or slightly half a foot higher than the minimum stages recorded under very low flows.

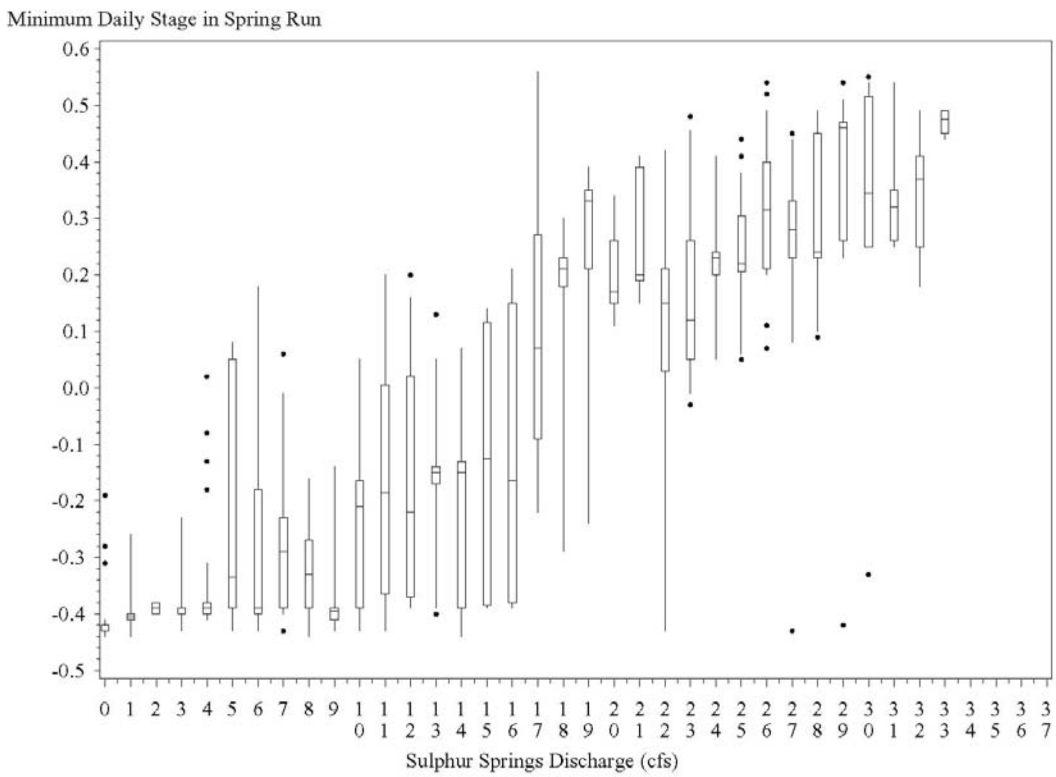

Figure 5-10. Box and whisker plot of daily minimum water levels in the upper spring run in 1 cfs flow classes from Sulphur Springs pool.

These results indicate that at as flows decline below 17 cfs a greater amount of the run bottom is exposed at low tides, changing these areas from sub-tidal habitats (always submerged) to inter-tidal habitats (exposed at low tide). This would have implications for some largely sessile organisms that require continuous inundation. Highly motile animals, such grass shrimp or fish, can migrate with the tides and utilize these areas as water levels rise and fall. The total amount of submerged habitat in Sulphur Springs is about 0.3 hectares (0.75 acres) at a water level of 0.0 feet, and 0.27 hectares (0.67 acres) at a water level of –0.4 feet (Figure 2-8). Thus, reduction of daily minimum stage from medium flows (17 to 24 cfs) to very low flows changes about 10 percent of the sub-tidal habitat in the run to inter-tidal habitat. However, this reduction occurs in the shallow margins of the spring pool, where the diversity of aquatic macroinvertebrates is the greatest (see Section 3.3.7.4). The potential effects of such manipulations combined with salinity changes is discussed in the context of significant harm to the upper spring run at the end of this chapter.

5.2.6 Salinity response in the lower spring run

Much of the minimum flow analysis focused on the upper spring run, as this represents over 85 percent of the total area of the entire spring run. Secondly, due to the presence of the weir, it is more isolated from the effects of the lower Hillsborough River and likely to maintain low salinity fauna that are scarce within the Lower Hillsborough River system in the dry season. With these considerations, the response of salinity in the lower spring run was determined not to be a critical indicator for evaluating minimum flows from the spring pool. In other words, the transition to a more saline fauna in the lower spring run could be allowed if the low salinity fauna in the upper spring run is maintained. However, the response of salinity in the lower run to flows from the spring pool provides useful information on general salinity relationships in the spring run system.

As discussed in Section 3.4, a continuous recorder was operated at the mouth of the spring that collected 15-minute data for temperature and specific conductance, which was converted by calculation to salinity. Stage was not measured at this recorder. A box and whisker plot of salinity at this recorder versus flow in 1 cfs increments is shown in Figure 5-11. In general, the distributions of salinity values for the flow classes showed breaks at similar flow rates as for the recorder in the upper run, but the salinity values at the mouth were higher. For example, median salinity values at the mouth show a break between 13 and 14 cfs, dropping from about 5-6 ppt to about 2-3 ppt. Seventy-fifth percentile values show a distinct break between 17 and 18 cfs, dropping from 8-9 ppt to values less than 3 ppt at higher flows.

To some extent, the breaks may represent the effect of lower salinity in the river at higher flows. However, the list of maximum salinity values for each day of flow record in Appendix I indicates that salinity remained high in the river at 18 cfs flow. Thus, the break at the mouth recorder may truly represent the effect of increased flushing by flow from the spring. Unlike the upper run, there were no conspicuous breaks in the 95th percentile and greater salinity values at 18 cfs, indicating brackish river water can periodically inundate the recorder at the mouth of the run at higher flows depending on tide and salinity conditions in the river. In summary, although the lower run may not be a critical criterion for minimum flow establishment, breaks in the salinity-flow relationship show some clear similarities to relationships in the upper run, supporting the validity of those findings.

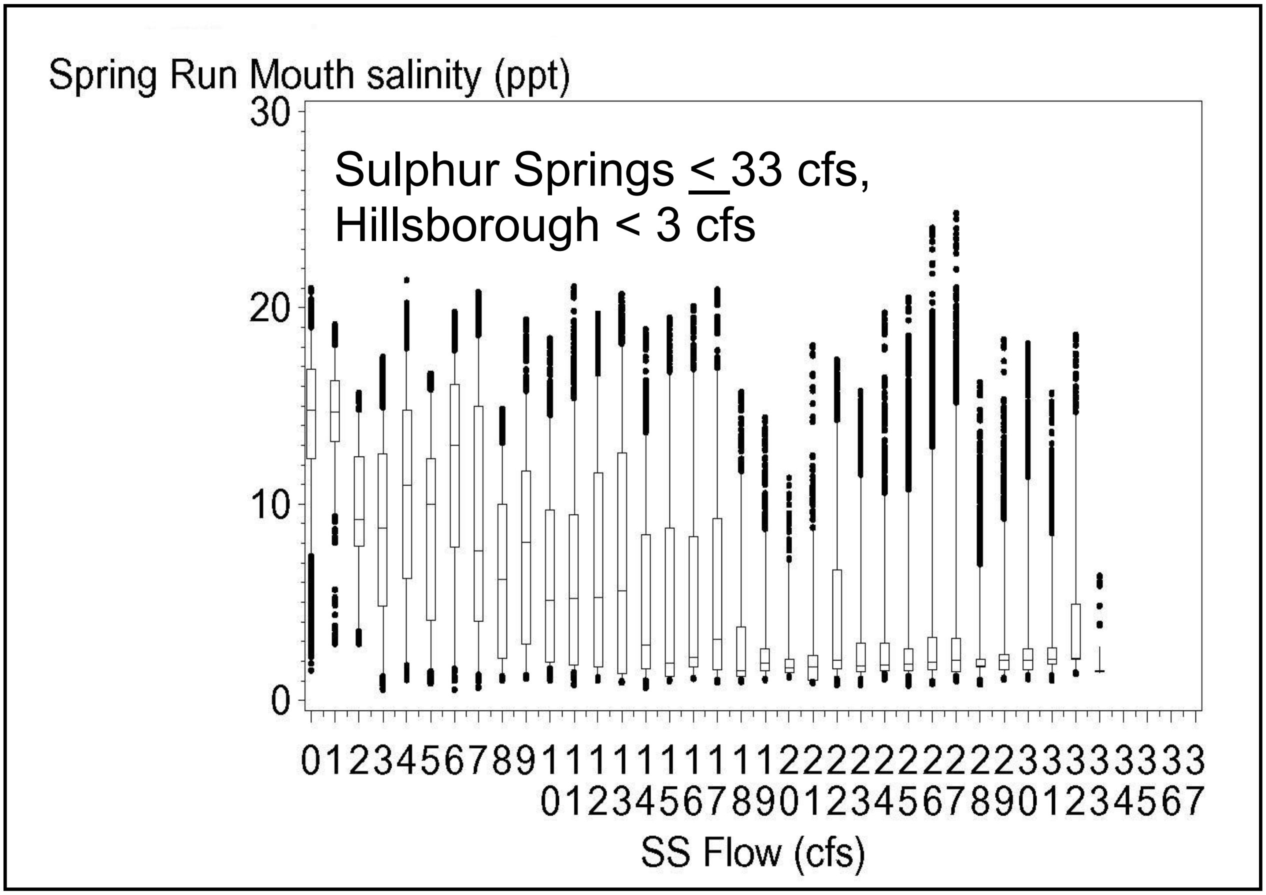

Figure 5-11. Box and whisker plot of 15 minute salinity measurements at the data recorder at the mouth of the spring run. Data restricted to periods when there was no flow to the lower river from the Hillsborough River reservoir.

5.2.7 Other potential effects of reduced flows.

Other characteristics of the upper spring run could potentially be affected by salinity incursions. As discussed in Section 3.7.1, mats of filamentous algae became widespread on the bottom of the spring run during the 200-2001 drought when large withdrawals were frequently made from the spring pool. A substantial reduction in the distribution of these algal mats accompanied the return of normal flow to the spring run in 2002 and 2003. It is not known what mechanism allowed the expansion of the algae during the drought, but reduced current velocities resulting from large springflow diversions may have been a factor. It is also not known what flows are necessary to prevent excessive expansions of filamentous algae in the spring run, but it is assumed that greater flows will reduce the potential for excessive growth of the filamentous algae.

Dissolved oxygen concentrations in the upper spring run could also possibly be affected by reduced flows. As discussed in Section 3.4, pronounced hypoxia was observed on one date by the University of Florida when flows were very low (<1 cfs) for quite some time. Hypoxia probably results from prolonged salinity incursions due the stratification of the water column, isolating bottom water from aeration. Salinity incursions that last only a few to several hours may not result in hypoxia, but continuous data are not available to test this hypothesis. Based on one-time mid-day sampling, much improved DO levels were observed on other days when flows were in the range of 13 to 31 cfs. Again, it is not possible to determine a threshold rate of flow to maintain healthy DO levels in the upper spring run. However, minimizing the probability of salinity incursions should provide an effective means for reducing the potential for hypoxia in the spring run.

5.3 Criterion 2 – Maintain low salinity habitats in the Lower Hillsborough River

As described in Section 3.7.1, Sulphur Springs provides nearly all the inflow of low salinity water to the Lower Hillsborough River during much of the year. This inflow provides important benefits to the Lower Hillsborough River by providing at least some amount low salinity habitats in the lower river and keeping salinity from reaching very high levels. As described in the Chapter 4, the maintenance of low salinity waters in the river is therefore an important criterion for establishing minimum flows for the spring.

5.3.1 Salinity distributions for different minimum flow scenarios predicted by a hydrodynamic salt transport model

The hydrodynamic model of the Hillsborough River described in Section 3.4.9.2 is an effective tool for evaluating the effect of flows from Sulphur Springs on salinity distributions in the Lower Hillsborough River. The model can be used to evaluate the longitudinal and vertical distribution of salinity in the river and calculate volumes of water within various salinity ranges. The scientific review panel for the Lower Hillsborough River recommended that the model be a key tool for evaluating the minimum flow needs of the Lower Hillsborough River (Montagna et al. 1999). This recommendation can apply to evaluating the effects of flows from Sulphur Springs on the salinity regime of the lower river as well.

As described in section 4.5, salinity zones of less than 4 (<4) ppt and less than 11 (<11) ppt were selected as indicators of salinity zones that could be used for the evaluation of minimum flows. The spatial distribution and volume of water within these salinity zones can be used to evaluate the distribution of oligohaline and low mesohaline habitats in the river. Graphical outputs of salinity distributions for six flow scenarios were presented in Section 3.9.2.2 to illustrate the effect of freshwater flows from the dam and flows from

Sulphur Springs on salinity distributions in the river. Graphics and tables from eight additional model runs are presented below to evaluate minimum flows from the spring in relation to the inflow needs of the lower river.

Table 5-3 lists the volumes of the <4 and <11 ppt salinity zones in the lower river for total of fourteen inflow scenarios. The volumes of the <4 ppt and <11 ppt salinity zones are listed for the entire lower river, and also separately for the regions of the river upstream of Sulphur Springs and from the spring downstream.

The function of minimum flows from Sulphur Springs in relation to the inflow needs of the Lower Hillsborough River are most important when there is no flow from the Hillsborough River reservoir. As previously described and illustrated in Figures 3-17 through 3-20, flows from the reservoir create freshwater and low salinity habitats in the lower river. The volume of water <4 and <11 ppt increase greatly with flow from the dam (scenarios 1 through 4 in Table 5-3). For example, the volume of <4 ppt water increases from 89,600 m^3 to 438,100 m^3 as flows increase from 10 to 60 cfs. At a flow of 60 cfs, freshwater extends to the mouth of Sulphur Springs, with waters of <4 and <11 ppt extending downstream from that point (Figure 3-19). Greater flows increase the volume of these salinity zones and push them further toward the mouth of the river.

As described in Section 3.9.2.2, when there is no flow from the reservoir brackish waters can migrate to the base of the dam. Under these conditions, a reverse salinity gradient is created, as a shallow, low salinity lens forms near the mouth of Sulphur Springs (Figure 3-16, also repeated as Figure 5-12). Under these conditions, the volume of water <4 ppt in the river is typically very small (1,900 m^3 in scenario 1, Table 5-3), and limited to very shallow water near the mouth of the spring run. This vertical salinity gradient near the spring mouth causes a pronounced density gradient that impedes the oxygenation of bottom waters and results in frequent hypoxia in that reach of the river.

As also previously discussed, moving some portion of flow from Sulphur Springs to the base of the dam can result in a net benefit to the lower river, as long as the minimum flows for the spring are met. Given a total flow rate of 31 cfs from the spring, moving 10 cfs of this water to the base of the dam results in a <4 ppt salinity zone of 30,500 m^3 (scenario 5). Nearly all of this low salinity water is located above Sulphur Springs, creating a horizontal salinity gradient with the lowest salinity values in the upstream areas near the dam (Figure 3-17, also repeated as Figure 5-13). Establishing low salinity habitats near the dam was a primary criterion in establishing the 10 cfs minimum flow for the Lower Hillsborough River, which can be provided by diversions from Sulphur Springs. This minimum flow, however, is currently being re-evaluated in ongoing studies that involve releases of freshwater from the dam

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Table 5-3. Volumes of water < 4 ppt and < 11 ppt in the lower river for fourteeen flow scenarios.

		Spring Flow (cfs)	Diversion to Flume (cfs)	Reservoir Release (cfs)	Volume <4 ppt (m^3*1000)	Volume <11 ppt (m^3* 1000)
Entire Lower River	1	31	0	0	1.9	355.6
	2	31	0	10	89.6	461.1
	3	31	0	60	438.1	991.1
	4	31	0	120	708.9	1391.2
	5	21	10	0	30.5	357.5
	6	18	10	0	25.5	335.6
	7	13	10	0	18.5	283.9
	8	10	10	0	14.5	245.7
	9	18	13	0	39.2	366.2
	10	13	18	0	54.8	367.6
	11	10	21	0	64.9	368.2
	12	18/10	10	0	20.6	299.7
	13	18/10	13/21	0	50.6	365.6
	14	13/10	10	0	18.1	273.7
Most upstream 3km	1	31	0	0	0.0	183.2
	2	31	0	10	78.6	185.3
	3	31	0	60	186.4	186.4
	4	31	0	120	187.5	187.5
	5	21	10	0	29.7	183.5
	6	18	10	0	25.2	182.1
	7	13	10	0	18.5	177.4
	8	10	10	0	14.5	167.6
	9	18	13	0	38.6	183.3
	10	13	18	0	54.5	183.3
	11	10	21	0	64.7	183.3
	12	18/10	10	0	20.6	179.7
	13	18/10	13/21	0	50.5	183.3
	14	13/10	10	0	18.1	175.8
Most downstream 13.3 km	1	31	0	0	1.9	172.4
	2	31	0	10	11.0	275.8
	3	31	0	60	251.8	804.7
	4	31	0	120	521.4	1203.7
	5	21	10	0	0.8	174.0
	6	18	10	0	0.3	153.5
	7	13	10	0	0.0	106.6
	8	10	10	0	0.0	78.1
	9	18	13	0	0.7	183.0
	10	13	18	0	0.4	184.4
	11	10	21	0	0.3	185.0
	12	18/10	10	0	0.0	120.1
	13	18/10	13/21	0	0.1	182.3
	14	13/10	10	0	0.0	97.5

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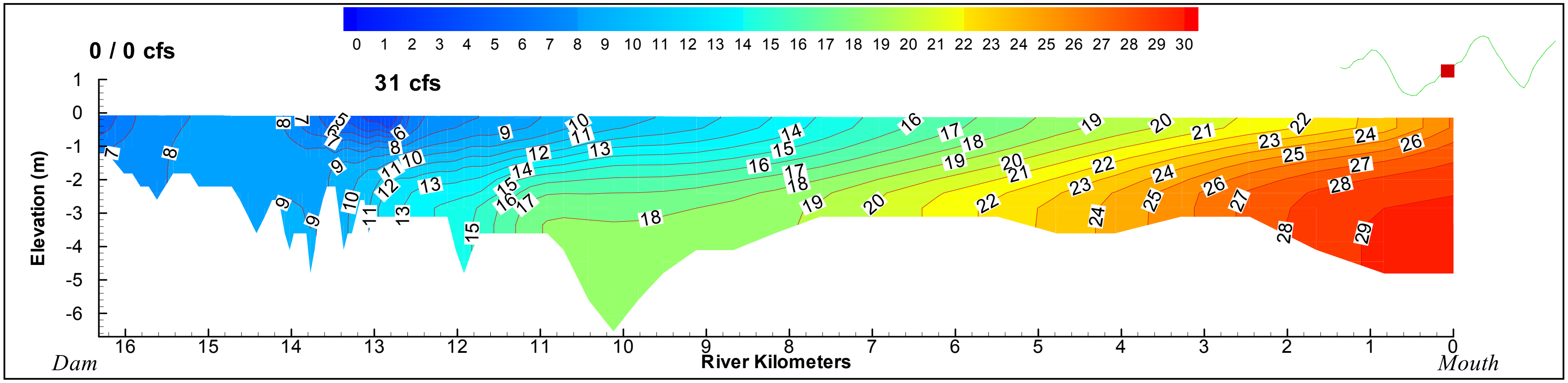

Figure 5-12. Two-dimensional plot of salinity distributions for inflows of 0 cfs of springwater at the dam and 31 cfs of springflow at Sulphur Springs.

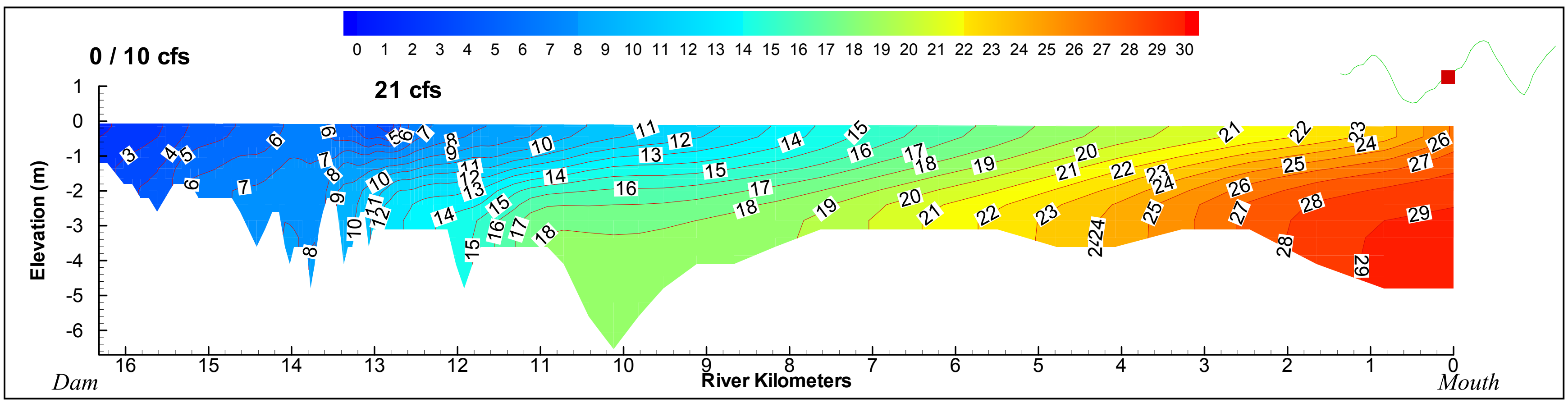

Figure 5-13. Two-dimensional plot of salinity distributions for inflows of 10 cfs of springwater at the dam and 21 cfs of springflow at Sulphur Springs.

Scenarios 6 through 8 in Table 5-3 show the effects of reducing flow from Sulphur Springs, while maintaining a flow of 10 cfs of water to the base of the Hillsborough River dam. Assuming a total flow of 31 cfs, scenario 6 would maintain a minimum flow of 18 cfs to the spring run, divert 10 cfs to the foot of the dam, and remove 3 cfs of water from the system for water supply. Compared to discharging all the springflow to either the base of the dam or the spring run (scenario 5), reducing the flow from 21 to 18 cfs at the spring run results in a 16.4% reduction in the volume of <4 ppt water (from 30,500 to 25,500 m^3). Most of this reduction occurs upstream of Sulphur Springs. The volume of <11 ppt water would be reduced by 6.1%, with most of this reduction occurring below Sulphur Springs

Scenario 7 would remove 8 cfs from the system, maintaining 10 cfs to the base of the dam and leaving 13 cfs discharging to the spring run. Compared to scenario 5 (no water removal), the volume of <4 ppt water would be reduced by 40% to 18,500 m^3, while the volume of water <11 ppt water would be reduced by 20.5%. Scenario 8 would remove 11 cfs from the system, maintaining 10 cfs to the base of the dam and leaving 10 cfs discharging to the spring run. Compared to scenario 5, the volume of <4 ppt water would be reduced by 52.4% to 14,500 m^3, while the volume of water <11 ppt would be reduced by 31.2%.

The salinity distributions for scenarios 6 through 8 are illustrated in Figures 5-14 though 5-16. Compared to scenario 5 (Figure 5-13), reductions of flow at the spring outfall result in the upstream movement of several isohalines above Sulphur Springs. These scenarios result in a reduction of inflow of low salinity spring water to the river, which through tidal action, increases salinity in the river upstream of the spring. Downstream of Sulphur Springs, the reduction of springflow results in the upstream movement of isohalines greater than 8 ppt, particularly near the water surface. For example, the 11 ppt isohaline at the water surface moves approximately 1.4 km upstream as springflow is reduced from 21 to 10 cfs (Figure 5-13 vs. Figure. 5-16).

These results show the amount of spring discharge to the spring run has important effects on salinity distributions in the Lower Hillsborough River. Assuming that 10 cfs of spring water is diverted to the base of the Hillsborough River dam, incrementally removing the additional flow to the spring run reduces the volume of valuable low salinity habitats in the lower river. Compared to a scenario of no water removal (scenario 5), the difference in the reduction in <4 ppt water between 18 and 13 cfs minimum flows at the spring is substantial (16.4% in scenario 6 vs. 40.0% in scenario 7). Similarly, the reduction in <11 ppt water volume is more than three times as great between these scenarios (6.1% vs. 20.6%). These differences in salinity zone volumes support the desirability of an 18 cfs minimum flow as opposed to 13 cfs, if it is assumed the remaining flows are removed from the system for water supply.

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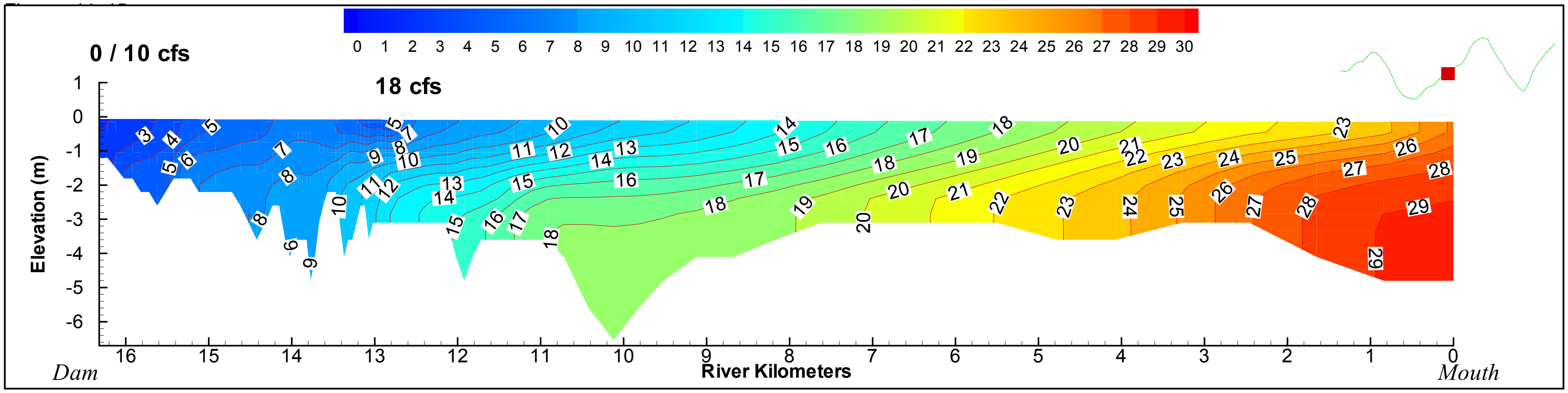

Figure 5-14. Two-dimensional plot of salinity distributions for inflows of 10 cfs of springwater at the dam and 21 cfs of springflow at Sulphur Springs. (Scenario 6)

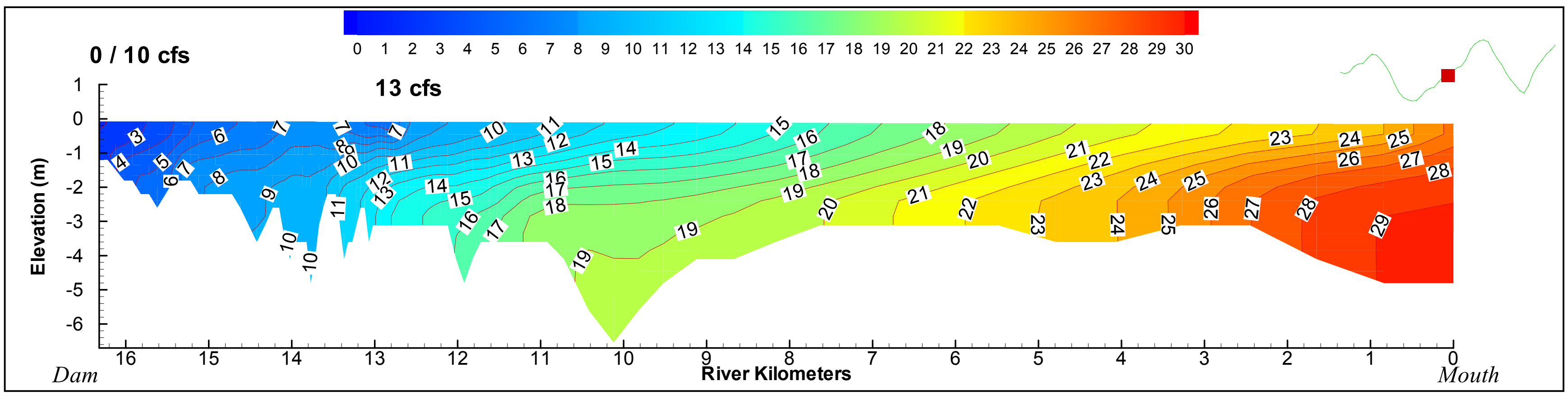

Figure 5-15. Two-dimensional plot of salinity distributions for inflows of 10 cfs of springwater at the dam and 13 cfs of springflow at Sulphur Springs. (Scenario 7)

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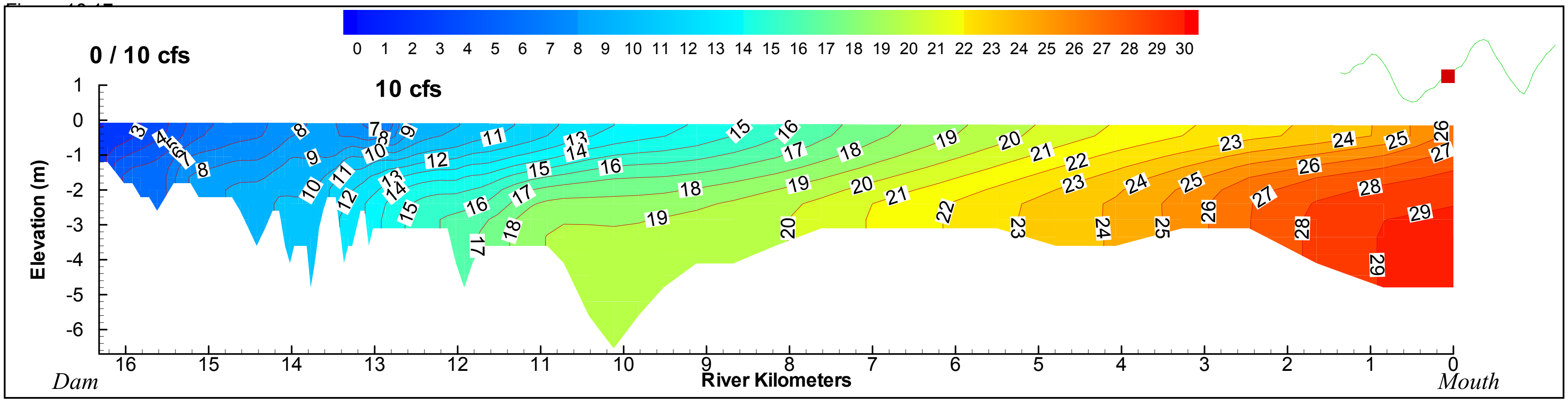

Figure 5-16. Two-dimensional plot of salinity distributions for inflows of 10 cfs of springwater at the dam and 10 cfs of springflow at Sulphur Springs. (Scenario 8)

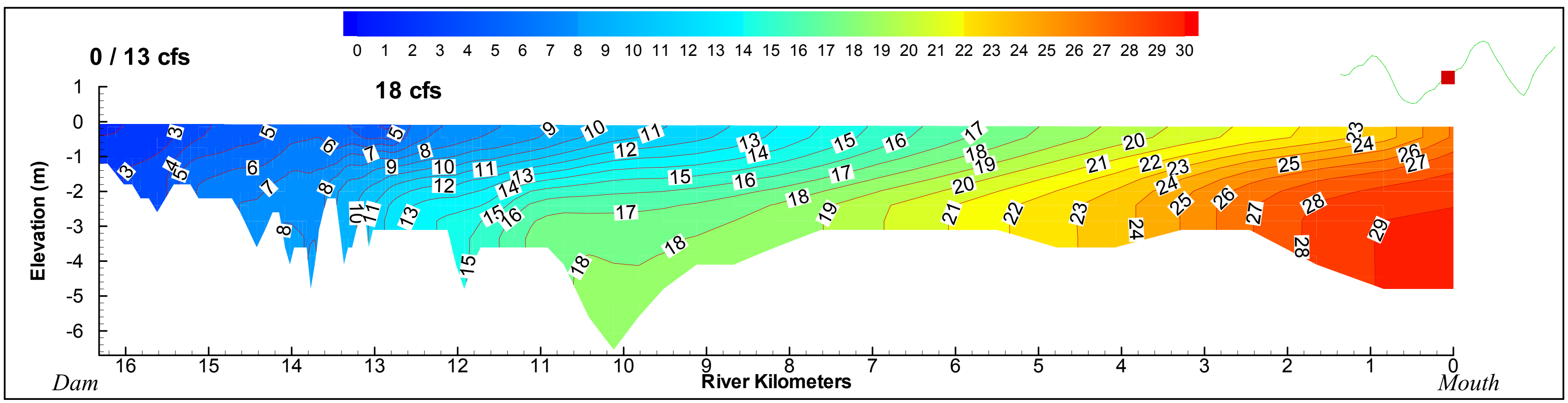

Figure 5-17. Two-dimensional plot of salinity distributions for inflows of 13 cfs of springwater at the dam and 18 cfs of springflow at Sulphur Springs. (Scenario 9)

Viewed strictly from the inflow needs of the lower river, a lesser minimum flow at the spring run could possibly be acceptable if all of the remaining flow was routed to the base of the dam. Scenarios 9 through 11 involve apportioning different amounts of the total 31 cfs average flow between the spring run and the base of the dam, with no removal of water from the system. For example, scenario 9 provides 18 cfs at the spring outfall and 13 cfs at the base of the dam. Scenarios 10 and 11 involve incrementally reducing flow to the spring run and increasing flow at the dam, with final scenario leaving 10 cfs at the spring run and 21 cfs at the dam. The salinity distributions for these scenarios are illustrated in Figures 5-17 through 5-19.

Moving additional water to the base of the dam increases the volume of <4 ppt water in the lower river and reduces salinity values upstream of spring outfall. For example, reducing flow at the spring run from 18 to 13 cfs increases the amount of <4 ppt water by 39.8%. All of this gain occurs upstream of the spring mouth, where the downstream movement of other isohalines results as well (Figure 5-17 vs. Figure 5-19). The differences in salinity distributions between these scenarios are much less apparent downstream of the spring mouth, where the mixing dynamics are less affected. The volumes of water <11 ppt show virtually no difference between these scenarios.

Although it can be considered a net benefit to the river to move as much water as possible to the base of the dam, this must be balanced with the flow needs of the upper spring run. If salinity incursions to the upper spring run are to be minimized, an 18 cfs minimum flow would be appropriate. However, if periodic salinity incursions are acceptable in the upper spring run, it would be advantageous to maintain a flow of 13 cfs in the spring run and move the remaining flow to the base of the dam. It is reiterated that such a scenario involves no removal of water from the system. If the remaining water were removed, the resulting scenario would be number 7, in which 13 cfs flows to the spring run while 10 cfs is diverted to the dam. This scenario results in a substantial reduction of both <4 and <11 ppt salinity zones from any of the scenarios that involve no removal. As described above, if it is assumed that water will be removed from the system, a minimum flow of 18 cfs provides greater protection to the river than the 13 cfs minimum flow.

As discussed in Section 5.2.2.1, salinity incursions into the upper spring run are related to tide stage in the lower Hillsborough River, and flows could be reduced when tide stages are low in the river without causing salinity incursions into the upper spring run. To examine the effect of stage dependent flows on salinity distributions in the lower river, three scenarios were run in which the minimum flow from the spring varied with tide stage. In scenarios 12 and 13, flows from the spring were maintained at 18 cfs when water levels in the river near the spring mouth were above 0.0 ft NGVD, and 10 cfs of flow from the spring when water levels in the river were below 0.0 feet.

This stage dependent minimum flow is combined with a minimum flow of 10 at the base of the Hillsborough River dam with the remaining waters removed from the system in scenario 12 (Figure 5-20). Assuming an average flow rate of 31 cfs, the quantity of

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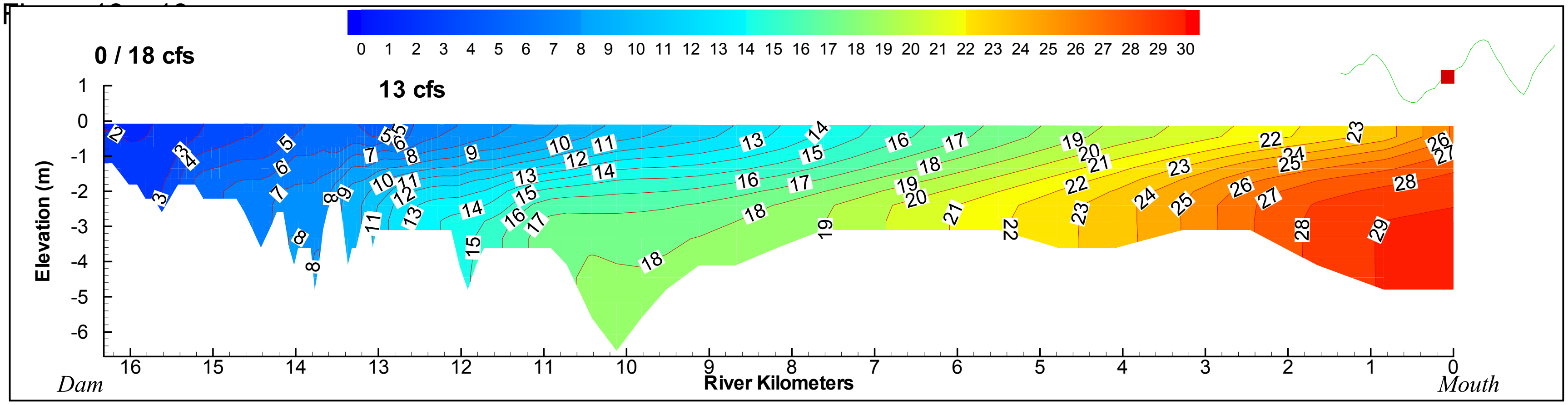

Figure 5-18. Two-dimensional plot of salinity distributions for inflows of 18 cfs of springwater at the dam and 13 cfs of springflow at Sulphur Springs. (Scenario 10)

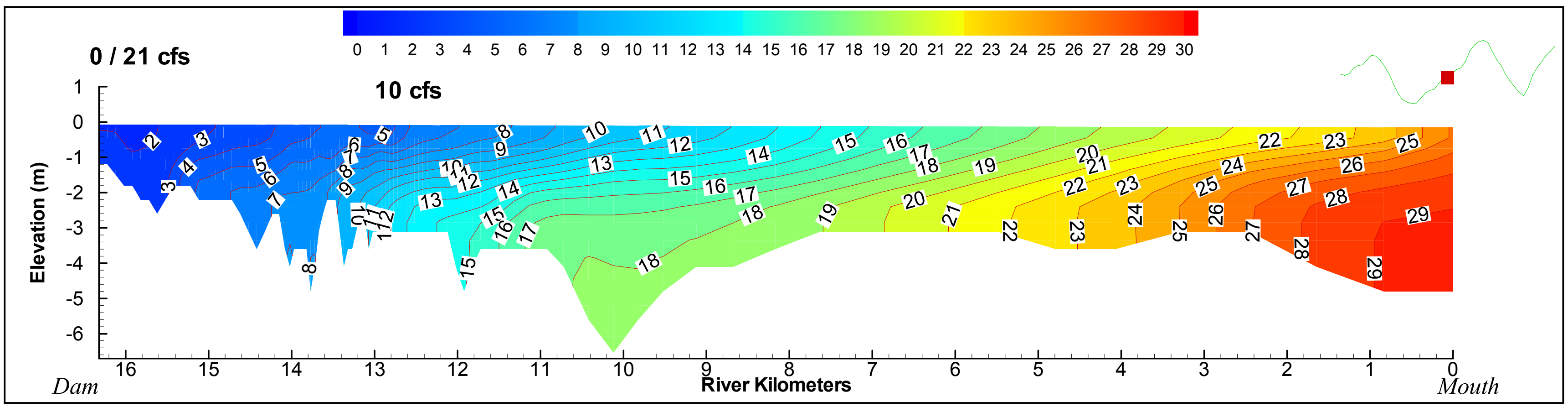

Figure 5-19. Two-dimensional plot of salinity distributions for inflows of 21 cfs of springwater at the dam and 10 cfs of springflow at Sulphur Springs. (Scenario 11)

water removed would fluctuate between 3 and 11 cfs. The volume of water <4 ppt salinity for this scenario is 20,600 m^3, which is intermediate between the volumes for the steady 18 cfs (25,500 m^3) and 13 cfs (18,500 m^3) minimum flows combined with 10 cfs of springflow diverted to the dam. The advantage of this scenario is that it would minimize salinity incursions into the upper spring run, but allow for increased water use. A tide based minimum flow fluctuating between 13 and 10 cfs released to the spring run (scenario 14) would result in a volume of <4 ppt water that is slightly less than the steady 13 cfs spring minimum flow (scenario 7). Ten cfs of springflow is diverted to the base of the dam in both scenarios.

Scenario 13 also uses a 18/10 cfs stage dependent flow schedule to the spring run, but there is no removal of water and all remaining flows are routed to the dam (Figure 5-21). The volumes of <4 ppt and <11 ppt water are comparable to the scenario in which 13 cfs is discharged to the spring run and 18 cfs is discharged at the base of the dam. Assuming no withdrawals from the system, the advantages of this scenario are that salinity incursions are minimized in the upper spring run, while increasing the amount of <4 ppt salinity zones in the lower river. Reducing spring flows from 18 to 10 cfs, will however, result is slightly lower water levels in the spring run during low tides (see Section 5.2.3).

5.4 Summary of incorporating criteria 1 and 2 low-salinity factors into a minimum flow for Sulphur Springs

The determination of minimum flows for Sulphur Springs is to prevent significant harm to the spring and Lower Hillsborough River that would result from water withdrawals. Although water supply use from Sulphur Springs has been intermittent in the past, the spring has long been an important back-up water supply source for the City of Tampa. Accordingly, the District has evaluated minimum flow scenario for the spring that would protect the associated ecological features of the spring run and lower river while allowing for continued water use within environmentally safe limits.

In establishing minimum flows, the District is directed by Florida statutes to account for previous structural alterations to the system. Sulphur Springs is a highly modified system: the pool is separated from the run by a water control structure; vertical walls line much of the shoreline; and a weir is located within the channel of the spring run. The District accounted for these alterations, particularly the effect of the weir, in the determination of minimum flows for Sulphur Springs. The District also considered how operation of the pumps and diversion facilities at the spring pool could be operated to protect the ecology of the system while allowing for water use.

The District's approach for using salinity as an ecological indicator for determining a minimum flow for Sulphur springs employed two criteria. First, maintain low salinity habitats in the upper spring run to maintain invertebrate community composition characteristic of the spring run. Although many of the species in the spring run are

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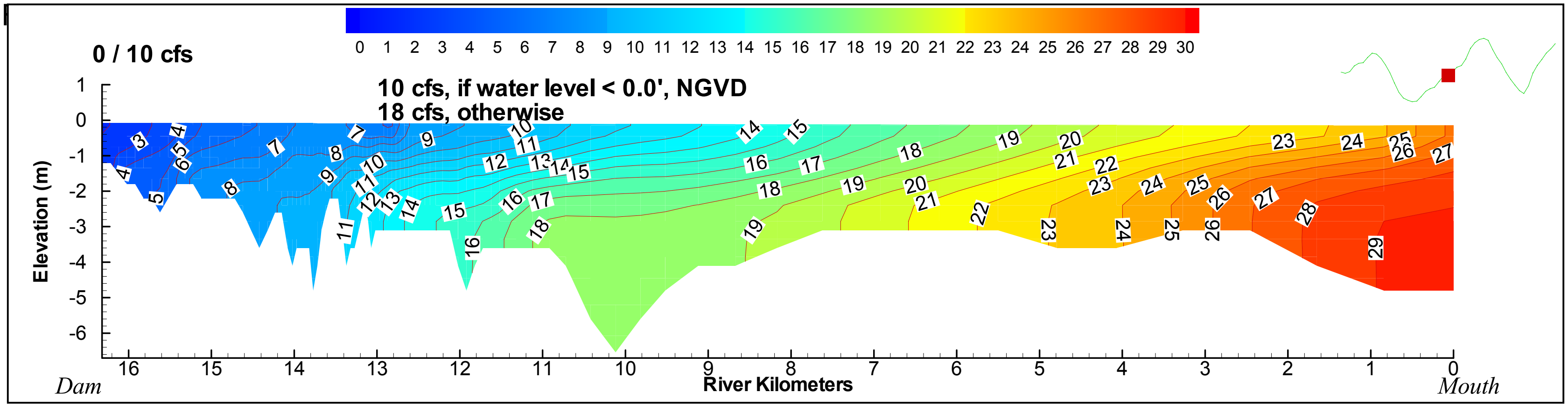

Figure 5-20. Two-dimensional plot of salinity distributions for inflows of 10 cfs of springwater at the dam and 18 to 10 cfs of springflow at Sulphur Springs, switching when stage in the river goes above or below 0 feet NGVD. (Scenario 12)

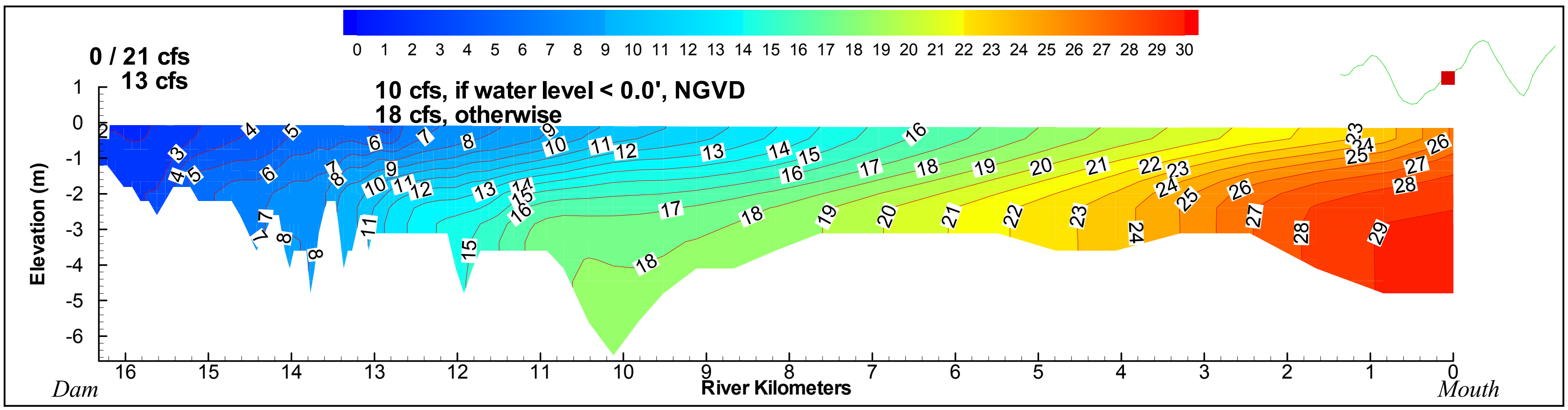

Figure 5-21. Two-dimensional plot of salinity distributions for inflows of 13 cfs of springwater at the dam and 18 cfs of springwater at Sulphur Springs when water levels in river above 0.0 feet; switching to 21 cfs at the dam and 10 cfs at Sulphur Springs when river stage goes below 0 feet NGVD. (Scenario 13)

euryhaline, there were also many freshwater species that can tolerate low levels of salinity or brief salinity exposures. The most conservative way to protect this community is to minimize salinity incursions into the spring run. The results presented in Section 5.2 indicate that a minimum flow of 18 cfs represents a distinct breakpoint that minimizes salinity incursions in the upper spring run. The biological results presented in Chapter 3 indicate that such a salinity regime would maintain a diverse invertebrate community that is characteristic of the spring run under normal flows (> 20 cfs).

The second criterion that uses salinity as an ecological indicator involves low salinity habitats in the Lower Hillsborough River. The distribution of <4 and <11 ppt salinity zone habitats in the lower river were used as ecological indicators for this report. In accordance with analyses conducted for the minimum flow for the Lower Hillsborough River, a diversion of a minimum of 10 cfs of spring water to the base of the Hillsborough River dam was assumed for all minimum flow scenarios. Assuming a 10 cfs of springflow diverted to the dam, reductions of flow to the spring run reduced the volumes of <4 and <11 ppt salinity zones in the lower river. There was a pronounced decline in the volumes of these salinity zones between 18 and 13 cfs, which were two minimum flows evaluated with regard to the inflow needs of the upper spring run.

The combined results of the criterion 1 and criterion 2 minimum flows indicate that 18 cfs would be an effective minimum flow to prevent significant harm to the spring run and maintain low salinity habitats in the Lower Hillsborough River. Based on criteria 1 and 2, this is the minimum flow that should be implemented for routine use on Sulphur Springs. Springflow above 18 cfs, that is not used for water supply or to meet the 10 cfs minimum flow at the Hillsborough River dam, should be diverted to the base of the dam to supplement the minimum flow there and expand low salinity habitats and improve flushing above Sulphur Springs.

The data presented in this report indicate a lower minimum flow that is based on tide stage levels in the Lower Hillsborough River could be implemented without resulting in salinity incursions into the upper spring run. This would allow additional water supply use from the spring without jeopardizing the community characteristics of the fauna in the upper spring run. However, compared to a steady minimum flow of 18 cfs, such a scenario would cause slight reductions in the volume of low salinity habitats in the lower Hillsborough River. A fluctuating minimum flow of 18 and 10 cfs that switched at a tide stage value of 0.0 ft in the river near the spring was evaluated in this report. The reductions in low salinity habitats in the lower river for this scenario are considered allowable.

Based on above, it is concluded that the minimum flow can be reduced to 10 cfs during times of low tide stage if salinity incursions can be prevented. A salinity monitor that reports real time data could be installed near the weir to provide a signal to adjust the pumping rate from the spring and increase the minimum flow to 18 cfs if there is evidence of salinity incursion from the river into the upper spring run. The 10 cfs value is established to limit the reduction of low salinity habitats in the lower river

The biological data collected for this project found pronounced changes in the invertebrate fauna of the spring corresponding to major reductions in flows from the spring pool during the 2000-2001 drought. Salinity in the run rose dramatically during the drought, when pumping from the pool reduced spring flows to zero or very low rates of flow. Despite the relative severity of these physico-chemical alterations, a recovery of the species richness of the spring run accompanied a return to normal flows. The determination of minimum flows can consider that periodic impacts to ecosystems can be tolerated if they are infrequent or of short duration and do not result in a permanent change in ecological characteristics. Such an approach could be considered for Sulphur Springs to allow the city additional water use during dry years when water supplies from the reservoir are low.

In this regard, a lower minimum flow could be considered for infrequent use if it is assured that such a minimum flow will not result in permanent changes or impacts to the ecosystem. In the case of Sulphur Springs, a minimum flow of 13 cfs could be used periodically and likely not result in longstanding harm to the ecology of the run and lower river. Maintaining a flow of 13 cfs would maintain markedly better conditions than what the spring run experienced during the 2000-2001. Salinity incursions at a springflow rate of 13 cfs appear to last no more than several hours during any day, and many of the species in the spring run would suffer no negative effects. If any species were lost, they would likely recolonize the spring when higher flows return.

Reiterating that 18 cfs is the preferred minimum flow for routine use, a minimum flow of 13 cfs could be acceptable with a return frequency that does not cause permanent harm to the ecology of the upper spring run. In unimpounded Florida rivers, the upstream movement of brackish waters into what are normally tidal freshwater zones happen during very dry years. It is suggested here that salinity incursions associated with a 13 cfs minimum flow would be acceptable if they occurred only every 2 – 3 years. With this return interval, the spring run would typically have a period of year or more to recover after period of salinity incursions. This would allow for recolonization by invertebrate species that have seasonal life cycles with reproduction in dry season.

The City's need for back-up water supplies from the Sulphur Springs has largely been during dry years. In that regard, the switch to a possible 13 cfs minimum flow could be based on water levels in the City's reservoir. This would allow increased use of the spring for water supply when the reservoir becomes low, but would occur only on an infrequent basis. A plot of average daily water levels for the period of 1988-2003 is presented in Figure 5-22. This time period was evaluated as withdrawals from the Hillsborough River reservoir have been near the current rate of water use (60- 66 mgd), thus these levels are indicative of current water level fluctuations in the reservoir. The number of days that water levels fell below 19 feet and the minimum stage each year are also listed in Table 5-4.

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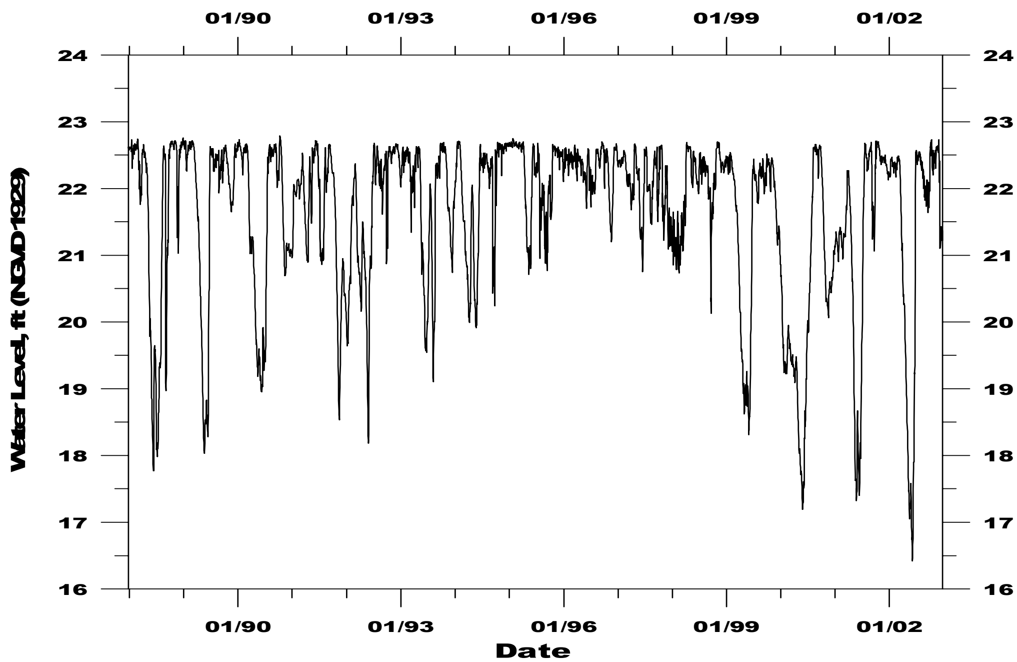

Figure 5-22. Average daily water levels in the Hillsborough River reservoir for 1988-2003.

Table 5-4. The number of days each year that water levels in the Hillsborough River reservoir were below 19 feet NGVD and the minimum stage for each year for 1988-2003		
Year	Number of days below 19 ft.	Minimum stage
1988	38	17.7
1989	39	18.0
1990	5	18.9
1991	9	18.5
1992	9	18.2
1993	0	19.1
1994	0	19.9
1995	0	20.7
1996	0	21.2
1997	0	20.8
1998	0	20.1
1999	37	18.3
2000	59	17.2
2001	48	17.3
2002	53	16.4
2003	0	22.1

Water levels dropped below 19 feet during half of the sixteen years from 1988-2003. However, these occurrences did not happen at regular intervals. Water levels did not fall below 19 feet for a six-year period from 1993-1998. However, water levels fell below 19 feet for five years in a row from 1988-1992 and four years in a row from 1999-2002. Water levels were below 19 feet for only 5 to 9 days during each of the last three years of the 1988-2002 period and slightly over five weeks during the first two years. Although low water occurrences happened during successive years, the relatively short period that a 13 cfs minimum flow would be in effect would probably allow sufficient period for recolonization by any species that were extirpated from the spring run by salinity incursions. Lower water levels were more prolonged during the 1999-2002 period, ranging from 37 to 59 days for those years. These occurrences happened during one of the most severe and prolonged drought the region has experienced, and should not be considered typical events.

These results show that simply linking a minimum flow of 13 cfs to water levels in the reservoir does not provide a perfect mechanism for providing a regular recurrence interval for implementing a reduced minimum flow. However, the duration of the reduced minimum flow each year is relatively short, and should allow for periods of recolonization during the dry seasons of most years. Also, the salinity incursions that will happen with a 13 cfs minimum flow should not exceed several hours each day, and the impacts to the invertebrate fauna of the spring should be must less dramatic than the changes observed during this study. Future biological monitoring of the spring run could be conducted during dry years to determine the effect of a 13 cfs minimum flow on the invertebrate fauna of spring run. The continuation of that 13 cfs minimum flow during low water levels, or possible use of a 13 cfs on a more frequent basis, could be linked to the results of such monitoring.

5.4.1 Application of minimum flows based on criteria 1 and 2

In summary, the minimum flow for Sulphur Springs based on criteria 1 and 2 (maintaining low salinity habitats in the spring run and river) is 18 cfs. This minimum flow may be reduced to 10 cfs during low tide stages in the lower Hillsborough River if it does not result in the movement of brackish waters from the river into the upper spring run. A minimum flow of 13 cfs can be implemented when water levels in the Hillsborough River reservoir fall below 19 feet NGVD. This minimum flow can also switch to 10 cfs at low tide stages in the lower river if it does not result in salinity incursions into the upper spring run. Evidence of a salinity incursion could be a salinity value at the upper spring run recorder that is more than 1 ppt greater than the concurrent salinity value in the spring pool.

Water use from the spring by the City of Tampa is regulated under a special condition in their water use permit for withdrawals from the reservoir. Because of the important functions that springflow has with regard to the ecology of the spring run and lower river, the intent of that condition is to ensure that Sulphur Spring is used only as a back-up water supply source that is used during times of impending water shortages. The condition specifies that withdrawals from Sulphur Springs cannot occur until water levels in the reservoir fall below 20 feet for the months from March through June, or below 18 feet for the remaining eight months of the year.

The minimum flows recommended by this report will require that pumpage rates from the spring be considerably less than the 20 mgd rate the City has used in the past. As previously discussed, the City now has the capability to manage withdrawals in increments which will allow much smaller withdrawal rates to be possible. Since the withdrawal rates will have to be reduced to meet minimum flows, it is recommended that linking spring withdrawals to water levels in the reservoir be dropped from the City's water use permit as long as minimum flows for Sulphur Springs are met. This will allow the City to withdraw water from Sulphur Springs much sooner, albeit at smaller withdrawal rates, to meet water supply needs in the dry season. It is reiterated the minimum flow will be linked to reservoir levels, so that slightly higher withdrawal rates will be possible if water supplies in the reservoir become low.

5.5 Criterion 3 - Maintain a thermal refuge for manatees

5.5.1 Purpose

Changes in water temperatures that would result from reducing or re-routing flows from Sulphur Springs were investigated to assess any adverse potential impacts to the biological communities in the spring run and lower river due to alterations of the spring's flow regime. As described earlier, the lower river and the spring run are utilized by the Florida manatee (*Trichechus manatus latritostris*), a federally listed endangered species. The water temperature of flow from Sulphur Springs remains near 25^{o} C throughout the year, while the waters of the lower river are more influenced by seasonal air temperatures and can be considerably cooler. During cold winter periods, the warmer water from Sulphur Springs provides a thermal refuge for manatees in the spring run and the lower river near the mouth of the spring run. Flows from the spring also benefit other species that are sensitive to cold, such as the snook, a highly valued saltwater game fish that is found in the lower river.

The objective of the analysis presented below was to evaluate the effect of reducing or re-routing flow from Sulphur Springs on water temperatures in the lower river during winter months. It was reasoned that water temperature in the spring run should be less sensitive to flow alterations than temperature in the nearby river. Therefore, if the requirements of a thermal refuge in the lower river near the spring were met, the thermal requirements of a refuge in the spring run would be met as well. Analyses were conducted to determine if the minimum flows that are recommended to meet salinity requirements of the spring run and lower river are sufficient to meet the temperature requirements of a thermal refuge for manatees in the lower river.

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5.5.2 Methods and description of thermal model

A two-dimensional laterally averaged hydrodynamic and water quality model was utilized to evaluate the effect of various flow scenarios on the thermal regime of the Lower Hillsborough River. This work was performed by Janicki Environmental, Inc. for the District. The model that used was CE-QUAL-W2, which was developed and is supported by the US Army Engineer Waterways Experiment Station (Cole and Wells 2000). At a minimum, the model predicts water surface elevations, velocities, and temperature at a specified time interval. The Hillsborough River temperature model developed using the CE_QUAL-W2 software was previously calibrated as described in Pribble et al. (2003). For the flow scenarios described in this report, the model was set to output data at hourly frequencies.

The model provides predictions that are laterally averaged (across the entire water body perpendicular to the direction of horizontal flow) so that the model integrates any lateral differences in velocities, temperatures, or other modeled constituents. Given the narrow width of the channel of the lower river, the District's LAMFE model indicated that three-dimensional modeling was not necessary to characterize circulation in the lower river (Chen et al. 2001). The thermal model accommodates multiple inflows and time-varying boundary conditions for surface elevation and temperature.

5.5.3 Model Data Requirements

The model requires the following input data:

- geometric data,
- initial conditions,
- boundary conditions, and
- hydraulic parameters.

The geometric data for the system being modeled were generated using the system bathymetry from the District's LAMFE model. The bottom depth as well as the lateral (cross-stream) width of the system at selected depths was estimated from the bathymetry. The grid construct derived for the modeled system was also based on the bathymetry from the LAMFE model, and was refined to provide the greatest resolution in those regions of greatest importance to the objectives of the model study.

Initial conditions were input for temperatures and salinity concentrations, as these variables can exert strong effects on water density and circulation. These conditions were input either as a single value over the entire domain as a vertical profile of values over all columns or as longitudinally and vertically varying fields over the model domain. Initial conditions were also input for downstream tidal elevation. The model scenarios included inflows to the model domain from Sulphur Springs. Like the LAMFE model, these scenarios were run assuming minimal rainfall and stormwater inflow below the dam. Associated with these scenarios were water temperatures and salinity concentrations of the inflow source. In order to allow predictions to be made under varying scenario conditions, the model also allows precipitation and withdrawals from the system to be modeled. Meteorological data (air temperature and wind speed and direction) were input to estimate evaporation.

Water surface elevation boundary conditions were also specified at the downstream limit of the model domain. Vertical temperature and constituent concentration profiles at the boundaries were input. Surface heat exchange was also estimated based on the input meteorological data, including air temperature, dew point temperature, wind speed and direction, and cloud cover. Hydraulic parameters input to the model included a horizontal dispersion coefficient for momentum and a horizontal dispersion coefficient for temperature and constituents. These values were set to be constant over time and over the entire spatial domain of the model. Bottom friction coefficient values were also input to the model.

5.5.4 Model Construct

The grid system utilized in this study was based on that previously developed for the LAMFE model. The grid system developed for the LAMFE model, as shown in Figure 5-23, included 32 columns along the river length and 16 vertical layers. Column lengths (distance along the river) varied, from 300 m in the upstream reaches of the river to greater than 800 m at the mouth. We adopted this grid system, and then refined if specifically for this study to provide greater resolution in the vicinity of the Sulphur Springs outfall. Columns 12 at Sulphur Springs and column and 13 (downstream of Sulphur Springs) of the LAMFE model were divided into 16 columns, each 50 m long Figure 5-23). The remainder of the LAMFE grid construct was unchanged.

5.5.5 Model Input Data

The thermal model was run under two sets of ambient temperature conditions that corresponded to two different time periods. These temperature conditions were based on threshold water temperature values suggested by staff of the Florida Fish and Wildlife Conservation Commission that are described in Chapter 4. The “coldest period” was defined as that time when water temperatures in the Lower Hillsborough River were the lowest observed during the period of record of monthly observations by the EPCHC since 1974. The “thermal refuge period” was defined as a period when the continuous recorders in the river and spring were operating (since 1999); water temperatures in the river near Sulphur Springs were greater than 20° C; and temperatures in the river upstream and downstream of Sulphur Springs were less than 20° C. Using temperature data from these periods, the effects of various flow scenarios were evaluated by

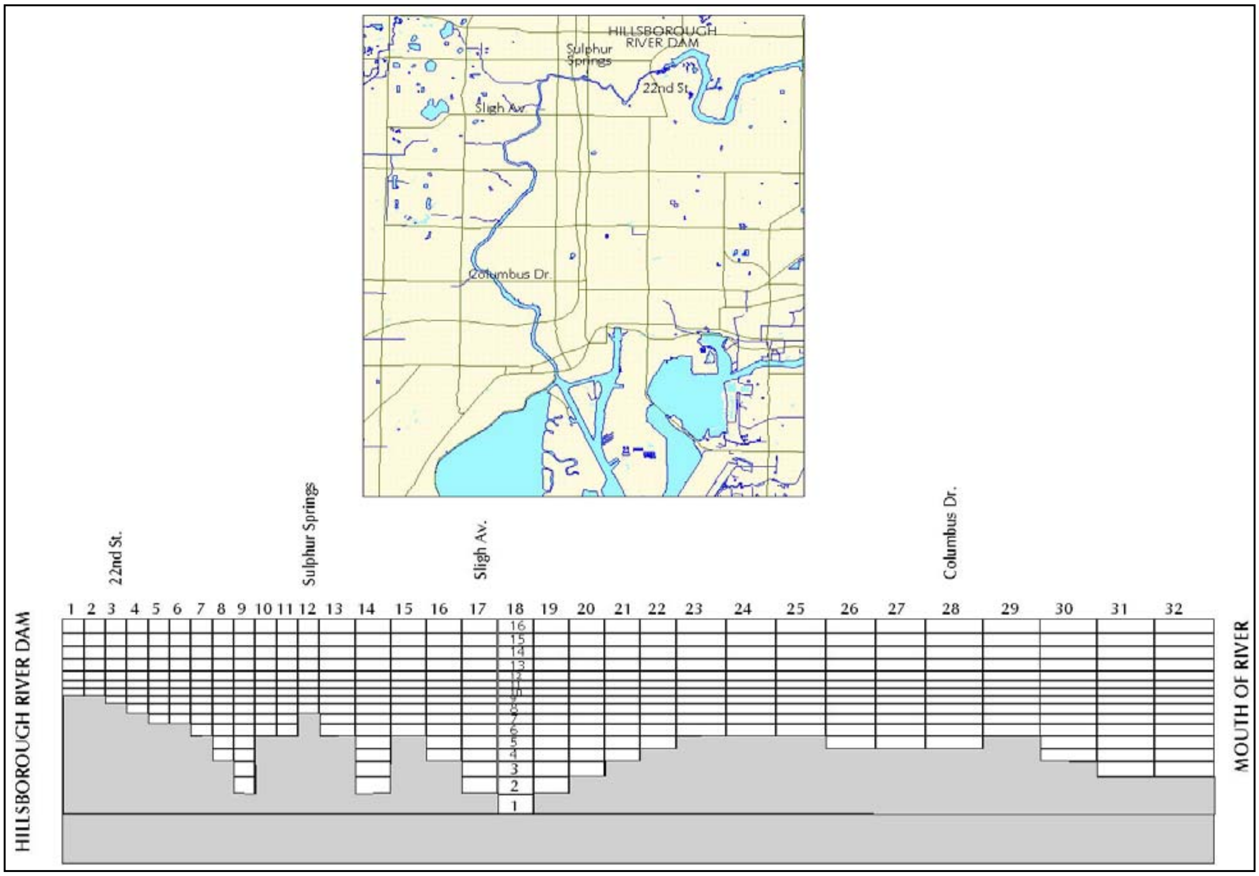

Figure 5-23. Model domain for SWFWMD salinity model and temperature model, with grid cell system for SWFWMD salinity model.

assigning different flow values for spring flows discharging to the spring run or diverted to the base of the dam.

The data used for the “coldest period” model scenarios were:

- Predicted water surface elevations every minute at Hillsborough Bay (the downstream boundary) from the TBONE Tide Predictor web site;
- Monthly water temperature and salinity at EPCHC Station 2 near Platt Street (the downstream boundary);
- Monthly water surface temperature for Sulphur Springs (tributary) from USGS; and
- Monthly water surface temperature for EPCHC Station 105 near Rowlett Park Drive (these data were assigned to represent the inflow temperature from the dam, the upstream boundary).

Flows for Sulphur Springs were set at constant values based on the different scenarios. Additionally, National Weather Service meteorological data were obtained for Tampa International Airport for the November 1976 through February 1977 period. The November 1976 through February 1977 period was identified as the period with the coldest water temperatures on record from the EPCHC data. These data were used for boundary conditions of wind speed and direction, air temperature, dew point, and cloud cover. The salinity of Sulphur Springs inflow was assumed to be constant.

The data used for the "thermal refuge" model scenarios were:

- Water surface elevation, temperature and salinity every fifteen minutes at Platt Street (the downstream boundary) from USGS;
- Water surface temperature and salinity every fifteen minutes for Sulphur Springs from USGS; and
- Monthly water surface temperature and salinity for EPCHC Station 105 near Rowlett Park Drive (these data were assigned to represent temperature at the upstream boundary).

Flows for Sulphur Springs (tributary) were set at constant values based on the different scenarios. Additionally, National Weather Service meteorological data were obtained for Tampa International Airport for the October through December 2002 period, which was identified as the period when water temperatures near the spring were above 20°C and those above and below the spring were below 20° C. These data were used for boundary conditions of wind speed and direction, air temperature, dew point, and cloud cover.

5.5.6 Results of the flow scenarios

A historic baseline and three different flow scenarios were run for both the "coldest period" (November 1976–February 1977) and the "thermal refuge period" (October–December 2002). In keeping with the intent of a minimum flows analysis, the baseline represents a condition of no withdrawals from the spring pool. Spring flow was set at the recent average flow rate of 31 cfs for the baseline analysis. The remaining scenarios represent different combinations of diversions from the spring pool (Table 5-5) Waters diverted from the pool were either removed from the system to simulate consumption for water supply, or diverted to the base of the dam to meet minimum flows for the Lower Hillsborough river.

The diversions that were modeled correspond to minimum flow scenarios that were recommended in Section 5.4 to meet the salinity requirements of the spring run and lower river. The thermal model was run to determine if these scenarios also meet the requirements of a thermal refuge for manatees the lower river near the spring. An exception to this is that minimum flows that alternate between 18 and 10 cfs or 13 and 10 cfs based on tide stage were not evaluated. Instead, a scenario that involves a constant minimum flow of 10 cfs to the spring run was simulated, with the assumption that if this minimum flow met the requirements of a thermal refuge, minimum flows that used 10 cfs in combination with higher minimum flow would as well.

As described in Section 4.3, minimum flows for Sulphur Springs will most likely be in effect when there is no flow from the Hillsborough River dam. Therefore, no discharge from the Hillsborough Reservoir was assumed for all thermal scenarios that were evaluated. A minimum flow of 10 cfs of spring flow diverted to the base of the dam was included in all non-baseline scenarios to comply with the adopted minimum flow for the Lower Hillsborough River. Comparison of this scenario with the historic baseline is used to see if the adopted minimum flow for the lower river meets the requirements of a thermal refuge for manatees.

Table 5-5. Flow regimes for the thermal modeling scenarios. All flows reported in cubic feet per second (cfs).

SCENARIOS	SPRING FLOW TO SPRING RUN	Spring flow to base of dam	Flow from reservoir	Removal for water supply
Baseline	31	0	0	0
A	18	10	0	3
B	13	10	0	8
C	10	10	0	11

These comparisons provide an estimate of temperature changes in the river near the mouth of the spring resulting from the combinations of rerouting of springflow to the base of the dam or removal of springflow to the reservoir. Based on communications with the FMRI (B.Ackerman, pers. Communication), it was agreed that two scenarios would be considered equivalent if difference between mean water temperatures for the cell in the river adjacent to the mouth of the spring was less than less than 2° C. This cell represents all vertical layers in a bank to bank section of the river that is 50 meters long centered at the spring mouth. It was assumed that if the temperature change in this cell was acceptable, that conclusion would also hold for the spring run, where the temperature change is expected to be less.

All four model scenarios were run for each of the two separate time periods, the “coldest period” (January-February 1977) and the “thermal refuge period” (November 29-December 4, 2003). The mean water temperatures in the cell adjacent to the mouth of the spring are listed for the baseline and each of the three scenarios in Table 5-6. The

ΔT represents the difference between the baseline temperature and the rerouting/removal scenario temperature, so that a negative value for ΔT denotes lower temperature for the rerouting/removal scenario than for the baseline scenario.

Table 5-6. Predicted mean temperature (°C), and changes from baseline, for all scenarios in the river cell at the mouth of Sulphur Springs.

Scenario	"Thermal Refuge"	ΔT	"Coldest"	ΔT
Historic Baseline	20.1		13.0	
A	20.1	0.0	12.6	- 0.4
B	19.9	- 0.2	12.4	- 0.6
C	19.7	- 0.4	12.3	- 0.7

All of the scenarios meet the threshold of a maximum -2.0^{o} C difference in mean water column temperatures for the simulation periods. The temperature difference for scenario A, or the 18 cfs minimum flow for routine operation, is zero for the recent "thermal refuge" period while the difference for the coldest period is only 0.4^{o} C. Reducing the flow to the spring run to 13 or 10 cfs increases the temperature differences from the baseline, but they do not exceed 0.7^{o} C in all cases.

5.5.7 Cumulative distributions of water temperatures

Cumulative distribution functions (CDFs) for predicted hourly temperatures show the frequency of occurrence of temperatures in the cell at the mouth of Sulphur Springs over all vertical layers (Figures 5-24 and 5-25). Figure 5-24 includes CDFs for the coldest period simulations while Figure 5-25 shows CDFs for the thermal refuge period. In both Figures, curves for the minimum flow scenarios are overlain over the curve for the historic baseline for comparison.

CDFs for the coldest period simulation show that even the historic baseline would not have kept mean water column temperatures above 15^{o} C, and manatees would have probably left the area to find warmer water. For the coldest half of these simulations (percentiles below the median) there was very little difference in the frequency of temperature values for the baseline and any of the minimum flow scenarios. During the warmer half of the observations (percentiles above 50), the maximum difference between any of the percentile values is about 1.3^{o} C for scenario A (18 cfs); 1.8^{o} C for scenario B (13 cfs); and 2.5^{o} C for scenario C (10 cfs). It is reiterated that scenario C is not a recommended minimum flow, and that 10 cfs would only be in effect during very low tide stages that occur about a quarter of the time.

CDF plots for the thermal refuge period (Figure 5-25) show warmer water temperatures in general, as water temperatures do not go below 17.4^{o} C in any case. In contrast to the coldest period scenarios, differences in percentile values are greatest for the lower temperatures in these simulations. The greatest difference in percentile values is about 1.4^{o} C between the historic simulation and scenario C.

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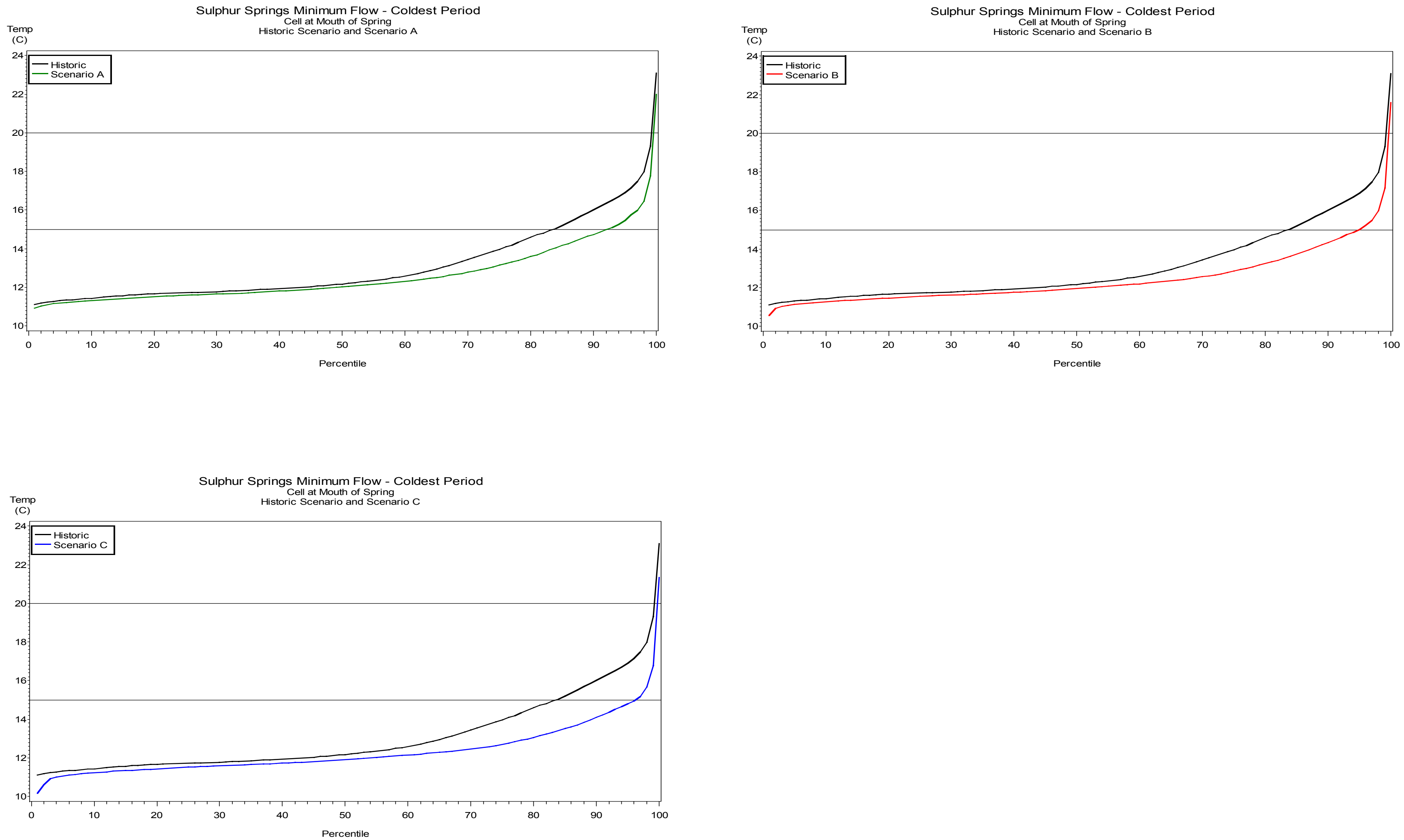

Figure 5-24. Cumulative distribution plots of water temperatures in the river cell near the mouth of the spring for the baseline and flow scenarios A, B, and C in the coldest period simulations.

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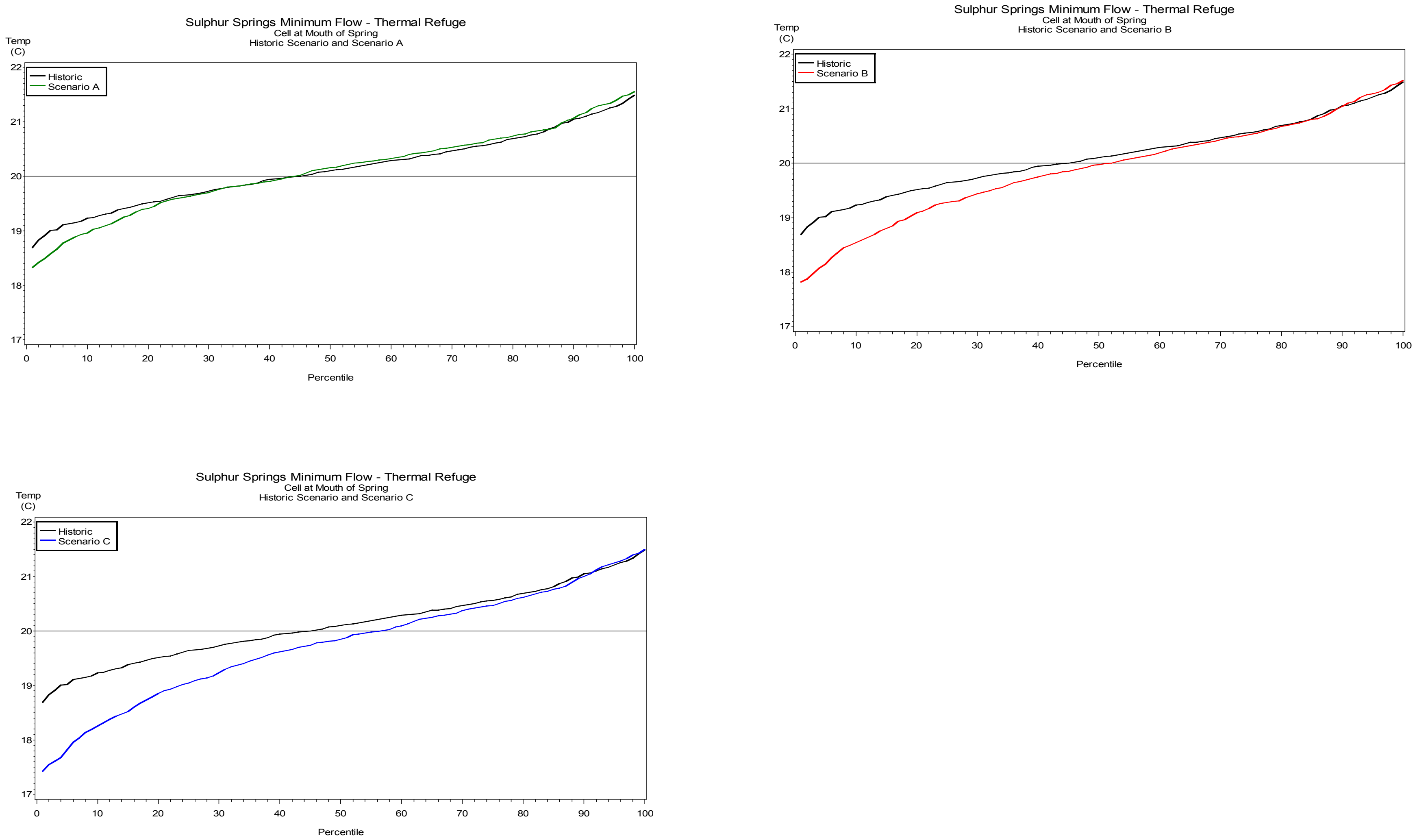

Figure 5-25. Cumulative distribution plots of water temperatures in the river cell near the mouth of the spring for the baseline and flow scenarios A, B, and C in the thermal refuge simulations.

5.5.8 Time series of water temperatures in surface and bottom waters

Time series plots of hourly outputs of water temperature in surface and bottom waters for the different scenarios are presented for the coldest period simulations in Figures 5-26 and 5-27**.** In these simulations water temperatures in the surface are warmer and much more variable than the bottom layers. Bottom water temperatures fluctuated near 12^{o} C for much of the period and never exceeded 15^{o} C, the suggested threshold for the lower end of a thermal refuge. In situations such as this, it is expected manatees would stay closer to the water surface where the spring flow exerts more of a thermal effect. It is also noted that there were virtually no differences in bottom temperatures between any of the scenarios, as the diversion of spring water mainly affected water temperature in the surface layer.

There were apparent differences in surface water temperatures between the four modeled springflow scenarios. Surface water temperatures for the historic scenario dipped below 15^{o} C for about one-sixth of the days in these coldest period simulations. Differences in surface water temperatures between the baseline and the flow scenarios increased as increasing springflow was removed, being least for scenario A and greatest for scenario C. The mean difference in surface temperature between the baseline and scenario A for the entire simulation period was 1.6^{o} C. The mean surface temperature difference between the baseline and scenario B was 2.3^{o} C, and 2.7^{o} C for scenario C. Both of these differences exceed the 2^{o} C threshold that was recommended by the FMRI. That recommendation, which was for mean temperatures in the entire river cell, was made before the model results were examined. Given the results plotted in Figure 5-26, it is suggested here that the 2^{o} C temperature change threshold should apply to where a thermal refuge is present, which is in the surface waters for the coldest period simulations. It is reiterated, however, these simulations are for the coldest water temperatures on record for the river dating back to the mid-1970s.

Water temperatures simulated for the thermal refuge period were considerably warmer. Bottom temperatures remained above 20^{o} C and were warmer than surface temperatures for nearly all of the simulation period. Such a switch in temperature differences between surface and bottom temperatures is supported by data from the recorders in the river near the spring, which show that differences between surface and bottom temperatures (surface – bottom) can fluctuate between positive and negative values during the winter (Figure 3-32). This is apparently due to the effects of both short-term and long-term cold periods on surface and bottom temperatures in the river. Regardless of which is warmer, both the model and the USGS recorders (Figure 3-33) indicate that short-term variations of water temperatures are much greater for surface layers, as density stratification in the river largely isolates bottom waters from the effects of short-term changes in air temperatures.

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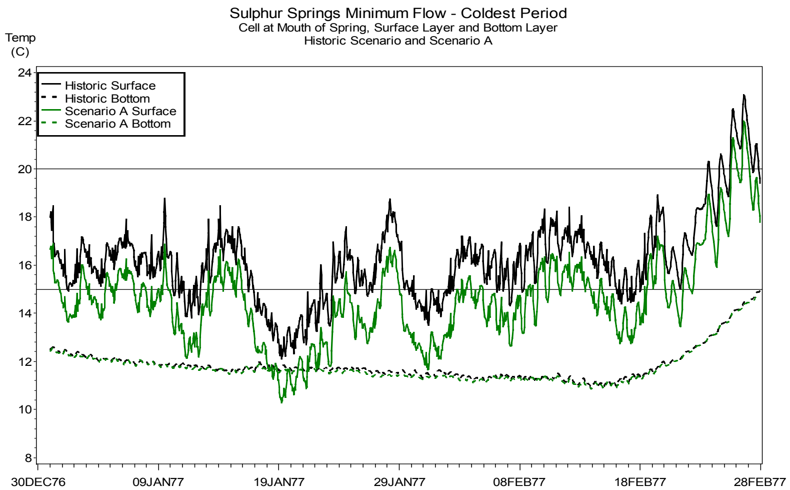

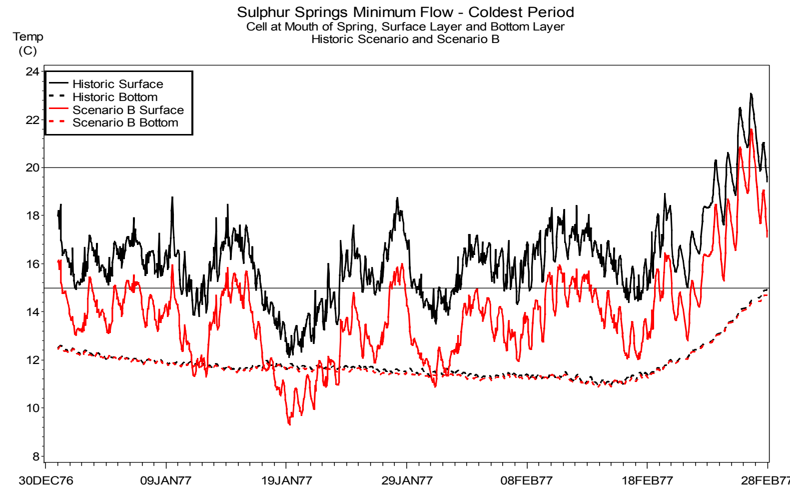

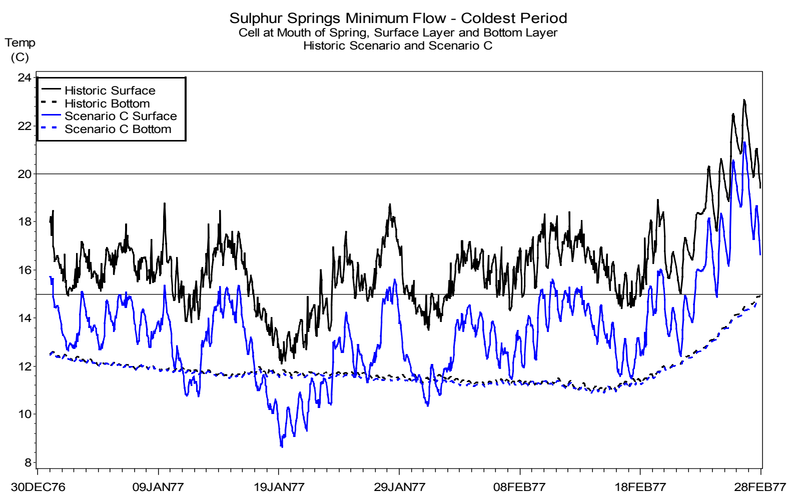

Figure 5-26. Time series plots of surface and bottom water temperatures for the baseline and flow scenarios A, B, and C for the coldest period simulations.

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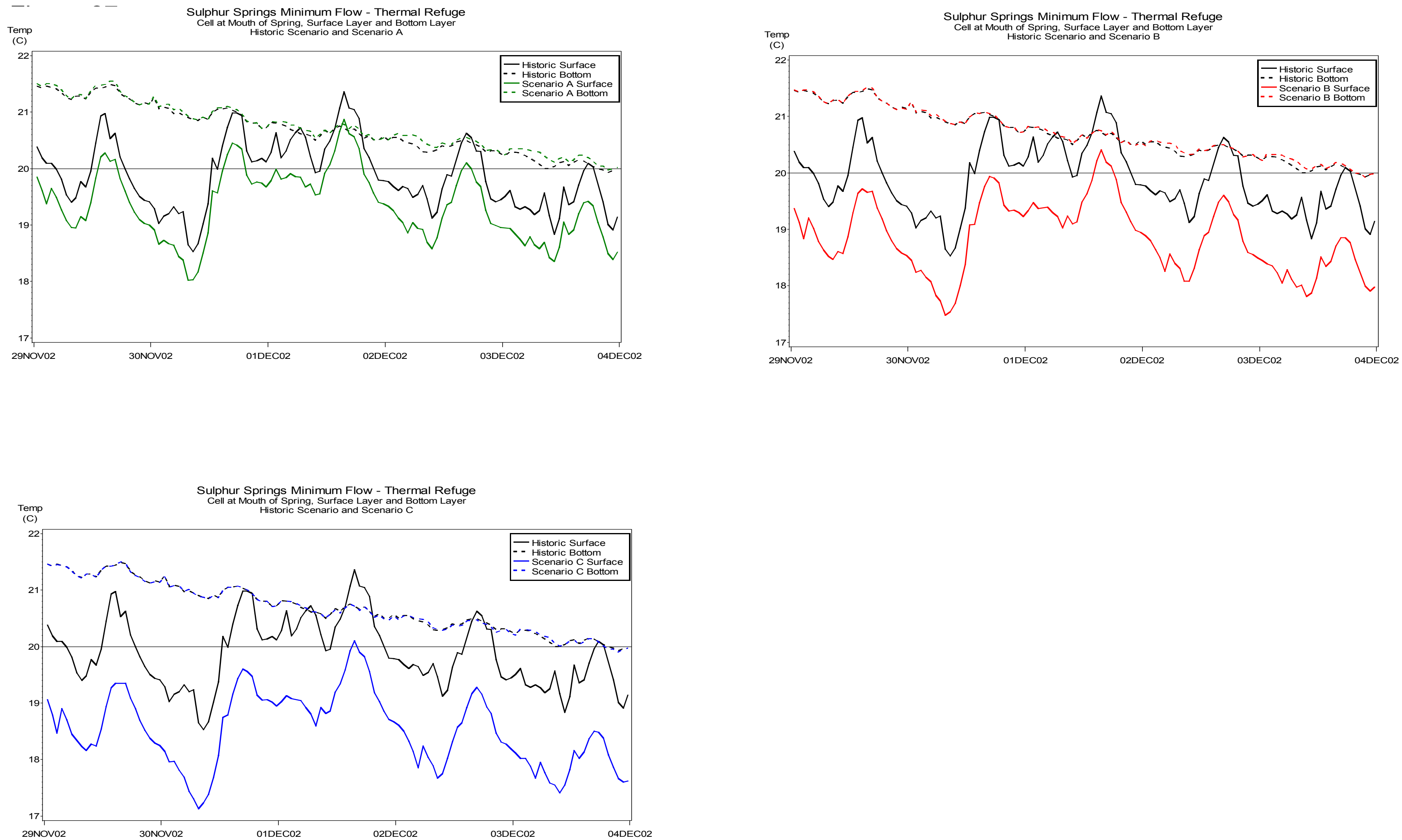

Figure 5-27. Time series plots of surface and bottom water temperatures for the baseline and flow scenarios A, B, and C for the thermal refuge simulations.

Similar to the coldest period simulations, the thermal refuge simulations also found little difference in bottom temperatures between any of the springflow scenarios. Again, there were differences in surface water temperatures, with these differences increasing with the amount of springflow removed from the system. Differences in mean temperatures between the baseline and the other scenarios for the entire thermal refuge period ranged from 0.53^{o} C degrees for scenario A to –1.35^{o} C degrees for scenario C It is reiterated that during these conditions temperatures were above 20^{o} C were in bottom waters.

5.5.9 Summary and application of thermal modeling results to a minimum flow for Sulphur Springs

The combined results for the coldest period and thermal refuge period scenarios indicate that that flows from Sulphur Springs have an effect on water temperatures in the lower Hillsborough River. This thermal effect is largely manifested in the surface layers above the pycnocline, or the depth at which there is strong vertical gradient in water density. The thermal refuge scenarios indicated that all of the springflow scenarios would provide a suitable thermal refuge when surface water temperatures fluctuated between 17 and 20^{o} C. The coldest period scenarios, however, indicated that only scenario A would not exceed the 2^{o} C change suggested by the FRMI. To prevent unacceptable changes to a thermal refuge in the lower river, scenario A (18 cfs flow to the spring run) should be required when water temperatures in the river fall to low values. As described in Section 5.4, scenario A is the recommended minimum flow for routine operation based on salinity criteria. Requiring scenario A to be in effect during very cold periods would be in keeping with the desirability of this flow rate based on other criteria.

Water temperature measurements are now collected at a number of sites in the Lower Hillsborough River and one or more of these sites could be continued with real time data availability to track the occurrence of low temperatures in the river. Based on the results of the thermal modeling simulations, it is recommended that if water temperatures in either surface or bottom waters fall below 15^{o} C, then a minimum flow of 18 cfs be required at Sulphur Springs with no adjustment for low tide stages. Using either surface or bottom as the trigger for the determination of low temperatures would ensure that this minimum flow would be implemented before the entire water column went below 15^{o} C.

Such a low temperature stipulation would likely be in effect for only short periods of time. A plot of daily surface and bottom temperatures for a continuous recorder located in the river about 100 meters upstream from Sulphur Springs was presented in Figure 3-31. Of the four winter seasons covered by this graphic, water temperatures were below 15^{o} C in either surface or bottom waters for a total of 11 days. Low reservoir levels and impending water shortages are most acute for the City of Tampa in the late spring toward the end of the dry season. The implementation of an 18 cfs minimum flow during relatively brief periods in the winter should thus have a very minor effect on the use of the spring to augment the City's water supplies during water shortages.

Considering these factors, the minimum flows recommended in Section 5.4.1 should be supplemented with a restriction that the minimum flow will be 18 cfs when water temperatures in either surface or bottom waters in the Lower Hillsborough River near the spring outfall are below 15^o C. The compete minimum flow recommendation for Sulphur Springs is:

The proposed minimum flow for Sulphur Springs is 18 cfs. This minimum flow may be reduced to 10 cfs during low tide stages in the lower Hillsborough River if it does not result in salinity incursions from the Lower Hillsborough River into the upper spring run. Salinity incursions shall be defined as when salinity values in the upper spring pool are 1 ppt greater than the concurrent salinity value in the spring pool. A minimum flow of 13 cfs can be implemented when water levels in the Hillsborough River reservoir fall below 19 feet NGVD. This minimum flow can be reduced to 10 cfs at low tide stages in the lower river if it does not result in salinity incursions into the upper spring run. A minimum flow of 18 cfs will be maintained if the temperature of either surface or bottom waters in the Lower Hillsborough River near the mouth of the spring are below 15^o C.

5.6 Future data collection in support of the minimum flows

The proposed minimum flows will require much more intensive management of flows from the spring than has been done in the past. The continuation of data recorders in the spring pool, the upper spring run, and the lower Hillsborough River will be necessary to determine if the management goals for salinity incursions and a thermal refuge are met. These data will need to be available on a real-time for basis if the City chooses to implement a tide-based 10 cfs minimum flow, or reduce the minimum flow to 13 cfs during water shortages in cold months.

It is recommended that benthic invertebrates continue to be sampled periodically to check the effectiveness of the minimum flows for maintaining invertebrate populations in the upper spring run. Also, the proposed minimum flows and relationships of flows from Sulphur Springs to the lower river should be examined as part of the re-evaluation of minimum flows to the Lower Hillsborough River which are scheduled for completion by 2005.

5.7. Consideration of future modifications to the structure at Sulphur Springs Run

This report, and the data relied upon for its analysis, are based on the existing configuration of the structure that separates the upper and lower spring run. However, there is a possibility that modification of this structure could provide additional protection from salinity incursions into the upper spring run, while providing for low salinity habitats and a thermal refuge in the Lower Hillsborough River. Further analysis of potential modifications to the existing structure on Sulphur Springs Run may provide an alternative to the minimum flows recommended in this report.

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CHAPTER 6

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APPENDIX A
(from Chapter 2)

Time series plots of water quality parameters for Sulphur Springs Pool from the City of Tampa's monthly sampling program, 1991 – 2002.

Sulphur Springs Water Quality 1991-2002
(City of Tampa)
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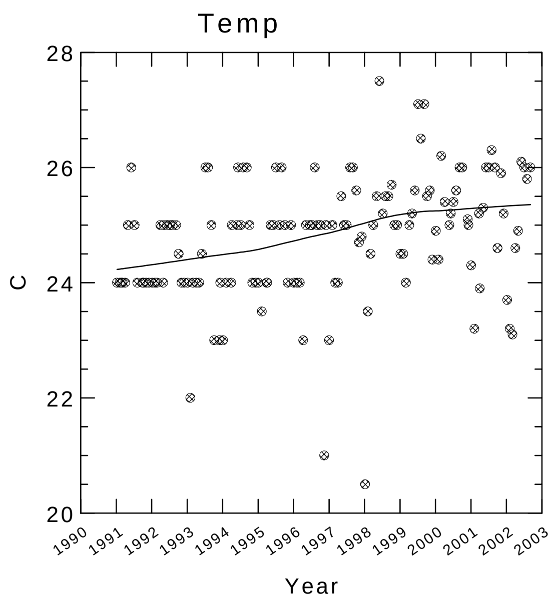

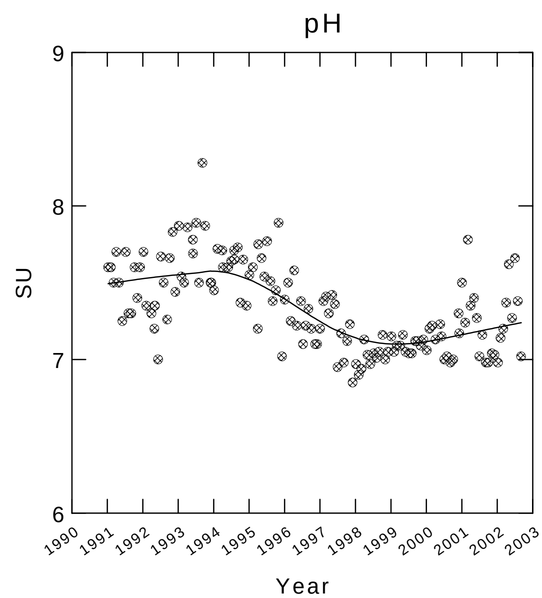

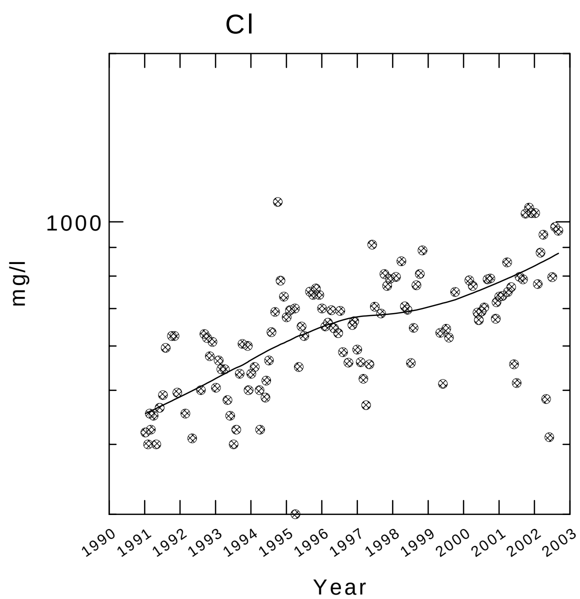

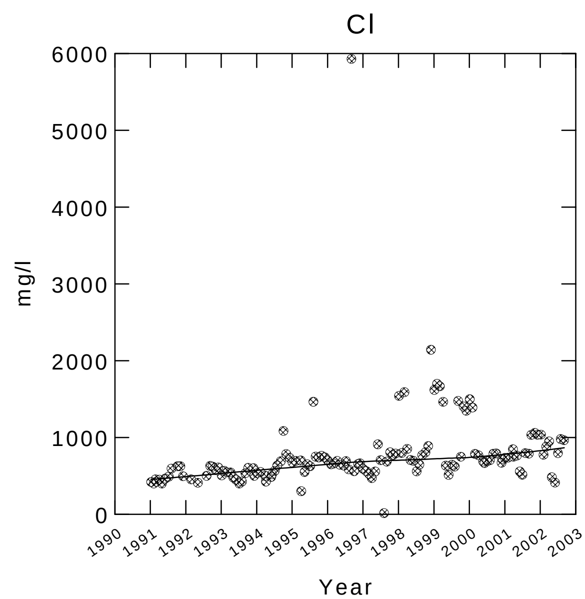

Sulphur Springs Water Quality 1991-2002
(City of Tampa)
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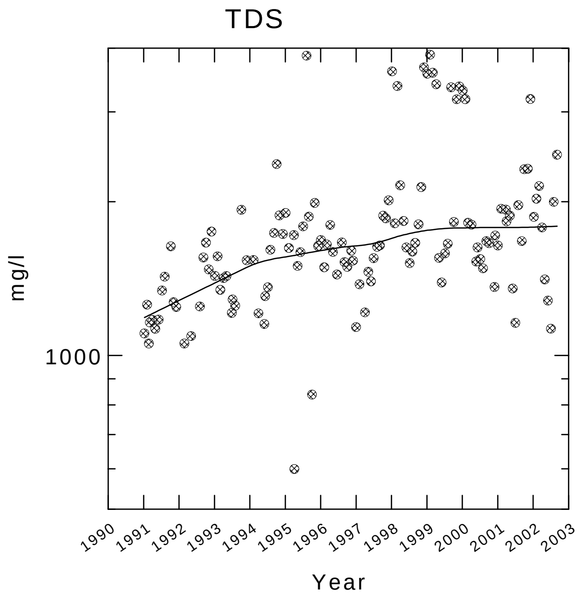

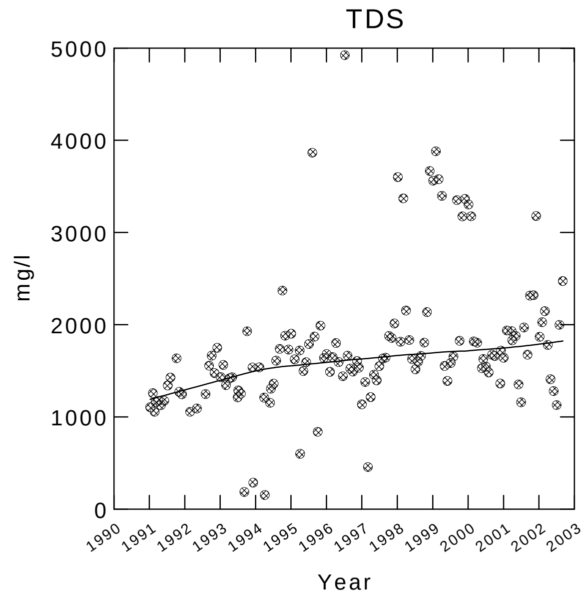

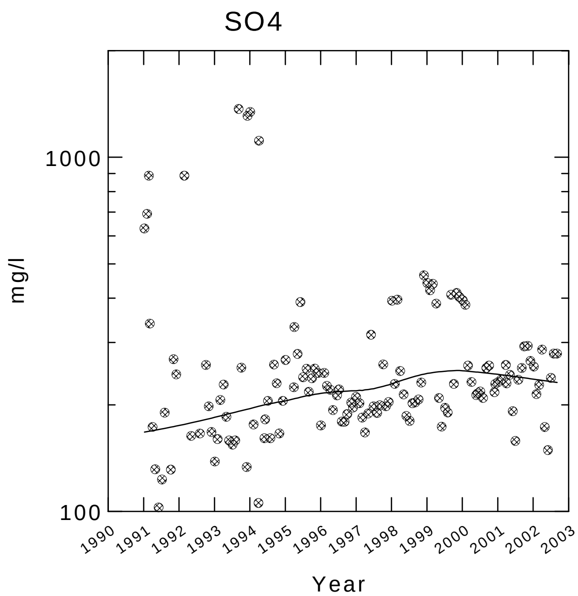

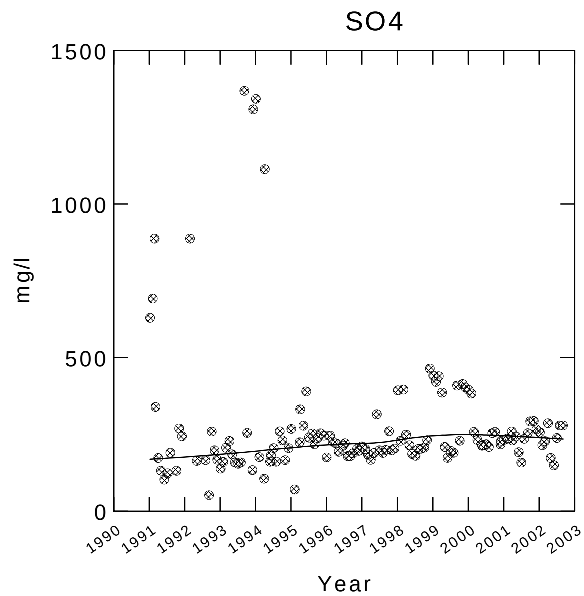

Sulphur Springs Water Quality 1991-2002

(City of Tampa)

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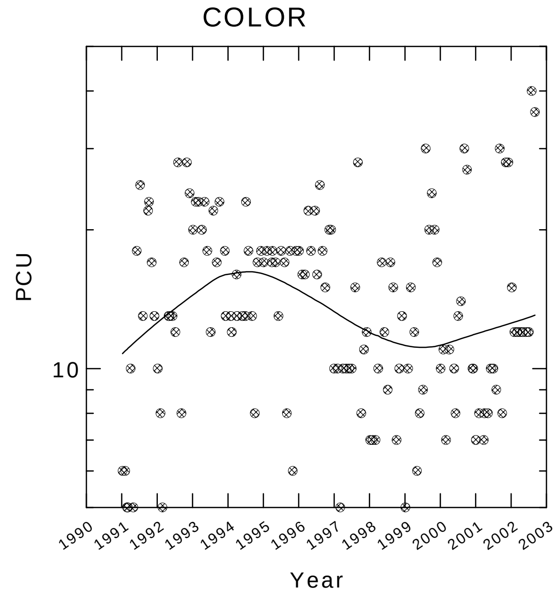

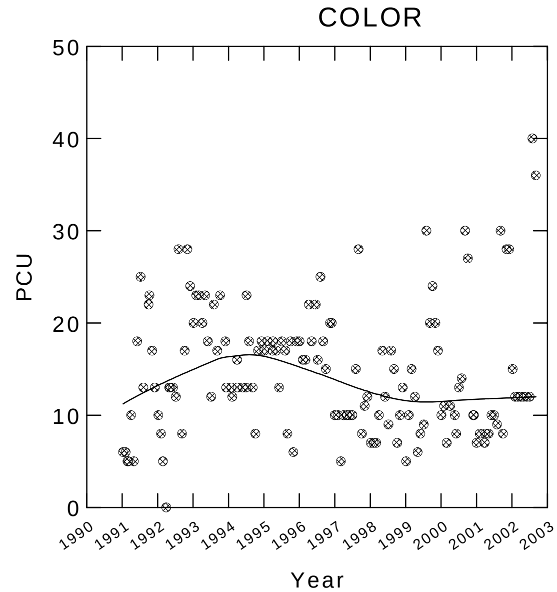

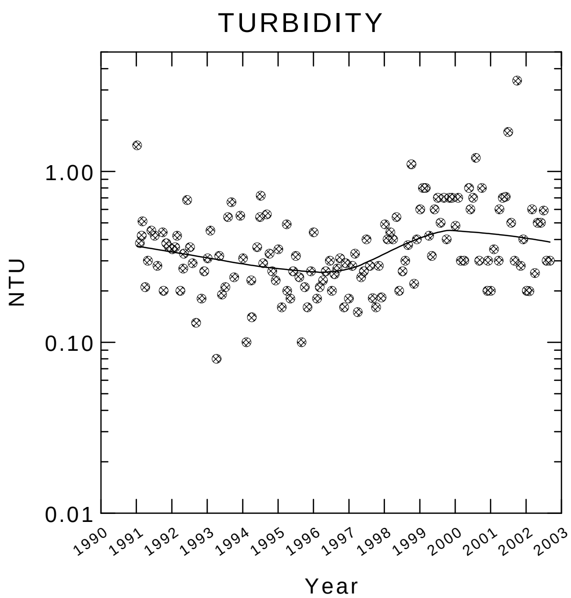

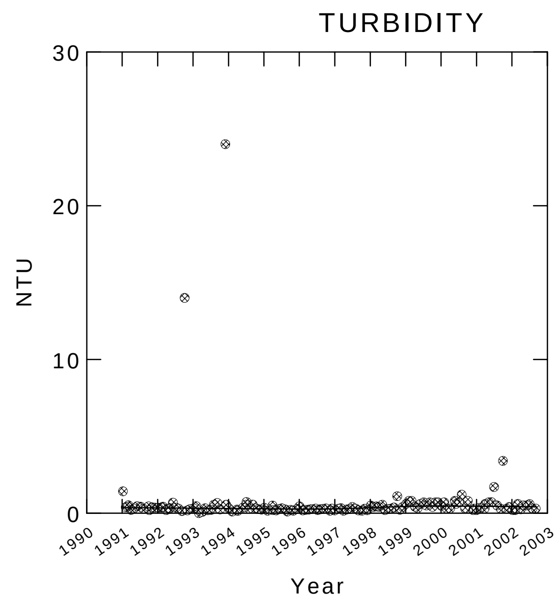

Sulphur Springs Water Quality 1991-2002
(City of Tampa)
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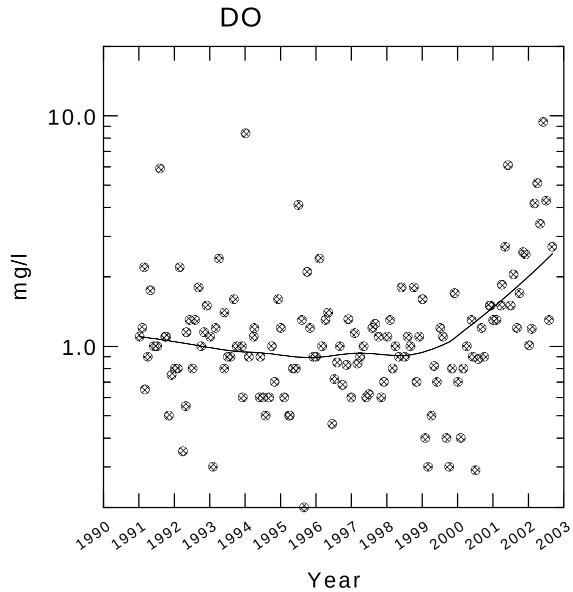

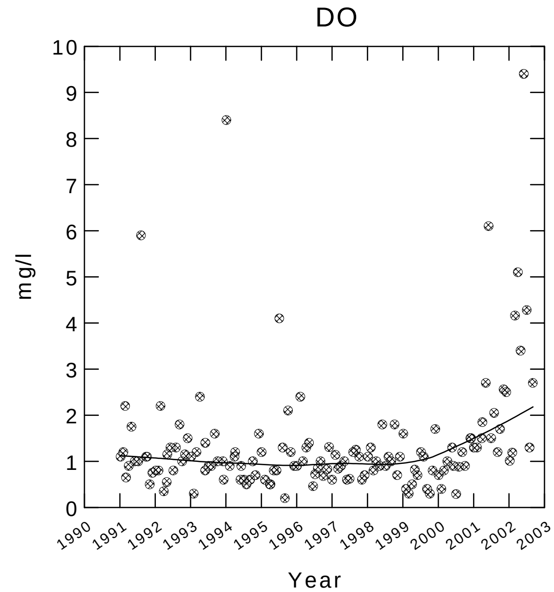

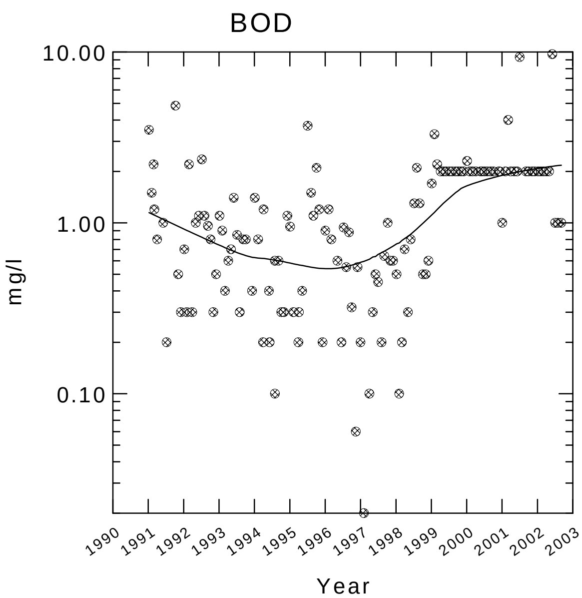

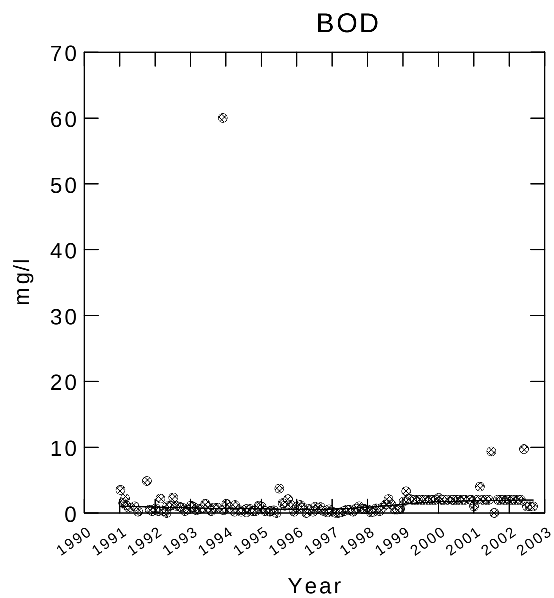

Sulphur Springs Water Quality 1991-2002
(City of Tampa)
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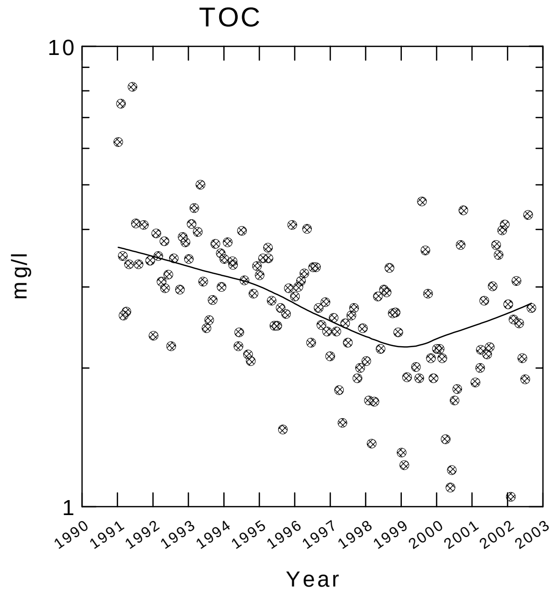

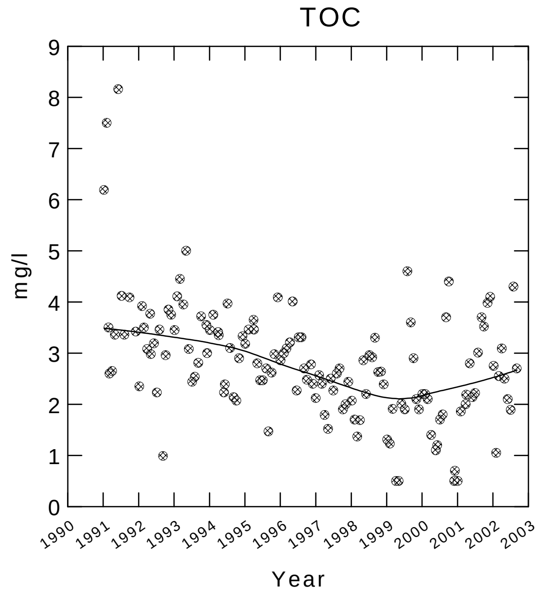

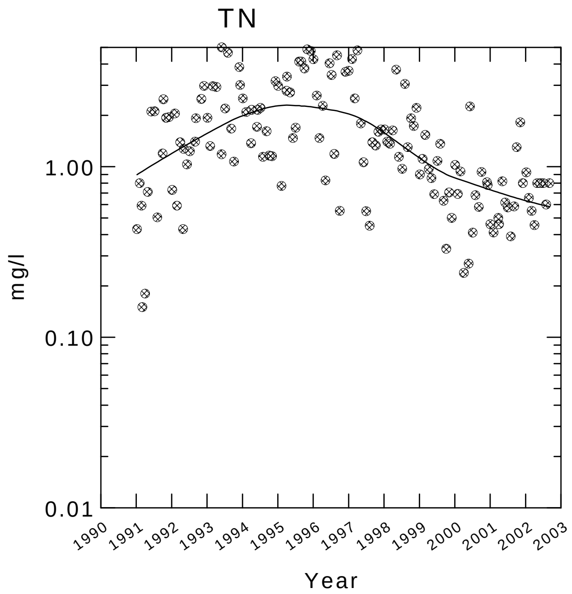

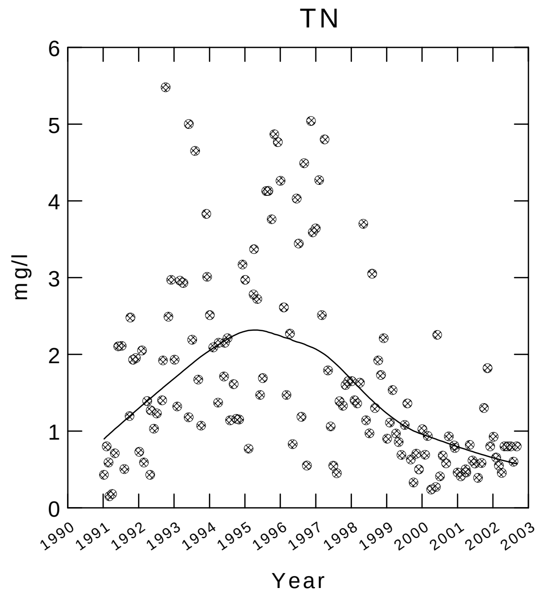

Sulphur Springs Water Quality 1991-2002
(City of Tampa)
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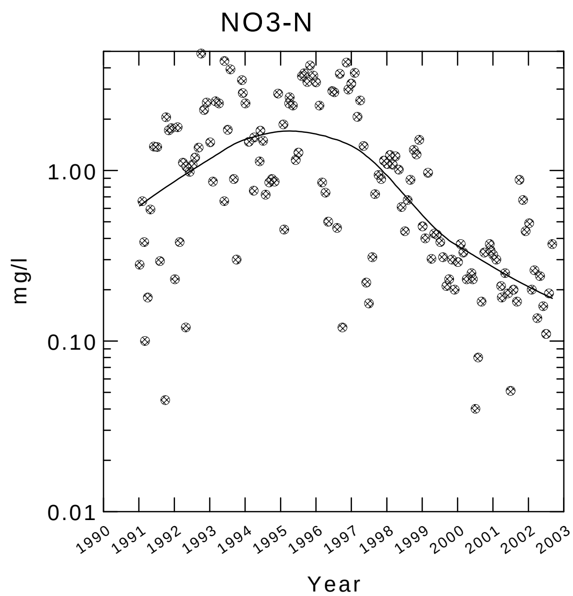

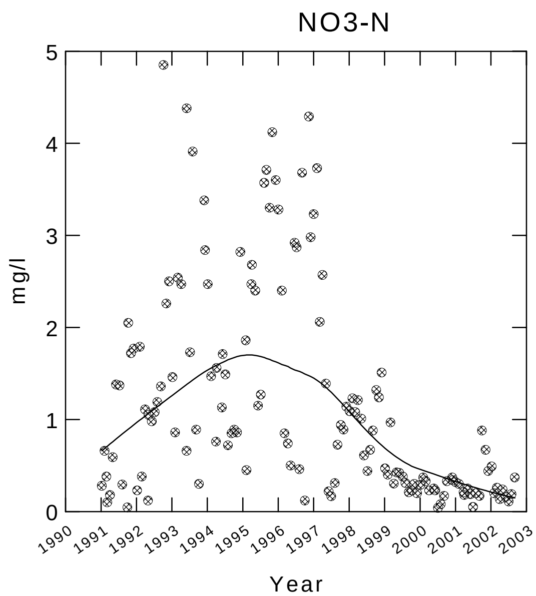

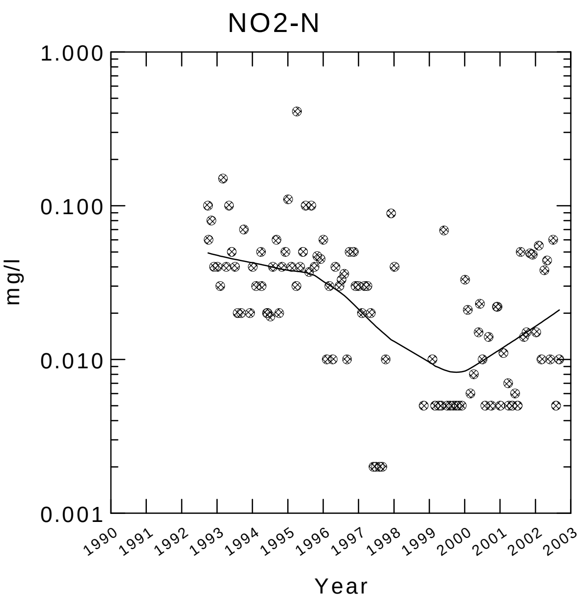

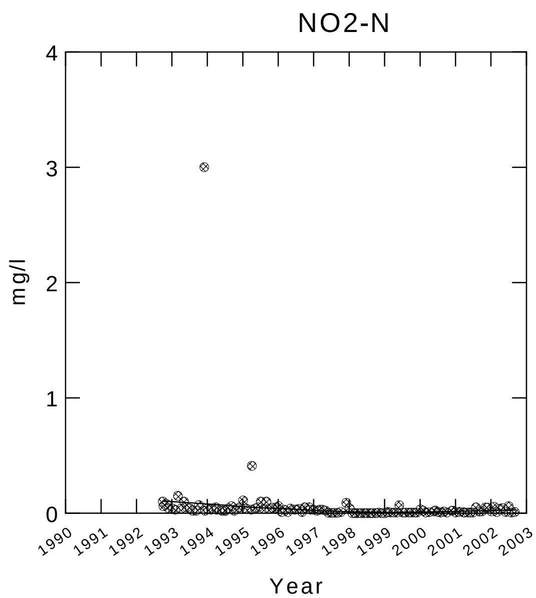

Sulphur Springs Water Quality 1991-2002
(City of Tampa)
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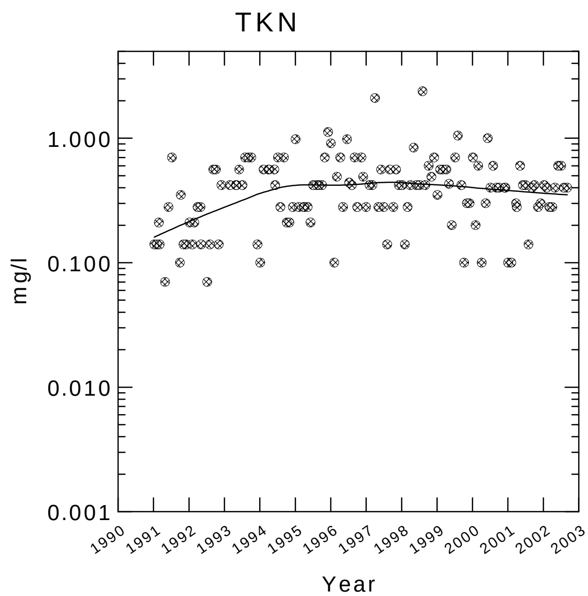
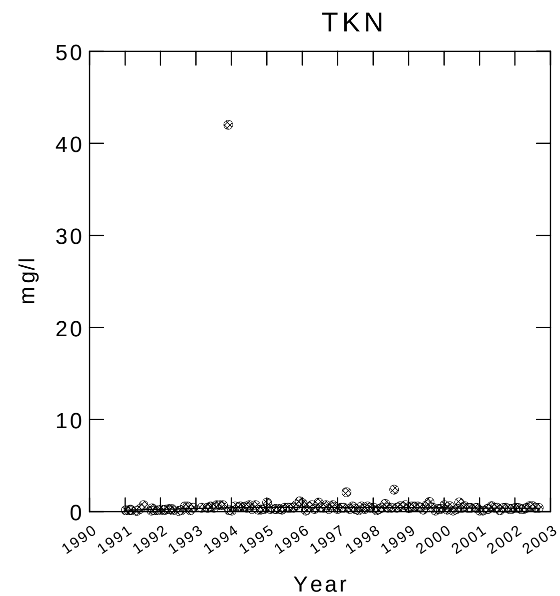
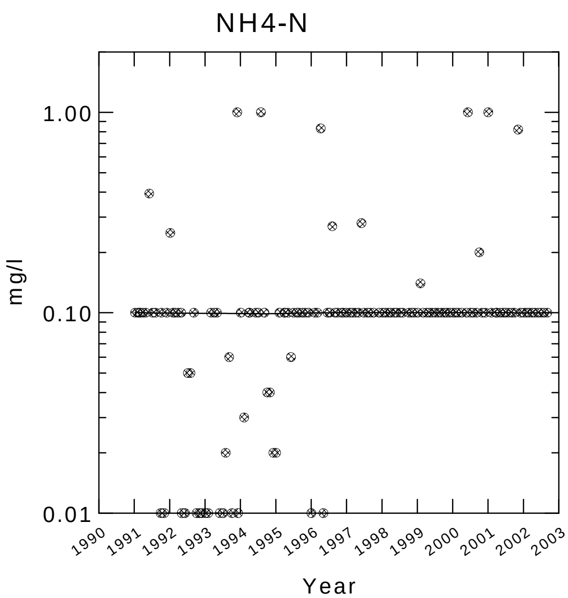
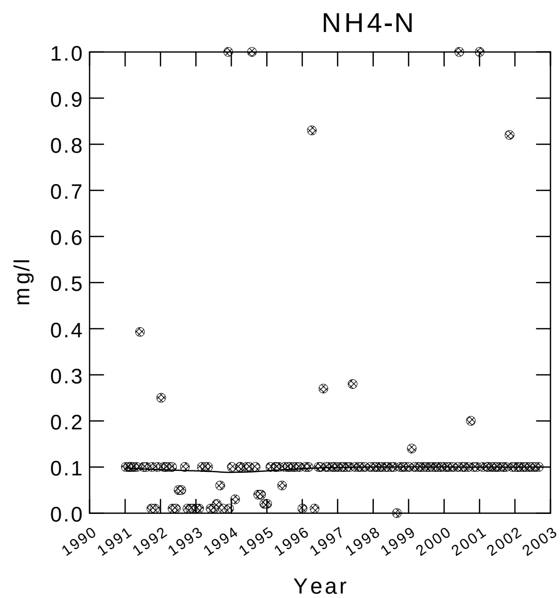
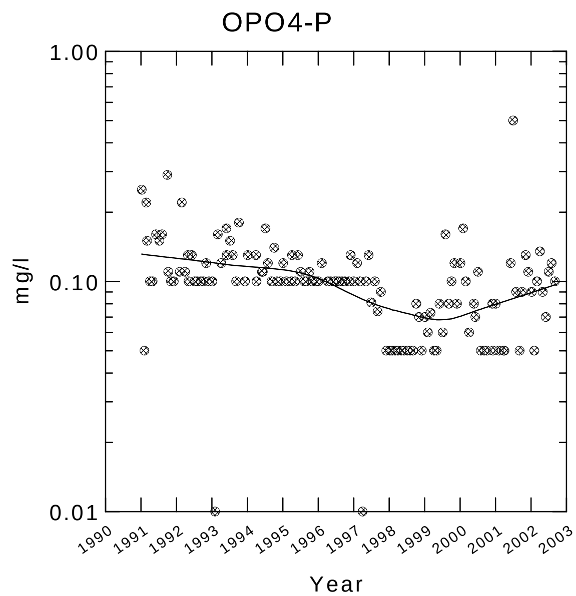


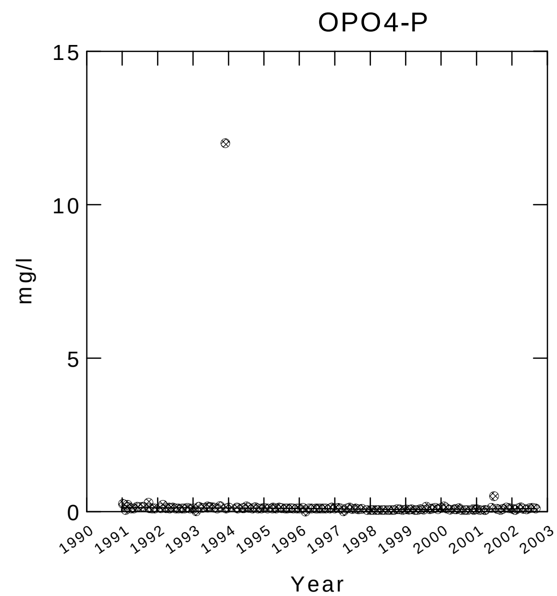


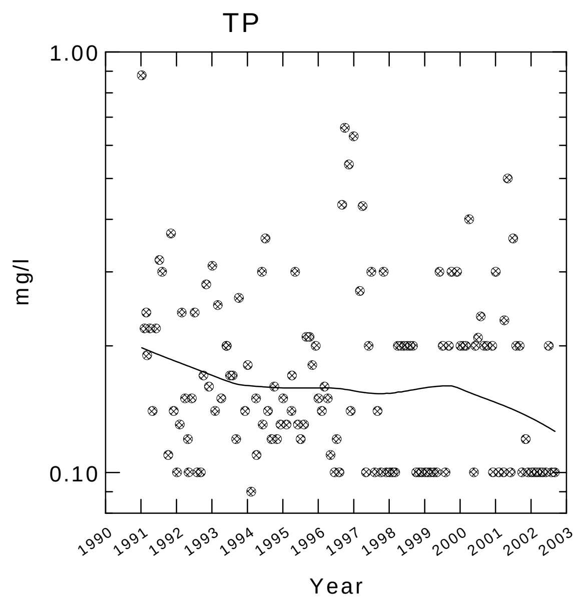


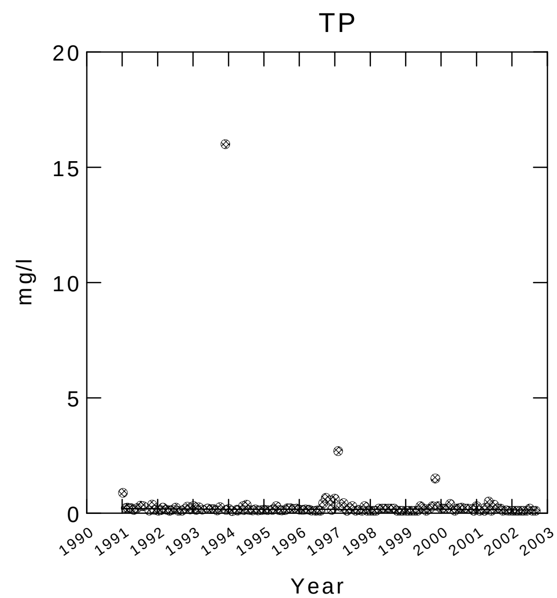


[The following parameters are displayed both as log and unlogged results with LOWESS Smoother for visual exploratory analysis.]

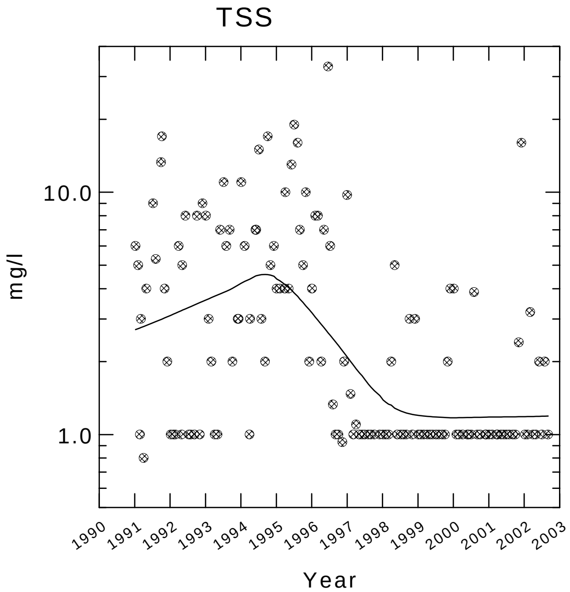


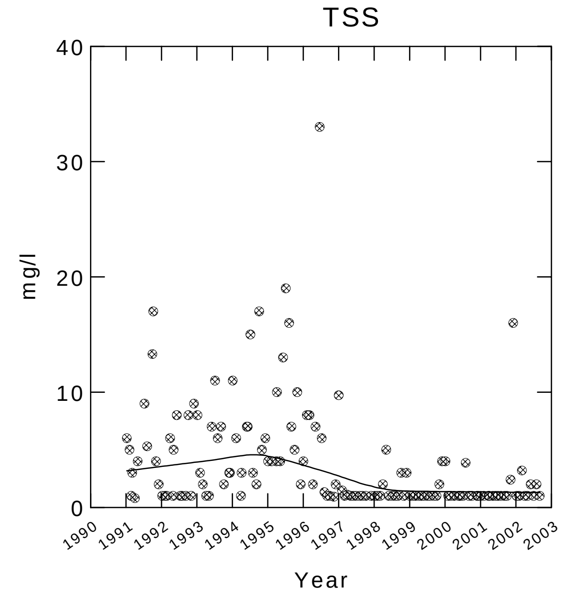


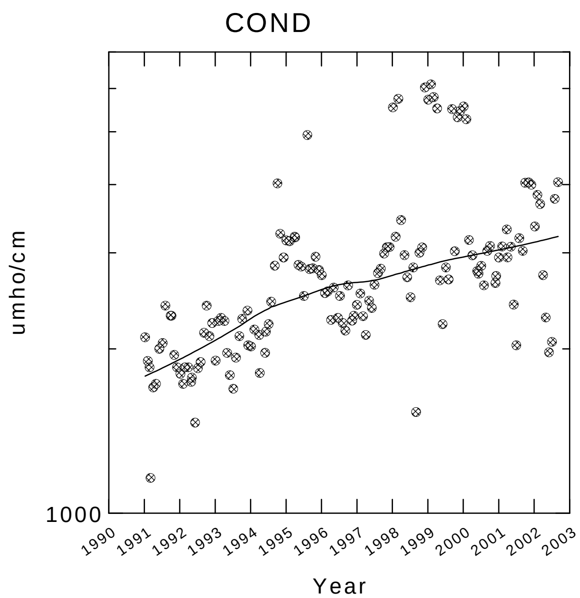


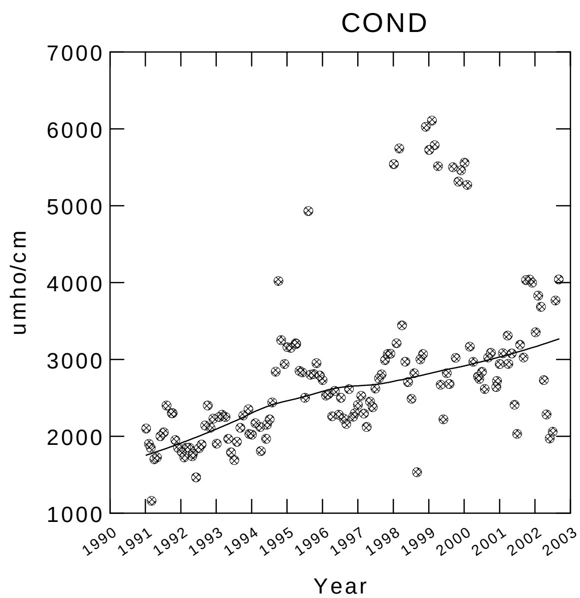


[The following parameters are displayed both as log and unlogged results with LOWESS Smoother for visual exploratory analysis.]

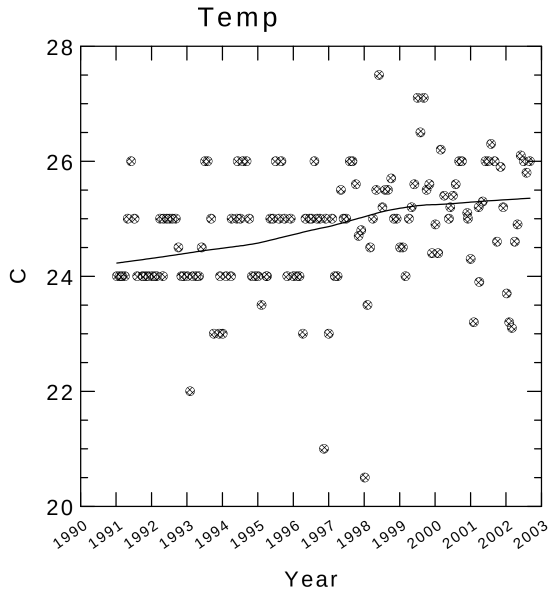








Sulphur Springs Water Quality 1991-2002
(City of Tampa)
[The following parameters are displayed both as log and unlogged results with LOWESS Smoother for visual exploratory analysis.]



APPENDIX B
(from Chapter 3)

Presence of macroinvertebrate taxa in Upper Sulphur Springs Run for five collections during 1997 – 2003.

Appendix B. Presence of macroinvertebrate taxa in Sulphur Springs on five dates based on qualitative collections by the Florida Fish and Wildlife Conservation Commission or the Florid Department of Environmental Protection (Nov 1997 only). Colors represent combinations of dates when taxa were present.

<u>Color Codes (n = number of taxa within each code)</u>
Orange = present only in November 1997 (n=12)
Yellow = present in 1997 and reappeared in Nov. 2001 or Dec. 2003 (n=10)
Red = present only in May 2000 or July 2001 (n=16)
Blue = first occurrence in Nov 2001 (n=8)
Green = first occurrence in Dec 2003 (n=23)
Unshaded = present in both no or low flow and normal flow conditions (n=45)

Date of sampling	**Nov. 19, 1997**	**May 25 2000**	**July 8 2001**	**Nov. 8 2001**	**Dec. xx 2003**
Preceding flow condition	**Prolonged normal flow**	**No flow**	**Low flow**	**Four months normal flow**	**Prolonged normal flow**
Total number of taxa present	**33**	**30**	**37**	**38**	**60**
Cnidaria					
Hydrozoa					
Hydridae					
Hydra sp.	---	---	---	---	P
Platyhelminthes					
Turbellaria	P	---	---	P	P
Nemertea					
Prostoma sp.	---	---	---	---	P
Nematoda	---	P	P	P	P
Annelida					
Aphanoneura	---	---	**P**	---	---
Hirudinea	P	---	P	P	P
Oligochaeta (total)	P	P	P	P	P
Enchytraeidae	---	---	P	---	---
Naididae (total)	P	P	P	P	P
Chaetogaster diastrophus	---	---	P	---	---
Dero digitata complex	---	---	---	---	P
Dero furcata/lodeni	---	---	---	P	P
Dero obtusa	P	---	---	---	---
Dero pectinata	---	---	P	---	---
Nais communis/variabilis	---	P	P	P	P
Pristina sp.	---	---	P	P	P
Pristina leidyi	---	---	P	P	P
Pristina synclites	---	---	---	---	P

Appendix B. Presence of macroinvertebrate taxa in Sulphur Springs on five dates based on qualitative collections by the Florida Fish and Wildlife Conservation Commission or the Florid Department of Environmental Protection (Nov 1997 only). Colors represent combinations of dates when taxa were present.

	Nov. 1997	May 2000	July 2001	Nov. 2001	Dec. 2003
Tubificidae (total)	P	P	P	P	P
Limnodrilus hoffmeisteri	P	---	P	P	P
UIWOCS	P		P	P	P
UIWCS	---	---	---	---	P
Polychaeta (total)	P	P	P	P	---
Nereidae					
Laeonereis culveri	P	P	---	---	---
Neanthes succinea	---	---	P	---	---
Stenoneries martini	---	P	---	---	---
Serpulidae	---	P	---	P	---
Ficopomatus miamiensis	---	P	---	P	---
Mollusca					
Gastropoda (total)	P	P	P	P	P
Ancylidae					
Ferrissia hendersoni	---	---	---	---	P
Hebetoncylus excentricus	---	---	---	---	P
Hydrobiidae unk.	---	P	P	P	P
Amnicola dalli johnsoni	P	---	---	---	---
Pyrgophorus platyrachis	P	P	P	P	P
Planorbidae					
Planorbella scalaris	P	---	---	---	---
Pleuroceridae					
Elimia floridensis	P	---	---	---	---
Thiaridae					
Melanoides sp.	P	P	P	P	P
Tarebia granifera	---	P	P	P	P
Pelecypoda					
Corbiculidae					
Corbicula fluminea	---	P	---	P	---
Cyrenoididae					
Cyrenoida floridana	---	---	---	---	P
Dreissenidae					
Mytilopsis leucophaeata	---	P	P	P	P
Mytilidae					
Modiolus modiolus sqamosus	P	---	---	---	---
Sphaeriidae					
Pisidium sp.	P	---	P	---	---

Appendix B. Presence of macroinvertebrate taxa in Sulphur Springs on five dates based on qualitative collections by the Florida Fish and Wildlife Conservation Commission or the Florid Department of Environmental Protection (Nov 1997 only). Colors represent combinations of dates when taxa were present.

	Nov. 1997	May 2000	July 2001	Nov. 2001	Dec. 2003
Arthropoda					
Crustacea					
Amphipoda (total)	P	P	P	P	P
Aoridae					
Grandidierella bonnieroides	P	---	P	P	P
Gammaridae					
Gammarus tigrinus	P	---	---	---	---
Hyalellidae					
Hyalella azteca	---	---	P	P	---
Talitridae					
Orchestia sp.	---	P	P	---	P
Orchestia uhleri	---	---	P	---	P
Cumacea					
Nannasticidae					
Alymyracuma sp.	P	---	---	---	---
Decapoda					
Palaemonidae					
Palaemonetes paludosus	---	---	---	---	P
Palaemonetes pugio	P	P	P	P	P
Xanthidae					
Rhithropanopeus harrisii	P	P	P	---	---
Isopoda (total)	P	P	P	P	P
Anthuridae					
Cyathura polita	P	---	---	P	P
Munnidae					
Munna reynoldsi	P	P	P	P	P
Sphaeromatidae					
Cassidinidea ovalis	P	P	P	---	P
Mysidacea					
Mysidae					
Taphromysis bowmani	P	---	---	---	---
Tanaidacea					
Tanaidae					
Tanais sp.	P	---	---	---	---
Aquatic Acari					
Hydracarina	---	P	P	P	P
Oribatidae	---	P	---	P	P

Appendix B. Presence of macroinvertebrate taxa in Sulphur Springs on five dates based on qualitative collections by the Florida Fish and Wildlife Conservation Commission or the Florid Department of Environmental Protection (Nov 1997 only). Colors represent combinations of dates when taxa were present.

	Nov. 1997	May 2000	July 2001	Nov. 2001	Dec. 2003
Insecta					
Ephemeroptera (total)	P	---	P	P	P
Baetidae					
Callibaetis floridanus	P	---	P	P	P
Odonata					
Anisoptera (total)	---	---	---	P	P
Corduliidae					
Epitheca princeps regina	---	---	---	---	P
Libellulidae					
Pachydiplax longipennis	---	---	---	P	---
Zygoptera (total)	P	---	---	P	P
Coenagrionidae					
Argia sedula	---	---	---	---	P
Enallagma civile	P	---	---	---	---
Enallagma pollutum	---	---	---	---	P
Ischnura sp.	---	---	---	---	P
Ischnura hastata	---	---	---	---	P
Ischnura ramburii	P	---	---	---	P
Hemiptera (total)	P	---	---	P	P
Mesoveliidae					
Mesovelia mulsanta	P	---	---	P	P
Naucoridae					
Pelicoris femoratus	---	---	---	---	P
Veliidae					
Microvelia sp.	---	---	---	---	P
Trichoptera (total)	P	---	---	P	P
Hydroptilidae e.I.					
Hydroptila sp.	P	---	---	P	P
Coleoptera (total)	---	---	P	---	---
Hydrophilidae					
Tropisternus blatchleyi	---	---	P	---	---
Diptera					
Ceratopogonidae (total)	---	P	---	P	P
Dasyhelea sp.	---	P	---	P	P
Chironomidae (total)	P	P	P	P	P
Ablabesmyia sp.	---	---	---	P	---
Ablabesmyia (Karelia) sp.	---	---	---	P	---
Labrundinia sp.	---	---	---	---	P
Labrundinia maculata	---	---	---	---	P
Larsia decolorata	---	---	P	---	---
Orthocladiinae e.I.	---	P	---	---	---
Cricotopus sp.	---	---	---	---	P
Cricotopus bicinctus	---	---	---	---	P
Pseudosmittia sp.	---	P	---	---	P

Appendix B. Presence of macroinvertebrate taxa in Sulphur Springs on five dates based on qualitative collections by the Florida Fish and Wildlife Conservation Commission or the Florid Department of Environmental Protection (Nov 1997 only). Colors represent combinations of dates when taxa were present.

	Nov. 1997	May 2000	July 2001	Nov. 2001	Dec. 2003
Thienemanniella sp.	---	---	P	---	---
Chironominae					
Chironomini e.I.					
Apedilum sp.	---	---	---	---	P
Chironomus sp.	P	P	P	P	P
Chironomus decorus group	---	---	---	P	P
Cryptochironomus sp.	---	---	---	P	---
Dicrotendipes sp.	---	P	P	---	P
Dicrotendipes lobus	---	P	---	P	P
Dicrotendipes neomodestus	---	P	P	---	P
Endotribelos hesperium	P	---	---	---	---
Parachironomus directus	---	---	---	P	---
Polypedilum beckae	---	---	---	---	P
Polypedilum halterale group	P	---	---	P	---
Polypedilum illinoense	P	---	---	---	P
Polypedilum scalaenum	P	---	---	---	---
Stenochironomus sp.	---	---	---	---	P
Pseudochironomini					
Pseudochironomus sp.	---	---	---	---	P
Tanytarsini					
Tanytarsus sp.	---	---	P	---	P
Dolichopodidae (total)	---	---	P	---	---
Ephydridae (total)	---	P	---	---	---
Parydra sp.	---	P	---	---	---
Setacera sp.	---	P	---	---	---
Stratiomyidae					
Odontomyia or Hedriodiscus	---	---	P	---	---

--- = taxon not collected
P = taxon present.
UIWCS = unidentifiable immature Oligochaeta with capilliform chaetae.
UIWOCS = unidentifiable immature Oligochaeta without capilliform chaetae.

APPENDIX C

(CHAPTER 3)

SULPHUR SPRINGS BENTHIC INFAUNA - PERCENT COMPOSITION. JULY 16, 2002 (FWC DATA)

Appendix C. Percent composition of aquatic invertebrate taxa collected using qualitative methods from six habitats in Sulphur Springs, Tampa, FL, on July 16, 2001.

	Habitat					
	Spring Run				Spring Encasement	
Taxa	Open Sand Sediment	Filamentous Algae	Shoreline Vegetation	Concrete Structure	Open Sand Sediment	Vertical Wall
Platyhelminthes						
Turbellaria	---	---	---	---	---	0.5
Nematoda	0.9	0.1	0.8	---	5.0	1.4
Annelida						
Aphanoneura	---	1.6	0.2	---	---	---
Oligochaeta (total)	0.6	1.6	13.6	12.3	9.6	9.4
Enchytraeidae	---	---	<0.1	---	---	---
Naididae (total)	---	1.6	9.6	5.3	1.0	9.4
Chaetogaster diastrophus	---	---	<0.1	---	---	---
Dero digitata complex	---	---	---	---	1.0	0.5
Dero pectinata	---	---	<0.1	---	---	0.5
Nais communis/variabilis	---	1.6	6.1	5.3	---	---
Pristina sp.	---	---	<0.1	---	---	---
Pristina leidyi	---	---	3.2	---	---	8.3
unknown Naididae	---	---	<0.1	---	---	---
Crustipellis or *Pristina*	---	---	---	---	---	0.8
Tubificidae (total)	0.6	---	3.9	7.0	8.6	---
Limnodrilus hoffmeisteri	0.3	---	0.1	---	2.9	---
UIWOCS	0.3	---	3.8	7.0	5.8	---
unk. imm. Oligochaeta	---	---	<0.1	---	---	---
Polychaeta (total)	1.7	---	---	1.7	---	---
Nereidae						
Neanthes succinea	1.7	---	---	---	---	---
unk. damaged Polychaeta	---	---	---	1.7	---	---
Hirudinia	---	---	---	---	3.8	2.2
Mollusca						
Gastropoda (total)	96.0	94.9	80.3	63.2	78.8	1.7
Hydrobiidae (total)	0.6	5.7	34.8	---	78.8	1.7

Appendix C. Percent composition of aquatic invertebrate taxa collected using qualitative methods from six habitats in Sulphur Springs, Tampa, FL, on July 16, 2001.

	Habitat					
	Spring Run				Spring Encasement	
Taxa	Open Sand Sediment	Filamentous Algae	Shoreline Vegetation	Concrete Structure	Open Sand Sediment	Vertical Wall
Thiaridae						
Melanoides sp. imm.	0.1	0.2	0.5	---	---	---
Melanoides tuberculatus	1.6	0.2	3.4	6.1	---	---
Tarebia granifera	93.7	88.8	41.5	57.0	---	---
Pelecypoda (total)	<0.1	0.1	0.3	10.5	---	---
Dreissenidae						
Mytilopsis leucophaeta	---	<0.1	0.1	4.4	---	---
Sphaeriidae imm.	---	0.1	---	---	---	---
Pisidium sp.	<0.1	---	0.1	---	---	---
imm. Pelecypoda	---	---	0.1	6.1	---	---
Arthropoda						
Crustacea						
Amphipoda (total)	---	0.1	0.2	4.4	2.9	83.5
Aoridae						
Grandidierella bonnieroides	---	---	---	4.4	---	---
Hyalellidae						
Hyalella azteca	---	0.1	---	---	2.9	83.5
Talitridae						
Orchestia sp.	---	---	0.1	---	---	---
Orchestia grillus	---	---	0.1	---	---	---
Isopoda (total)	---	---	0.5	1.7	---	---
Munnidae						
Munna reynoldsi	---	---	<0.1	1.7	---	---
Sphaeromidae						
Cassidinidea ovalis	---	---	0.5	---	---	---
Decapoda						
Xanthidae						
Rithropanopeus harrisii	---	1.6	0.4	0.9	---	---
Palaemonidae (total)	---	---	0.5	---	---	---
Palaemonetes sp. imm.	---	---	<0.1	---	---	---
Palaemonetes pugio	---	---	0.5	---	---	---

Appendix C. Percent composition of aquatic invertebrate taxa collected using qualitative methods from six habitats in Sulphur Springs, Tampa, FL, on July 16, 2001.

	Habitat					
	Spring Run				**Spring Encasement**	
Taxa	**Open Sand Sediment**	**Filamentous Algae**	**Shoreline Vegetation**	**Concrete Structure**	**Open Sand Sediment**	**Vertical Wall**
Aquatic Acari						
Hydracarina	---	---	0.1	---	---	---
Insecta						
Ephemeroptera (total)	---	---	0.3	---	---	---
Baetidae e.i.	---	---	0.2	---	---	---
Callibaetis floridanus	---	---	0.1	---	---	---
Coleoptera						
Hydrophilidae						
Tropisternus blatchleyi	---	---	0.1	---	---	---
Diptera						
Dolichipodidae	---	---	<0.1	---	---	---
Chironomidae	0.8	---	2.4	5.3	---	0.5
Tanypodinae						
Larsia decolorata	---	---	0.1	---	---	---
Orthocladiinae						
Thienemanniella sp.	---	---	<0.1	---	---	---
Chironominae (damaged)	<0.1	---	0.1	---	---	---
Chironomini						
Chironomus/Einfeldia sp.	0.8	---	---	---	---	0.5
Dicrotendipes sp.	---	---	2.1	5.3	---	---
Dicrotendipes neomodestus	---	---	<0.1	---	---	---
Tanytarsini						
Tanytarsus sp.	---	---	0.1	---	---	---
Stratiomyidae						
Odontomyia or *Hedriodiscus* sp.	---	---	0.1	---	---	---
Total Taxa	8	10	27	10	6	8

--- = taxon not present.
unk. = unknown
imm. = unidentifiable immature noninsect
UIWOCS = unidentifiable immature Oligochaeta without capilliform setae.

Appendix C. Percent composition of aquatic invertebrate taxa collected using qualitative methods from six habitats in Sulphur Springs, Tampa, FL, on July 16, 2001.
e.i. = unidentifiable early instar insect

APPENDIX D
(from Chapter 3)

Percent composition of macroinvertebrates collected using qualitative methods in six habitats in Upper Sulphur Springs Run on December 9, 2003.

APPENDIX D. Percent composition of aquatic invertebrate taxa collected using qualitative methods from six habitats in Sulphur Springs, Tampa, FL, on December 9, 2003.

	Habitat					
Taxa	**Open Sand Sediment**	**Filamentous Algae**	**Shoreline Vegetation**	**Cattails**	**Organic Debris Packs**	**Snags***
Cnidaria						
Hydrozoa						
Hydra sp.	0.1	1.1	---	---	1.1	---
Cordylophora lacustris	---	P	---	---	---	---
Platyhelminthes						
Turbellaria	2.3	1.7	---	0.3	---	---
Nemertea						
Hoplonemertea						
Prostoma sp.	0.1	0.1	<0.1	1.0	<0.1	---
Nematoda	2.8	15.6	---	3.0	4.1	3.3
Annelida						
Aphanoneura	---	<0.1	---	---	---	---
Oligochaeta (total)	27.0	4.1	0.4	2.1	0.9	3.3
Naididae (total)	2.1	0.7	0.4	2.1	0.2	3.3
Chaetogaster diastrophus						
Dero digitata complex	1.9	<0.1	0.1	---	---	---
Dero lodeni	---	---	---	---	0.2	---
Dero pectinata						
Nais communis/variabilis	---	<0.1	---	0.3	---	---
Pristina sp.	---	---	---	1.7	---	---
Pristina aequiseta		<0.1				
Pristina leidyi	0.2	0.6	0.2	0.1	---	3.3
Pristina synclites	---	---	0.1	---	---	---
unknown Naididae	---	<0.1	<0.1	---	---	---
Crustipellis or *Pristina*						
Tubificidae (total)	24.7	3.5	---	<0.1	0.6	---
Limnodrilus hoffmeisteri	1.0	---	---	---	<0.1	---
UIWOCS	23.6	3.3	---	---	0.6	---
UIWCS	---	0.2	---	<0.1	0.1	---

APPENDIX D. Percent composition of aquatic invertebrate taxa collected using qualitative methods from six habitats in Sulphur Springs, Tampa, FL, on December 9, 2003.

Taxa	Habitat: Open Sand Sediment	Filamentous Algae	Shoreline Vegetation	Cattails	Organic Debris Packs	Snags*
unk. imm. Oligochaeta	0.2	---	---	---	0.1	---
Hirudinia	---	---	<0.1	<0.1	<0.1	---
Mollusca						
Gastropoda (total)	16.7	2.0	31.3	24.6	51.3	33.3
Ancylidae (imm.)	---	---	0.2	---	---	---
Ferrissia hendersoni	---	---	0.1	---	---	---
Hebetoncylus excentricus	---	---	<0.1	---	0.2	---
Hydrobiidae (total)	1.4	0.4	23.3	21.2	9.3	---
Pyrgophorus platyrachis	1.2	0.4	16.0	21.2	9.3	3.3
unknown Hydrobiidae	0.2	<0.1	7.3	---	---	---
Thiaridae						
Melanoides sp.	---	---	0.6	0.4	0.1	---
Melanoides tuberculatus	---	---	---	---	---	---
Tarebia granifera	15.2	1.6	6.4	3.1	41.7	30.0
Pelecypoda (total)	---	---	---	---	0.6	---
Cyrenoididae						
Cyrenoida floridana	---	---	---	0.1	0.6	---
Dreissenidae						
Mytilopsis leucophaeta	---	---	---	---	---	6.7
Arthropoda						
Crustacea						
Amphipoda (total)	9.8	16.1	1.0	3.6	9.8	10.0
Aoridae						
Grandidierella bonnieroides	9.2	16.1	0.3	0.4	9.7	10.0
Hyalellidae						
Hyalella azteca	0.4	---	---	---	---	---
Talitridae						
Orchestia sp.	---	---	0.2	3.0	0.1	---
Orchestia uhleri	---	---	0.5	0.2	---	---
unk. imm. Amphipoda	0.2	---	---	---	---	---

APPENDIX D. Percent composition of aquatic invertebrate taxa collected using qualitative methods from six habitats in Sulphur Springs, Tampa, FL, on December 9, 2003.

	Habitat					
Taxa	**Open Sand Sediment**	**Filamentous Algae**	**Shoreline Vegetation**	**Cattails**	**Organic Debris Packs**	**Snags**[*]
Cumacea (total)	1.0	0.2	---	---	---	---
Nannasticidae						
Alymyracuma sp.	1.0	0.2	---	---	---	---
Isopoda (total)	38.0	53.4	38.0	41.7	13.1	43.3
Anthuridae						
Cyathura polita	---	<0.1	0.2	0.1	---	---
Munnidae						
Munna reynoldsi	35.9	52.4	7.3	22.1	6.5	30.0
Sphaeromidae						
Cassidinidea ovalis	2.1	0.9	30.5	19.5	6.6	13.3
Palaemonidae (total)	---	---	0.1	---	---	---
Palaemonetes sp. imm.	---	---	<0.1	---	---	---
Palaemonetes pugio	---	---	<0.1	---	---	---
Aquatic Acari (total)	0.2	0.8	3.7	10.6	13.7	---
Hydracarina	0.1	0.3	2.2	6.9	4.1	---
Oribatidae	0.1	0.5	1.5	3.7	9.6	---
Insecta						
Ephemeroptera (total)	---	---	0.5	---	<0.1	---
Baetidae .						
Callibaetis floridanus	---	---	0.5	---	<0.1	---
Odonata						
Anisoptera (total)	---	---	<0.1	---	<0.1	---
Corduliidae						
Epitheca princeps regina	---	---	---	---	<0.1	---
unknown imm. Anisoptera	---	---	<0.1	---	---	---
Zygoptera (total)	---	<0.1	5.4	---	2.5	---
Coenagrionidae e.i.	---	---	4.6	0.8	2.3	---
Argia sedula	---	---	<0.1	---	<0.1	---
Enallagma sp.	---	---	0.7	---	---	---
Enallagma pollutum	---	---	<0.1	---	0.2	---
Ischnura sp.	---	---	<0.1	---	---	---
Ischnura hastata	---	---	---	---	<0.1	---

APPENDIX D. Percent composition of aquatic invertebrate taxa collected using qualitative methods from six habitats in Sulphur Springs, Tampa, FL, on December 9, 2003.

Taxa	Open Sand Sediment	Filamentous Algae	Shoreline Vegetation	Cattails	Organic Debris Packs	Snags*
	Habitat					
Ischnura ramburii	---	---	<0.1	---	---	---
Hemiptera (total)	---	---	<0.1	0.8	---	---
Mesoveliidae						
Mesovelia musanti	---	---	<0.1	0.1	---	---
Naucoridae						
Pelicoris femoratus	---	---	---	0.1	---	---
Veliidae e.i.	---	---	---	<0.1	---	---
Microvelia sp.	---	---	---	<0.1	---	---
Trichoptera (total)	0.6	4.2	16.7	9.1	<0.1	---
Hydroptilidae e.i.	0.1	1.8	1.8	4.3	<0.1	---
Hydroptila sp.	0.5	2.4	14.8	4.8	<0.1	---
Diptera						
Ceratopogonidae (total)	---	---	---	1.2	---	---
Daseyhelia sp.	---	---	---	1.2	---	---
Chironomidae (total)	1.5	0.7	2.7	1.1	2.9	---
Tanypodinae						
Labrundinia sp.	---	---	<0.1	---	---	---
Labrundinia maculata	---	---	---	---	0.1	---
Orthocladiinae e.i.	---	---	0.1	---	---	---
Cricotopus sp.	---	---	0.2	---	---	---
Cricotopus bicinctus	<0.1	---	0.5	---	---	---
Pseudosmittia sp.	---	---	---	---	0.2	---
Chironominae (damaged)	---	---	0.2	---	---	---
Chironomini e.i.	---	<0.1	0.2	0.1	0.1	---
Apedilum sp.	---	---	0.2	---	---	---
Chironomus sp.	0.6	<0.1	0.1	---	<0.1	---
Chironomus decorus	0.1	---	0.1	0.2	<0.1	---
Chironomus stigmaterus	0.1	---	---	---	---	---
Cryptochironomus sp.	<0.1	---	---	---	---	---
Dicrotendipes sp.	0.2	0.3	0.7	0.5	---	---
Dicrotendipes neomodestus	0.1	0.1	---	0.3	---	---
Dicrotendipes lobus	0.2	0.1	0.2	---	---	---

APPENDIX D. Percent composition of aquatic invertebrate taxa collected using qualitative methods from six habitats in Sulphur Springs, Tampa, FL, on December 9, 2003.
Table 1 (continued).

Taxa	Habitat: Open Sand Sediment	Filamentous Algae	Shoreline Vegetation	Cattails	Organic Debris Packs	Snags*
Dicrotendipes sp. A	<0.1	---	---	---	---	---
Polypedilum sp.	---	---	<0.1	---	0.1	---
Polypedilum beckae	---	---	---	---	<0.1	---
Polypedilum illinoense	---	---	0.1	---	---	---
Polypedilum scalaris	0.2	<0.1	---	---	2.3	---
Stenochironomus sp.	---	---	---	---	<0.1	---
Pseudochironomini						
Pseudochironomus sp.	---	---	---	<0.1	---	---
Tanytarsini						
Tanytarsus sp.	---	---	0.1	---	---	---
Total Taxa	25	27	33	27	30	8

--- = taxon not present.
imm. = unidentifiable immature noninsect
e.i. = unidentifiable early instar insect
unk. = unknown
UIWOCS = unidentifiable immature Oligochaeta without capilliform setae.
* = handpicking only

APPENDIX E
(from Chapter 3)

Abundances of macroinvertebrate taxa in Upper Sulphur Springs Run for collections on May 25, 2000 and November 8, 2001, and December 9, 2003.

Appendix E. Abundance of macroinvertebrate taxa collected from Sulphur Springs Run for three dates during 2001 through 2003. Means, coeeficients of variation (cv) and percent composition are presented

	BARE SAND			FILAMENTOUS ALGAE			COMBINED HABITATS		
	NUMBER / M^2 (CV)			NUMBER / M^2 (CV)			NUMBER / M^2 (CV)		
	% of total			% of total			% of total		
	May 25, 2000	**November 8, 2001**	**December 9, 2003**	**May 25, 2000**	**November 8, 2001**	**December 9, 2003**	**May 25, 2000**	**November 8, 2001**	**December 9, 2003**
TAXON									
Cnidaria									
Hydrozoa									
Cordylophora lacustris	---	---	P		P	P		P	P
Hydra sp.			91 (2.65)			378 (1.25)			115 (2.53)
			0.1			0.4			0.1
Platyhelminthes									
Turbellaria	---	143 (1.79)	2,109 (0.87)	---	1,525 (0.71)	1556 (0.52)	---	719 (1.38)	2,063 (0.84)
		0.5	2.0		1.6	1.7		1.2	2.0
Nemertea									
Prostoma sp.	---	---	198 (1.57)	---	4 (3.16)	67 (0.47)	---	2 (4.90)	187 (1.48)
			0.2		<0.1	0.1		<0.1	0.2
Nematoda	7,973 (1.06)	1,260 (1.00)	9,294 (1.04)	1,628 (1.07)	3,952 (0.98)	14,268 (0.75)	3,743 (1.53)	2,382 (1.23)	9,709 (1.02)
	14.7	4.1	8.8	2.8	4.1	15.6	6.6	4.1	9.3
Annelida									
Aphanoneura	---	---	---		13 (2.25)	22 (1.41)		6 (3.59)	2 (0.12)
					<0.1)	<0.1		<0.1	<0.1
Aeolosoma	---	---		47 (2.13)			31 (2.68)		
				0.1			0.1		
Oligochaeta (total)	1,761 (0.91)	6,448 (0.65)	20,643 (0.74)	878 (1.75)	14,442 (0.69)	3,734 (0.93)	1,172 (1.35)	9,779 (0.82)	19,234 (0.76)
	3.2	20.9	19.6	1.5	14.9	4.1	2.1	16.8	18.5
Enchytraeidae (total)	---	---		---	4 (3.16)		---	2 (4.9)	
					<0.1)			<0.1	
Naididae (total)	---	105 (1.78)	3,720 (0.96)	89 (4.00)	2,489 (0.96)	622 (0.91)	59 (4.90)	1,098 (1.76)	3,462 (0.96)
		0.3	3.5	0.2	2.6	0.7	0.1	1.9	3.3
Nais communis	---	---		89 (4.00)	---		59 (4.90)	---	
				0.2			0.1		
Crustipellis or Pristina	---	---		22 (4.00)	---		15 (4.90)	---	
				<0.1			<0.1		
Chaetogaster sp.	---	---		---	58 (2.05)		---	24 (3.31)	
					0.1			<0.1	
Chaetogaster diastrophus	---	---		---	18 (3.16)		---	7 (4.90)	
					<0.1			<0.1	
Dero sp.	---	---		---	18 (3.16)		---	7 (4.90)	
					<0.1			<0.1	

	BARE SAND			FILAMENTOUS ALGAE			COMBINED HABITATS		
	NUMBER / M^2 (CV)			NUMBER / M^2 (CV)			NUMBER / M^2 (CV)		
	% of total			% of total			% of total		
	May 25, 2000	**November 8, 2001**	**December 9, 2003**	**May 25, 2000**	**November 8, 2001**	**December 9, 2003**	**May 25, 2000**	**November 8, 2001**	**December 9, 2003**
Dero digitata complex	---	35 (1.74)	3,439 (1.05)	---	320 (1.14)	22 (1.41)	---	153 (1.81)	3,154 (1.08)
		0.1	3.3		0.3	<0.1		(0.3	3.0
Dero furcata			10 (3.82)			---			9 (3.5)
			<0.1						<0.1
Dero furcata/lodeni	---	---	---	---	9 (3.16)	---	---	4 (4.90)	---
					<0.1			<0.1	
Dero pectinata	---	35 (1.74)		---	267 (0.89)		---	131 (1.48)	
		0.1			0.3			0.2	
Nais communis complex			12 (4.69)			22 (1.41)			13 (4.42)
			<0.1			<0.1			<0.1
Nais variabilis	---	---		---	---		---	---	
Pristina sp.	---	---	---	---	18 (3.16)	---	---	7 (4.90)	---
					<0.1			<0.1	
Pristina aequiseta			8 (4.69)			22 (1.41)			9 (4.42)
			<0.1			<0.1			<0.1
Pristina leidyi	---	---	251 (1.27)	---	1,640 (1.20)	533 (1.06)	---	683 (2.17)	275 (1.25)
			0.2		1.7	0.6		1.2	0.3
Pristina synclites	---	---	---	---	18 (3.16)	---	---	7 (4.90)	---
					<0.1			<0.1	
unknown Naididae	---	35 (2.07)		---	124 (1.17)	22 (1.41)	---	72 (1.60)	2 (0.12)
		0.1			0.1	<0.1		0.1	<0.1
Tubificidae (total)	1,761 (0.91)	6,264 (0.65)	16,911 (0.70)	761 (1.73)	10,681 (0.65)	3,023 (0.91)	1,094 (1.34)	8,105 (0.71)	15,754 (0.72)
	3.2	20.3	16.1	1.3	11.0	3.3	1.9	13.9	15.1
Limnodrilus hoffmeisteri	---	343 (0.69)	877 (0.74)	3 (4.00)	267 (1.34)	44 (1.41)	2 (4.90)	311 (0.93)	808 (0.80)
		1.1	0.8	<0.1	0.3	<0.1	<0.1	0.5	0.8
UIWCS	---	3 (3.74)	2 (4.69)	---	---	---	---	2 (4.90)	2 (4.30)
		<0.1	<0.1					<0.1	<0.1
UIWOCS	1,761 (0.91)	5,918 (0.66)	16,032 (0.74)	758 (1.74)	10,415 (0.64)	2,978 (0.91)	1,093 (1.34)	7,792 (0.72)	14,944 (0.75)
	3.2	19.2	15.2	1.3	10.8	3.3	1.9	13.4	14.4
Opistocystidae									
Crustipellis tribranchiata	---	---		---	187 (1.06)		---	78 (2.00)	
					0.2			0.1	

	BARE SAND			FILAMENTOUS ALGAE			COMBINED HABITATS		
	NUMBER / M^2 (CV)			NUMBER / M^2 (CV)			NUMBER / M^2 (CV)		
	% of total			% of total			% of total		
	May 25, 2000	**November 8, 2001**	**December 9, 2003**	**May 25, 2000**	**November 8, 2001**	**December 9, 2003**	**May 25, 2000**	**November 8, 2001**	**December 9, 2003**
Crustipellis or *Pristina*	---	---		---	876 (1.40)		---	365 (2.43)	
					0.9			0.6	
Polychaeta									
Serpulidae									
Ficopomatus miamiensis	---	---		---	---		---	---	
Nereidae									
Leoneris culveri	---	---		69 (2.77)	---		46 (3.44)	---	
				0.1			0.1		
Stenoneries martini	---	---		147 (1.91)	---		98 (2.43)	---	
				0.2			0.2		
Serpulidae, damaged	---	---		---	---		---	---	
Spionidae									
Streblospic benedicti	---	---		6 (4.00)	---		4 (4.90)	---	
				<0.1			<0.1		
Imm. Polychaeta	38 (1.88)	---		136 (3.41)	---		96 (3.95)	---	
	0.1			0.2			0.2		
Unknown Annelida	---	---		6 (4.00)	---		4 (4.90)	---	
				<0.1			<0.1		
Hirudinea	---	---	---	---	---	---	---	---	---
Mollusca									
Gastropoda (total)	44,306 (0.72)	20,787 (0.51)	20,413 (0.71)	54,673 (0.65)	39,423 (0.49)	1,800 (0.16)	51,218 (0.67)	28,552 (0.60)	18,862 (0.66)
	81.9	67.4	19.4	94.4	40.7	2.0	90.4	49.0	18.1
Ancylidae									
Ferrissia hendersoni			---			---			---
Hebetoncylus excentricus			---			---			---
Hydrobiidae unk.	539 (0.94)	127 (2.34)	194 (0.78)	4,350 (1.15)	542 (1.77)	22 (1.41)	3,080 (1.44)	300 (2.25)	180 (0.83)
	1.0	0.4	0.2	7.5	0.6	<0.1	5.4	0.5	0.2
Pyrgophorus platyrachis	517 (1.03)	13,772 ()	711 (0.60)	4,328 (1.16)	27,488 (0.60)	333 (1.41)	3,058 (1.46)	19,458 (0.78)	680 (0.67)
	0.9	44.5	0.7	7.5	28.4	0.4	5.4	33.4	0.6
Thiaridae									
Melanoides sp.	---	16 (1.77)	16 (1.81)	---	44 (1.70)	---	---	28 (1.93)	15 (1.66)
		0.1	<0.1		<0.1			<0.1	<0.1
Melanoides tuberculata	50 (1.61)	---		414 (0.67)	---		293 (0.98)	---	
	0.1			0.7			0.5		
M. turricula	---	---		6 (4.00)	---		4 (4.90)	---	
				<0.1			<0.1		
Taribia granifera	43,717 (0.73)	6,921 (0.82)	19,378 (0.74)	49,901 (0.67)	11,348 (0.61)	1,445 (0.11)	47,839 (0.68)	8,766 (0.74)	17,884 (0.69)
	80.8	22.4	18.4	86.1	11.7	1.6	84.4	15.0	17.2
unidentifiable imm. Gastropoda			85 (1.69)			---			78 (1.55)
			0.1						0.1

	BARE SAND			FILAMENTOUS ALGAE			COMBINED HABITATS		
	NUMBER / M^2 (CV)			NUMBER / M^2 (CV)			NUMBER / M^2 (CV)		
	% of total			% of total			% of total		
	May 25, 2000	**November 8, 2001**	**December 9, 2003**	**May 25, 2000**	**November 8, 2001**	**December 9, 2003**	**May 25, 2000**	**November 8, 2001**	**December 9, 2003**
Pelecypoda (total)		---	6 (3.43)		71 (1.29)	---		30 (2.28)	6 (3.14)
			<0.1		0.1			0.1	<0.1
Corbiculidae									
Corbicula fluminea	---	---	2 (4.69)	---	---	---	---	---	2 (4.30)
			<0.1						<0.1
Cyrenoididae									
Cyrenoida floridana	---	---	---	---	18 (3.16)	---	---	7 (4.90)	---
					<0.1			<0.1	
Dreissenidae									
Mytilopsis leucophaeata	---	---	---	3 (4.00)	53 (1.61)	---	2 (4.90)	22 (2.70)	---
				<0.1	0.1		<0.1	<0.1	
Sphaeriidae			4 (4.69)		---				4 (4.30)
Sphaerium occidentalis			<0.1						<0.1
Arthropoda									
Crustacea									
Amphipoda (total)	---	1,553 (1.60)	19,299 (0.91)	---	26,661 (0.42)	14,780 (0.37)	---	12,014 (1.21)	18,922 (0.87)
		5.0	18.4		27.5	16.1		20.6	18.2
Talitridae									
Orchestia sp.	---	---		---	---		---	---	
Aoridae									
Grandidierella bonnieroides	---	1,445 (1.68)	18,697 (0.91)	---	14,135 (1.05)	14,780 (0.37)	---	6,732 (1.70)	18,371 (0.87)
		4.7	17.8		14.6	16.1		11.5	17.7
Hyalellidae									
Hyalella azteca	---	108 (1.16)	123 (1.20)	---	12,704 (0.82)	---	---	5,356 (1.70)	113 1 (1.10)
		0.3	0.1		13.1			9.2	0.1
unidentifiable imm. Amphipoda			481 (1.20)			---			441 (1.10)
			0.5						0.4
Cumacea (total)	---	3 (3.74)	6,655 (1.45)	---	---	178 (0.71)	---	2 (4.90)	6,115 (1.39)
		<0.1	6.3			0.2		<0.1	5.9
Nannasticidae									
Alymyracuma sp.	---	3 (3.74)	6,655 (1.45)	---	---	178 (0.71)	---	2 (4.90)	6,115 (1.39)
		<0.1	6.3			0.2		<0.1	5.9
Decapoda									
Brachyura									
Rhithropanopeus harrissii	---	---		---	---		---	---	
Palaemonidae									
Palaemonetes pugio	---	---	---	---	---	---	---	---	---

	BARE SAND			FILAMENTOUS ALGAE			COMBINED HABITATS		
	NUMBER / M^2 (CV)			NUMBER / M^2 (CV)			NUMBER / M^2 (CV)		
	% of total			% of total			% of total		
	May 25, 2000	November 8, 2001	December 9, 2003	May 25, 2000	November 8, 2001	December 9, 2003	May 25, 2000	November 8, 2001	December 9, 2003
Isopoda (total)		124 (1.53)	24,415 (1.02)		8,059 (0.89)	48,851 (0.17)		3,430 (1.76)	26,451 (0.95)
		0.4	23.2		8.3	53.4		5.9	25.4
Anthuridae									
Cyathura polita	6 (2.83)	---	4 (4.69)	---	18 (3.16)	22 (1.41)	2 (4.90)	7 (4.90)	6 (4.94)
	<0.1		<0.1		<0.1	<0.1	<0.1	<0.1	<0.1
Munnidae									
Munna reynoldsi	---	124 (1.53)	23,643 (1.02)	---	8,041 (0.89)	47,984 (0.18)	---	3,423 (1.76)	25,671 (0.95)
		0.4	22.5		8.3	52.4		5.9	24.7
Sphaeromidae									
Cassidinidea ovalis	---	---	766 (1.25)	---	---	845 (0.15)	---	---	773 (1.16)
			0.7			0.9			0.7
Aquatic Acari (total)	---	6 (3.74)	293 (1.38)	---	1,707 (1.14)	733 (0.56)	---	715 (2.09)	330 (1.31)
		<0.1	0.3		1.8	0.8		1.2	0.3
Hydracarina	---	6 (3.74)	111 (1.56)	---	1,569 (1.16)	311 (0.20)	---	657 (2.11)	128 (1.45)
		<0.1	0.1		1.6	0.3		1.3	0.1
Oribatidae	---	---	180 (1.34)	11 (4.00)	138 (1.79)	422 (0.82)	7 (4.90)	57 (2.95)	200 (1.30)
			0.2	<0.1	0.1	0.5	<0.1	0.1	0.2
Insecta									
Collembola	---	---		---	---		---	---	
Ephemeroptera (total)	---	6 (3.74)	---	---	89 (1.41)	---	---	41 (2.23)	---
		<0.1			0.1			0.1	
Baetidae e.l.	---	---	---	---	36 (2.11)	---	---	15 (3.39)	---
					<0.1			<0.1	
Callibaetis floridanus	---	---	---	---	18 (3.16)	---	---	7 (4.90)	---
					<0.1			<0.1	
Caenidae									
Caenis diminuta	---	6 (3.74)		---	18 (3.16)		---	11 (3.59)	
		<0.1			<0.1			<0.1	
Odonata									
Anisoptera									
Libellulidae									
Pachydiplax longipennis	---	---		---	---		---	---	
Zygoptera (total)	---	---	14 (2.97)	---	18 (3.16)	22 (1.41)	---	7 (4.90)	15 (2.84)
			<0.1		<0.1	<0.1		<0.1	<0.1

	BARE SAND			FILAMENTOUS ALGAE			COMBINED HABITATS		
	NUMBER / M^2 (CV)			NUMBER / M^2 (CV)			NUMBER / M^2 (CV)		
	% of total			% of total			% of total		
	May 25, 2000	November 8, 2001	December 9, 2003	May 25, 2000	November 8, 2001	December 9, 2003	May 25, 2000	November 8, 2001	December 9, 2003
Coenagrionidae e.I.	---	---	12 (2.81)	---	18 (3.16)	---	---	7 (4.90)	11 (2.58)
			<0.1		<0.1			<0.1	<0.1
Enallagma sp.			2 (4.69)			---			2 (4.30)
			<0.1						<0.1
Hemiptera									
Mesoveliidae									
Mesovelia sp.	---	---	---	---	---	---	---	---	---
Trichoptera (total)	---	6 (3.74)	705 (1.10)	---	120 (1.40)	3,889 (1.03)	---	54 (2.25)	970 (1.09)
		<0.1	0.7		0.1	4.2		0.1	0.9
Hydroptilidae e.I.	---	---	18 (2.34)	---	18 (2.11)	1,645 (1.11)	---	7 (4.90)	154 (2.24)
			<0.1		<0.1	1.8		<0.1	<0.1
Hydroptila sp.	---	6 (3.74)	622 (1.19)	---	98 (1.63)	2,245 (0.97)	---	44 (2.50)	757 (1.17)
		<0.1	0.6		0.1	2.5		0.1	0.7
Leptoceridae e.I.	---	---	2 (4.69)	---	4 (3.16)	---	---	2 (4.90)	2 (4.30)
			<0.1		<0.1			<0.1	<0.1
Diptera									
Ceratopogonidae (total)			2 (4.69)			---			2 (4.30)
			<0.1						<0.1
Bezzia/Palpomyia complex			2 (4.69)			---			2 (4.30)
			<0.1						<0.1
Dasyhelia sp.	6 (2.83)	---		---	---		2 (4.90)	---	
	<0.1						<0.1		
Chironomidae (total)	28 (1.70)	511 (0.84)	925 (1.05)	239 (2.98)	724 (0.58)	645 (1.02)	168 (3.47)	600 (0.72)	902 (1.05)
	0.1	1.7	0.9	0.4	0.7	0.7	0.3	1.0	0.9
Tanypodinae e.I.	6 (2.83)	---	18 (2.22)	---	9 (3.16)	---	2 (4.90)	4 (4.90)	17 (2.04)
	0.1		<0.1		<0.1		<0.1	<0.1	<0.1
Ablabesmyia sp.	---	---	2 (4.69)	---	18 (3.16)	---	---	7 (4.90)	2 (4.30)
			<0.1		<0.1			<0.1	<0.1
Ablabesmyia (Karelia) sp.	---	---		---	36 (2.1)	---	---	15 (3.39)	
					<0.1			<0.1	
Ablabesmyia ramphe group	---	3 (3.74)		---	178 (1.25)		---	80 (2.17)	
		<0.1			0.2			0.1	
Djalmabatista pulchra	---	19 (2.54)	12 (2.81)	---	18 (3.16)	---	---	19 (2.73)	11 (2.58)
		0.1	<0.1		<0.1			<0.1	<0.1

	BARE SAND			FILAMENTOUS ALGAE			COMBINED HABITATS		
	NUMBER / M^2 (CV)			NUMBER / M^2 (CV)			NUMBER / M^2 (CV)		
	% of total			% of total			% of total		
	May 25, 2000	**November 8, 2001**	**December 9, 2003**	**May 25, 2000**	**November 8, 2001**	**December 9, 2003**	**May 25, 2000**	**November 8, 2001**	**December 9, 2003**
Procladius sp.			2 (4.69)			---			2 (4.30)
									<0.1
Orthocladiinae (e.i.)			2 (4.69)			---			2 (4.30)
			<0.1						<0.1
Cricotopus bicinctus			6 (2.58)			---			6 (2.37)
			<0.1						<0.1
Cricotopus or *Orthocladius*			2 (4.69)			---			2 (4.30)
			<0.1						<0.1
Rheosmittia sp.			2 (4.69)			---			2 (4.30)
			<0.1						<0.1
Chironominae									
Chironomini e.I.	---	6 (3.74)	44 (2.00)	---	36 (2.11)	44 (0.00)	---	19 (2.73)	44 (1.83)
		<0.1	<0.1		<0.1	<0.1		<0.1	<0.1
Chironomus sp.	---	410 (1.03)	190 (1.91)	39 (2.50)	124 (1.91)	44 (1.41)	26 (3.11)	291 (1.30)	178 (1.87)
		1.3	0.2	0.1	0.1	<0.1	<0.1	0.5	0.2
Chironomus decorus group	6 (2.83)	---	174 (2.02)	---	---	---	2 (4.90)	---	160 (1.85)
	<0.1		0.2				<0.1		0.1
Chironomus/Eninfeldia sp.	17 (1.98)	---		200 (3.11)	---		139 (3.67)	---	
	<0.1			0.3			0.2		
Chironomus stigmaterus			6 (3.43)			---			6 (3.14)
			<0.1						<0.1
Cryptochironomus sp.	---	19 (1.51)	8 (2.76)	---	9 (3.16)	---	---	15 (1.91)	7 (2.53)
		0.1	<0.1		<0.1			<0.1	<0.1
Dicrotendipes sp.	---	---	137 (1.28)	---	240 (1.10)	311 (1.41)	---	100 (2.05)	152 (1.29)
			0.1		0.2	0.3		0.2	0.1
Dicrotendipes fumidus			8 (4.69)			---			7 (4.30)
			<0.1						<0.1
Dicrotendipes lobus	---	---	42 (1.27)	---	---	67 (0.47)	---	---	44 (1.20)
			<0.1			0.1			<0.1
D. neomodestus	---	---	156 (1.07)	---	---	133 (1.41)	---	---	154 (1.10)
			0.1			0.1			0.1
Dicrotendipes sp. A			2 (4.69)			---			2 (4.30)
			<0.1						<0.1

	BARE SAND			FILAMENTOUS ALGAE			COMBINED HABITATS		
	NUMBER / M^2 (CV)			NUMBER / M^2 (CV)			NUMBER / M^2 (CV)		
	% of total			% of total			% of total		
	May 25, 2000	November 8, 2001	December 9, 2003	May 25, 2000	November 8, 2001	December 9, 2003	May 25, 2000	November 8, 2001	December 9, 2003
Goeldichironomus sp.	---	6 (3.74)		---	27 (2.25)		---	15 (2.89)	
		<0.1			<0.1			<0.1	
Goeldichironomus holoprasinus	---	6 (3.74)		---	---		---	4 (4.90)	
		<0.1						<0.1	
Parachironomus sp.	---	---		---	4 (3.16)		---	2 (4.90)	
					<0.1			<0.1	
Parachironomus directus	---	---		---	---		---	---	
Polypedilum sp.			4 (4.69)			---			4 (4.30)
			<0.1						<0.1
Polypedilum flavum			2 (4.69)			---			2 (4.30)
			<0.1						<0.1
Polypedilum halterale	---	41 (1.30)		---	27 (2.25)		---	35 (1.58)	
		0.1			<0.1			0.1	
Polypedilum scalaenum group			105 (1.57)			44 (1.41)			100 (1.56)
			0.1			<0.1			0.1
Ephydridae									
Parydra sp.	---	---		---	---		---	---	
Setacera sp. (pilicornis)	---	---		11 (4.00)	---		7 (4.90)	---	
				<0.1			<0.1		
Unknown Ephydrid	---	---		---	---		---	---	
Mean (per sample) Total Organisms	54,118 (0.58)	30,839 (0.44)	105,144 (0.49)	57,927 (0.62)	96,812 (0.36)	91,523 (0.27)	56,657 (0.59)	58,328 (0.70)	104,009 (0.47)
Total Taxa	10	22	44	17	39	26	20	42	45
Mean (per sample) species	5 (0.32)	9.7 (0.16)	18.5	6 (0.29)	16.6 (0.25)	21.0	6 (0.31)	12.6 (0.36)	18.7
Mean (per sample) Diversity	0.84 (0.45)	1.77 (0.21)	2.50	0.80 (0.51)	2.61 (0.13)	2.19	0.81 (0.48)	2.12 (0.26)	2.47
Mean (per sample) Evenness	0.39 (0.55)	0.54 (0.18)	0.60	0.31 (0.45)	0.65 (0.10)	0.50	0.34 (0.50)	0.59 (0.17)	0.59

P = taxon present.

--- = taxon not collected.

UIWCS = unidentifiable immature Oligochaeta with capilliform setae.

UIWOCS = unidentifiable immature Oligochaeta without capilliform setae.

e.i. = early instar insect not identifiable to species.

APPENDIX F
(from Chapter 3)

Summary of water temperatures for ambient water quality stations monitored by the Environmental Protection Commission of Hillsborough County 1999-2002 and the period of record at each station.

APPENDIX F – HILLSBOROUGH RIVER TEMPERATURE SUMMARY

1999-02 Median													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Platt	14.57	19.32	20.27	23.15	26.02	28.83	29.68	29.83	29.27	26.03	22.47	18.45	Platt
Rowlett	16.68	19.25	21.03	25.23	26.92	28.67	28.97	28.35	27.00	26.42	21.87	21.62	Rowlett
Columbus	17.78	19.18	21.72	25.18	27.42	29.97	29.42	29.25	27.77	26.88	21.78	21.17	Columbus
Sligh	19.53	20.80	23.03	25.57	28.30	29.33	28.17	27.97	27.13	26.23	23.28	22.75	Sligh
1999-02 Minimum													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Platt	13.67	15.37	18.47	22.37	23.40	28.60	28.90	28.73	29.27	22.93	21.23	17.40	Platt
Rowlett	16.20	18.53	18.00	21.97	25.37	25.37	27.40	28.30	24.70	22.17	17.40	17.00	Rowlett
Columbus	15.50	18.37	19.53	23.37	25.20	28.43	27.63	28.53	24.50	23.63	21.00	17.43	Columbus
Sligh	17.83	19.40	22.37	25.40	25.53	25.80	27.47	27.50	24.50	24.83	21.87	17.70	Sligh

Period of Record Median													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	POR
Platt	16.83	17.63	20.00	23.00	26.13	28.77	29.57	29.47	29.00	26.00	23.17	19.38	1974-2002
Rowlett	16.10	19.10	21.00	23.77	26.92	28.00	29.00	28.30	27.00	24.40	21.73	17.52	1974-2002
Columbus	16.77	19.00	21.08	24.12	27.37	29.18	29.33	28.67	27.20	25.03	21.87	19.00	1979-2002
Sligh	19.53	20.80	23.03	25.57	28.30	29.33	28.17	27.97	27.13	26.23	23.28	22.75	1999-2002
Period of Record Minimum													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	POR
Platt	10.50	10.00	15.90	17.00	22.30	26.00	23.50	27.00	26.00	19.50	19.50	12.00	1974-2002
Rowlett	13.50	11.00	15.80	20.60	24.00	25.00	27.00	26.00	24.00	21.00	14.00	14.60	1974-2002
Columbus	13.50	16.00	15.83	20.50	24.50	25.50	26.90	26.40	24.00	23.10	18.00	15.10	1979-2002
Sligh	17.83	19.40	22.37	25.40	25.53	25.80	27.47	27.50	24.50	24.83	21.87	17.70	1999-2002

APPENDIX G
(from Chapter 5)

Daily values for spring flow, salinity and water levels in the spring run and the lower river during the six experimental releases.

Appendix G

Daily values for mean, minimum and maximum salinity at the Sulphur Springs Run recorder and daily values for maximum water level (stage) and surface salinity at the Hillsborough River near Sulphur Springs recorder for the six controlled release experiments. Days on which vertical profiles were measured in the spring run are highlighted in bold.

Experiment Number 1

Date	SPRINGFLOW (CFS)	RUN MEAN SALINITY (PPT)	RUN MIN SALINITY (PPT)	RUN MAX SALINITY (PPT)	RIVER MAX STAGE (FT. NGVD)	RIVER MAX SALINITY (PPT)
24NOV2001	31.0	2.0	2.0	2.0	1.7	20.5
25NOV2001	31.0	2.0	2.0	2.0	1.7	20.3
26NOV2001	**31.0**	**2.0**	**2.0**	**2.0**	**1.5**	**20.0**
27NOV2001	31.0	.	.	.	1.7	19.3
28NOV2001	23.0	2.0	1.9	2.0	1.9	18.6
29NOV2001	17.0	2.0	2.0	2.0	2.1	17.2
30NOV2001	**23.0**	**2.0**	**2.0**	**2.0**	**2.0**	**15.7**
01DEC2001	30.0	2.0	1.9	2.0	2.0	14.1
02DEC2001	31.0	2.0	1.9	2.0	1.7	13.0

Experiment Number 2

Date	SPRINGFLOW (CFS)	RUN MEAN SALINITY (PPT)	RUN MIN SALINITY (PPT)	RUN MAX SALINITY (PPT)	RIVER MAX STAGE (FT. NGVD)	RIVER MAX SALINITY (PPT)
01DEC2001	30.0	2.0	1.9	2.0	2.0	14.1
02DEC2001	31.0	2.0	1.9	2.0	1.7	13.0
03DEC2001	**31.0**	**2.0**	**1.9**	**2.0**	**1.6**	**12.7**
04DEC2001	17.0	2.0	1.9	2.0	1.2	13.4
05DEC2001	9.8	1.9	1.9	2.0	1.2	14.9
06DEC2001	**19.0**	**1.9**	**1.9**	**1.9**	**1.0**	**16.4**
07DEC2001	29.0	1.9	1.9	1.9	1.5	17.2

Experiment Number 3

Date	SPRINGFLOW (CFS)	RUN MEAN SALINITY (PPT)	RUN MIN SALINITY (PPT)	RUN MAX SALINITY (PPT)	RIVER MAX STAGE (FT. NGVD)	RIVER MAX SALINITY (PPT)
09DEC2001	31.0	.	.	.	1.5	16.9
10DEC2001	**31.0**	**.**	**.**	**.**	**1.7**	**16.6**
11DEC2001	18.0	1.8	1.8	1.8	2.0	16.5
12DEC2001	12.0	1.8	1.8	1.8	2.1	16.1
13DEC2001	**19.0**	**1.9**	**1.8**	**1.9**	**2.3**	**16.0**
14DEC2001	31.0	1.8	1.8	1.8	2.4	14.9
15DEC2001	31.0	1.8	1.8	1.8	2.3	14.1

Experiment Number 4

Date	SPRINGFLOW (CFS)	RUN MEAN SALINITY (PPT)	RUN MIN SALINITY (PPT)	RUN MAX SALINITY (PPT)	RIVER MAX STAGE (FT. NGVD)	RIVER MAX SALINITY (PPT)
01MAR2002	10.0	1.8	1.8	1.8	0.8	12.2
02MAR2002	11.0	2.1	1.8	4.0	2.8	12.4
03MAR2002	11.0	1.9	1.8	1.9	2.4	11.0
04MAR2002	16.0	1.9	1.9	1.9	0.4	9.4
05MAR2002	**25.0**	**1.8**	**1.8**	**1.9**	**0.3**	**14.2**
06MAR2002	17.0	1.7	1.7	1.8	1.2	15.7
07MAR2002	12.0	1.7	1.7	1.7	1.3	20.1
08MAR2002	**16.0**	**1.7**	**1.7**	**1.8**	**1.1**	**21.8**
09MAR2002	25.0	1.8	1.8	1.8	1.0	21.9
10MAR2002	26.0	1.8	1.7	1.8	0.9	21.5
11MAR2002	26.0	1.7	1.7	1.7	1.4	20.6

Experiment Number 5

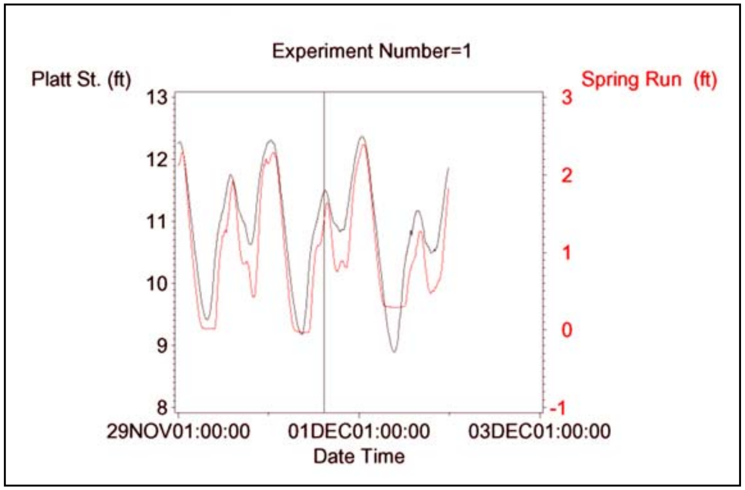
Date	SPRINGFLOW (CFS)	RUN MEAN SALINITY (PPT)	RUN MIN SALINITY (PPT)	RUN MAX SALINITY (PPT)	RIVER MAX STAGE (FT. NGVD)	RIVER MAX SALINITY (PPT)
01JUN2002	14.0	1.0	1.0	1.2	1.8	20.6
02JUN2002	14.0	1.0	0.9	1.0	1.4	21.1
03JUN2002	13.0	1.0	0.9	1.0	1.4	21.4
04JUN2002	13.0	1.0	0.9	1.0	1.5	22.0
05JUN2002	13.0	1.0	0.9	1.0	1.8	23.0
06JUN2002	13.0	1.0	0.9	1.1	2.0	22.6
07JUN2002	13.0	1.1	0.9	3.2	2.2	22.4
08JUN2002	13.0	1.2	0.9	2.7	2.1	21.8
09JUN2002	13.0	1.1	0.9	2.5	2.0	20.2
10JUN2002	13.0	2.0	0.9	10.5	2.4	19.4
11JUN2002	13.0	1.8	0.9	7.8	2.3	18.1
12JUN2002	**13.0**	**2.9**	**0.9**	**12.6**	**2.7**	**18.7**
13JUN2002	15.0	1.0	0.9	1.0	2.8	19.2
14JUN2002	17.0	1.3	0.9	5.1	2.9	19.2

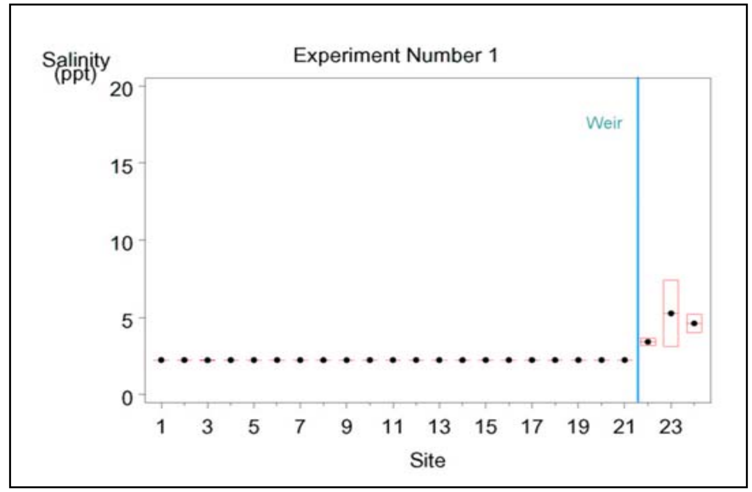
Experiment Number 6

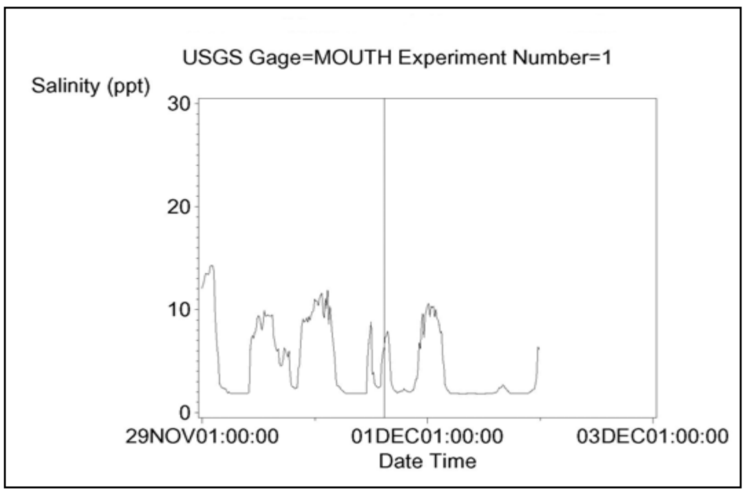
Date	SPRINGFLOW (CFS)	RUN MEAN SALINITY (PPT)	RUN MIN SALINITY (PPT)	RUN MAX SALINITY (PPT)	RIVER MAX STAGE (FT. NGVD)	RIVER MAX SALINITY (PPT)
15JUN2002	15.0	1.0	0.9	1.0	2.6	19.5
16JUN2002	13.0	0.9	0.9	1.0	2.3	20.0
17JUN2002	13.0	0.9	0.9	0.9	2.2	19.9
18JUN2002	7.3	1.1	0.9	1.8	2.7	12.2
19JUN2002	2.5	1.3	0.9	2.6	2.4	12.6
20JUN2002	**2.5**	**0.9**	**0.9**	**1.0**	**1.7**	**12.1**
21JUN2002	2.5	1.0	0.9	1.9	2.2	12.3
22JUN2002	2.5	1.3	0.9	4.6	2.8	12.1
23JUN2002	2.5	1.2	1.0	2.3	2.4	12.4

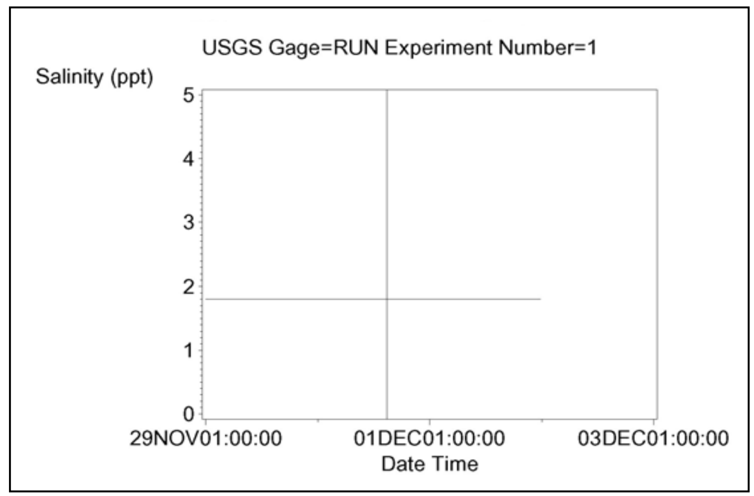
APPENDIX H
(from Chapter 5)

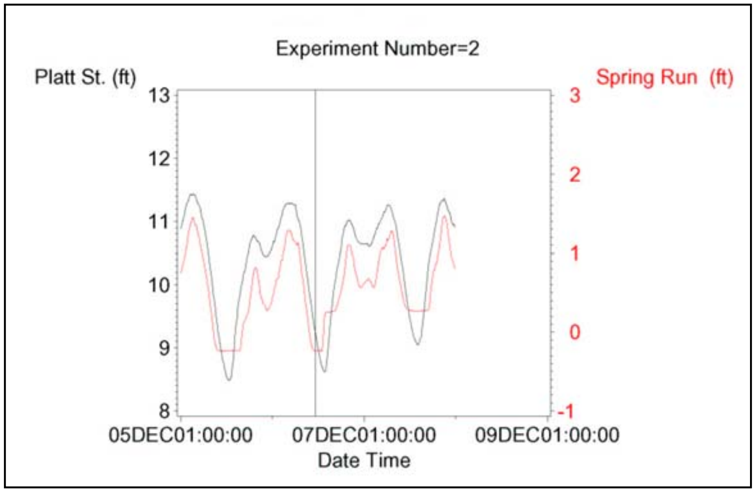
Time series plots of 15-minute data for water levels and salinity at continuous recorders in the lower river, the upper spring run, and the spring run mouth during the six experimental releases.

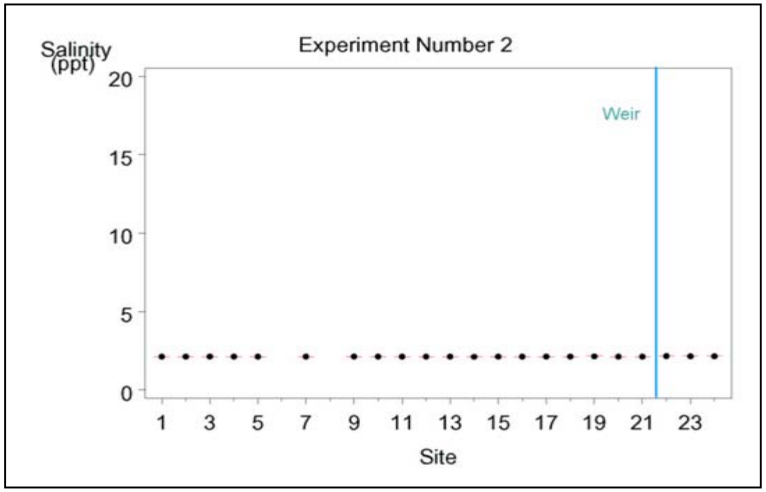

Experiment Number=1
Platt St. (ft)
Spring Run (ft)
13
12
11
10
9
8
3
2
1
0
-1
29NOV01:00:00
01DEC01:00:00
03DEC01:00:00
Date Time

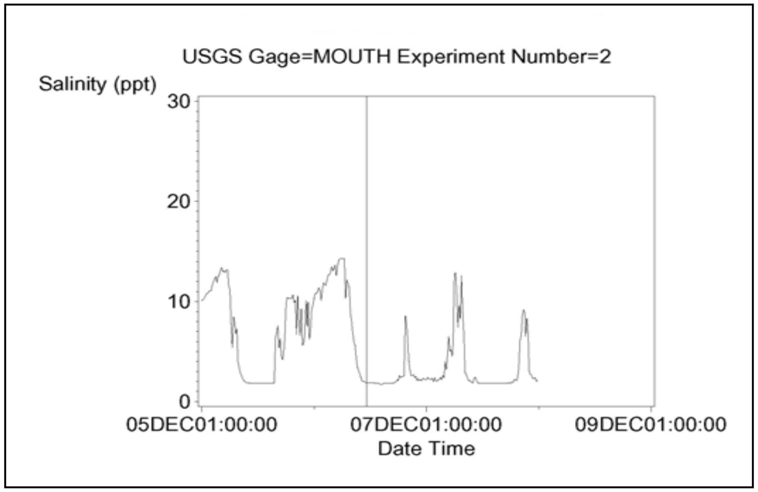

Experiment Number 1
Salinity (ppt)
20
15
10
5
0
Weir
1
3
5
7
9
11
13
15
17
19
21
23
Site

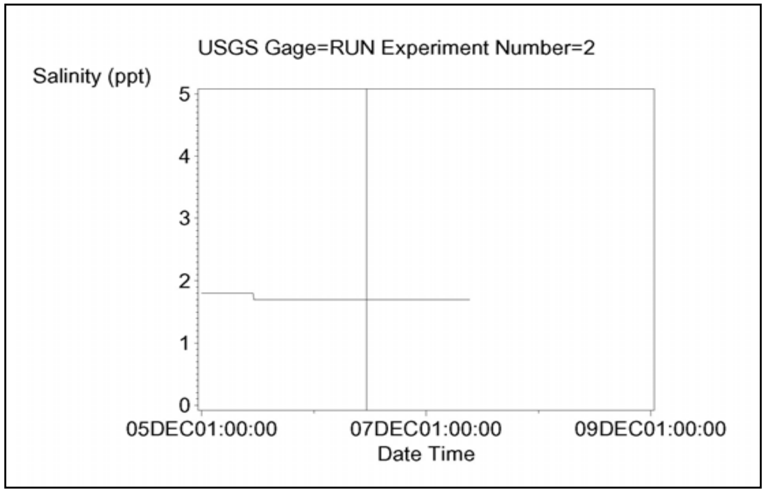

USGS Gage=MOUTH Experiment Number=1
Salinity (ppt)
30
20
10
0
29NOV01:00:00
01DEC01:00:00
03DEC01:00:00
Date Time

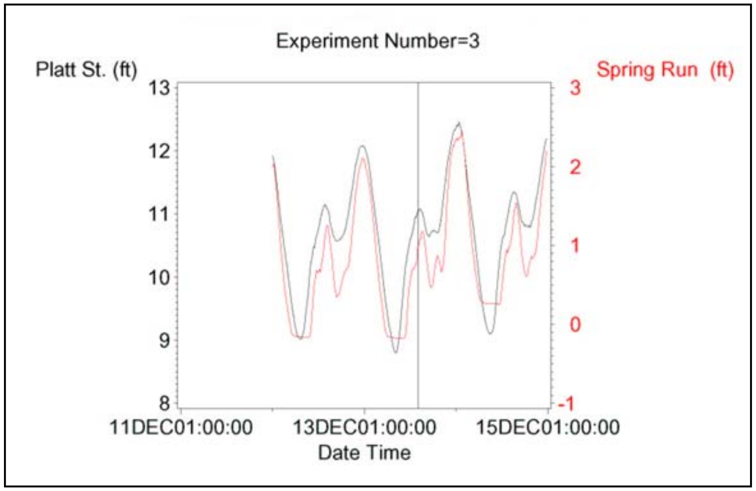

USGS Gage=RUN Experiment Number=1
Salinity (ppt)
5
4
3
2
1
0
29NOV01:00:00
01DEC01:00:00
03DEC01:00:00
Date Time

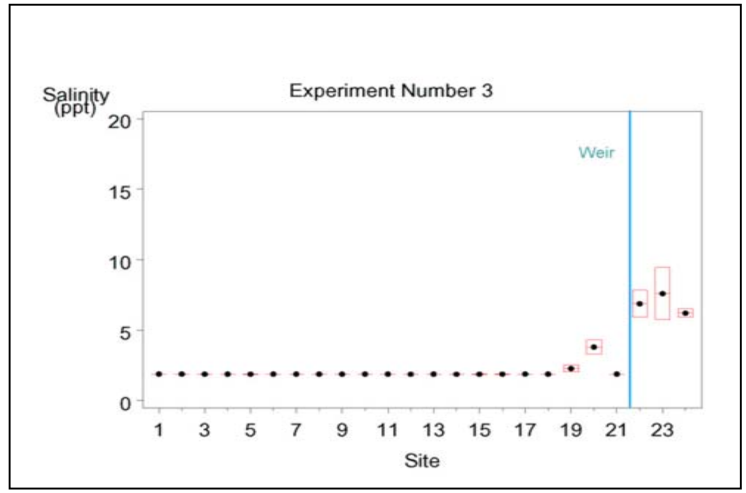

Experiment Number=2
Platt St. (ft)
Spring Run (ft)
13
12
11
10
9
8
3
2
1
0
-1
05DEC01:00:00
07DEC01:00:00
09DEC01:00:00
Date Time

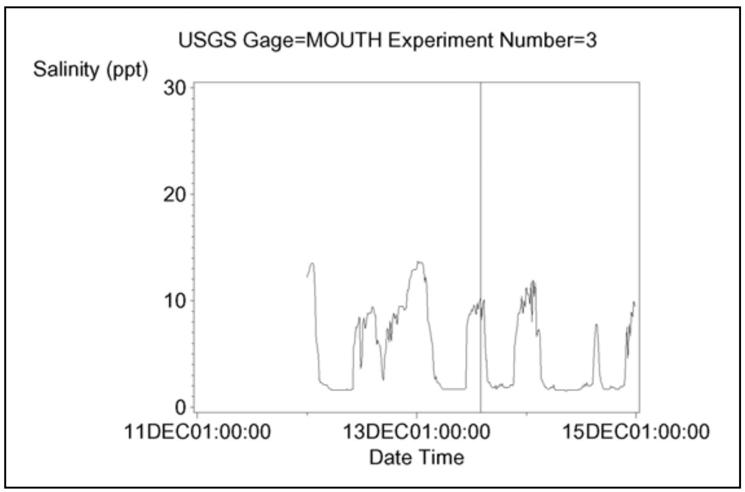

Experiment Number 2
Salinity (ppt)
20
15
10
5
0
Weir
1
3
5
7
9
11
13
15
17
19
21
23
Site

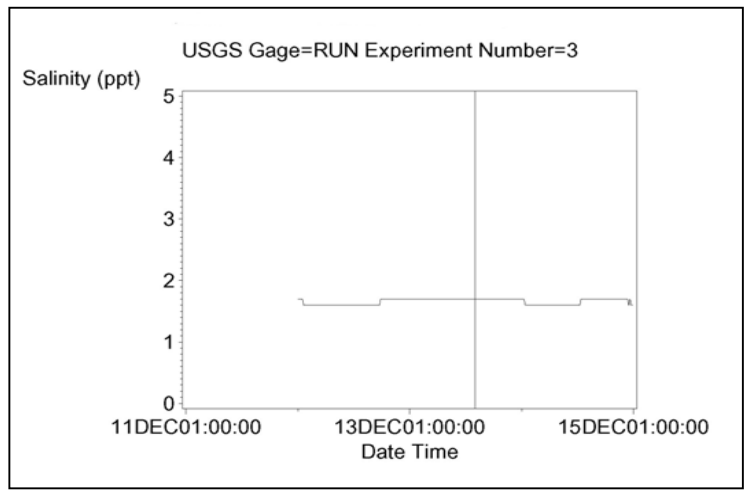

USGS Gage=MOUTH Experiment Number=2
Salinity (ppt)
30
20
10
0
05DEC01:00:00
07DEC01:00:00
09DEC01:00:00
Date Time

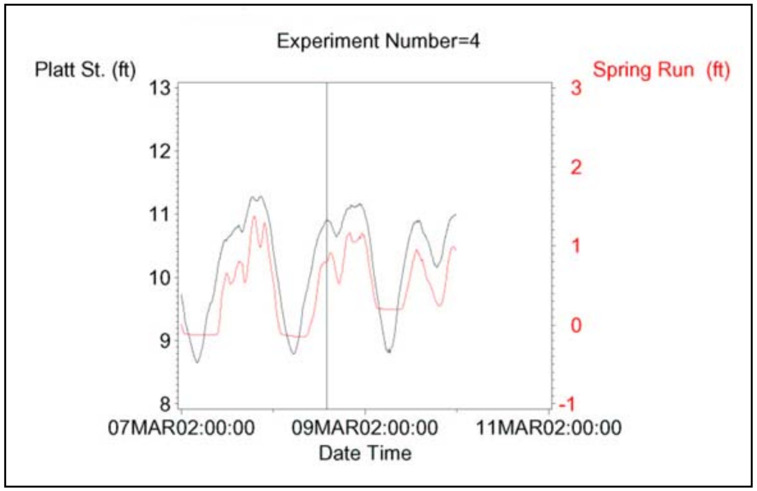

USGS Gage=RUN Experiment Number=2
Salinity (ppt)
5
4
3
2
1
0
05DEC01:00:00
07DEC01:00:00
09DEC01:00:00
Date Time


Experiment Number=3
Platt St. (ft)
Spring Run (ft)
13
12
11
10
9
8
3
2
1
0
-1
11DEC01:00:00
13DEC01:00:00
15DEC01:00:00
Date Time

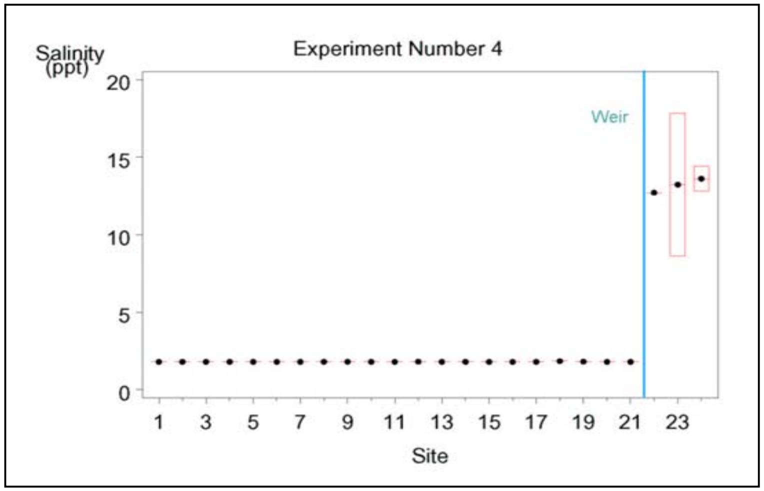

Experiment Number 3
Salinity (ppt)
20
15
10
5
0
Weir
1
3
5
7
9
11
13
15
17
19
21
23
Site


USGS Gage=MOUTH Experiment Number=3
Salinity (ppt)
30
20
10
0
11DEC01:00:00
13DEC01:00:00
15DEC01:00:00
Date Time

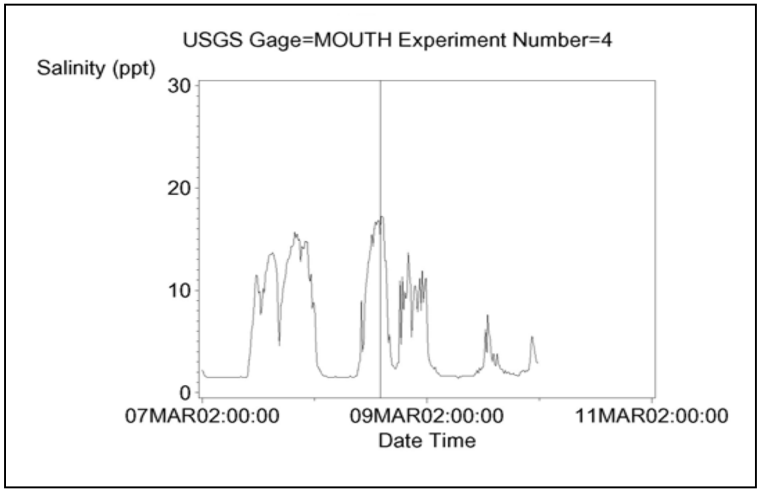

USGS Gage=RUN Experiment Number=3
Salinity (ppt)
5
4
3
2
1
0
11DEC01:00:00
13DEC01:00:00
15DEC01:00:00
Date Time



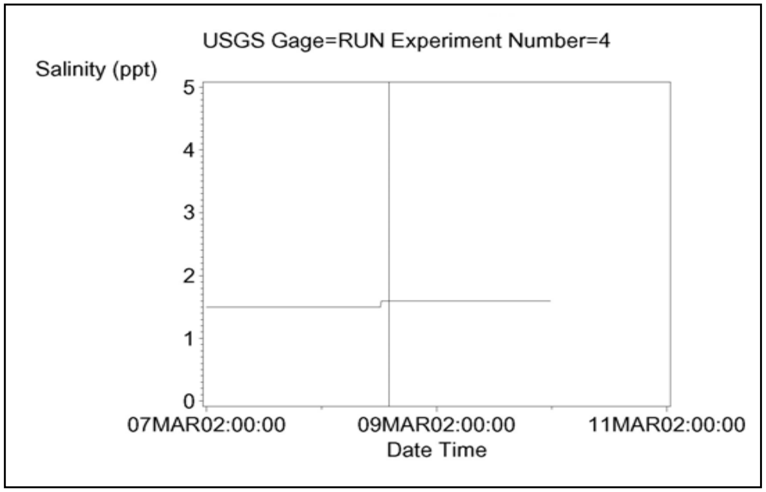
Experiment Number=4
Platt St. (ft)
Spring Run (ft)
13
12
11
10
9
8
3
2
1
0
-1
07MAR02:00:00
09MAR02:00:00
11MAR02:00:00
Date Time



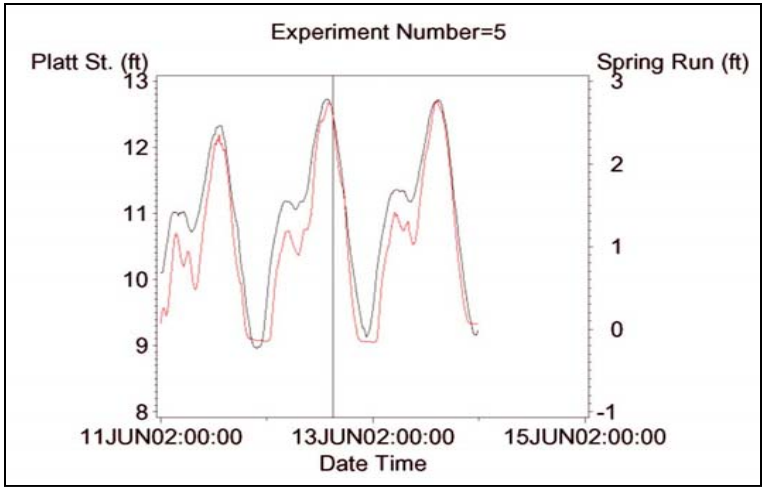
Experiment Number 4
Salinity (ppt)
Weir
20
15
10
5
0
1
3
5
7
9
11
13
15
17
19
21
23
Site



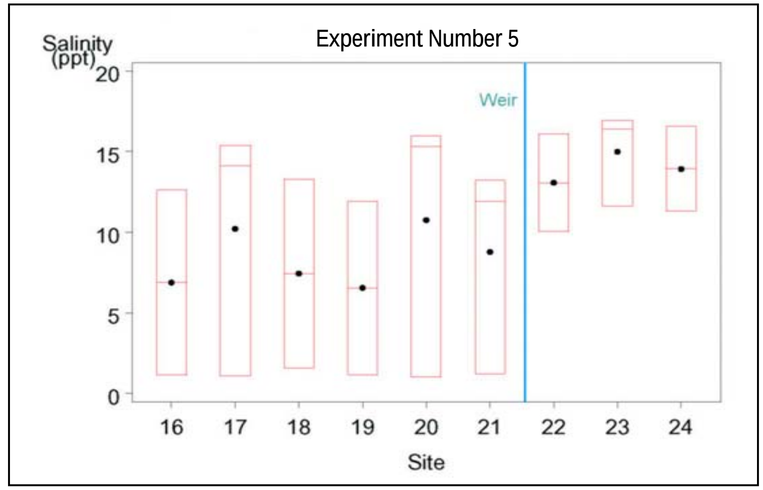
USGS Gage=MOUTH Experiment Number=4
Salinity (ppt)
30
20
10
0
07MAR02:00:00
09MAR02:00:00
11MAR02:00:00
Date Time



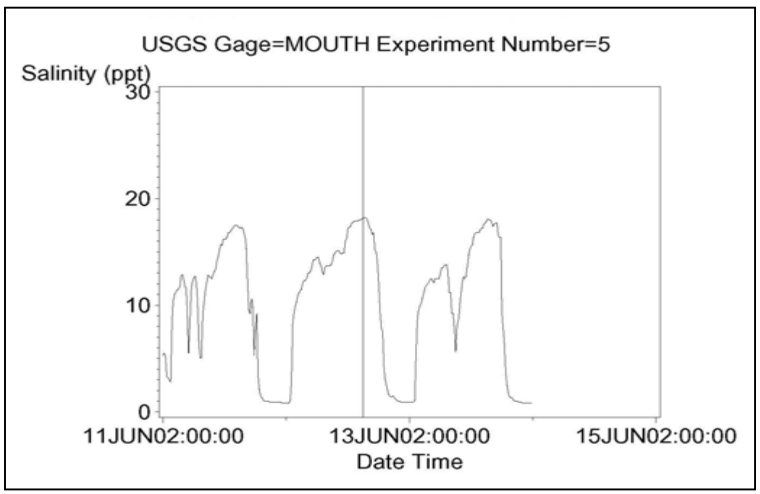
USGS Gage=RUN Experiment Number=4
Salinity (ppt)
5
4
3
2
1
0
07MAR02:00:00
09MAR02:00:00
11MAR02:00:00
Date Time



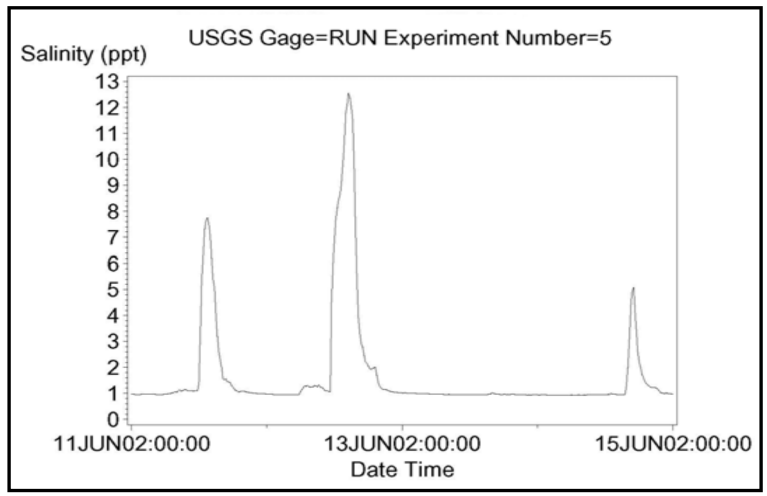
Experiment Number=5
Platt St. (ft)
Spring Run (ft)
13
12
11
10
9
8
3
2
1
0
-1
11JUN02:00:00
13JUN02:00:00
15JUN02:00:00
Date Time



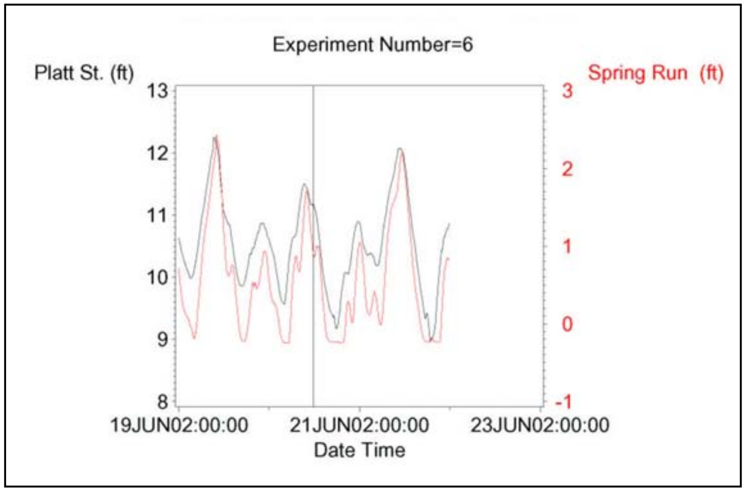
Experiment Number 5
Salinity (ppt)
20
15
10
5
0
Weir
16
17
18
19
20
21
22
23
24
Site

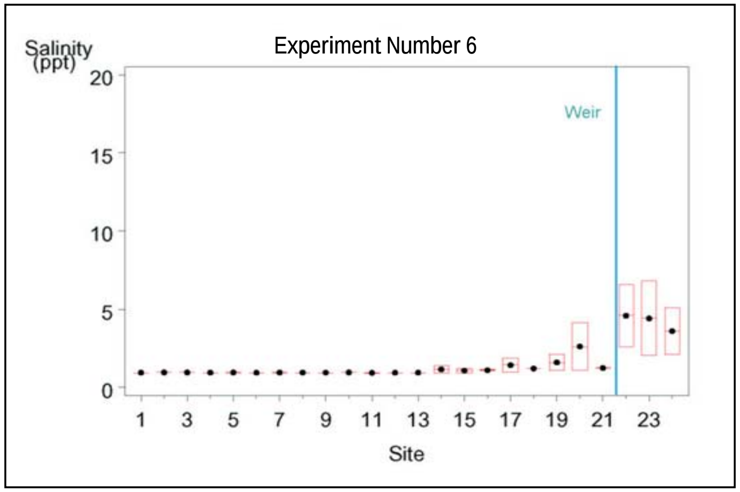


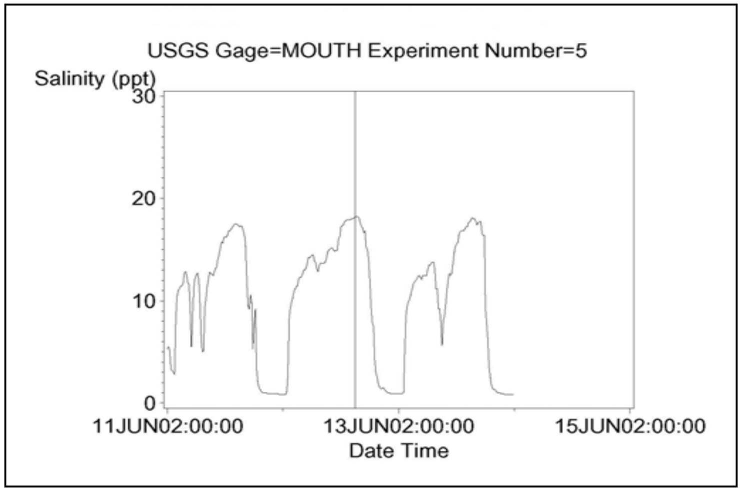
USGS Gage=MOUTH Experiment Number=5
Salinity (ppt)
30
20
10
0
11JUN02:00:00
13JUN02:00:00
15JUN02:00:00
Date Time

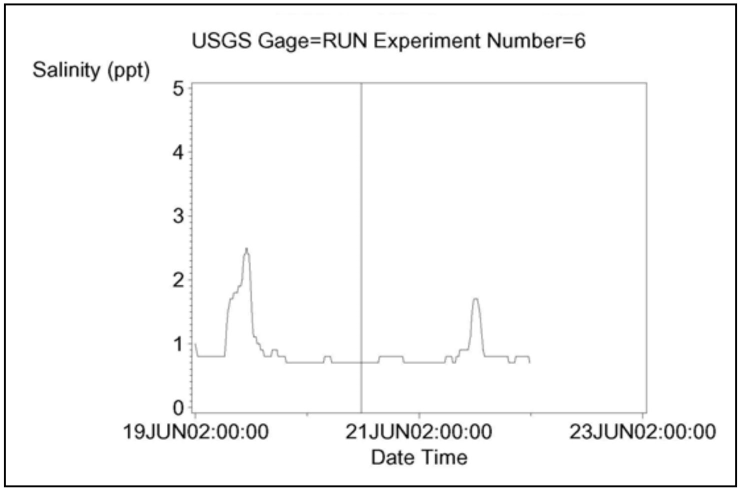


USGS Gage=RUN Experiment Number=5
Salinity (ppt)
13
12
11
10
9
8
7
6
5
4
3
2
1
0
11JUN02:00:00
13JUN02:00:00
15JUN02:00:00
Date Time


Experiment Number=6
Platt St. (ft)
Spring Run (ft)
13
12
11
10
9
8
3
2
1
0
-1
19JUN02:00:00
21JUN02:00:00
23JUN02:00:00
Date Time


Experiment Number 6
Salinity (ppt)
20
15
10
5
0
Weir
1
3
5
7
9
11
13
15
17
19
21
23
Site


USGS Gage=MOUTH Experiment Number=5
Salinity (ppt)
30
20
10
0
11JUN02:00:00
13JUN02:00:00
15JUN02:00:00
Date Time


USGS Gage=RUN Experiment Number=6
Salinity (ppt)
5
4
3
2
1
0
19JUN02:00:00
21JUN02:00:00
23JUN02:00:00
Date Time

APPENDIX I
(from Chapter 5)

Daily values for salinity and water levels at the data recorders in the upper spring run and the Hillsborough River near Sulphur Springs listed for flow classes in 1 cfs increments for average daily flows between 5 and 20 cfs.

Appendix I

Daily values for minimum and maximum salinity at the Sulphur Springs Run recorder and daily values for daily maximum stage and salinity at the Hillsborough River near Sulphur Springs recorder. All values listed for 1 cfs flow classes between 5 and 20 cfs from Sulphur Springs pool. Salinity difference is the daily maximum salinity minus the daily minimum salinity. Difference values greater than 1.5 ppt highlighted in bold. Records for maximum river stage values begin October 1, 2000.

---------------------------------- FLOW CLASS (CFS)=5 ----------------------------------

Date	SPRINGFLOW (CFS)	PRECEDING DAY FLOW	RUN MIN SALINITY (PPT)	RUN MAX SALINITY (PPT)	SALINITY DIFFERENCE (PPT)	RIVER MAX STAGE (FT. NGVD)	RIVER MAX SALINITY (PPT)
09JUN1999	5.1	0.0	1.1	9.1	8.0	.	.
29MAR2000	5.5	17.0	1.6	8.0	6.4	.	20.2
04APR2000	4.8	0.0	1.7	17.0	15.3	.	16.7
06APR2000	4.8	14.0	1.5	11.6	10.1	.	14.8
11APR2000	5.0	9.1	1.5	13.5	12.0	.	17.4
25JUL2000	4.6	3.7	1.5	5.9	4.4	.	14.4
29JUL2000	5.4	4.2	0.9	12.3	11.4	.	15.8
31JUL2000	5.4	5.8	1.6	11.8	10.2	.	15.8
22MAR2001	4.7	9.7	1.3	5.5	4.2	1.1	18.2
29MAR2001	5.1	13.0	1.2	10.3	9.1	2.5	15.5
29MAY2001	5.5	3.5	1.4	13.6	12.2	1.7	20.1
12MAY2002	5.4	2.5	1.1	5.2	4.1	2.3	16.4

---------------------------------- FLOW CLASS (CFS)=6 ----------------------------------

Date	SPRINGFLOW (CFS)	PRECEDING DAY FLOW	RUN MIN SALINITY (PPT)	RUN MAX SALINITY (PPT)	SALINITY DIFFERENCE (PPT)	RIVER MAX STAGE (FT. NGVD)	RIVER MAX SALINITY (PPT)
27MAR2000	5.8	0.0	1.9	14.0	12.1	.	19.1
09MAY2000	6.2	0.0	1.6	15.6	14.1	.	18.8
30JUL2000	5.8	5.4	1.1	11.2	10.1	.	16.1
07MAY2001	6.0	3.5	1.5	14.7	13.3	1.7	18.9
17MAY2001	6.3	11.0	1.1	5.5	4.4	1.2	24.4
18MAY2001	6.3	6.3	1.1	7.2	6.1	1.3	24.8
24MAY2001	5.7	9.4	1.0	10.7	9.6	2.0	20.9
24JUN2002	5.6	2.5	1.0	3.9	2.9	3.2	13.3

---------------------------------- FLOW CLASS (CFS)=7 ----------------------------------

Date	SPRINGFLOW (CFS)	PRECEDING DAY FLOW	RUN MIN SALINITY (PPT)	RUN MAX SALINITY (PPT)	SALINITY DIFFERENCE (PPT)	RIVER MAX STAGE (FT. NGVD)	RIVER MAX SALINITY (PPT)
07JUN1999	7.1	19.0	1.0	6.2	5.2	.	.
24APR2000	6.8	0.0	2.2	15.5	13.3	.	18.2
10MAY2000	6.9	6.2	1.3	12.9	11.6	.	19.3
01AUG2000	7.4	5.4	1.4	4.1	2.7	.	9.9
02AUG2000	7.2	7.4	1.4	5.4	4.0	.	8.8
03AUG2000	7.5	7.2	1.3	3.7	2.3	.	9.5

04AUG2000	7.1	7.5	1.4	2.9	1.5	.	11.0
05AUG2000	7.1	7.1	1.4	1.9	0.5	.	12.3
06AUG2000	**7.4**	**7.1**	**1.4**	**3.7**	**2.2**	**.**	**13.1**
07AUG2000	**7.5**	**7.4**	**1.4**	**4.7**	**3.3**	**.**	**13.6**
08AUG2000	7.5	7.5	1.4	1.7	0.3	.	14.4
09AUG2000	**6.9**	**7.5**	**1.2**	**3.2**	**2.0**	**.**	**15.5**
10AUG2000	**6.8**	**6.9**	**1.4**	**6.7**	**5.3**	**.**	**15.8**
11AUG2000	**7.3**	**6.8**	**1.5**	**5.2**	**3.7**	**.**	**17.5**
09MAY2001	**6.7**	**9.8**	**1.2**	**6.1**	**4.9**	**1.9**	**20.3**
10MAY2001	**7.0**	**6.7**	**1.2**	**14.2**	**13.1**	**2.2**	**21.5**
11MAY2001	**7.0**	**7.0**	**1.1**	**15.1**	**13.9**	**1.9**	**22.5**
14MAY2001	**7.0**	**3.5**	**1.2**	**8.9**	**7.7**	**1.2**	**23.4**
21MAY2001	**6.6**	**3.5**	**1.2**	**14.7**	**13.5**	**2.1**	**22.2**
18JUN2001	**6.6**	**3.5**	**1.6**	**8.6**	**7.0**	**1.7**	**19.8**
06JUL2001	**7.3**	**3.5**	**1.2**	**6.8**	**5.5**	**2.2**	**16.5**
21MAY2002	6.8	14.0	1.0	1.0	0.0	0.7	17.2
28MAY2002	**6.8**	**2.5**	**1.8**	**11.8**	**10.1**	**2.5**	**17.8**
18JUN2002	7.3	13.0	0.9	1.8	0.9	2.7	12.2

---------------------------------- FLOW CLASS (CFS)=8 ----------------------------------

Date	SPRINGFLOW (CFS)	PRECEDING DAY FLOW	RUN MIN SALINITY (PPT)	RUN MAX SALINITY (PPT)	SALINITY DIFFERENCE (PPT)	RIVER MAX STAGE (FT. NGVD)	RIVER MAX SALINITY (PPT)
22FEB2000	**8.4**	**11.0**	**1.7**	**6.8**	**5.0**	**.**	**13.6**
19MAR2001	**7.6**	**12.0**	**1.4**	**8.2**	**6.9**	**1.4**	**19.9**
16APR2001	8.3	8.9	1.4	1.4	0.0	1.1	20.1
11JUN2001	8.3	15.0	1.0	2.1	1.1	2.2	18.3
21JUN2001	**8.3**	**13.0**	**1.1**	**9.8**	**8.7**	**2.4**	**16.4**
25JUN2001	**7.8**	**3.5**	**1.5**	**7.7**	**6.2**	**1.9**	**15.5**
14MAY2002	**7.8**	**8.7**	**1.2**	**5.1**	**3.9**	**2.3**	**15.9**

---------------------------------- FLOW CLASS (CFS)=9 ----------------------------------

Date	SPRINGFLOW (CFS)	PRECEDING DAY FLOW	RUN MIN SALINITY (PPT)	RUN MAX SALINITY (PPT)	SALINITY DIFFERENCE (PPT)	RIVER MAX STAGE (FT. NGVD)	RIVER MAX SALINITY (PPT)
18FEB2000	**9.2**	**22.0**	**1.6**	**9.8**	**8.2**	**.**	**17.2**
10APR2000	**9.1**	**0.0**	**1.5**	**8.5**	**7.0**	**.**	**15.0**
12AUG2000	**8.7**	**7.3**	**1.5**	**6.7**	**5.2**	**.**	**18.5**
26MAR2001	**8.6**	**3.5**	**1.5**	**11.3**	**9.8**	**1.3**	**16.4**
13APR2001	8.9	14.0	1.4	1.6	0.2	2.0	17.4
14APR2001	9.5	8.9	1.4	1.4	0.1	1.8	18.4
15APR2001	8.9	9.5	1.4	1.4	0.0	1.8	19.1
29APR2001	**8.9**	**18.0**	**1.0**	**10.1**	**9.1**	**1.5**	**19.1**
23MAY2001	9.4	12.0	1.1	1.1	0.1	2.4	20.7
01JUN2001	**9.4**	**12.0**	**1.0**	**6.4**	**5.4**	**1.8**	**22.3**
13MAY2002	**8.7**	**5.4**	**0.9**	**8.3**	**7.4**	**2.4**	**16.3**

--------------------------------- FLOW CLASS (CFS)=10 ---------------------------------

Date	SPRINGFLOW (CFS)	PRECEDING DAY FLOW	RUN MIN SALINITY (PPT)	RUN MAX SALINITY (PPT)	SALINITY DIFFERENCE (PPT)	RIVER MAX STAGE (FT. NGVD)	RIVER MAX SALINITY (PPT)

28FEB2000	9.8	0.0	1.9	9.7	7.8	.	18.2
07MAR2000	10.0	21.0	1.6	7.8	6.3	.	15.0
15FEB2001	10.0	22.0	1.5	2.6	1.1	1.3	19.0
22FEB2001	10.0	22.0	1.6	8.8	7.3	1.8	20.1
20MAR2001	10.0	7.6	1.3	6.7	5.4	1.6	19.1
21MAR2001	9.7	10.0	1.4	8.1	6.8	1.8	17.3
03APR2001	10.0	24.0	1.4	3.7	2.3	1.7	18.8
08MAY2001	9.8	6.0	1.3	1.5	0.1	1.5	19.3
30MAY2001	10.0	5.5	1.2	1.6	0.3	1.0	21.0
05DEC2001	9.8	17.0	1.9	2.0	0.1	1.2	14.9
24FEB2002	10.0	11.0	1.8	1.8	0.0	1.7	15.5
25FEB2002	10.0	10.0	1.8	1.8	0.0	2.0	15.6
27FEB2002	10.0	11.0	1.8	3.2	1.4	2.6	14.8
28FEB2002	9.9	10.0	1.8	1.8	0.0	1.0	12.9
01MAR2002	10.0	9.9	1.8	1.8	0.0	0.8	12.2

---------------------------------- FLOW CLASS (CFS)=11 ----------------------------------

Date	SPRINGFLOW (CFS)	PRECEDING DAY FLOW	RUN MIN SALINITY (PPT)	RUN MAX SALINITY (PPT)	SALINITY DIFFERENCE (PPT)	RIVER MAX STAGE (FT. NGVD)	RIVER MAX SALINITY (PPT)
21FEB2000	11.0	0.0	1.8	9.9	8.1	.	13.5
16MAR2000	11.0	24.0	1.4	10.1	8.7	.	18.1
31OCT2000	11.0	3.5	1.8	12.6	10.8	1.9	18.8
04JAN2001	11.0	25.0	1.4	1.6	0.1	0.7	23.3
31JAN2001	11.0	24.0	1.3	3.3	2.0	1.4	17.6
07FEB2001	11.0	23.0	1.4	10.4	9.0	1.5	20.2
13MAR2001	11.0	12.0	1.4	9.3	7.9	2.4	14.4
16MAY2001	11.0	13.0	1.1	1.2	0.1	1.2	24.0
06JUN2001	11.0	3.8	1.3	3.5	2.3	2.3	11.4
19JUN2001	11.0	6.6	1.5	1.7	0.2	1.9	18.6
22FEB2002	11.0	18.0	1.7	1.7	0.1	1.7	16.8
23FEB2002	11.0	11.0	1.7	1.8	0.1	1.3	16.6
26FEB2002	11.0	10.0	1.8	2.3	0.5	2.3	15.1
02MAR2002	11.0	10.0	1.8	4.0	2.2	2.8	12.4
03MAR2002	11.0	11.0	1.8	1.9	0.0	2.4	11.0
25APR2002	11.0	22.0	0.8	8.1	7.3	2.0	18.4

---------------------------------- FLOW CLASS (CFS)=12 ----------------------------------

Date	SPRINGFLOW (CFS)	PRECEDING DAY FLOW	RUN MIN SALINITY (PPT)	RUN MAX SALINITY (PPT)	SALINITY DIFFERENCE (PPT)	RIVER MAX STAGE (FT. NGVD)	RIVER MAX SALINITY (PPT)
27OCT2000	12.0	30.0	2.4	10.7	8.3	2.1	18.7
02NOV2000	12.0	25.0	1.6	2.6	1.0	2.2	21.2
21DEC2000	12.0	26.0	1.4	1.5	0.1	1.4	20.0
11JAN2001	12.0	25.0	1.4	5.9	4.5	2.0	19.3
01MAR2001	12.0	21.0	1.5	4.3	2.8	1.7	16.4
09MAR2001	12.0	13.0	1.3	8.6	7.4	1.9	19.5
10MAR2001	12.0	12.0	1.2	10.2	9.0	2.6	18.4
12MAR2001	12.0	14.0	1.3	9.5	8.1	2.1	15.2

14MAR2001	12.0	11.0	1.4	9.3	7.9	1.6	15.4
15MAR2001	12.0	12.0	1.4	6.7	5.3	2.5	15.9
16MAR2001	12.0	12.0	1.4	6.9	5.5	1.9	14.8
17MAR2001	12.0	12.0	1.3	3.8	2.5	0.9	17.2
18MAR2001	12.0	12.0	1.3	1.4	0.2	1.1	19.6
09APR2001	12.0	3.5	1.6	10.9	9.2	1.8	13.9
23APR2001	12.0	3.5	1.5	13.3	11.8	1.9	17.6
22MAY2001	12.0	6.6	1.2	1.2	0.1	2.3	20.9
31MAY2001	12.0	10.0	1.1	1.2	0.2	1.4	21.9
26JUN2001	12.0	7.8	1.5	1.5	0.1	2.1	16.8
02JUL2001	12.0	18.0	0.9	1.5	0.6	2.0	7.8
12DEC2001	12.0	18.0	1.8	1.8	0.0	2.1	16.1
07MAR2002	12.0	17.0	1.7	1.7	0.0	1.3	20.1
29MAY2002	12.0	6.8	1.0	13.4	12.4	2.6	19.3
01JUL2002	12.0	17.0	1.0	1.0	0.0	1.9	13.5

--------------------------------- FLOW CLASS (CFS)=13 ---------------------------------

Date	SPRINGFLOW (CFS)	PRECEDING DAY FLOW	RUN MIN SALINITY (PPT)	RUN MAX SALINITY (PPT)	SALINITY DIFFERENCE (PPT)	RIVER MAX STAGE (FT. NGVD)	RIVER MAX SALINITY (PPT)
26FEB2001	13.0	3.5	1.8	13.5	11.7	1.6	16.4
05MAR2001	13.0	3.5	1.6	4.0	2.5	1.3	18.3
08MAR2001	13.0	21.0	1.3	2.8	1.5	1.5	20.5
28MAR2001	13.0	14.0	1.0	8.1	7.1	1.7	16.6
15MAY2001	13.0	7.0	1.2	1.3	0.1	1.2	23.7
20JUN2001	13.0	11.0	1.2	1.5	0.3	2.0	16.5
15MAY2002	13.0	7.8	1.0	1.7	0.7	1.7	16.3
16MAY2002	13.0	13.0	1.0	1.5	0.5	2.0	17.2
30MAY2002	13.0	12.0	1.0	12.8	11.7	2.7	20.5
31MAY2002	13.0	13.0	1.0	10.2	9.2	2.5	21.3
03JUN2002	13.0	14.0	0.9	1.0	0.1	1.4	21.4
04JUN2002	13.0	13.0	0.9	1.0	0.0	1.5	22.0
05JUN2002	13.0	13.0	0.9	1.0	0.1	1.8	23.0
06JUN2002	13.0	13.0	0.9	1.1	0.2	2.0	22.6
07JUN2002	13.0	13.0	0.9	3.2	2.3	2.2	22.4
08JUN2002	13.0	13.0	0.9	2.7	1.7	2.1	21.8
09JUN2002	13.0	13.0	0.9	2.5	1.6	2.0	20.2
10JUN2002	13.0	13.0	0.9	10.5	9.5	2.4	19.4
11JUN2002	13.0	13.0	0.9	7.8	6.8	2.3	18.1
12JUN2002	13.0	13.0	0.9	12.6	11.6	2.7	18.7
16JUN2002	13.0	15.0	0.9	1.0	0.1	2.3	20.0
17JUN2002	13.0	13.0	0.9	0.9	0.0	2.2	19.9
25JUN2002	13.0	5.6	1.0	1.0	0.1	2.6	1.9
26JUN2002	13.0	13.0	0.9	1.0	0.1	2.5	3.1
27JUN2002	13.0	13.0	0.9	1.1	0.3	2.2	13.1
02JUL2002	13.0	12.0	1.0	1.0	0.0	1.1	12.7

--------------------------------- FLOW CLASS (CFS)=14 ---------------------------------

Date	SPRINGFLOW (CFS)	PRECEDING DAY FLOW	RUN MIN SALINITY (PPT)	RUN MAX SALINITY (PPT)	SALINITY DIFFERENCE (PPT)	RIVER MAX STAGE (FT. NGVD)	RIVER MAX SALINITY (PPT)
13MAR2000	14.0	2.8	1.8	3.6	1.8	.	16.0
05APR2000	14.0	4.8	1.5	1.7	0.2	.	15.1
03FEB2001	14.0	3.5	1.5	1.6	0.1	0.7	20.3

12FEB2001	**14.0**	**3.5**	**1.7**	**4.6**	**2.9**	**1.1**	**16.1**
19FEB2001	14.0	3.5	1.8	1.8	0.1	1.7	21.6
11MAR2001	**14.0**	**12.0**	**1.4**	**10.4**	**9.0**	**1.6**	**16.9**
27MAR2001	14.0	8.6	1.4	1.6	0.2	1.0	16.4
30MAR2001	**14.0**	**5.1**	**1.1**	**4.0**	**2.9**	**2.4**	**10.8**
12APR2001	14.0	15.0	1.4	1.5	0.1	2.1	16.4
27JUN2001	14.0	12.0	1.2	1.5	0.3	1.3	15.7
16JUL2001	**14.0**	**3.5**	**1.5**	**8.7**	**7.1**	**1.7**	**21.4**

---------------------------------- FLOW CLASS (CFS)=14 ----------------------------------
(continued)

Date	SPRINGFLOW (CFS)	PRECEDING DAY FLOW	RUN MIN SALINITY (PPT)	RUN MAX SALINITY (PPT)	SALINITY DIFFERENCE (PPT)	RIVER MAX STAGE (FT. NGVD)	RIVER MAX SALINITY (PPT)
17MAY2002	14.0	13	1.0	1.2	0.2	2.6	16.3
18MAY2002	14.0	14	1.0	1.1	0.1	2.5	16.1
19MAY2002	14.0	14	1.0	1.0	0.0	2.0	15.3
20MAY2002	14.0	14	1.0	1.0	0.0	0.9	16.7
01JUN2002	14.0	13	1.0	1.2	0.2	1.8	20.6
02JUN2002	14.0	14	0.9	1.0	0.1	1.4	21.1
28JUN2002	14.0	13	0.9	1.0	0.1	2.5	15.9
29JUN2002	14.0	14	1.0	1.0	0.1	1.8	14.5

---------------------------------- FLOW CLASS (CFS)=15 ----------------------------------

Date	SPRINGFLOW (CFS)	PRECEDING DAY FLOW	RUN MIN SALINITY (PPT)	RUN MAX SALINITY (PPT)	SALINITY DIFFERENCE (PPT)	RIVER MAX STAGE (FT. NGVD)	RIVER MAX SALINITY (PPT)
27DEC2000	**15.0**	**26.0**	**1.4**	**10.4**	**9.0**	**1.8**	**21.0**
30DEC2000	**15.0**	**3.5**	**1.7**	**11.9**	**10.2**	**1.4**	**21.9**
13JAN2001	**15.0**	**3.5**	**1.4**	**11.5**	**10.0**	**1.3**	**19.2**
11APR2001	15.0	19.0	1.5	1.6	0.1	2.5	15.8
07JUN2001	15.0	11.0	1.1	1.5	0.3	2.3	11.3
08JUN2001	15.0	15.0	1.0	1.1	0.2	2.0	13.2
09JUN2001	15.0	15.0	1.0	1.0	0.1	2.0	15.1
10JUN2001	15.0	15.0	1.0	1.0	0.0	2.1	16.8
28JUN2001	15.0	14.0	1.1	1.2	0.1	1.3	15.4
09JUL2001	**15.0**	**20.0**	**1.1**	**3.3**	**2.2**	**2.1**	**16.1**
13JUN2002	15.0	13.0	0.9	1.0	0.1	2.8	19.2
15JUN2002	15.0	17.0	0.9	1.0	0.1	2.6	19.5

---------------------------------- FLOW CLASS (CFS)=16 ----------------------------------

Date	SPRINGFLOW (CFS)	PRECEDING DAY FLOW	RUN MIN SALINITY (PPT)	RUN MAX SALINITY (PPT)	SALINITY DIFFERENCE (PPT)	RIVER MAX STAGE (FT. NGVD)	RIVER MAX SALINITY (PPT)
25APR2000	16.0	6.8	1.7	2.1	0.4	.	18.2
23DEC2000	16.0	3.5	1.5	1.6	0.1	0.9	20.4
06JAN2001	**16.0**	**3.5**	**1.6**	**15.8**	**14.2**	**1.6**	**23.3**
29JUN2001	16.0	15.0	0.9	1.1	0.2	1.6	15.0
04MAR2002	16.0	11.0	1.9	1.9	0.0	0.4	9.4
08MAR2002	16.0	12.0	1.7	1.8	0.1	1.1	21.8

------------------------------------ FLOW CLASS (CFS)=17 ------------------------------------

Date	SPRINGFLOW (CFS)	PRECEDING DAY FLOW	RUN MIN SALINITY (PPT)	RUN MAX SALINITY (PPT)	SALINITY DIFFERENCE (PPT)	RIVER MAX STAGE (FT. NGVD)	RIVER MAX SALINITY (PPT)
28MAR2000	17.0	5.8	1.6	1.9	0.3	.	19.0
26APR2000	17.0	16.0	1.4	1.7	0.2	.	19.9
03NOV2000	**17.0**	**12.0**	**1.6**	**13.8**	**12.2**	**1.8**	**22.4**
24APR2001	17.0	12.0	1.4	1.5	0.1	1.9	17.5
29NOV2001	17.0	23.0	2.0	2.0	0.0	2.1	17.2
04DEC2001	17.0	31.0	1.9	2.0	0.0	1.2	13.4
06MAR2002	17.0	25	1.7	1.8	0.1	1.2	15.7
14JUN2002	**17.0**	**15**	**0.9**	**5.1**	**4.1**	**2.9**	**19.2**
30JUN2002	17.0	14	1.0	1.0	0.1	1.4	12.9
03JUL2002	17.0	13	1.0	1.1	0.1	1.3	14.4

------------------------------------ FLOW CLASS (CFS)=18 ------------------------------------

Date	SPRINGFLOW (CFS)	PRECEDING DAY FLOW	RUN MIN SALINITY (PPT)	RUN MAX SALINITY (PPT)	SALINITY DIFFERENCE (PPT)	RIVER MAX STAGE (FT. NGVD)	RIVER MAX SALINITY (PPT)
26MAY1999	18.0	17.0	1.3	1.4	0.1	.	.
27MAY1999	18.0	18.0	1.2	1.3	0.1	.	.
25APR2001	18.0	17.0	1.3	1.4	0.1	1.9	17.4
26APR2001	18.0	18.0	1.2	1.3	0.1	1.3	17.1
27APR2001	18.0	18.0	1.1	1.2	0.1	1.5	17.7
28APR2001	18.0	18.0	1.1	1.1	0.0	2.0	18.0
30JUN2001	18.0	16.0	0.8	1.0	0.2	1.6	13.5
01JUL2001	18.0	18.0	0.9	1.0	0.0	1.8	4.3
07JUL2001	18.0	7.3	1.2	1.3	0.1	2.4	16.2
11DEC2001	18.0	31.0	1.8	1.8	0.0	2.0	16.5
21FEB2002	18.0	26.0	1.7	1.7	0.0	1.9	16.3

------------------------------------ FLOW CLASS (CFS)=19 ------------------------------------

Date	SPRINGFLOW (CFS)	PRECEDING DAY FLOW	RUN MIN SALINITY (PPT)	RUN MAX SALINITY (PPT)	SALINITY DIFFERENCE (PPT)	RIVER MAX STAGE (FT. NGVD)	RIVER MAX SALINITY (PPT)
28MAY1999	19.0	18.0	1.2	1.2	0.0	.	.
29MAY1999	19.0	19.0	1.2	1.2	0.0	.	.
30MAY1999	19.0	19.0	1.1	1.2	0.1	.	.
02JUN1999	19.0	20.0	1.1	1.1	0.0	.	.
03JUN1999	19.0	19.0	1.1	1.2	0.0	.	.
04JUN1999	19.0	19.0	1.1	1.1	0.1	.	.
05JUN1999	19.0	19.0	1.1	1.1	0.0	.	.
06JUN1999	19.0	19.0	1.1	1.1	0.0	.	.
10JUN1999	19.0	5.1	1.1	1.1	0.0	.	.
11JUN1999	19.0	19.0	1.0	1.1	0.1	.	.
12JUN1999	19.0	19.0	1.0	1.0	0.0	.	.
01OCT1999	19.0	36.0	2.3	2.6	0.3	.	12.4
10APR2001	19.0	12.0	1.6	1.6	0.1	1.7	14.6
06DEC2001	19.0	9.8	1.9	1.9	0.0	1.0	16.4
13DEC2001	19.0	12.0	1.8	1.9	0.0	2.3	16.0
30JAN2002	19.0	22.0	2.5	2.9	0.4	2.0	12.6
21MAR2002	19.0	23.0	1.6	1.6	0.0	1.7	14.3

---------------------------------- FLOW CLASS (CFS)=20 ----------------------------------

Date	SPRINGFLOW (CFS)	PRECEDING DAY FLOW	RUN MIN SALINITY (PPT)	RUN MAX SALINITY (PPT)	SALINITY DIFFERENCE (PPT)	RIVER MAX STAGE (FT. NGVD)	RIVER MAX SALINITY (PPT)
01JUN1999	20.0	21.0	1.1	1.1	0.0	.	.
16FEB2000	20.0	27.0	2.0	2.0	0.1	.	18.0
13AUG2000	20.0	8.7	1.3	1.7	0.4	.	6.1
27FEB2001	20.0	13.0	1.7	1.8	0.1	1.2	15.6
06MAR2001	20.0	13.0	1.6	1.6	0.0	1.3	20.4
08JUL2001	20.0	18.0	1.2	1.3	0.1	2.1	16.2