Impacts of Withdrawals on the Thermal Regime of the Weeki Wachee River

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EXECUTIVE SUMMARY

Under Sections 373.042 and 373.0421 of the Florida Statutes, the Southwest Florida Water Management District (SWFWMD) is developing minimum flows and levels (MFL). Under this study, the MFL for Weeki Wachee Springs is being developed in order to protect a critical resource, the West Indian Manatee. Manatee utilize the warm waters of Weeki Wachee Spring run, which maintain temperatures generally above 20°C, as a refuge when offshore waters go below tolerable levels.

In order to evaluate the change in temperature within the Weeki Wachee Spring run, a three-dimensional hydrodynamic model was developed utilizing the Environmental Fluid Dynamics Code (EFDC). The model allowed for the projection of the intrusion of the colder, higher saline waters into the estuarine portions of the Weeki Wachee River under varying freshwater flows from the spring. The model input conditions and calibration data came from continuous and discrete monitoring data collected from 2003 to 2005.

The calibrated model was applied under critical offshore temperature conditions, as well as low flows and high flows from Weeki Wachee Spring. These low flow and high flow scenarios represented baseline conditions upon which reduced flows were applied. Critical condition offshore temperatures were calculated using a relationship developed between offshore temperature and local air temperature. The relationship was applied to measured air temperatures over the last 35 years to define the critical water temperatures. Offshore water level and salinity represented typical time varying conditions.

Utilizing the baseline scenarios, manatee habitat refuge areas and volumes were defined as waters that met the following criteria:

- Daily average temperatures were greater than 20°C over a critical 3-day period
- Passage for manatee was available upstream based upon District defined minimum depths

Utilizing these baseline conditions, incremental flow reductions were applied until the manatee refuge area or volume reduction was greater than 15 percent. The flow reduction corresponding to the 15 percent reduction in manatee refuge volume or surface area represented the maximum allowable flow reduction.

For the Weeki Wachee Spring, it was determined that the most critical period was low offshore temperatures corresponding with low flow from the springs. Under this condition, the maximum flow reduction that corresponded to a 15 percent reduction in manatee habitat area/volume was less than a 5 percent reduction in flow. While the analysis showed that less than a 5 percent flow reduction would be allowed in order to avoid changes in habitat greater than 15 percent, the available manatee refuge is capable of supporting over 1363 manatee, well above the present number that utilize Weeki Wachee Springs.

1.0 INTRODUCTION

1.1 PROJECT OVERVIEW AND OBJECTIVES

The Southwest Florida Water Management District (SWFWMD) is in the process of developing methods and rules for the establishment and implementation of minimum flows and levels (MFL) for priority water bodies within its jurisdiction as directed under Sections 373.042 and 373.0421 of the Florida Statutes. Under Section 373, an MFL is 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.*

Based upon these regulatory requirements, the District recognizes that a critical ecological resource within Florida is the West Indian Manatee. During winter months, manatee utilize warm discharges, such as Weeki Wachee Springs, as thermal refuge from the colder waters of the Gulf of Mexico. The available area, or volume, of water for the manatee to congregate within is dependant upon the rates of flow coming out of the spring and the intrusion of colder denser water beneath the outgoing spring discharge. At higher flows, the springs are able to push incoming colder waters further downstream increasing the area/volume for manatee to take refuge within. Additionally, at higher flows, depths within the spring run increase providing a greater volume of water and allowance for passage upstream over shallow areas. Correspondingly, reduction in flow from the springs reduces the available refuge and may have deleterious impacts upon returning manatee herds.

The goal of this study is to determine the changes in the volume and area of the thermal refuge based upon prescribed reductions in flow from Weeki Wachee Springs. Based upon the flow/area/volume relationships developed, allowable flow reductions were defined in order to assure that no adverse impacts will occur to the West Indian Manatee that utilize the spring run.

1.2 SITE DESCRIPTION

Weeki Wachee Springs, located in the Town of Weeki Wachee in Hernando County, Florida, is a first magnitude spring with a mean annual discharge of approximately 167 cfs (period 1967 to 2005). Figure 1-1 shows the location in relation to the State of Florida and the Gulf

Figure 1-1
Location Map

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of Mexico. Weeki Wachee Spring, and Twin Dees Spring, provide the source water to the Weeki Wachee River, which flows for a distance of approximately 6.8 miles (11 km) from its headwaters down to a confluence with the Mud River approximately 1 mile (1.4 km) from the Gulf of Mexico (Figure 1-2). The Twin Dees spring provides an average of 17 cfs of flow to the Weeki Wachee River. The Weeki Wachee main spring and the Twin Dees spring are both near the headwaters within one-half mile of one another.

The Mud River is a shallow tidal creek that extends inland approximately 1.5 miles (2.4 km) from its confluence with the Weeki Wachee. The Mud River receives a minimal amount of inflow at its headwaters from the Mud River spring and the Salt spring. The water flowing from Mud River spring and Salt spring is relatively salty with bottom median salinities near 16 ppt for the period 1985 to 2005. The salinity levels then drop moving toward the confluence with the Weeki Wachee River. The average flow rate from Mud River spring is 45 cfs. Figure 1-2 shows the Weeki Wachee River in relation to the Mud River and the Gulf of Mexico along with the locations of the spring discharges.

1.3 REPORT OUTLINE

This report presents the results of all tasks completed under this study. The remainder of the report is broken down into six sections these are:

- Section 2: Methodologies
- Section 3: Ambient Conditions Overview
- Section 4: Model Development and Calibration
- Section 5: Critical Conditions Determination
- Section 6: Minimum Flow Determination for Manatee Habitat Protection
- Section 7: Summary and Conclusions

Section 2 summarizes the methodologies utilized in the development of the minimum flows. This includes an overview of the manatee protection issues, criteria for manatee protection, modeling approach, critical conditions determination, and the development of the minimum flows.

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Figure 1-2

Site Map
Weeki Wachee and Mud River System

Section 3 presents the baseline geometric, hydrodynamic, thermal, and salinity conditions within the Weeki Wachee River, Mud River, and offshore waters. Additionally, the local meteorological conditions are summarized which influence temperatures within the system. The baseline conditions come from available historic data, as well as data collected for this study.

Section 4 presents the development of the hydrodynamic model for the system including development of input conditions, simulation periods, and model calibration.

Section 5 summarizes the critical conditions utilized within the model to determine the minimum flows.

Section 6 presents the analyses of the model data to determine allowable minimum flows from the spring for protection of the manatee thermal refuge.

Section 7 presents a summary of the findings of the study, including recommendations on the allowable flow reductions.

2.0 METHODOLOGY

2.1 GENERAL OVERVIEW OF MANATEE PROTECTION ISSUES

The Florida Fish and Wildlife Conservation Commission has performed a statewide aerial survey for manatee counts every year since 1991. Based on the data from these surveys, the Florida manatee population has increased more or less steadily since 1991, going from 1,267 in 1991, to 1,823 in 1995, to 2,223 in 2000, and to 3,116 in 2006. This growth in population has created a need for preservation of thermal refuges where manatee can congregate during the colder winter months.

During the colder winter months in Florida, when temperatures drop below 66°F to 68°F (19°C to 20°C), manatee seek refuge in warmer waters such as those which flow from Weeki Wachee Springs. Typically, spring flow temperatures remain at a near constant temperature of 73°F (23°C). The period of time when this occurs is termed the “manatee season”; this period extends from November through March.

For the Weeki Wachee River, the cooler water enters the spring run at its confluence with the Mud River (Figure 1-2). The lower portion of the Weeki Wachee River, below the spring run, is tidally connected to the Gulf of Mexico; the water within this portion of the river is brackish to saline. The cooler, higher saline waters from the Gulf of Mexico are denser than the spring water due to lower temperature and salt content. This denser water moves up the Weeki Wachee below the fresher/warmer spring discharge. The degree to which the cooler water moves up into the Weeki Wachee spring run is dependant upon the offshore water levels, the temperature/salinity of the incoming waters, and the rate of flow coming out of the spring. When offshore water levels are high, water temperatures are low, and the flow rates from the spring are down, the cooler water will move further into the spring run and reduce the area available for manatee to seek refuge.

Manatees tend to congregate just above the interface of the cooler and warmer waters, and move upstream as cooler waters intrude further into the system. The amount of refuge available is a function of the accessible volume of water above the interface. In a report developed for Blue Springs (SJRWMD, 2006), evaluations were made on the carrying capacity of the spring run. The carrying capacity was calculated from manatee count data gathered by Blue Springs State Park rangers, and the results evaluated against overall surface area and spring run length. The analyses were based upon 924 surveys conducted from 1981 through 2000. The analyses provided densities of manatee on a per-square-foot of surface water area within the suitable habitat upstream of the cold water/warm water interface. For the coldest days, a mean density of 0.007 manatee/ft^2 was calculated. For the highest usage days, a mean density of 0.012 manatee/ft^2 was calculated. These data provide the means for defining a "standard" manatee based upon real data, and allow for determination of the potential carrying capacity of Weeki Wachee spring run.

The determination of accessible is based upon typical manatee dimensions. Based upon discussions with District Staff, where depths drop below 3.8 feet (1.2 m), these areas are not deemed "accessible" and if tidal fluctuations do not bring the depths up high enough for Manatee to pass through, the areas above would not be considered part of the available thermal refuge. This assumption is supported by results of the Blue Springs surveys that showed average depths for congregation and gave depths of greater than 3 feet as the most prevalent. Surveys of the Weeki Wachee spring and run identified some shallow areas that could limit passage. The only specific shallow location identified in this survey was below the mouth of the spring pool (USMMC, 2006).

2.2 CRITERIA FOR MANATEE PROTECTION

Based upon the discussions within the previous sections, the SWFWMD has defined criteria to be used in the determination of allowable impacts to the thermal refuge within the Weeki Wachee River. The criteria are based upon a loss of accessible refuge surface area, where refuge area is defined as that with at least a 3.8 foot depth for manatee to congregate within. The allowable loss in refuge area has been defined as 15 percent based upon previous District evaluations of acceptable habitat loss for MFL development (SWFWMD, 2006; 2004; 2002; nd).

Table 2-1 presents allowable thermal refuge surface area losses for both an acute and a chronic condition. The acute condition is based upon manatee physiology and the animals ability to withstand temperatures below 59°F (15°C) for a period of not more than 4 hours. The chronic condition is based upon the animal's ability to withstand temperatures below 68°F (20°C) for a period of not more than 3 days (SJRWMD, 2006).

Table 2-1. Thermal Criteria for Manatee used in Weeki Wachee

Under critical conditions and relative to baseline[1] conditions, no more than:
• 15% <u>loss</u> in total volume $\geq 20^oC$
  o at a minimum depth of 3.8 feet at mean low tide
  o with a minimum 3.8 foot depth access at mean high tide
  o for a critically cold event lasting 3 days.
 	
• 15% <u>loss</u> in total area $\geq 20^oC$
  o at a minimum depth of 3.8 feet at mean high tide
  o with a minimum 3.8 foot depth access at mean high tide
  o for a critically cold event lasting 3 days.
 	
• 15% <u>increase</u> in total volume $\leq 15^oC$
  o at a minimum depth of 3.8 feet at mean low tide
  o with minimum 3.8 foot depth access at mean high tide
  o and persisting more than 4 hours.
 	
• 15% <u>increase</u> in total area $\leq 15^oC$
  o at a minimum depth of 3.8 feet at mean high tide
  o with minimum 3.8 foot depth access at mean high tide
  o and persisting more than 4 hours.

[1] Baseline conditions are defined as critical temperature regime in the absence of withdrawals.

2.3 HYDRODYNAMIC AND THERMAL MODELING

In order to develop projections of the change in the temperature conditions within the Weeki Wachee River it was necessary to simulate the dynamic response of the cold water intrusion under varying discharge rates from the spring. Analyses of the data showed that the thermal refuge area extended down to the confluence with the Mud River. The data showed that the degree of intrusion of colder water into the thermal refuge zone was controlled by the hydrodynamic and thermal conditions within the Lower Weeki Wachee and the Mud River. Further examination of the data showed that at times there was some degree of density stratification within the Mud River and the lower portions of the Weeki Wachee spring run. This stratification was caused by a combination of salinity and cold-water intrusion. Finally, a key controlling factor in the temperature distribution of the estuarine portion of the Weeki Wachee River was the variation in temperature within the Gulf of Mexico. In order to provide an adequate boundary condition, the model needed to be capable of accurately representing a tidally driven, time varying boundary condition that extended into the Gulf of Mexico.

Based upon the baseline hydrodynamic and thermal conditions in the system, it was necessary to utilize a 3-dimensional hydrodynamic and thermal model. For this study, the Environmental Fluid Dynamics Code (EFDC) was chosen. EFDC is a general purpose modeling package for simulating one, two or three-dimensional flow, transport and biogeochemical process in surface water systems including: rivers, lakes, estuaries, reservoirs, wetlands and near shore to shelf scale coastal regions. The EFDC model was originally developed at the Virginia Institute of Marine Science for estuarine and coastal applications and is considered public domain software. The model is presently supported and distributed by EPA Region IV.

EFDC solves finite-differenced forms of the hydrostatic Navier-Stokes equations, together with a continuity equation, and transport equations for salt, temperature, turbulent kinetic energy and turbulent macroscale (Hamrick, 1992a; 1992b). The equations are solved horizontally on a curvilinear, orthogonal grid, and vertically on a stretched sigma-grid. Vertical diffusion coefficients for momentum, mass, and temperature are determined by the level 2.5 turbulent closure scheme of Mellor and Yamada (1982) and Galperin et al. (1988).

In addition to its ability to simulate the key physics within the system, EFDC was chosen for use on this project based upon the following additional criteria:

- EFDC is a public domain model presently supported and distributed by EPA for use in estuarine and riverine environments.
- EFDC runs within the Windows XP environment and has pre- and post-processors for data processing and viewing. This provides for simple porting to SWFWMD personnel.
- EFDC has been successfully applied on a similar study for a thermal refuge at Blue Springs off the St. Johns River (SJRWMD, 2006).

2.4 CRITICAL CONDITIONS DETERMINATION

In order to provide adequate protection to the manatee refuge within the Weeki Wachee River, it is necessary to determine the allowable flow reductions under critical conditions, i.e., conditions where reductions in the thermal refuge would be greatest. Critical conditions for this study focused on development of long-term offshore water temperatures using air-temperature data from 1970 through 2006. The offshore temperature data were matched with typical water level fluctuations within the Gulf of Mexico, and critical seasonal flows from the springs. Section 5 provides a detailed discussion of the development of the critical conditions.

2.5 MINIMUM FLOW DETERMINATION FOR MANATEE PROTECTION

Utilizing the EFDC model, along with the critical conditions identified above, simulations of the flows, water levels, temperatures, and salinities were run under varying spring discharge rates. Baseline spring discharge conditions, which represented both a high flow and low flow period from the spring, were established and simulated in the model under the critical offshore temperatures and tides. The simulation was conducted over a complete manatee season, and the model output analyzed to provide the spatial distribution of the daily average temperature conditions. From this output, the temporal variation in the manatee refuge areas and volumes were determined as that volume/area of water that meets the criteria outlined in Section 2.2. Once these baseline conditions were established, the flows were incrementally reduced until the net change in manatee refuge volume or surface area (i.e. that area under which manatee can congregate) reaches 15 percent. This point defines the maximum flow reduction.

3.0 AMBIENT CONDITIONS OVERVIEW

Data for the Weeki Wachee and Mud River, utilized in this study, came from various sources. This included existing data gathered under ongoing and past programs, as well as data gathered under a monitoring program implemented as part of this study.

Appendix A presents tables showing the available data considered for this study. Within Appendix A, three tables are shown. The first lists data sources that were utilized for boundary and model input conditions. The second table lists sources that were utilized for instream data for model comparison purposes. The final table simply lists other data sources, some of which were directly utilized, and some that were not. For each data source the type of data, period of record, location, and frequency are listed.

Appendix B presents a report outlining data that were collected directly as part of this study to supplement available existing data. These data included:

- ADCP measurements of flow at various cross-sections within the estuarine and spring run portions of the Weeki Wachee River,
- water surface elevation data collected in conjunction with the ADCP flow measurements,
- salinity and temperature data,
- reconnaissance data and photos collected to characterize the system, and to help in the definition of shading for the thermal modeling.

These data were gathered over a 3-day period in March of 2006. The primary goal of the data collection was to quantify the tidal prism entering the estuarine portion of the Weeki Wachee River to assure that the hydrodynamic model is moving sufficient volumes of saline water into and out of the system.

The following presents discussions of the data to characterize the range and variation of the ambient conditions within the Weeki Wachee River, the Mud River, and the nearshore zone.

3.1 PHYSICAL CONDITIONS (GEOMETRY AND BATHYMETRY)

Figures 3-1a and 3-1b present plan views of the Weeki Wachee River, the Mud River and the immediate nearshore areas. These figures also provide the locations where continuous and discrete data were gathered. The Weeki Wachee River overall is relatively narrow and shallow. Figure 3-2 provides a longitudinal plot of the centerline depths moving upstream along the Weeki Wachee River, the depths are relative to the national geodetic vertical datum of 1929 (NGVD).

Weeki Wachee Spring and Twin Dees Spring provide the source water to the Weeki Wachee River, which flows for a distance of approximately 6.6 miles (10.6 km) from its headwaters down to a confluence with the Mud River approximately 1 mile (1.4 km) from the Gulf of Mexico.

The Mud River is a shallow tidal creek that extends inland from its confluence with the Weeki Wachee River approximately 1.5 miles (2.4 km). Depths within the estuarine portion of the Weeki Wachee River and the Mud River range from less than 1 foot (0.3 m) to 10 feet (3 m), with the system becoming shallower moving upstream to the headwaters of the Mud River.

3.2 SPRING DISCHARGE

Figure 3-3 presents the historic mean, minimum, and maximum flows for Weeki Wachee and Twin Dees springs from 1967 through 2005. Examination of the data shows that flows historically have ranged from as high as 250 cfs down to a minimum near 85 cfs. Yearly differences in flows were generally on the order of 50 to 75 cfs with the highest flows typically in September and October, and the lowest flows typically in June.

Figure 3-4 presents box and whisker plots of the monthly flows providing the median (center of box), the 25th and 75th percentiles (box edges) and the 10th and 90th percentiles (lines). During the critical winter months, flows are generally not at their lowest, but they do show a general trend of decrease from October through April. This means that during the Manatee Season, the flows are not at their lowest, but generally near mean conditions, and decrease as the offshore waters get colder.

Figure 3-1a
U.S.G.S. Continuous Monitoring Stations
Weeki Wachee and Mud River System

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Figure 3-1b
SWFWMD Monthly Sampling Stations
Weeki Wachee and Mud River System

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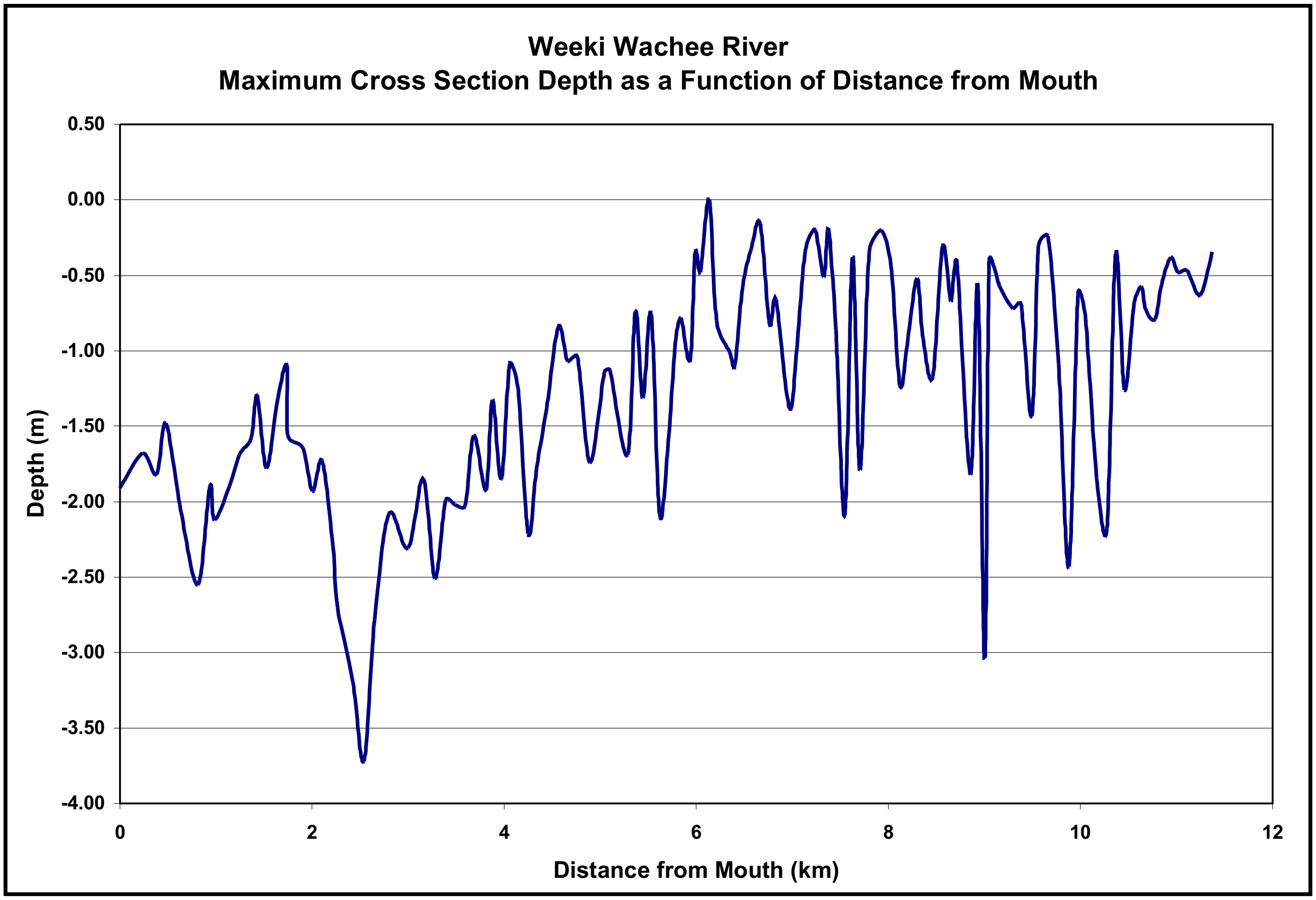

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Figure 3-2
Centerline Longitudinal Bathymetry for Weeki Wachee River

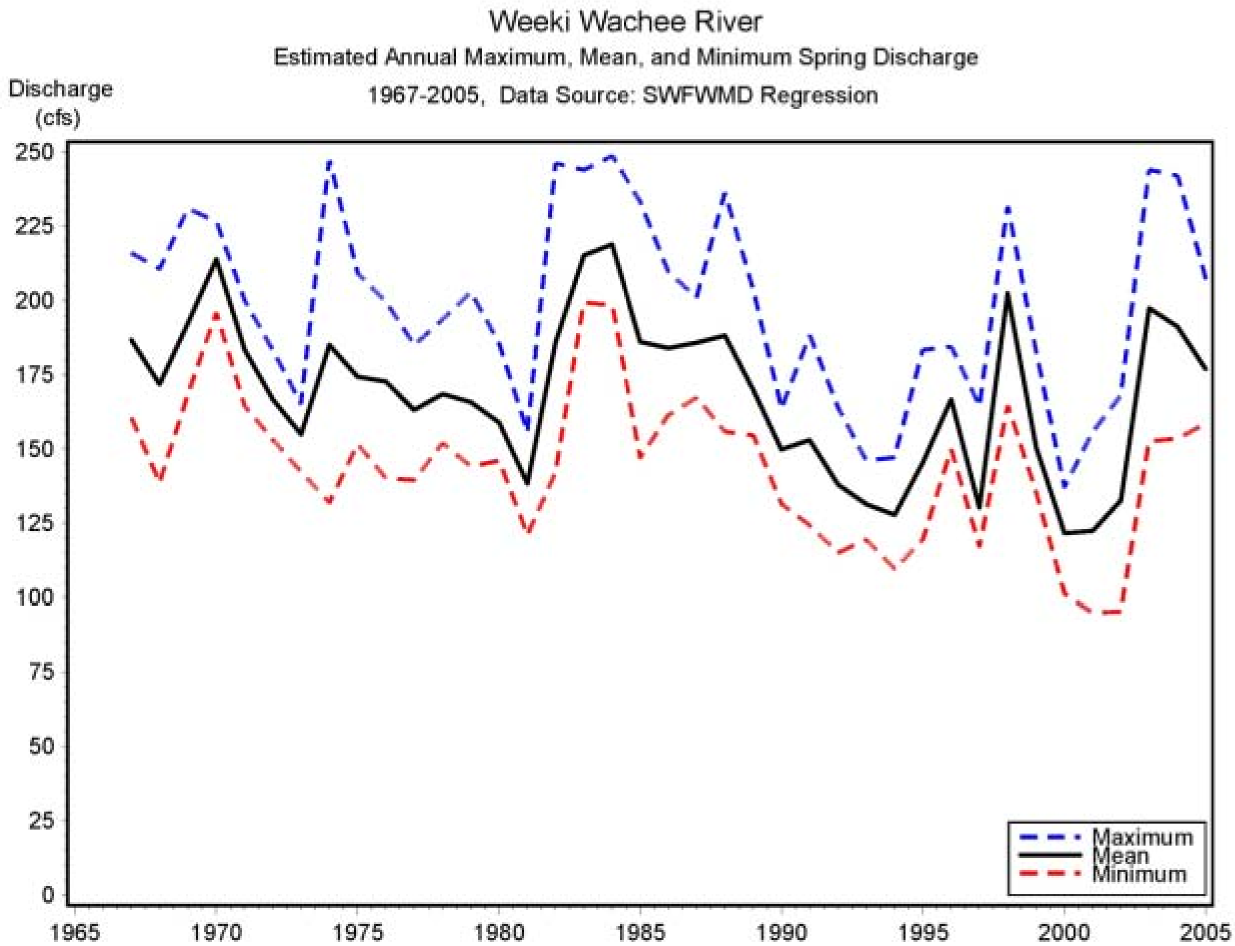

Figure 3-3
Historic Mean, Minimum, and Maximum Flows For
Weeki Wachee and Twin Dees Springs, 1967-2005

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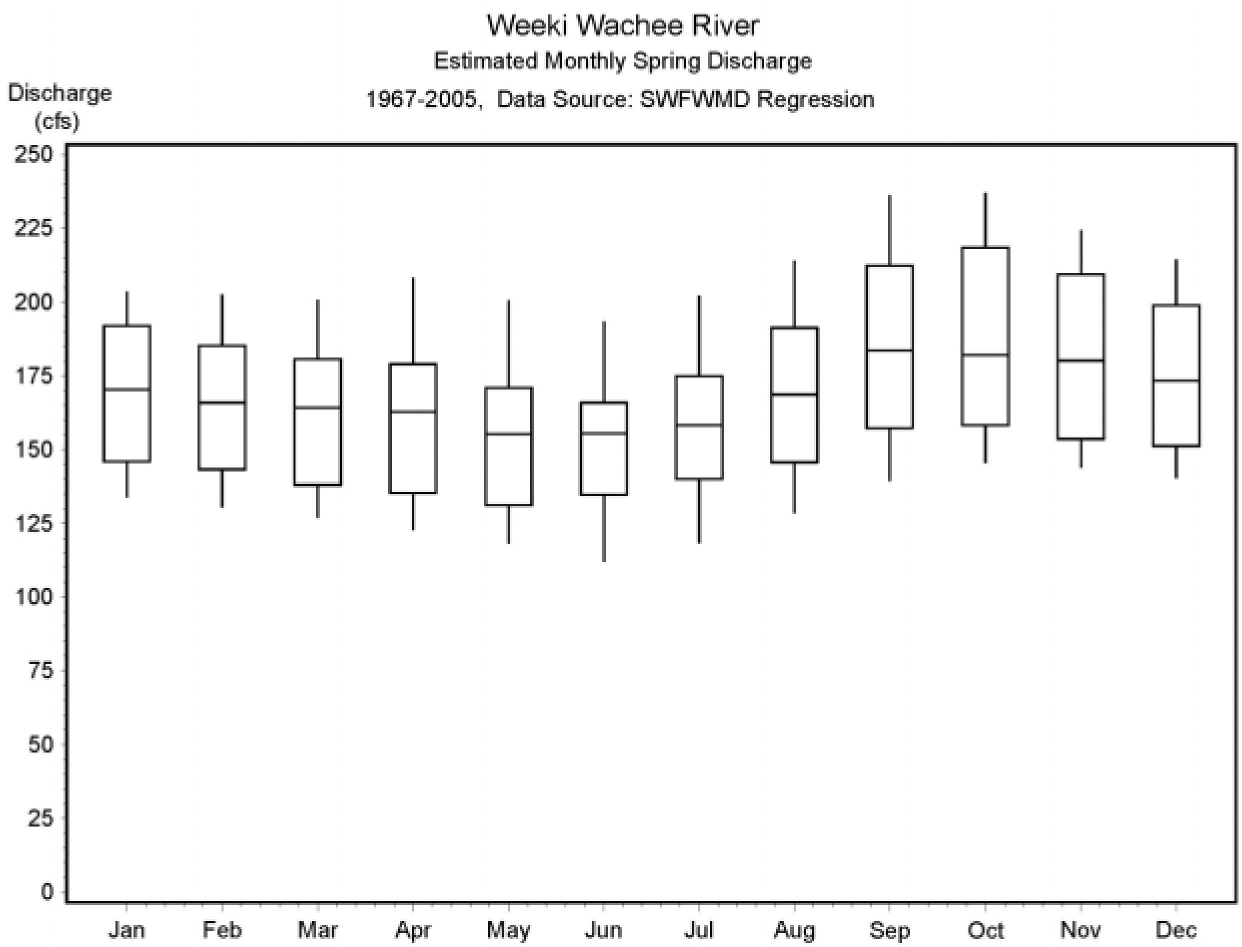

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Figure 3-4
Monthly Discharges from Weeki Wachee and Twin Dees Springs, 1967-2005

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3.3 OFFSHORE WATER LEVELS, SALINITY, AND WATER TEMPERATURE

The water levels within the Weeki Wachee River and the Mud River are primarily driven by the tidal fluctuations within the Gulf of Mexico. Given the unique nature of the Gulf of Mexico tides, these fluctuations vary from diurnal (single daily high and low) to semi-diurnal (two daily highs and lows). Additionally, superimposed upon the daily fluctuations are long-term fluctuations in the mean water level. Figure 3-5 presents the maximum, minimum, and mean daily water levels for the year 2003 at the gage near the confluence with the Gulf of Mexico (Bayport). This gage is located at river mile 0.11 (0.2 km). The data show a large variation in the highs and lows with a typical seasonal pattern, i.e. greater fluctuations in the winter along with an overall lower mean water level. Table 3-1 presents statistics showing the lowest water levels measured during the 2003-2005 time period (-2.0 feet (-0.6 m), NGVD) and the highest (4.9 feet (1.5 m), NGVD).

Figure 3-6 presents the annual average daily maximum and minimum water levels. The data show that in general the water level ranges and fluctuations remain relatively constant from year to year, i.e. within 0.3 feet (0.1 m).

One factor that can influence the intrusion of colder water into the Weeki Wachee spring run is salinity. Higher saline waters will move upstream due to density currents that push the higher density saline waters into the system underneath the lower density freshwater. This is exacerbated when the offshore saline waters are cooler than the upstream freshwater, increasing the density difference and therefore the degree of intrusion. Figure 3-7 presents a plot of the mean, maximum, and minimum salinities at the Bayport station for the years 2003 to 2005. The results show that at the mouth of the Weeki Wachee River salinity levels vary widely. Table 3-1 presents percentile statistics for the measured salinity at Bayport. The salinities range from as low as 1.2 ppt to as high as 24.9 ppt. Examination of the plots of the 2003 to 2005 salinity statistics shows that the salinities measured at Bayport were generally higher during the winter months, both on a mean and maximum basis.

Time series of temperatures to quantify the offshore conditions were available from two locations. The first was from the Bayport gage at the mouth of the Weeki Wachee River, the second was at Aripeka, which is approximately 10 kilometers south of Bayport. Figure 3-8 presents plots of the temperature from both stations for 2003 to 2005. Table 3-1 provides

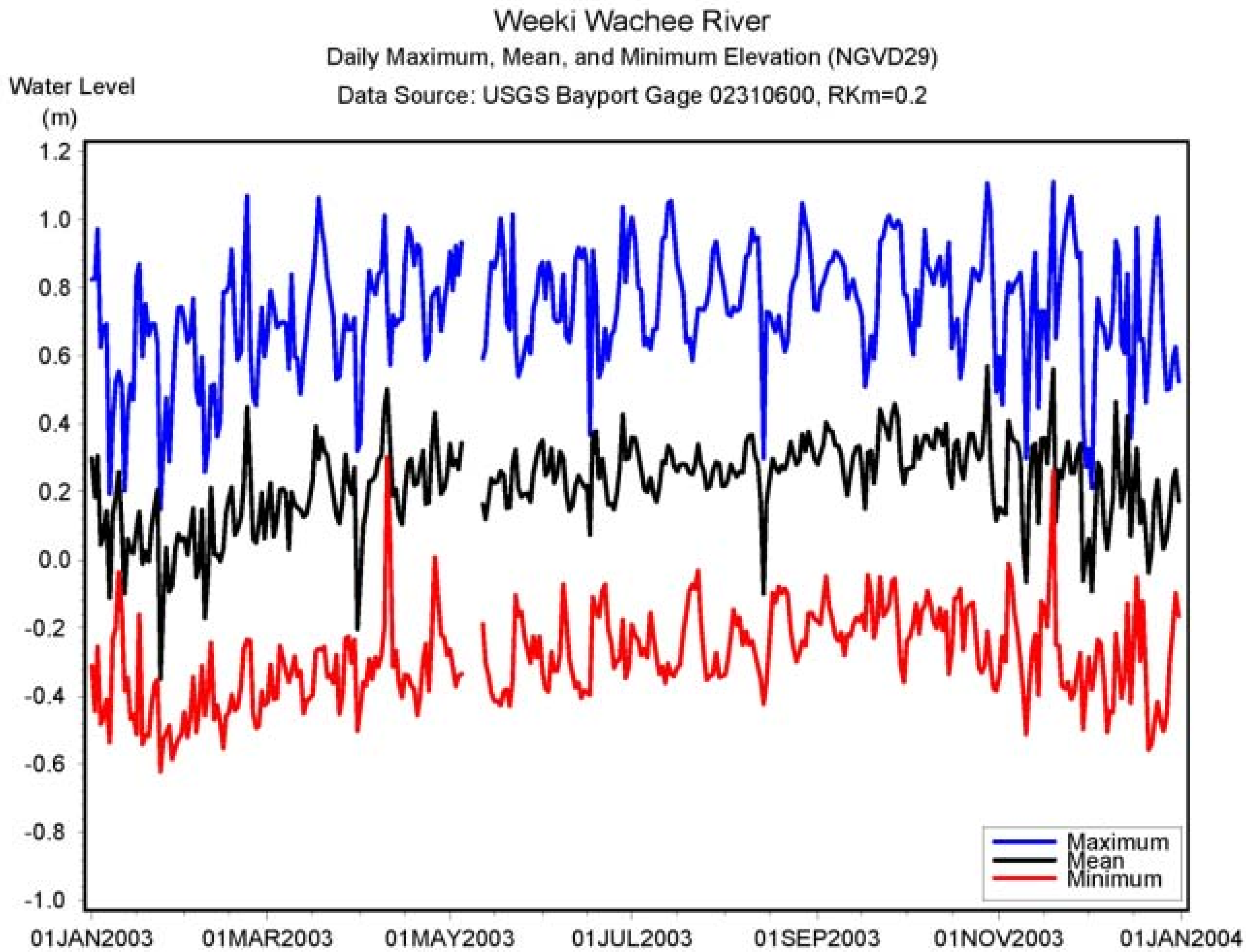

Figure 3-5
Daily Maximum, Mean, and Minimum Water Level
Measured at Bayport for 2003

Table 3-1. Water Level, Salinity, and Water Temperature Distributions at Bayport, and Water Temperature Distribution at Aripeka.

Percentile	Water Level 15-Minute 2003-2005 (m NGVD 29)	Salinity 15-Minute 2003-2005 (ppt)	Bayport Daily Mean Temperature 2003-2005 (°C)	Aripeka Daily Mean Temperature 2002-2005 (°C)
100th	1.524	24.9	32.7	32.7
99th	0.917	20.3	31.5	31.9
95th	0.747	17.2	30.3	30.9
90th	0.643	15.1	29.5	30.3
75th	0.451	11.6	27.9	28.9
50th	0.219	7.3	25.1	25.8
25th	-0.024	5.0	20.9	20.6
10th	-0.222	3.9	17.8	17.4
5th	-0.317	3.4	16.5	16.1
1st	-0.457	2.5	14.2	14.0
0th	-0.628	1.2	10.1	12.6

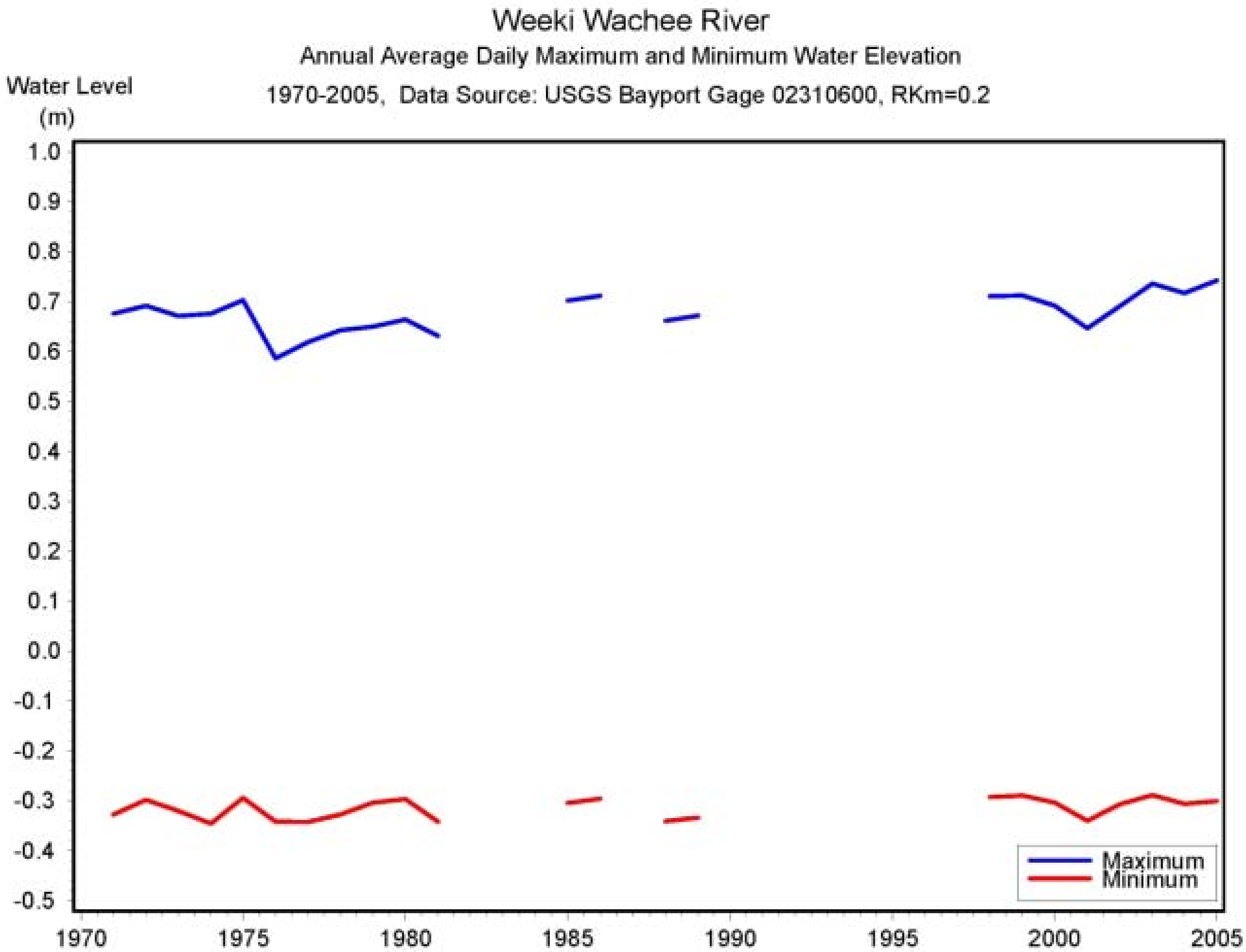

Figure 3-6
Annual Average Daily Maximum and Minimum Water Levels at Bayport, 1970-2005

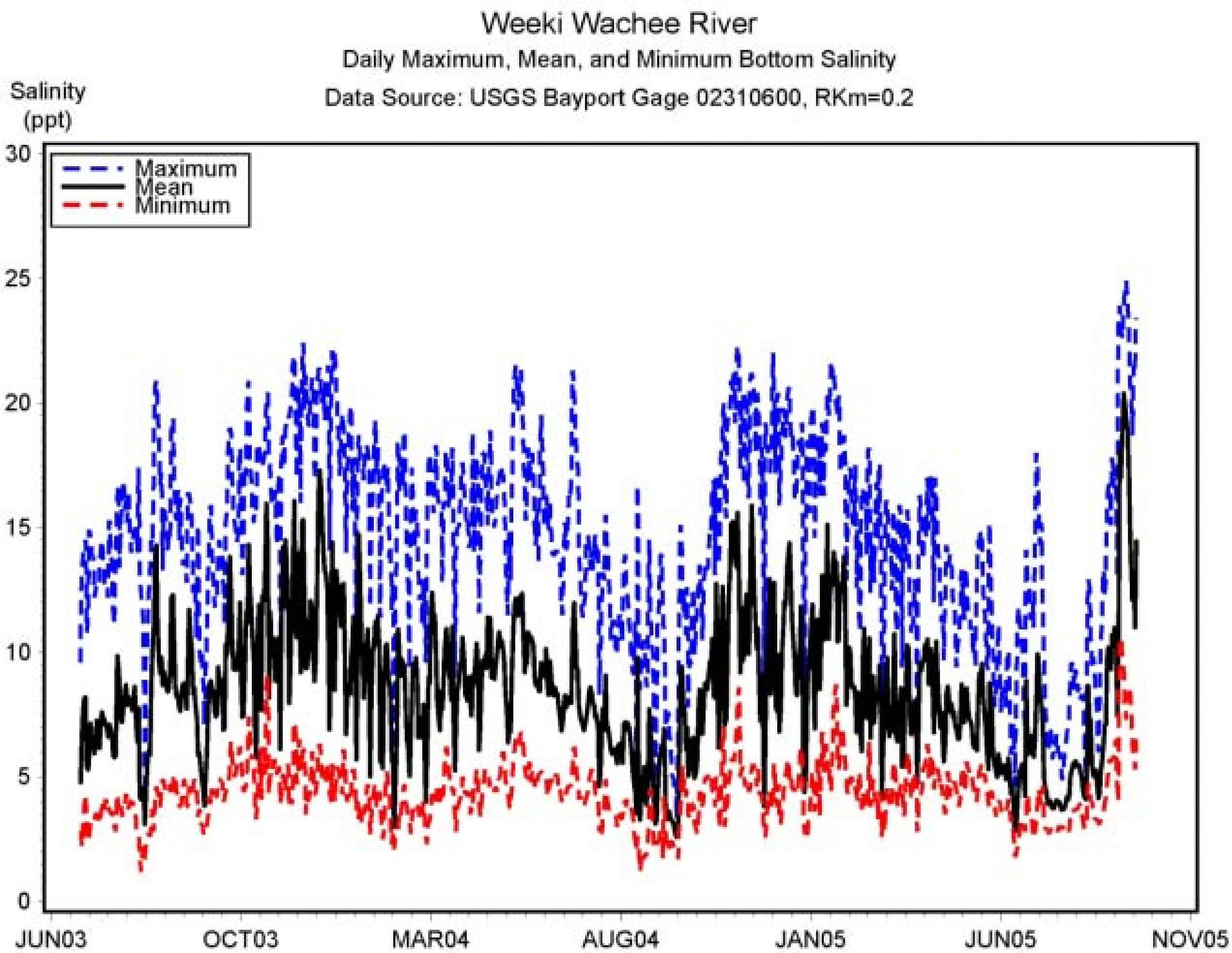

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Figure 3-7
Daily Maximum, Mean, and Minimum Bottom Salinity Measured at Bayport, June 2003- October 2005

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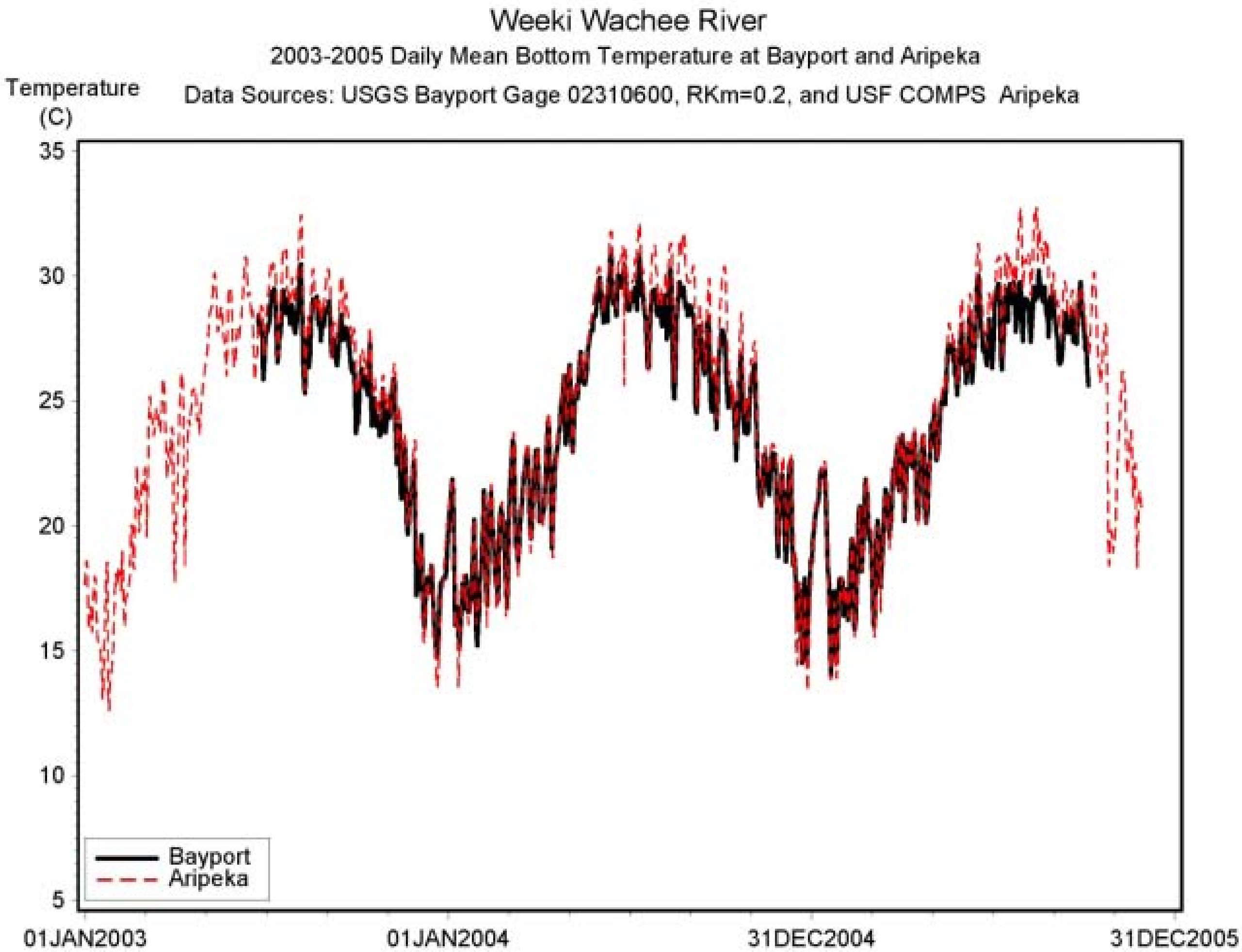

05-1186 Fig 3-8.CDR 08/24/07

Figure 3-8
Daily Mean Bottom Water Temperature at Bayport and Aripeka, 2003-2005

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the percentile statistics. The data show that daily mean water temperatures at both stations are very similar. The ranges for both stations go from lows near 10 to 13 °C to highs near 32°C. The two winter low periods occurred between December and February with both sites showing two significant low periods that lasted approximately 2 to 4 days.

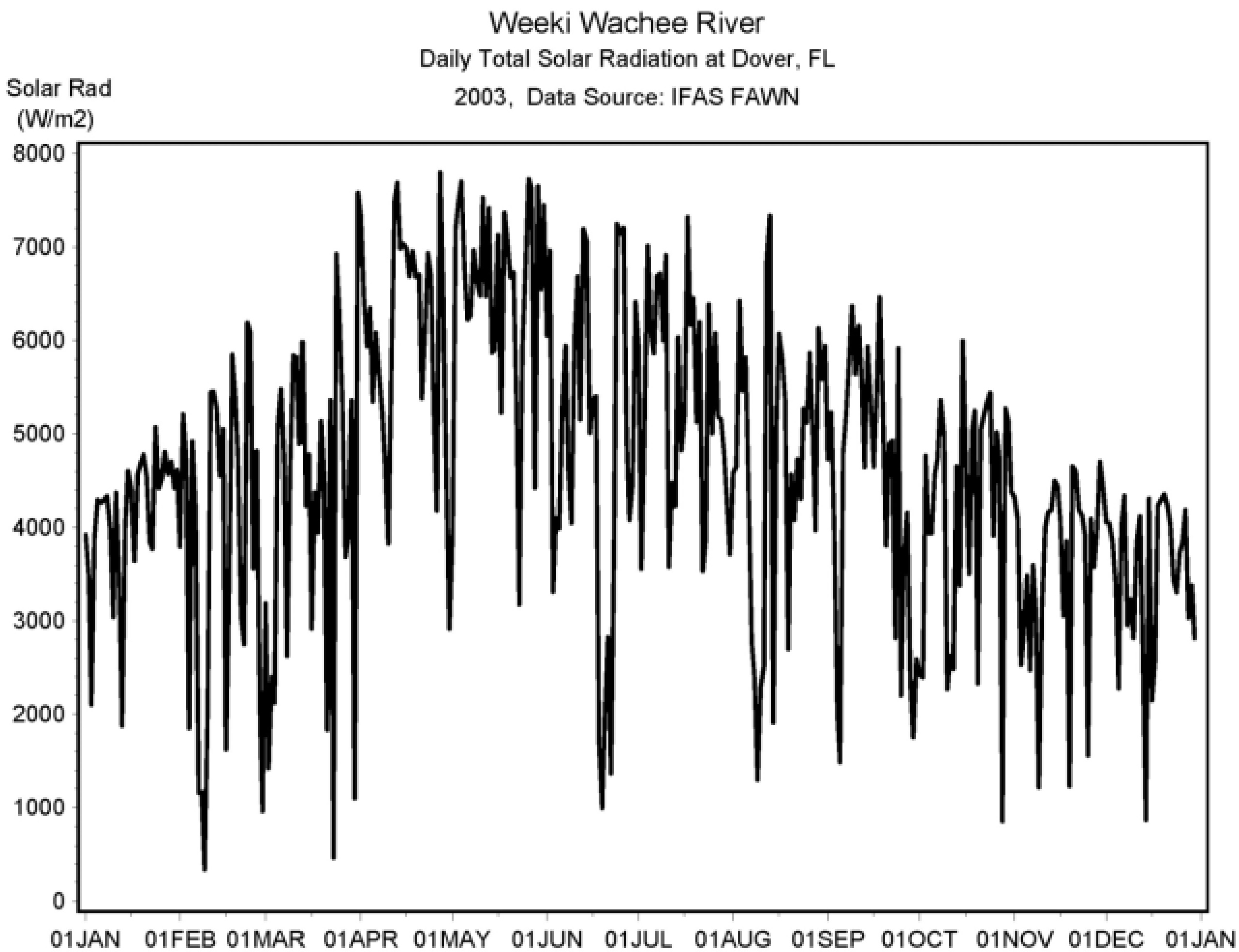
3.4 METEOROLOGY

Meteorological data for this project were obtained from a variety of sources. Air temperature and rainfall were taken from a local station near Weeki Wachee (NOAA NCDC 089430). The air temperature and rainfall data covered 1970 to 2005. Wind speed was obtained from a station at Homosassa; these data were measured from 1999 to 2004 (USF COMPS Program – HOM). Dewpoint temperature, atmospheric pressure, and cloud cover were obtained from Tampa International Airport. These data were measured from 1997 to the present. Finally, solar radiation data were obtained from Dover, FL. These data were measured from 2000 to 2005 (FAWN Program - DOVF1). Figure 3-9 presents a time series of daily solar radiation as measured at the Dover station in 2003.

Tables 3-2 and 3-3 provide statistical evaluations of the data described above. The data show the range of conditions experienced at the site. Of particular interest is the air temperature data, which shows temperatures as low as -3.3°C. This provides the critical conditions during the cold winter months when the air temperature brings the local water temperature below tolerable levels for manatee.

3.5 WATER LEVEL, TEMPERATURE, AND SALINITY CONDITIONS WITHIN THE WEEKI WACHEE SPRING RUN

Figure 3-1a provided the locations of the continuous water level, salinity, and temperature measurements within the Weeki Wachee spring run. Within the Weeki Wachee spring run (above the confluence with the Mud River) there were three stations that measured continuous water levels. These gages were located at river mile [1.4 miles (2.3 km), 2.3 miles (3.6 km), and 4.5 miles (7.3 km)]. Additionally, the station 1.4 miles (2.3 km) upstream collected continuous salinity and temperature.



05-1186 3-9.CDR 02/15/07

Figure 3-9
Daily Total Solar Radiation at Dover, Florida, 2003

Table 3-2. Meteorological Data Statistics

Percentile	Homosassa Wind Speed Hourly 1999-2004 (m/s)	Weeki Wachee Daily Air Temperature 1970-2005 (°C)	TIA Daily Dewpoint Temperature 1997-2005 (°C)	TIA Daily Atmospheric Pressure 1997-2005 (mbar)	Weeki Wachee Daily Rainfall 1970-1005 (in)
100th	36.1	31.1	30.0	1036	12.0
99th	11.7	29.4	25.6	1028	2.3
95th	9.0	28.3	24.4	1024	1.0
90th	7.8	27.8	23.9	1022	0.5
75th	5.9	26.7	22.8	1020	0
50th	4.5	22.8	19.4	1017	0
25th	3.2	17.8	14.4	1014	0
10th	2.1	12.8	8.3	1012	0
5th	1.5	9.4	5.0	1010	0
1st	0	5.0	-1.1	1007	0
0th	0	-3.3	-9.4	980	0

Table 3-3. Solar Radiation and Cloud Cover Statistics

Percentile	Dover Solar Radiation Daily 2000-2005 (W/m^2)	TIA Cloud Cover Daily 1997-2005 (%)
100th	10735	100
99th	7900	100
95th	7449	75
90th	6984	75
75th	6070	44
50th	4755	13
25th	3683	13
10th	2440	0
5th	1630	0
1st	676	0
0th	225	0

In addition to the continuous measurements, monthly temperature and salinity measurements were collected at various stations along the Weeki Wachee and Mud Rivers. Figure 3-1b provided the locations of the discrete samples collected by the SWFWMD on a monthly basis during the years 2003 to 2005.

Figures 3-10 through 3-12 present the plots of the mean, minimum and maximum daily water surface elevations in the year 2004. The data show that tidal fluctuations occur within the Weeki Wachee spring run well upstream of the confluence with the Mud River. The fluctuations are damped moving upstream. By Station USGS 02310530, the tidal fluctuations are nearly completely damped. This corresponds to the location where the centerline elevations (shown in Figure 3-2) are highest.

Figures 3-13 and 3-14 present the measured daily mean, maximum, and minimum surface and bottom salinities and temperatures respectfully at USGS 02310551. This station is located approximately at river mile 1.4 (2.3 km). Examination of the data shows that salinity conditions range from 0 ppt up to over 20 ppt. In general, the highest salinity conditions occur for short time periods corresponding with high tide. The significant difference between the salinity means and the maximums demonstrates this.

Figure 3-15 presents representative longitudinal salinities and temperatures from the discrete sampling. In January of 2005, the discrete sampling measured an intrusion of cold water. The vertically averaged salinity and temperature for this discrete sampling are plotted versus the stations presented in Figure 3-1b. The data show the distinct break between the intrusion of colder water at the confluence of the Mud River and the Weeki Wachee spring run, with the higher saline/low temperature water.

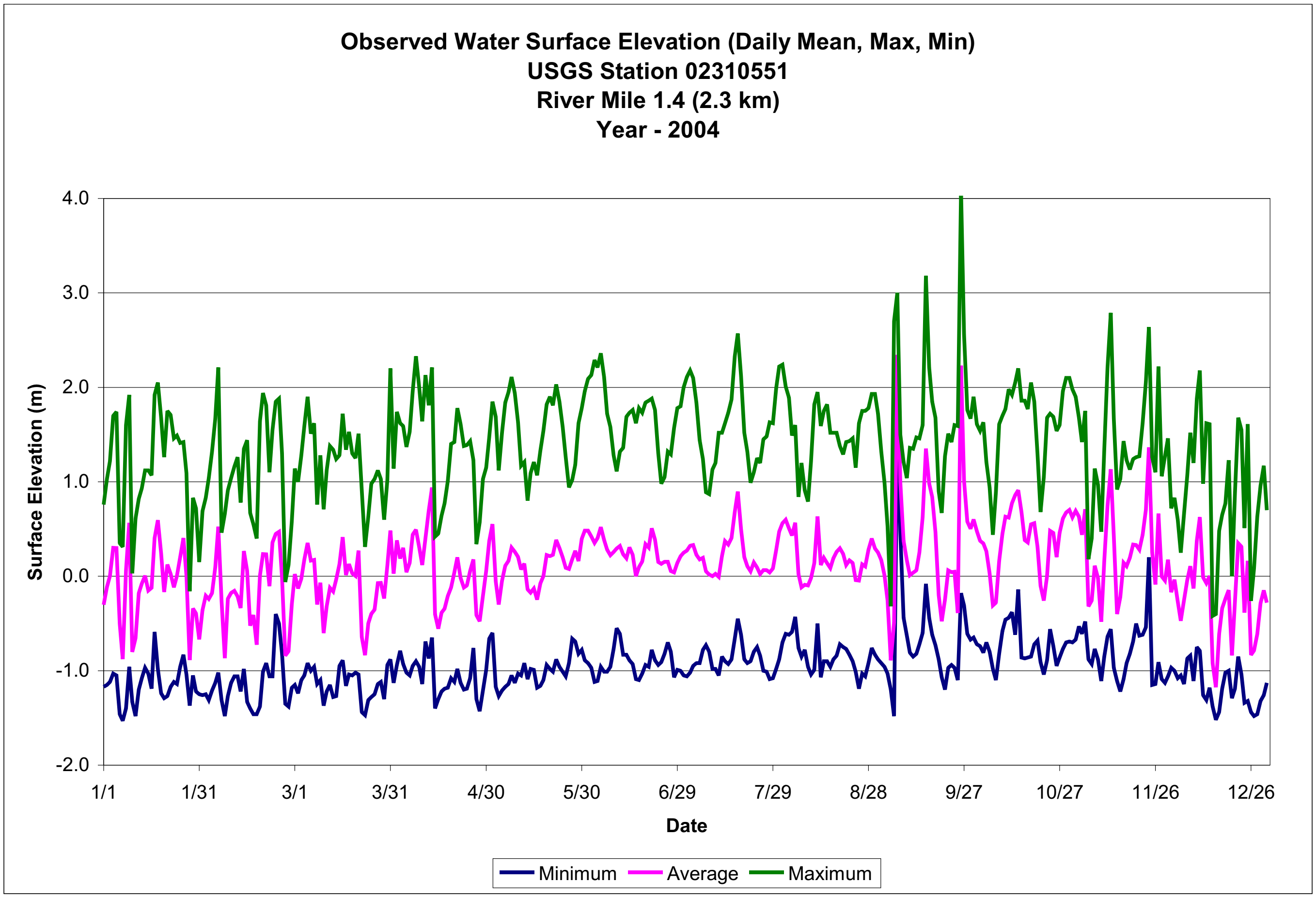


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Figure 3-10
Daily Maximum, Mean, and Minimum Water Level Measured at USGS 20310551 for 2004

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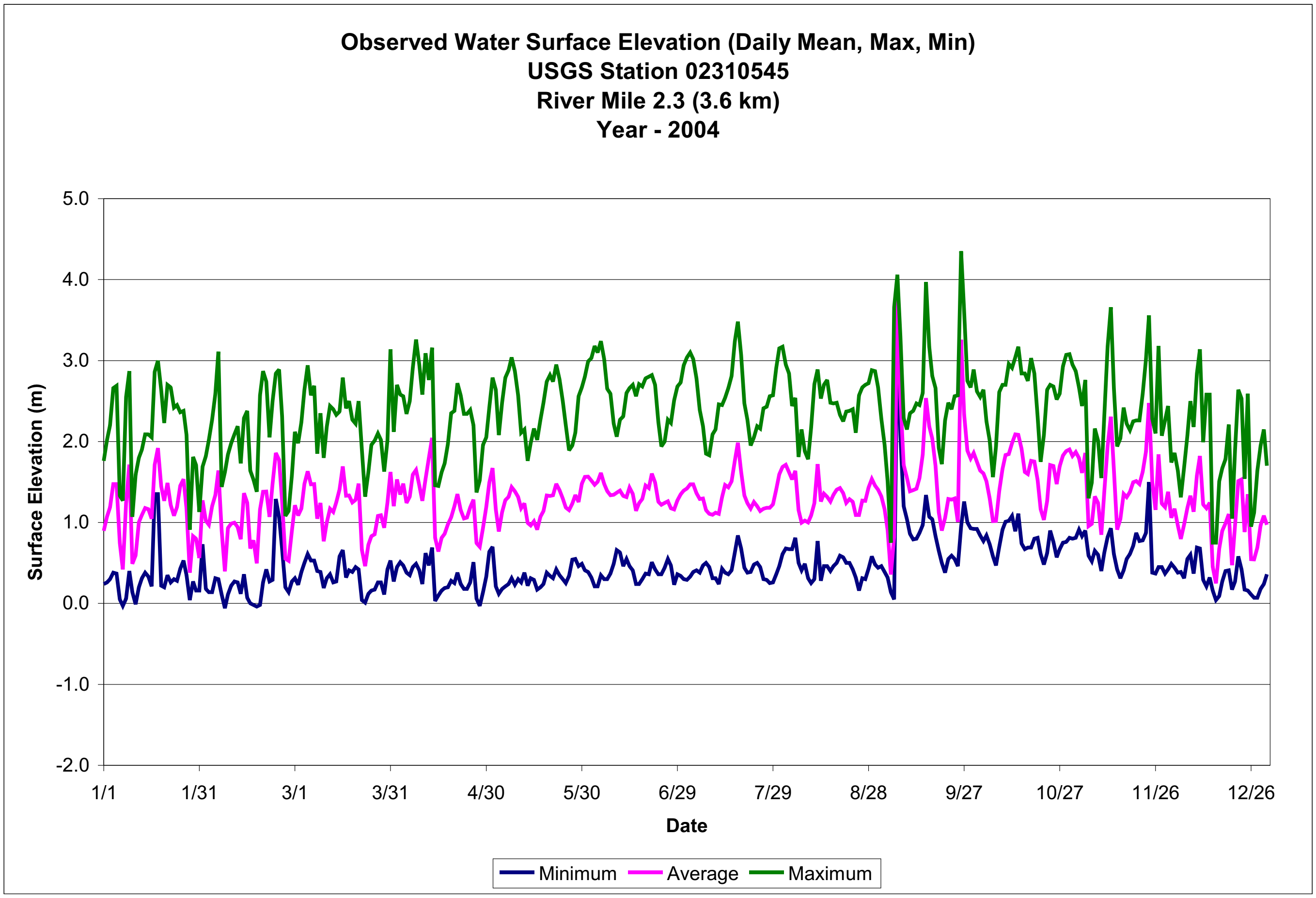

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Figure 3-11

Daily Maximum, Mean, and Minimum Water Level Measured at USGS 20310545 for 2004

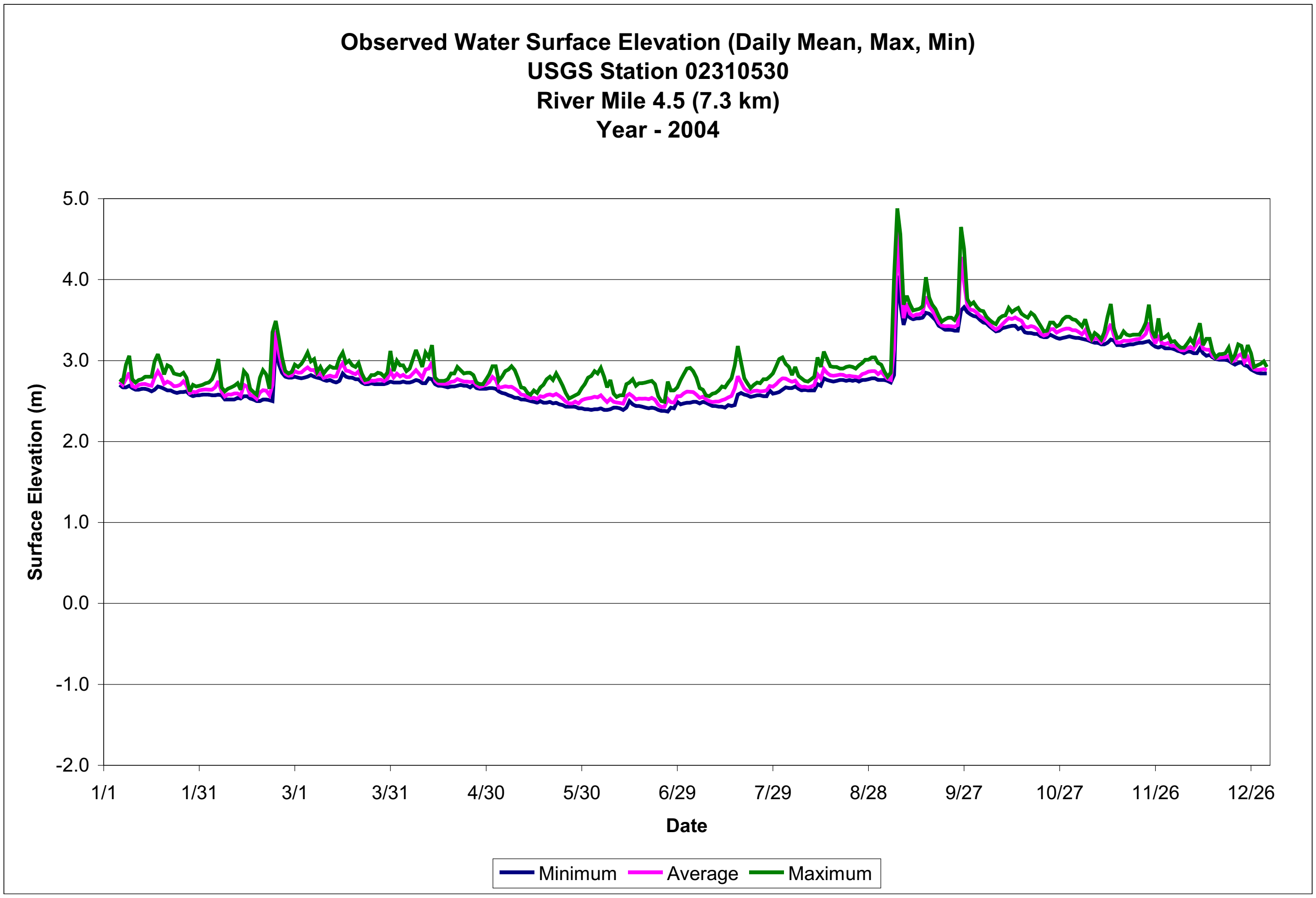

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Figure 3-12
Daily Maximum, Mean, and Minimum Water Level Measured at USGS 20310530 for 2004

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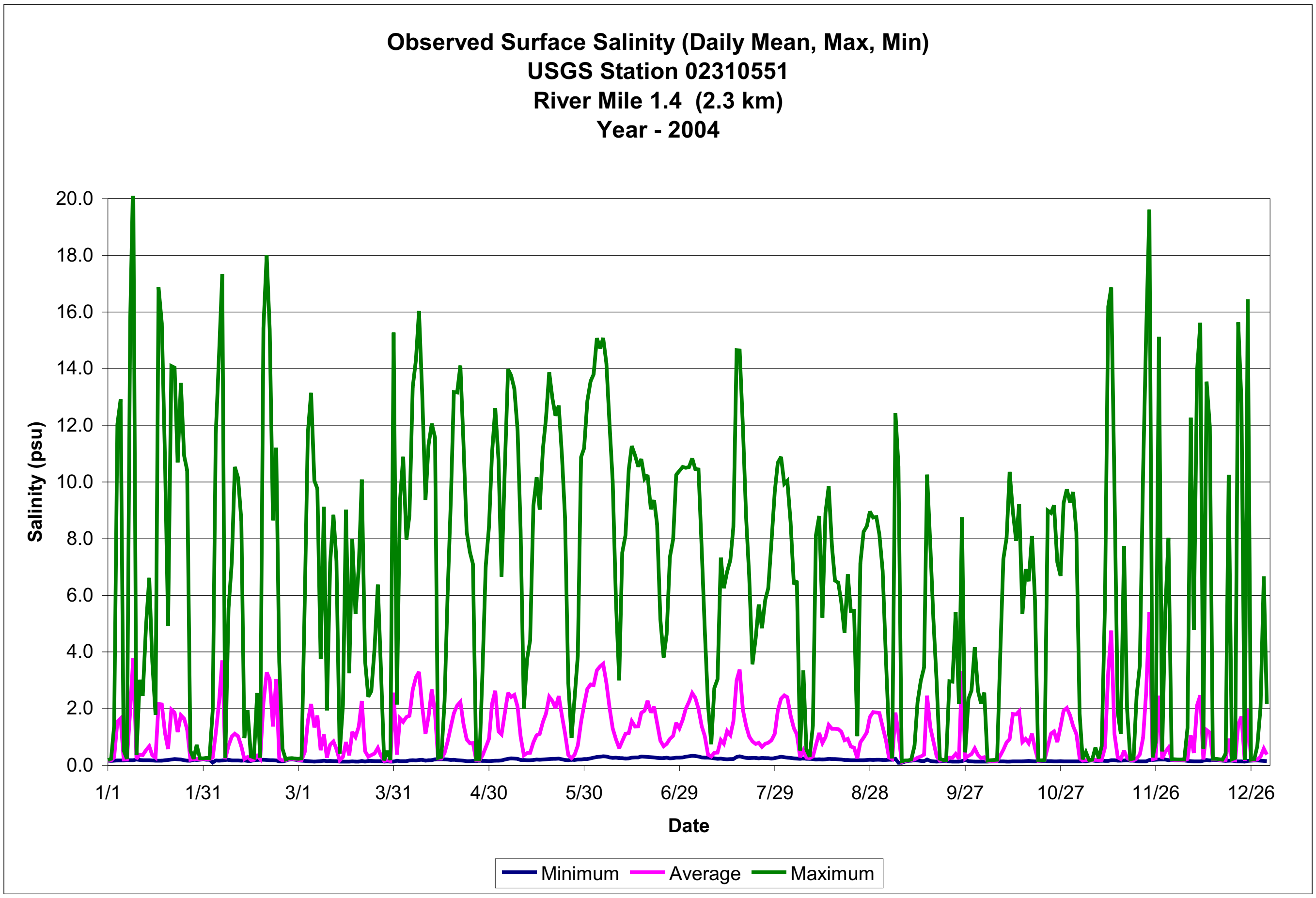

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Figure 3-13a

Daily Maximum, Mean, and Minimum Surface Salinities Measured at USGS 20310551 for 2004

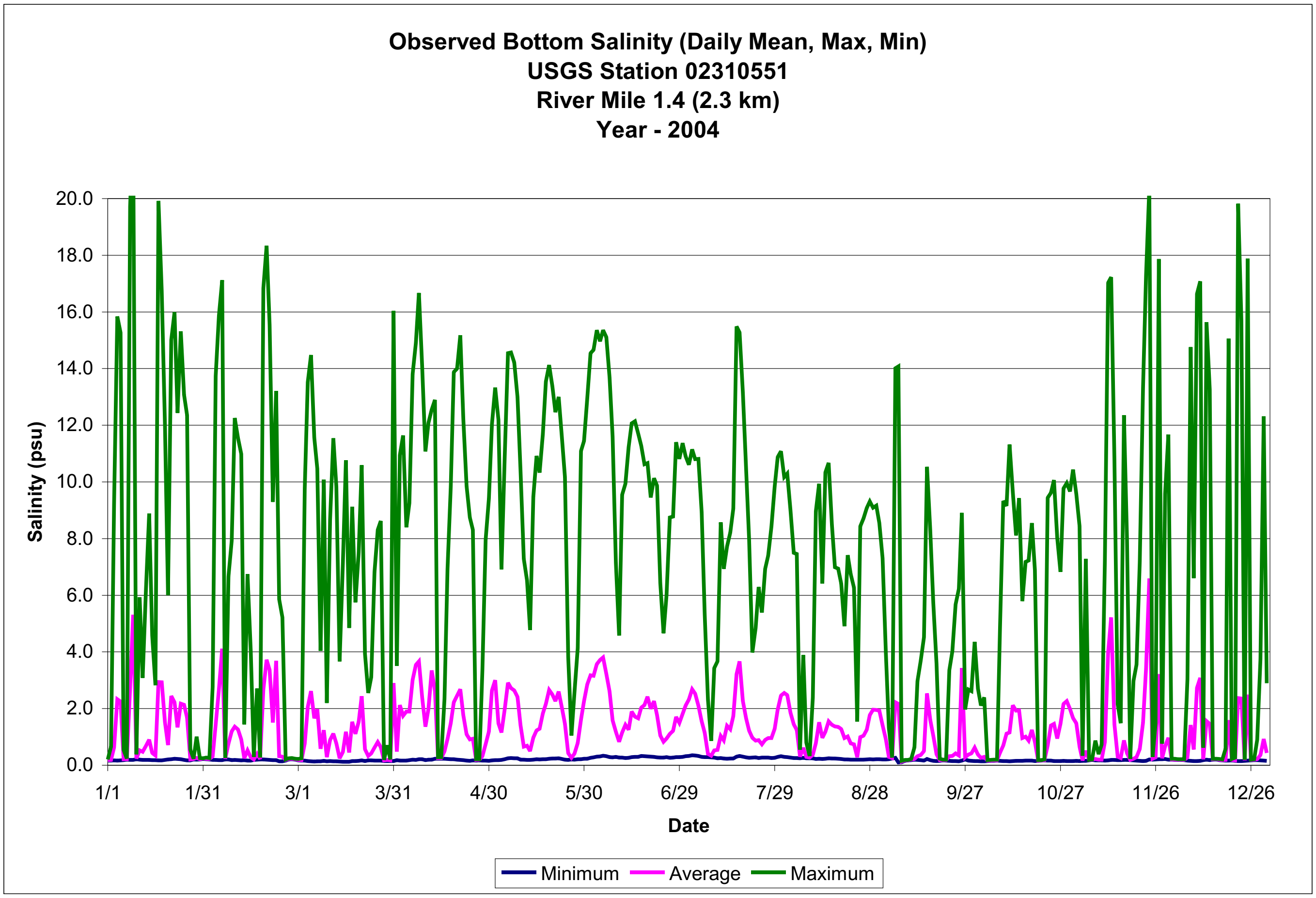

Figure 3-13b
Daily Maximum, Mean, and Minimum Bottom Salinities Measured at USGS 20310551 for 2004

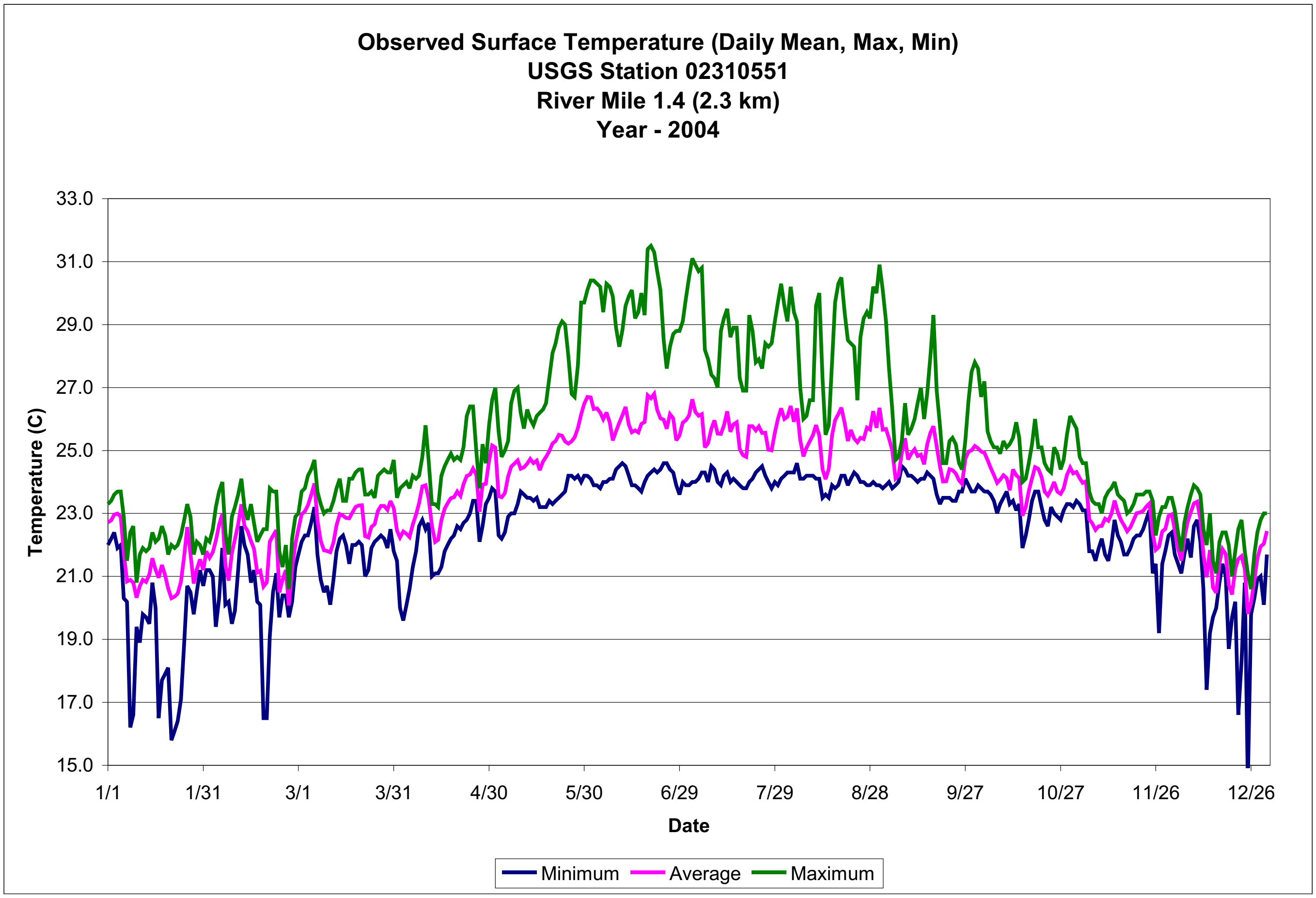

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Figure 3-14a
Daily Maximum, Mean, and Minimum Surface Temperatures Measured at USGS 20310551 for 2004

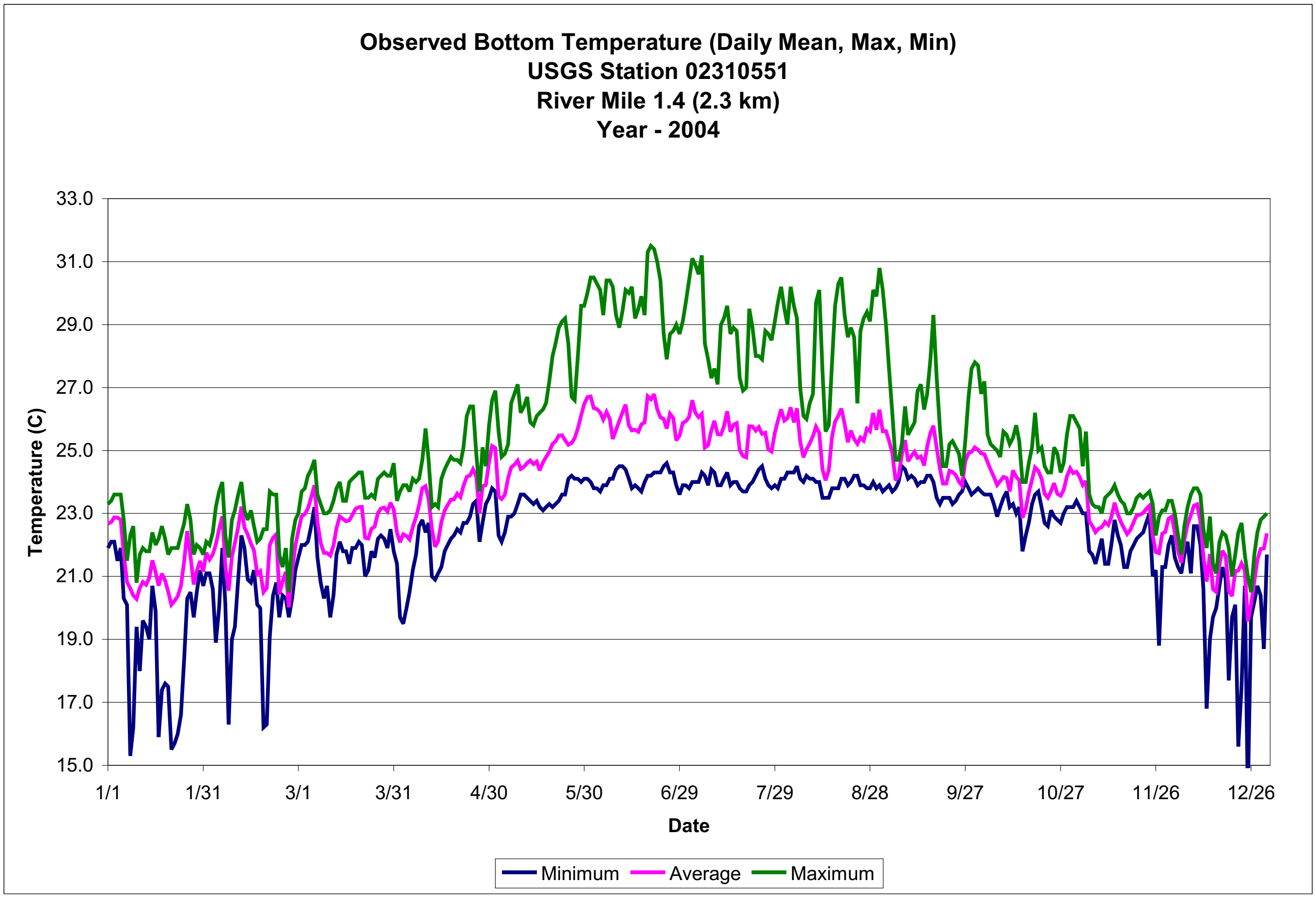

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Figure 3-14b
Daily Maximum, Mean, and Minimum Bottom Temperatures Measured at USGS 20310551 for 2004

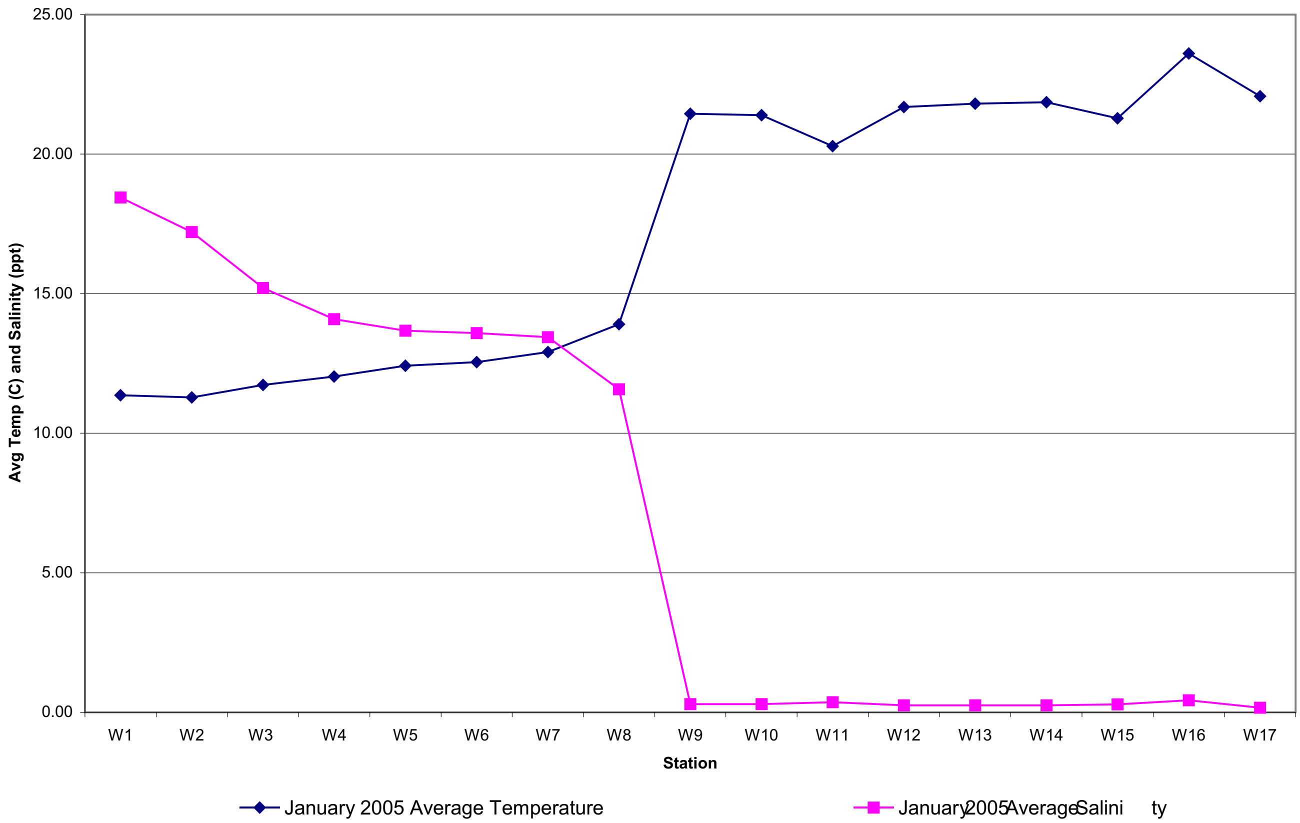

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Figure 3-15

Longitudinal Measured Salinities and Temperatures along the Weeki Wachee River and Mud River Estuary

4.0 MODEL DEVELOPMENT AND CALIBRATION

In Section 2, a general discussion of the modeling methodology utilized for this study was presented along with a description of the model to be utilized. In this Section, the model development and calibration are presented. The model development includes the creation of the model grid to represent the geometric conditions; the determination of model boundary and input conditions; and the calibration of the model to a specified period of time representative of the conditions to be simulated under the evaluation scenarios. The following presents the results of the model calibration.

4.1 CALIBRATION PERIOD

The model calibration period was chosen as a 4-month period in the winter of 2003-2004 from November 1, 2003 through February 28, 2004. During this period, continuous data were available at the boundary stations as well as the interior stations along the Weeki Wachee spring run for comparison purposes. Additionally, discrete data were available from the SWFWMD sampling as outlined in Appendix A and within Section 3.

4.2 MODEL GRID AND BATHYMETRY

Figure 4-1 presents the model grid utilized for the simulations. The grid extends approximately 1 mile (1.6 km) offshore from the entrance to the estuarine portion of the Weeki Wachee River and includes all of the Mud River up to Mud Springs, as well as the Weeki Wachee spring run up to its headwaters. Within the lower estuarine portion, the geometry is represented with 3-cells across which split into single cells moving up the Weeki Wachee spring run and the Mud River. The average cell lengths range from 100 to 200 feet (30.5 to 61 m).

The EFDC model is capable of simulating both 2-dimensional and 3-dimensional conditions. For the purposes of this study, the model is 3-dimensional with four cells in the vertical. This was to allow the representation of vertical salinity and temperature stratification, and the intrusion of the colder waters beneath the outgoing spring flow.

Figure 4-2 presents the model bathymetry. Depths within the cells were based upon available data, including the following (all depths are referenced to NGVD):

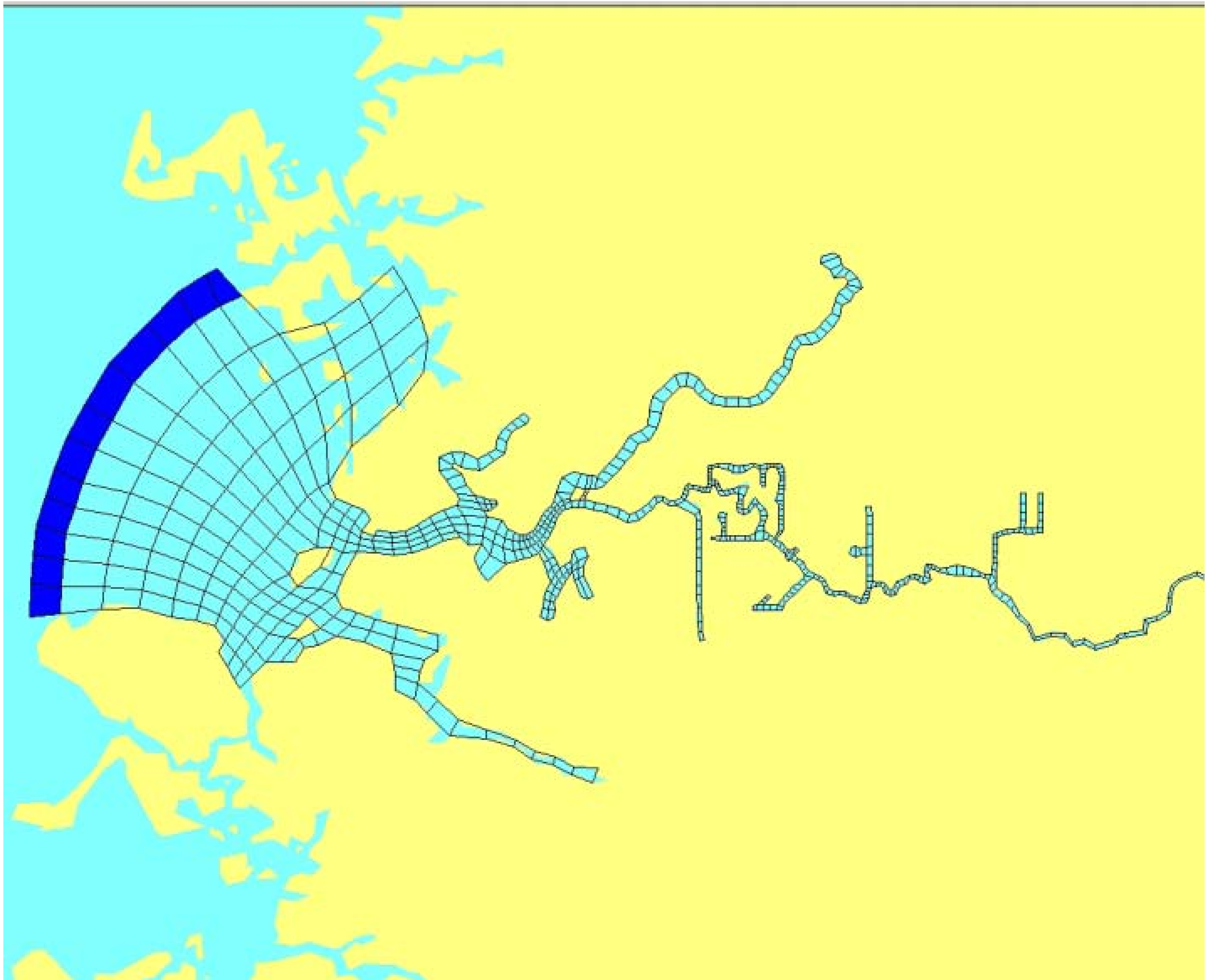

Figure 4-1
Model Grid

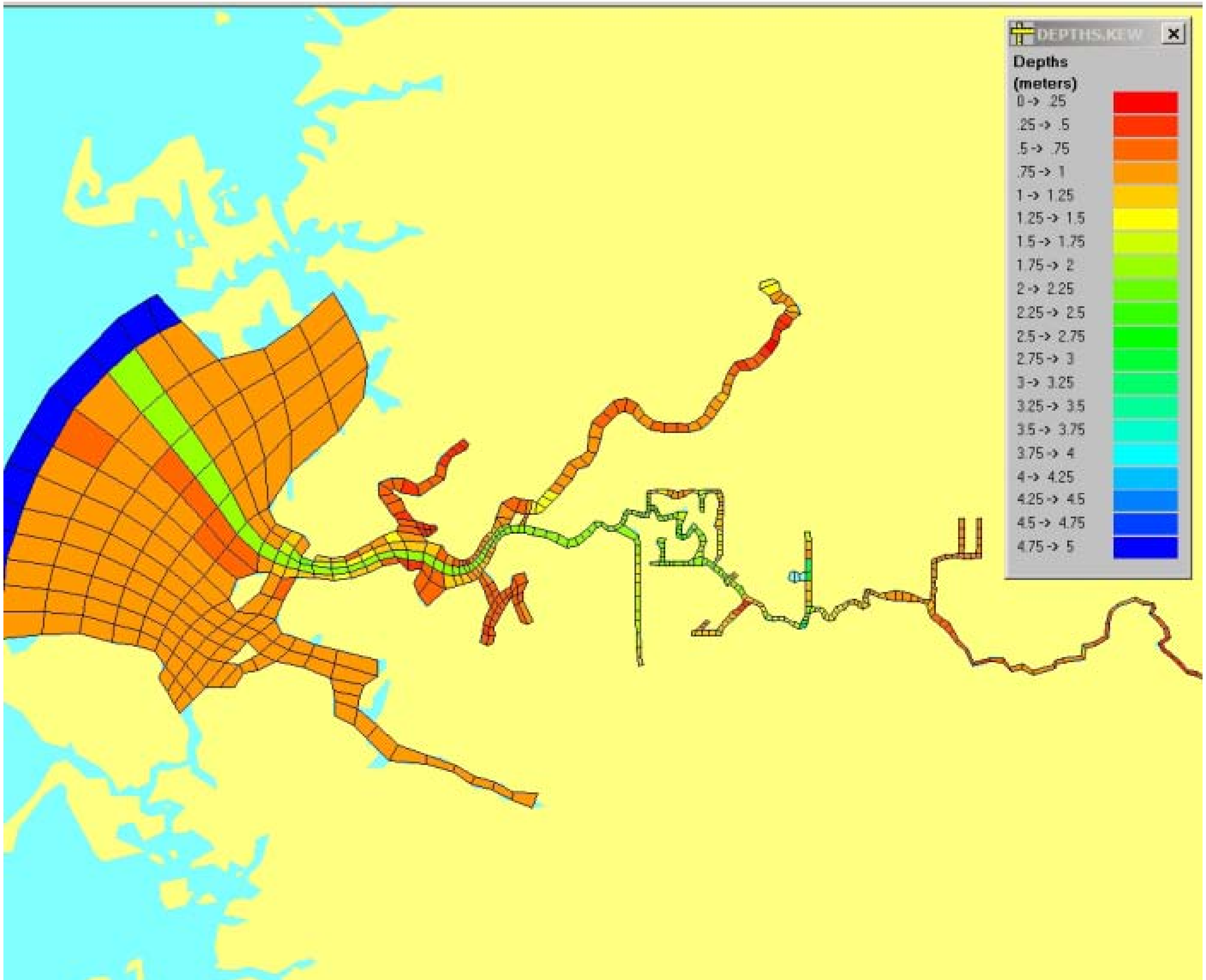

Figure 4-2
Model Bathymetry

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- NOAA bathymetric surveys
- University of Florida cross-sections of the Mud River and Weeki Wachee Rivers

Depth data were imported into an ASCII file containing a longitude, latitude and depth for each point. The depths were initially imported into the model grid with the use of a bin sort routine, often used when there is a relatively large amount of data (more than one point per cell). Depth values for cells that did not contain data points were interpolated or extrapolated from adjacent cells with known depths automatically.

The initial gridded depth data were reviewed for consistency with the chart and cross sectional data. Adjustments were made where appropriate to maintain cross-sectional area at measured sections and comparable grids cell locations along the model grid.

4.3 MODEL INPUT CONDITIONS

For the simulation of the winter period in 2003-2004, the following boundary conditions were needed;

- Offshore: water level, salinity and temperature
- Meteorologic: wind, solar radiation, air temperature, atmospheric pressure
- Upstream: inflow rates, salinities, and temperatures for Weeki Wachee/Twin Dees Springs and Mud Spring

4.3.1 OFFSHORE BOUNDARY

Figures 4-3 and 4-4 present the measured water level, temperature and salinity for the Bayport station. The Bayport station data was used for the open boundary, to specify the model tides, temperature and salinity. The model grid open boundary is approximately 1.0 mile (1.6 km) offshore from the mouth of the river (where the Bayport gage is located). This necessitates a very small offset for the salinity and surface elevation boundary conditions to account for the distance between the measurement location and the boundary cell itself. The salinity was increased by 2 ppt and the tides offset by 2 minutes to match the model predicted values at the Bayport model cell, while the temperature appeared not to require any offset. This form of boundary matching is a common approach to setting offshore boundary conditions where more nearshore data are available.

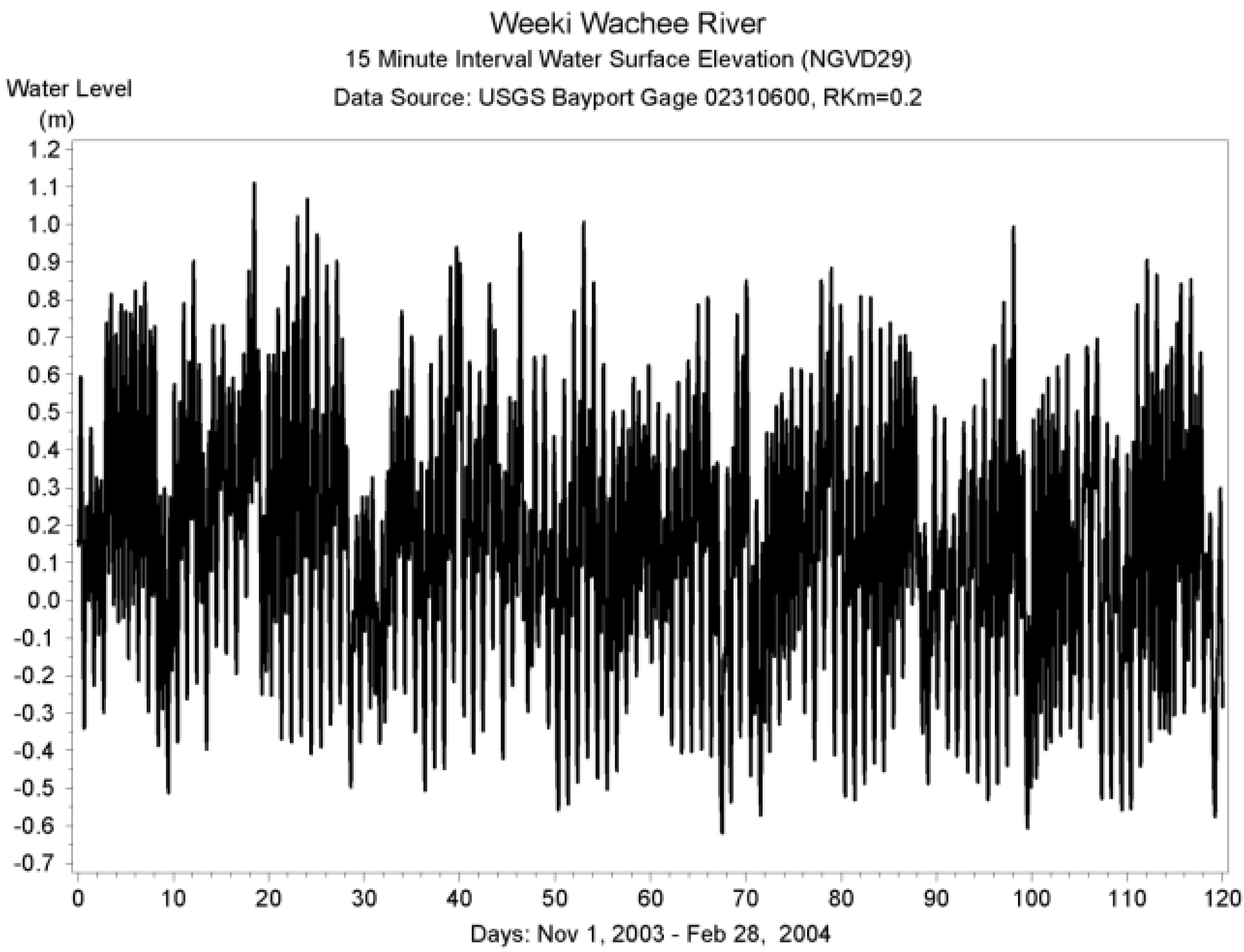

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Figure 4-3
Offshore Water Level Forcing for Calibration Run,
15 Minute Frequency

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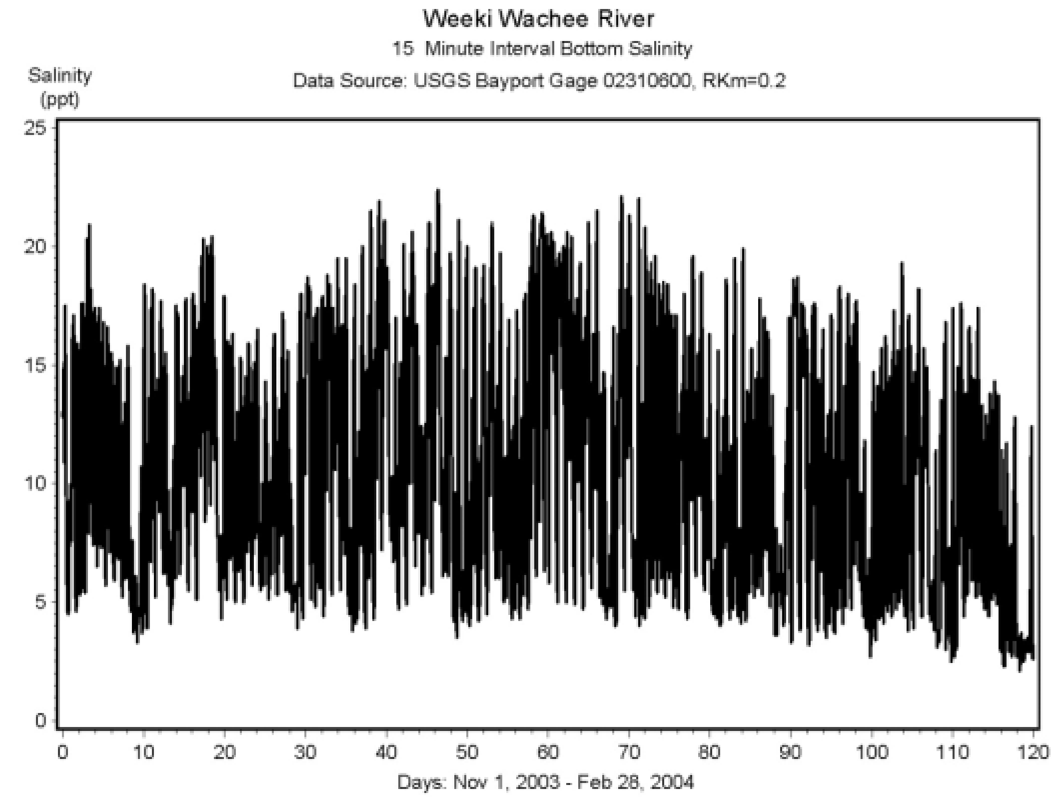

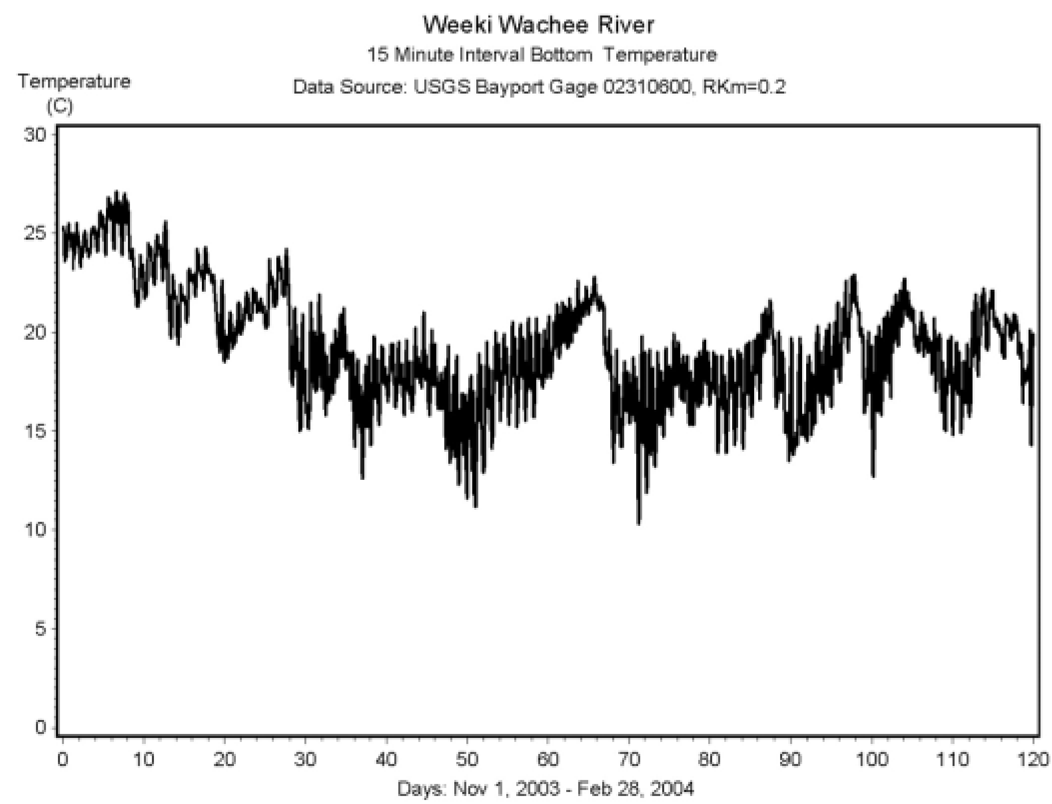

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Figure 4-4
Offshore Salinity and Temperature for Calibration Run,
15 Minute Frequency

4.3.2 METEOROLOGIC

Figures 4-5 through 4-9 present the measured solar radiation, wind speed and direction, air temperature, atmospheric pressure, and cloud cover utilized in the model for the simulation period. The sources for each were:

- Tampa International Airport: Air temperature, atmospheric pressure, and cloud cover.
- IFAS FAWN Station at Dover: Solar radiation
- USF Comps Homosassa River Entrance: Wind speed and direction

In addition to the data described above, during the field monitoring program that was conducted for this study, a photo reconnaissance was conducted along the Weeki Wachee River and the upper portions of the Mud River. During this photo reconnaissance, vegetation cover conditions were recorded moving upstream in both systems. Figure 6 within Appendix B provides the locations of the photo monitoring waypoints. These data were utilized to define the potential incident solar radiation, or the degree of shading utilized within the numerical model. The following briefly describes the estimation.

The downstream confluence and much of the estuarine portions of the Weeki Wachee River are essentially 0 percent shaded. The first real shading starts upstream of the confluence of the Weeki Wachee spring run with the Mud River. That point is indicated with a yellow 958 waypoint in the map. Estimations of the shaded area used incremental values (0, 25, 50, 75 and 100 percent). A basic description for each is:

- 0 = no shade
- 25 = just edges of sky shaded
- 50 = half the open sky covered
- 75 = only some splotches/patches of light remaining
- 100 = full canopy

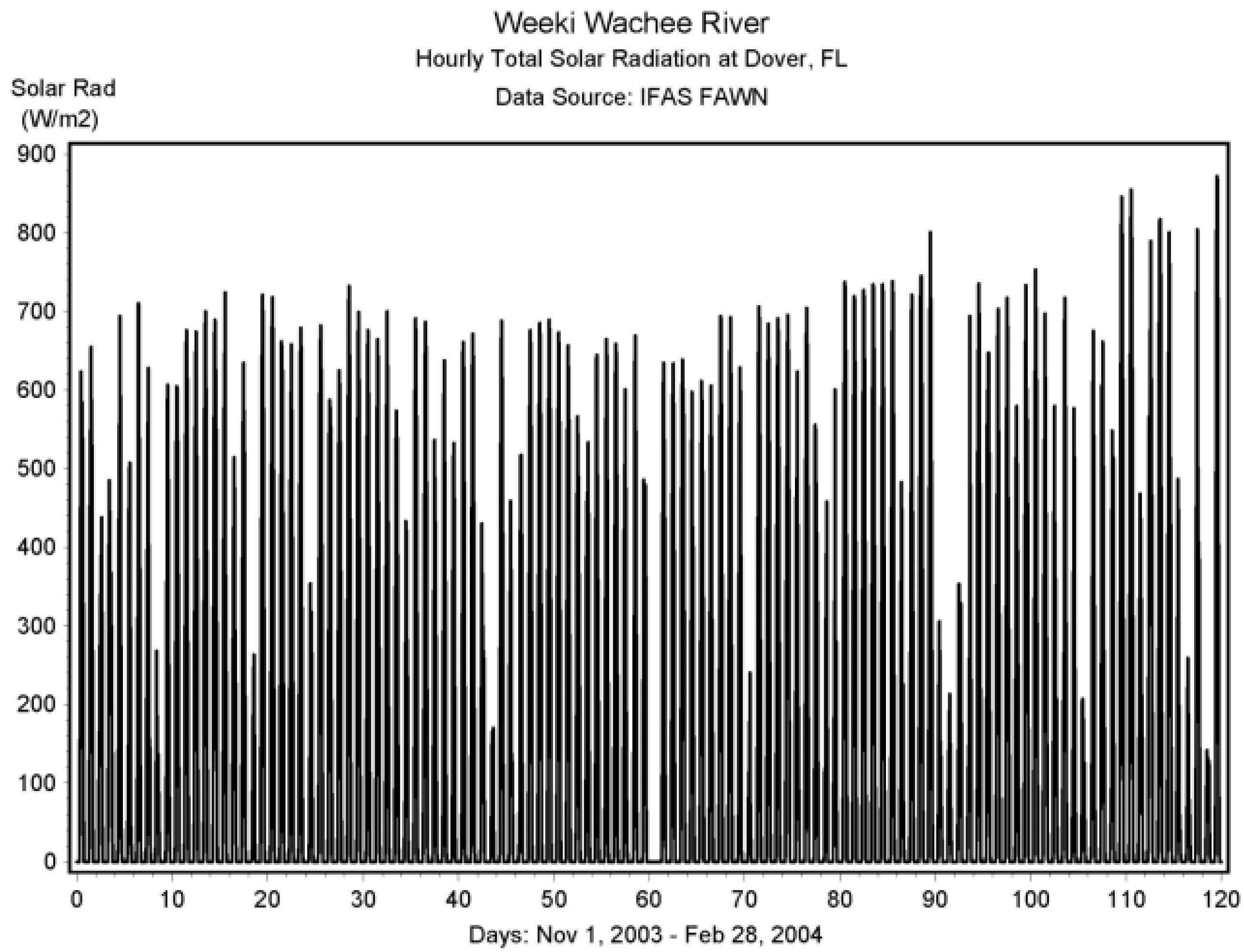

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Figure 4-5
Hourly Total Incident Solar Radiation at Dover, Florida, for Calibration Run

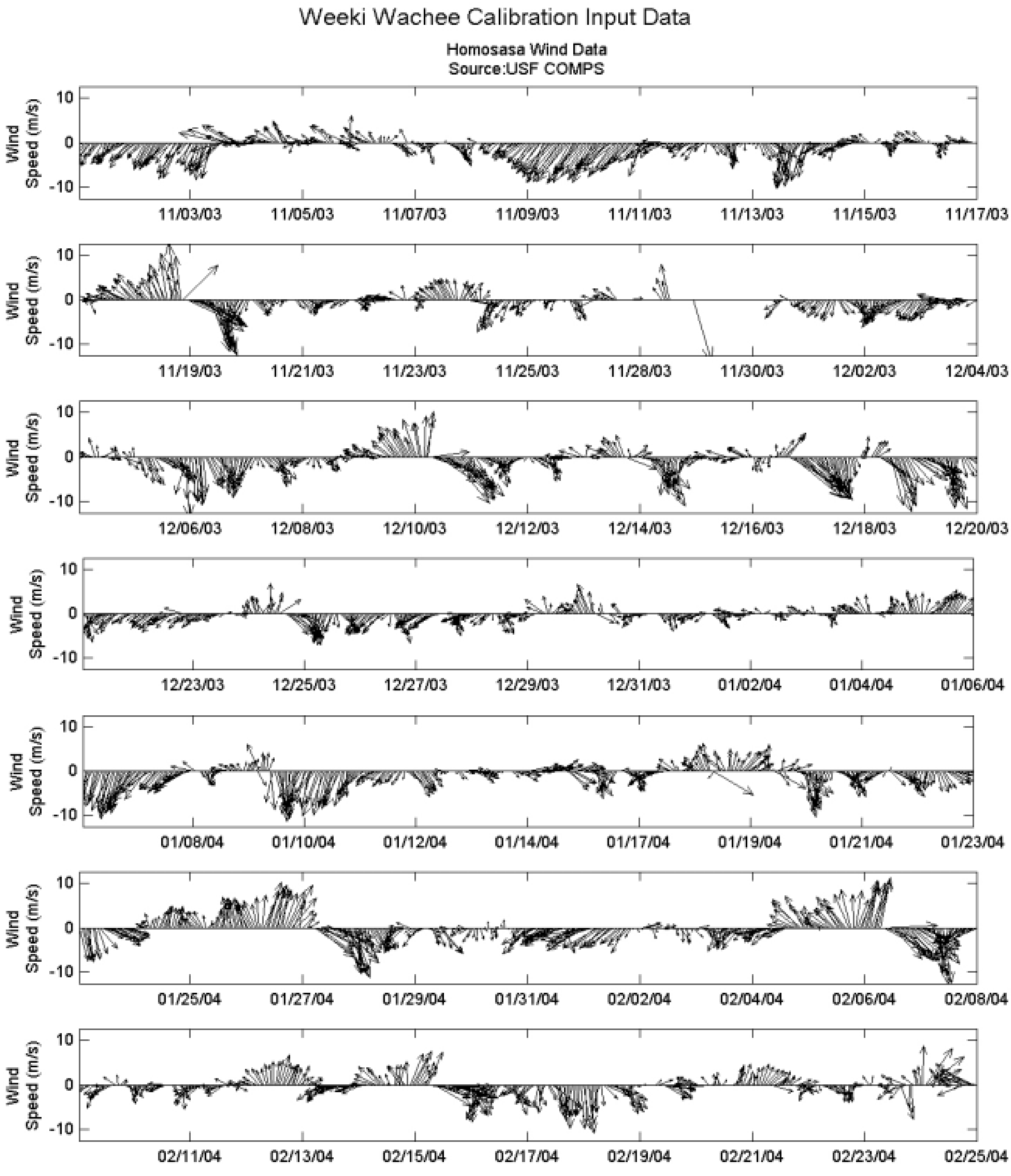

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Figure 4-6
Wind Speed and Direction

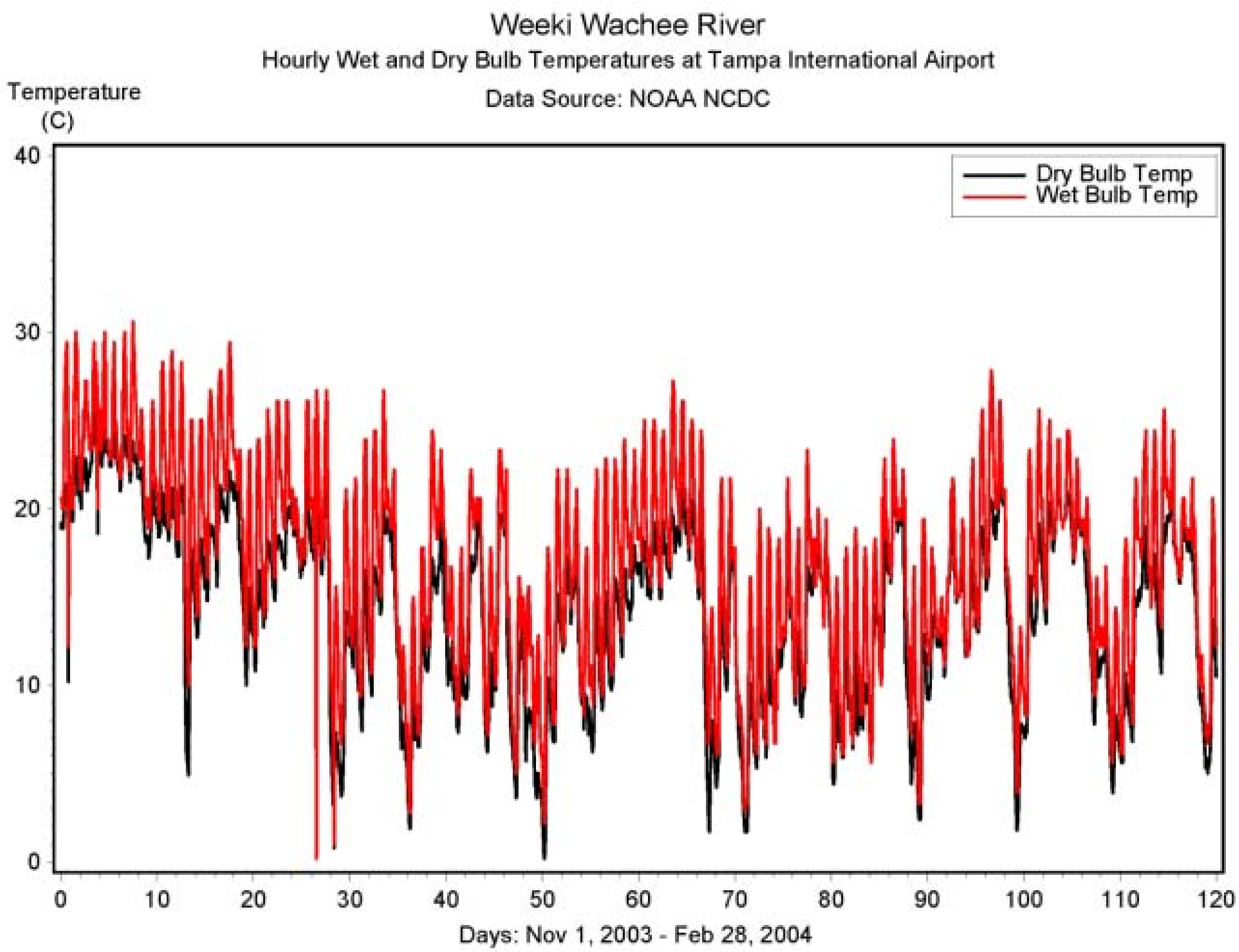

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Figure 4-7
Hourly Wet and Dry Bulb Temperatures at Tampa International Airport, for Calibration Run

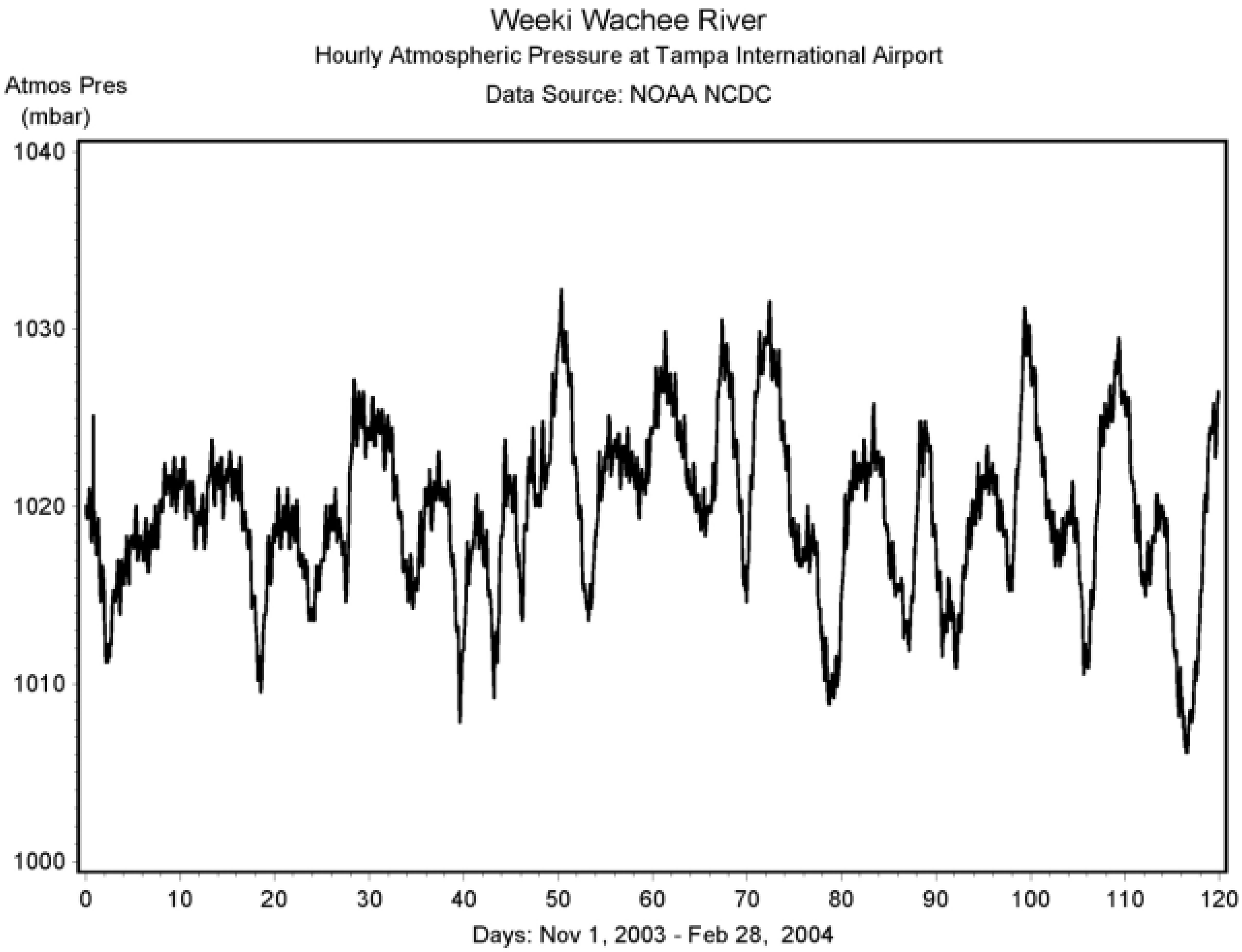

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Figure 4-8
Hourly Atmospheric Pressure at Tampa International Airport, for Calibration Run

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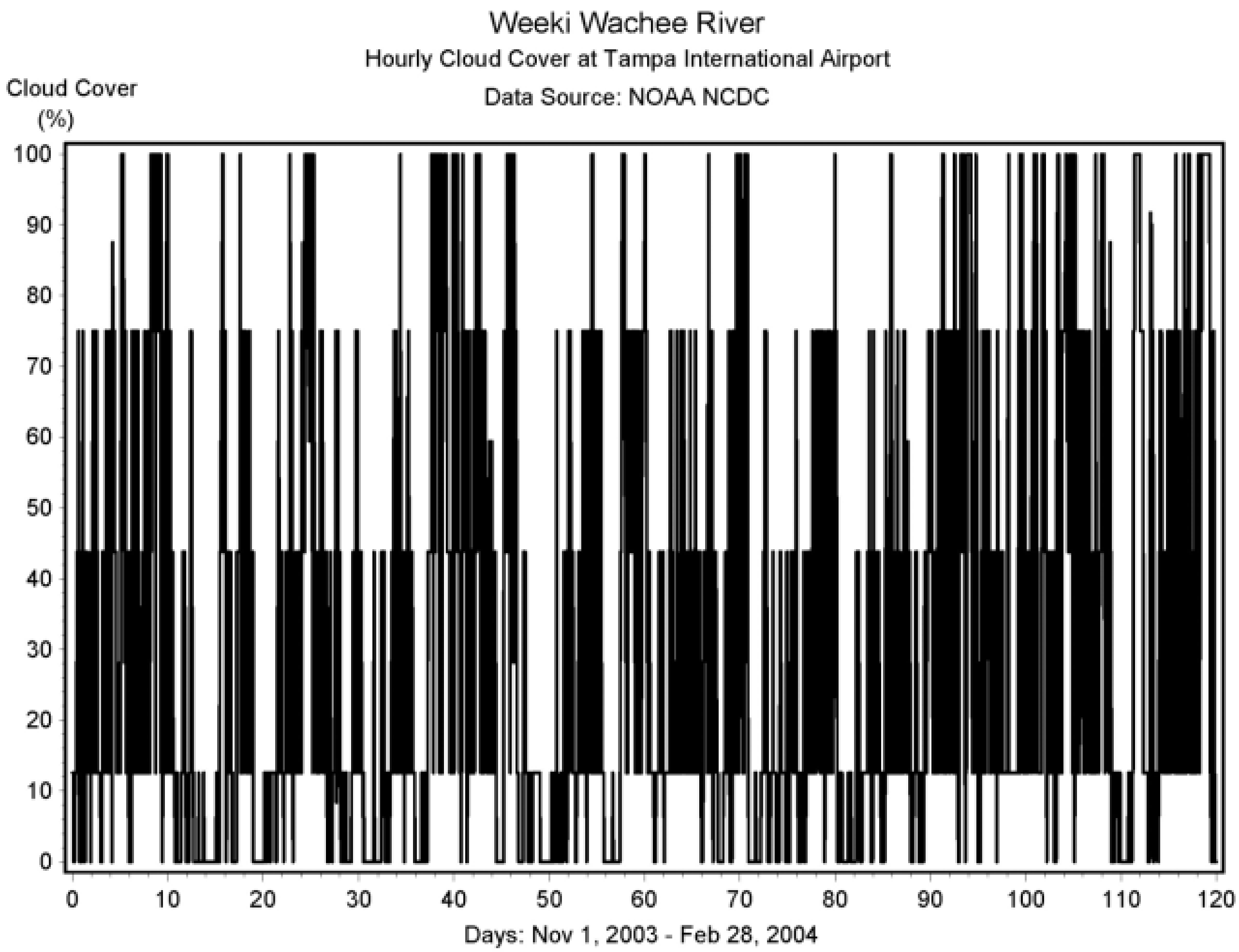

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Figure 4-9
Hourly Cloud Cover Percentage at Tampa International Airport, for Calibration Run

The assignment of shading between 25 and 75 was somewhat tricky because of the time of day and angle of the picture when taken. The total fraction of short wave solar radiation reaching the water surface was adjusted in the model based on the amount of shading.

4.3.3 SPRING FLOWS

Figure 4-10 presents the time series of flows from Weeki Wachee and Twin Dees springs as well as the flow from Mud Spring. For Mud Spring a constant flow of 45 cfs was input. This flow assumption was based upon limited available data. For Weeki Wachee and Twin Dees springs the flow for the calibration period ranged from near 230 cfs down to near 170 cfs.

4.4 MODEL CALIBRATION

Sections 4-1 through 4-3 presented the geometric and boundary conditions utilized to drive the model simulations for comparison during the calibration period (November 1, 2003 through February 28, 2004). The model simulations were then compared to the continuous measurements at the USGS stations along the Weeki Wachee spring run (USGS 02310545 and USGS 02310551). These were the continuous monitoring stations that were located within the critical area of the manatee thermal refuge (see Figure 3-1a). The following presents the result of the calibrations.

Figures 4-11 and 4-12 present comparisons of the measured and predicted water surface elevations along the Weeki Wachee River. The comparisons show that the model overpredicts the fluctuations in the river, but is able to capture the general mean water level changes that occur through the calibration period. Presently the model overpredicts the extent of tidal intrusion into the Weeki Wachee River and is not able to simulate the degree of damping that occurs as the tidal wave propagates upstream near USGS 02310530, where the bottom elevations rise to above 0 NGVD. The calibration focused on assuring that the simulation of the intrusion of saline waters was represented, which was the more primary focus of the model.

Figures 4-13a and b present comparisons of the measured and predicted surface and bottom salinities at USGS 02310551. The data show that the model is able to capture the general physics of the salinity intrusion. These are short-term highly dynamic events (on the order of 3 to 4 hours) that are difficult to simulate.

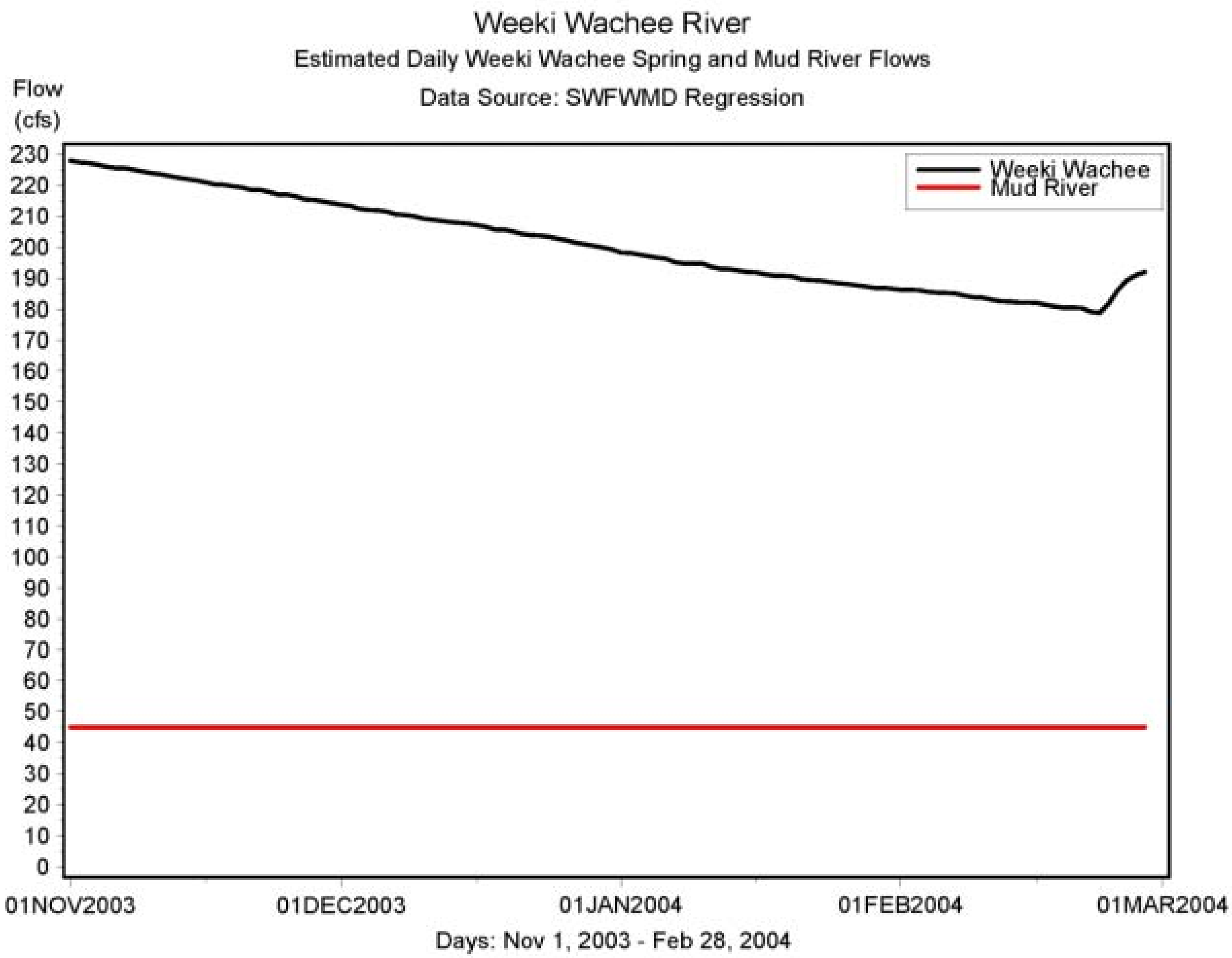

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Figure 4-10
Daily Flows from Weeki Wachee Spring and Mud River, for Calibration Run

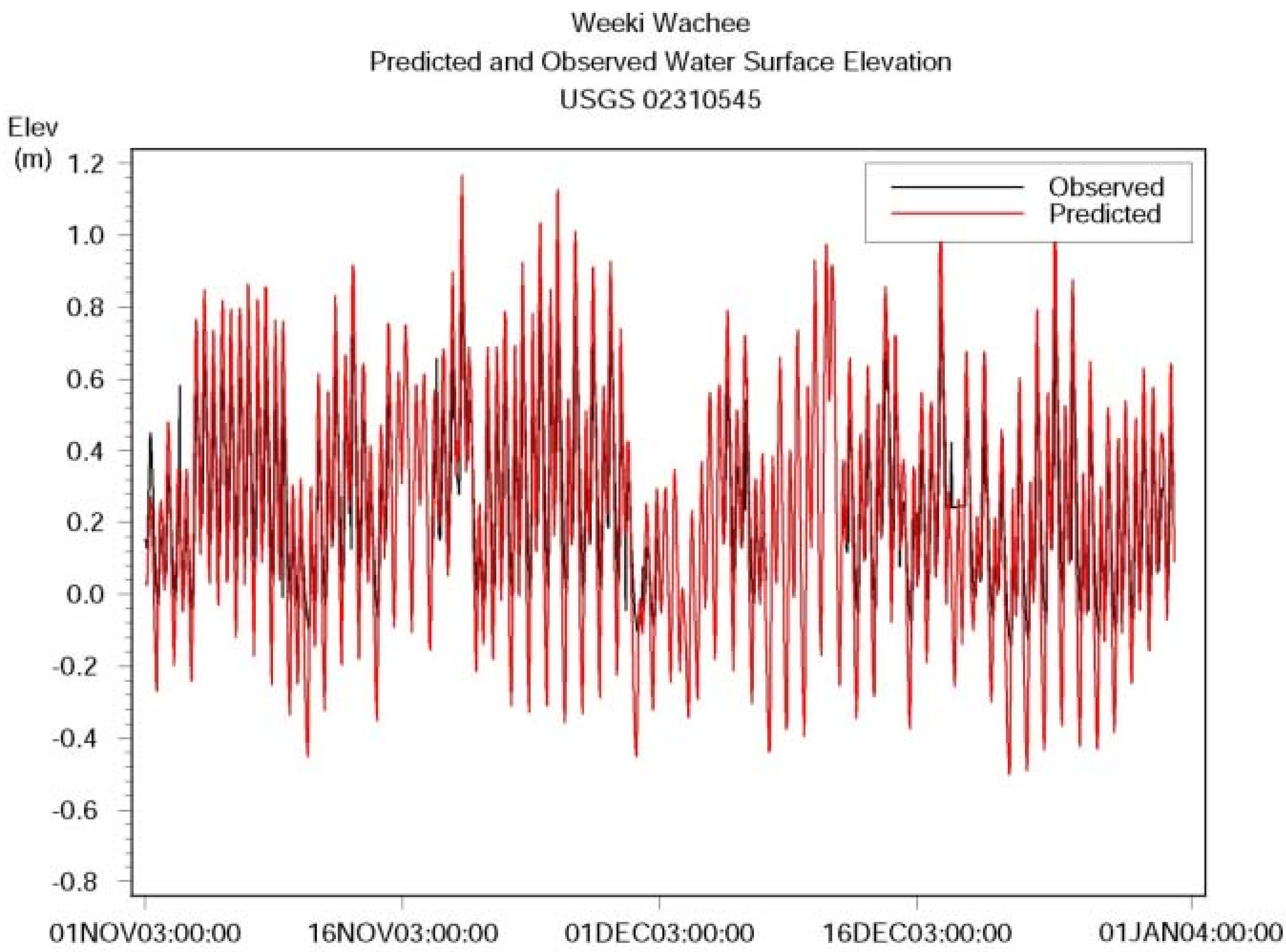

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Figure 4-11
Predicted and Observed Water Surface Elevation
USGS 02310545

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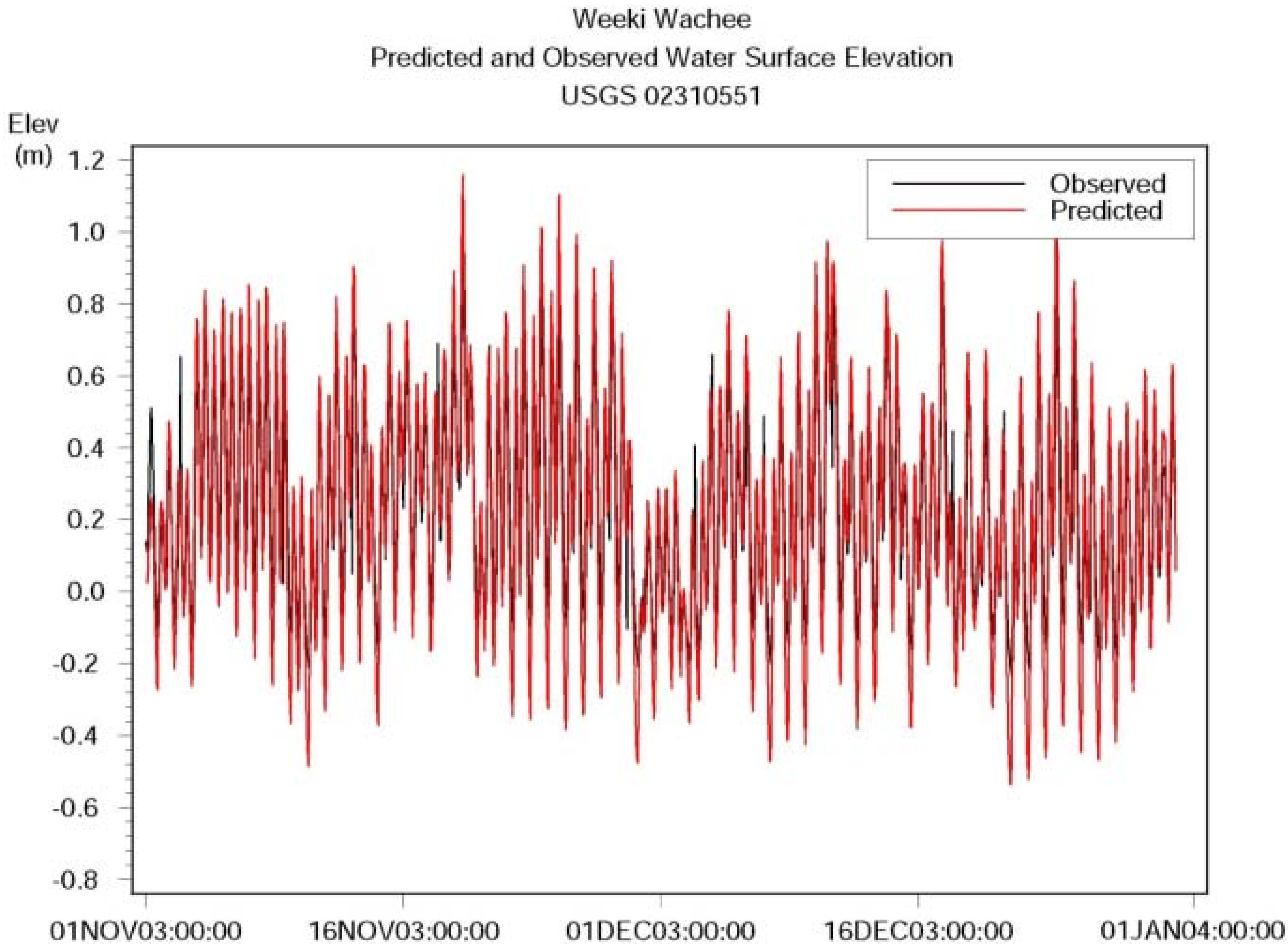

05-1186 4-12.CDR 04/23/07

Figure 4-12
Predicted and Observed Water Surface Elevation
USGS 02310551

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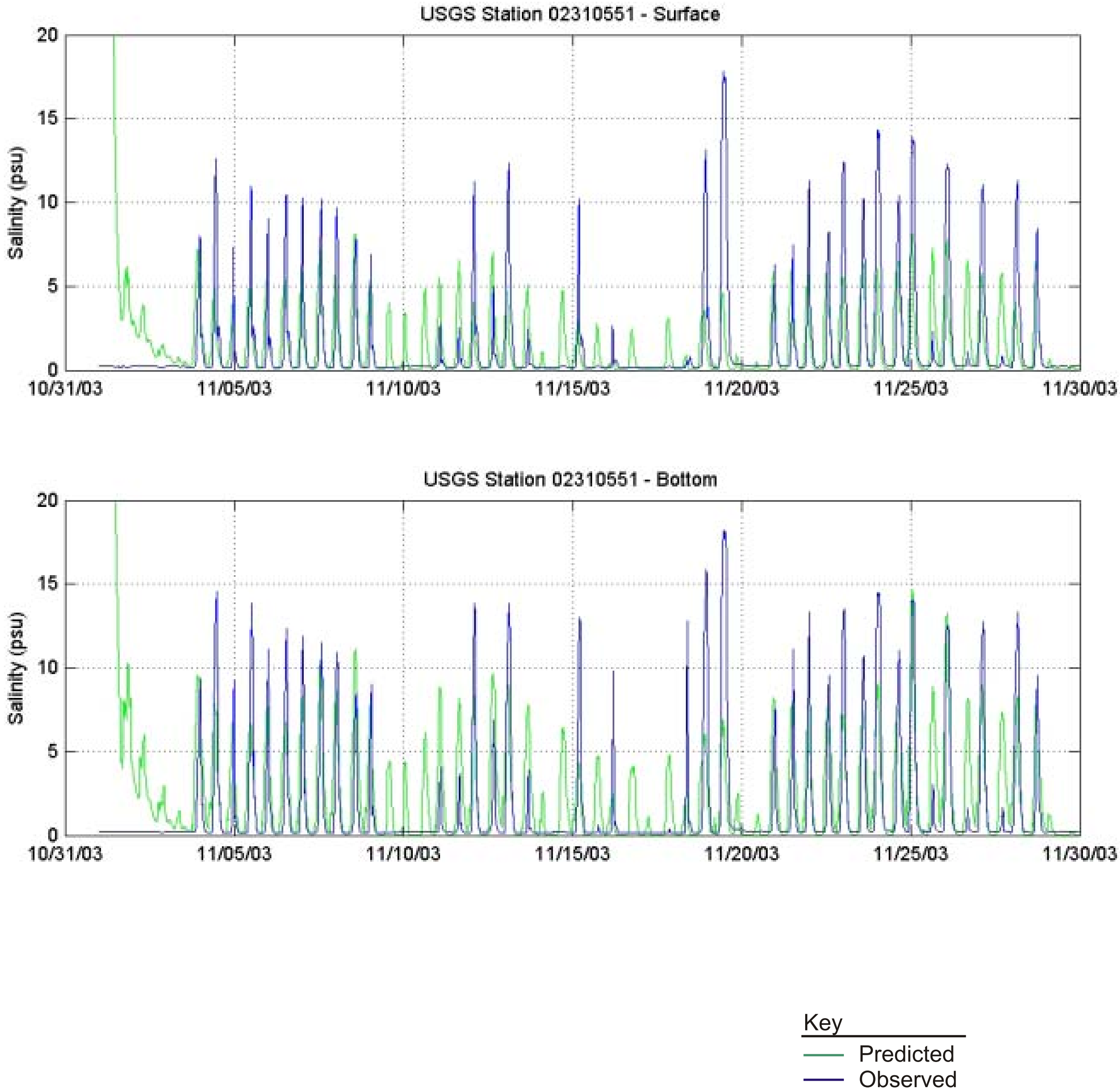

Figure 4-13a
Comparison of Simulated and Measured Surface and Bottom Salinities at USGS 02310551 for November 2003

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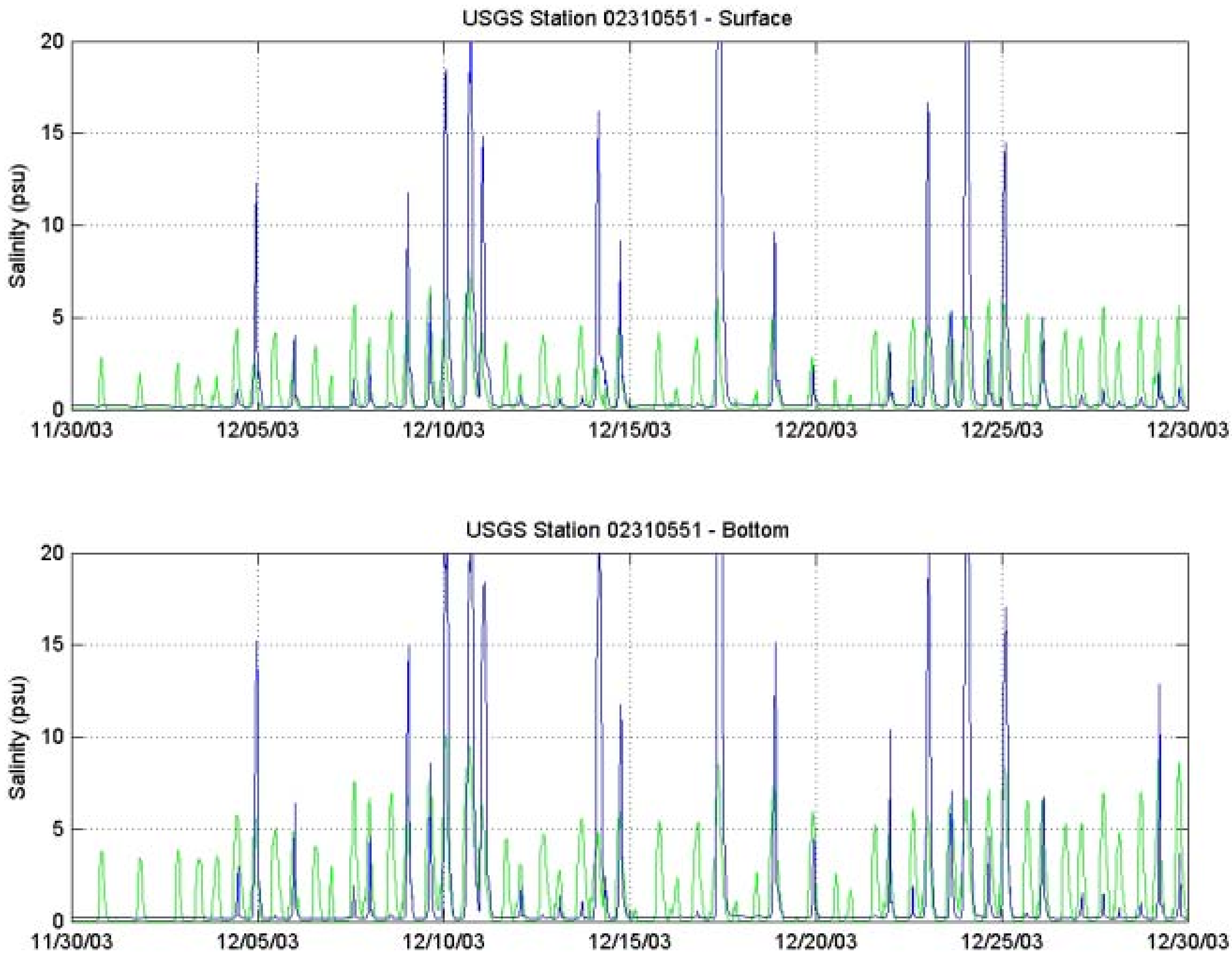


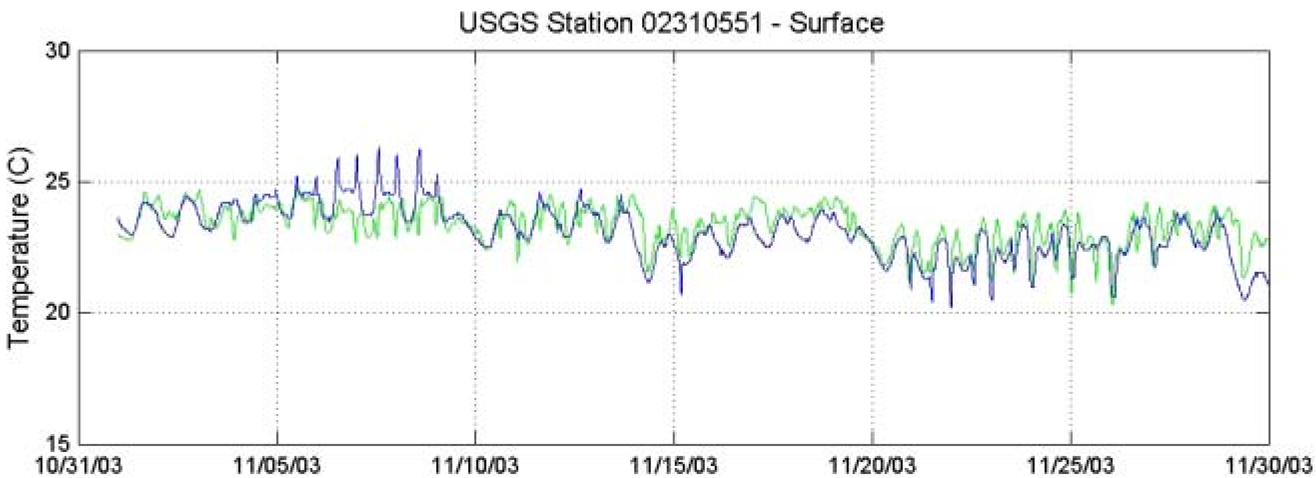
Key
Predicted
Observed

05-1186 4-13b.CDR 09/20/07

Figure 4-13b
Comparison of Simulated and Measured Surface and Bottom Salinities at USGS 02310551 for December 2003

Figures 4-14a and b present comparisons of the measured and predicted surface and bottom temperatures at USGS 02310551. Table 4-1 presents the calibration statistics for the salinity and temperature. Examination of the plots shows that while the model at times does not capture the short duration spikes (this corresponds to where the model misses the salinity intrusion), the more long-term temperature trends and changes are simulated well with overall errors generally low. For the purposes of a net change in temperature for 3-day daily average events the model simulated temperatures are reasonable.

The calibration goal was to focus on simulation of the temperature accurately within the time scale needed for the critical conditions simulations. As the simulations were evaluating the daily average temperatures over 3-day periods, the temperature calibration is sufficient and reasonable. The short duration low temperature events that at times are missed, are of a time scale significantly shorter than the evaluation period.



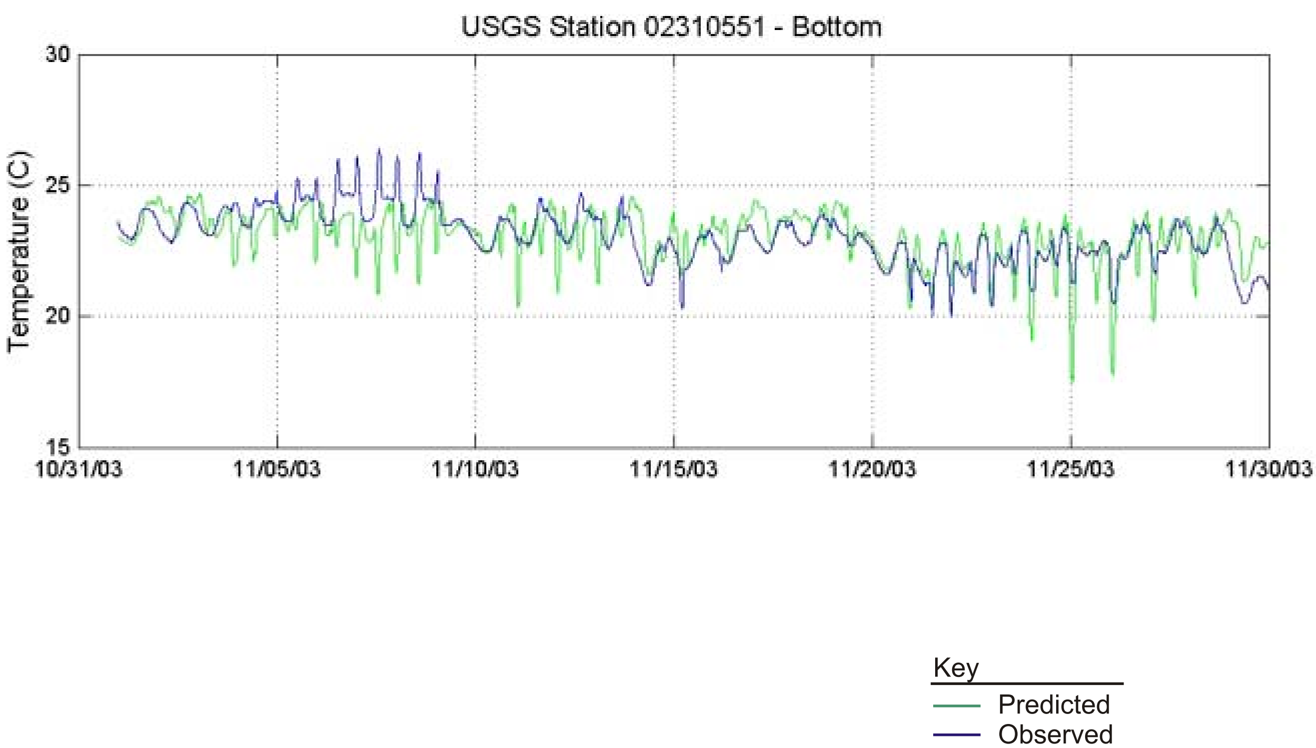


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Figure 4-14a

Comparison of Simulated and Measured Surface and Bottom Temperatures at USGS 02310551 for November 2003

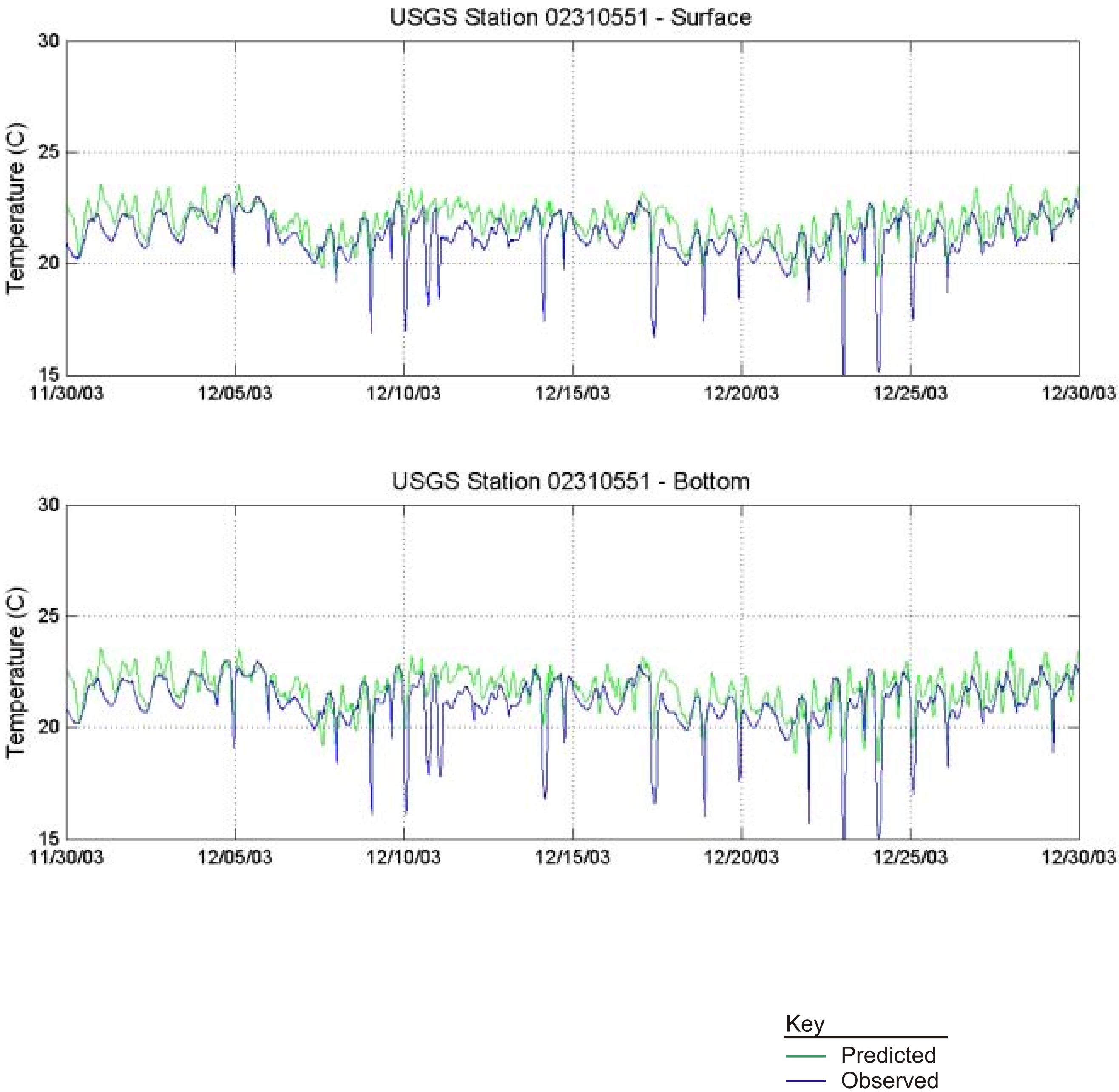

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Figure 4-14b

Comparison of Simulated and Measured Surface and Bottom Temperatures at USGS 02310551 for December 2003

Table 4-1. Salinity and Temperature Model Calibration Statistics

Temperature	Obs Surface	Model Surface	Surface Diff	Obs Bottom	Model Bottom	Bottom Diff
Min	14.70	19.25	4.55	13.80	17.49	3.69
Mean	22.18	22.61	0.43	22.09	22.35	0.26
Max	26.30	24.82	-1.48	26.40	24.69	-1.71
5th Percentile	20.20	20.78	0.58	20.10	20.36	0.26
50th Percentile	22.20	22.63	0.43	22.10	22.40	0.30
95th Percentile	24.40	24.21	-0.19	24.40	24.12	-0.28

Salinity	Obs Surface	Model Surface	Surface Diff	Obs Bottom	Model Bottom	Bottom Diff
Min	0.14	0.00	-0.14	0.15	0.00	-0.15
Mean	1.16	1.38	0.22	1.45	2.21	0.76
Max	23.55	25.01	1.46	24.95	25.01	0.06
5th Percentile	0.16	0.00	-0.16	0.17	0.00	-0.17
50th Percentile	0.21	0.32	0.11	0.21	0.80	0.59
95th Percentile	7.26	5.23	-2.03	10.25	7.69	-2.55

5.0 CRITICAL CONDITIONS DETERMINATION

In order to assess the impacts of flow reductions from Weeki Wachee springs on the Manatee criteria outlined in Section 2, and to be protective of the Manatee population under the range of conditions which will occur in the future, it is important to define a set of critical conditions under which the assessments will be conducted. In the case of the Weeki Wachee thermal refuge, the critical components included the following:

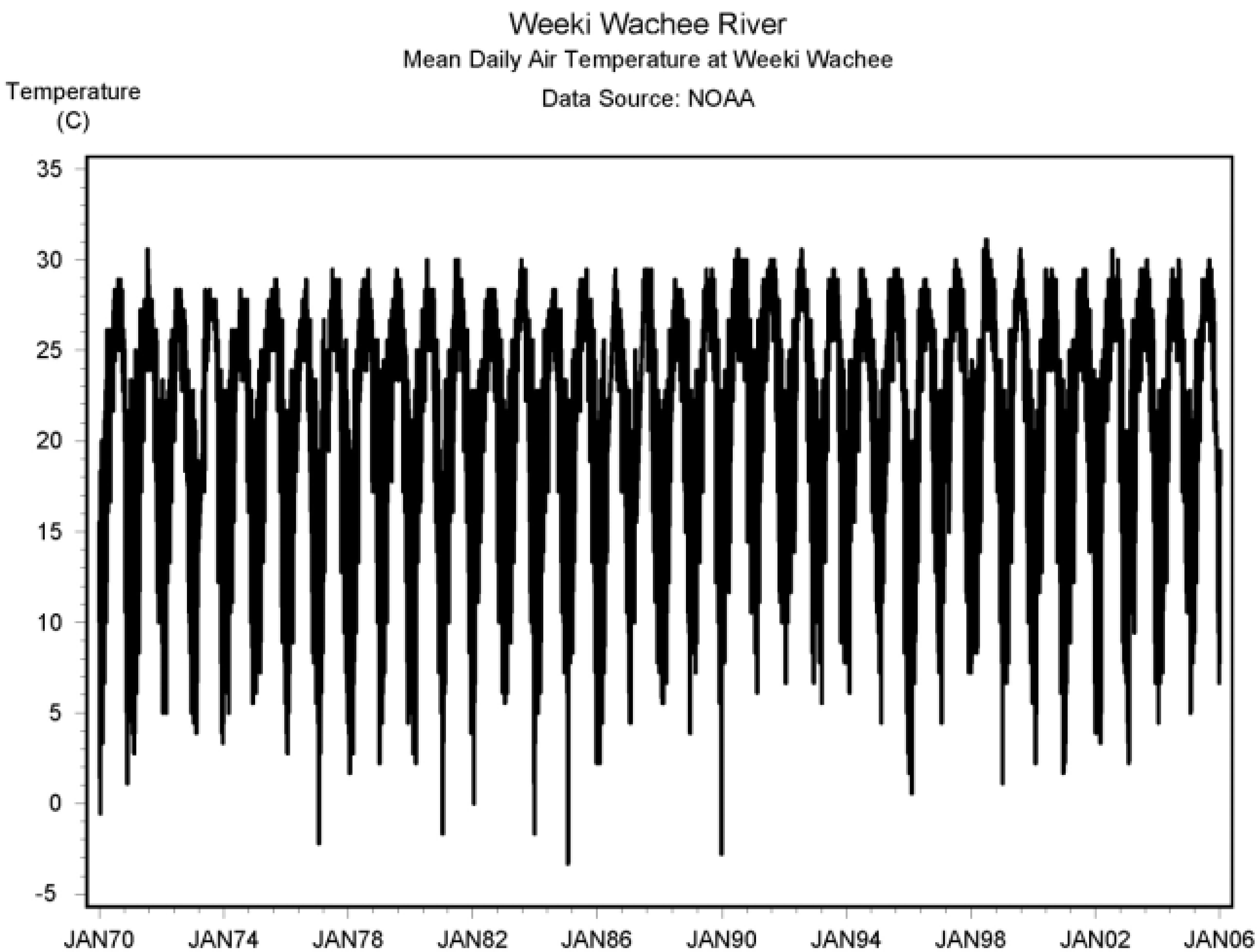
- local meteorology (specifically air temperature)
- offshore water temperature
- offshore water level fluctuations (astronomically and meteorologically driven)
- Spring flows

These were the input conditions put into the model described in Section 4. The following outlines the methodology utilized in the development of the critical conditions and the input values.

5.1 METEOROLOGY AND OFFSHORE WATER TEMPERATURE

It was necessary to determine a time-period when critical conditions of offshore water temperature (low temperatures) existed to ascertain the effects of potential flow reductions on the thermal refuge during the most conservative period. Temperature records at Bayport, which supplied the downstream water temperature boundary condition for the model calibration presented in Section 4, exist only for June 24, 2003 – October 5, 2005. The daily air temperature record at Weeki Wachee, in comparison, extends from 1969 to the present (Figure 5-1). Examination of the air temperature record found that a critical cold period occurred during the winter 2000-2001. During this period, lowest mean daily temperatures were near 0°C.

A method to estimate the water temperature at Bayport as a function of daily air temperature would allow derivation of a long-term water temperature record, from which the critical period could be extracted. The relationship between observed mean daily air temperatures at Weeki Wachee and observed mean daily water temperatures at Bayport (for the 2003 to 2005 period) is displayed in Figure 5-2. Figure 5-3 then shows the predicted versus measured water temperatures using the relationship, the results show an r2 of 0.90 (n=711).



05-1186 Fig 5-1.CDR 08/24/07

Figure 5-1
Mean Daily Air Temperature at Weeki Wachee

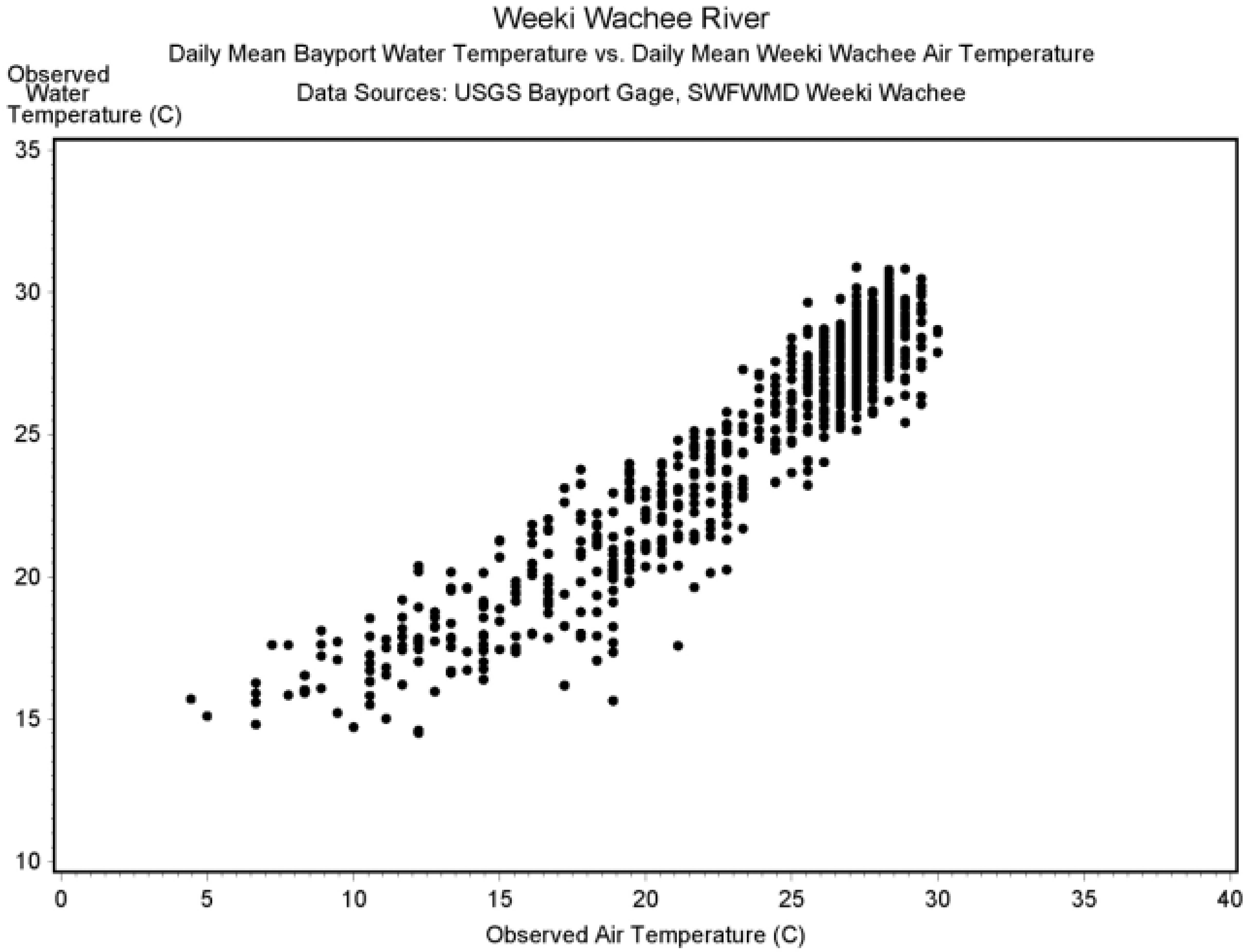


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Figure 5-2

Relationship Between Observed Mean Daily Water Temperature at Bayport and Observed Mean Daily Air Temperature at Weeki Wachee

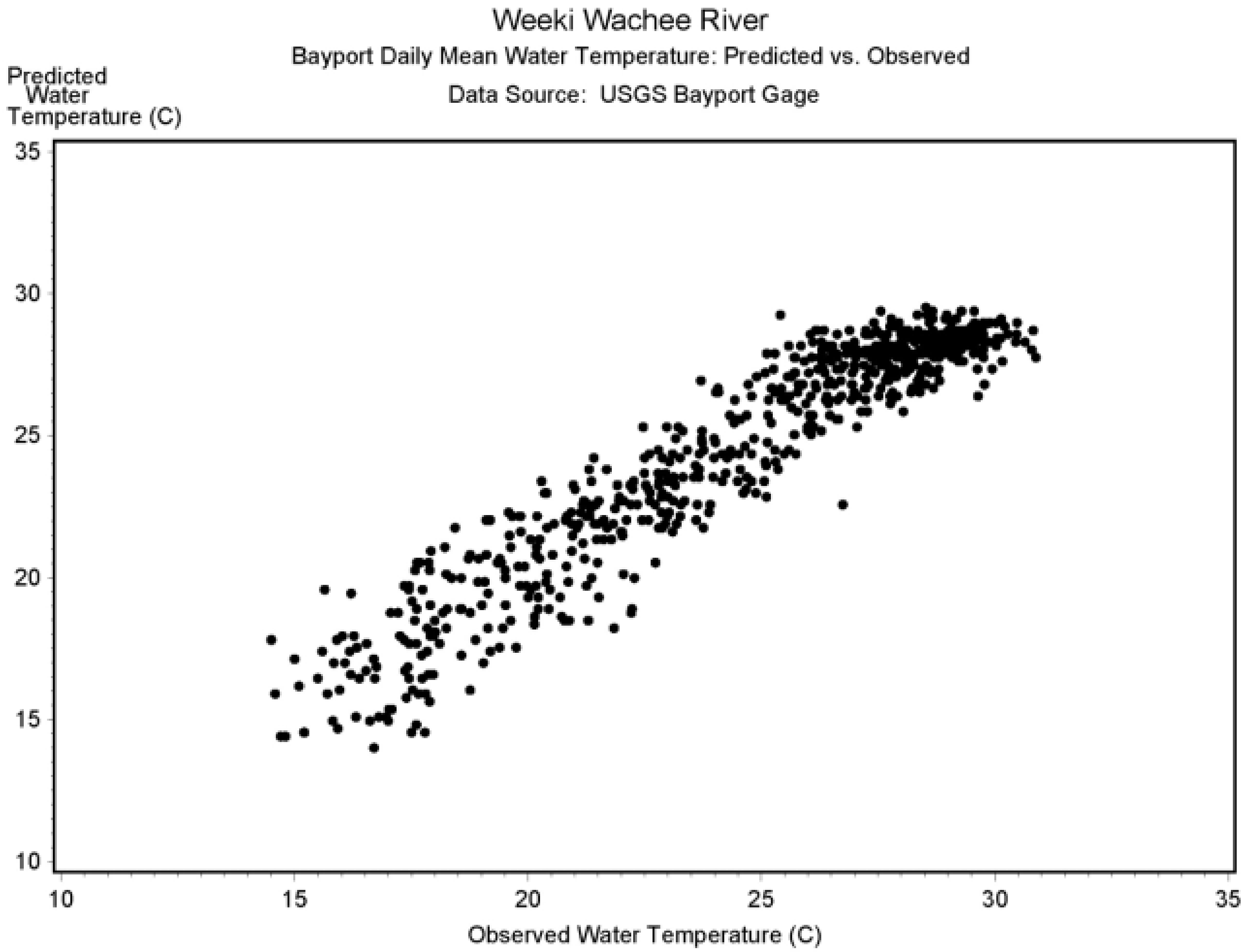

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Figure 5-3
Predicted and Observed Daily Mean Water Temperature at Bayport, with $r^2 = 0.90$

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The predicted mean daily water temperatures are related to the mean daily air temperature as follows:

TEMPw=7.72884+0.73532*TEMPa3,

Where,

TEMPw = mean daily water temperature,

TEMPa3 = (TEMPa+TEMPa-1+TEMPa-2)/3,

TEMPa = the same-day air temperature

TEMPa-1 = the previous day's air temperature, and

TEMPa-2 = the air temperature of two days ago.

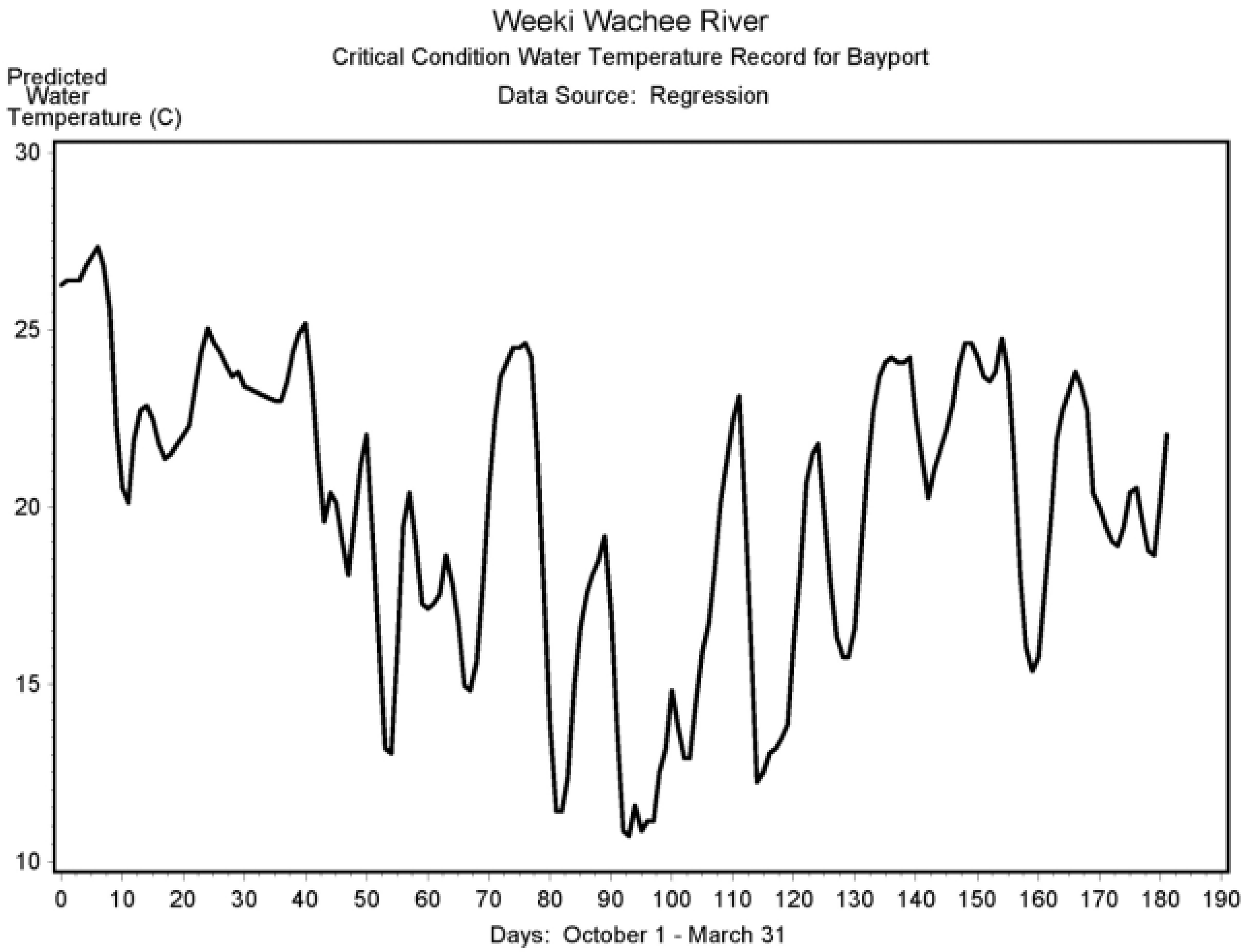
The air temperatures from the previous two days were incorporated to provide for longer-term impacts of air temperature on water temperature.

A water temperature record for October 2000 – March 2001 was developed using the relationship described above, and is provided in Figure 5-4. This record provided the downstream boundary condition for water temperature for the critical-condition flow reduction scenarios.

The meteorologic boundary conditions for the flow reduction simulations were derived from the measured data for the 2000-2001 period identified above. This provides consistency with the data utilized to derive the offshore temperature conditions.

5.2 OFFSHORE WATER LEVEL AND SALINITY

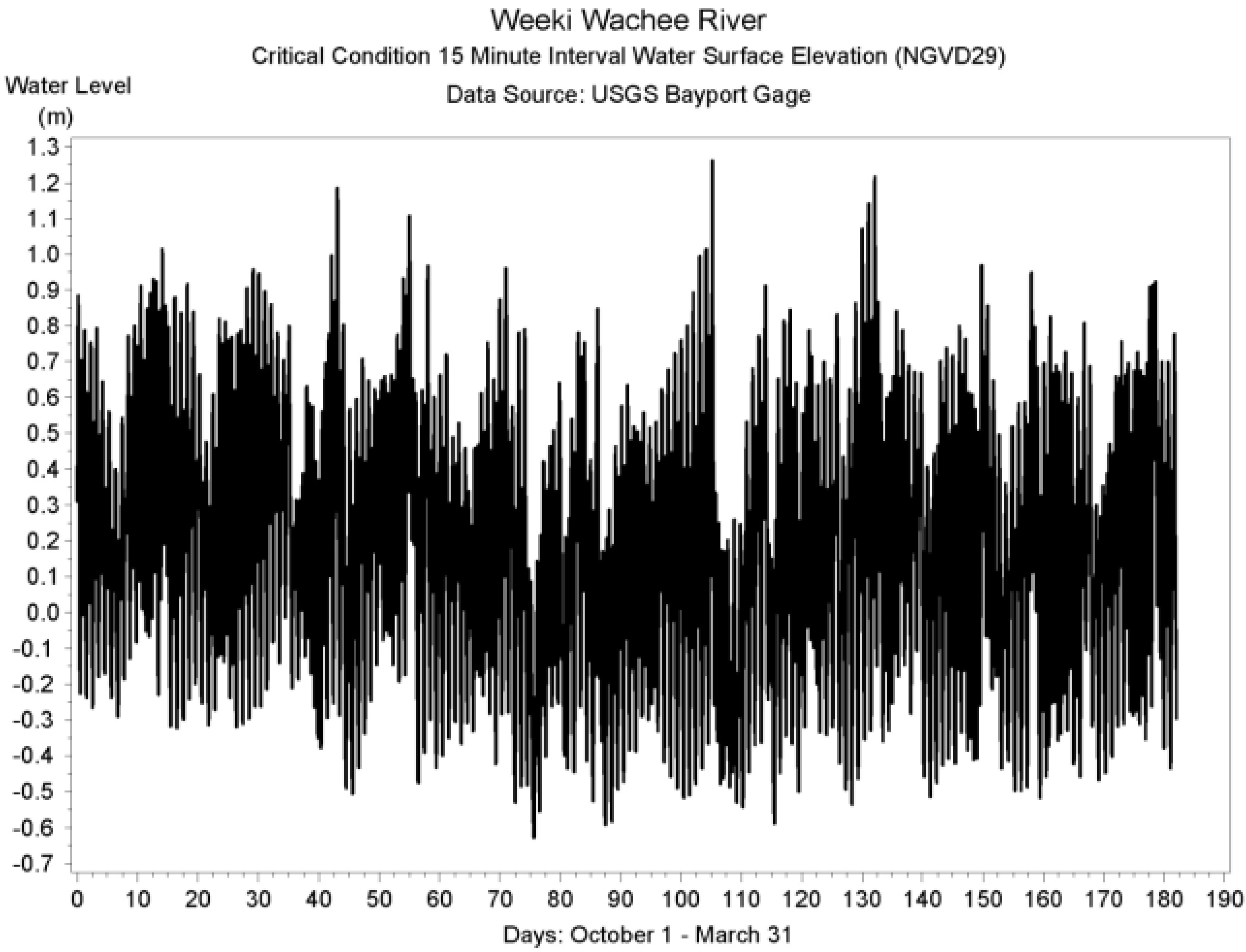
The offshore water level conditions are highly variable and are caused by both astronomical and meteorologic forcing. Identification of a critical period based upon this variability would be difficult, therefore it was determined that a reasonably representative offshore condition be chosen. The offshore condition would need to include sufficient high and low periods and be reflective of typical tides during the colder winter months. For this reason, the period October 2004-March 2005 was chosen as the offshore water level forcing record from the Bayport station. The Bayport tidal record for the critical condition scenarios is provided in Figure 5-5. For consistency, the salinity record for this period was also chosen, the salinity record for this same period is provided in Figure 5-6.



05-1186 5-4.CDR 02/15/07

Figure 5-4

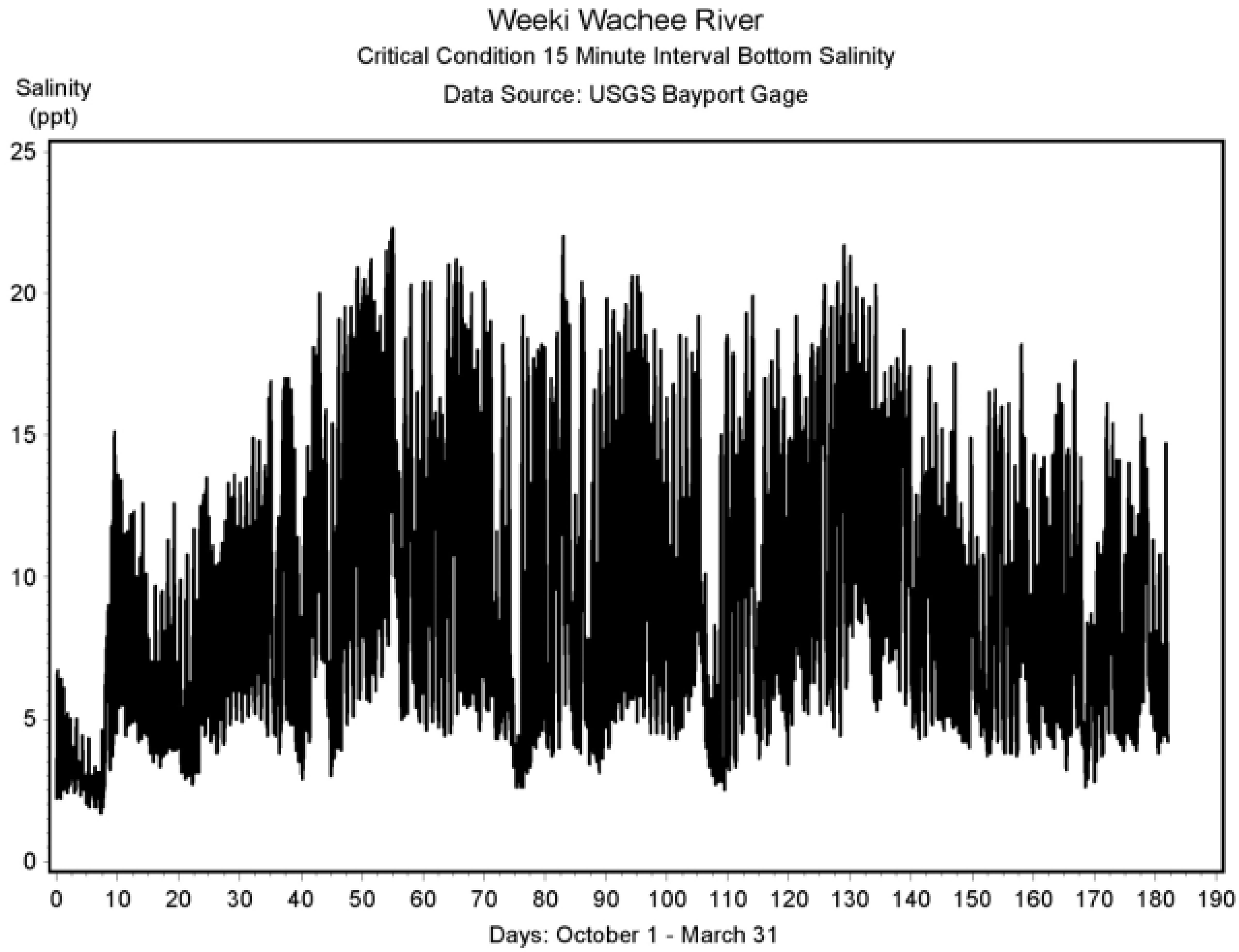
Critical Condition Water Temperature Record for Bayport, Based on Regression Relating Bayport Water Temperature to Air Temperature at Weeki Wachee



05-1186 5-5.CDR 02/15/07

Figure 5-5

Critical Condition Offshore Water Level Forcing for Flow Reduction Scenarios, 15 Minute Frequency



05-1186 5-6.CDR 02/15/07

Figure 5-6
Critical Condition Bottom Salinity for Flow Reduction Scenarios, 15 Minute Frequency

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5.3 SPRING DISCHARGE AND TEMPERATURE

The Weeki Wachee estimated daily discharge for two extreme flow conditions were used to examine the effects of flow reductions during critical temperature conditions. Figure 3-3 presented the historic mean, maximum and minimum flows from Weeki Wachee springs from 1965 to the present. From this data, two periods were chosen that reflected both high and low flow conditions from the springs. The high flow critical condition scenarios utilize spring flows for October 2004-March 2005, with flows as displayed in Figure 5-7. The low flow critical condition scenarios utilize spring flows for October 2000-March 2001, with flows as provided in Figure 5-8. Mud River flows were set to a constant 45 cfs, as in the calibration run. For both systems, inflow temperatures were set to a constant 23°C, as in the calibration run.

5.4 OVERVIEW OF CRITICAL CONDITION

In order to understand the nature of the critical conditions utilized, a joint probability analysis was performed. Appendix C presents plots of the joint probabilities for the high and low flow scenarios utilized.

In order to define the joint probability, the daily records for the manatee season (10/1 through 3/31) from the air temperature, flow and tide data were extracted. For air temperature and flow, 1970 through 2005 data were utilized. For the tide, the maximum daily height for 1986 through 2005 was utilized. These were then ranked and a probability plotting position (Cunane) was determined for each day. This is based upon data from the manatee season.

Using the periods that we chose for our runs, a mean probability for each element was calculated. The average probability of the tide height was 0.42 and the probability of the high flows chosen was 0.84. The low flow chosen was a probability of 0.03. The joint probability (plotted in Appendix C) for the high flow and low flow demonstrated that the high flow event represents a relatively common occurrence while the low flow event (the more critical) represented an extreme condition.

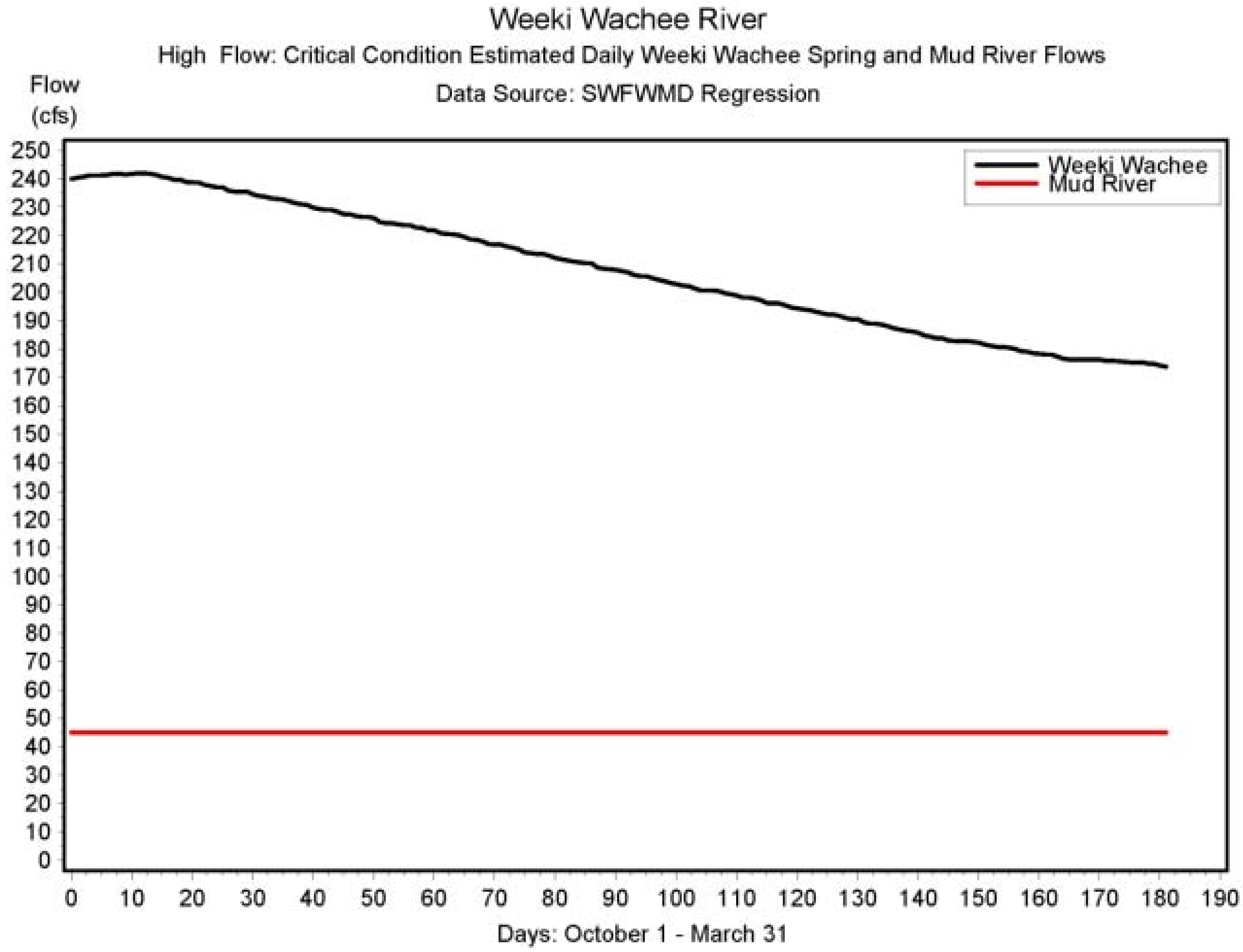
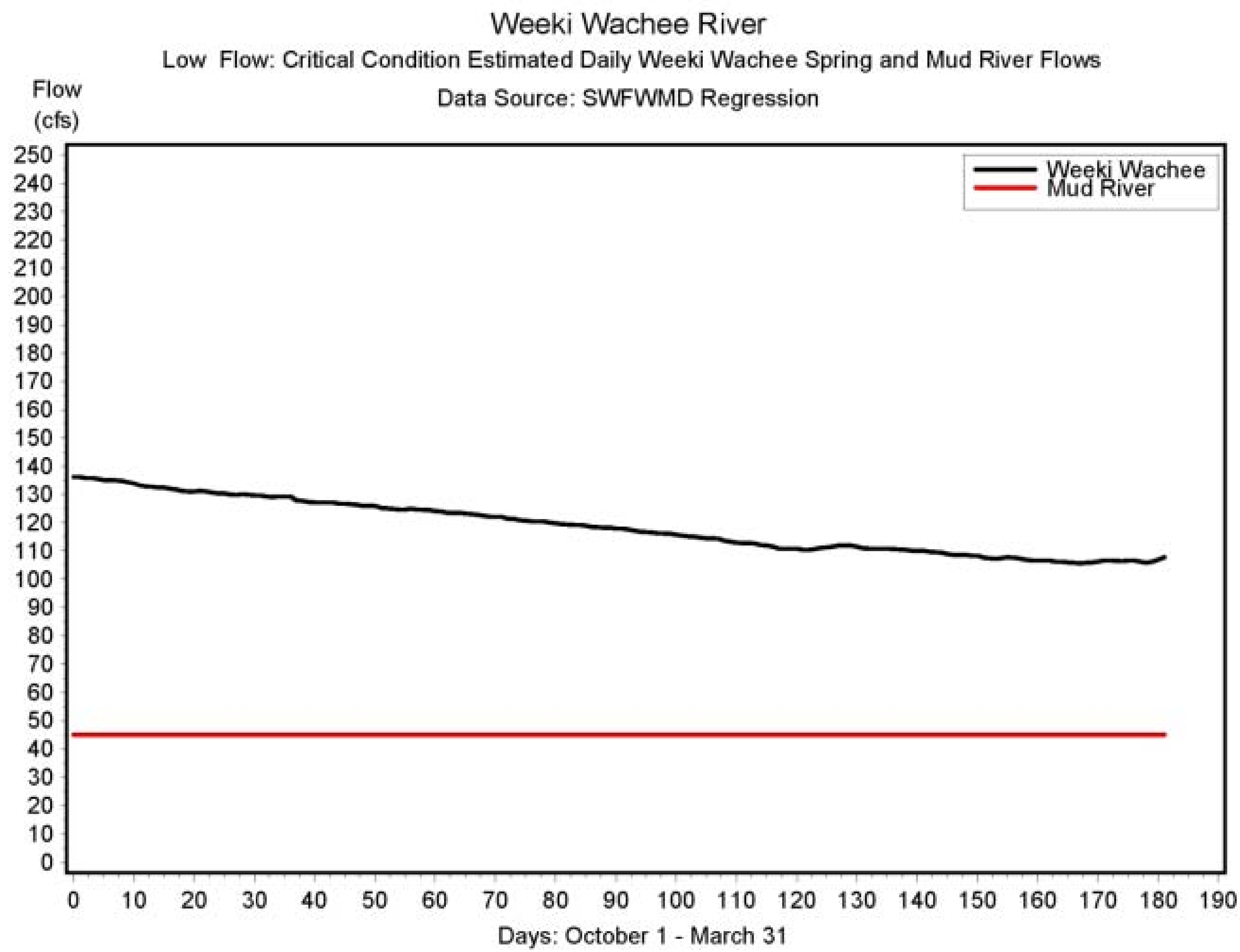


Figure 5-7
High Flow Scenario: Critical Condition Daily Flows from Weeki Wachee Spring and Mud River for Flow Reduction Scenarios (2004-2005)



05-1186 5-8.CDR 09/20/07

Figure 5-8

Low Flow Scenario: Critical Condition Daily Flows from Weeki Wachee Spring and Mud River for Flow Reduction Scenarios (2000-2001)

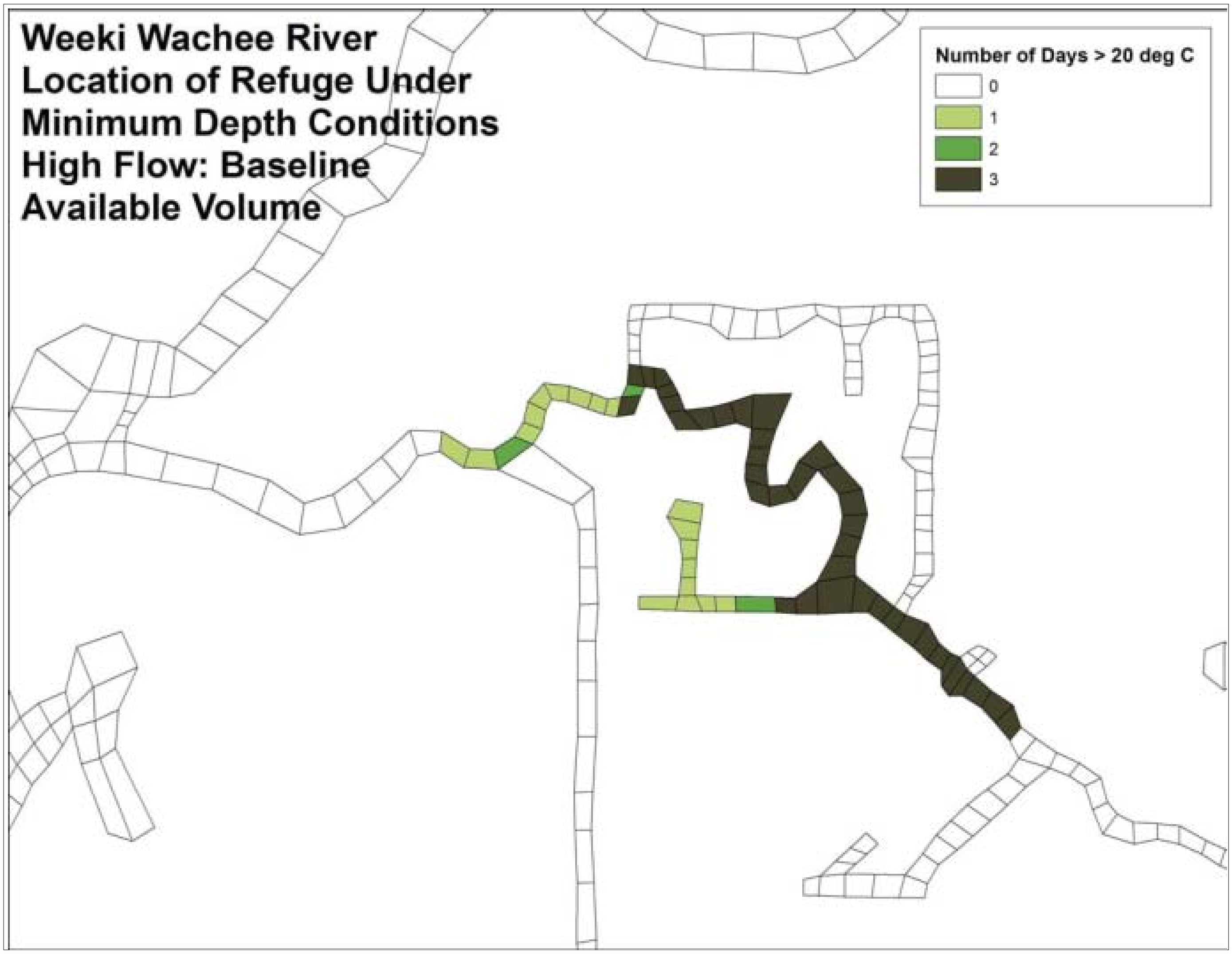
6.0 MINIMUM FLOW DETERMINATION FOR MANATEE HABITAT PROTECTION

Utilizing the critical conditions outlined in Section 5, model runs were performed in order to develop the baseline minimum refuge areas and volumes. The baseline conditions were then compared to a series of flow reductions to determine at what point the surface area or volume of available manatee refuge was reduced by the allowable habitat reduction. The allowable habitat reduction was defined in Section 2 as 15 percent. As discussed earlier, for the flow reduction scenarios, all other model inputs (other than Weeki Wachee flow) were identical to the baseline run conditions. The following outlines the methodology for the determination of the baseline areas, and the results under the two critical flow conditions outlined in Section 5.

6.1 BASELINE REFUGE AREA/VOLUME DETERMINATION

In order to determine the allowable flow reductions that do not exceed the 15 percent habitat reduction target, it is necessary to define a baseline refuge area and volume that will be compared to the area/volume under the reduced flow conditions. The baseline is defined as the minimum area/volume that meets the chronic manatee protection criteria outlined in Section 2, Table 2-1. The chronic condition was utilized for the analyses because the acute criteria (<15°C for more than 4 hours consecutively) was not violated within the Weeki Wachee River area under the critical conditions outlined. The following describes the methodology used to define baseline.

Median daily temperatures for each model grid cell were calculated from the model output for each flow scenario. The median daily temperatures from each scenario were assigned to three-day periods, in keeping with the time frame for the chronic condition. For the baseline of the high flow critical condition scenario, and for the baseline of the low flow critical condition scenario, the volumes and surface areas of ≥20°C water were determined as the mean of the daily values during the three-day period. The metrics were limited to the region of the river shown in Figure 6-1. This region was selected as being accessible to manatees under even the lowest tidal conditions. The region is upstream of the shallow sill at the Mud River confluence, and downstream of the point in the river where depths at lowest tidal levels would not allow for manatee passage upstream to warmer waters.



December 30 - January 1

Location of available refuge volume (volume ≥ 20 °C) for high flow baseline scenario. Volumes upstream and downstream of this refuge volume, and in side canals, may not be accessible to manatee passage during lowest tidal conditions. All cells outside of refuge volume are left uncolored, but this does not necessarily signify temperatures less than 20 °C.

05-1186 Fig 6-1.CDR 09/17/07

Figure 6-1

Location of Available Refuge Volume (volume =20°C) for High Flow Baseline Scenario (3.8' minimum depth)

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For the flow reduction determinations, two baseline flow conditions were outlined in Section 5. The first represents a high baseline flow condition and the second represents a low baseline flow condition. The following presents the results from both.

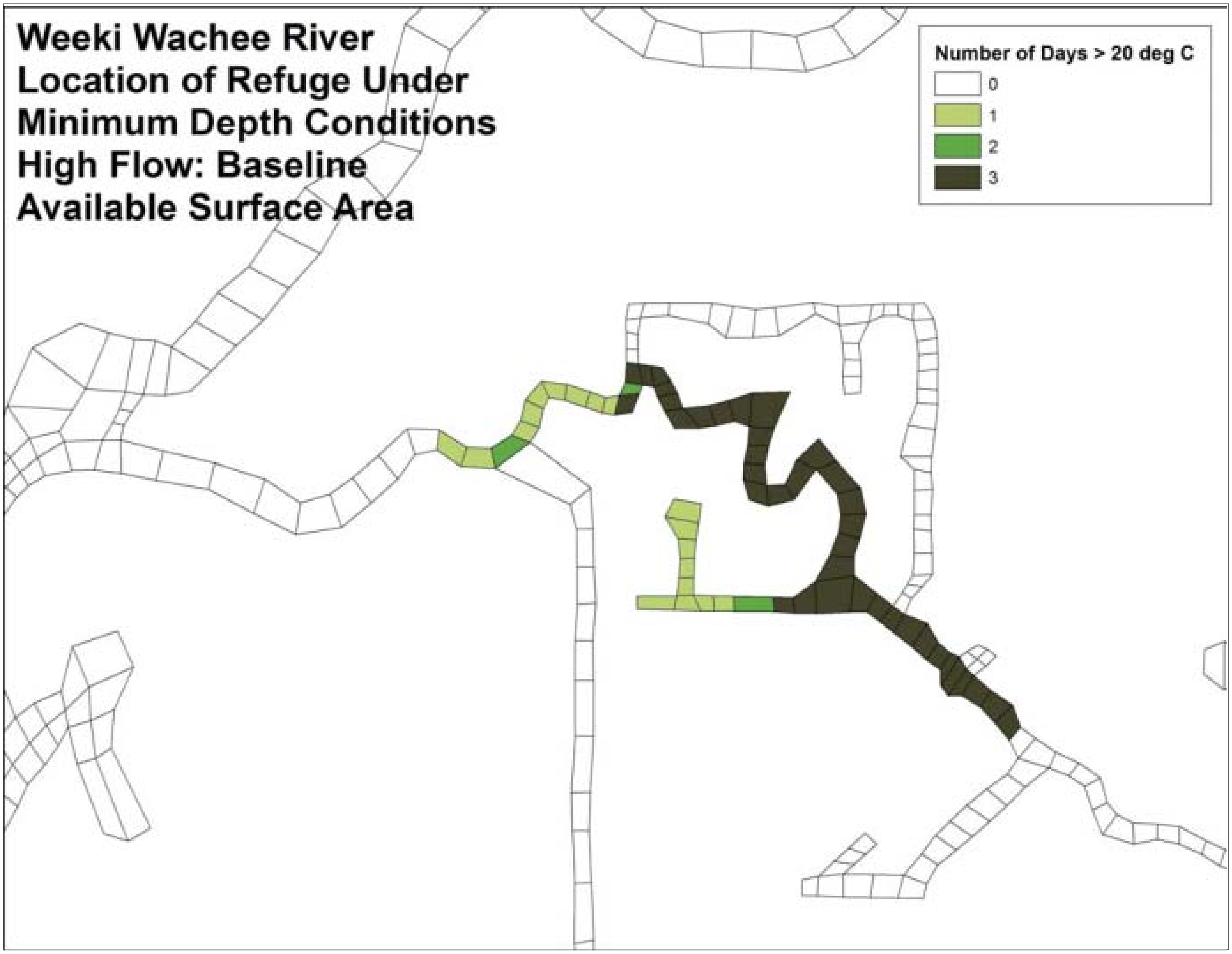
6.2 MINIMUM FLOW DETERMINATION: HIGH FLOW BASELINE

Figure 6-1 shows the location of the available refuge volume provided by the high flow baseline scenario for the period when the changes due to flow reductions are greatest, December 30-January 1. This coincides with the period when water temperatures declined suddenly (Figure 5-4, around day 90). The three-day average volume of this baseline high flow refuge is 92,000 m^3, which is also the minimum volume available during the baseline scenario. The average surface area over the three-day period (Figure 6-2) is 37,200 m^2, which is also the minimum surface area available during the high flow baseline scenario.

For both the volumes and surface areas, the model grid cells included in the available refuge were selected as having median daily temperatures of ≥20°C during at least one day of the critical 3-day period. Thus, the average volumes and surface areas are the results of changes in the extents over the three-day period, but the total extent over which ≥20°C conditions were found during all days of the three-day period is shown.

The location of the available refuge volume in the 5 percent flow reduction scenario (Figure 6-3), with a volume of 85,900 m^3, represents a 7 percent reduction from the baseline, and the refuge surface area for this scenario (Figure 6-4), 34,900 m^2, represents a 6 percent reduction from the baseline. The 10 percent flow reduction scenario, with a volume of 77,400 m^3, results in a 16 percent loss of volume compared to the baseline (Figure 6-5). The available refuge surface area in this scenario (Figure 6-6), 33,500 m^2, represents an 10 percent loss of refuge area. For the 25 percent flow reduction, the volume is reduced by 53 percent and the surface area is reduced by 49 percent, to 43,000 m^3 and 18,900 m^2, respectively, with the location of the volume refuge as shown in Figure 6-7, and that for the surface area refuge in Figure 6-8. For the 50 percent flow reduction, the refuge volume is reduced by 70 percent to 27,400 m^3, as shown in Figure 6-9, and the refuge surface area by 71 percent to 10,700 m^2, as shown in Figure 6-10.

Figures 6-11 and 6-12 show the percentage reductions in refuge volumes and surface areas, respectively, in relation to the baseline metrics, for the three-day period during which



December 30 - January 1

Location of available refuge surface area (surface area ≥ 20 °C) for high flow baseline scenario. Areas upstream and downstream of this refuge area, and in side canals, may not be accessible to manatee passage during lowest tidal conditions. All cells outside of refuge surface area are left uncolored, but this does not necessarily signify temperatures less than 20 °C.

05-1186 Fig 6-2.CDR 09/17/07

Figure 6-2

Location of Available Refuge Surface Area (surface area =20°C) for High Flow Baseline Scenario (3.8' minimum depth)

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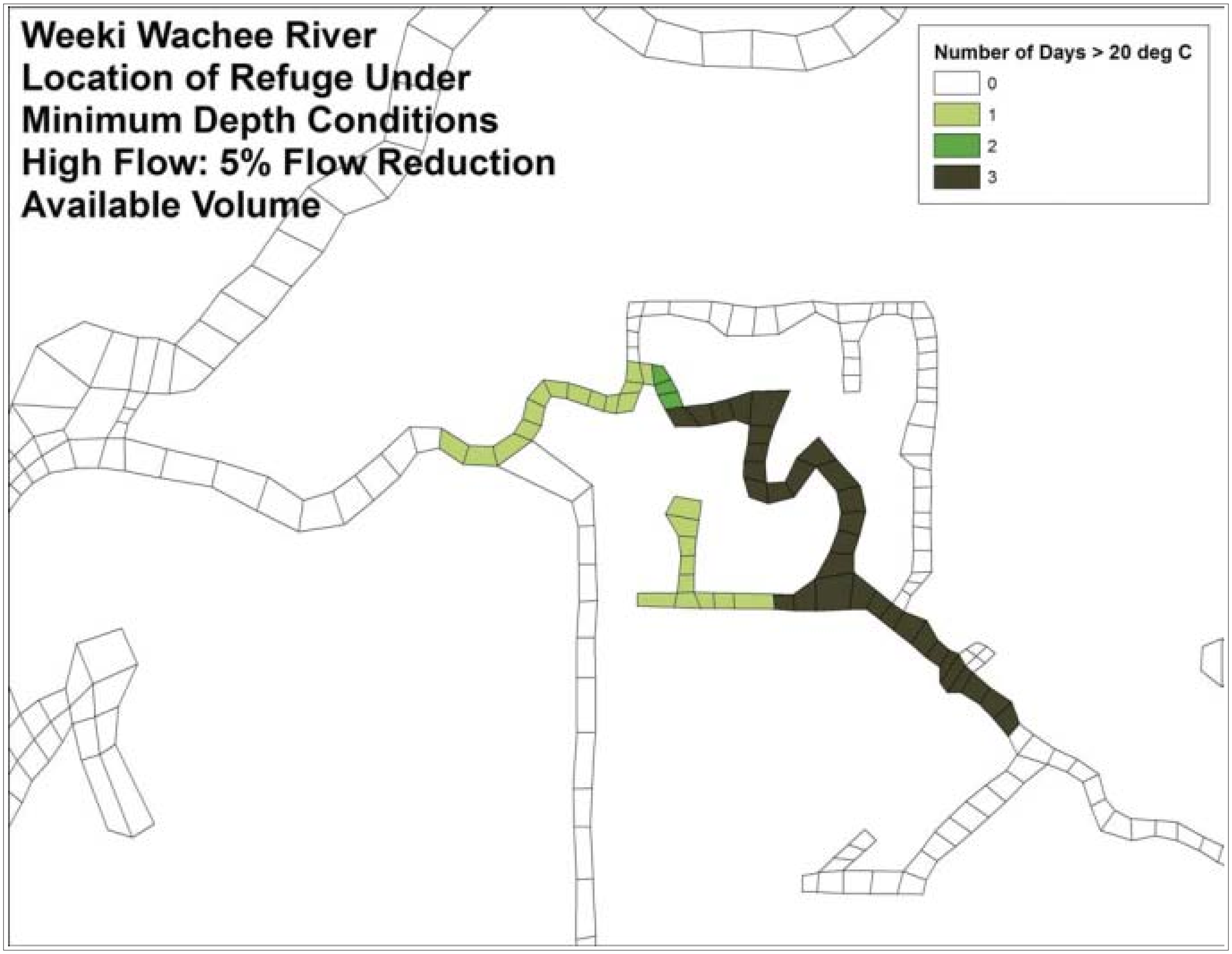

December 30 - January 1

05-1186 Fig 6-3.CDR 09/17/07

Figure 6-3
Location of Available Refuge Volume (volume =20°C) for High Flow 5% Flow Reduction Scenario (3.8' minimum depth)

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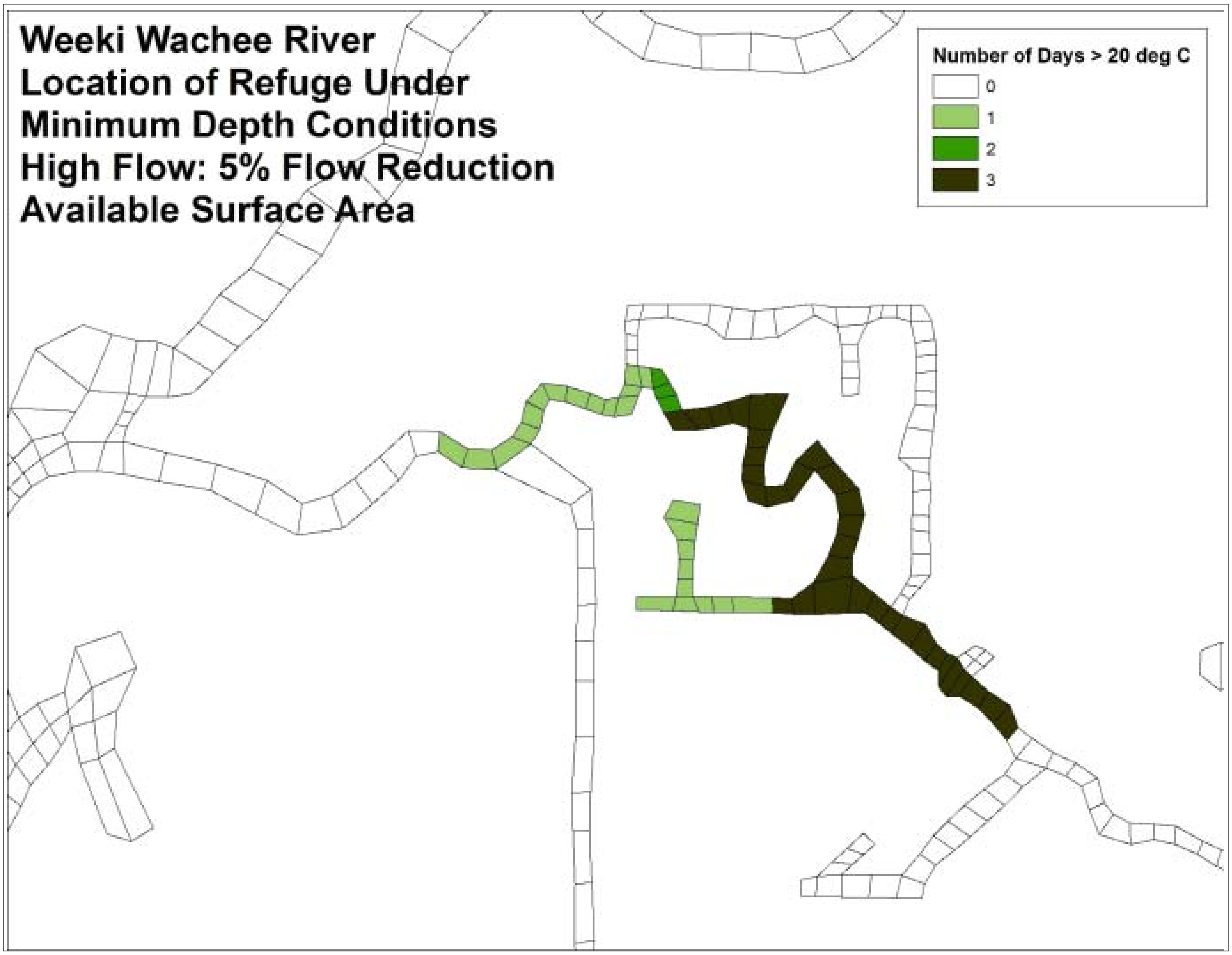

December 30 - January 1

05-1186 Fig 6-4.CDR 09/17/07

Figure 6-4

Location of Available Refuge Surface Area (surface area =20°C) for High Flow 5% Flow Reduction Scenario (3.8' minimum depth)

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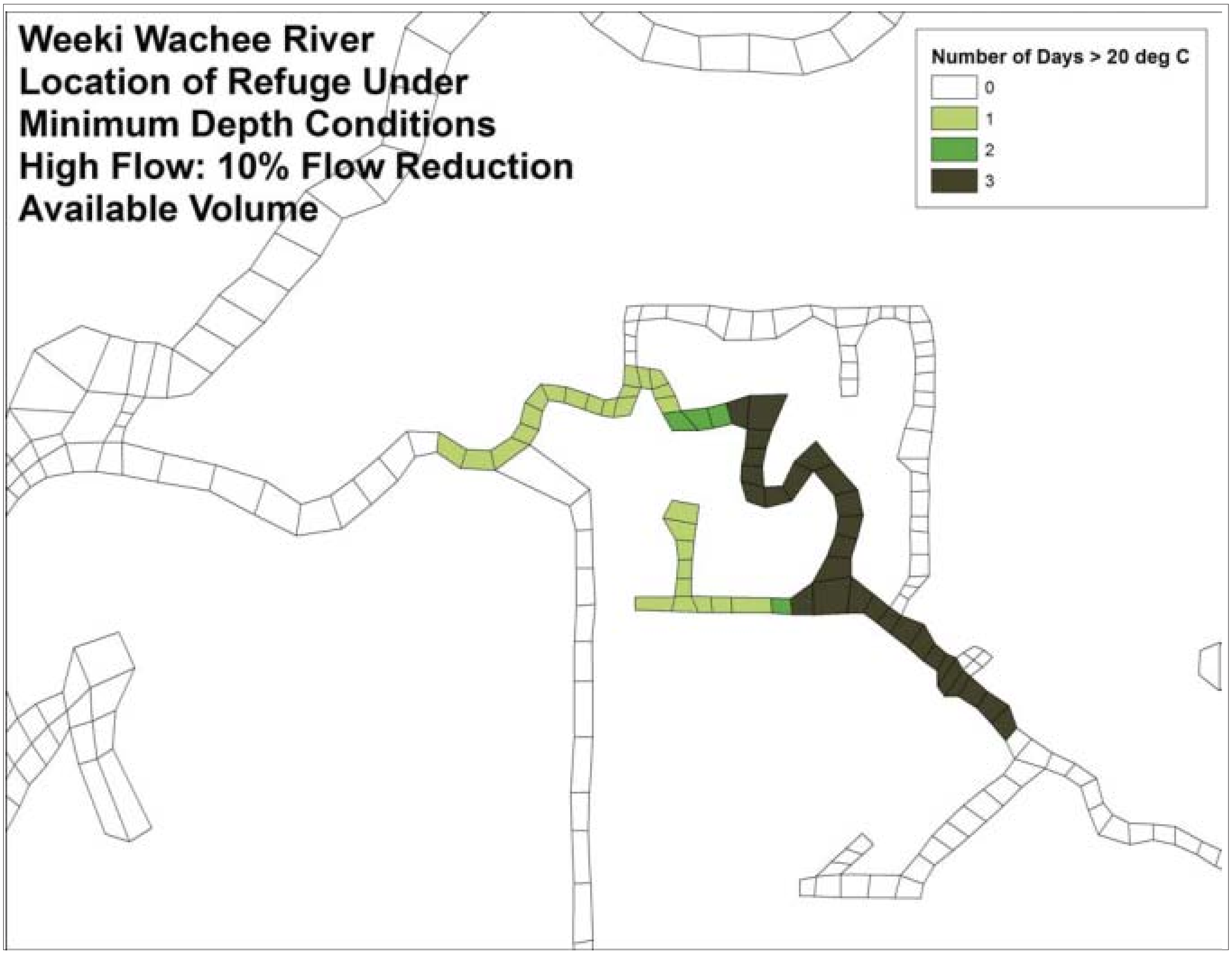

December 30 - January 1

05-1186 Fig 6-5.CDR 09/17/07

Figure 6-5
Location of Available Refuge Volume (volume =20 °C) for High Flow 10% Flow Reduction Scenario (3.8’ minimum depth)

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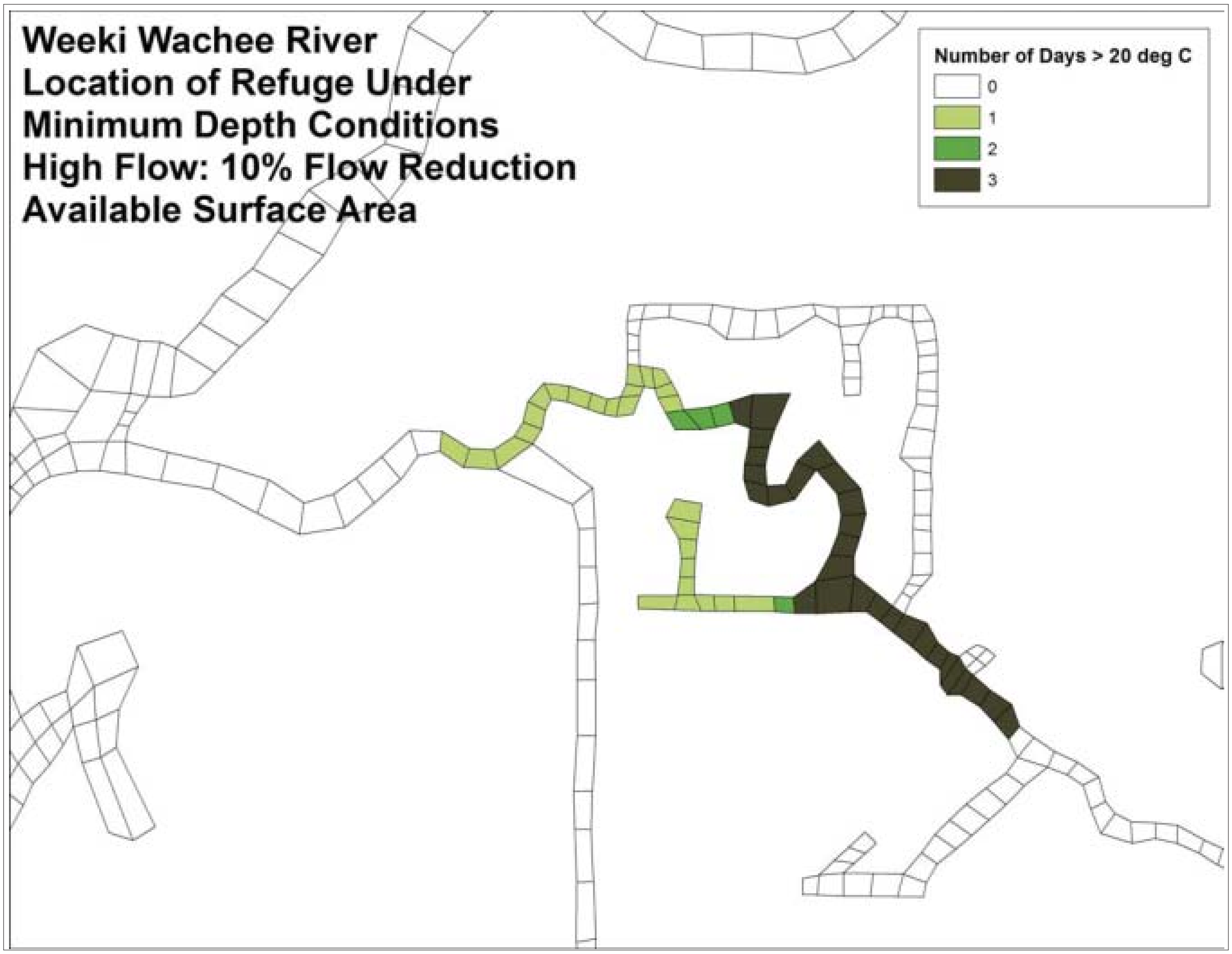
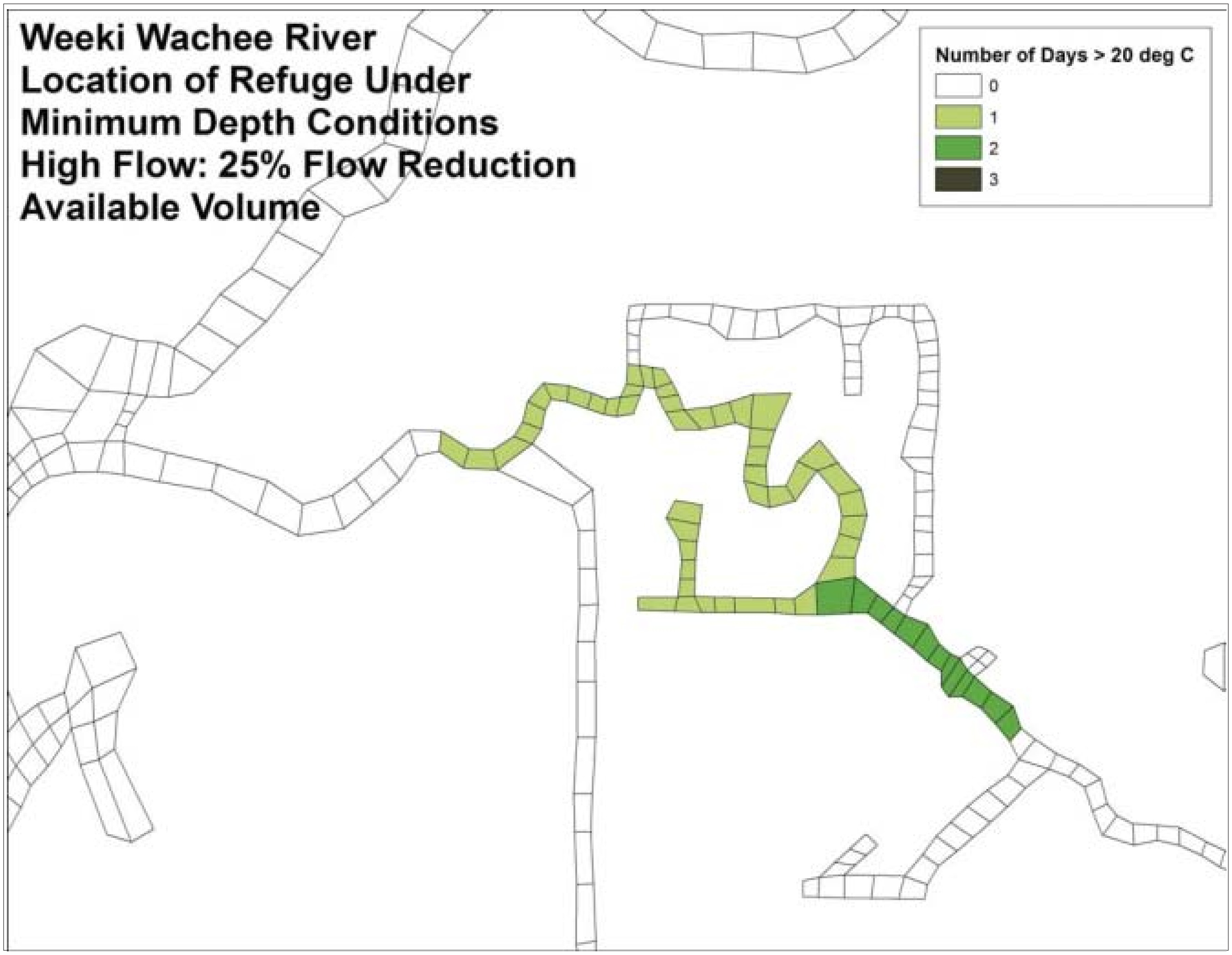


December 30 - January 1

05-1186 Fig 6-6.CDR 09/17/07

Figure 6-6

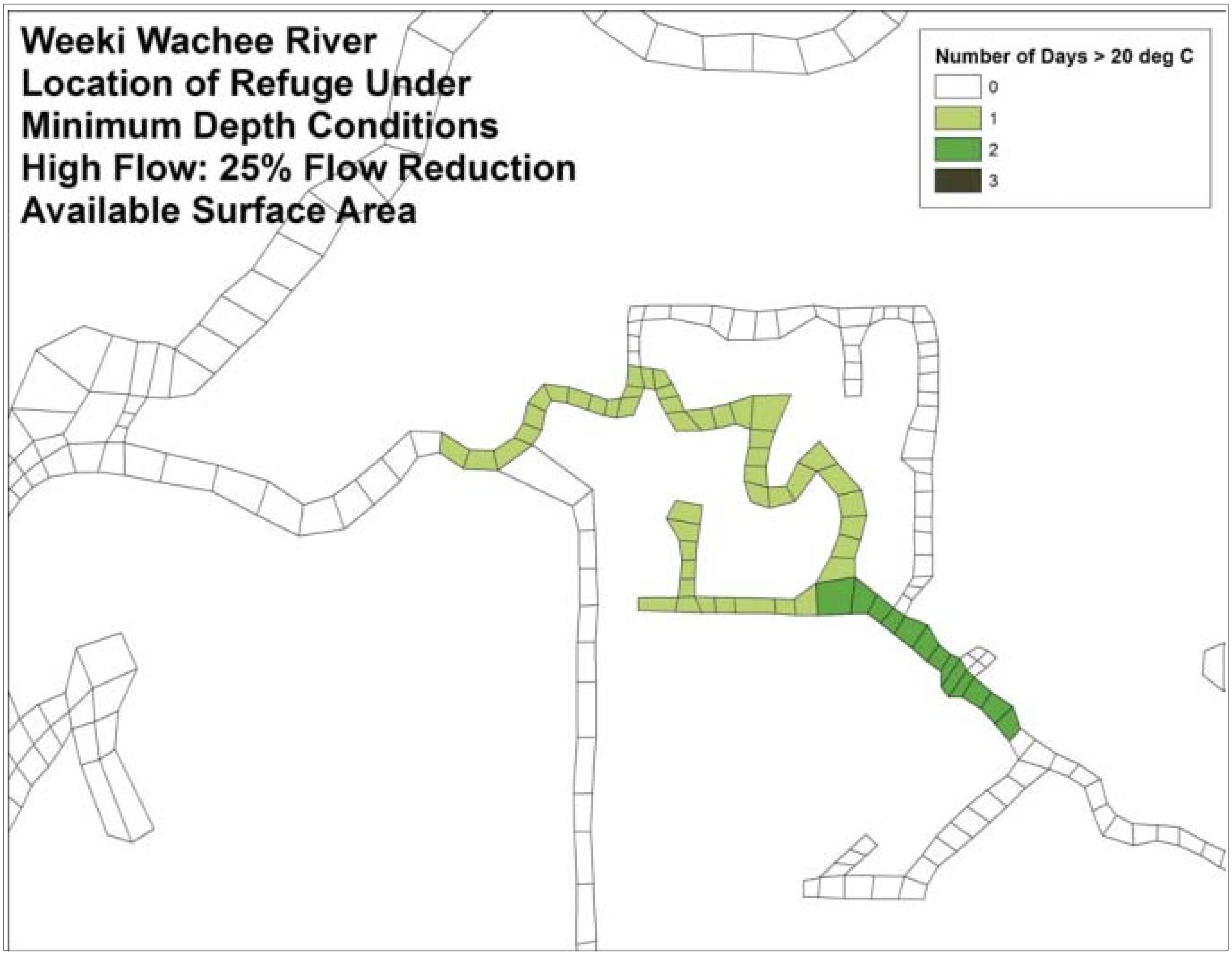
Location of Available Refuge Surface Area (surface area =20°C) for High Flow 10% Flow Reduction Scenario (3.8' minimum depth)



December 30 - January 1

05-1186 Fig 6-7.CDR 09/17/07

Figure 6-7
Location of Available Refuge Volume (volume =20°C) for High Flow 25% Flow Reduction Scenario (3.8' minimum depth)

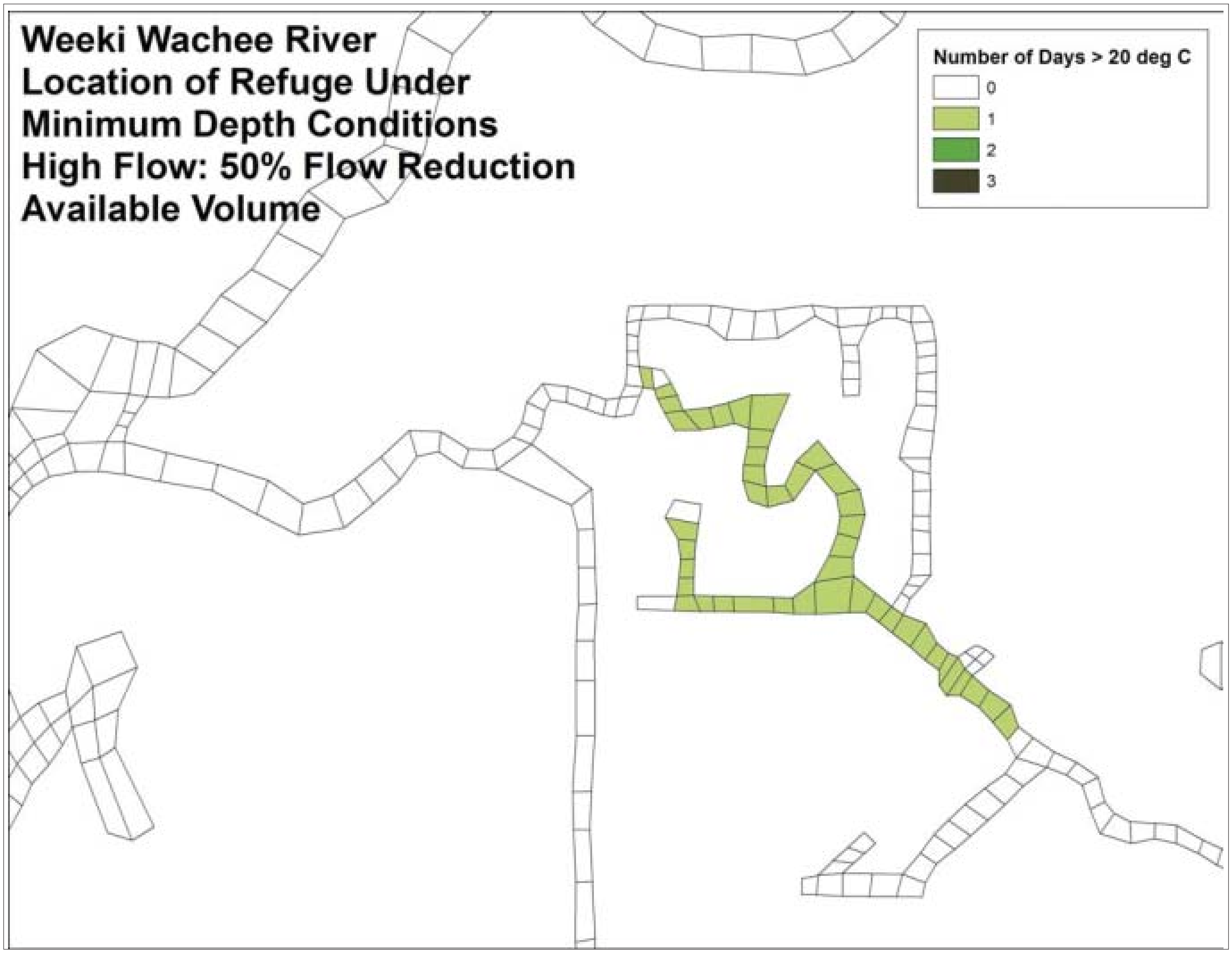


December 30 - January 1

05-1186 Fig 6-8.CDR 09/17/07

Figure 6-8

Location of Available Refuge Surface Area (surface area =20°C) for High Flow 25% Flow Reduction Scenario (3.8' minimum depth)

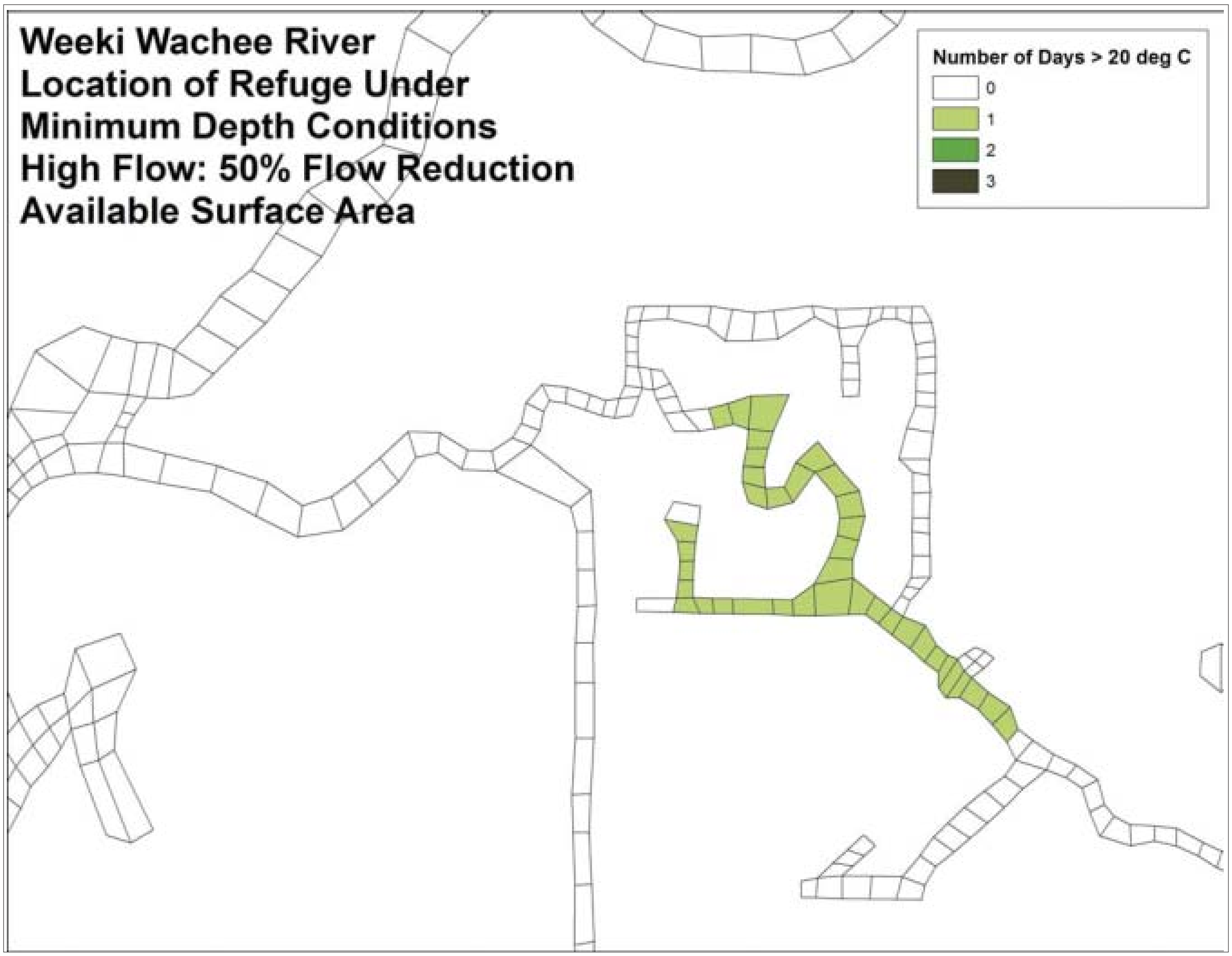


December 30 - January 1

05-1186 Fig 6-9.CDR 09/17/07

Figure 6-9

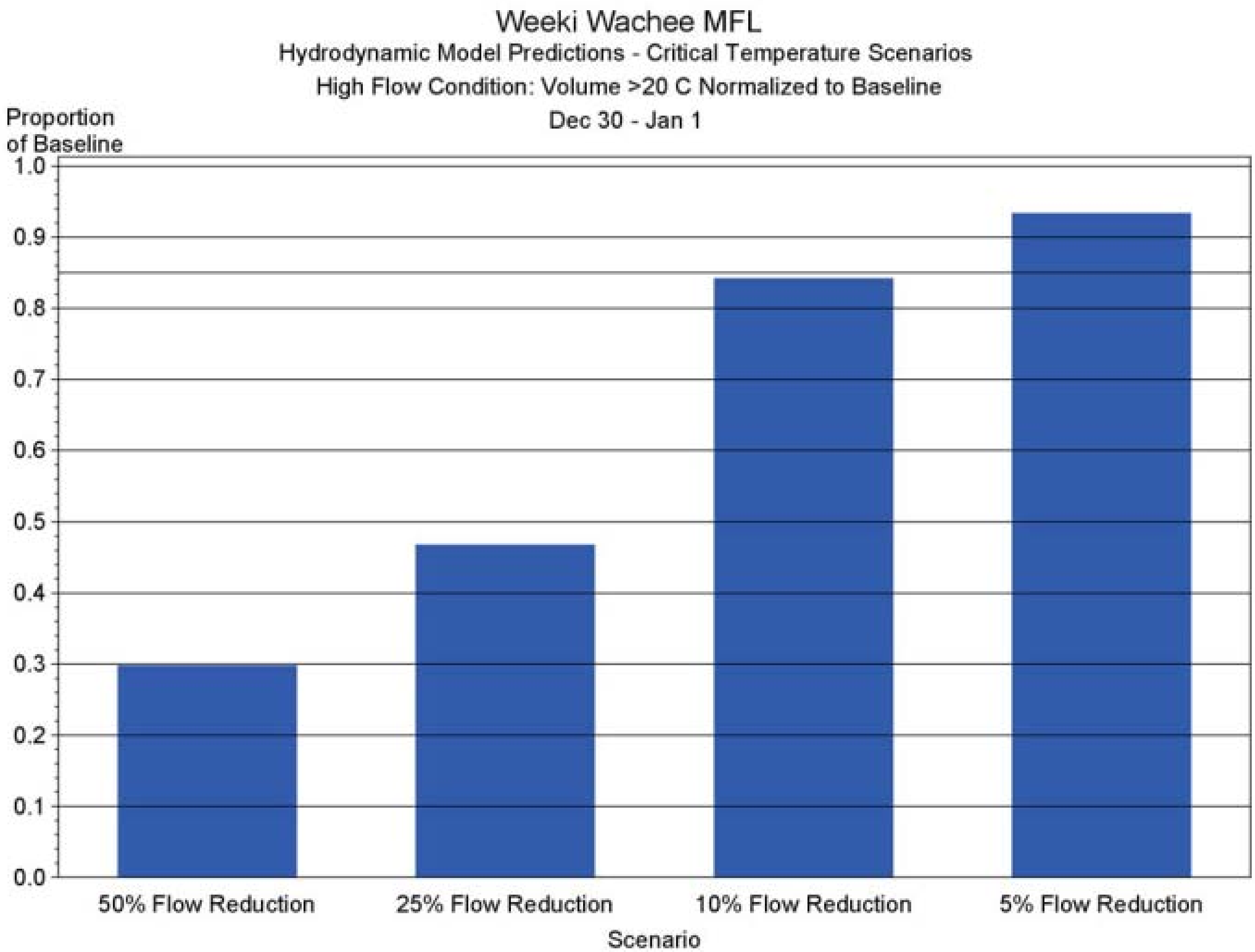
Location of Available Refuge Volume (volume =20°C) for High Flow 50% Flow Reduction Scenario (3.8’ minimum depth)



December 30 - January 1

05-1186 Fig 6-10.CDR 09/17/07

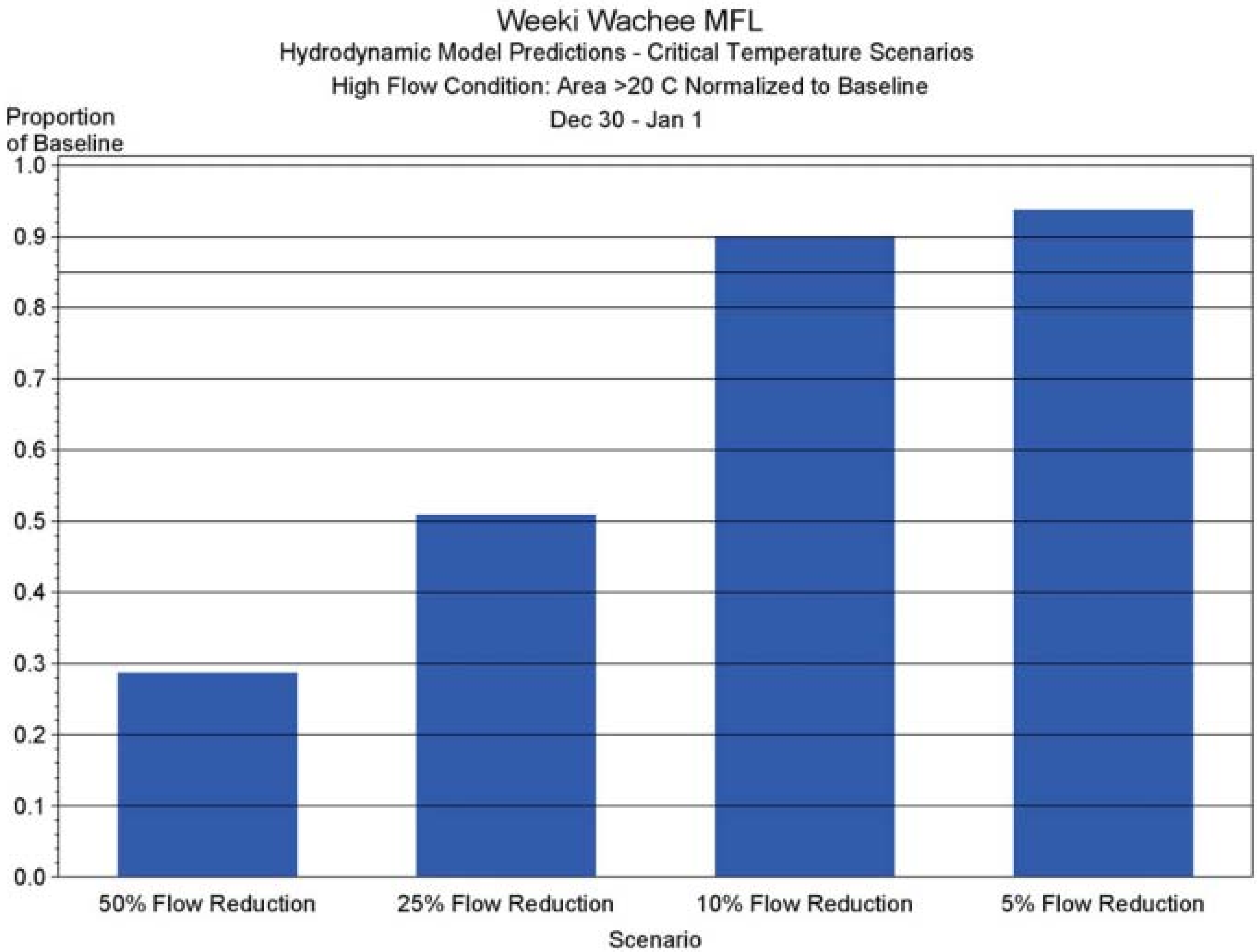
Figure 6-10
Location of Available Refuge Surface Area (surface area =20°C) for High Flow 50% Flow Reduction Scenario (3.8' minimum depth)



The horizontal line at 0.85 on the y-axis shows the 15% habitat reduction threshold.

05-1186 Fig 6-11.CDR 09/17/07

Figure 6-11
High Flow Condition: Comparison of Refuge Volume Reductions Resulting from Flow Reduction Scenarios for the 3-Day Period with Largest Reductions, December 30-January 1 (3.8' minimum depth)



The horizontal line at 0.85 on the y-axis shows the 15% habitat reduction threshold.

05-1186 Fig 6-12.CDR 09/17/07

Figure 6-12
High Flow Condition: Comparison of Refuge Surface Area Reductions Resulting from Flow Reduction Scenarios for the 3-Day Period with Largest Reductions, December 30-January 1 (3.8' minimum depth)

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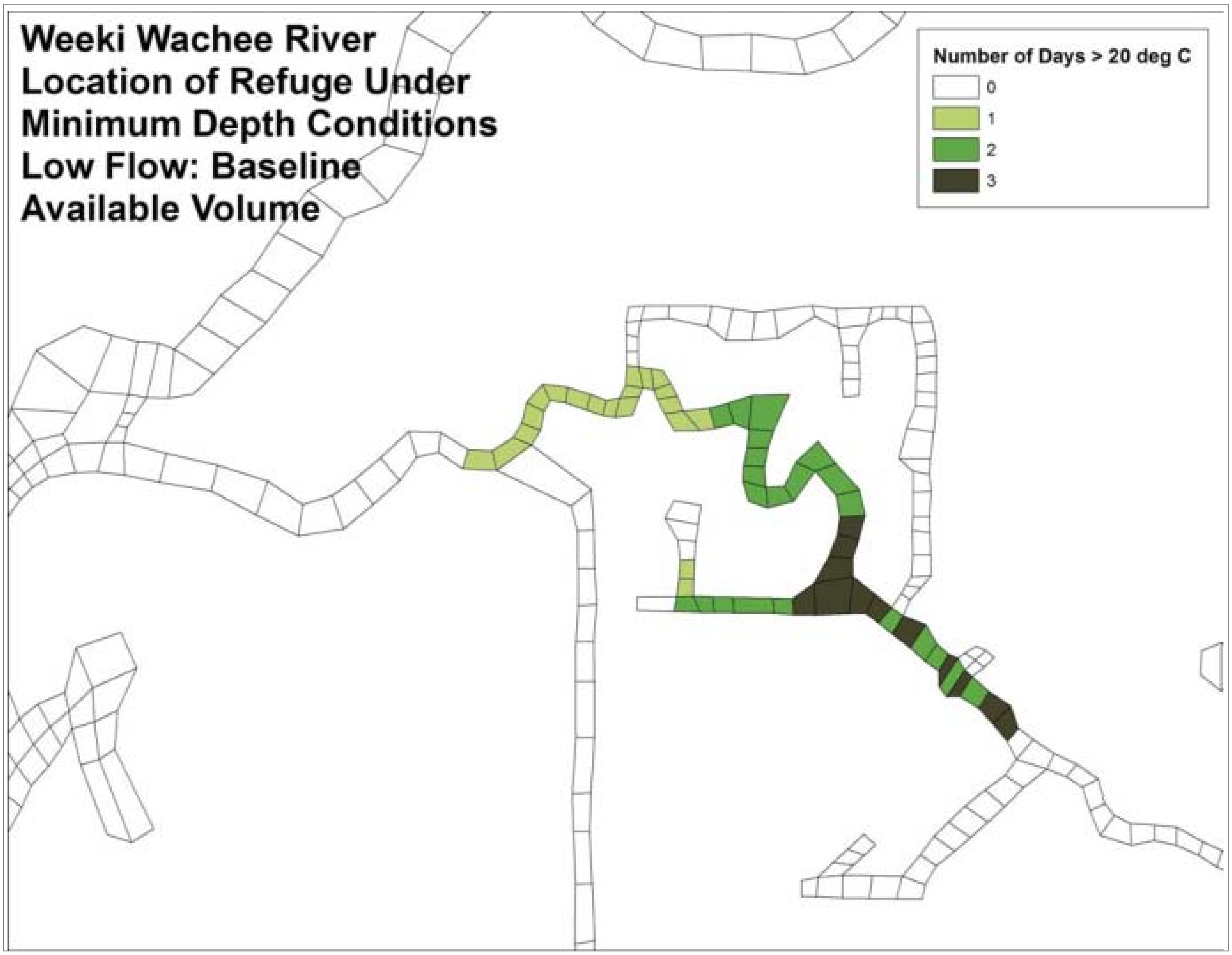
greatest reductions occurred. For the high flow condition, the 10 percent flow reduction violates the reduction criteria for the volume, while the surface area for the 10 percent flow reduction does not violate the criteria. The violation is just above the criteria for the volume (16 percent versus 15 percent). Both volume and area changes under the 25 percent flow reduction significantly violate the volume and surface area change critieria. This suggests that for the high flow condition, a flow reduction just under 10 percent is the greatest flow reduction allowable to maintain the habitat requirements with respect to the manatee temperature criteria.

6.3 MINIMUM FLOW DETERMINATION: LOW FLOW BASELINE

As demonstrated in Section 6.2, the change in percent habitat due to incremental flow reductions becomes greater as the flows are reduced. This is due to a reduction in the upstream opposing gradient causing a greater net movement into the refuge area. Therefore the low flow baseline becomes the more critical condition relative to habitat change, as well as available baseline habitat volume and area. The following presents the results of the flow reductions for the low flow baseline condition.

Figure 6-13 shows the location of the available refuge volume provided by the low flow baseline scenario for the period when the changes due to flow reductions are greatest, January 3-5. This coincides with the period when water temperatures were very low (Figure 5-4, around day 94). The three-day average volume of this refuge for this three-day period (Figure 6-13) is 55,700 m^3, which is also the minimum volume available during the low flow baseline scenario. The average surface area over the three-day period (Figure 6-14) is 27,500 m^2, which is also the minimum surface area available during the low flow baseline scenario.

For both the volumes and surface areas, the model grid cells included in the available refuge were selected as having median daily temperatures of ≥20°C during at least one day of the period. Thus, the average volumes and surface areas are the results of changes in the extents over the three-day period, but the total extent over which ≥20°C conditions were found during any one day of the three-day period is shown.



January 3-5

Location of available refuge volume (volume ≥ 20 °C) for low flow baseline scenario. Areas upstream of this refuge area, in most side canals, and downstream of the Mud River junction may not be accessible to manatee passage during lowest tidal conditions. All cells outside of refuge volume are left uncolored, but this does not necessarily signify temperatures less than 20 °C.

05-1186 Fig 6-13.CDR 09/17/07

Figure 6-13
Location of Available Refuge Volume (volume =20°C) for Low Flow Baseline Scenario (3.8’ minimum depth)

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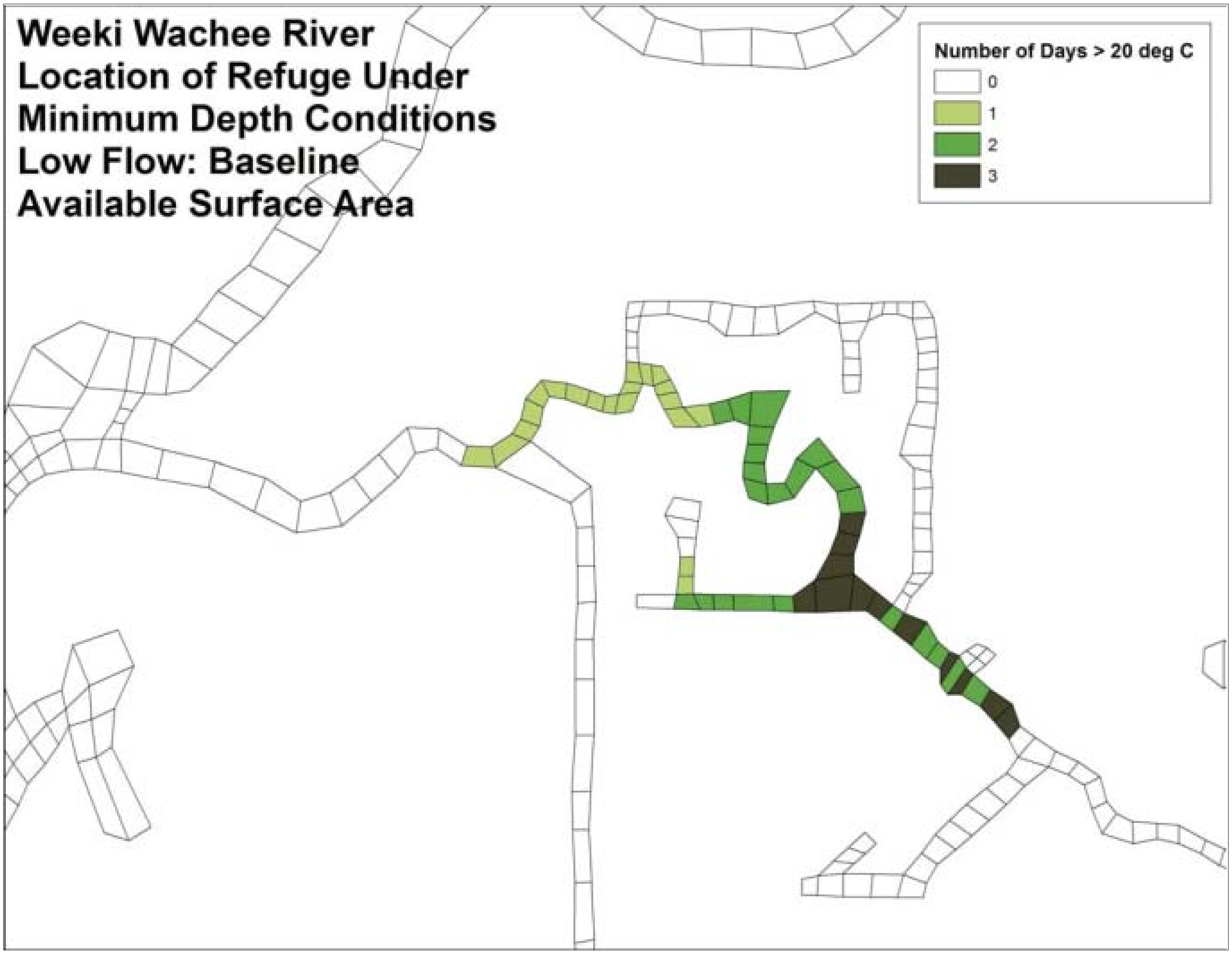


January 3-5

Location of available refuge surface area (surface area ≥ 20 °C) for low flow baseline scenario. Areas upstream of this refuge area, in most side canals, and downstream of the Mud River junction may not be accessible to manatee passage during lowest tidal conditions. All cells outside of refuge surface area are left uncolored, but this does not necessarily signify temperatures less than 20 °C.

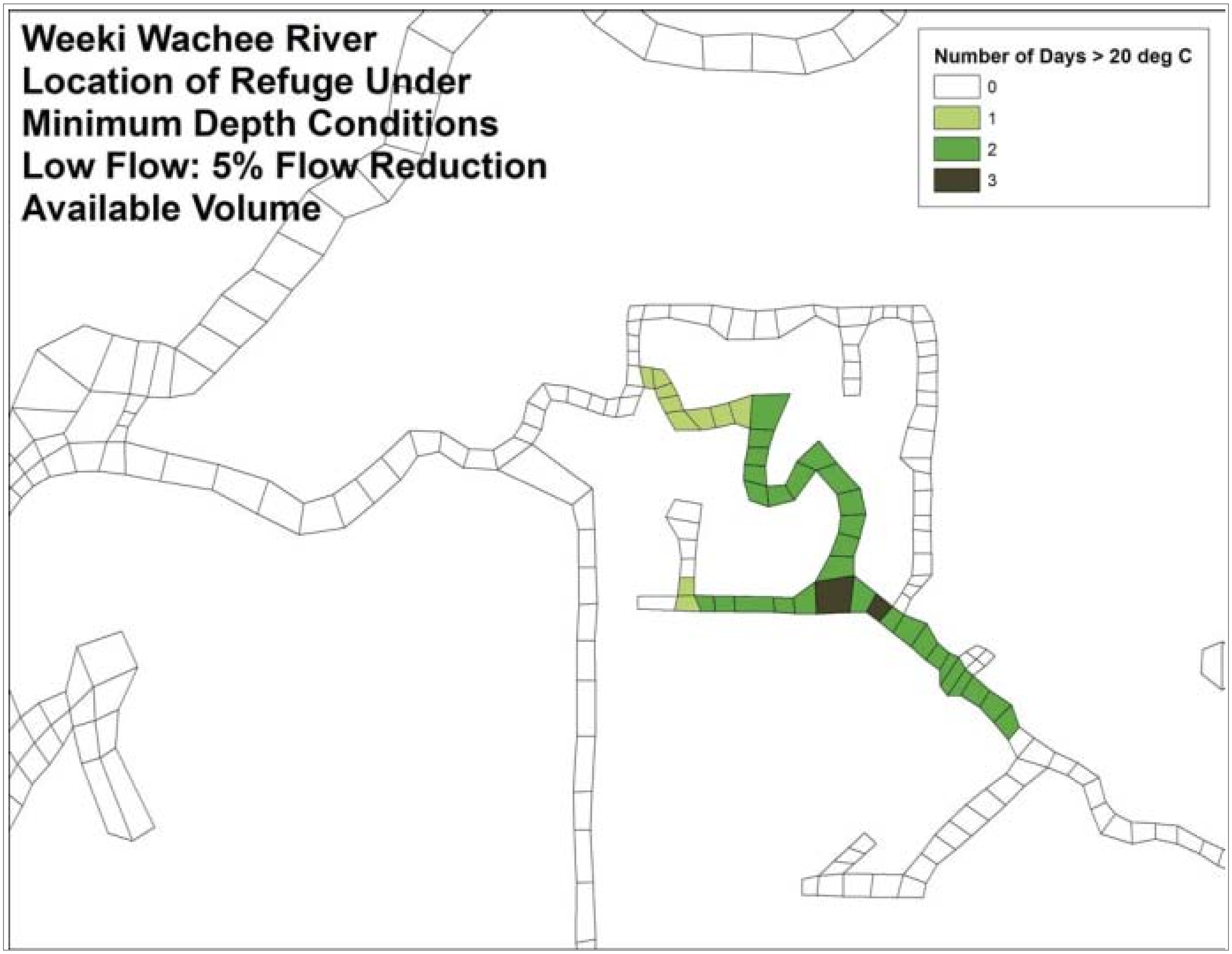
05-1186 Fig 6-14.CDR 09/17/07

Figure 6-14
Location of Available Refuge Surface Area (surface area =20°C) for Low Flow Baseline Scenario (3.8'minimum depth)

The location of the available refuge volume in the 5 percent flow reduction (Figure 6-15), when the volume is 46,100 m^3, is a 17 percent reduction from the baseline volume. The available refuge surface area for the 5 percent flow reduction (Figure 6-16), 21,100 m^2, is a 23 percent reduction from the baseline surface area. Under the 10 percent flow reduction scenario, the volume in the refuge is 37,900 m^3, representing a 32 percent reduction from the baseline (Figure 6-17). For the surface area of the refuge, a 10 percent flow reduction results in an area of 18,200 m^2, a 34 percent reduction from the baseline (6-18). For the 25 percent flow reduction, the volume is reduced by 80 percent, to 11,300 m^3, and the surface area by 78 percent, to 6,000 m^2, with the location of the volume refuge as shown in Figure 6-19, and that for the surface area refuge in Figure 6-20. For the 50 percent flow reduction, the refuge volume and surface area no longer exist, with all daily median temperatures within the potential refuge zone less than 20°C for the three-day period.

Figures 6-21 and 6-22 show the percentage reductions in refuge volume and area, respectively, in relation to the low flow baseline metrics, for the three-day period during which greatest reductions occurred. For the low flow condition, for both volume and surface area, the maximum reductions for the 5 percent flow reduction scenario are greater than the 15 percent allowable habitat reduction. This suggests that this low flow condition provides the limiting condition for the critical condition temperatures, and that a 15 percent habitat change threshold occurs at some flow reduction less than the minimum of 5 percent examined.

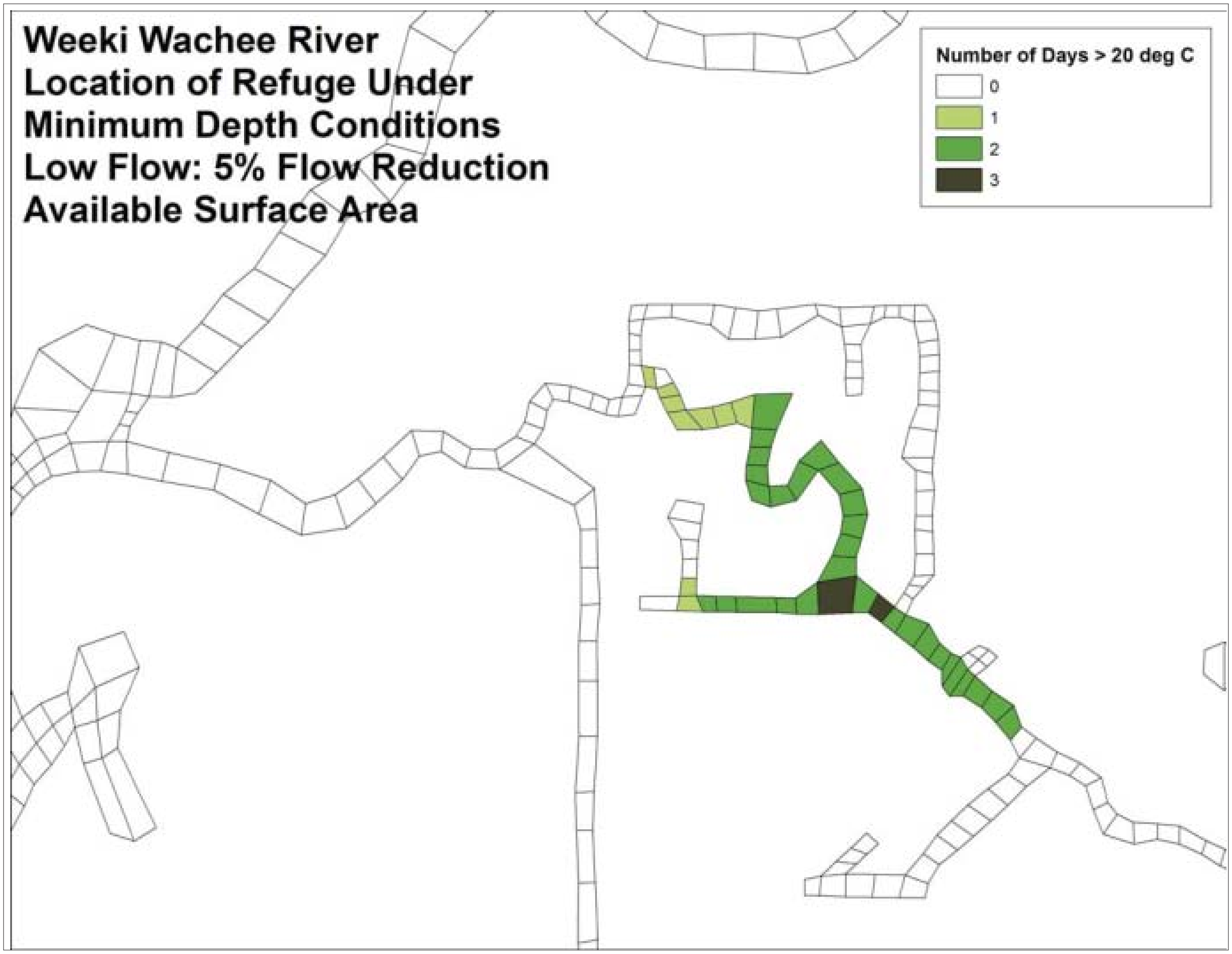
At the 5 percent flow reduction for the low flow condition, there are two three-day periods when refuge volumes and refuge surface areas drop below 85 percent of low flow baseline refuge, with a maximum volume reduction of 17 percent and a maximum surface area reduction of 23 percent. Given that this is a worst-case scenario, with lowest water levels from the period of record and lowest temperatures (derived from lowest air temperatures during the period of record), the 5 percent flow reduction scenario may be considered as the maximum reduction while still maintaining habitat reduction of 15 percent or less for almost all of the time, with the exception of two three-day periods.



January 3-5

05-1186 Fig 6-15.CDR 09/17/07

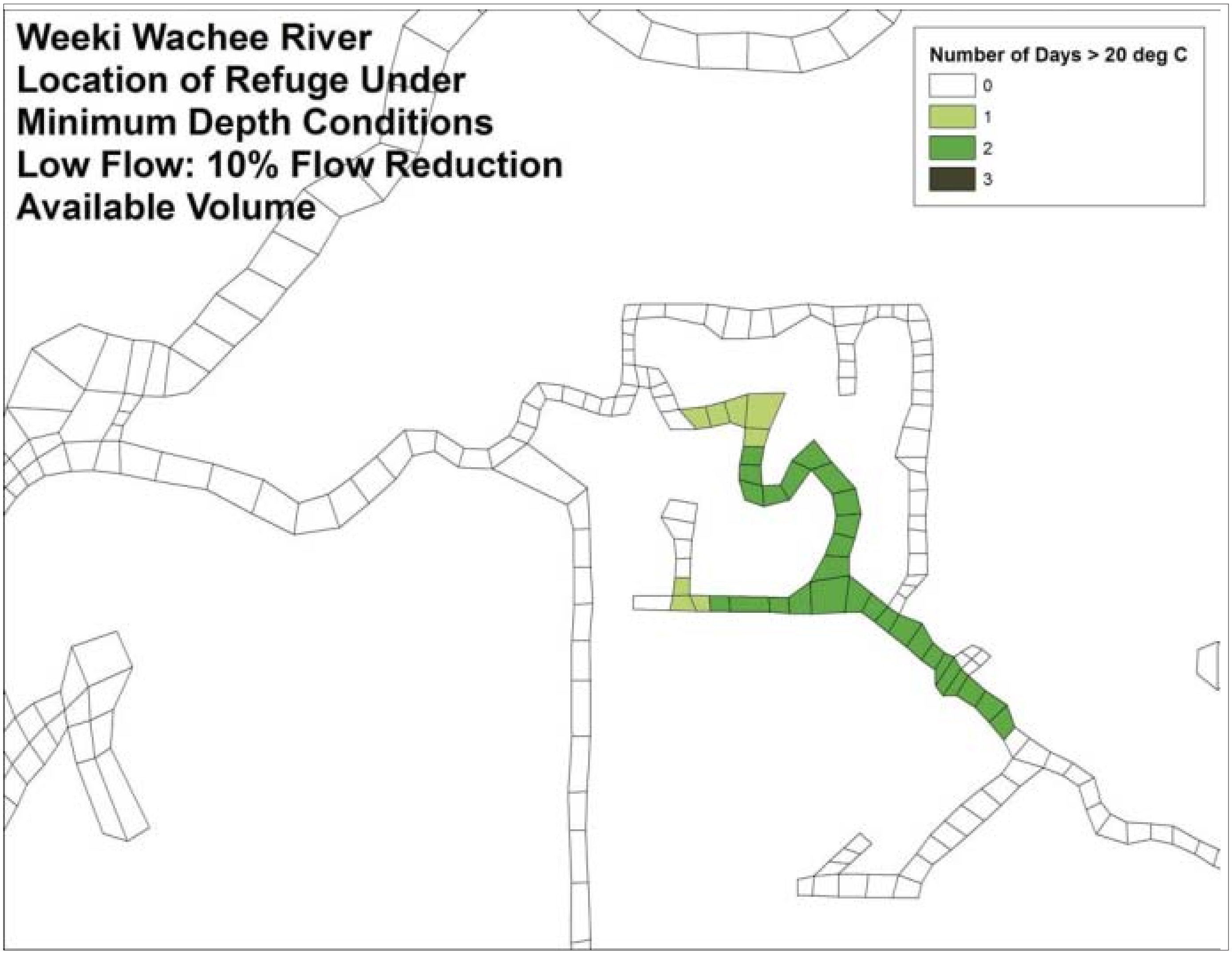
Figure 6-15
Location of Available Refuge Volume (volume =20°C) for Low Flow 5% Flow Reduction Scenario (3.8' minimum depth)



January 3-5

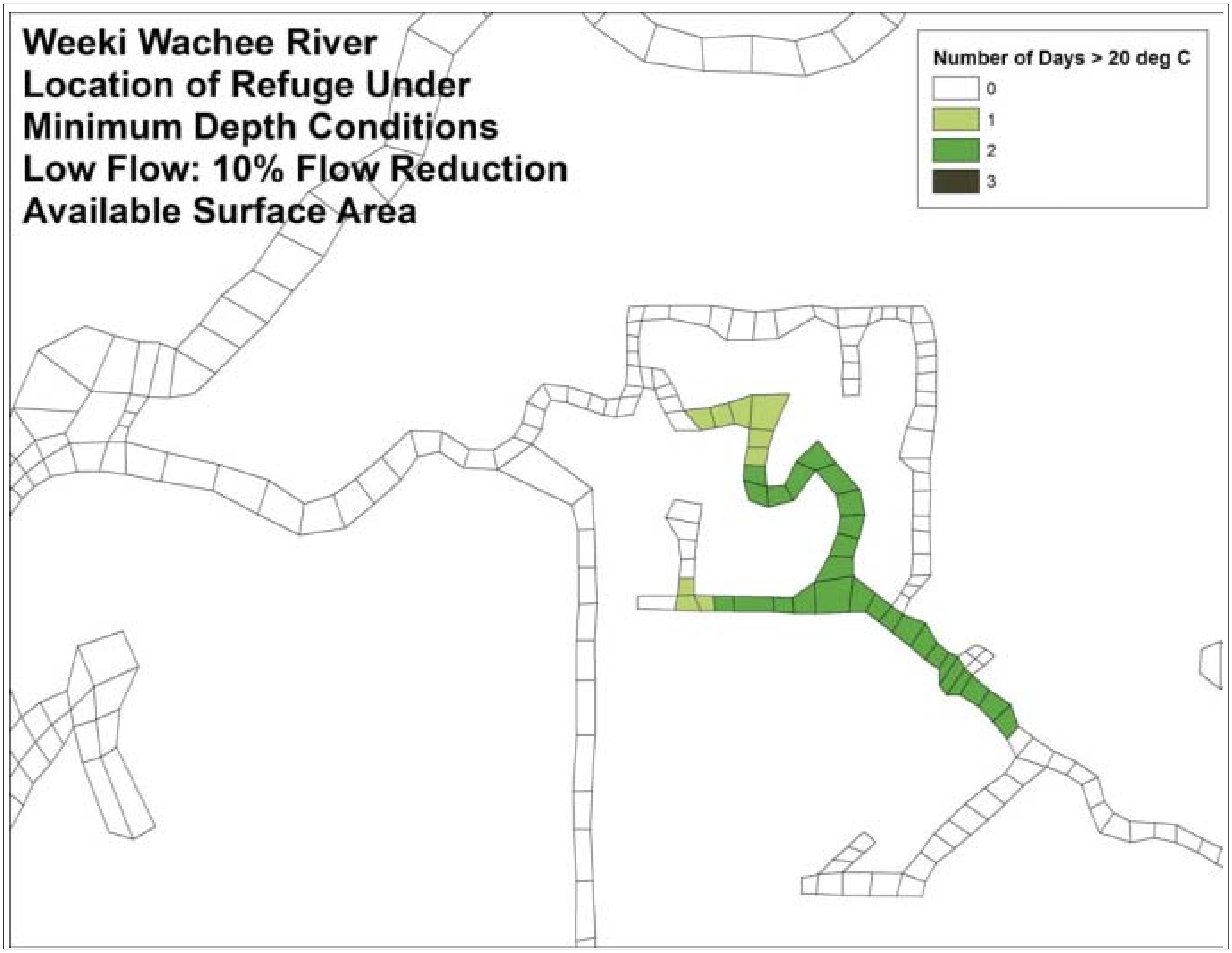
05-1186 Fig 6-16.CDR 09/17/07

Figure 6-16
Location of Available Refuge Surface Area (surface area =20°C) for Low Flow 5% Flow Reduction Scenario (3.8' minimum depth)



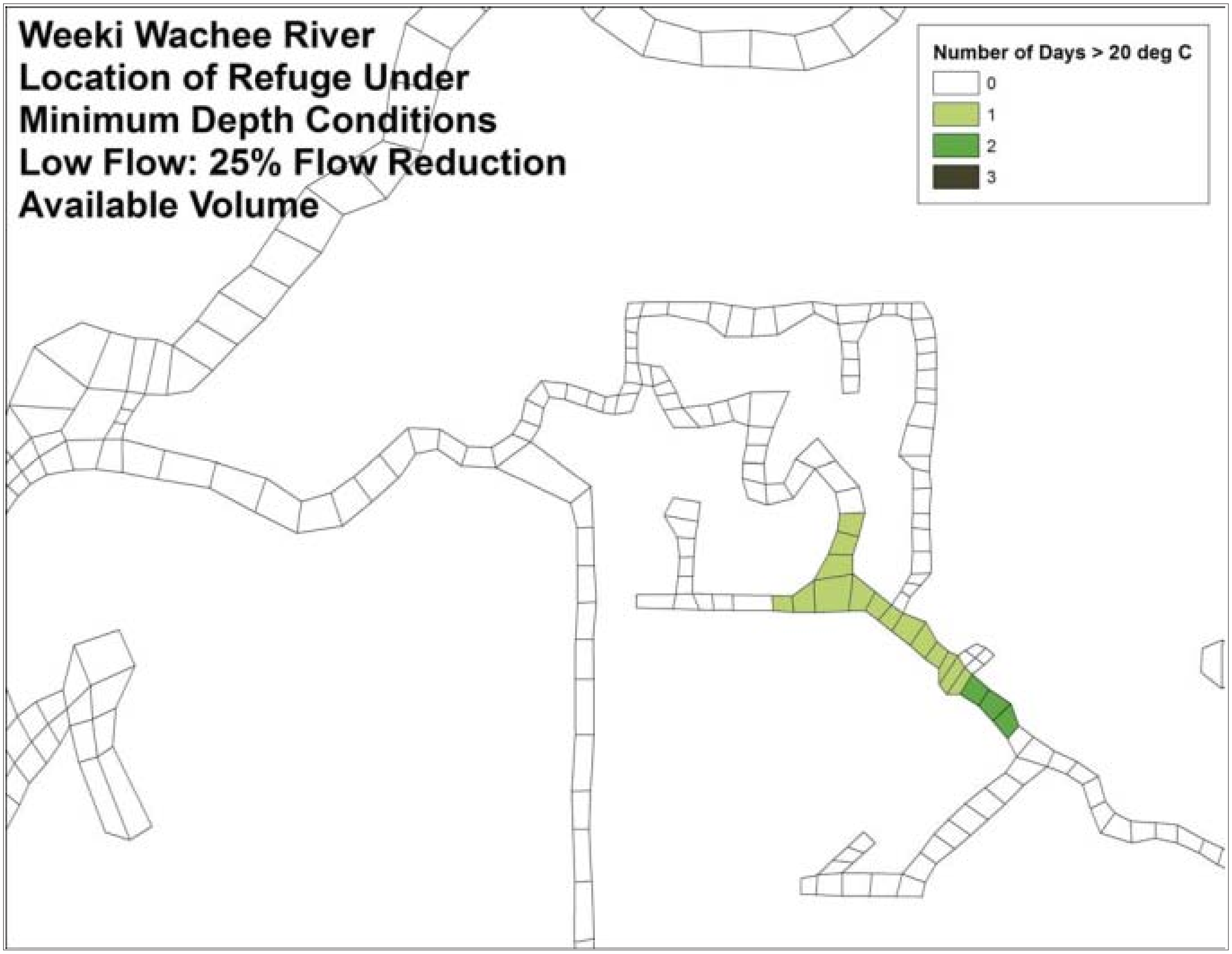
January 3-5

Figure 6-17
Location of Available Refuge Volume (volume =20°C) for Low Flow 10% Flow Reduction Scenario (3.8' minimum depth)



January 3-5

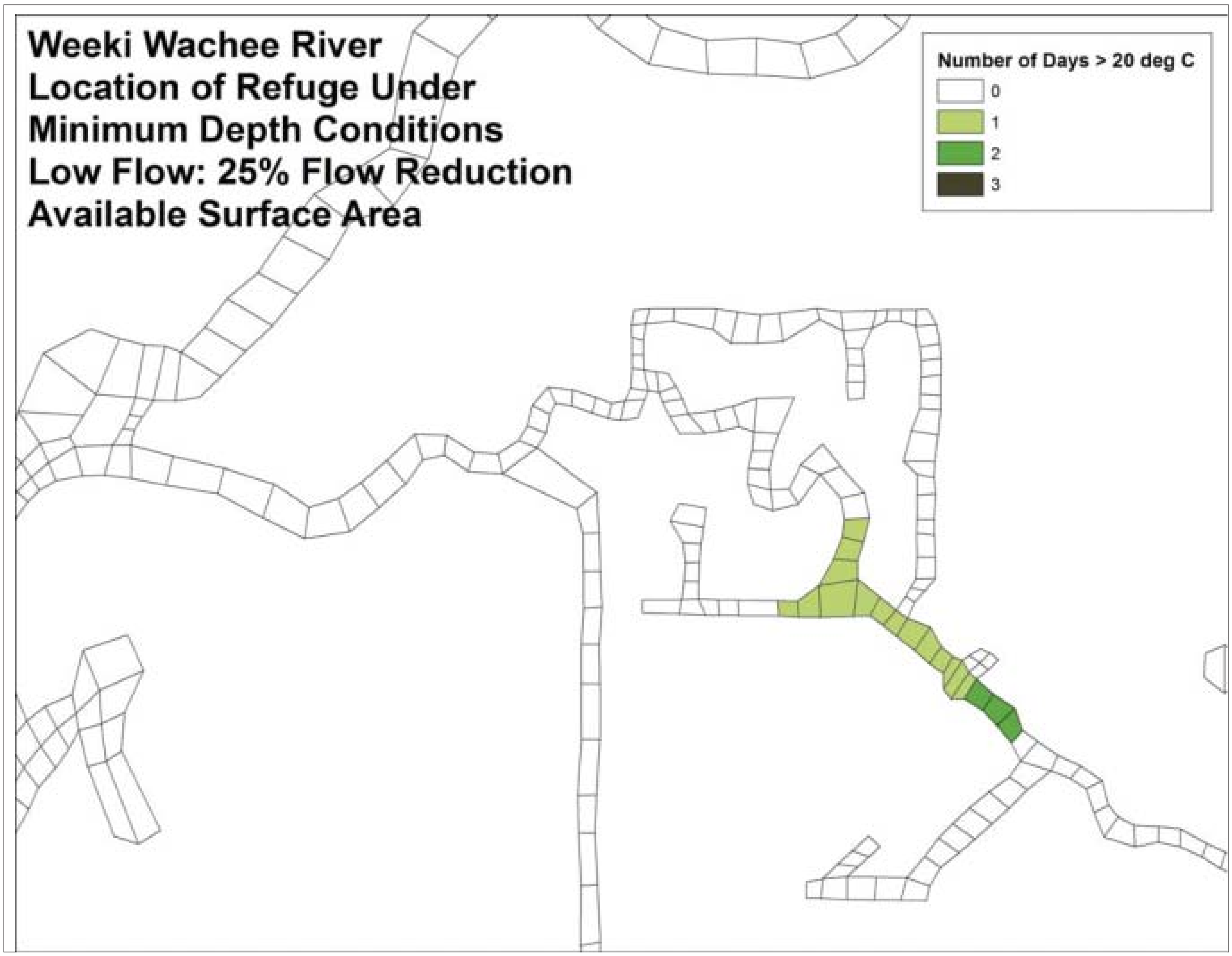
Figure 6-18
Location of Available Refuge Surface Area (surface area =20°C) for Low Flow 10% Flow Reduction Scenario (3.8' minimum depth)



January 3-5

05-1186 Fig 6-19.CDR 09/17/07

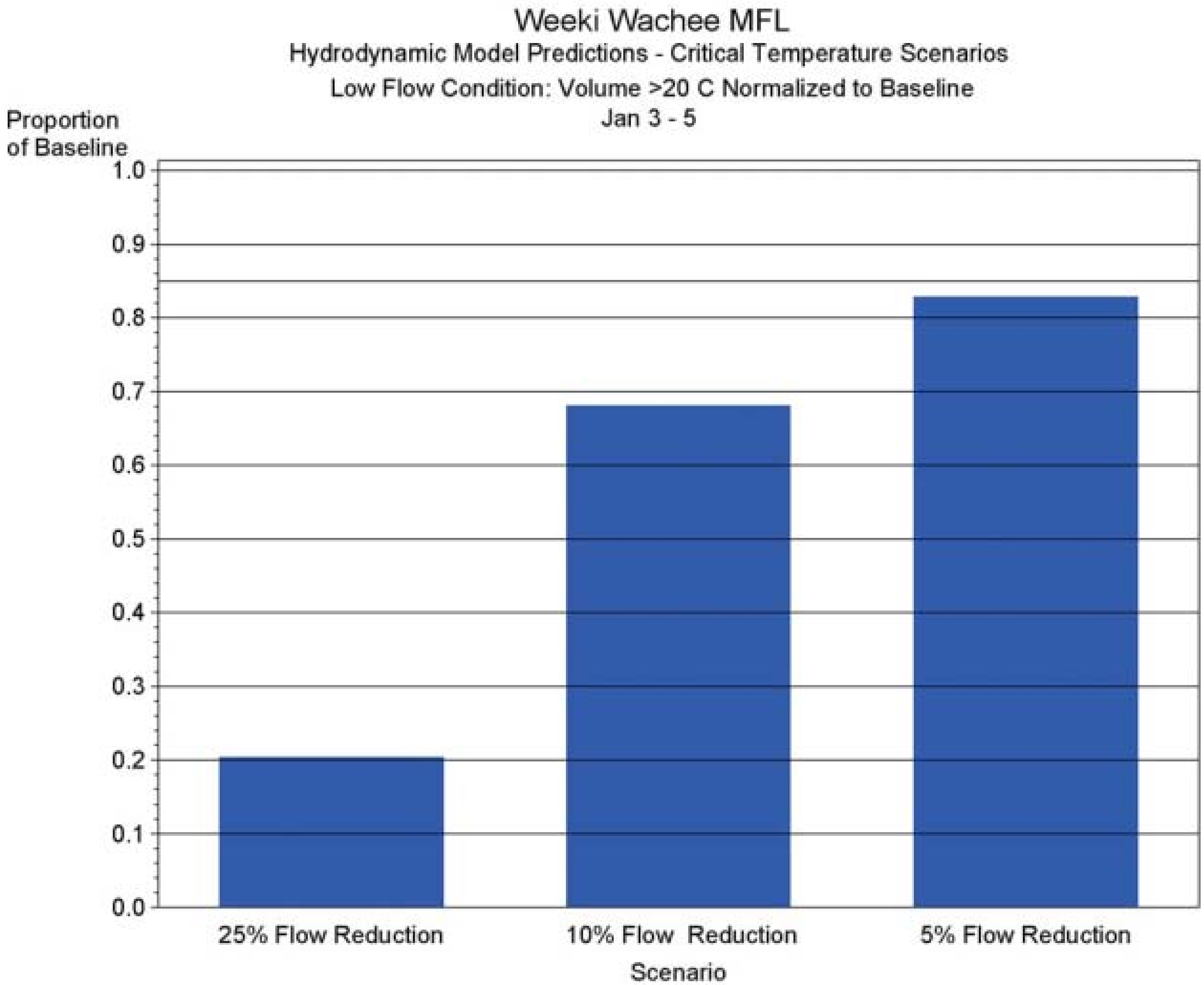
Figure 6-19
Location of Available Refuge Volume (volume =20°C) for Low Flow 25% Flow Reduction Scenario (3.8' minimum depth)



January 3-5

05-1186 Fig 6-20.CDR 09/17/07

Figure 6-20
Location of Available Refuge Surface Area (surface area =20°C) for Low Flow 25% Flow Reduction Scenario (3.8' minimum depth)

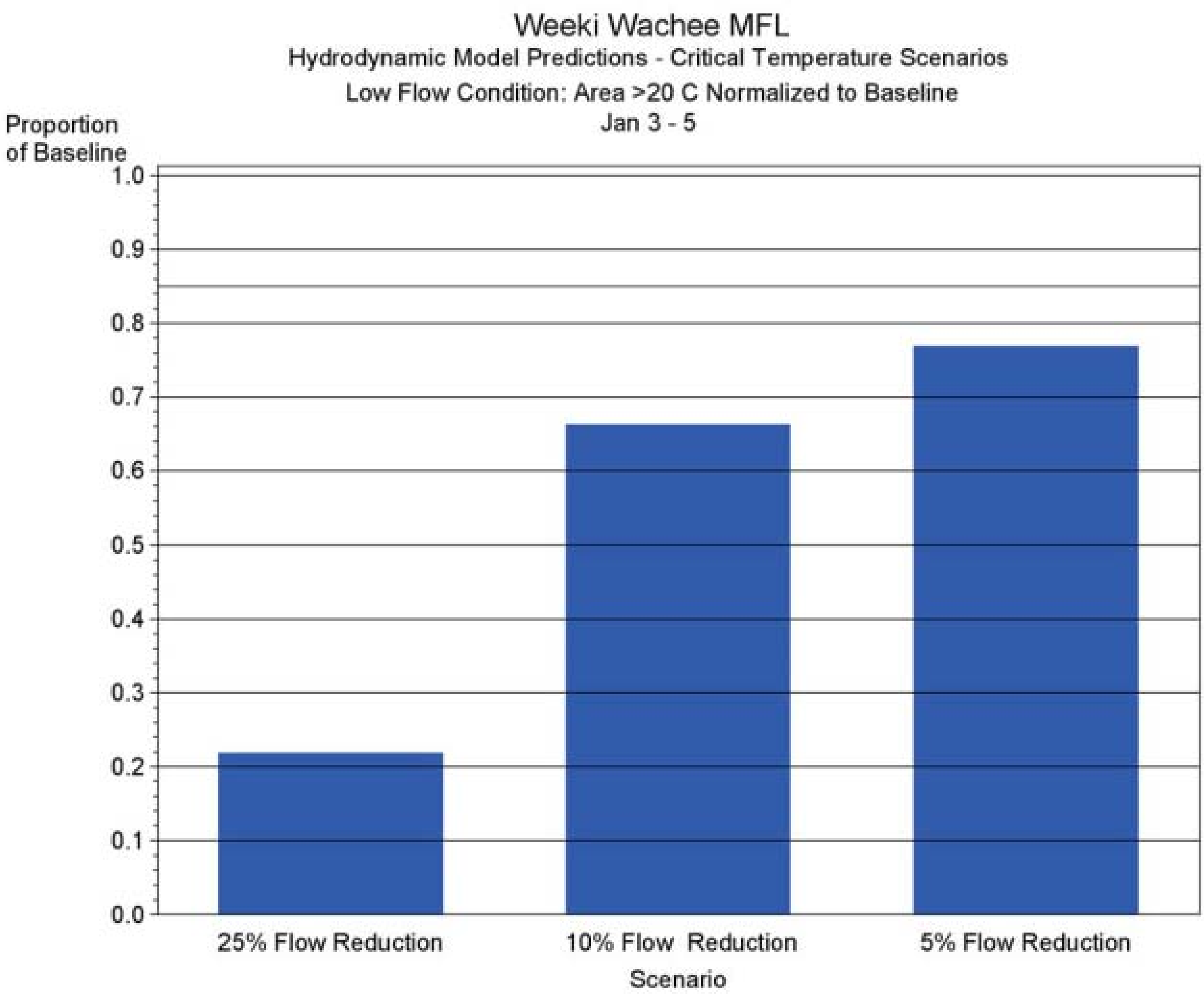


The horizontal line at 0.85 on the y-axis shows the 15% habitat reduction threshold. Note that there is no volume of =20°C water for the 50% flow reduction scenario.

05-1186 Fig 6-21.CDR 09/17/07

Figure 6-21
Low Flow Condition: Comparison of Refuge Volume Reductions Resulting from Flow Reduction Scenarios for the 3-Day Period with Largest Reductions, January 3-5 (3.8' minimum depth)

ATM APPLIED TECHNOLOGY & MANAGEMENT
Janicki Environmental, Inc.



05-1186 Fig 6-22.CDR 09/17/07

The horizontal line at 0.85 on the y-axis shows the 15% habitat reduction threshold. Note that there is no surface area of =20°C water for the 50% flow reduction scenario.

Figure 6-22
Low Flow Condition: Comparison of Refuge Surface Area Reductions Resulting from Flow Reduction Scenarios for the 3-Day Period with Largest Reductions, January 3-5 (3.8' minimum depth)

ATM APPLIED TECHNOLOGY & MANAGEMENT Janicki Environmental, Inc.

6.4 MANATEE CARRYING CAPACITY

The minimum available surface area during the cold periods from the low flow baseline scenario, the critical flow condition for habitat, is 27,500 m^2. Given a manatee density of 0.006 manatee/ft^2, this corresponds to habitat available for 1,776 manatees. For the 5 percent low flow reduction scenario, with a minimum available surface area of 21,100 m^2, the available habitat will support 1,363 manatees. Even for the 25 percent reduction scenario of the low flow runs, with a minimum available surface area of 6,000 m^2, the available habitat will support 387 manatees.

7.0 SUMMARY AND CONCLUSIONS

Under this study, a numerical model was developed for the Weeki Wachee and Mud Rivers to simulate the change in the extent and volume of the thermal refuge for West Indian manatee. The EFDC model developed was capable of accurately simulating the intrusion of colder waters from the Gulf of Mexico into the Weeki Wachee River and the net change in this intrusion under reduced flow conditions. This was based upon calibration to time series of bottom and surface temperatures and salinities within the key refuge habitat area for the manatees and using measured water level, temperature, salinity and flow boundary conditions.

Utilizing the calibrated model, along with District defined manatee refuge protection criteria, baseline manatee habitat volumes and areas were established. These baseline volumes and areas represented both high flow and low flow conditions. Utilizing an allowable habitat net loss of 15 percent, and incremental flow reductions, minimum allowable flow reductions were determined to be protective of the manatee habitat.

For the Weeki Wachee Spring run, it was determined that the most critical period was low offshore temperatures corresponding with low flow from the springs. Under this condition, the maximum flow reduction that corresponded to a 15 percent reduction in manatee habitat area/volume was less than a 5 percent reduction in flow. While the analysis showed that less than a 5 percent flow would be allowed in order to avoid changes in habitat greater than 15 percent, the available manatee refuge is capable of supporting over 1363 manatees, well above the present number that utilize Weeki Wachee Springs.

REFERENCES

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Southwest Florida Water Management District, (SWFWMD), 2004. Alafia River Minimum Flows and Levels Freshwater Segment including Lithia and Buckhorn Springs. Southwest Florida Water Management District, Ecologic Evaluation Section, internal peer review draft.

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Southwest Florida Water Management District, Resource Conservation and Development Department. Brooksville, FL. Draft report.

Appendix A

Impact of Withdrawals on the Thermal Regime of the Weeki Wachee and Mud Rivers:

Task 1.1 – Existing Data Compilation

APPLIED TECHNOLOGY AND MANAGEMENT

DRAFT REPORT

IMPACT OF WITHDRAWALS ON THE THERMAL REGIME OF THE WEEKI WACHEE AND MUD RIVERS

TASK 1.1
EXISTING DATA COMPILATION

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April 21, 2006

Table 1: Model Input & Boundary Condition Data

Data Type	Data Source	Location	Period Available	Frequency
Rainfall	NOAA NCDC	Weeki Wachee	10/01/1969-01/31/2006	Daily
Winds	USF COMPS	Homosassa River entrance	04/01/1999-11/28/2005	6-minute
Winds	USF COMPS	Aripeka, South Fork Hammock Creek Bridge	01/01/2004-11/28/2005	6-minute
Air Temperature, Rainfall	NOAA NCDC	Weeki Wachee	10/01/1969-01/31/2006	Daily
Meteorology (Atm Pres, Air Temp, Cloud Cover)	NOAA NCDC	Tampa International Airport	01/01/1949-12/31/2005	Hourly
Solar Radiation	FAWN-IFAS	Dover	01/01/2000-12/31/2005	Hourly
Boundary Condition Water Surface Elevation	USGS	Bayport	01/01/2003-05/05/2003 05/12/2003-10/05/2005 12/05/2005-02/07/2006	15-minute
Boundary Condition Specific Conductivity (Salinity)	USGS	Bayport	06/24/2003-10/05/2005	15-minute
Boundary Condition Water Temperature	USGS	Bayport	06/24/2003-10/05/2005	15-minute
Spring Discharge	USGS/SWFWMD Regression	Weeki Wachee well	06/15/1966-11/13/2005	Daily
Salinity/Temperature Initial Conditions	SWFWMD-COAST	3 Stations in Weeki Wachee River	07/1997-12/2004	Monthly
Salinity/Temperature Initial Conditions	SWFWMD 02-05	17 Stations in Weeki Wachee River, 5 Stations in Mud River	07/1997-12/2004	Monthly
Water Surface Elevation Initial Conditions	USGS	Station 02310530, near Rkm=7.27	08/14/2003-10/07/2003 11/04/2003-12/18/2003 01/06/2004-10/05/2005	15-minute
Water Surface Elevation Initial Conditions	USGS	Station 02310551, near Rkm=1.70	06/24/2003-06/03/2005 06/16/2005-10/05/2005	15-minute
Water Surface Elevation Initial Conditions	USGS	Station 02310545, near Rkm=6.63	01/01/2003-02/04/2003 06/06/2003-04/18/2003 04/22/2003-11/15/2003 11/17/2003-12/07/2003 12/11/2003-10/12/2005 10/18/2005-02/07/2006	15-minute
Bathymetry	SWFWMD-USF	Weeki Wachee River system	NA	NA

Table 2: Model Calibration-Verification Data

Data Type	Data Source	Location	Period Available	Frequency
Water Surface Elevation	USGS	Station 02310530, near Rkm=7.27	08/14/2003-10/07/2003 11/04/2003-12/18/2003 01/06/2004-10/05/2005	15-minute
Water Surface Elevation	USGS	Station 02310551, near Rkm=2.25	06/24/2003-06/03/2005 06/16/2005-10/05/2005	15-minute
Water Surface Elevation	USGS	Station 02310545, near Rkm=3.63	01/01/2003-02/04/2003 06/06/2003-04/18/2003 04/22/2003-11/15/2003 11/17/2003-12/07/2003 12/11/2003-10/12/2005 10/18/2005-02/07/2006	15-minute
Salinity/Temperature	SWFWMD_Project_COAST	10 Station, 3 in Weeki Wachee River, 7 outside of mouth	07/1997-12/2004	Monthly
Salinity/Temperature	SWFWMD_02_05	13 Stations in Weeki Wachee River, 5 Stations in Mud River, 4 Stations outside mouth	07/2003-7/2005	Monthly
Salinity/Temperature	USGS	Station 02310551, near Rkm=2.25	06/24/2003-06/03/2005 06/16/2005-10/05/2005	15-minute

Table 3: Additional Data

Data Type	Data Source	Location	Period Available	Frequency
Salinity/Temperature	EPCHC	Egmont Key	01/1974-12/2005	Monthly
Salinity/Temperature	SWFWMD-USGS_1984	12+ sites Weeki Wachee River/Mud River	01/1984 (1 sample), 06/1985-09/1985	Monthly
Salinity/Temperature	SWFWMD-MML_84_85	16 sites Weeki Wachee River/Mud River	01/04/1984-12/08/1985	Monthly 1984, every 2 months 1985
Salinity/Temperature	SWFWMD_85_86	26 sites Weeki Wachee River/Mud River	05/1985-07/1986	Monthly or more frequently
Salinity/Temperature	SWFWMD_1991	8 sites Weeki Wachee River	01/1991-12/1991	Monthly
Salinity/Temperature	SWFWMD_94_95	17 sites Weeki Wachee River	03/1994-10/1995, 07/1996	Monthly or more frequently
Salinity/Temperature	SWFWMD-UF_WQ_RPT	20 sites, 15 sites in Weeki Wachee River, 3 sites along transect	08/1998-01/2001	Quarterly
Air Temperature	NOAA NCDC	Gainesville	01/01/1984-12/31/2005	Hourly
Air Temperature	FAWN-IFAS	Brooksville	03/27/2000-12/31/2005	Daily
Sea Surface Temperature	Naval Research Lab MODAS	Gulf of Mexico, Including Nearshore	01/01/1997-12/31/2005	Daily
Sea Surface Salinity	Naval Research Lab MODAS	Gulf of Mexico, Including Nearshore	01/01/2002-12/31/2005	Daily

Appendix B

Impact of Withdrawals on the Thermal Regime of the Weeki Wachee and Mud Rivers:

Task 1.2 – Field Program Notes and Data March 2006

APPLIED TECHNOLOGY AND MANAGEMENT

DRAFT REPORT

IMPACT OF WITHDRAWALS ON THE THERMAL REGIME OF THE WEEKI WACHEE AND MUD RIVERS

TASK 1.2
FIELD PROGRAM NOTES AND DATA
MARCH 2006

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April 21, 2006

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ADCP Transect Data

Figure 1: ACDP Transect Locations

Table 1: ADCP Transect Data

Transect Location	File name	Distance made good [ft]	Length [ft]	Transect time [s]	Max depth [ft]	Area [ft2]	River width [ft]	Average boat speed [ft/s]	Average boat course [deg]	Flow speed [ft/s]	Flow direction [deg]	Total discharge [ft3/s]	Top discharge [ft3/s]	Mea sured discharge [ft3/s]	Bottom discharge [ft3/s]	Left shore discharge [ft3/s]	Right shore discharge [ft3/s]	Begin Shore
Confluence	WW\WW_002r.000	374.99	385.22	73.81	7.7	2387.8	390.33	5.22	155.48	1.02	56.7	-2019.93	-1207.73	-415.98	-319.48	-8.37	-68.37	RIGHT
Confluence	WW\WW_003r.000	366.25	371.82	64.76	7.85	2300.16	379.64	5.74	338.41	1.11	75.99	-2867.87	-1810.64	-524.02	-441.78	-35.41	-56.02	LEFT
Confluence	WW\WW_012r.000	369.44	378.32	81.47	8.42	2628.12	413.14	4.64	157.36	0.78	68.45	-2074.97	-1213.93	-443.53	-322.52	-56.92	-38.07	RIGHT
Confluence	WW\WW_013r.000	301.94	311.99	57.1	8.58	2368.36	369.25	5.46	336.25	0.64	68.5	-1507.08	-840.53	-327.16	-273.13	-26.87	-39.39	LEFT
Confluence	WW\WW_014r.000	322.54	324.64	55.7	8.61	2537.49	396.55	5.83	159.01	0.57	55.07	-1532.27	-867.65	-316.45	-263.74	-34.09	-50.34	RIGHT
Confluence	WW\WW_019r.000	373.16	383.06	96.79	8.53	2705.02	431.26	3.96	336.5	0.41	264.91	1158.42	705.98	214.71	196.38	27.08	14.28	LEFT
Confluence	WW\WW_020r.000	369.68	372.38	114.2	8.62	2592.23	411.76	3.26	160.64	0.5	257.87	1935.37	1191.76	358.12	304.85	19.11	61.53	RIGHT
Confluence	WW\WW_026r.000	329.86	336.29	146.93	8.57	2349.43	392.13	2.29	161.75	0.94	249.08	1973.11	1090.02	426.32	319.55	63.93	73.28	RIGHT
Confluence	WW\WW_027r.000	332.2	337.75	114.9	8.53	2399.26	399.2	2.94	343	0.86	252.73	1872.87	1035.41	388.98	292.51	53.97	102	LEFT
Confluence	WW\WW_028r.000	332.23	342.05	167.82	8.04	2147.89	377.59	2.04	157.07	0.83	245.09	1890.79	1067.78	344.14	256.07	84.18	138.63	RIGHT
Confluence	WW\WW_029r.000	337.13	341.8	99.58	8.31	2368.21	398.91	3.43	342.9	0.98	248.17	2387.39	1389.76	460.26	380.82	59.4	97.16	LEFT
Confluence	WW\WW_031r.000	208.88	215.83	89.14	6.18	1270.03	280.86	2.42	157.68	0.55	214.29	54.93	-58.85	-10.8	-5.63	67.45	62.76	RIGHT
Confluence	WW\WW_032r.000	245.08	248.97	107.94	6.26	1604.15	347.22	2.31	330.4	0.75	277.73	888.81	546.11	102.15	101.64	63.67	75.24	LEFT
Confluence	WW\WW_036r.000	194.02	195.2	71.73	5.91	941.58	233.49	2.72	162.79	0.37	258.61	1034.66	725.36	134.43	114.7	19.96	40.2	RIGHT
Confluence	WW\WW_037r.000	237.49	244.78	98.89	5.91	1418.38	318.17	2.48	331.52	0.48	245.92	521.83	282.34	52.63	49.72	90.05	47.09	LEFT
Confluence	WW\WW_038r.000	262.28	276.47	86.35	5.95	1178.14	331.91	3.2	333.16	0.76	250.66	-475.75	-340.75	-64.28	-70.72	0	0	LEFT
Confluence	WW\WW_039r.000	232.11	234.47	73.82	5.69	845.37	268.93	3.18	158.97	1.23	275.01	826.42	607.52	113.27	105.63	0	0	RIGHT
Confluence	WW\WW_043r.000	215.66	220.82	71.03	5.62	779.55	272.58	3.11	164.81	0.92	243.61	673.9	499.09	92.74	82.07	0	0	RIGHT
Confluence	WW\WW_044r.000	213.85	215.98	75.21	5.84	1098.35	261.95	2.87	339	0.63	259.1	827.08	484.99	90.36	83.53	94.09	74.11	LEFT
Confluence	WW\WW_048r.000	181.7	184.28	82.87	5.89	739.2	181.35	2.22	153.63	0.28	40.57	441.38	426.51	79.2	68.76	0	-133.1	RIGHT
Confluence	WW\WW_049r.000	64.19	64.19	25.76	3.97	0	135	2.49	131.14	0	0	0	0	0	0	0	0	LEFT
Confluence	WW\WW_054r.000	301.79	305.86	105.15	6.45	1581.37	320.06	2.91	152.52	0.6	91.7	-274.81	-122.26	-27.77	-44.17	-37.75	-42.86	RIGHT
Confluence	WW\WW_055r.000	236.42	246.64	94.02	6.37	1424.94	290.87	2.62	336.23	0.45	126.19	-429.54	-221.88	-41.75	-47.89	-61.55	-56.47	LEFT
Mud River	WW\WW_010r.000	123.18	130.13	26.46	6.99	806.05	148.18	4.92	125.52	1.22	25.42	-1185.68	-727.39	-168.49	-172.82	-59.8	-57.17	RIGHT
Mud River	WW\WW_011r.000	126.05	131.5	23.67	6.83	953.23	172.97	5.56	306.69	0.58	23.09	-464.48	-276.49	-74.4	-68.02	-13.26	-32.31	LEFT
Mud River	WW\WW_023r.000	152.02	161.28	66.84	6.95	918.88	167.46	2.41	306.37	0.77	225.39	616.41	373.56	95.47	84.29	39.66	23.44	LEFT
Mud River	WW\WW_024r.000	156.52	164.15	88.44	6.57	790.31	151.16	1.86	128.05	0.67	208.22	880.47	591.96	125.57	108.85	31.46	22.63	RIGHT
Mud River	WW\WW_033r.000	7.67	7.7	2.78	3.12	0	90	2.77	307.08	0	0	0	0	0	0	0	0	LEFT
Weeki Wachee	WW\WW_004r.000	57.05	62.15	18.8	8.23	776.62	121.13	3.31	7.63	0.59	105.79	-405.98	-185.94	-85.75	-72.1	-32.34	-29.86	LEFT
Weeki Wachee	WW\WW_007r.000	0	0	0	3.22	0	40	0	0	0	0	0	0	0	0	0	0	RIGHT
Weeki Wachee	WW\WW_021r.000	64	65.95	36.22	8.6	648.55	115.51	1.82	15.63	0.44	280.86	208.26	90.01	43.25	26.98	16.43	31.58	LEFT
Weeki Wachee	WW\WW_022r.000	80.18	85.11	48.05	8.34	523.39	88.64	1.77	186.72	0.44	281.08	215.94	112.79	50.27	29.53	5.73	17.62	RIGHT
Weeki Wachee	WW\WW_034r.000	44.38	44.62	26.47	6.06	157.2	92.6	1.69	10.43	1.4	296.74	223.88	160.23	30.21	33.45	0	0	LEFT
Weeki Wachee	WW\WW_035r.000	42.62	43.6	21.59	6.13	373.99	100.3	2.02	188.57	1.21	288.16	303.77	91.08	17.31	21.49	99.37	74.52	RIGHT
Weeki Wachee	WW\WW_040r.000	42.41	42.87	25.77	5.91	164.18	78.89	1.66	187.83	1.42	308.51	222.8	159.49	30.08	33.23	0	0	RIGHT
Weeki Wachee	WW\WW_042r.000	42.72	43.65	21.59	5.84	127.36	81.96	2.02	196.53	1.42	292.44	348.1	244.37	46.46	57.27	0	0	RIGHT
Weeki Wachee	WW\WW_045r.000	45.2	46.41	25.07	5.99	163.74	94.29	1.85	178.98	0.53	319.38	-83.92	-63.43	-11.7	-8.79	0	0	RIGHT
Weeki Wachee	WW\WW_046r.000	39.93	41.19	20.9	6.03	165.53	128.64	1.97	175.54	0.61	277.32	-60.23	-43.31	-8.16	-8.75	0	0	RIGHT
Weeki Wachee	WW\WW_047r.000	51.07	52.55	27.16	6.1	197.25	114.88	1.93	181.55	0.8	320.25	116.44	83.04	15.68	17.72	0	0	RIGHT
Weeki Wachee	WW\WW_051r.000	42.65	43.75	23.68	6.15	157.36	98.04	1.85	185.67	0.49	320.85	166.75	122.4	22.83	21.53	0	0	RIGHT
Weeki Wachee	WW\WW_052r.000	52.28	53.83	28.55	6.1	244.18	114.04	1.89	179.46	0.86	291.89	388.31	285.42	53.19	49.69	0	0	RIGHT
Weeki Wachee	WW\WW_053r.000	43.93	44.74	23.68	5.69	196.47	105.34	1.89	188.83	0.45	267.23	101.97	74.62	13.94	13.4	0	0	RIGHT

Tide Gage Data

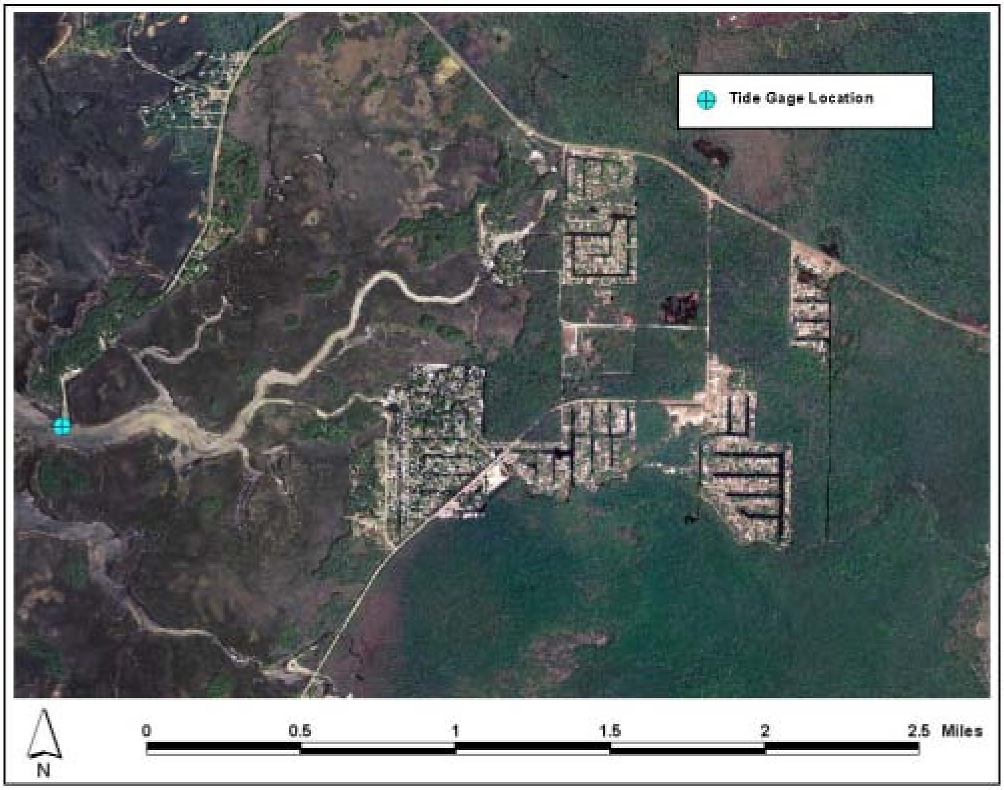


Figure 2: Tide Gage Location

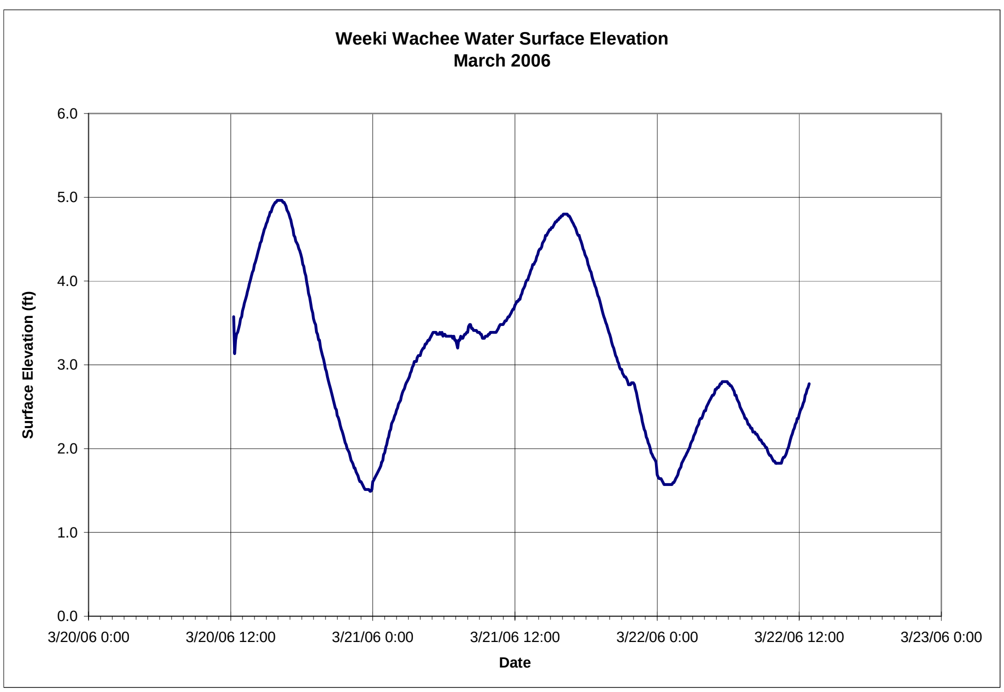


Figure 3: Tide Gage Water Surface Elevation

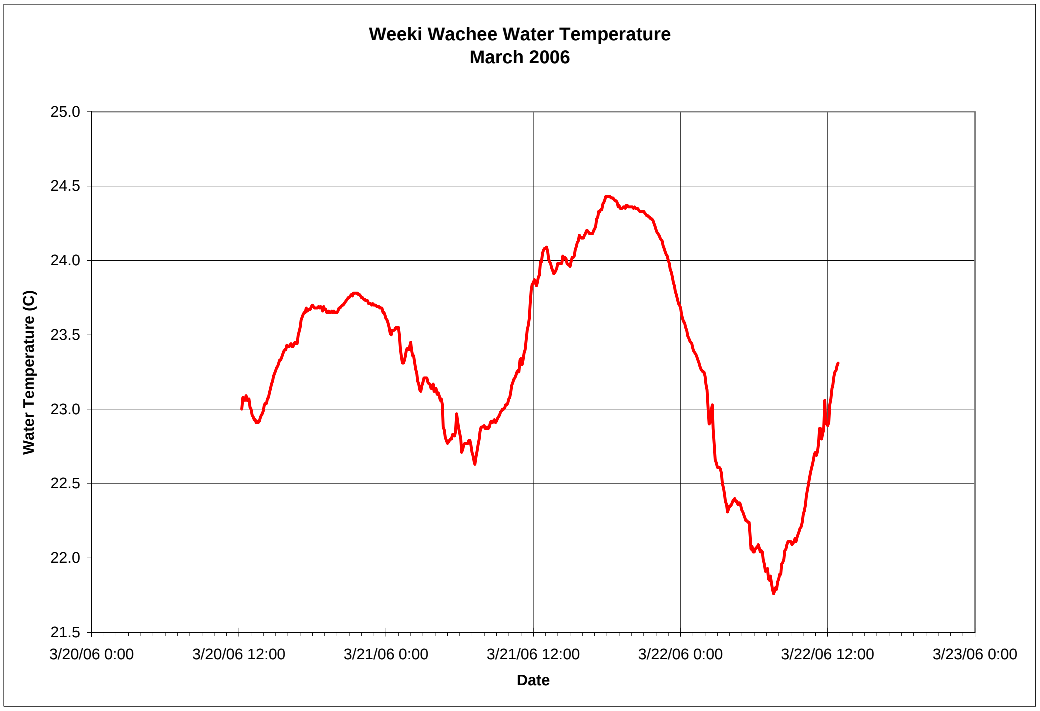


Figure 4: Tide Gage Water Temperature

Table 2: Weather Data for 3/20/06- 3/22/06

Weeki Wachee Weather - Weather Underground			
EST	**3/20/2006**	**3/21/2006**	**3/22/2006**
Max TemperatureF	84	82	79
Mean TemperatureF	72	70	68
Min TemperatureF	60	57	57
Max Dew PointF	65	70	55
MeanDew PointF	56	62	48
Min DewpointF	55	51	40
Max Humidity	90	97	81
Mean Humidity	68	82	55
Min Humidity	41	51	25
Max Sea Level PressureIn	30.04	29.95	30.1
Mean Sea Level PressureIn	29.98	29.9	30.01
Min Sea Level PressureIn	29.89	29.87	29.94
Max VisibilityMiles	10	10	10
Mean VisibilityMiles	9	6	10
Min VisibilityMiles	2	0	10
Max Wind SpeedMPH	14	23	13
Mean Wind SpeedMPH	8	2	4
Max Gust SpeedMPH	20	34	
PrecipitationIn	0	0	0
CloudCover	2	1	1
Events		Fog-Rain	

Salinity and Temperature Data

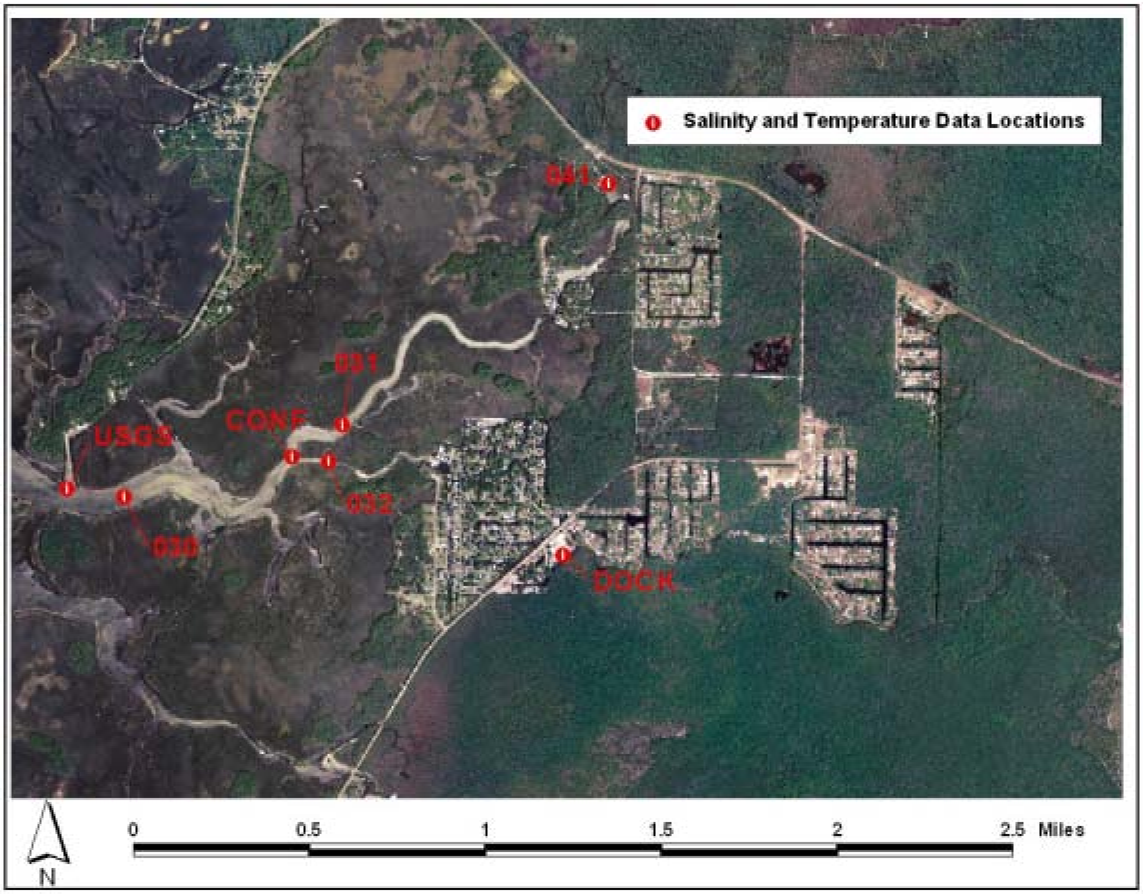


Figure 5: Salinity and Temperature Locations

Table 3: Salinity and Temperature Data

Location	Date	Time	Depth (ft)	Temperature (C)	Salinity (ppt)
USGS	03/20/2006	12:20	1.4	23.0	8.0
USGS	03/20/2006	12:20	4.4	22.9	8.2
USGS	03/20/2006	12:26	0.4	23.0	8.1
USGS	03/20/2006	12:26	4.4	22.9	8.3
DOCK	03/21/2006	7:05	Middle	22.2	0.4
030	03/21/2006	7:40	Surface	21.9	3.1
030	03/21/2006	7:40	Bottom	22.2	4.4
031	03/21/2006	8:32	Surface	21.2	6.6
031	03/21/2006	8:32	3.6	21.9	9.3
032	03/22/2006	11:20	Surface	23.0	0.4
032	03/22/2006	11:20	4.2	23.0	0.4
041	03/22/2006	~ 13:00	Surface	24.6	7.7
041	03/22/2006	~ 13:00	5.0	24.8	19.3
CONF	03/22/2006	14:10	Surface	23.5	5.0
CONF	03/22/2006	14:10	5.0	23.5	5.0

Weeki Wachee River Reconnaissance

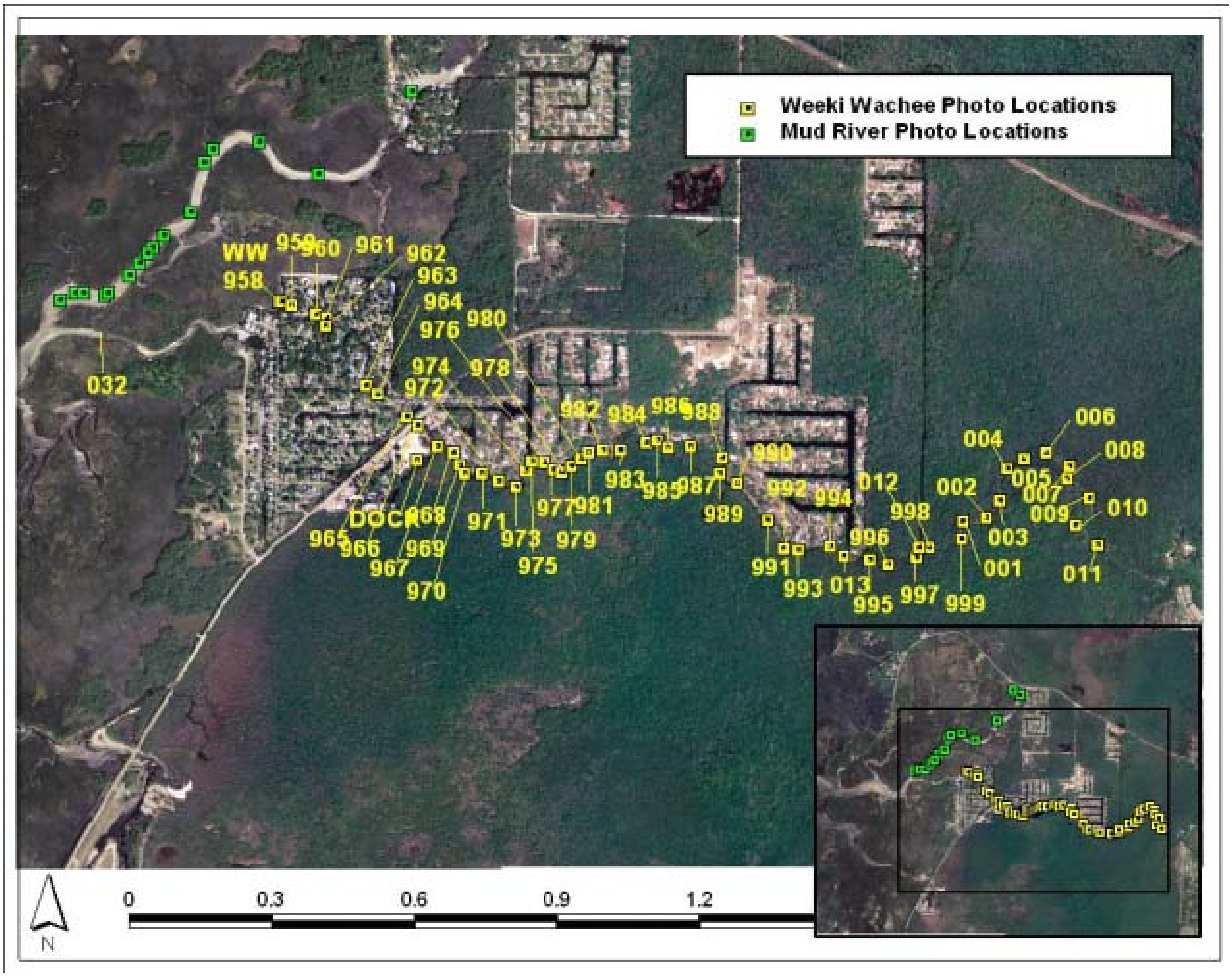


Figure 6: Weeki Wachee River Photo Locations

Mud River Reconnaissance

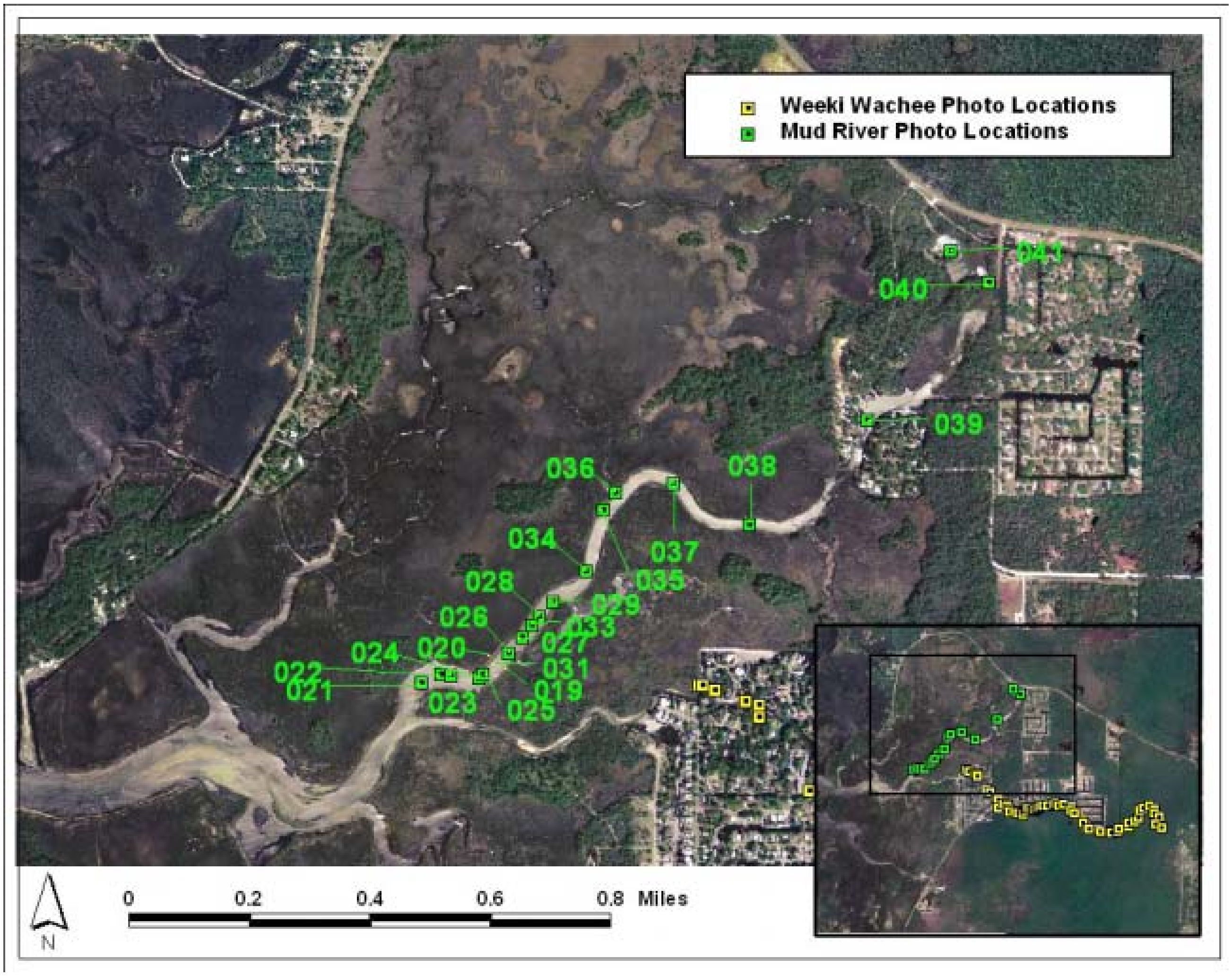


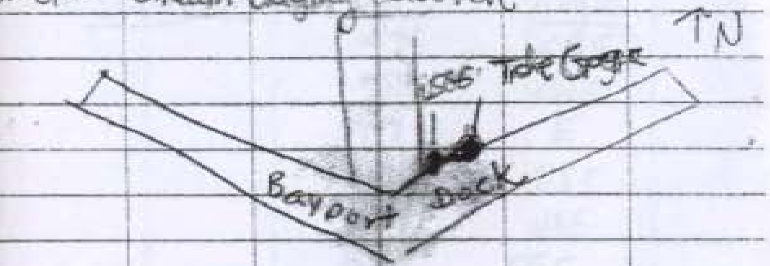
Figure 7: Mud River Photo Locations

Field Notes

Location Baypoint, FL (WW) Date 03/20/06

Project / Client Weeki Wachee

USGS Stream Gaging Station



Tide Gage Placement

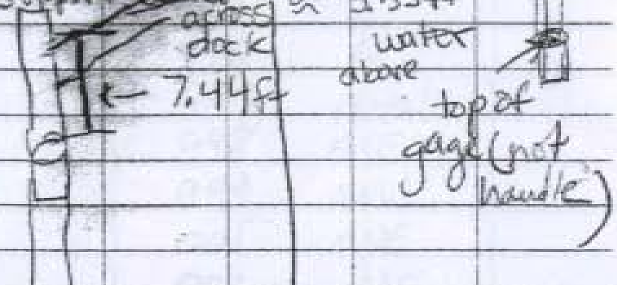
≈ NAD83 (ft)	Time	12:16 03/20/06
WGS 84 True N	Position	N 28.533771° W082.65017°

			Salinity	TEMP	Depth
Bottom	①	Top	8.0ppt	23.0°C	1'5"
Depth	12:20	Bottom	8.2ppt	22.9°C	4'5"
≈ 5'5"	②	Top	8.1ppt	23.0°C	0'5"
	12:26	Bottom	8.3ppt	22.9°C	4'5"

12:39

7.44 ft from top gage to top of support board across dock

≈ 3.55 ft water above top of gage (not handle)



Location WW, FL Date 03/20/06

Project / Client

PICTURE	Waypoint	Angle
21	958	SW
	959	NE
	960	SE
	961	SSW
	962	SE
	963	NE
	964	NW
	965	NW
36	966	ENE
	Dock	
37	967	SSE
	968	S
	968	S
	969	SSE
	970	SE
	971	SSE
	972	SSE
	973	ENE
	974	ENE
	975	ESE
	976	SSE
	977	ESE
	978	ENE

Project / Client ____________

Picture	WPT	Angle
	979	ENE
	980	ENE
	981	E
	982	SSE
	983	NNE
	984	ESE
	985	S
	986	E
	987	ESE
	988	SSW
	989	SSE
	990	SSE
	991	SSE
	992	ESE
	993	ENE
	994	SE
	995	S
	996	N
	997	NNW
	998	ENE
	999	NNW
	001	ENE
	002	NE

Project / Client ____________

PIC	WPT	°
	003	N
	004	ENE
	005	E
	006	SE
	007	SW
	008	ESE
	9	SSE
	10	SSE
	11	SE

Waypoint 12 is a major split in the W.W. spring run. IT flows away from the main channel.

WPT 13 upstream end of development

3/21/2005

WPT 014 taken @ 14:03 on left bank @ lower confluence [illegible]

Project / Client

WPT 015 taken @ right bank on lower confluence transect at 14:06. (1st upstream of tide gage dock)

WPT 016 Initial Marsh Velocity readings on lower confluence transect at 14:14.
.1 m/s Surface
.1 m/s Bottom (past [illegible] ring)

WPT 017 taken @ right bank of transect WW @ 14:48.

WPT 018 taken @ left bank of transect WW @ 14:49

WPT 019 taken @ left bank of transect MUD @ 15:06

WPT 020 taken @ right bank of transect MUD @ 15:09

Project / Client

WPT 021 plot 82
22 / 83

3/22/06

WPT "Dock" 7:05am
Salinity 0.4 ppt
temp °C 22.2 °C

WPT 030 7:40 am
Salinity
Surface Sal. ppt Temp 21.9°C
Bottom 4.4 ppt Temp 22.2°C
92 Right Bank lower confluence transect
93 Left Bank " "
94 Downstream " "
95 Upstream " "

WPT 031 8:32am JDC USA Electronics
Airfoil flow measure instrument
→ Velocity ◦ flow watch
Surface .1 → .3 m/s flipped back + forth
Bottom .0 → .1 m/s between
→ Depth 3.63 ft
ppt Temp
Salinity Srf Ranged Ca. → 7.0 21.2°C
Bottom 9.3 ppt 21.9°C

Mud River Transect length is 150 ft
(only had 100 ft tape to measure)

Project / Client:

Mud River transect Photos 8:41

96 Right Bank Pell

97 Upstream

98 Right bank Downstream

99 Left Bank Downstream

100 my feet

Staff gauge @ USGS @ 10:10 = 9.72

tide gage meas @ same time = 7.52'

water line to tide gage top = 1.91'

water depth @ tide gauge = 3.80'

WPT 32 11:20 Weeki Wachee Transect

PHOTOS # 101 Left Bank Weeki Wachee Transect.

102 Right Bank " "

103 Upstream " "

104 Downstream " "

Salinity (ppt)		Temp (°C)
Surface	0.4	23.0
Bottom	0.4	23.0

Depth 4.24 ft

Note!: Lots Algae on bottom of WW Springs

Project / Client

Staff gage @ USGS Dock = 10.66 @ 12:47

Tide Gage Removal 12:53

Upper MUD River photos/waypoints

WPT	Photo	Angle	Notes
033	105	WNW	
034	106	NNW	
035	107	E	
036	108	WNW	sm. tributary
037	109	SE	
038	110, 111	E	
039	112	ENE	
040	113	N	
041	114	W	end of Mud R.
	115	E	look from "

Salinity: surface: 7.7 PPT 24.6°C

~5' deep: 19.3 PPT 24.8°C

Photos 116 (north) Canal @ end of Mud R.

117 (south) " " " " " "

 Location ______ Date 3/22/06

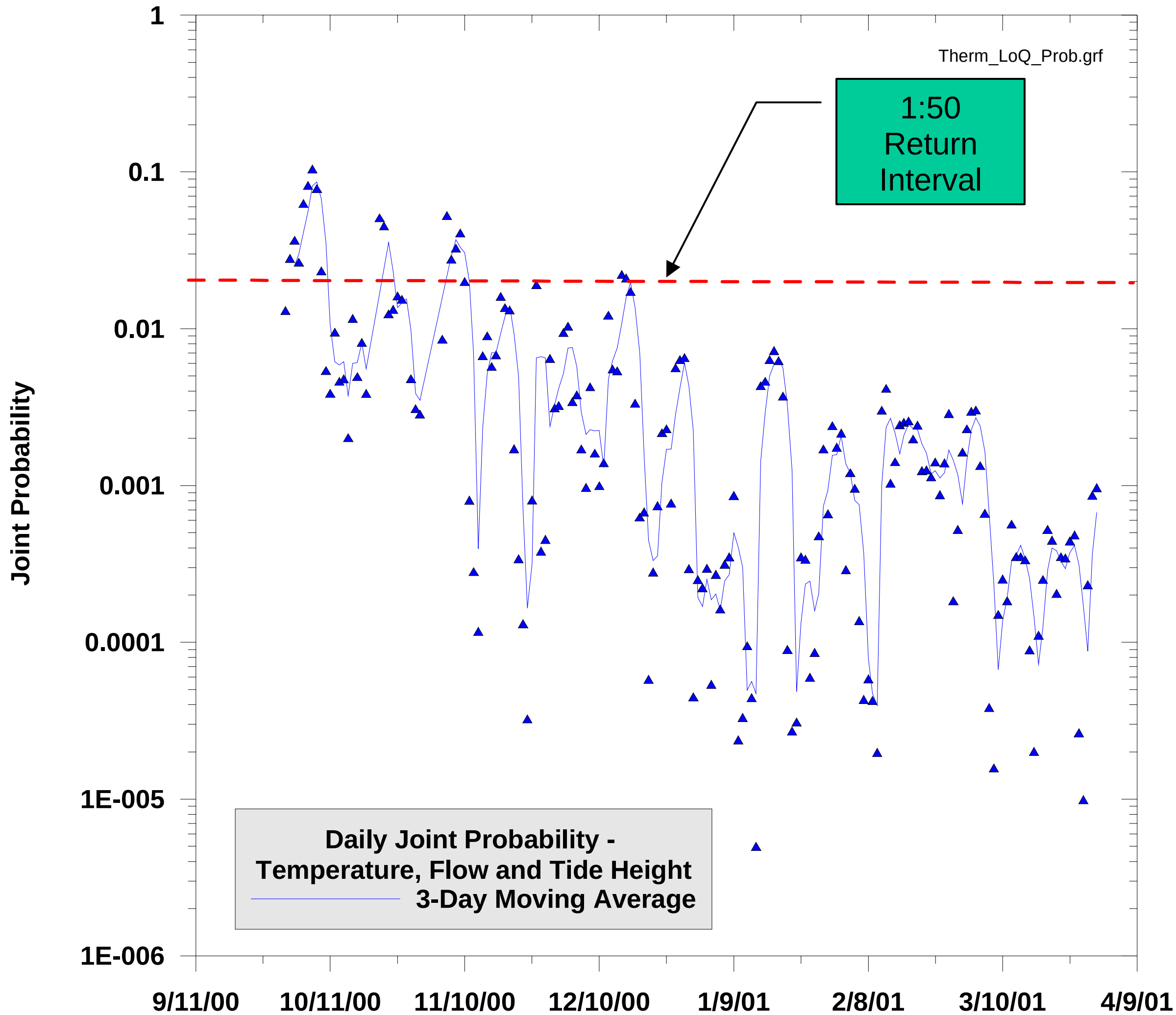
Project / Client ______

Salinity: surface 5.0 ppt 23.5°C @ 1410
~5' deep 5.0 ppt 23.5°C

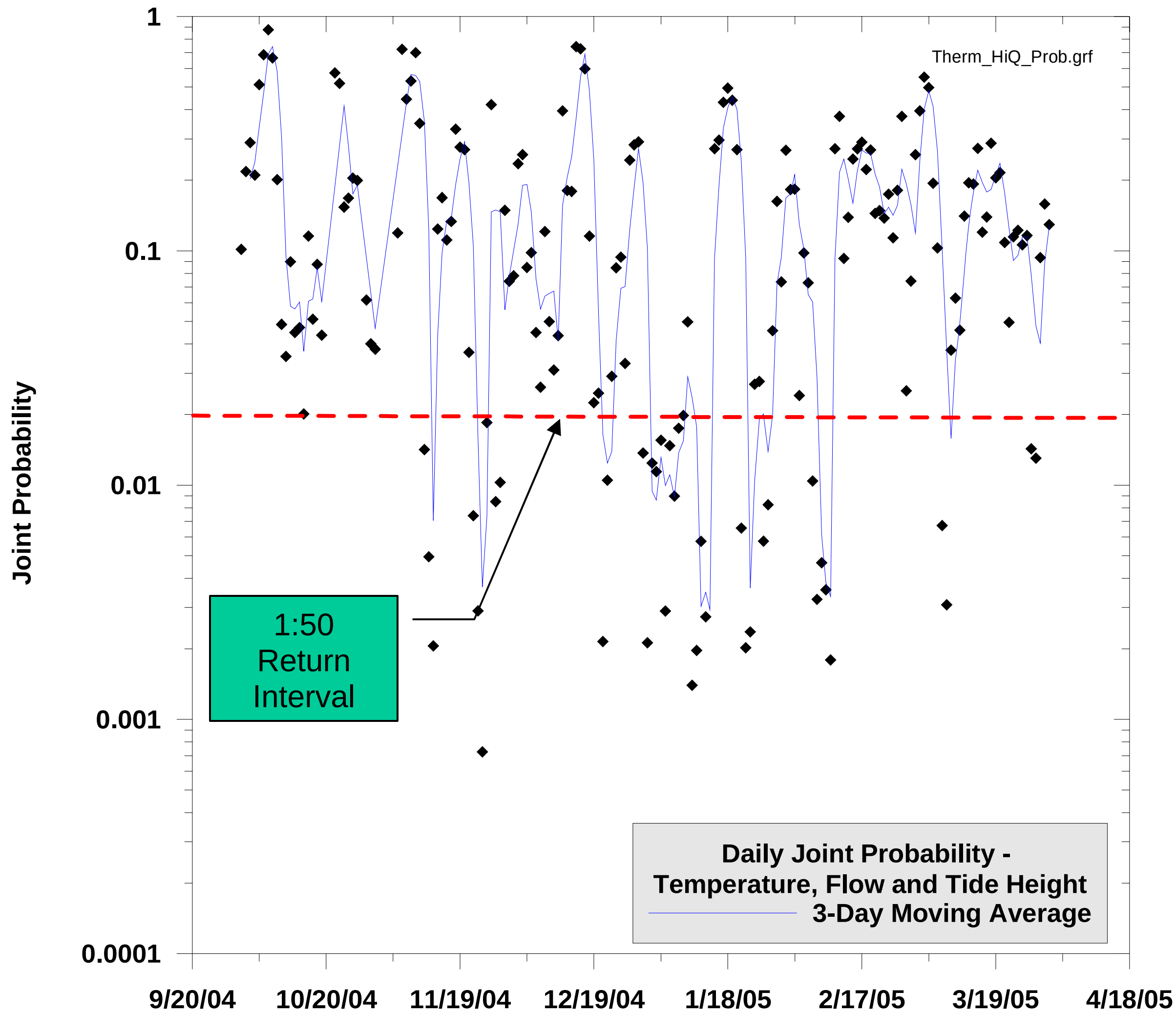
@ WPT "Conf"

Appendix C

Joint Probability of Occurrence Figures


Joint Probability
1
0.1
0.01
0.001
0.0001
1E-005
1E-006
9/11/00
10/11/00
11/10/00
12/10/00
1/9/01
2/8/01
3/10/01
4/9/01
Therm_LoQ_Prob.grf
1:50 Return Interval
Daily Joint Probability - Temperature, Flow and Tide Height
3-Day Moving Average

Low flow


Joint Probability
1
0.1
0.01
0.001
0.0001
9/20/04
10/20/04
11/19/04
12/19/04
1/18/05
2/17/05
3/19/05
4/18/05
Therm_HiQ_Prob.grf
1:50 Return Interval
Daily Joint Probability - Temperature, Flow and Tide Height
3-Day Moving Average

High flow