Impacts of Withdrawals on the Chassahowitzka River System

for

Southwest Florida Water Management District
Under PO 07PO0001577

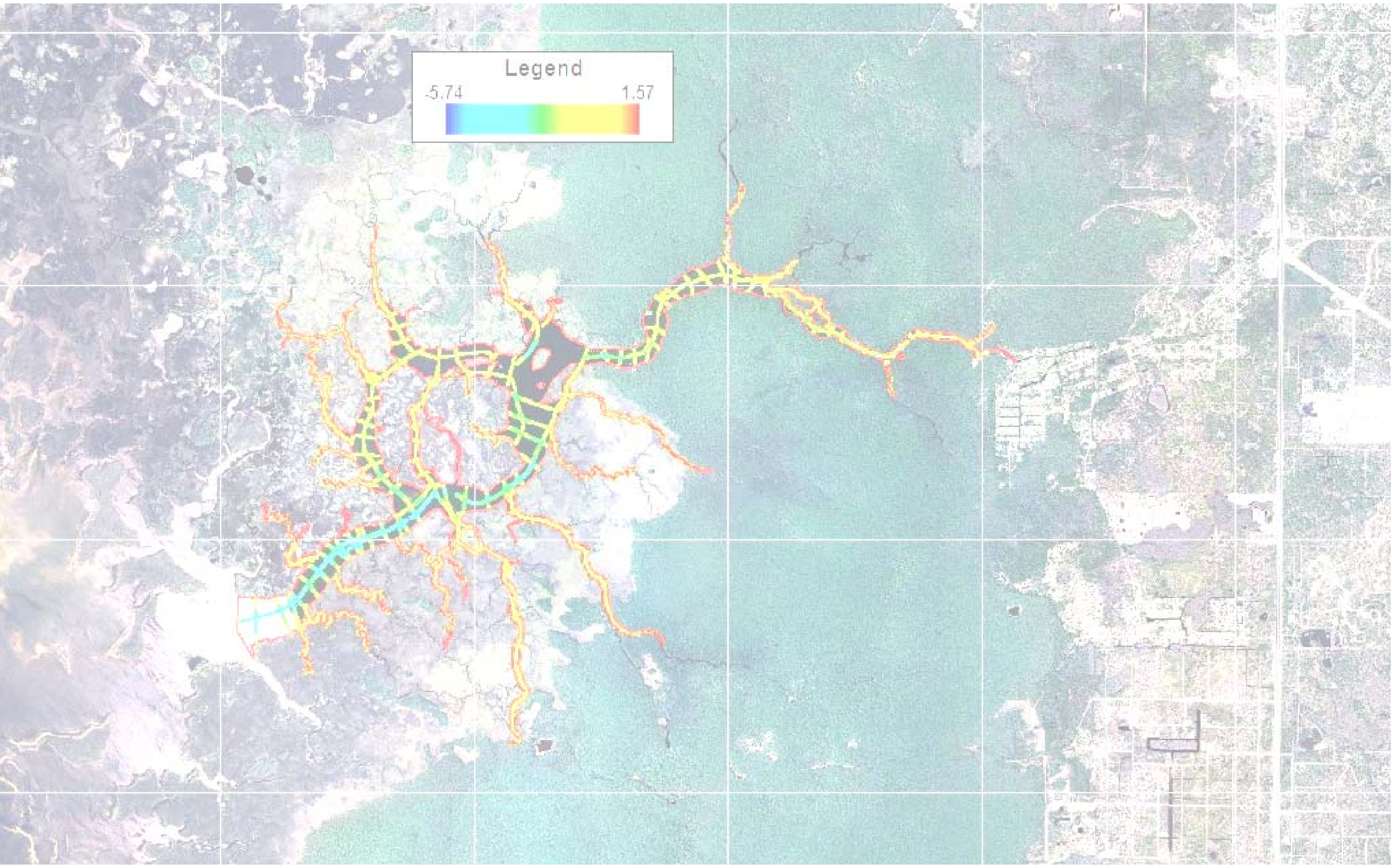

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Table of Contents

List of Tables

List of Figures

Note - The term 'baseline' as used in this report refers to daily discharge as reported by the USGS.

1 Introduction

1.1 Project Overview

Dynamic Solutions, LLC (DSLLC) was tasked by the Southwest Florida Water Management District (SWFWMD) to conduct a salinity and temperature study of the Chassahowitzka River system. This work supports an ongoing Minimum Flows and Levels (MFL, FL Statutes 373.042 and 373.0421) assessment for the Chassahowitzka that is currently being conducted by the SWFWMD. The three main tasks conducted by DSLLC included:

- Development of a three dimensional hydrodynamic model of the Chassahowitzka River System.
- Determination of the areas in the Chassahowitzka system that meet manatee habitat criteria during critical conditions
- Determination of salinity changes and the resulting changes in the volume, area and shoreline lengths of salinity regimes due to reductions in spring flows.

This report provides an overview of the data and methodology used to calibrate the hydrodynamic model. The report also presents the results of the model scenario analysis.

1.2 Site Description

The Chassahowitzka River System is located along the West coast of Florida in a region known as the Springs Coast (Figure 1-1). A map of the Chassahowitzka River System with the system highlighted on a satellite image is shown in Figure 1-2. The coordinate grid shown is NAD83 UTM Zone 17, in meters.

The average depth of water in the system is 3.12 feet (0.95 meters) with the deepest part around 14.76 feet with an open water area of about 255 hectares (ha). With an average spring discharge of about 106 ft^3/s (3 m^3/s) (see Section 5.3), the daily inflows only makes up about 8% of the Chassahowitzka's volume.

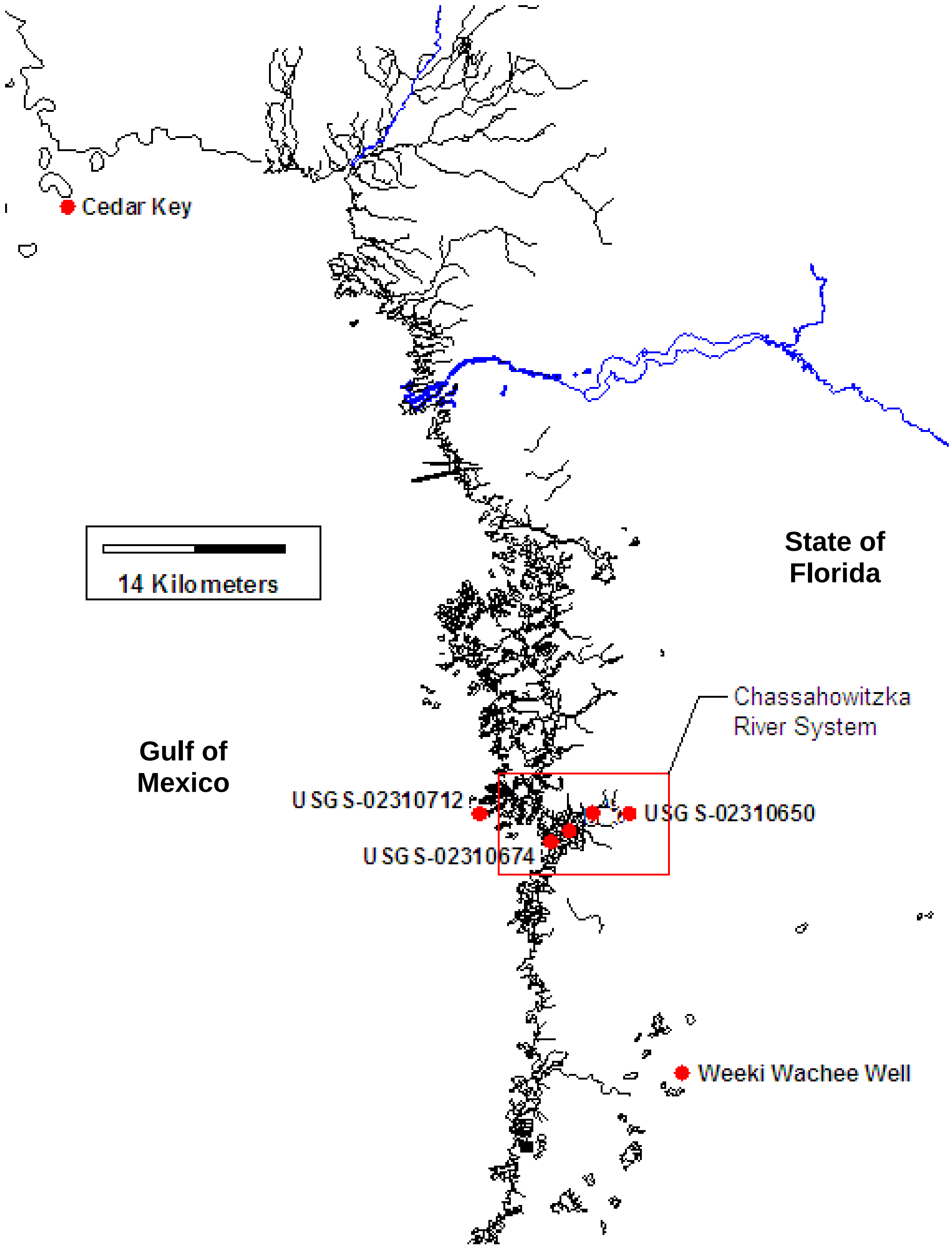


Figure 1-1 Springs Coast map showing the Chassahowitzka River System and locations of the continuous monitoring stations.

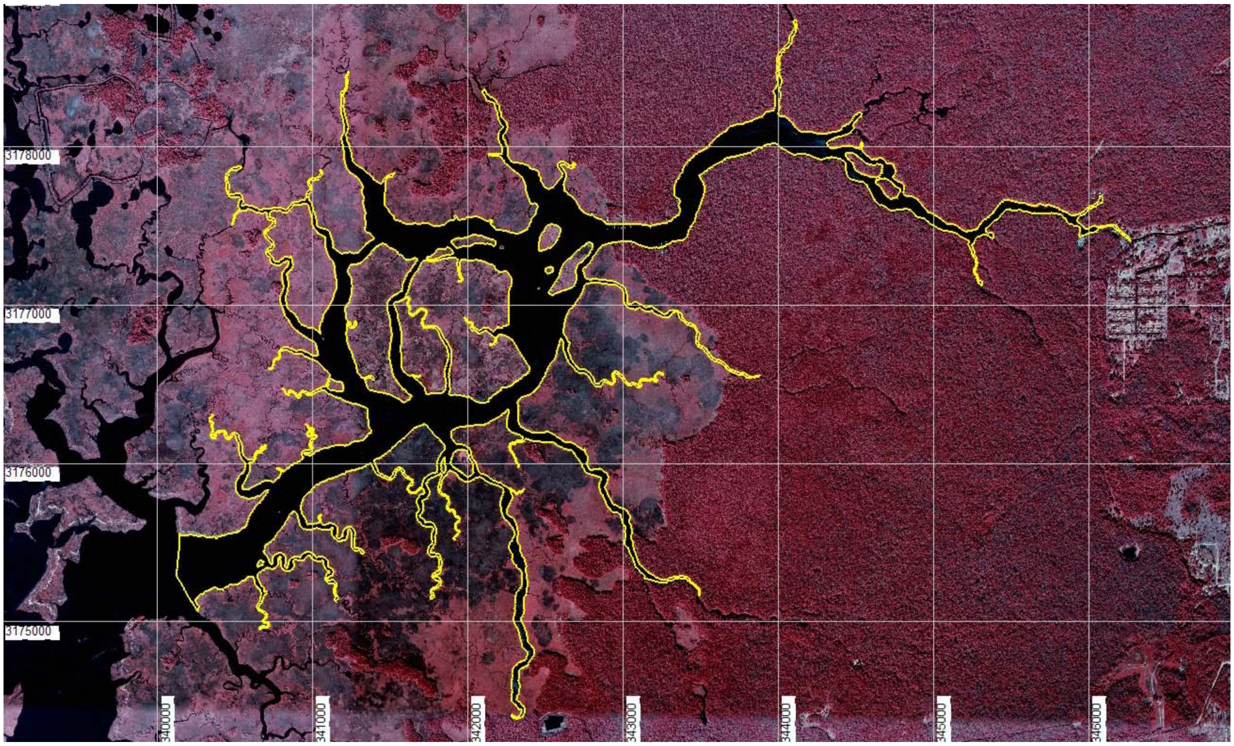


Figure 1-2 Chassahowitzka River System

2 Methodology

2.1 Manatee Protection Issue

Manatees frequent the Chassahowitzka springs year around. During winter months, in order to survive cold weather, when water temperatures in the Gulf drop below 68 °F (20 °C), manatees seek refuge in warm water. Typically during winter months, the water temperature at the river mouth is colder than the spring discharges. The spring flow temperatures usually are in the range of 71.6-73.4 °F (22-23°C). Therefore, warm spring flow plays an important role in creation of refuge areas for manatees. Reduction of spring flow in association with high tidal level and cold weather are major factors in reducing manatee refuge area.

2.1.1 Thermal Criteria for Manatee Protection

The SWFWDM has defined Critical cold conditions to use as baseline in the determination of allowable impacts to the thermal refuge within the Chassahowitzka River.

Thermal Criteria - Volume and Area for Baseline and Reduced Flow Scenarios:

<u>Chronic</u>

- Refuge minimum depth = 3.8 ft (1.16 m) at low tide,
- Refuge is accessible at high tide – minimum high tide depth > 3.8 ft (1.16 m).
- Must remain >=68 °F (20°C) for duration of critically cold 3 day period.

<u>Acute</u>

- Refuge minimum depth = 3.8 ft (1.16 m) at low tide,
- Refuge is accessible at high tide – minimum high tide depth > 3.8 ft (1.16 m).
- The temperatures cannot be <= 59 °F (15 °C) for 4 or more hours.

2.1.2 Minimum Reduction Flow for Manatee Protection

An understanding of the low flow characteristics of spring discharge is essential to facilitate protection of the manatee refuge areas. The occurrence of low flow on a cold day may significantly reduce the suitable refuge area available for manatees. The frequency of low flow condition can be computed from long term continuous records. Long term continuous records, for the Chassahowitzka River System, were only available for several recent years therefore, a regression model was used to compute the flows from available representative historic data. A similar approach was applied for water level and temperature of the river system.

Based on long term statistics of flow, temperature and water level, a reference scenario was selected and a series of EFDC runs with reduced flow were conducted to study an impact of flow on the refuge area for manatee.

2.2 Salinity Regime Reduction Analysis

The reduction of spring flows into the Chassahowitzka River System has direct impacts on the salinity regimes in the estuary. With a decreasing fresh water inflow volume, the Chassahowitzka River System will become more saline. The SWFWMD has defined the critical salinity ranges as:

- 0 to 2 ppt,
- 0 to 5 ppt,
- 0 to 10 ppt, and
- 0 to 15 ppt.

For each of these salinity ranges, the spring flow reduction that results in a 15% loss of volume, area and/or shoreline lengths needs to be determined.

2.3 Hydrodynamic and Thermal Modeling

In order to develop projections of the change in the flow and temperature within the Chassahowitzka River system it was necessary to develop a modeling tool predict the fresh/saline water and thermal dynamics under a range of historic and projected scenarios. For this study, the Environmental Fluid Dynamics Code (EFDC) was selected (Hamrick, 1992). The EFDC model was calibrated for the conditions found in the Chassahowitzka River system, then the calibrated model served as a tool in prediction of the hydrodynamic processes.

2.3.1 EFDC/EFDC_Explorer Modeling System

Hydrodynamic models account for the movement of surface waters where water motion is influenced by cross-sectional area, depth and bottom slope of the water body, freshwater inflows, water surface elevation and physical processes such as bottom friction, winds, turbulent mixing and vertical stratification induced by water temperature and salt content (i.e., density).

2.3.1.1 Overview of EFDC

The Environmental Fluid Dynamics Code (EFDC) is a general-purpose modeling package for simulating three-dimensional flow, transport, and biogeochemical processes in surface water systems including: rivers, lakes, estuaries, reservoirs, wetlands, and near shore to shelf scale coastal regions. The public domain EFDC model was originally developed at the Virginia

Institute of Marine Science for estuarine and coastal applications. In addition to hydrodynamic and salinity and temperature transport simulation capabilities, EFDC includes sub-models to simulate sediment transport, eutrophication, and the transport and fate of toxic contaminants in the water and sediment bed. EFDC is unique among advanced surface water models since it uses a single source code to interface hydrodynamics (Hamrick, 1992) with sediment transport (Tetra Tech, 2000), toxic chemicals (Tetra Tech, 1999) and eutrophication (Park et al., 1995) within a single source code (Hamrick, 1996). The code is widely used by Federal agencies, including the Army Corps of Engineers, EPA and the USGS.

2.3.1.2 Governing Physics of EFDC

The EFDC hydrodynamic model is a variable density, unsteady flow model that uses the Boussinesq approximation, hydrostatic pressure field and internal solutions of vertical eddy viscosity and diffusivity. The EFDC model solves the vertically hydrostatic, free-surface, turbulent-averaged equations of motions for a variable density fluid.

Dynamically coupled transport equations for turbulent kinetic energy, turbulent length scale, salinity, and temperature are solved. The two turbulence parameter transport equations implement the Mellor-Yamada level ‘2.5’ turbulence closure scheme (Mellor and Yamada, 1982; Galperin et al., 1988). The bottom stress formulation for friction, accounting for the rate of momentum loss at the sediment bed/water interface, is represented using a turbulent boundary layer formulation based on a quadratic function of near-bottom velocity. Water temperature is solved as an integral part of the hydrodynamic model with heat transport simulated using the atmospheric heat exchange model developed by Rosati and Miyakoda (1988) in which solar radiation at the water surface is reduced as a function of depth in the water column.

The state equations and numerical solution methods used in the EFDC hydrodynamic model are given in Hamrick (1992; 1996), Blumberg and Mellor (1987) and Martin and McCutcheon (1999). The interested reader is referred to these sources since the equations of the model are not presented in this technical report.

2.3.1.3 Numerical Solution Schemes of EFDC

The spatial domain of a water body can be represented in EFDC using (a) either Cartesian, or curvilinear orthogonal, coordinates in the horizontal (x,y) domain; and (b) a stretched, or sigma, coordinate scheme in the vertical (z) domain. The numerical scheme used in EFDC to solve the equations of motion uses a second-order accurate, spatial finite difference scheme on a staggered or C grid. The model's time integration uses a second-order accurate, two time-level, finite difference scheme with an internal/external mode splitting procedure to separate the internal shear, from the external free surface gravity wave. The external mode solution is semi-implicit, and simultaneously computes the two-dimensional surface elevation field by a preconditioned conjugate gradient procedure. The external solution is completed by the calculation of the depth averaged velocities using the new surface elevation field. The model's semi-implicit external solution allows large time steps that are constrained only by the stability criteria of the explicit central difference or high-order upwind advection scheme (Smolarkiewicz and Margolin, 1993) used for the nonlinear accelerations.

Horizontal boundary conditions for the external mode solution include options for simultaneously specifying the surface elevation only, the characteristic of an incoming wave (Bennett and McIntosh, 1982), free radiation of an outgoing wave (Bennett, 1976; Blumberg and Kantha, 1985), or the normal volumetric flux on arbitrary portions of the boundary. The EFDC model's internal momentum equation solution, at the same time step as the external, is implicit with respect to vertical diffusion. The internal solution for the momentum equations is in terms of the vertical profile of shear stress and velocity shear. Time splitting inherent in the two time-level scheme is controlled by periodic insertion of a second-order accurate two-time level trapezoidal step. In addition to the general 3D(xy,z) spatial domain, the EFDC model can also be readily configured as a two-dimensional model in either the horizontal (2D: x,y) or vertical (2D: x,z) planes.

The EFDC model implements a second-order accurate in space and time, mass conservation fractional-step solution scheme for the Eulerian transport equations for salinity, temperature, suspended sediment, water quality constituents, and toxic contaminants. The transport equations are temporally integrated at the same time step or twice the time step of the momentum equation solution (Smolarkiewicz and Margolin, 1993). The advective step of the transport solution uses either the central difference scheme used in the Blumberg-Mellor (1987) model or a hierarchy of positive definite upwind difference schemes. The highest accuracy upwind scheme, second-order accurate in space and time, is based on a flux-corrected transport version of Smolarkiewicz's multidimensional positive definite advection transport algorithm (Smolarkiewicz and Clark, 1986; Smolarkiewicz and Grabowski, 1990), which is monotonic and minimizes numerical diffusion. The horizontal diffusion step, if required, is explicit in time, while the vertical diffusion step is implicit. Horizontal boundary conditions include time variable material inflow concentrations, upwind outflow, and a damping relaxation specification of climatological boundary concentration.

2.3.1.4 Enhancements to EFDC

The version of EFDC used for this project had a number of enhancements to the base EPA EFDC code (www.epa.gov/ceampubl/swater/efdc/index.htm). These enhancements have been made to EFDC to assist model development and application. Key enhancements to the EFDC code include the following:

- Dynamic memory allocation allows the user to use the same executable code for applications to different water bodies. Dynamic allocation eliminates the need to re-compile the EFDC code for different applications because of different maximum array sizes required to specify the computational grid domain and time series input data sets. Dynamic allocation also helps prevent inadvertent errors and provides better traceability for source code development.
- Enhanced heat exchange options that use equilibrium temperatures for the water and atmospheric interface and spatially variable sediment bed temperatures.
- New output snapshot controls for targeting specific periods for high frequency output within the standard regular output frequency.
- Streamlining the code for quicker execution times.
- Customizing linkage of model results for the Windows-based EFDC_Explorer graphical pre- and post-processor for EFDC.

2.3.1.5 State Variables and Computed Output Variables of EFDC

Hydrodynamic models simulate velocity and transport fields, elevation of the free water surface; and bottom stress. The state variables of EFDC include: stage height or free water surface elevation; salinity, water temperature and velocity. A three-dimensional application of EFDC simulates velocity in three-dimensions (x,y,z) as the 'u' and 'v' horizontal (x,y) components and the 'w' vertical (z) component. Turbulent kinetic energy and turbulent macroscale length scale parameters are also included as state variables in EFDC. Water density is computed in EFDC as a function of water temperature and salinity. EFDC computes horizontal diffusivity as an output variable of the model from horizontal turbulent closure methods. EFDC also computes vertical eddy viscosity and vertical eddy diffusivity from vertical turbulence closure schemes as output variables of the model.

2.3.2 EFDC_Explorer Description

EFDC_Explorer is a Windows-based pre- and post processor for the EFDC model (Craig, 2008). It is designed to support model set-up, Cartesian and curvilinear grid generation, testing, calibration, and data visualization, including plots and animation, of model results (www.ds-international.biz).

3 Physical Conditions Overview

3.1 Bathymetric Data

The SWFWMD contracted the University of South Florida (USF) to conduct a bathymetric survey of the Chassahowitzka River System (USF, 2007). Transects were collected at a maximum spacing of 492 feet (150 meters). Figure 3-1 provides a plot of the raw transect points. The color of each data point is defined by the reported elevation of that point and the values for the blue and red ends of the color ramp. The elevation datum for this data was NAVD88. The data was converted into Mean Tide Level (MTL) by shifting the elevations +0.26 feet (0.08 meters) to (the average NAVD88 minus MTL for the Clearwater (8726724) and Cedar Key (8727520).

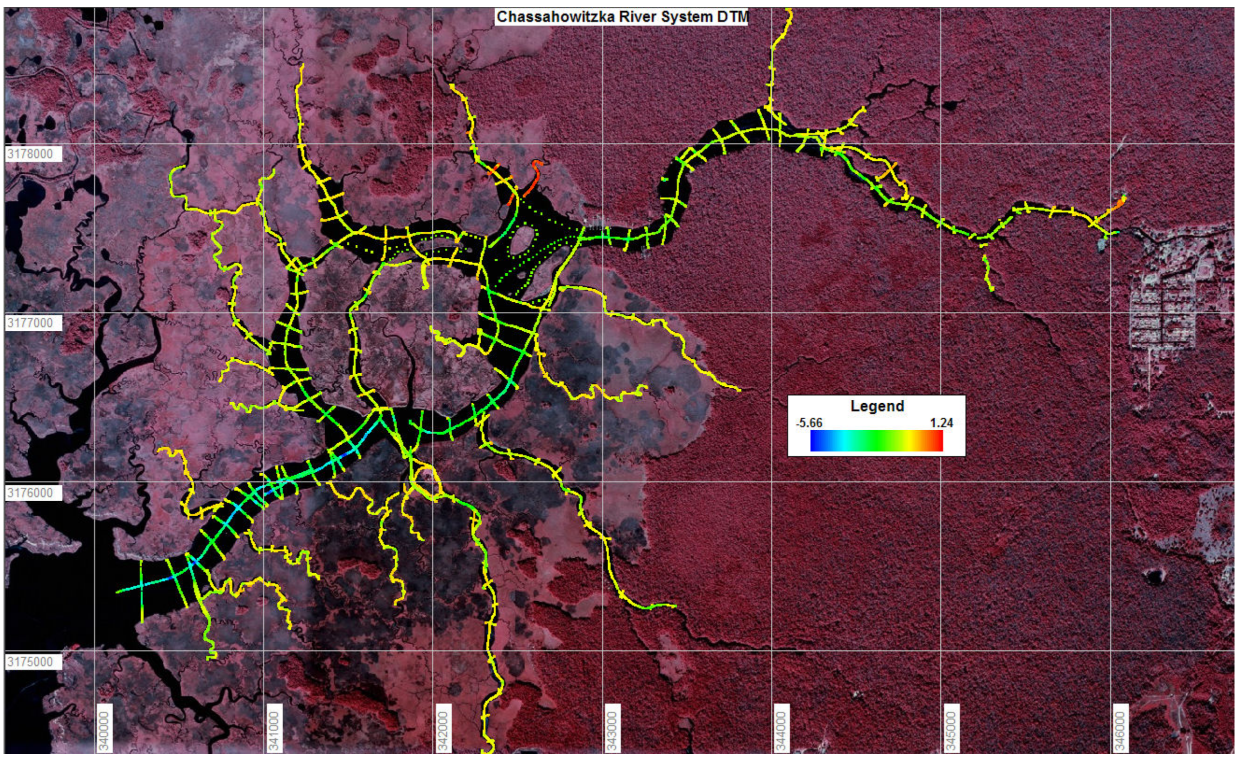


Figure 3-1 USF bathymetric data for the Chassahowitzka River System.

From the raw USF transects and estimated depths derived from the measured data, a digital terrain model (DTM) was produced (Figure 3-2). The DTM used a 32.8 ft (10m) by 32.8 ft (10m) grid which allowed fine scale assessments of depths and volumes. The SWFWMD provided a river distance definition GIS coverage. The numbers shown along the Chassahowitzka River in Figure 3.2 are the distances along the centerline upstream from river kilometer (RK) 0.0.

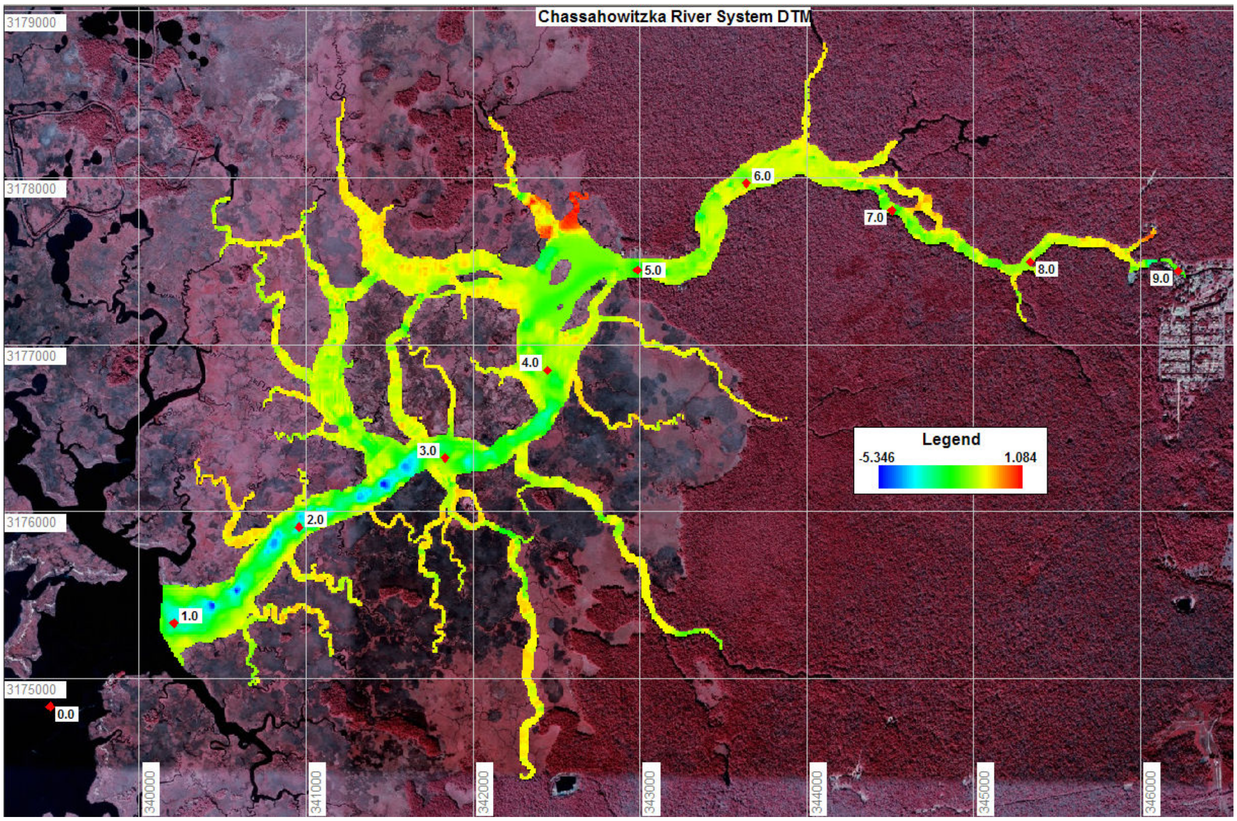


Figure 3-2 Digital Terrain Model of the Chassahowitzka River System with River Kilometers.

3.1.1 Volume by River Kilometer

Using the Chassahowitzka DTM (Figure 3-2), the volume and area by river kilometer was determined. The river was broken into 0.31 mile (0.5 kilometer) segments and assigned a river kilometer (RK) using the SWFWMD centerline. Figure 3-3 shows the river segmentation used for this analysis. Table 3-1 provides the volume and areas by RK, assuming a water surface elevation of MTL.

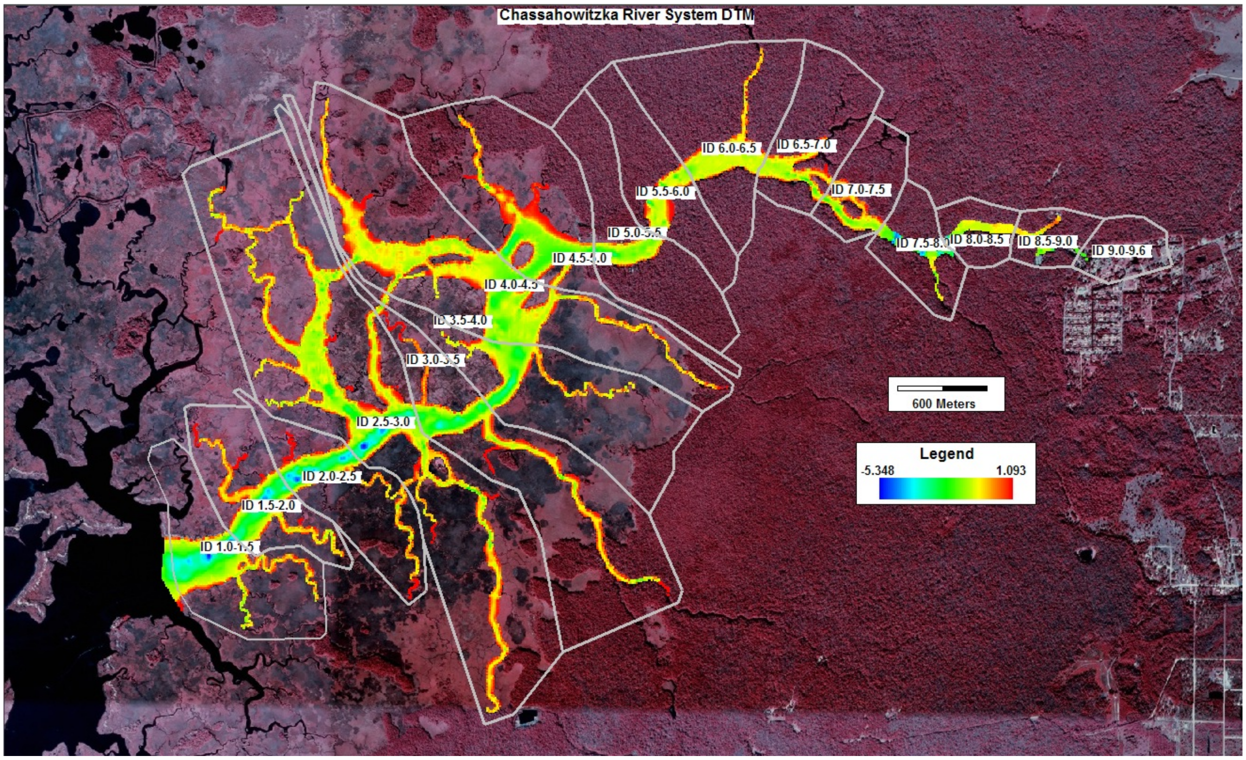


Figure 3-3 Area-Volume segmentation polygons for the Chassahowitzka River System.

Table 3-1 Volume-Area-Shoreline Lengths[1,2,3] by RK for the Chassahowitzka River System.

RK ID	RK	Area (m^2)	Storage (m^3)	Length (km)	Average Depth (m)	Cumulative Area (m^2)	Cumulative Storage (m^3)	Cumulative Length (km)
1.0-1.5	1	177,300	296,908	2.498	1.67	2,245,800	2,387,999	68.959
1.5-2.0	1.5	147,200	205,239	4.684	1.39	2,068,500	2,091,091	66.461
2.0-2.5	2	110,800	184,959	4.555	1.67	1,921,300	1,885,853	61.777
2.5-3.0	2.5	510,700	489,935	19.449	0.96	1,810,500	1,700,893	57.223
3.0-3.5	3	171,000	175,353	7.183	1.03	1,299,800	1,210,958	37.773
3.5-4.0	3.5	120,600	142,344	4.052	1.18	1,128,800	1,035,606	30.590
4.0-4.5	4	447,600	370,316	10.024	0.83	1,008,200	893,262	26.538
4.5-5.0	4.5	177,300	191,605	4.334	1.08	560,600	522,946	16.514
5.0-5.5	5	54,400	65,838	0.988	1.21	383,300	331,341	12.180
5.5-6.0	5.5	65,300	59,501	1.049	0.91	328,900	265,502	11.192
6.0-6.5	6	98,900	76,005	2.315	0.77	263,600	206,002	10.143
6.5-7.0	6.5	57,000	45,152	1.774	0.79	164,700	129,996	7.828
7.0-7.5	7	42,100	32,563	1.727	0.77	107,700	84,844	6.054
7.5-8.0	7.5	27,500	26,998	1.734	0.98	65,600	52,282	4.327
8.0-8.5	8	24,000	15,619	1.011	0.65	38,100	25,284	2.593
8.5-9.0	8.5	13,800	9,593	1.441	0.7	14,100	9,665	1.582
9.0-9.6	9	300	72	0.141	0.24	300	72	0.141

[1]Vertical Datum: Mean Tide Level (MTL)
[2]Area and volumes are based on a flat water surface of 0.0 meters MTL.
[3]Regression Equations:

Storage = $-1335 \cdot RK^4 + 26843 \cdot RK^3 - 131142 \cdot RK^2 - 340674 \cdot RK + 2879028$ ($R^2 = 0.9965$)

Area = -1522.2*RK4 + 32925*RK3 - 198581*RK2 - 53880*RK + 2555100 (R2 =0.9932)

Length = -0.115*RK4 + 2.3117*RK3 - 14.276*RK2 + 17.645*RK + 66.915 (R2 =0.988)

3.1.2 Coastal Bathymetric Data

In addition to the Chassahowitzka River System data, bathymetric data was needed for the area offshore for a few miles. This data was needed in order to build the model into the Chassahowitzka Bay for the Gulf open boundary. Figure 3-4 shows the bathymetric data obtained from NOAA (http://www.ngdc.noaa.gov/mgg/coastal/coastal.html). The vertical datum of the NOAA data was adjusted to the MTL for the Chassahowitzka.

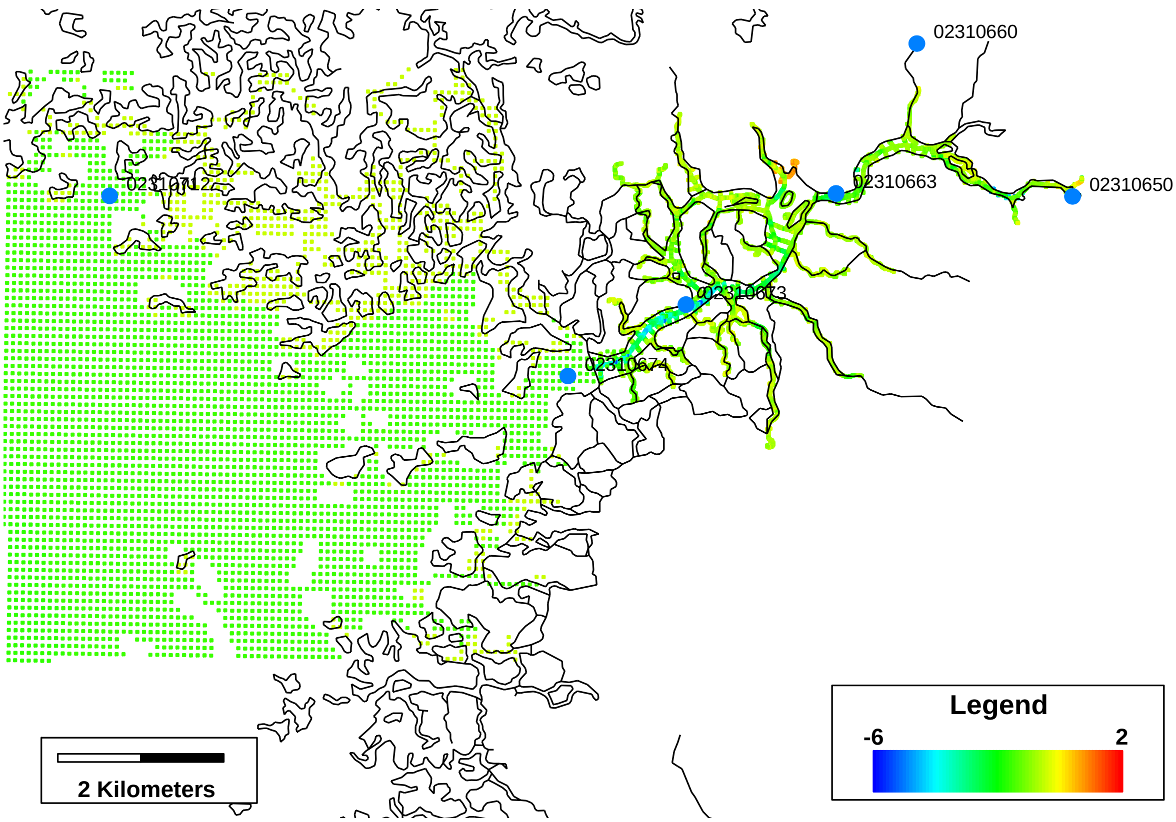


Figure 3-4 Chassahowitzka Bay & River bathymetric data.

3.2 USGS/NOAA Continuous Data Sets

The SWFWMD has contracted the United States Geological Survey (USGS) to install, maintain and collect data for a number of sites along the Springs Coast. The stations used for this study on the Chassahowitzka River system are shown in Figures 1-1 (regional area) and 3-5 (Chassahowitzka system only) and summarized in Table 3-2.

The types of data collected at these stations were stage, temperature and conductivity. Only one station, 02310650, Chassahowitzka near Homosassa, reported flows. The data is stored every 15 minutes. The complete parameter/data inventory is shown in Table 3-2. For the Chassahowitzka system, most of the data were available beginning in 2003 with more stations coming on line in the later years.

In addition to stage and/or flow, several of the stations also recorded temperature and conductivity data. Depending on the station, either one or two depths were collected. The sensors are at fixed elevations, therefore the depths vary throughout the tide cycle. For the “surface” sensors sometimes the water levels dropped below these sensors, resulting in the sensors being out of the water. The sensors continued to collect data therefore, the records had to be post-processed to remove invalid temperatures and conductivity data when the sensors were out of the water. The fixed elevations of the sensors along with the measured water surface elevations were used to identify the invalid data periods.

Along with the Chassahowitzka System USGS gages, it was necessary to gather longer periods of record data from regional gages. The data assembled included hourly and daily tide levels and water temperatures. An important source of data for the Chassahowitzka MFL analysis was the long term tidal data collected at the Cedar Key station (NOAA 8727520, see Fig. 1-1). The daily maximum and minimum tide levels were available back to the year 1965.

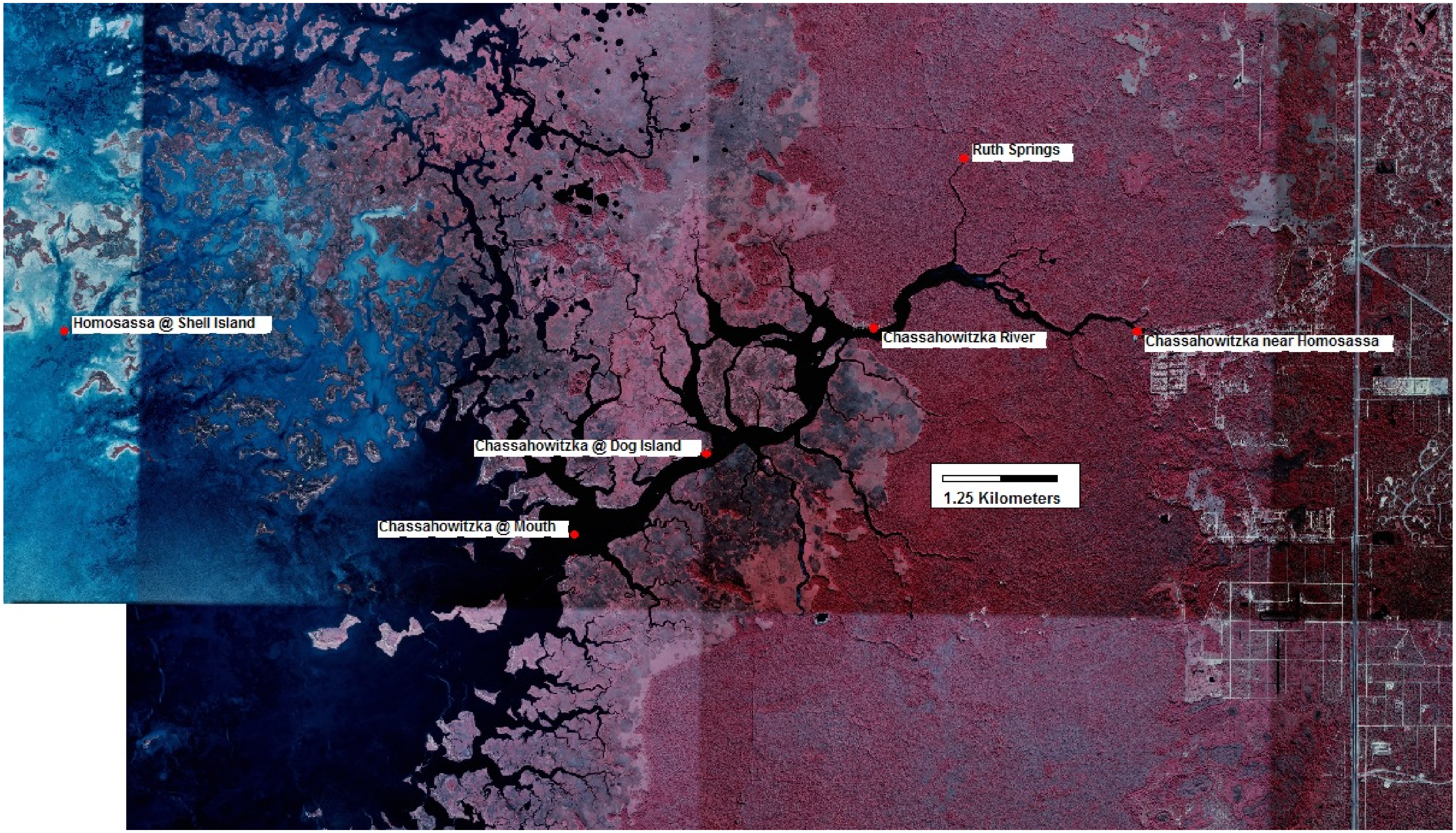


Figure 3-5 Location map of the Chassahowitzka River continuous monitoring stations.

Table 3-2 Continuous Data Inventory for the Chassahowitzka River Withdrawals Study

Name	Station Number	Type	Interval	# Valid Points	# Invalid Points	# Missing Points	Overall Data Coverage Beginning	Overall Data Coverage Ending
Homosassa near	USGS-02310712	Stage	15 min	32373	4010	1	14-Sep-06	28-Sep-07
Shell Island	02310712, Depth = 0.515	Temperature	15 min	36278	105	1	14-Sep-06	28-Sep-07
	02310712, Depth = 1.277	Temperature	15 min	34958	1425	1	14-Sep-06	28-Sep-07
	02310712, Depth = 0.515	Salinity	15 min	36279	104	1	14-Sep-06	28-Sep-07
	02310712, Depth = 1.277	Salinity	15 min	34958	1425	1	14-Sep-06	28-Sep-07
Chassahowitzka	USGS-02310674	Stage	15 min	48199	0	20536	11-Oct-05	27-Sep-07
near Mouth	02310674, Depth =0.393	Temperature	15 min	41515	6684	20536	11-Oct-05	27-Sep-07
	02310674, Depth = 1.790	Temperature	15 min	47863	336	20536	11-Oct-05	27-Sep-07
	02310674, Depth = 0.393	Salinity	15 min	48198	0	20537	11-Oct-05	27-Sep-07
	02310674, Depth = 1.790	Salinity	15 min	48199	0	20536	11-Oct-05	27-Sep-07
Chassahowitzka	USGS-02310673	Stage	15 min	67806	0	3709	12-Sep-05	27-Sep-07
near Dog Island	02310673, Depth = 0.213	Salinity	15 min	50276	17529	3710	12-Sep-05	27-Sep-07
	02310673, Depth = 0.671	Salinity	15 min	67507	298	3710	12-Sep-05	27-Sep-07
	02310673, Depth = 0.213	Temperature	15 min	50851	16954	3709	12-Sep-05	27-Sep-07
	02310673, Depth = 0.671	Temperature	15 min	67508	298	3709	12-Sep-05	27-Sep-07
Chassahowitzka	USGS-02310663	Stage	15 min	153977	0	582	1-May-03	27-Sep-07
River	02310663, Depth = 1.061	Salinity	15 min	153976	0	583	1-May-03	27-Sep-07
	02310663, Depth = 1.061	Temperature	15 min	153977	0	582	1-May-03	27-Sep-07
Chassahowitzka near Homosassa	USGS-02310650	Flow	1440min	3257	674	0	20-Feb-97	25-Nov-07
Cedar Key	NOAA 8727520	Stage	60 min	658533	38814	0	1-Jan-00	17-Dec-07
		Daily max	1440min	14846	859	0	1-Jan-65	31-Dec-07
Weeki Wachee Well	USGS-283201082315601	Stage	7200min	12621	0	31	15-Jun-66	18-Oct-07

3.3 Spring Discharge

Spring discharge is the primary freshwater source into the Chassahowitzka River System. However, only the Chassahowitzka Main Spring (see Figure 3-7) has the flows continuously recorded. The flows are monitored by the USGS gaging station 02310650. The data availability for this station was summarized in the previous section. This leaves the remaining identified springs without continuous monitoring. Fortunately, there has been a number of discrete measurements for many of these springs. Figure 3-6 provides a location map of the six recognized significant springs for the Chassahowitzka River System. Table 3-3 summarizes the average flows from these springs during a period from 1988 to 1989 and average salinity of a number of samplings between 1993 and1997.

In addition to the identified springs, the Chassahowitzka System receives discharge from smaller springs and diffuse groundwater discharge. The impacts of these smaller springs were not directly addressed. However, during the hydrodynamic model calibration the model sensitivity analysis indirectly addressed these smaller discharges.

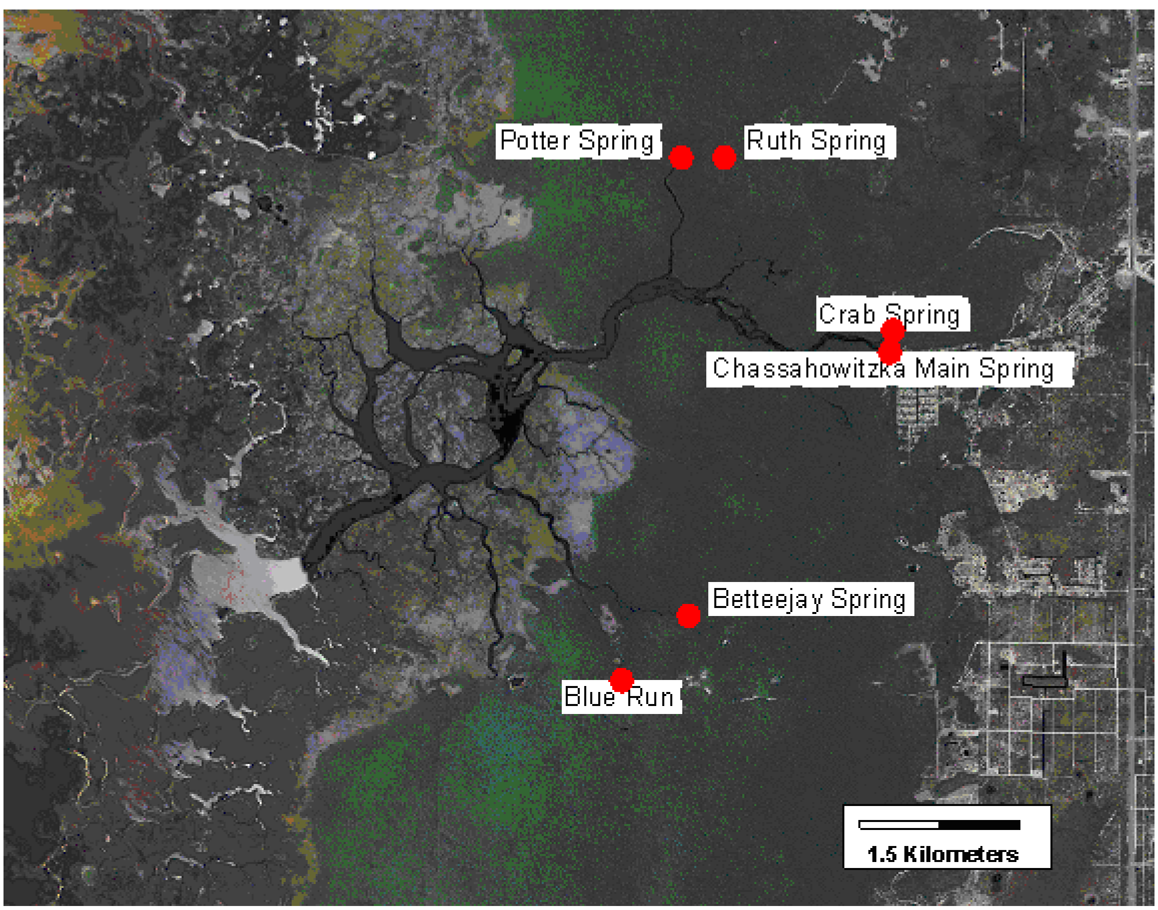


Figure 3-6 Location and Distribution of Springs in the Chassahowitzka Springs Group

Table 3-3 Discharge information for several Springs in the Chassahowitzka Group.

Springs Name	Average Discharge (cms)	(cfs)	Salinity (ppt)
Crab Creek	1.38	48.7	3.2
Potter Creek	0.53	18.6	5.5
Baird	0.16	5.7	6.5
Beteejay Head Spring	0.18	6.4	<1
Blue Run	0.19	6.6	4.3

(Source: "The Hydrology and Water Quality of Select Springs in the Southwest Florida" Water Management District, Prepared by the Water Quality Monitoring Program Southwest Florida Water Management District May 2001.
Mote Marine Laboratory, "Chassahowitzka National Wildfile Refuge Status and Trends", Report submitted to US Fish and Wildlife Service, Denver, Colorado, Technical Report Number 579, July 10,1998)

3.4 Meteorological Data

In order to accurately simulate the water temperatures in the Chassahowitzka River System, atmospheric conditions are needed. The required parameters are wind speed, wind direction, barometric pressure, dry bulb temperature, wet bulb temperature (or relative humidity), solar radiation and cloud cover. Because the atmospheric conditions are highly variable, hourly data are the standard temporal resolution needed. These data play a significant role in the hydrodynamics of a system like the Chassahowitzka. Therefore, it is important to pick a meteorological data station that has excellent data quality as well as representative of the area being modeled. The St. Petersburg/Clearwater International Airport meteorological station (WBAN 12842) was selected. Hourly data is available for the entire period of interest. Figures 3-7 and 3-8 present the data for the Year 2006.

Another meteorological data station was used for the determination of the critical thermal habitat. The smaller St. Petersburg Airport (WBAN 92806) station was used since it was closer to the Chassahowitzka. However, this station did not have sufficient temporal resolution or a complete data record needed for the hydrodynamic modeling. Just daily dry bulb temperatures were used from this site.

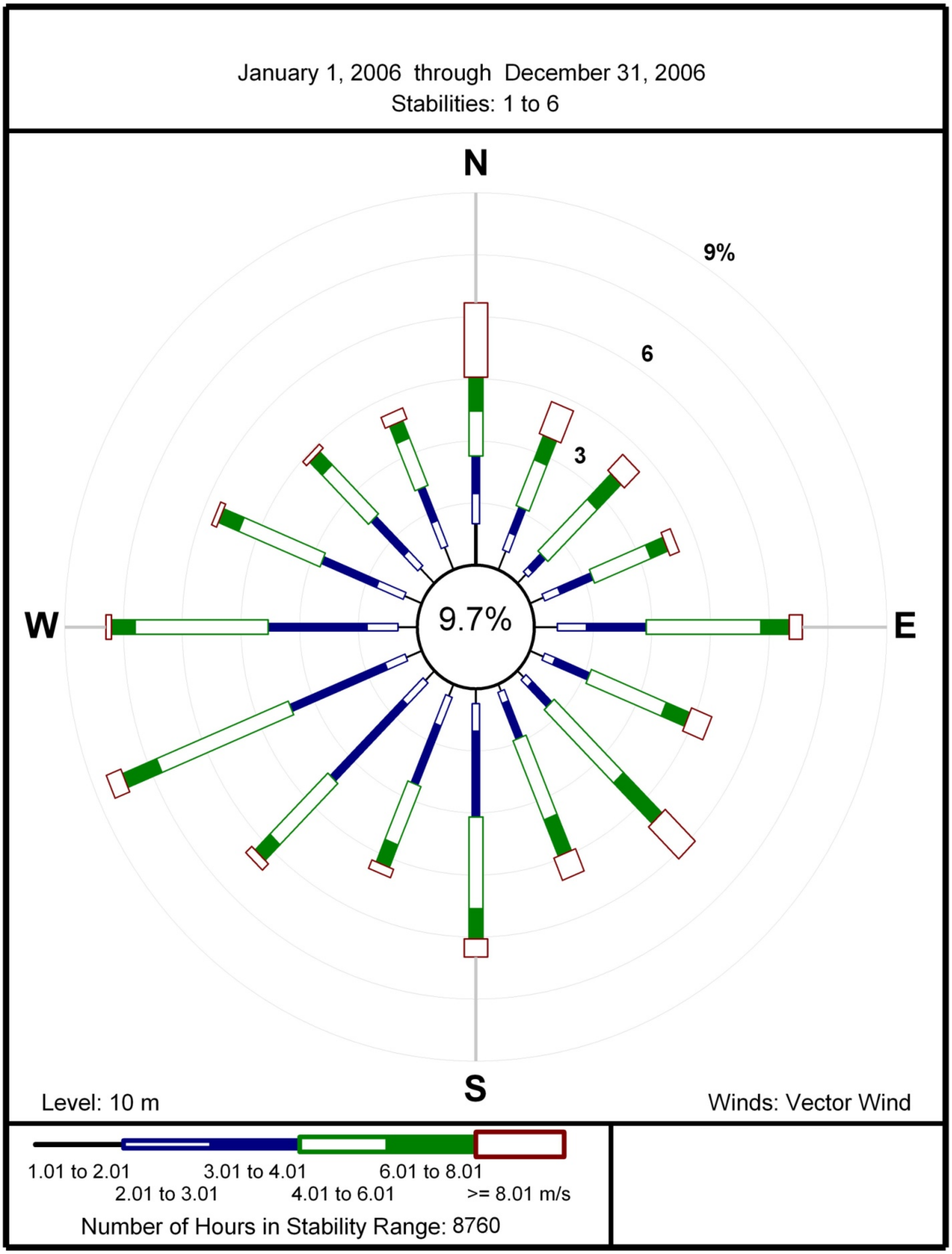


Figure 3-7 Wind rose for the St. Petersburg/Clearwater Airport meteorological data.

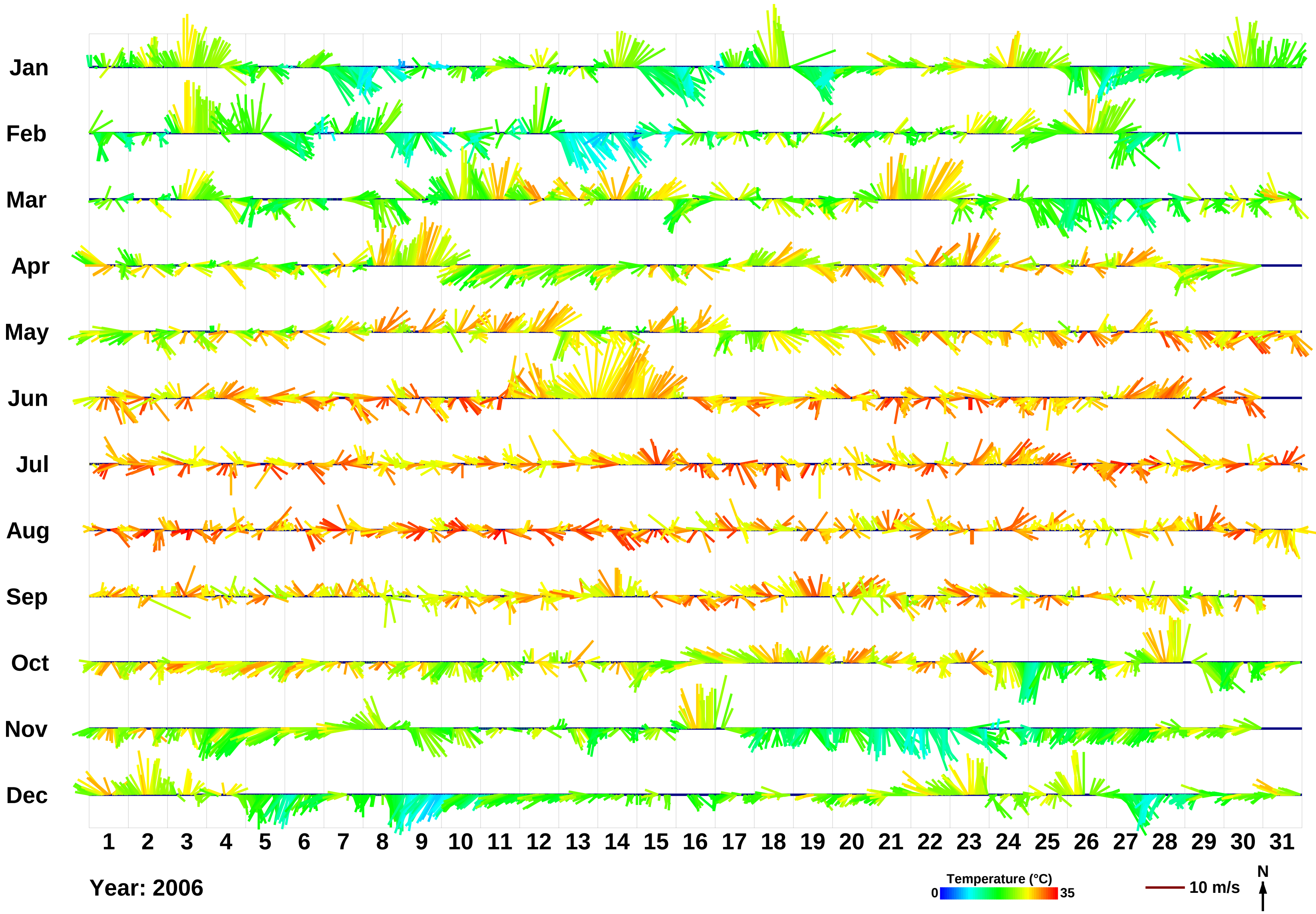


Figure 3-8 Wind speed and direction stick plot for the Year 2006 for St. Petersburg/Clearwater Airport.

4 Model Development and Calibration

4.1 Calibration Period

The period considered for model calibration was the 2006-2007 manatee season. The selected model simulation period was from November 1, 2006 to February 28, 2007. During this 4-month period there existed the best available overlap of the flow, temperature, salinity and meteorology data for both boundary conditions and for calibration comparison data. This period corresponded to a relatively low spring discharge period.

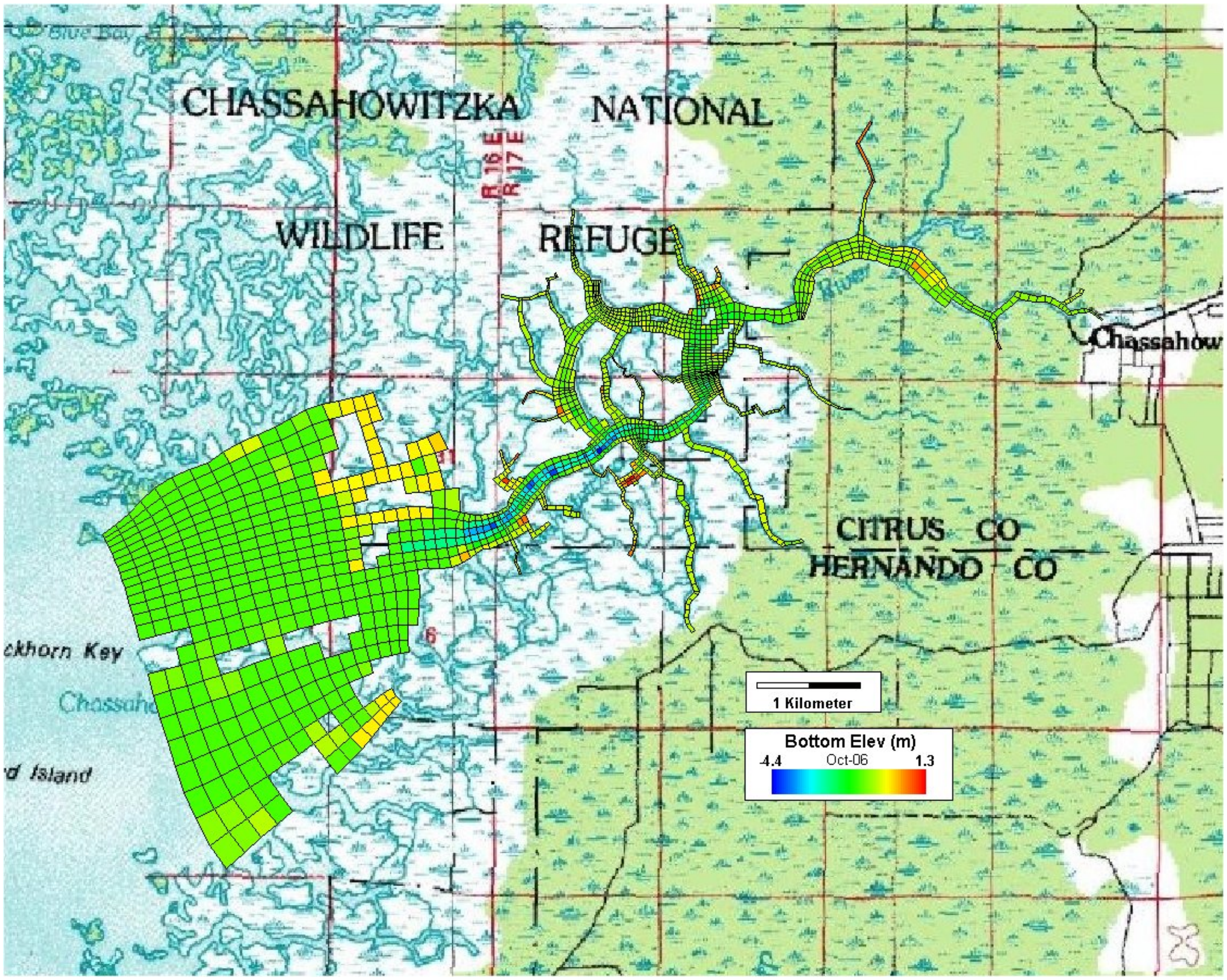


Figure 4-1 Final grid with bathymetry (vertical datum: MTL).

4.2 Grid Development and bathymetry

Figure 4-1 provides a plot of the final grid. The grid has 1639 horizontal cells and four vertical layers. A typical grid in the river area has a size of about 164ft (50m) wide and 262ft (80m) long. The grid was developed using the Delft RGFGrid program. The grid created by RGFGrid was then configured for EFDC by importing the GRD file into EFDC_Explorer. Final minor editing to the grid was performed using EFDC_Explorer.

Bathymetry data from field survey of Chassahowitzka River System (University of South Florida) along with NOAA grid bathymetry data (http://www.ngdc.noaa.gov/mgg/coastal/coastal.html) of the Chassahowitzka bay were used to define depths within the cells. All elevations were referenced to MTL.

The EFDC model grid was configured with 4 layers to address the salinity and temperature related density dependent dynamics. For the vertical discretization, the layers were evenly split, with each layer representing 25% of the water depth for each cell.

4.3 Boundary Condition

For the simulation of the winter period in 2006-2007, the following boundary conditions were needed:

- Upstream: Inflow rates, water temperature and salinities
- Offshore: water level, water temperature and salinities
- Atmospheric: wind, air temperature, humidity, atmospheric pressure and solar radiation

The EFDC model boundary condition locations are shown in Figure 4-2. Each of the inflows are shown and labeled (i.e. Chassahowitzka Main Spring, Potter, etc) with the basin ID. The “W” label identifies the open boundary to the West and whose tide stage, temperature and salinity represent the Chassahowitzka Bay.

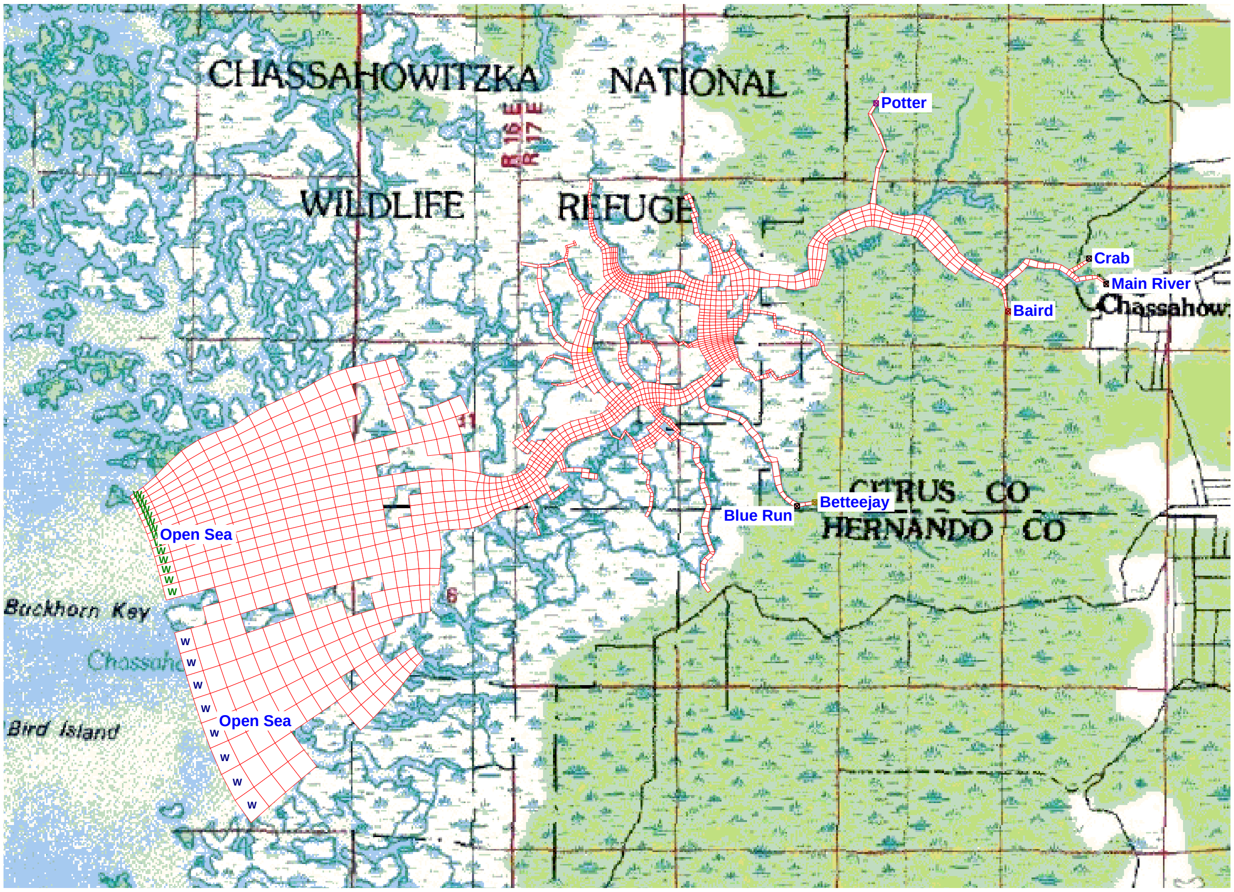


Figure 4-2 Location of the Boundary Conditions

Flow Boundary Conditions

The EFDC model was configured for the flows from the following springs:

- Chassahowitzka Main Spring (ID: Main Spring)
- Crab
- Baird
- Potter
- Beteejay
- Blue Run

For Chassahowitzka Main Spring, daily flow, hourly salinities and water temperature recorded at Station "Chassahowitzka near Homosassa" (USGS 02310650) are used. For remaining streams, a steady discharge and salinity taken from references in Table 3-3 were used.

Figures 4-3 and 4-4 show the time series of discharge and temperature "Main River" boundary.

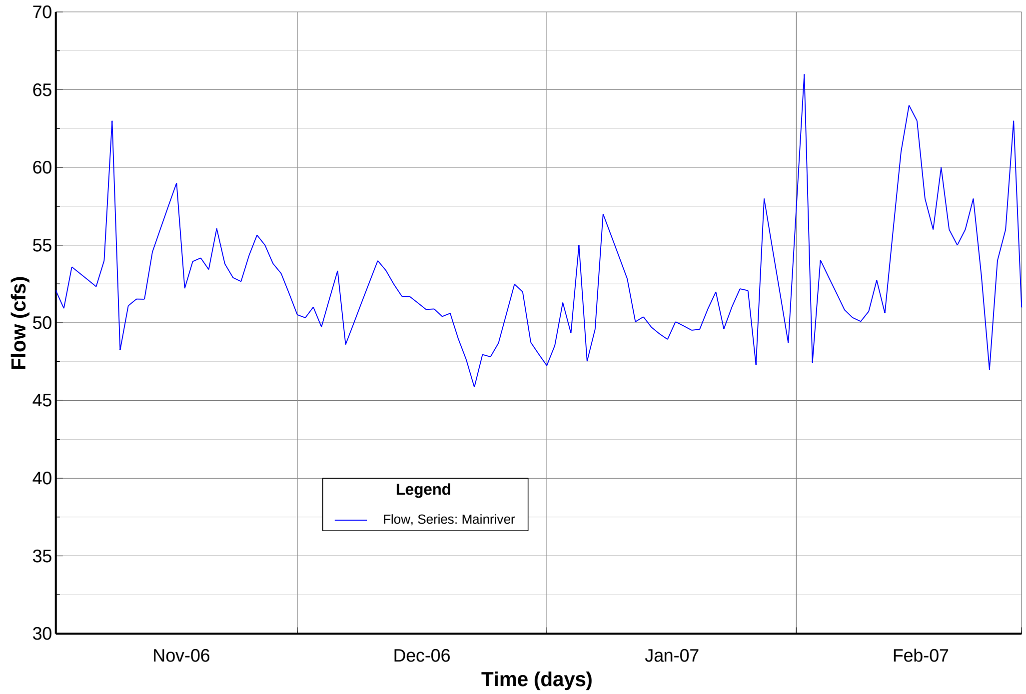


Figure 4-3 Flows for the "Main River" boundary group during the calibration period.

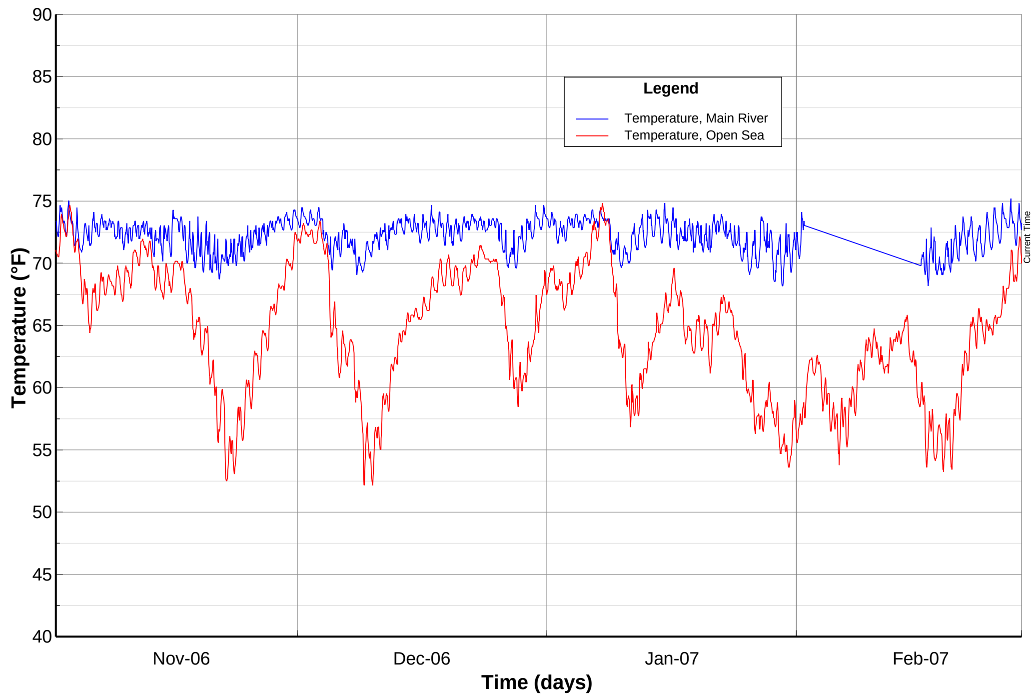


Figure 4-4 Water temperature for the Main River and Open Sea boundary groups during the calibration period.

Open Sea Conditions

An open boundary was set for the cells along the western edge of the model and labeled as “W” in the Figure 4-2. Time series of the water gages and salinities recorded at Chassahowitzka mouth USGS 02310674) and Water temperature at Shell Island (USGS 02310712) is used for open sea boundary condition. The salinity was increased by 4 ppt to match the model predicted values at the River mouth (USGS 02310674) while the temperature and water level appeared not to require any offset. The Figures 4-4, 4-5 and 4-6 show time series for Open Sea boundary, respectively, for temperature, water surface elevation and salinity.

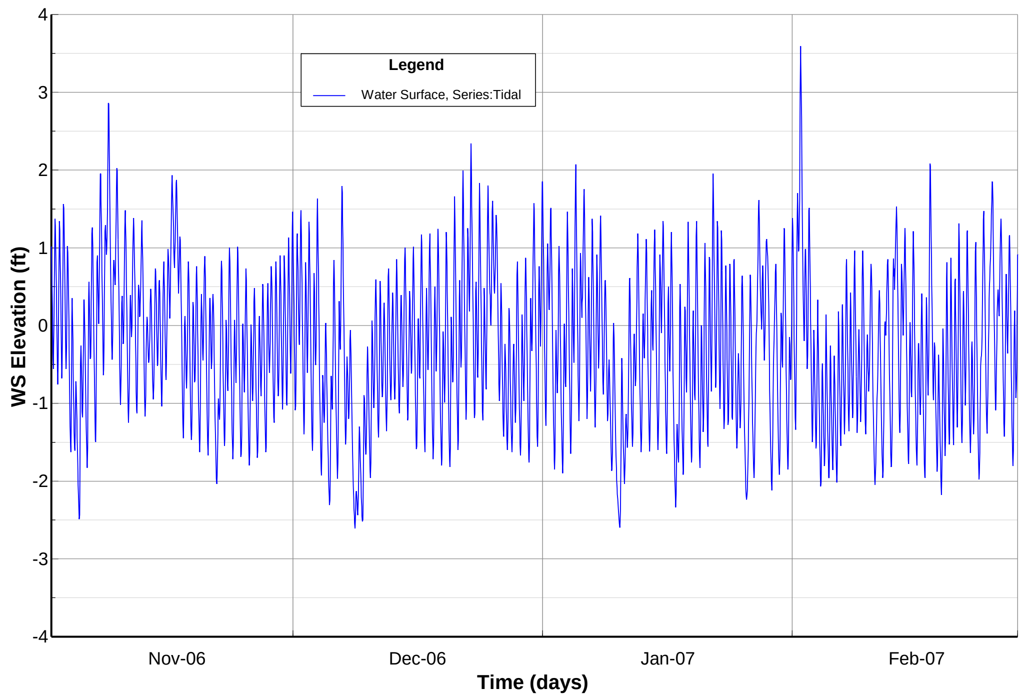


Figure 4-5 Boundary Condition: Water levels at Open Sea.

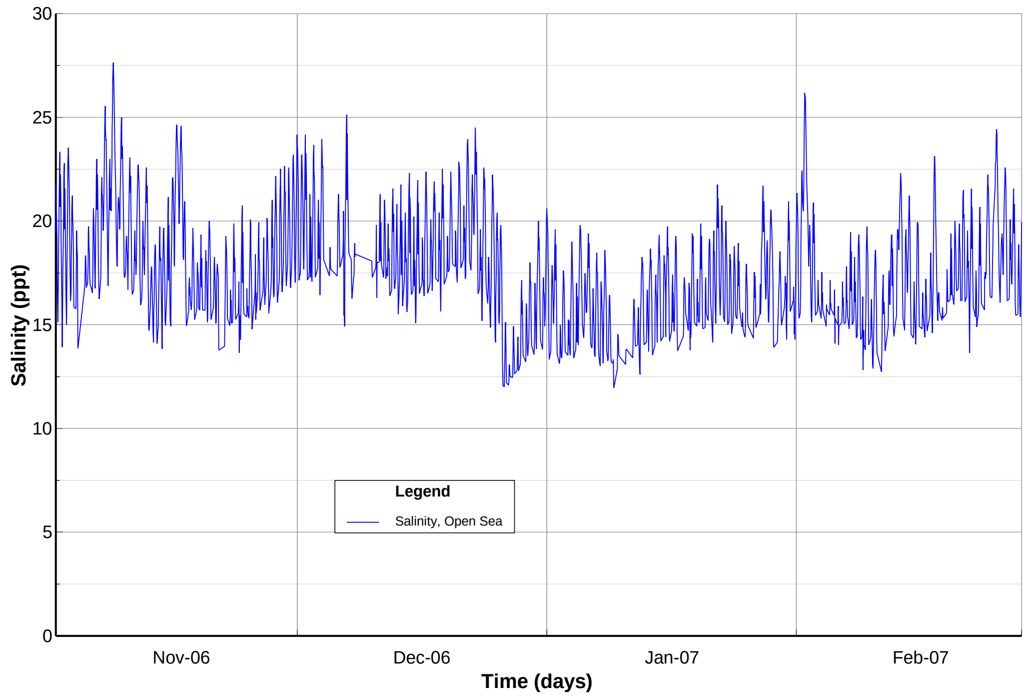


Figure 4-6 Boundary Condition: Salinity at Open Sea

<u>Atmospheric and Wind Conditions</u>

Winds and atmospheric conditions are very important inputs to a hydrodynamic model for large water bodies. For certain periods of time, winds may be the dominant forcing for flows, especially for the surface layer. Hourly data was compiled for the simulation periods of interest using the St. Petersburg-Clearwater International Airport, FL station.

The atmospheric conditions of temperature, humidity, rainfall, evaporation, barometric pressure, solar radiation and cloud cover are important for the heat sub-model within EFDC. These data are entered into EFDC via the ASER.INP file. This file has been constructed for the simulation periods of interest.

4.4 Model Calibration

4.4.1 Tide Signal Calibration

The model ran with a 5 second time step, providing a stable numerical solution for the entire calibration period. The model simulations results were then compared to the continuous measurements at USGS stations River Mouth (02310674), Dog Island (02310673) and Chassahowitzka River (02310663). Figures 4-7 and 4-8 present comparisons of the measured and predicted water level at 2 places in the system. Based on a review of the model's response to tidal fluctuations, inflow and wind stresses, the model was considered reasonable and representative for the flow and water levels.

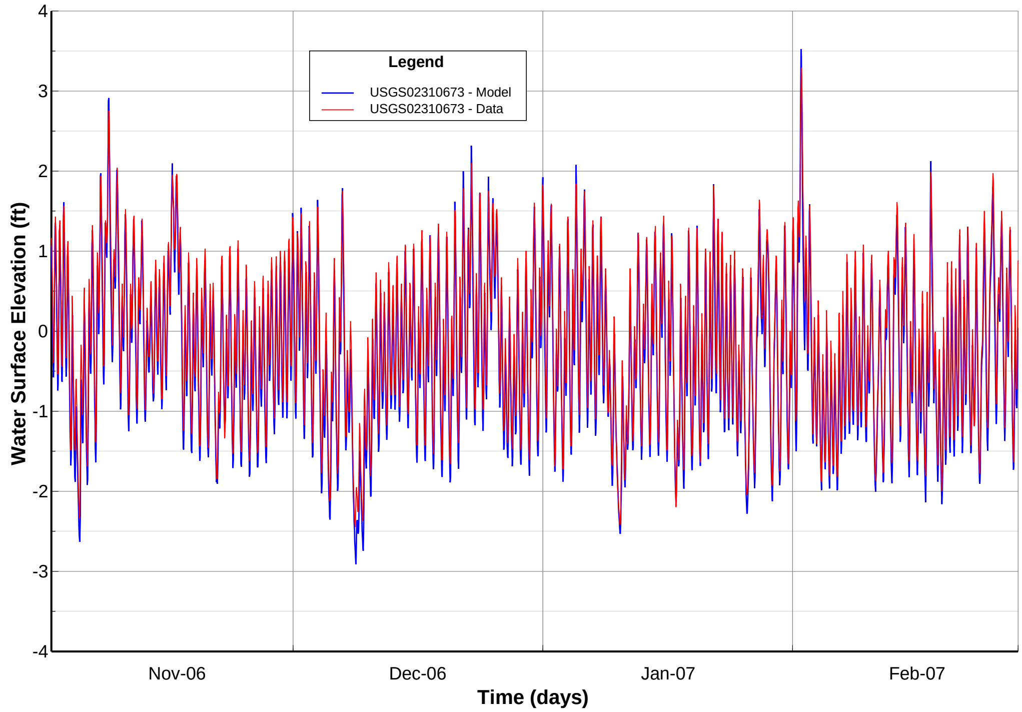


Figure 4-7 Chassahowitzka River at the Dog Island (USGS 02310673): Stage.

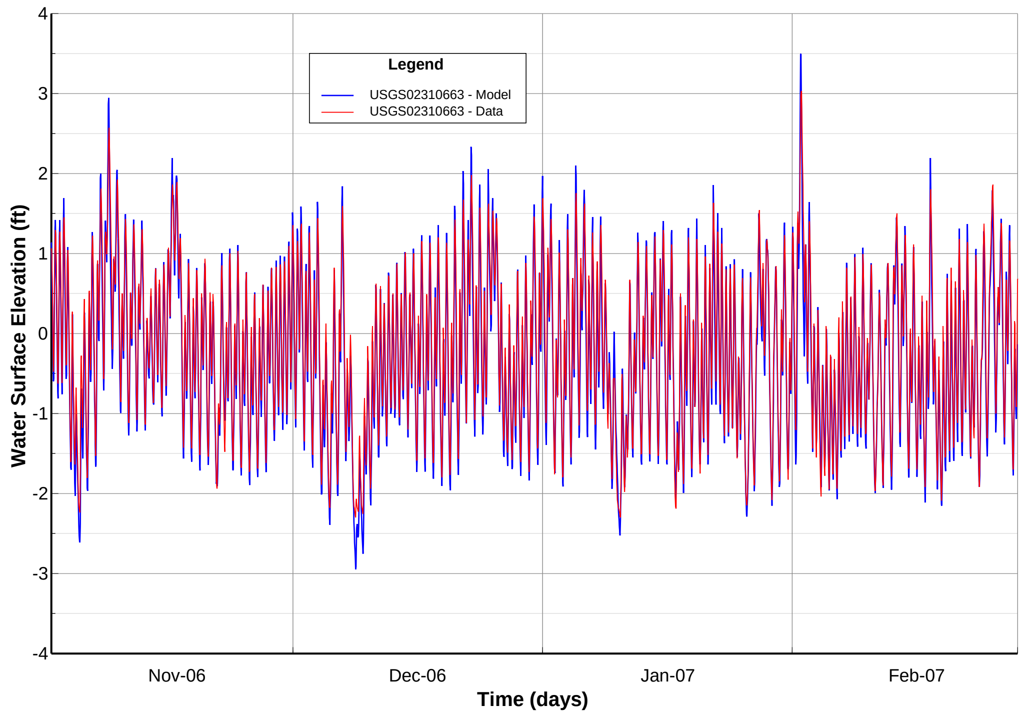


Figure 4-8 Chassahowitzka River near Chassahowitzka (USGS 02310663): Stage.

4.4.2 Salinity Calibration

Figures 4-9 through 4-11 show the salinity calibration results for Stations 02310673 and 02310663. The model layers were selected differently for each station in accordance with the elevation of the top and bottom sensors. For example, the Dog River station (USGS 02310673), the sensors are only 1.48 feet (0.45 meter) apart. The top sensor routinely came out of the water during low tides (see the discussion in Section 3.2). Therefore the "top" and "bottom" designations of the sensors only refer to their relative position to each other, not necessarily with respect to water depths. For the Dog River station the "top" sensor corresponds to the models top layer (layer 4) and the "bottom" sensor corresponds to layer 3 (the 2nd layer from the top). For the Chassahowitzka River station (USGS 02310663), there was only one sensor level located at the "bottom" which corresponded to the model's layer 1.

For the Dog River "top" layer, because the record was filtered to remove data when the sensor was out of the water, the lower salinities during ebb tide have been largely removed from the comparison. Therefore, the data misses the lower salinity periods (Figure 4-9). Overall, the model does a good job of representing the salinity trend during the period.

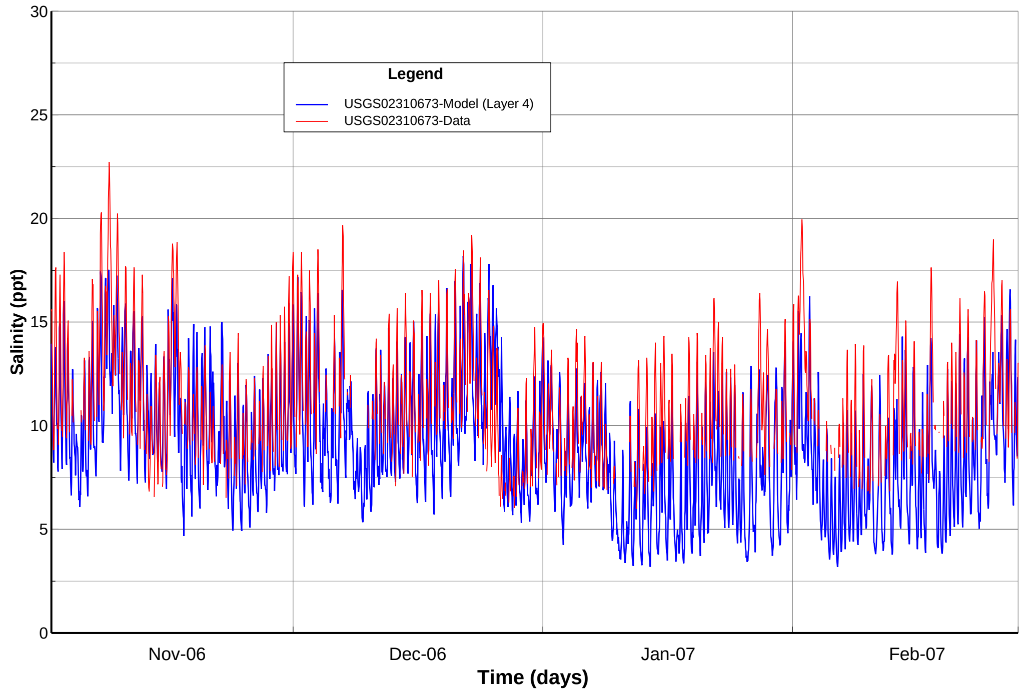


Figure 4-9 Chassahowitzka River at the Dog Island (USGS 02310673): Top Salinity.

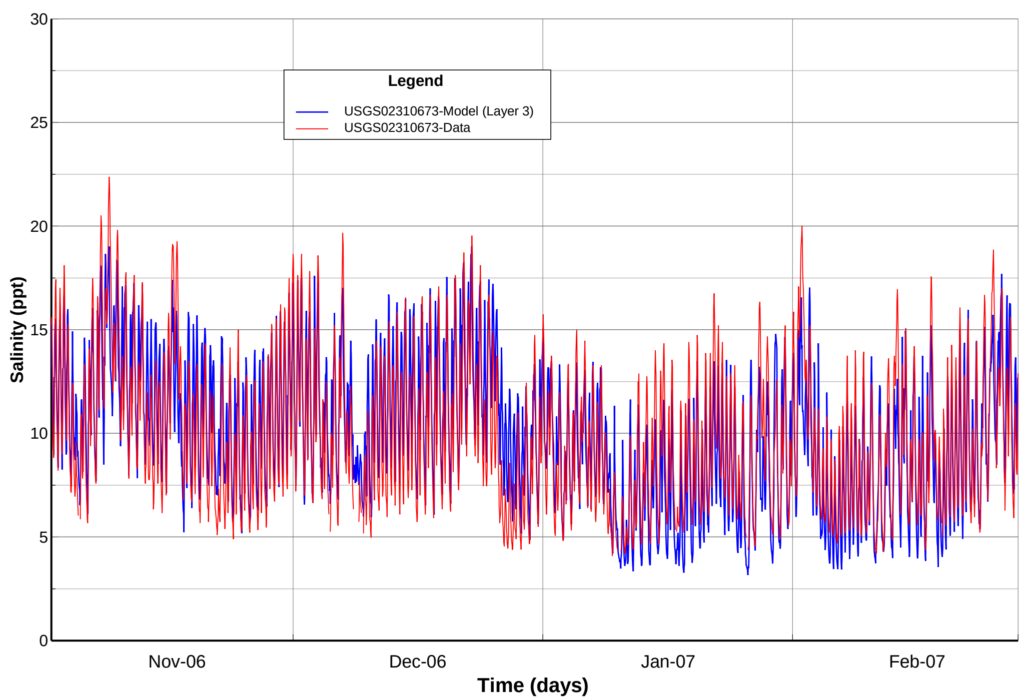


Figure 4-10 Chassahowitzka River at the Dog Island (USGS 02310673): Bottom Salinity.

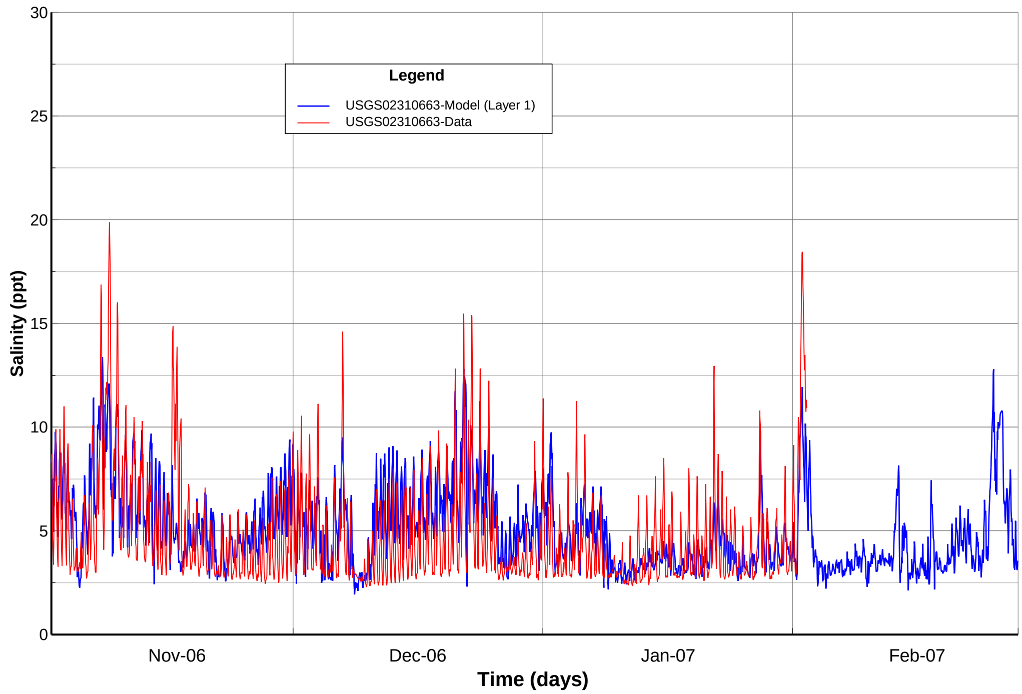


Figure 4-11 Chassahowitzka River near Chassahowitzka (USGS 02310663): Salinity.

4.4.3 Water Temperature Calibration

Figures 4-12 through 4-14 show the temperature results for calibration Stations 02310673 and 02310663. The temperature calibration reproduced the cycles of cold fronts moving through the area, producing cooling followed by warming trends.

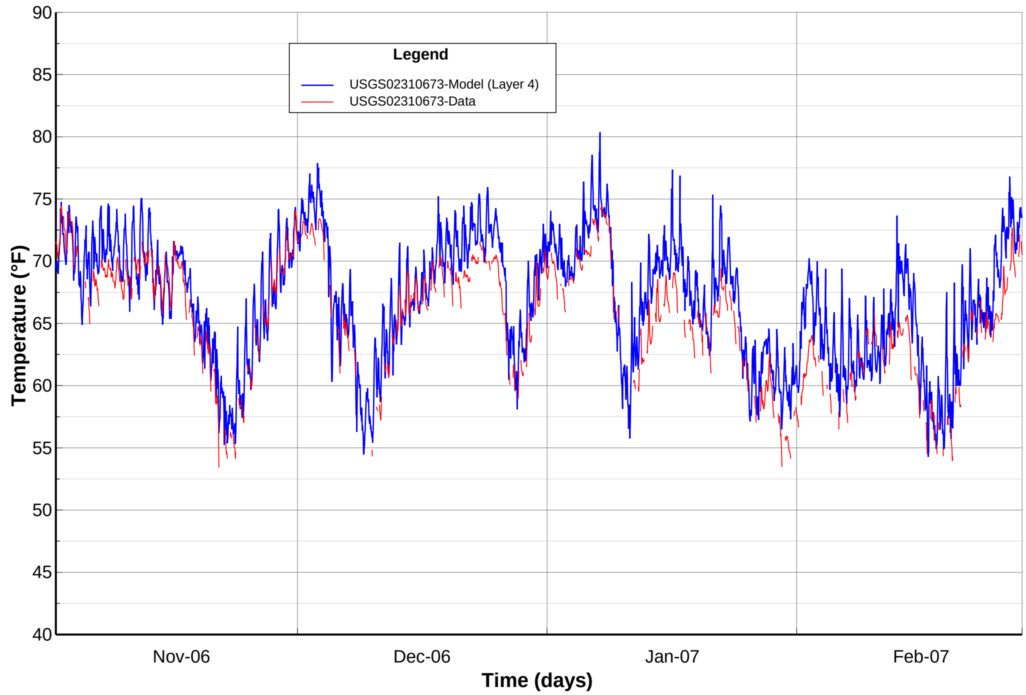


Figure 4-12 Chassahowitzka River at Dog Island (USGS 02310673): Top Water Temperature.

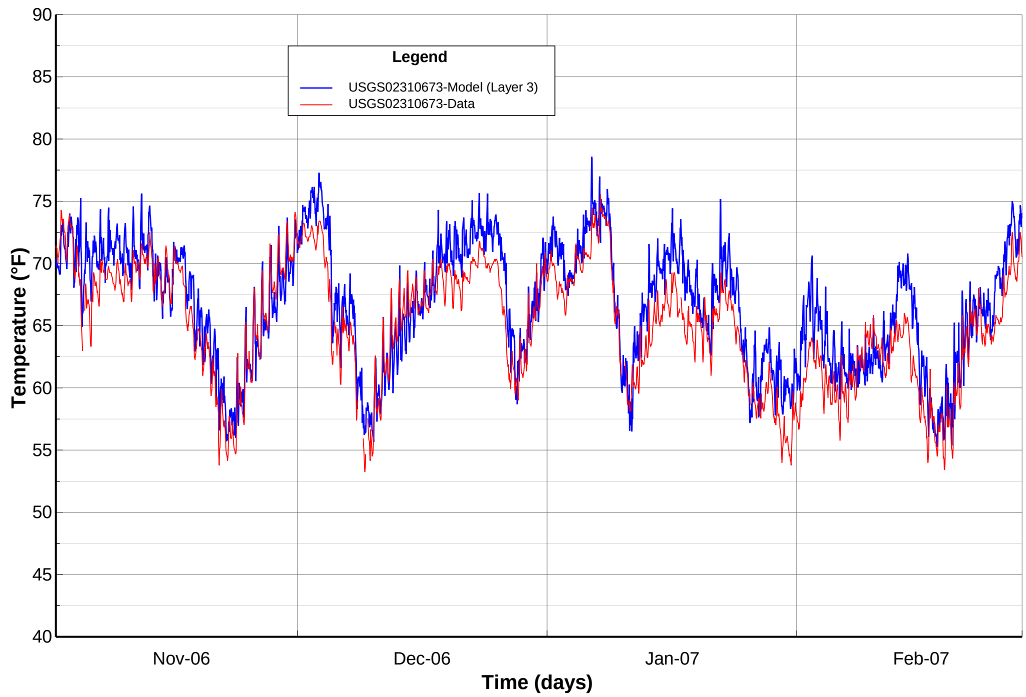


Figure 4-13 Chassahowitzka River at Dog Island (USGS 02310673): Bottom Water Temperature.

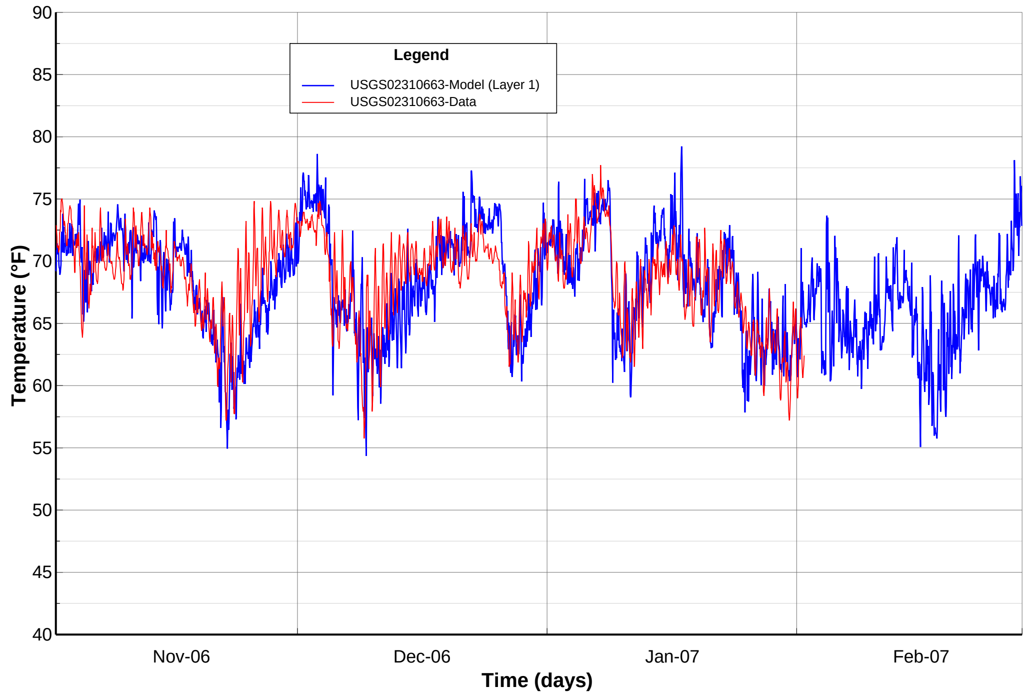


Figure 4-14 Chassahowitzka River near Chassahowitzka (USGS 02310663): Water Temperature.

4.4.4 Calibration Statistics

Nash-Sutcliffe Efficiency Coefficient

To determine the accuracy of model calibration outputs the Nash-Sutcliffe efficiency coefficient (NSEC) was used. It is defined as:

$$NSEC = 1 - \frac{\sum_{i=1}^{N}(O_i - X_i)^2}{\sum_{i=1}^{N}(O_i - O_M)^2}$$

Where :

O_i – The observed value at time i,
X_i – The modeled value at time i,
O_M – The mean of the observed values.

Basically, the closer the model efficiency coefficient is to 1, the more accurate the model is.

Root Mean Square Error

The error statistic used to determine the sensitivity of the model is the root mean square error (RMSE) as defined as:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(O_i - X_i)^2}{N}}$$

Where:

AE – The average error statistic
O – The observed value,
X – The corresponding model value in space and time, and
N – The number of valid data/model pairs.

Tables 4-1, 4-2 and 4-3 provide summaries of the calibration statistics for salinity, temperature and water surface elevation, respectively. Upon reviewing the calibration plots and calibration metrics, the salinity, temperature and water surface calibration was judged to be good and sufficiently representative of the Chassahowitzka River System. The calibrated model was then ready to be used as for the study of reduced flow and thermal criteria of the System.

Table 4-1 Salinity (ppt) Calibration Statistics for Nash-Sutcliffe and RMS error.

Station ID	Layer/ Type	Starting Date/Time	Ending Date/Time	# Pairs	Nash-Sut	RMS	Data Avg	Model Avg
USGS 02310674	Surface	30-Oct-06	28-Feb-07	2236	0.26	2.21	13.75	14.84
USGS 02310674	Bottom	30-Oct-06	28-Feb-07	2927	-0.70	4.15	12.58	15.93
USGS 02310673	Surface	30-Oct-06	28-Feb-07	1839	0.37	2.28	11.53	10.63
USGS 02310673	Bottom	30-Oct-06	28-Feb-07	2880	0.73	1.78	9.94	10.09
USGS 02310663	Bottom	30-Oct-06	2-Feb-07	2298	0.45	1.90	4.86	5.30
Composite				12180	0.19	2.53		

Table 4-2 Temperature (°F) Calibration Statistics for Nash-Sutcliffe and RMS error.

Station ID	Layer/ Type	Starting Date/Time	Ending Date/Time	# Pairs	Nash -Sut	RMS	Data Avrg	Model Avrg
USGS 02310674	Surface	30-Oct-06	28-Feb-07	2248	0.77	2.32	65.50	66.69
USGS 02310674	Bottom	30-Oct-06	28-Feb-07	2927	0.73	2.55	64.79	65.19
USGS 02310673	Surface	30-Oct-06	28-Feb-07	1843	0.71	2.54	65.89	67.61
USGS 02310673	Bottom	30-Oct-06	28-Feb-07	2878	0.72	2.54	65.20	66.84
USGS 02310663	Bottom	30-Oct-06	1-Feb-07	2278	0.34	2.96	68.76	68.36
Composite				12174	0.66	2.58		

Table 4-3 Water Surface (ft) Calibration Statistics for Nash-Sutcliffe and RMS error.

Station ID	Layer/ Type	Starting Date/Time	Ending Date/Time	# Pairs	Nash -Sut	RMS	Data Avrg	Model Avrg
USGS 02310674	Surface	30-Oct-06	28-Feb-07	2927	0.978	0.14	-0.271	-0.294
USGS 02310673	Surface	30-Oct-06	28-Feb-07	2927	0.928	0.25	-0.090	-0.306
USGS 02310663	Surface	30-Oct-06	28-Feb-07	2927	0.947	0.22	-0.184	-0.307
Composite				8781	0.951	0.20		

4.5 Sensitivity Analysis

To test the sensitivity of the calibrated model, a series of runs were conducted to evaluate the model's response to the following scenarios:

- Half of the fresh water inflows,
- Double the fresh water inflows, and
- Double number of vertical layers (to 8 layers)

Figure 4-16 through 4-19 show the comparisons of the temperature and salinity at station 02310663. Tables 4-4 and 4-5 show the comparison of RMS errors for the three sensitivity runs relative to the calibration run.

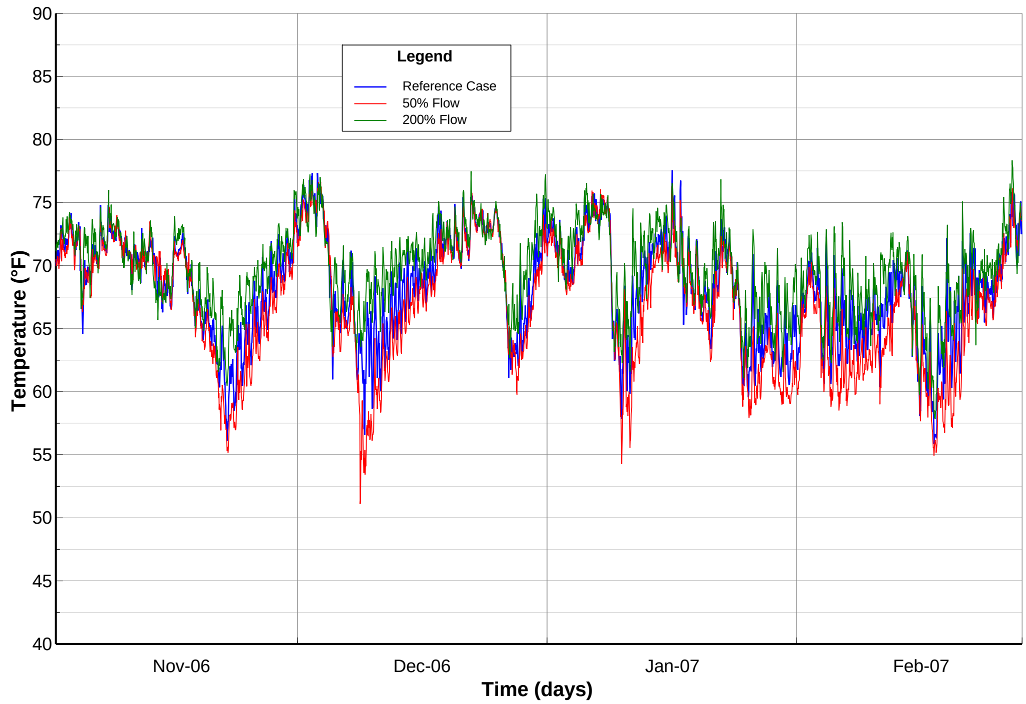


Figure 4-15 Fresh Water Inflow Sensitivity: Temperature Comparison at USGS 02310663.

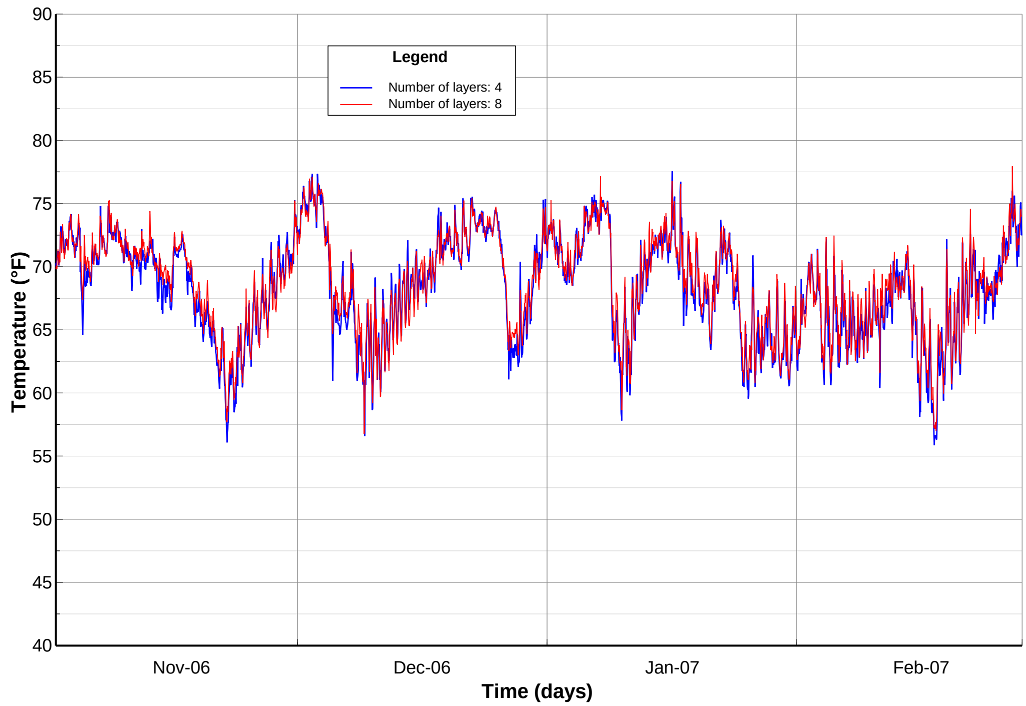


Figure 4-16 Number of Layers Sensitivity: Temperature Comparison at USGS 02310663.

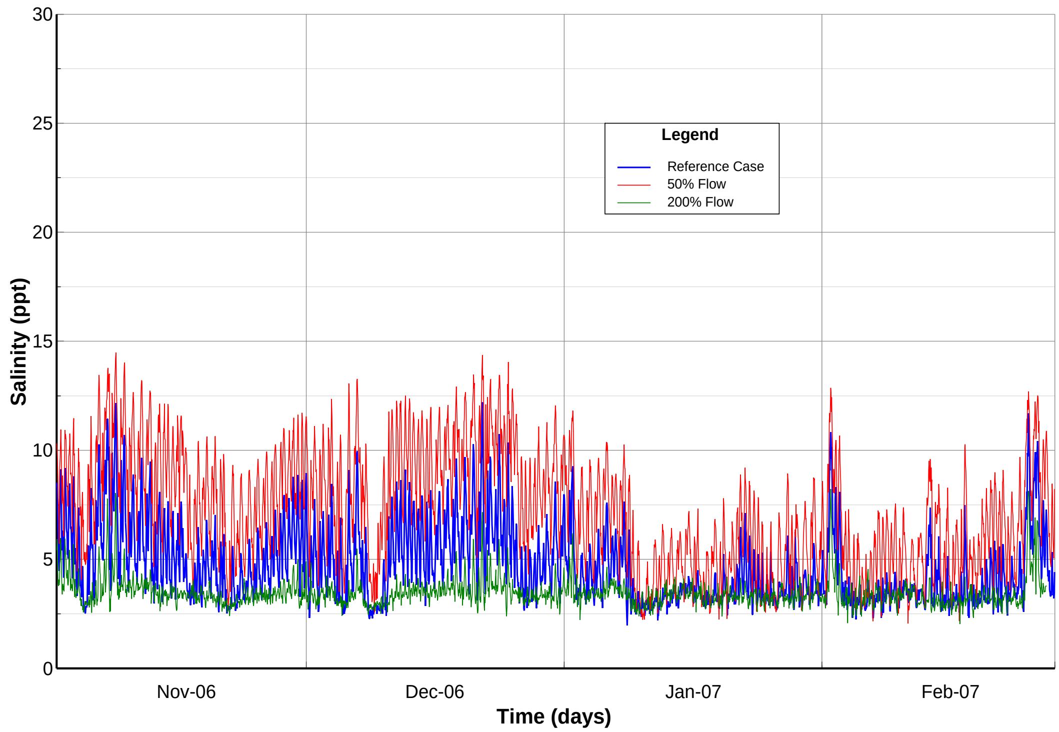


Figure 4-17 Fresh Water Inflow Sensitivity: Salinity Comparison at USGS 02310663.

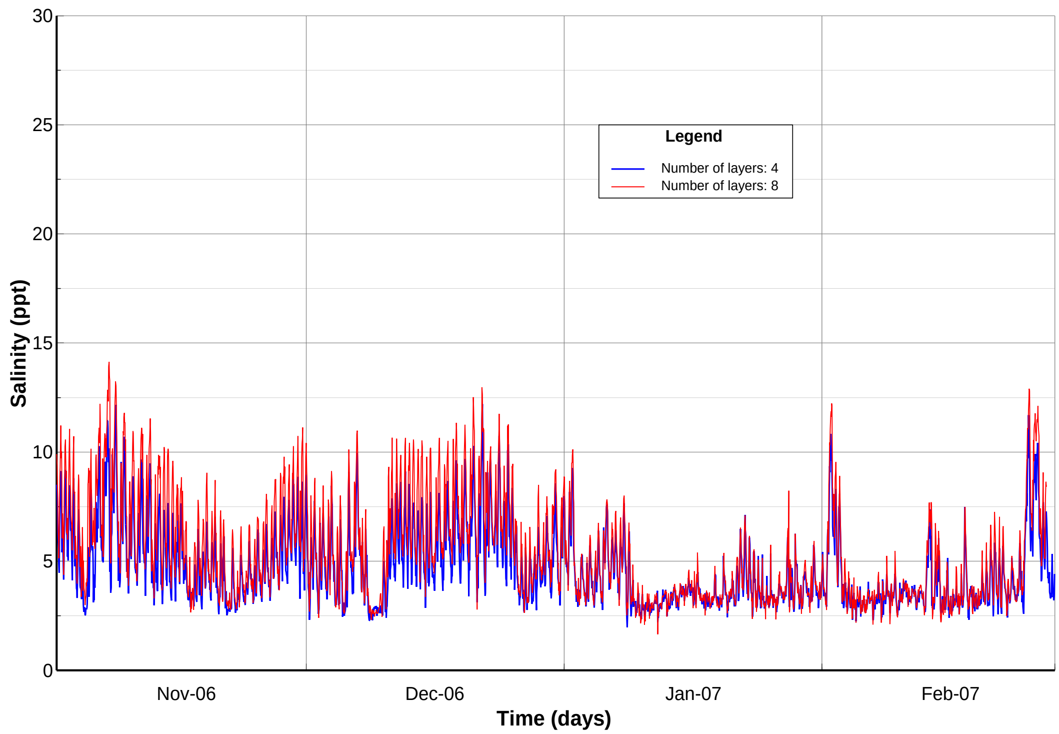


Figure 4-18 Double Number of Layers Sensitivity: Salinity Comparison at USGS 02310663.

Table 4-4 Sensitivity analysis: Comparison of RMS errors for salinity.

			RMS Error			
Station ID	Layer	# Pairs	Base Case	N=8	Half Flow	Doubled Flow
USGS02310674	Surface	2236	2.21	2.32	2.67	2.07
USGS02310674	Bottom	2927	4.15	3.95	4.65	3.39
USGS02310673	Surface	1839	2.28	2.26	2.50	4.24
USGS02310673	Bottom	2880	1.78	2.26	3.03	3.02
USGS02310663	Bottom	2298	1.90	2.37	4.04	2.52
Composite		12180	2.53	2.70	3.46	3.02

Table 4-5 Sensitivity analysis: Comparison of RMS errors for water temperatures (°F).

			RMS Error			
Station ID	Layer	# Pairs	Base Case	N=8	Half Flow	Doubled Flow
USGS02310674	Surface	2248	2.32	2.21	2.29	2.39
USGS02310674	Bottom	2927	2.55	2.49	2.49	2.48
USGS02310673	Surface	1843	2.54	2.50	2.48	2.96
USGS02310673	Bottom	2878	2.54	2.53	2.47	3.06
USGS02310663	Bottom	2278	2.96	2.66	3.57	3.11
Composite		12174	2.58	2.48	2.65	2.79

4.6 Calibration Period Flows Comparison to Long Term Record

In order to put the calibration period into perspective, relative to the long term record, the monthly average flows for the Chassahowitzka Main Spring (USGS Station 02310650) from the calibration period was compared to the long term monthly averages for the same station. The long term record used was a combination of measured and synthesized (see Section 5.3) daily average flows for the period of June 1966 until November 2007. Table 4-6 provides a summary of this analysis showing the long term average flows as well as the minimum and maximum monthly flows and the dates they occurred.

Table 4-6 Monthly average flows for the period of record for the Chassahowitzka Main Spring.

Month	Average (cfs)	Maximum (cfs)	Maximum Date	Minimum (cfs)	Minimum Date
January	63.6	75.6	Jan-1984	51.2	Jan-2007
February	62.5	75.9	Feb-1970	50.1	Feb-2001
March	61.8	78.4	Mar-1998	46.3	Mar-1997
April	60.7	75.9	Apr-1970	40.3	Apr-1997
May	59.3	73.5	May-1970	40.6	May-1997
June	59.0	72.0	Jun-1970	39.9	Jun-1997
July	60.7	75.2	Jul-1984	39.9	Jul-1997
August	63.6	81.2	Aug-1984	41.7	Aug-1997
September	66.4	81.6	Sep-1974	41.7	Sep-1997
October	67.4	81.2	Oct-1982	44.5	Oct-1997
November	66.0	79.5	Nov-1982	48.4	Nov-1997
December	64.6	76.3	Dec-1982	50.5	Dec-2006
Average	62.9				

These long term monthly average flows were then compared to the monthly average flows for the calibration period. Figure 4-19 shows the graphical comparison for the 2006-2007 manatee season. The long term minimum and maximum monthly average flows are shown by the vertical lines shown at each monthly record. It can be clearly seen that the flows were quite low during the calibration period. In fact the average monthly flow for January was the lowest on record and during December it was very near the minimum flow. The average flow for the entire calibration period was 52.6 cfs (1.49 m^3/s) compared to an average of the average monthly flows of 64.3 cfs (1.82 m^3/s) for the same four months from the long term record.

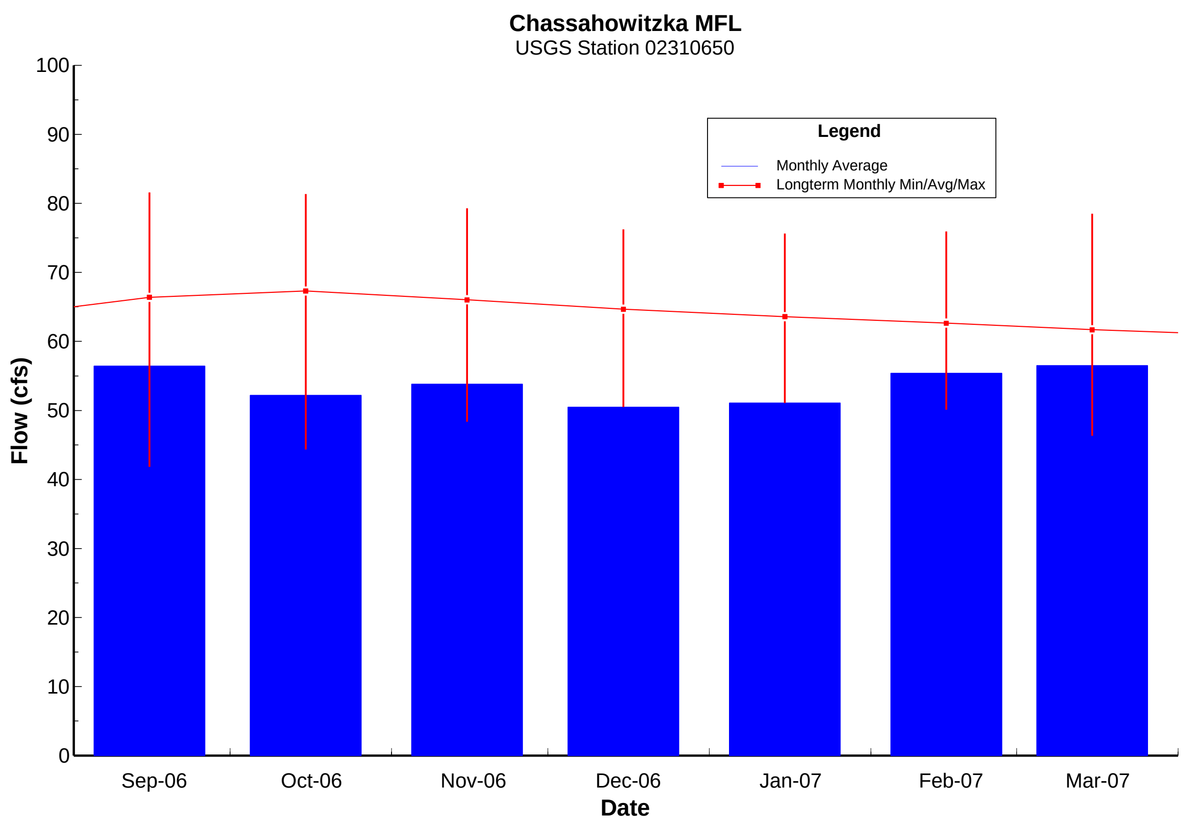


Figure 4-19 2006-2007 Manatee season monthly flows comparison to long term monthly averages.

5 Critical Conditions Determination

As mentioned in the Section 2, in order to assess the impacts of the flow reductions from Chassahowitzka River system on the Manatee habitat, it was important to determine a critical condition that would allow for comparisons of suitable habitat areas and volumes. In the case of Chassahowitzka thermal refuge condition for manatee community, the following components were considered:

- Water temperatures
- Water levels
- Spring discharges

In order to determine the critical conditions a joint probability (JP) analysis was conducted using the components above. The critical condition was selected from by determining the “worst case” scenario as defined by having a return interval of 50 years. Because the return interval is large it was important to obtain as long a historical record of these three parameters as reasonably available. The approaches and methods used to extend limited measured data and the composite data series are presented in this section. Once the appropriate time series were available, these data were used to conduct the JP analysis to select the “worse case” scenario for manatee habitat.

5.1 Water Temperature

Minimum water temperature is a critical element for manatee survival during the winter. The longest water temperature observation record existed for the USGS station 02310663. The data record extends from 2003-05-01 to present. A method to estimate historic water temperature as a function of daily minimum air temperatures would allow the synthesis of the needed long term record. For the Chassahowitzka case, the daily air temperature at St. Petersburg Airport (WBAN 92806) was used. The relationship between minimum daily water temperature at USGS 02310663 and 3 days back average of the minimum daily air temperature is shown in Figure 5-1. The regression equation was:

$Tw=29.7088+0.6392*Ta_3$

where:

Tw=minimum daily water temperature (°F),

Ta= the same day minimum daily air temperature (°F),

Ta_1= the previous day’s minimum air temperature (°F),

Ta_2= the minimum air temperature from two days ago (°F).

$Ta_3=(Ta+Ta_1+Ta_2)/3$.

The regression used 1311 data pairs and had a correlation coefficient R^2= 0.8866. Figures 5-2 and 5-3 show the resulting minimum daily water temperature time series for the manatee seasons from 1966 to 2007. Where measured data existed they were used in place of the predicted temperatures.

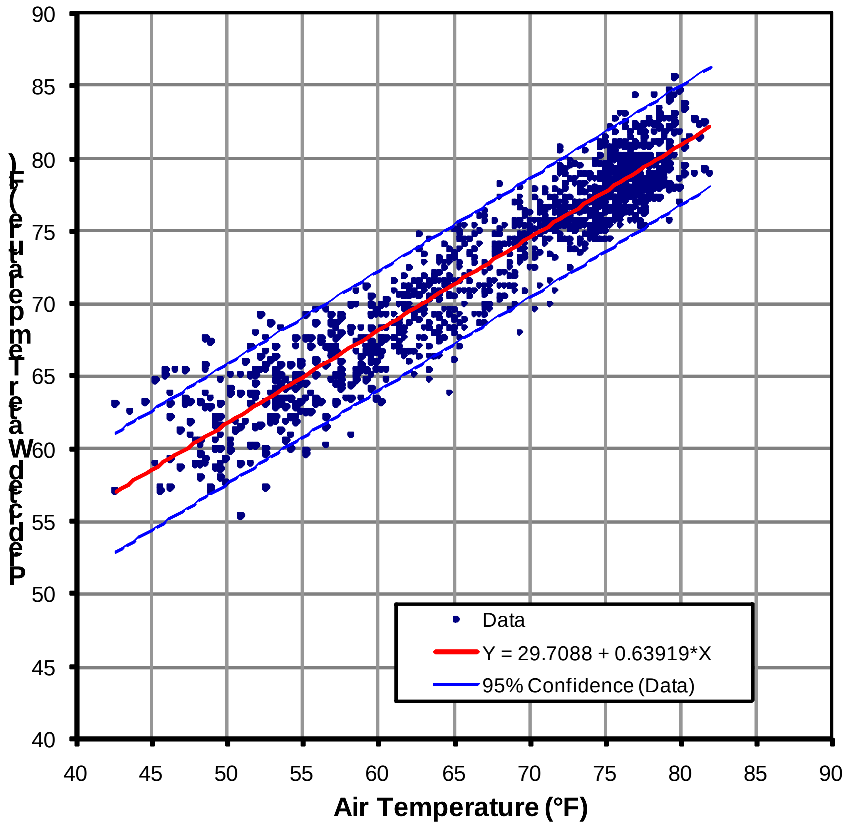


Figure 5-1 Water temperature (^oF) / air temperature (^oF) regression.

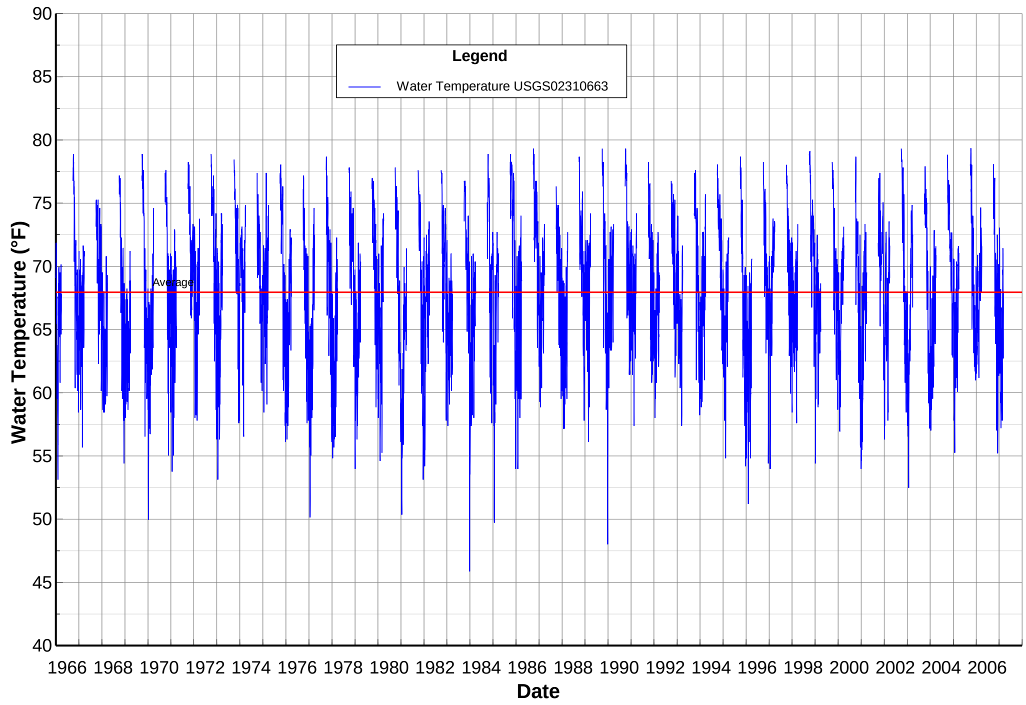


Figure 5-2 Daily minimum water temperatures at USGS 02310663.

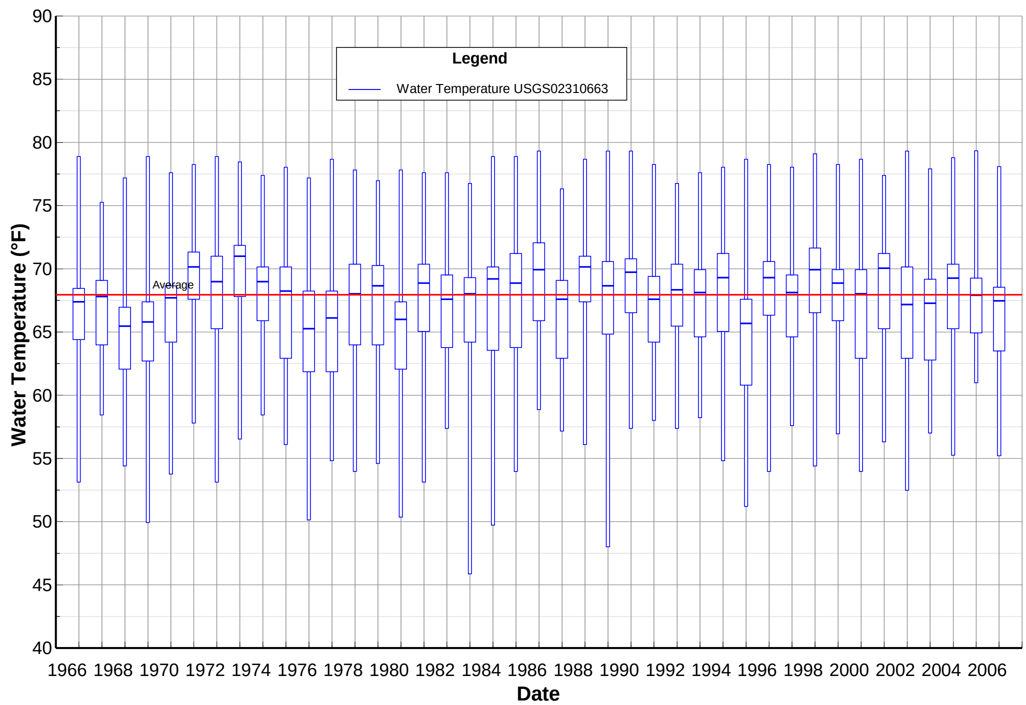


Figure 5-3 Manatee season box & whisker plot of the daily minimum water temperature at USGS 02310663.

5.2 Water Level

The longest tidal record in the region was found at Cedar Key Station (NOAA 8727520). A simple linear regression between maximum daily water levels at the Cedar Key station and USGS 02310663 (Chassahowitzka River) was conducted. The regression equations determined was:

$WL\_{02310663}=0.13870+0.66233*WL\_{Cedar}$

In which both WL's are in feet and referred to MTL.

The regression used 1425 data pairs and had a correlation coefficient $R^2=0.7717$. Figure 5-4 shows the regression relationship while Figures 5-5 and 5-6 show the resulted maximum daily water level time series of the Manatee seasons from 1966 to 2007 after filling missing historic period with predicted data.

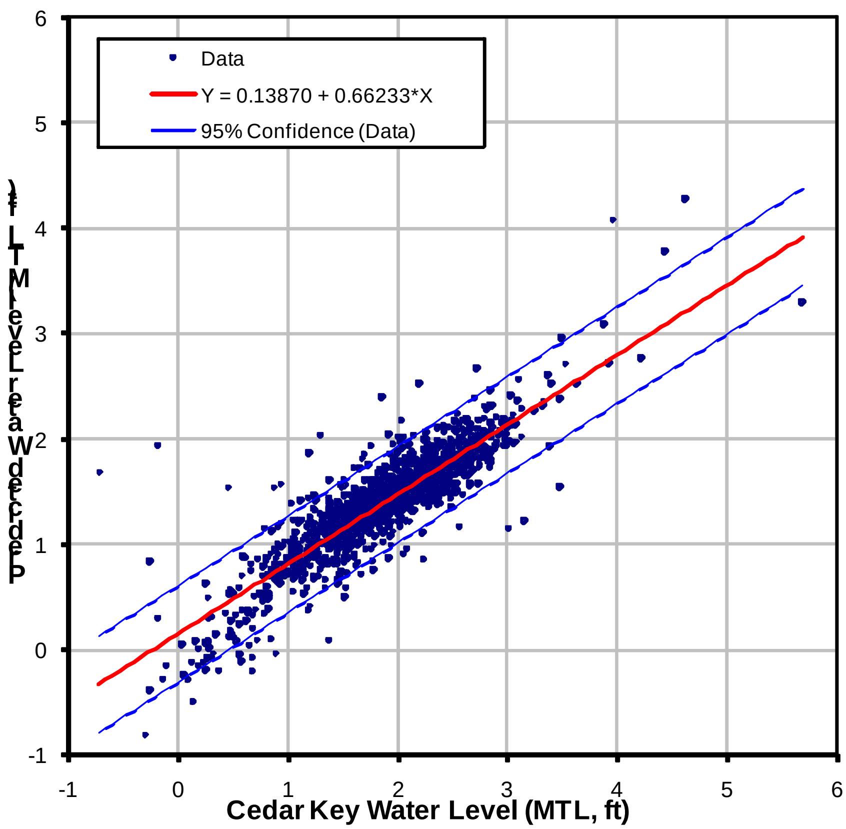


Figure 5-4 Water Level (ft) / Cedar Key Water Level (ft) Regression

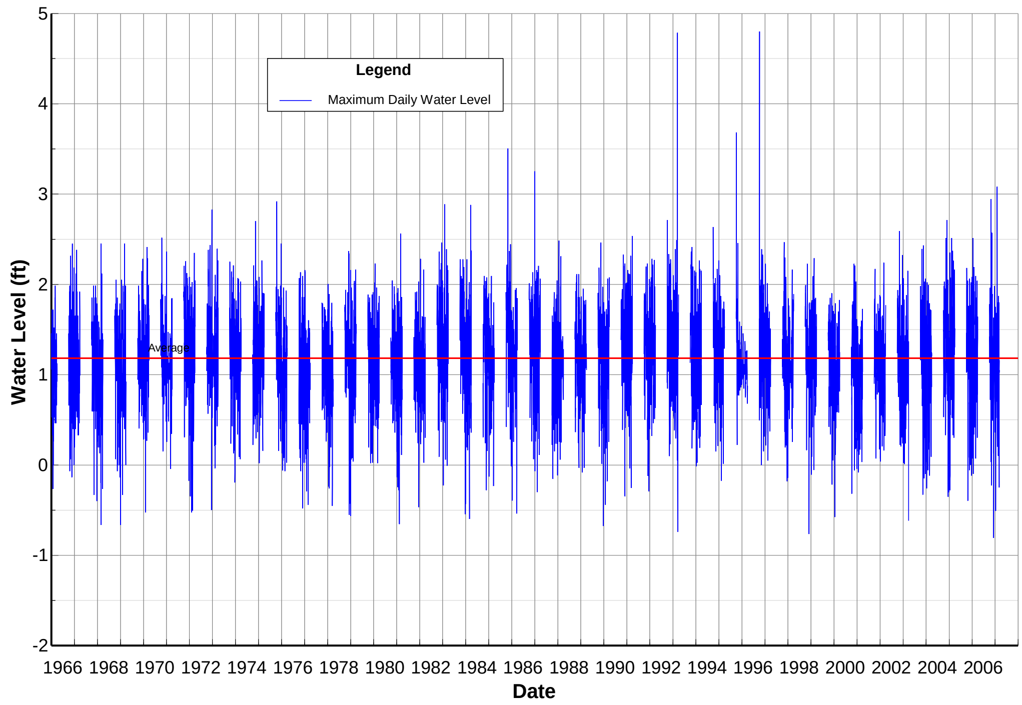


Figure 5-5 Daily maximum water levels at USGS 02310663.

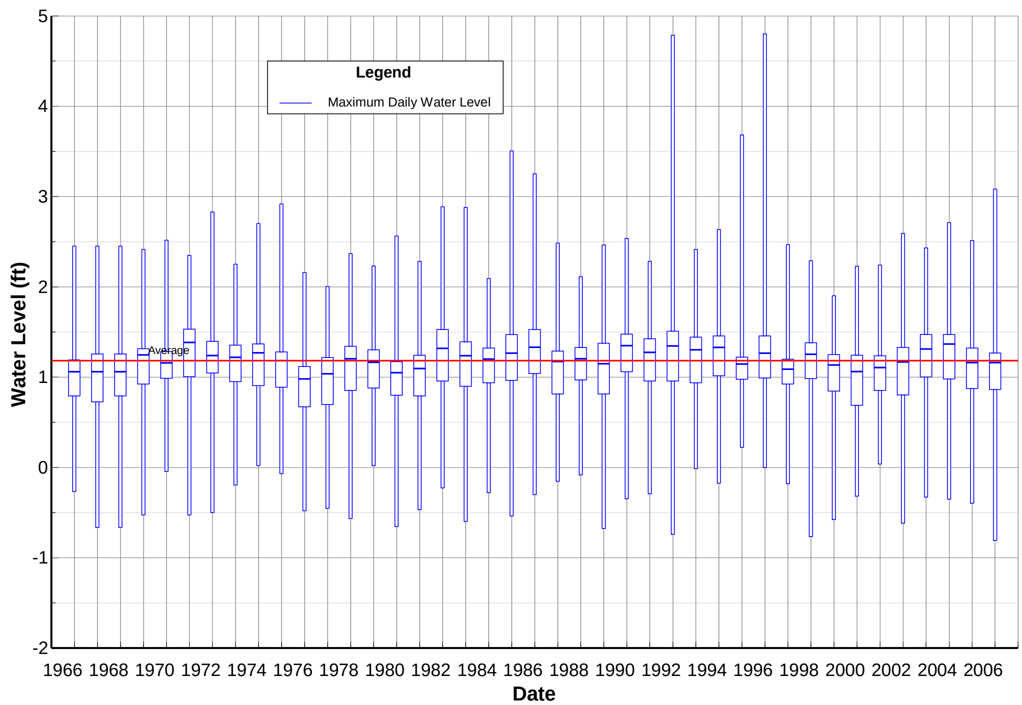


Figure 5-6 Manatee season box & whisker plot of the daily maximum water levels at USGS 02310663.

5.3 Flow

For the flow component, the Chassahowitzka Main gage (USGS 02310650) was used. A relationship between the daily flows (Flow_02310650 in cfs) and the water levels in the Weeki Wachee well (WW_WL in feet) (see Fig 1-1 for the well's location) was conducted. Figure 5-7 shows the data and the regression. The resulting predictor equation was:

Flow_02310650=12.4276+2.92446*WW_WL

The regression used 3260 data pairs and had an R^2=0.7525. Figure 5-8 shows the final resulting flows for the manatee seasons for the period of interest.

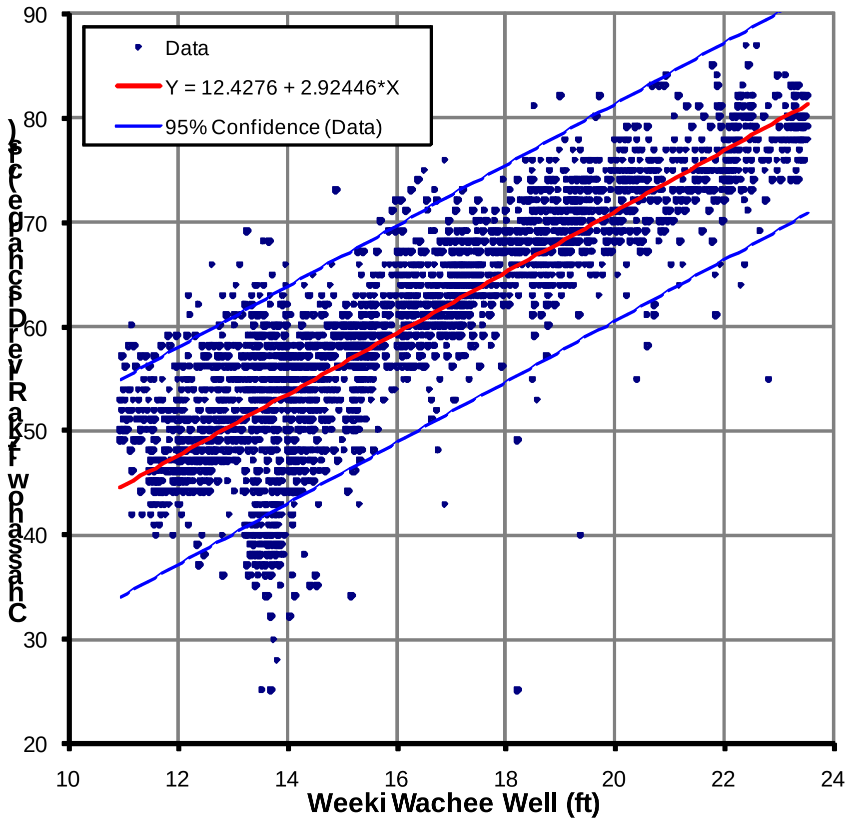


Figure 5-7 River Flow Rate / Weeki Wachee Well Regression.

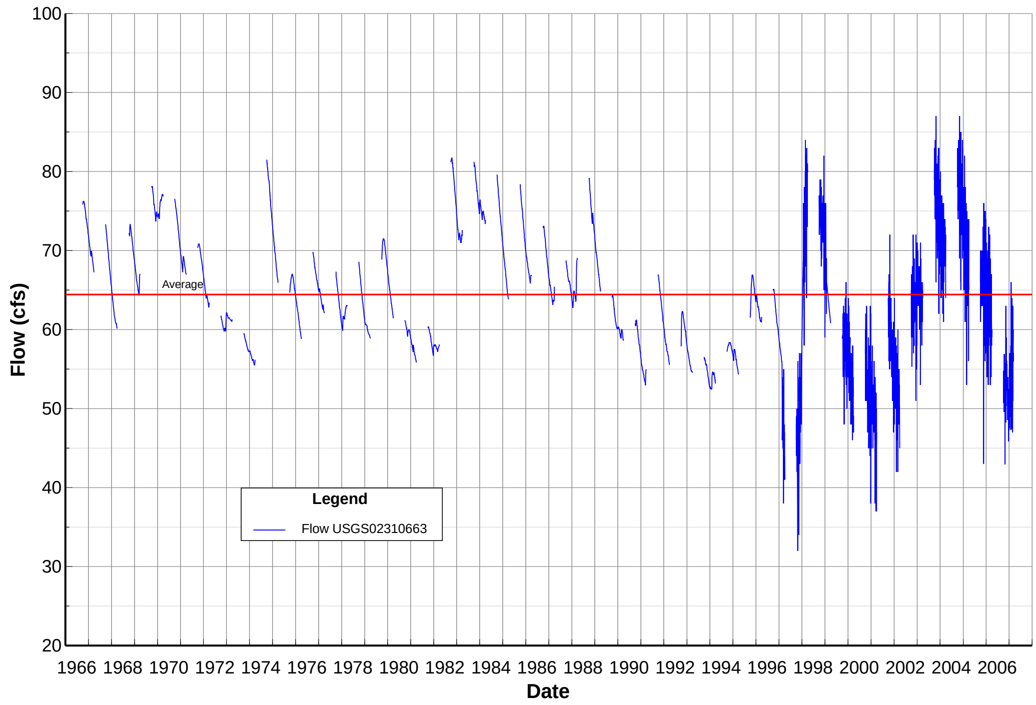


Figure 5-8 Manatee season daily flows at USGS 02310650.

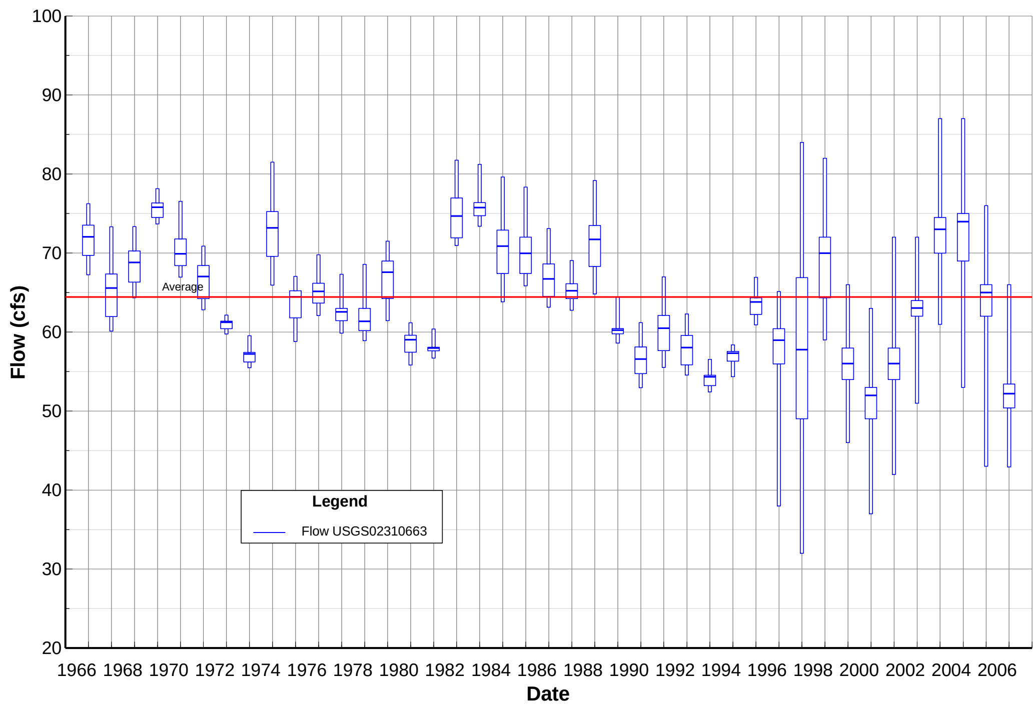


Figure 5-9 Manatee season box & whisker plot of daily flows at USGS 02310650.

5.4 Joint Probability

Once the data records for the three parameters needed for the JP analysis were complete, the JP analysis was conducted. The JP analysis was conducted using 41 manatee seasons, 1967 through 2007, with the following parameters:

- The daily maximum water levels,
- Daily flow rates, and
- Three day running average of the daily minimum water temperatures.

The Cunanne probability rank (P = (rank-0.4)/(n+0.2)) was computed for each of the series. Figure 5-10 shows the resulting box & whisker plot of the daily joint probability (JP) for each manatee season. The lowest JP in winter 2001-2002 indicates the worst conditions for manatee habitat occurred during that period.

For each year (i.e. manatee season) a JP from the day with the minimum temperature was selected from the daily JP's. Using these 41 JP's a Log Pearson distribution with exceedance statistic of 0.02 (i.e. 50 year return interval) was estimated following USGS's Bulletin #17B "guidelines for determining flood flow frequency". Details of the calculation are given in Appendix A.

The 50 year return interval JP was estimated to be 2.98×10^{-5}. A plot of the annual minimum JP's is shown in Figure 5-11. Consistent with the visual scan of the JP time series box & whisker plot (Fig 5-10), the 2001-2002 manatee season is one of the two worst scenarios, with JP lower than the estimated 50 year return JP value.

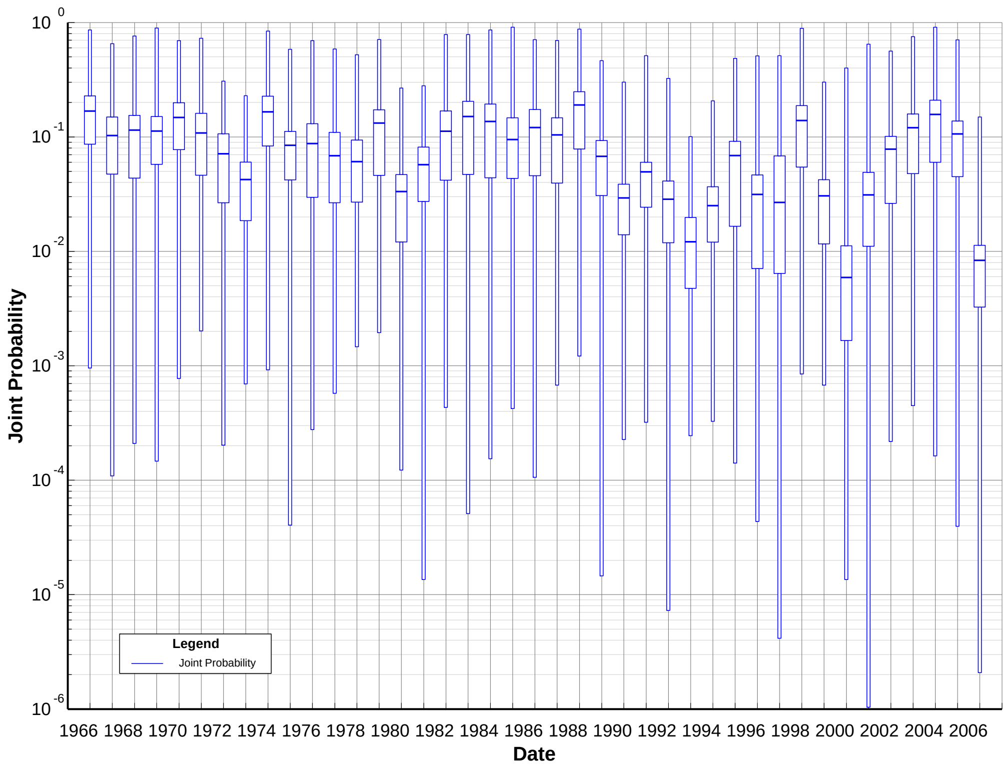


Figure 5-10 Annual Mean of Joint Probability

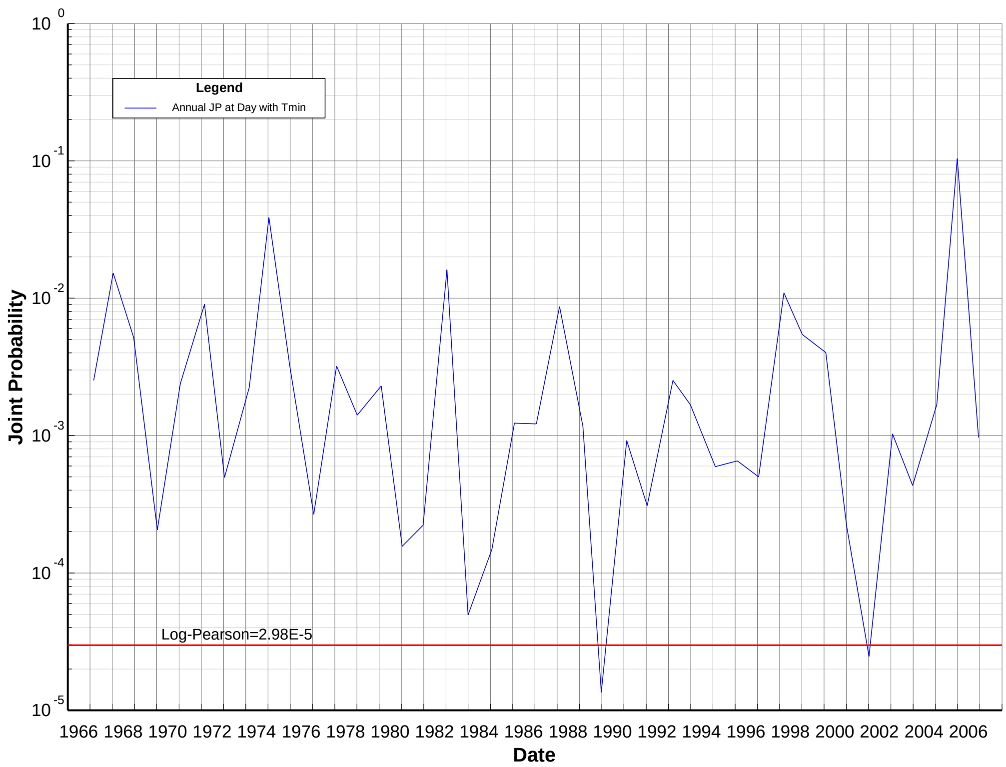


Figure 5-11 Annual JP of the day with minimum temperature

6 Minimum Flow Determination for Manatee Habitat Protection

6.1 Base “Worst Case” Scenario

Based on the JP analysis presented in the previous section, the season 2001-2002 was selected as the “worse case” scenario Manatee season. Specifically, the 3 day period of January 4-6, 2002 was selected as base scenario for manatee habitat protection study.

The calibrated hydrodynamic model was used to set up the base run for this scenario with the following boundary conditions:

Open sea boundary

Hourly water level was regressed from hourly water level at Cedar Key (NOAA 8727520) as mentioned in Section 5-2.

Water temperature (^oC) (USGS 02310674) was regressed from 3-day back average mean air temperature (^oC) of the St. Petersburg with the resulted equation:

WT_0674=0.010026+1.0906 T_a

with an n=501 and R^2=0.94657.

Salinity in the Gulf was repeated using the same months from the 2006 period from the calibration run.

Main River boundary

Flow rate: measured data at USGS 02310650 as discussed in Section 5-4

Water temperature and salinity for the Main River spring was repeated using the same months from the 2006 period from the calibration run.

Other minor springs

All boundary conditions were the same as in the calibration run.

Atmospheric condition

Atmospheric data and wind data as measured at St. Petersburg during the 2001-2002 manatee season.

Boundary conditions for the Main River boundary group and the Open Sea group are shown in Figures 6-1 and 6-2. During this period the Gulf temperatures dropped to 50^{o}F (10^{o}C) while spring discharges were warmer than 68^{o}F (20^{o}C).

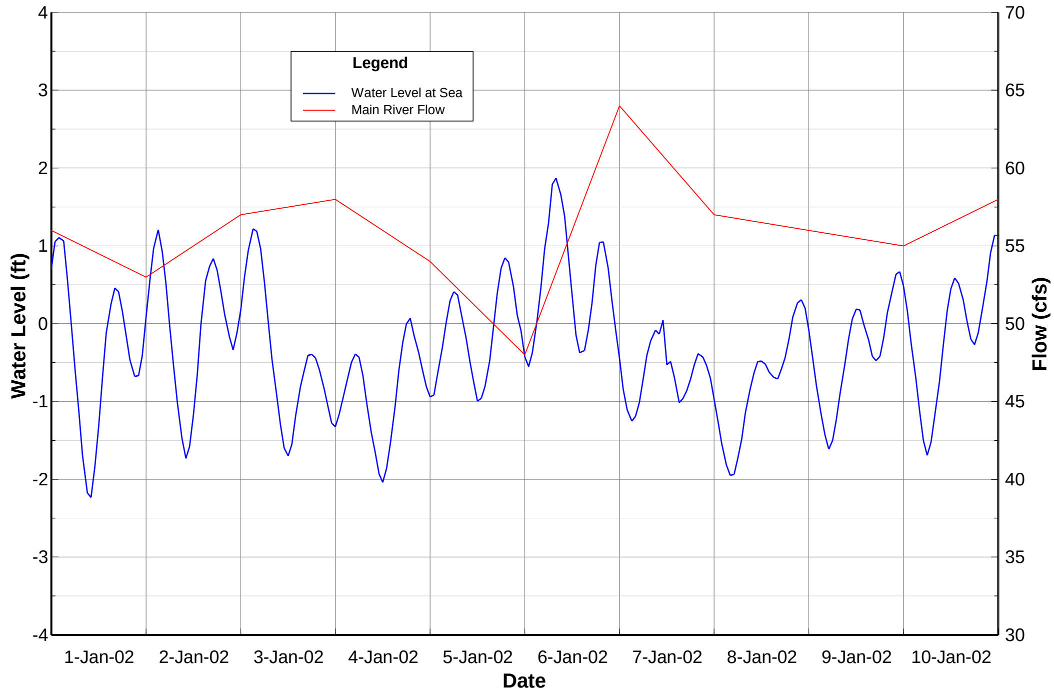


Figure 6-1 Boundary Condition; Water Level and Flow

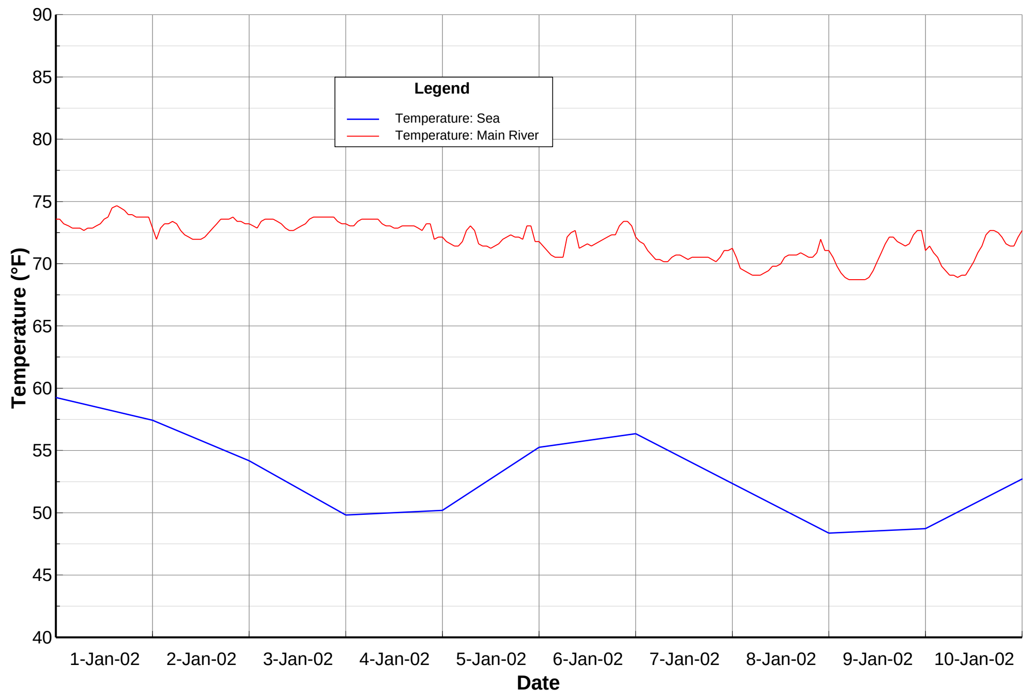


Figure 6-2 Boundary Condition; Water Temperature

6.2 Habitat Analysis: Chronic Condition

Using the critical manatee habitat thermal criteria described in Section 2-2, the manatee refuge area was estimated from model results. During this period there were no areas inside of the Chassahowitzka River System that had manatee habitat meeting the chronic habitat criteria. Figure 6-3 provides a map of the model grid. If any suitable manatee habitat had been found during the period shown the model cells would have been shaded in green.

As part of the investigation as to the cause for no suitable habitat other periods of time were investigated. Figure 6-4 shows a map of the manatee refuge area found on Jan-04-2007 which was from the calibration model. This period had a joint probability for temperature, spring flows and water levels of 0.00143 (see Section 5.4). The green cells indicate the areas that meet the chronic criteria. The suitable manatee habitat area was 43 ha with a corresponding volume of 1.3 million m^3.

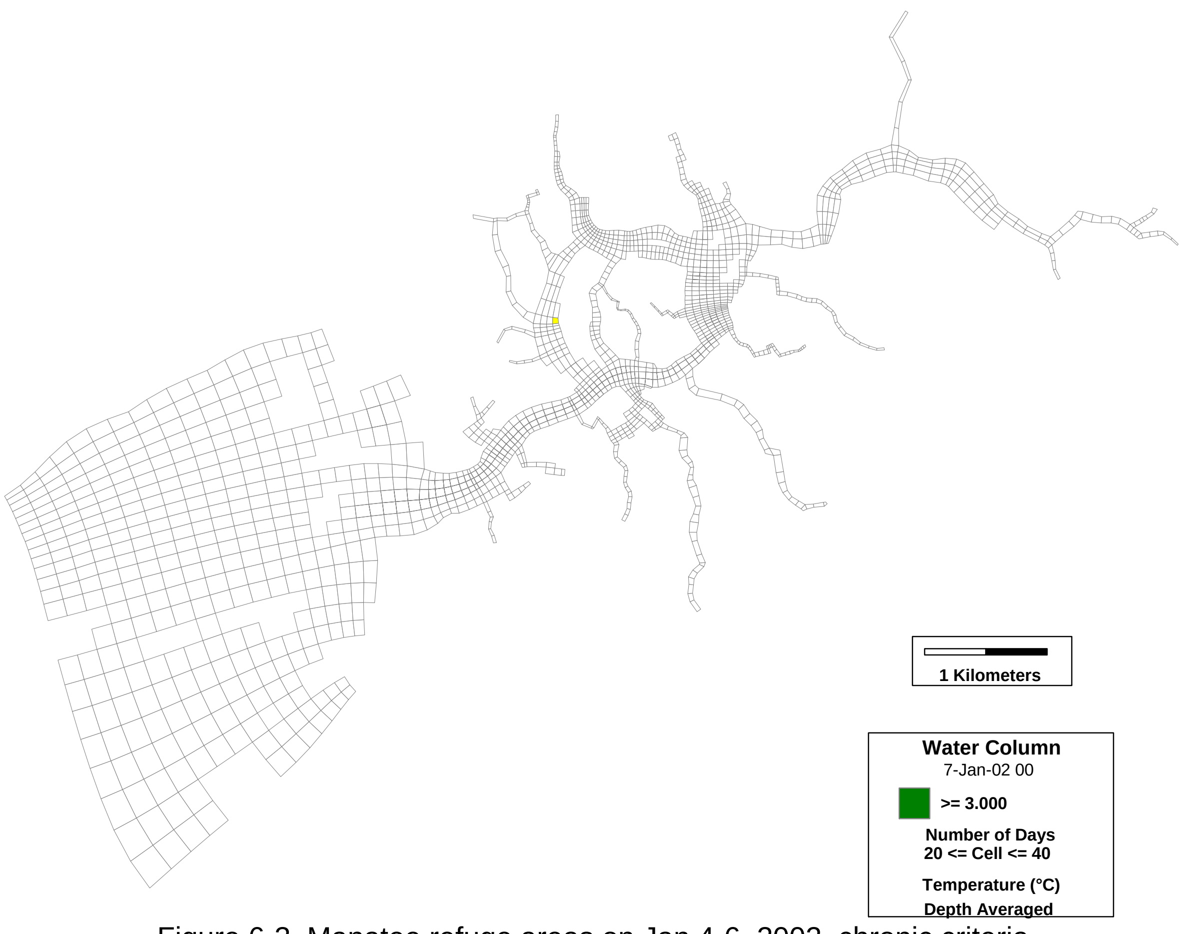


Figure 6-3 Manatee refuge areas on Jan 4-6, 2002, chronic criteria.

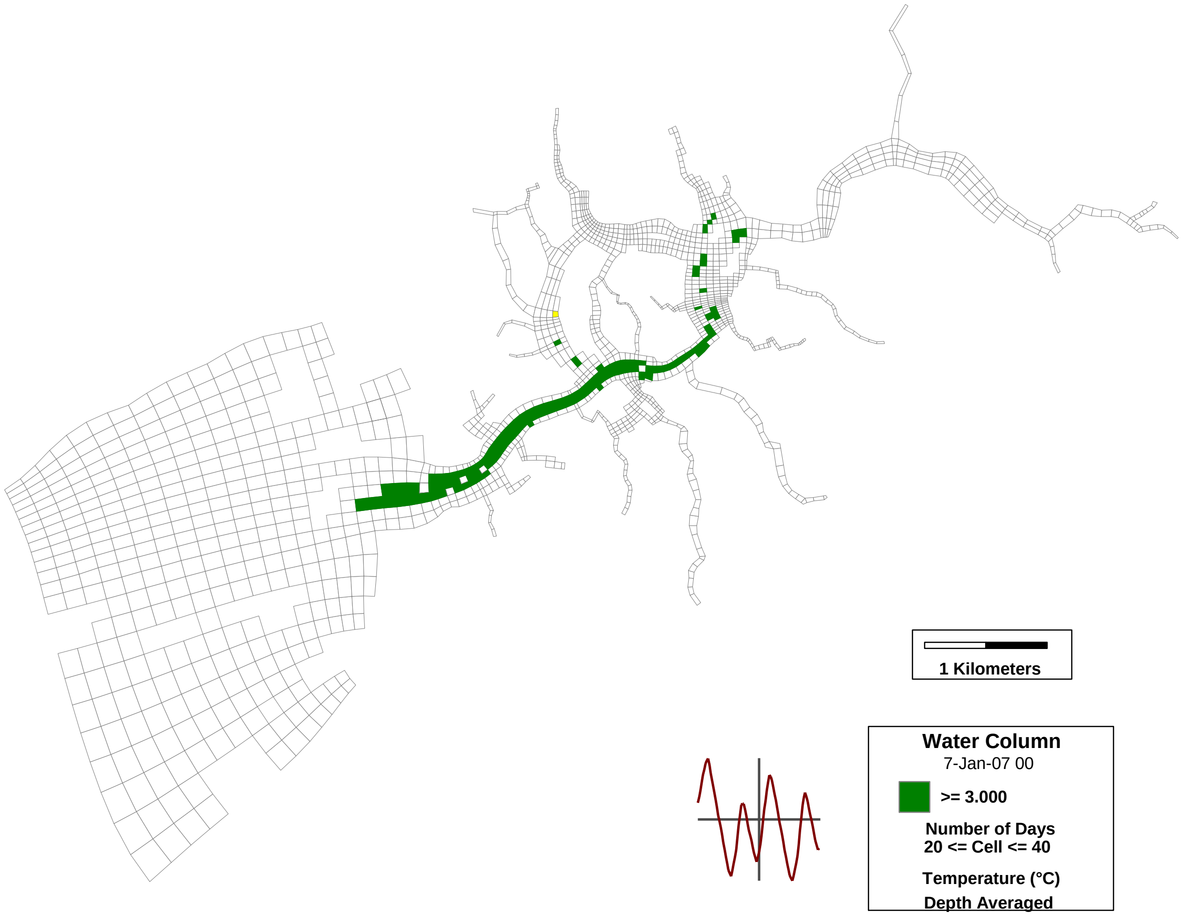


Figure 6-4 Manatee refuge areas on Jan 4-6, 2007, chronic criteria.

Another approach used to investigate the issue was to review the water temperatures. Figure 6-5 shows typical plan view of water temperature during the "worst case" period. Sections of the river that are shaded in red meet the thermal criteria of >= 68°F (20°C). Much of the upper river meets the temperature criteria. However, water depths, especially at low tide, are less than 3.8 ft (1.16m) (Figure 6-6). The middle to lower part of the system has sufficient depths but are often strongly influenced by the Gulf temperatures, so they are too cold.

Since there were no manatee habitat area meeting the chronic habitat criteria there were no additional analysis was needed to evaluate reduced spring flow conditions.

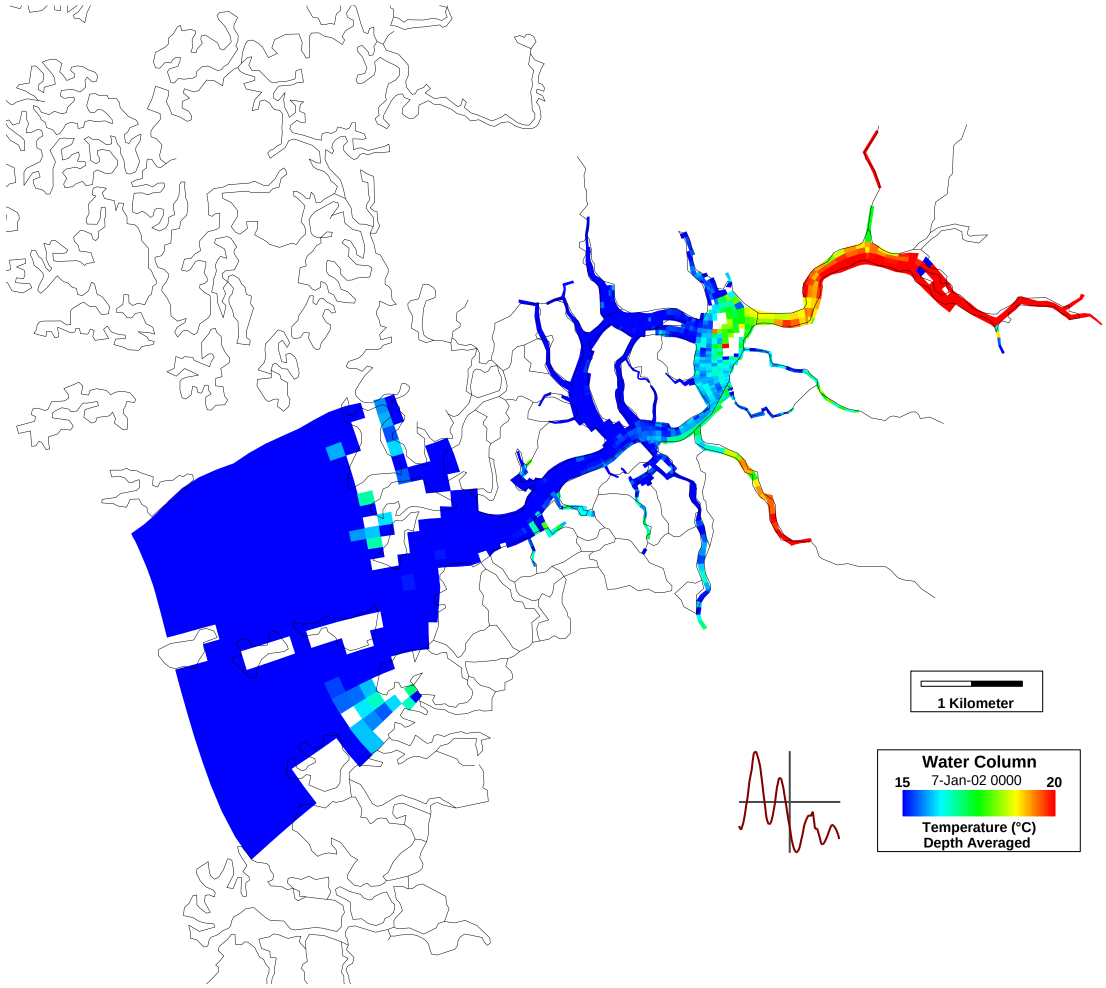


Figure 6-5 Plan View of water temperatures during the critically cold period.

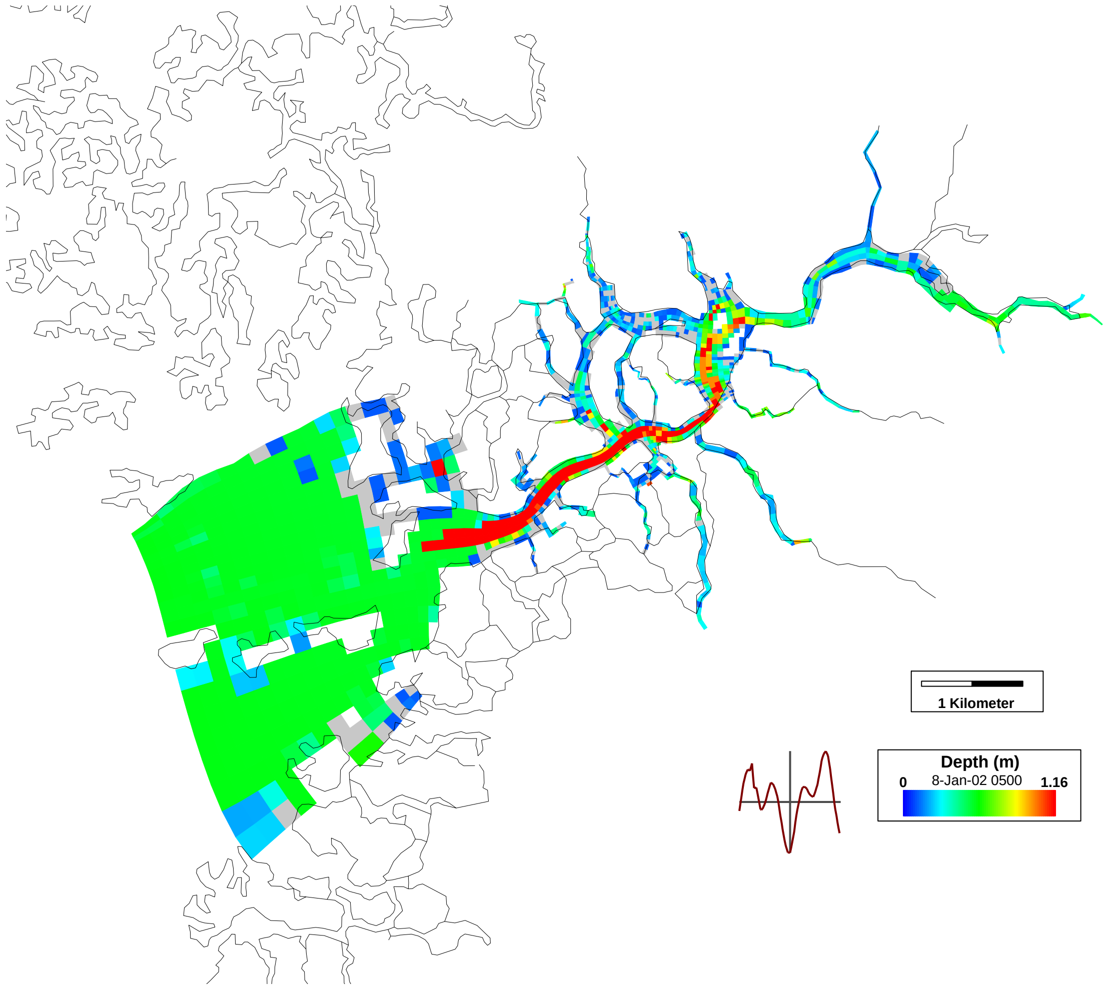


Figure 6-6 Plan View of water depths at low tide during the critically cold period.

To provide another perspective of the thermal and depth conditions during the critically cold period, longitudinal profiles of temperature (Figure 6-8) and salinity (Figure 6-9) were extracted from the model results. Figure 6-7 shows the location of the profile (i.e. black line) along with the reference points also shown on the profiles. These plots show the advert conditions related to the depth and temperature within the Chassahowitzka system. It is just too shallow for the manatees to access the warm waters associates with the spring discharge.

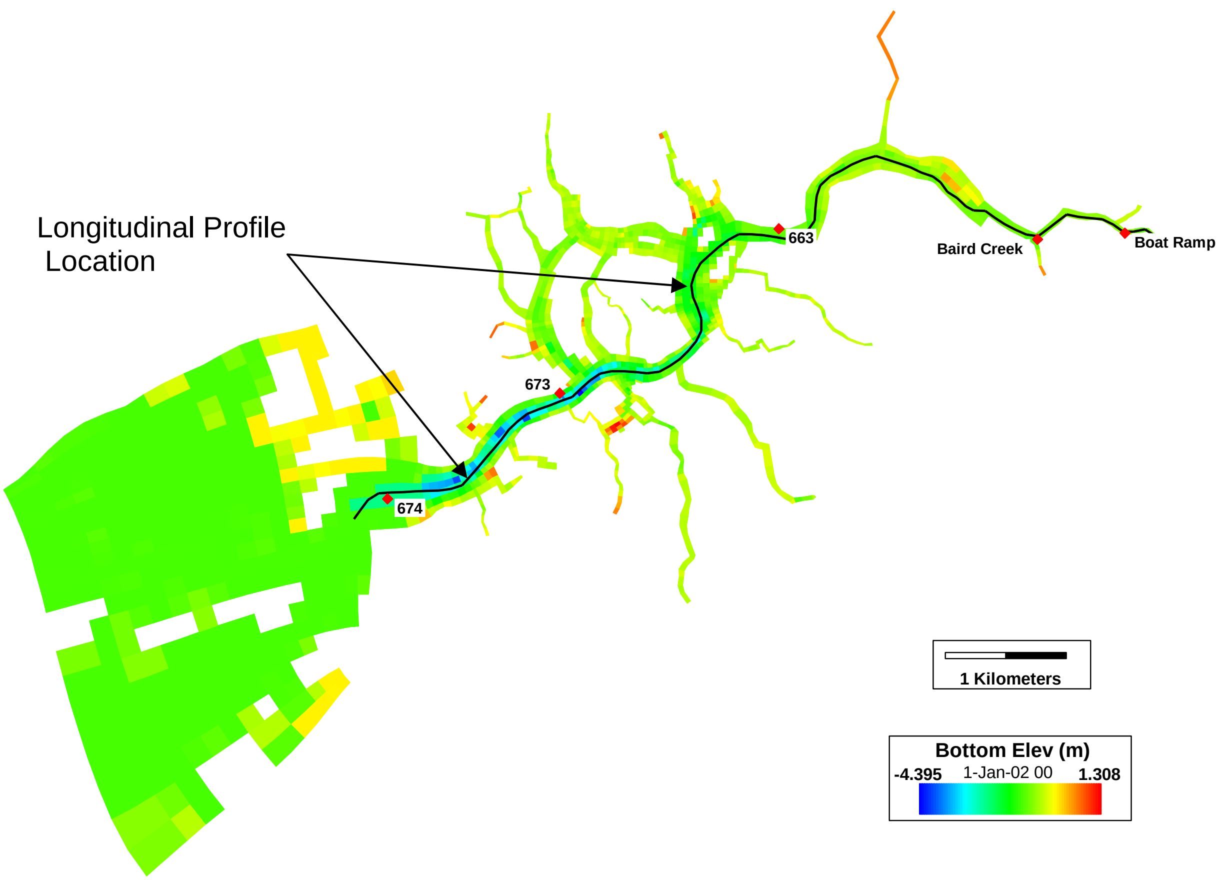


Figure 6-7 Model domain showing longitudinal profile location and reference points.

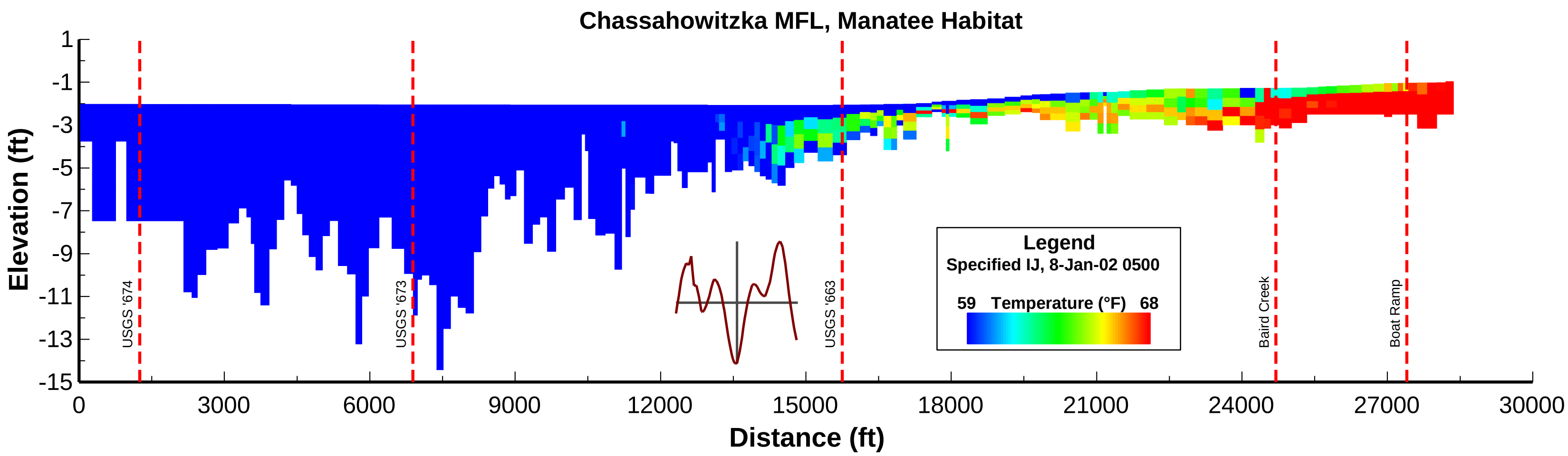


Figure 6-8 Longitudinal profile of water temperatures at low tide.

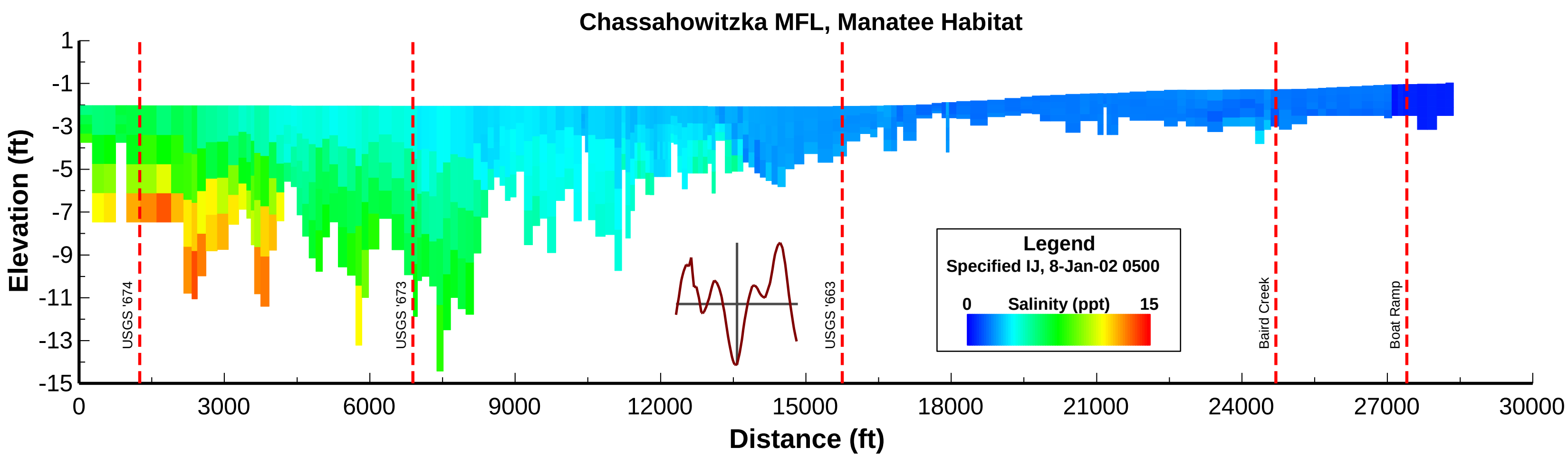


Figure 6-9 Longitudinal profile of salinity at low tide.

6.3 Habitat Analysis: Acute Conditions

Using the acute manatee habitat thermal criteria described in Section 2-2, the manatee refuge area was estimated from model results. As opposed to the chronic habitat criteria, there were some small areas in the Chassahowitzka River System that meet the acute manatee habitat criteria. Figure 6-10 provides a map showing the manatee habitat areas that meet the acute criteria. For this period the suitable habitat area was 11 ha with a volume of 0.16 million m^3.

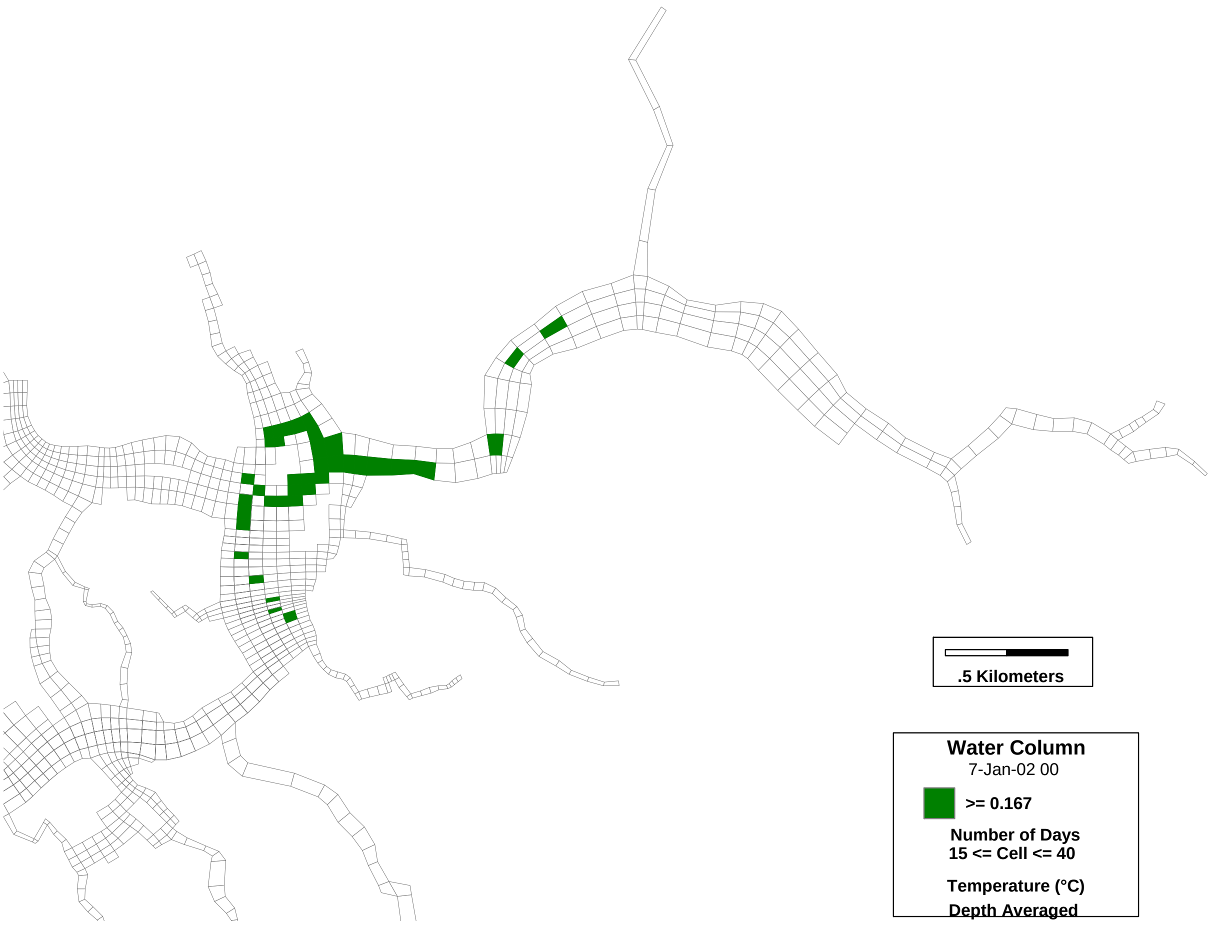


Figure 6-10 Example manatee refuge areas on Jan 4-6, 2002, acute criteria.

A series of runs with reduced spring discharge was conducted to determine which flow rate(s) resulted in a habitat area and volume loss of 15% at this the acute condition. It was determined that an 11% flow reduction caused a 15% loss in habitat area and a 15% flow reduction resulted in a 15% loss of habitat volume.

7 Salinity Impact Analysis

In order to address the impact of spring flow reductions on the salinity regime in the Chassahowitzka River System a series of hydrodynamic model runs were conducted. The spring flow reduction scenarios analyzed were:

- Base Case: No reduction,
- 10% Reduction,
- 20% Reduction, and
- 40% Reduction.

7.1 Selection of Salinity Analysis Period

For each of these flow scenarios a three year period was simulated. The three year period was to reflect a "typical" period. For this analysis, the "typical" period was defined as a three year period whose cumulative distribution function (CDF) of spring discharge is similar to the long term record. An analysis was conducted by comparing a moving annual three year block CDF to the long term CDF. The three year period selected was 2004-2006. Figure 7-1 shows the comparisons of the CDF's. The long term CDF using daily flows from 1966 to 2007 is shown as a black line in Figure 7-1. The three year CDF for 2004 to 2006 is shown as a red line. The other CDFs shows the year to year variability.

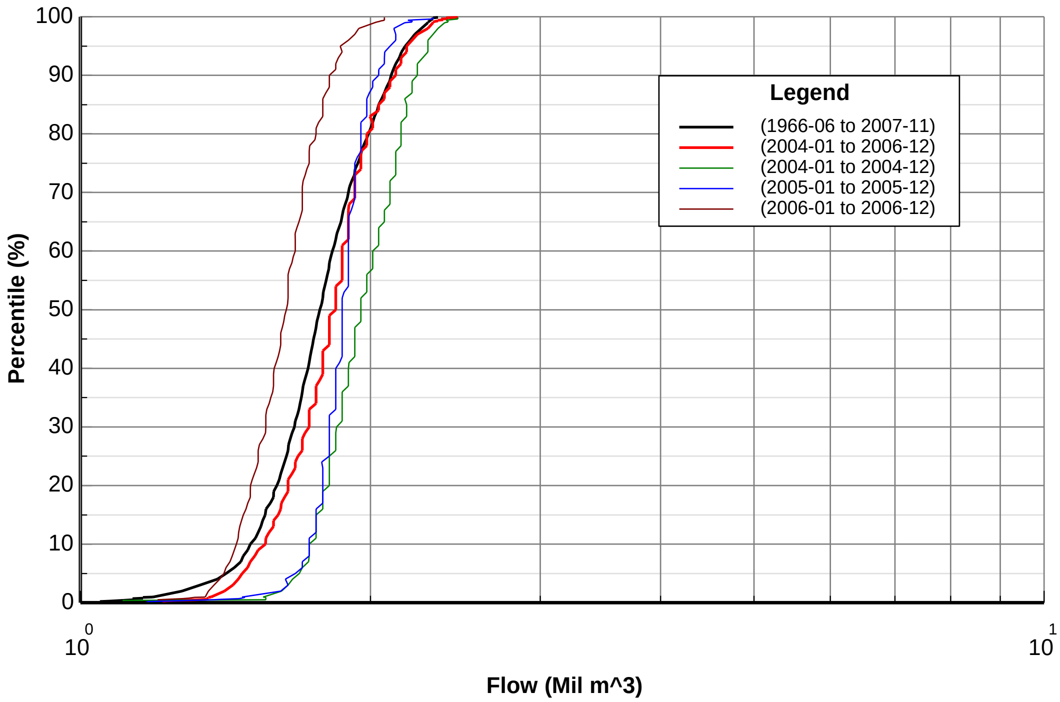


Figure 7-1 Cumulative distribution functions of spring discharge for the 2004 to 2006 period.

7.2 Salinity Analysis Procedure

For each of the flow scenarios listed above for the 2004 to 2006 period the total volumes areas and shoreline lengths for the following salinity ranges were computed:

- 0.0 to 2.0 ppt,
- 0.0 to 5.0 ppt,
- 0.0 to 10.0 ppt, and
- 0.0 to 15.0 ppt.

For this analysis only the Chassahowitzka River System upstream of RK 1.0 was used. The reader is referred to Figure 3-2 for the location of RK 1.0 and the river kilometer system. This is the region which has site specific bathymetric data collected by USF.

To determine if the salinity range analysis needed to be split into seasons, e.g. wet versus dry season, an analysis of the long term flow records for the Chassahowitzka Main Spring flow gaging station (USGS 02310650) was conducted. Table 4-6 and Figure 7-2 summarize the monthly average flows for the entire record from June 1966 until November 2007. While there is some seasonal variation, the magnitudes of the variations are small compared to the average flows. Therefore, it was determined that a seasonal salinity analysis was not needed. The salinity impact analysis was conducted on the entire 3 year period of 2004 to 2006. Figure 7-3 shows the monthly average flows for this period compared to the long term record.

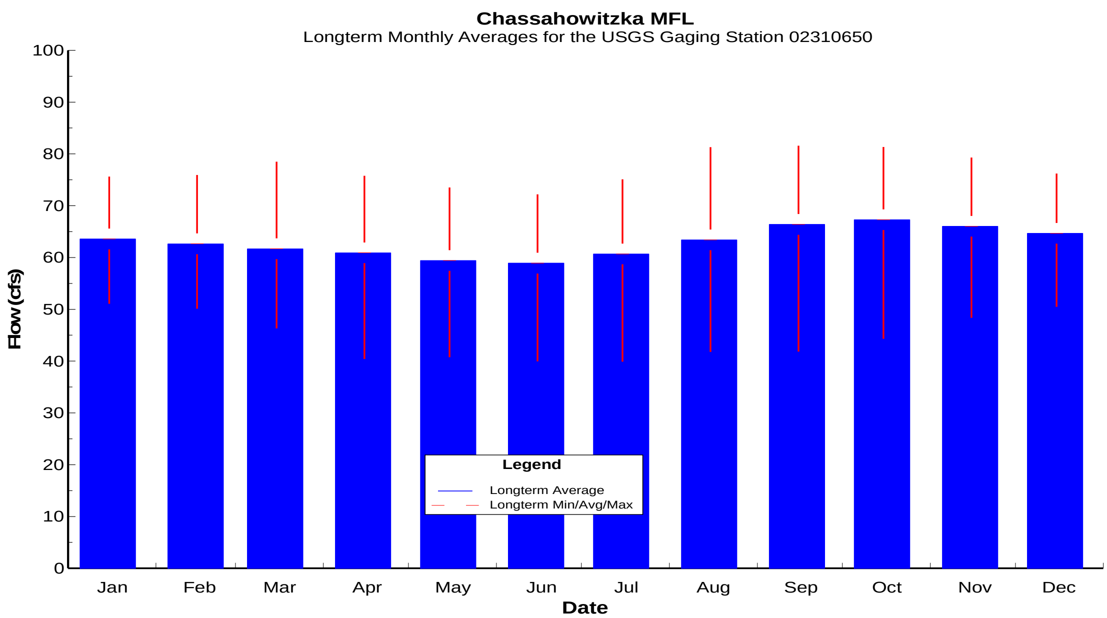


Figure 7-2 Long term monthly flow averages for USGS 02310650.

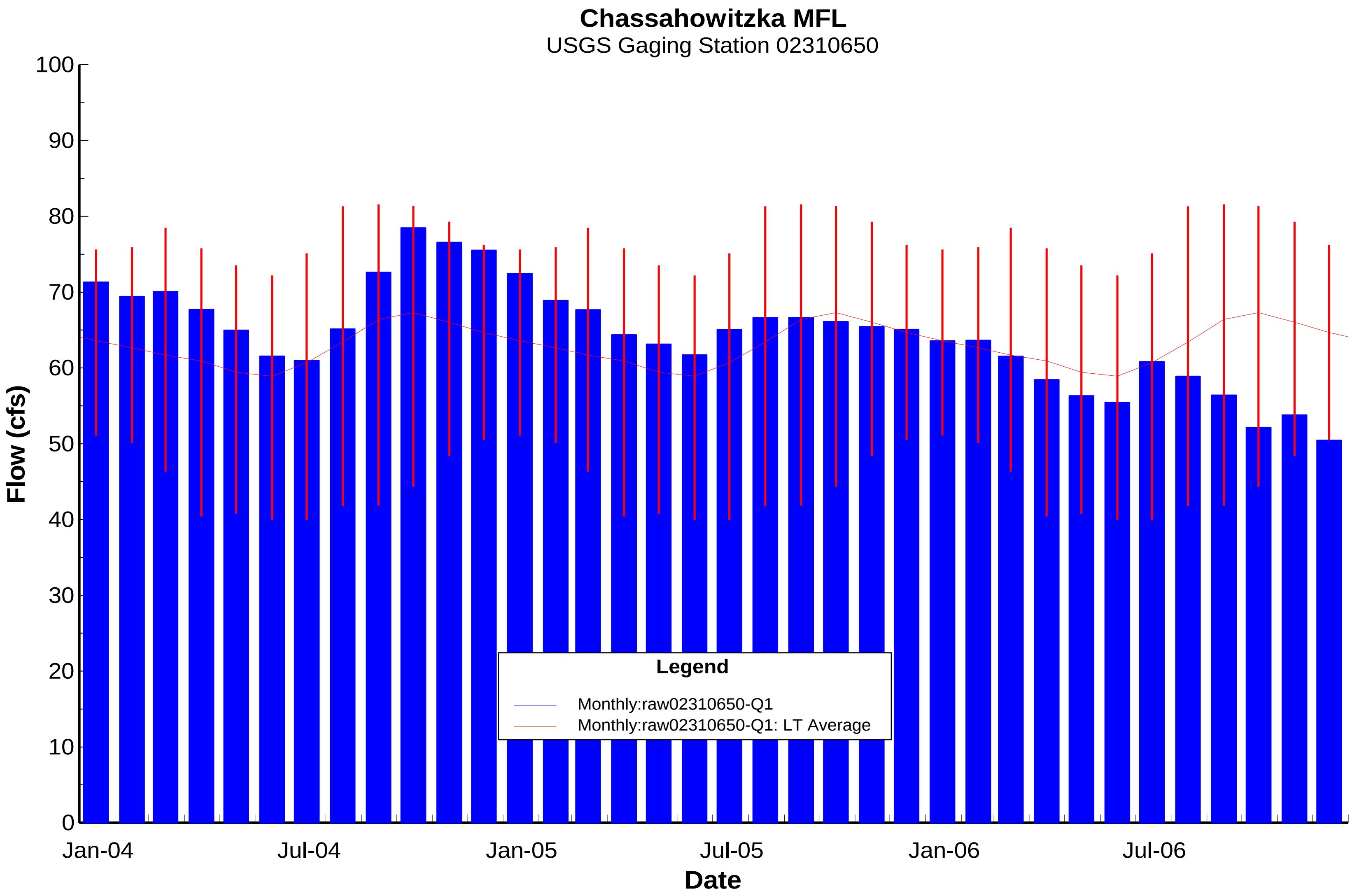


Figure 7-3 Monthly average flows of USGS 02310560 for the salinity analysis period.

7.3 Model Results

Four model runs were set up using exactly the same boundary conditions with the exception of the spring discharges. For the flow reduction runs, the flow rates for all the spring inflows were reduced by the corresponding fraction. Using the model results, the volumes, areas and shoreline lengths for each of the salinity ranges were computed. As an example Figures 7-4, 7-5 and 7-6 show the time series of volumes, areas and shoreline lengths for the Base Case, respectively.

Using these computed volumes, areas and shoreline lengths, CDF's were computed for each salinity range and scenario. Figures 7-7, 7-8 and 7-9 show the CDF's for volumes, areas and shoreline lengths, respectively, for the Base Case.

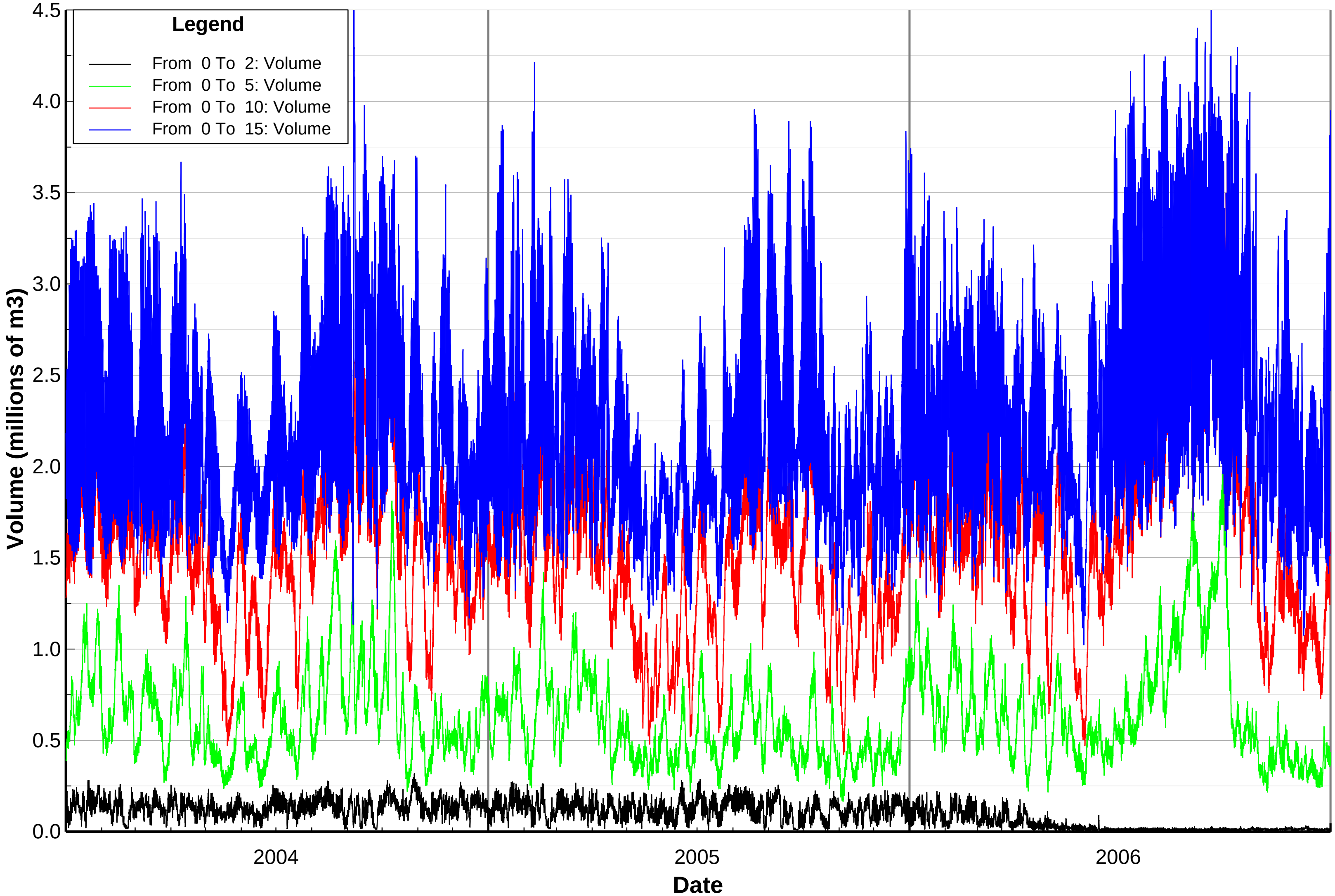


Figure 7-4 Time series of Base Case volumes for the specified salinity ranges.

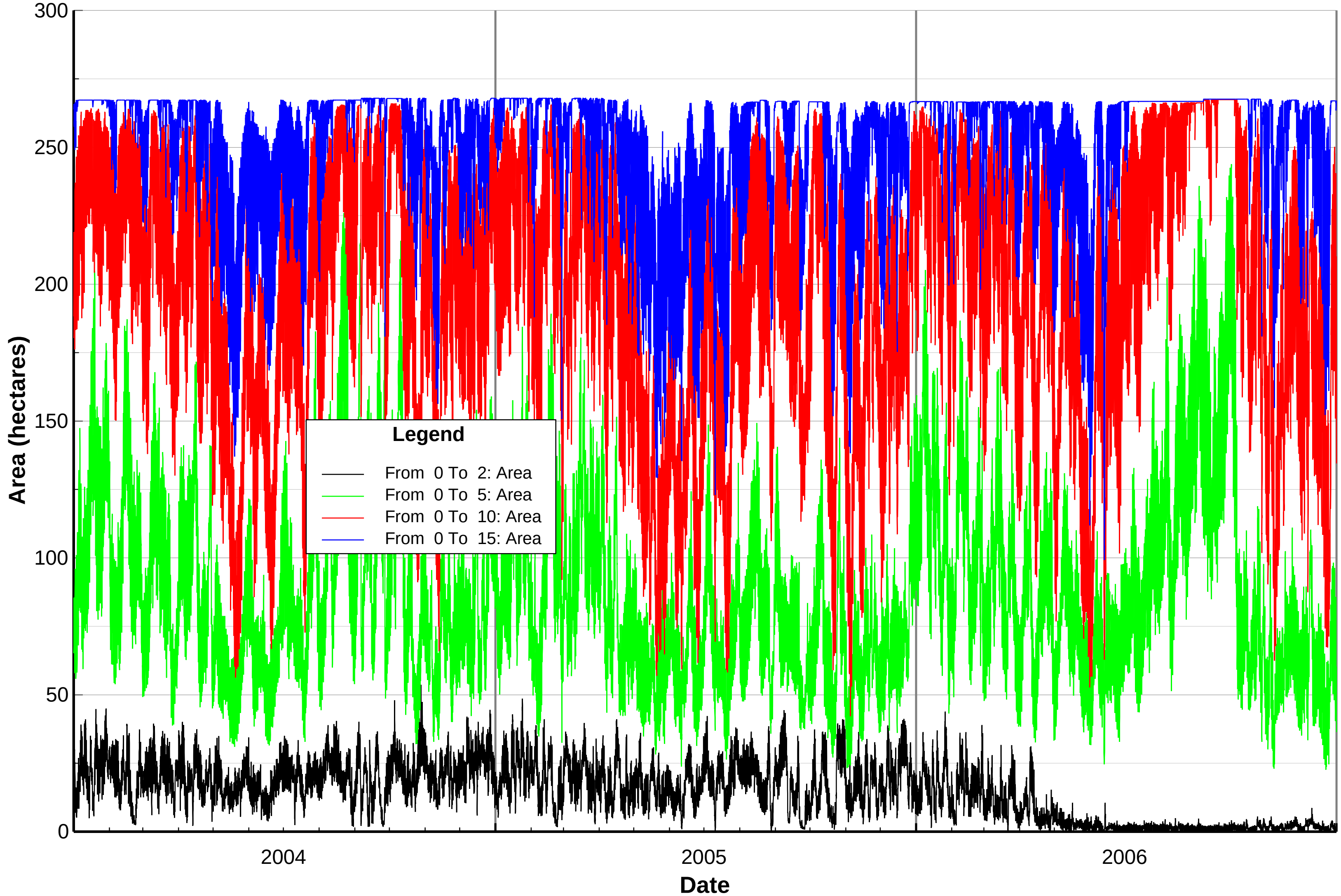


Figure 7-5 Time series of Base Case areas for the specified salinity ranges.

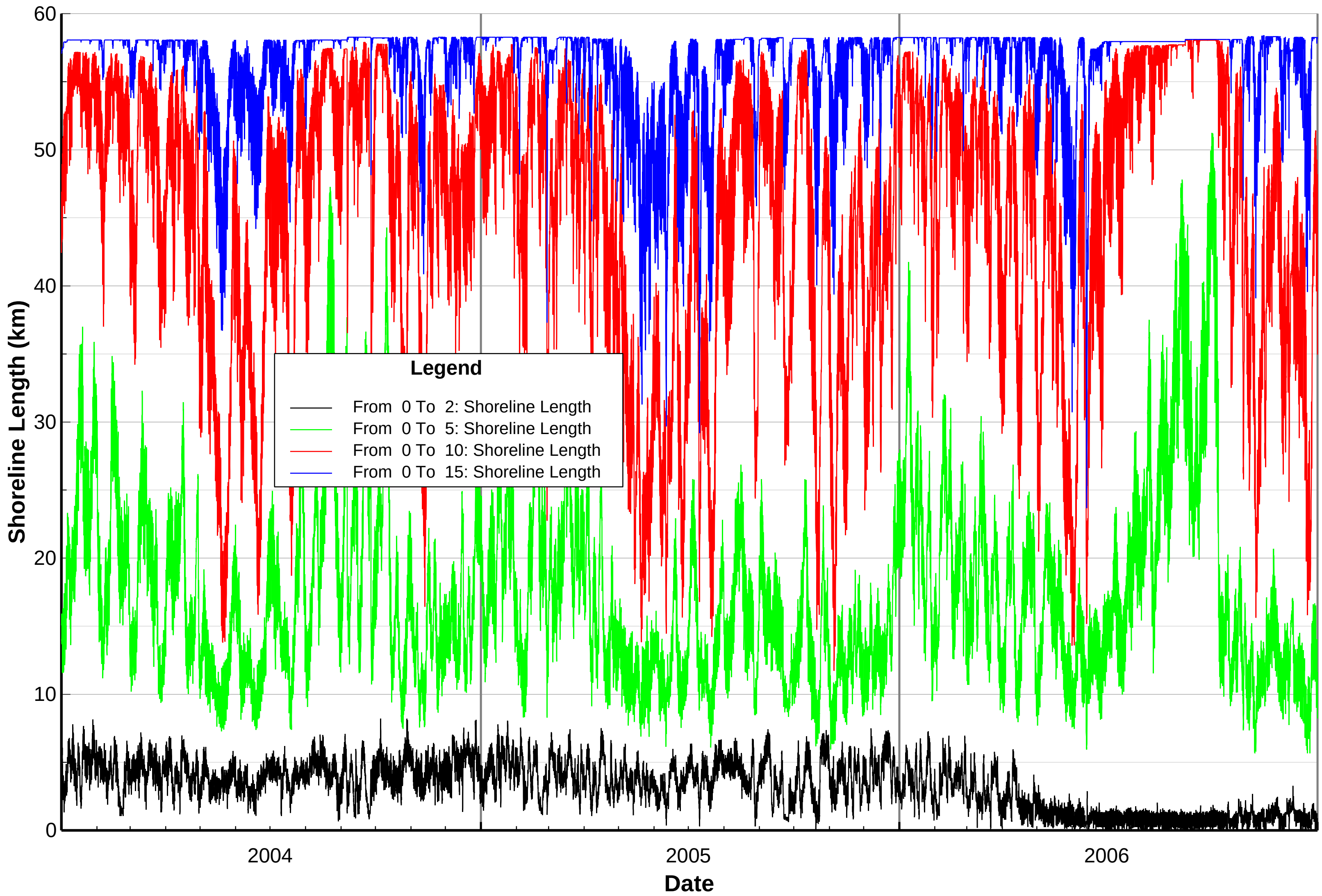


Figure 7-6 Time series of Base Case shoreline lengths for the specified salinity ranges

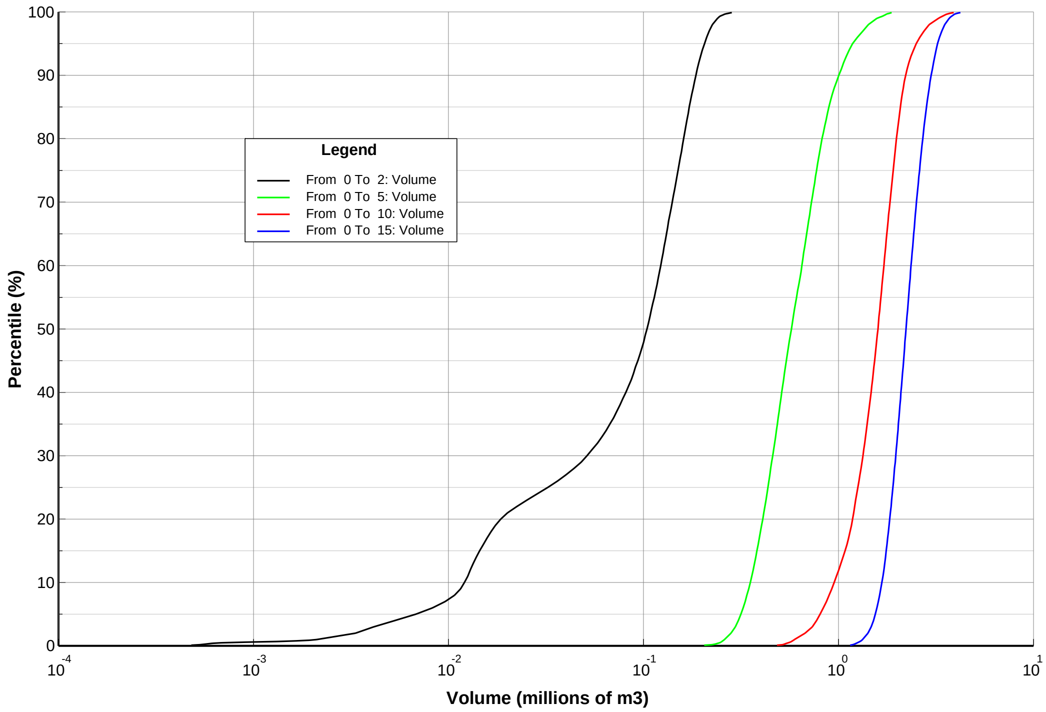


Figure 7-7 CDF's for the Base Case volumes for the specified salinity ranges.

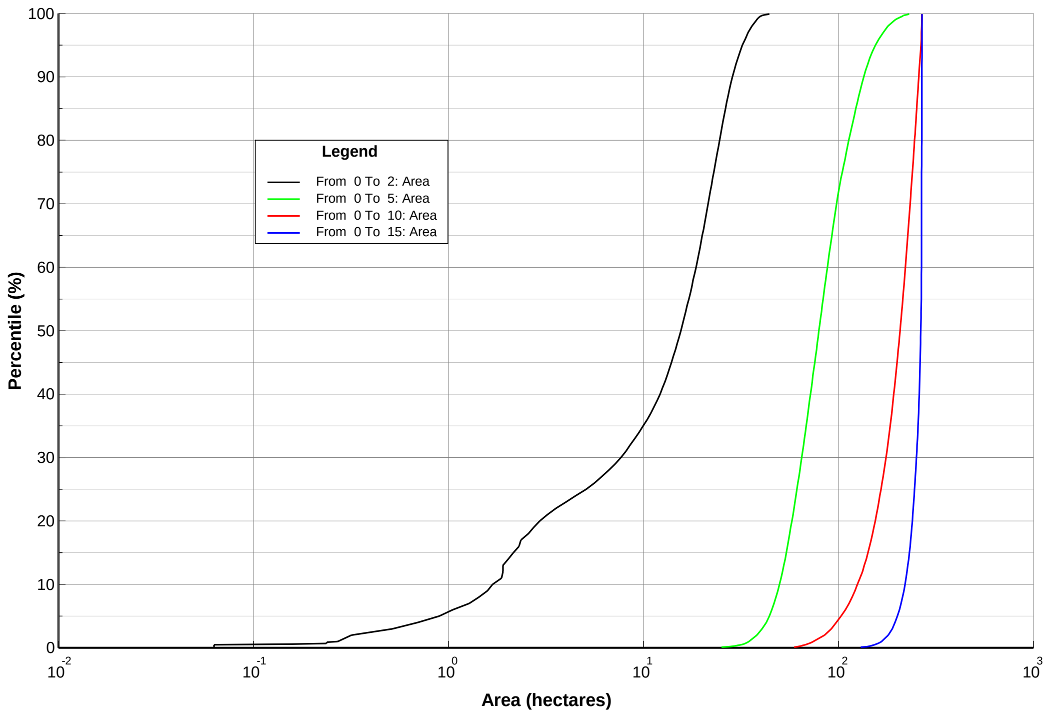


Figure 7-8 CDF's for the Base Case areas for the specified salinity ranges.

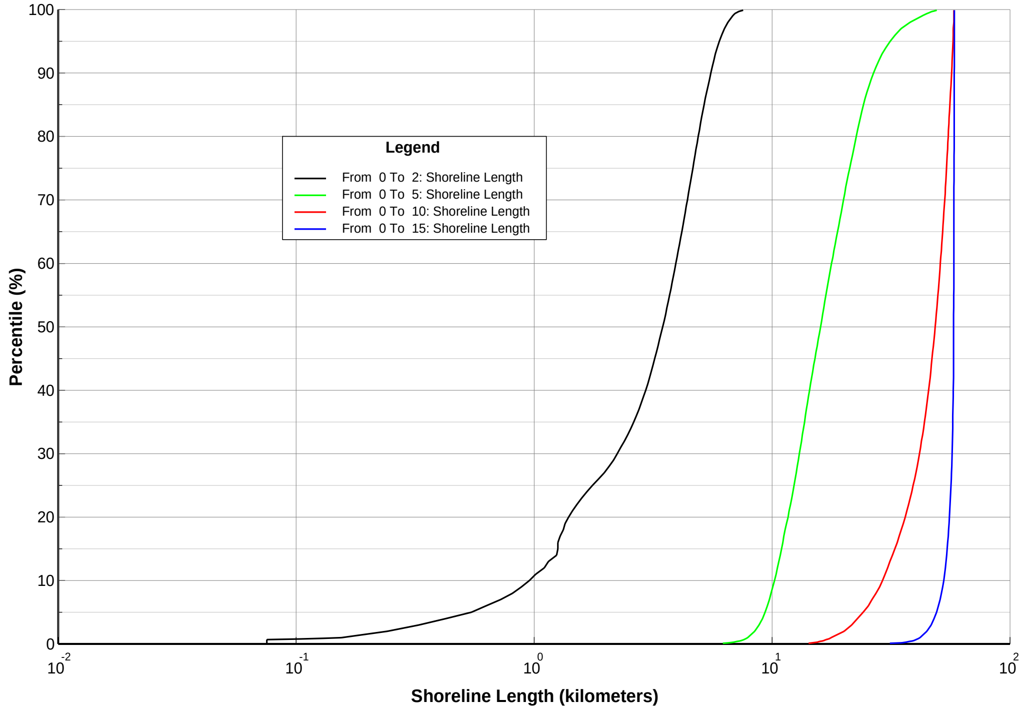


Figure 7-9 CDF's for the Base Case shoreline lengths for the specified salinity ranges.

The CDF's for each scenario and salinity range were grouped by salinity range on separate plots for volumes, areas and shoreline lengths. Using CDF's was determined to be the best approach for comparing the relative impacts due to the flow reductions on the salinity regime. The axes representations were reversed from the CDF's shown earlier, i.e. for the Y axis now represents volumes or areas or shoreline lengths and the X axis now represents the cumulative time. This was done to simplify the analysis in the following sections.

Figures 7-10 to 7-13 show the resulting comparisons for volumes. The percentage of time shown in the X axis correlates to the cumulative time. As an example, for Figure 7-10 for the Baseline case, 40% of the time the volume of 0-2 ppt salinity water is equal to or less than 82,400 m^3, or 29% of the reference volume, (84,000/284,000).

Figure 7-13 shows that for the Chassahowitzka system, a 15% reduction (632,700 m^3) of the 0 to 15 ppt salinity range is not advisable. As the freshwater flows decrease, the system becomes more saline. However, because the base case volumes are large, relative to the system, a 15% reduction in volume would require an unreasonable (and undesirable) reduction in flows. Therefore, the 0 to 15 ppt range is presented for completeness but was not included in the final MFL recommendations.

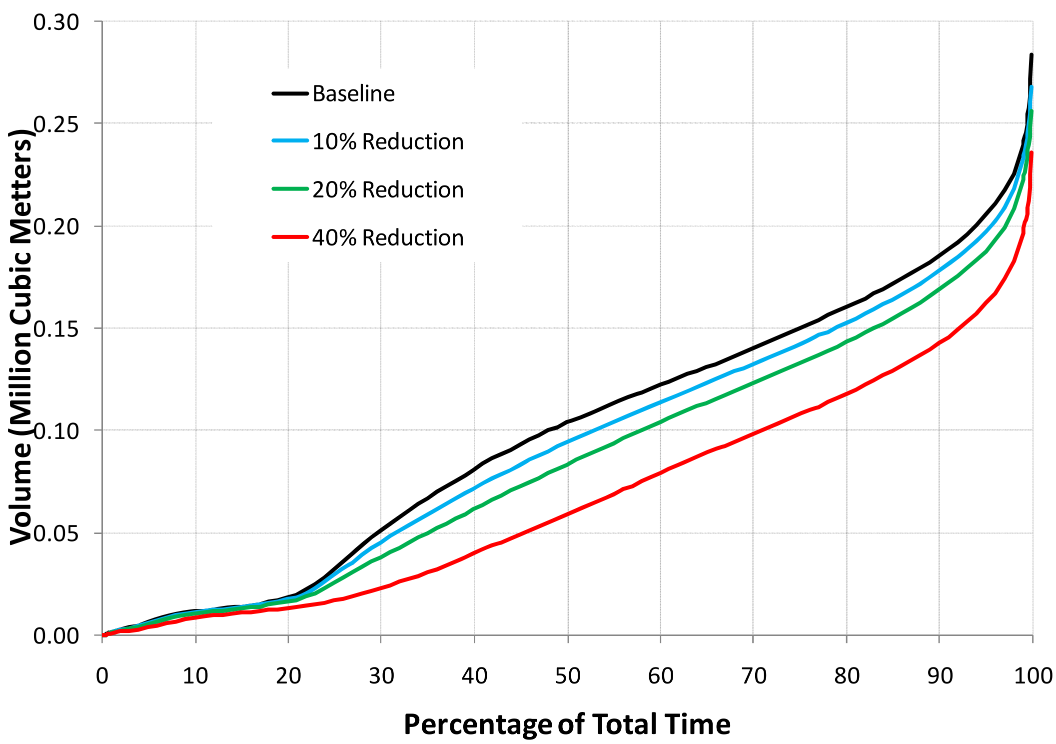


Figure 7-10 Volumetric analysis CDF's: Salinity range 0 to 2 ppt.

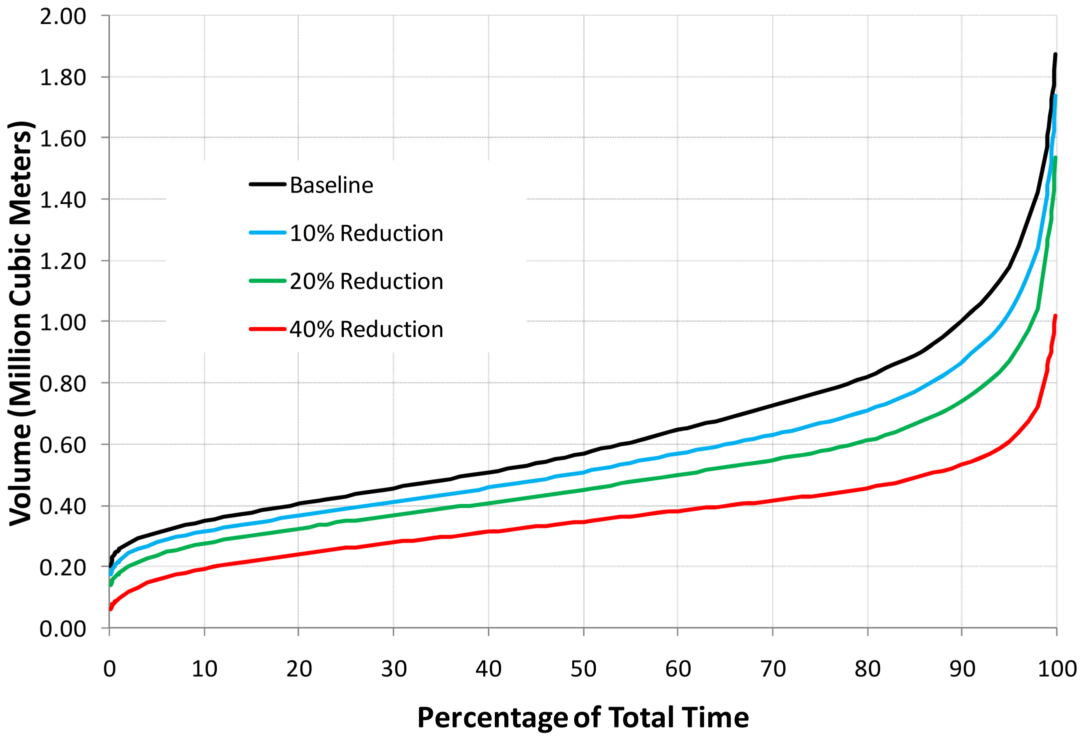


Figure 7-11 Volumetric analysis CDF's: Salinity range 0 to 5 ppt.

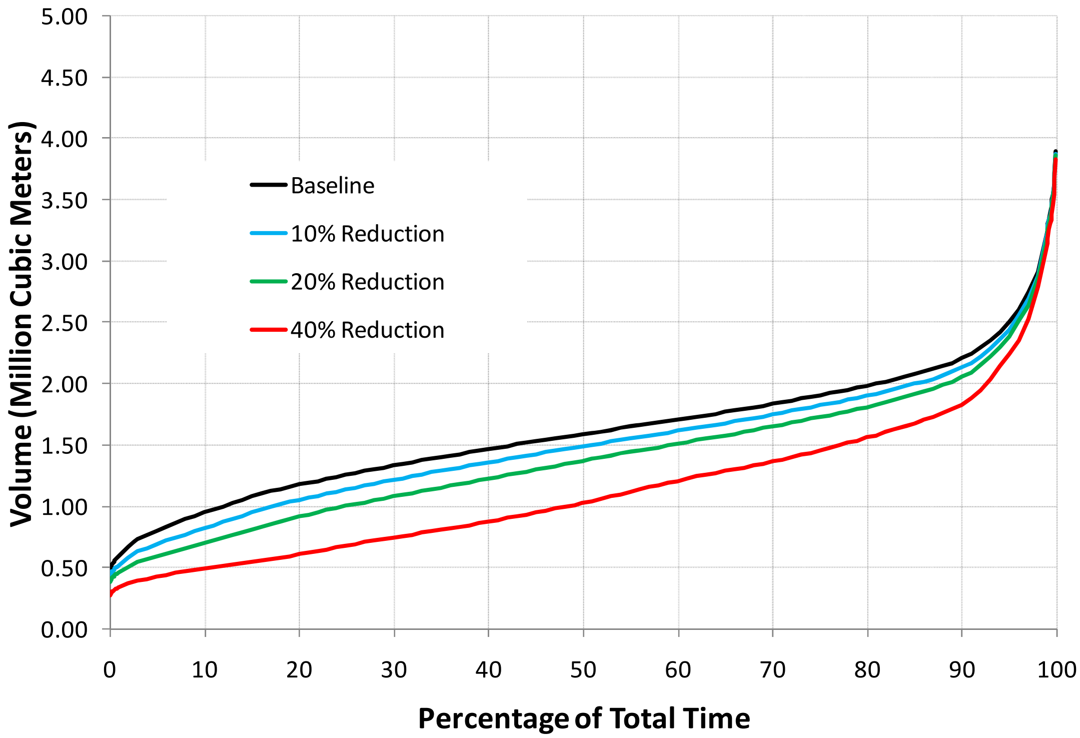


Figure 7-12 Volumetric analysis CDF's: Salinity range 0 to 10 ppt.

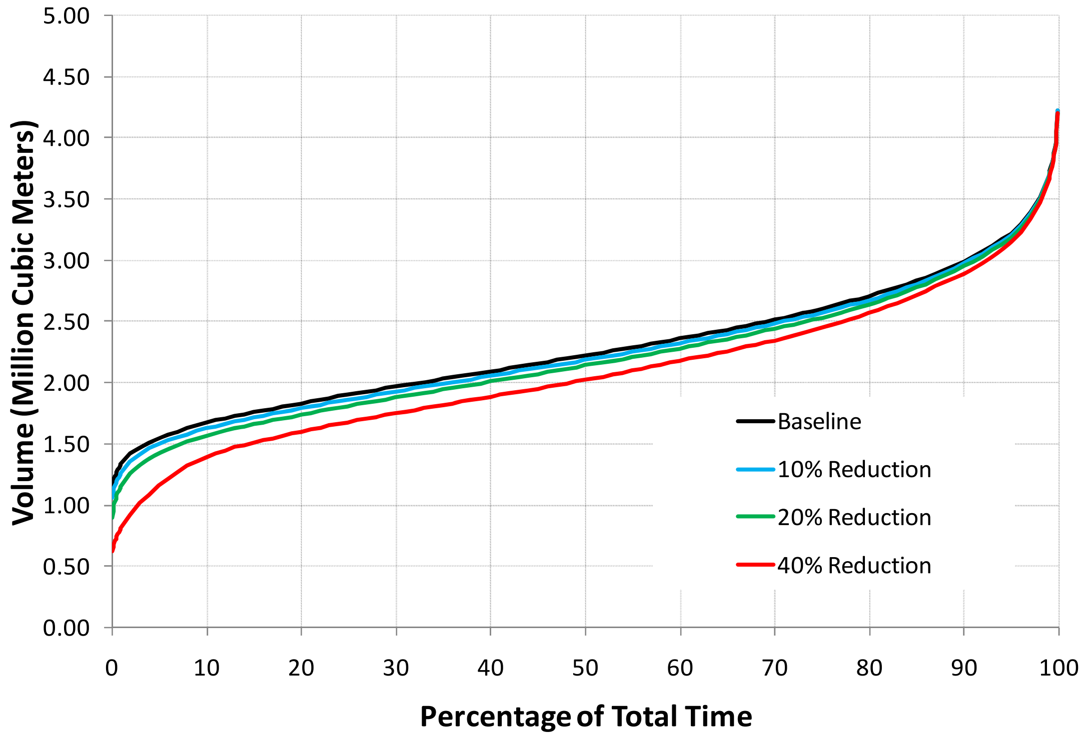


Figure 7-13 Volumetric analysis CDF's: Salinity range 0 to 15 ppt.

Figures 7-14 to 7-17 show the resulting comparisons for areas. The percentage of time shown in the X axis correlates to the cumulative time. As an example, for Figure 7-14 for the Baseline case, 40% of the time the area of 0-2 ppt salinity water is equal to or less than 12.4 ha, or 28% of the reference area (12.4/44.17).

As with the volume CDF's the 15% reduction of areas (40.11 ha) for the 0 to 15 ppt salinity range is not advisable (Figure 7-17). In fact, the 0 to 10 ppt salinity range is also marginal as there is a large percentage of time where the entire estuary meets these conditions. Figure 7-16 shows that for times greater than the 80 percentile level would require flow reductions for much more than 40%. A 15% reduction in area would require an unreasonable (and undesirable) reduction in flows. Therefore, the 0 to 15 ppt range is presented for completeness but was not included in the final MFL recommendations.

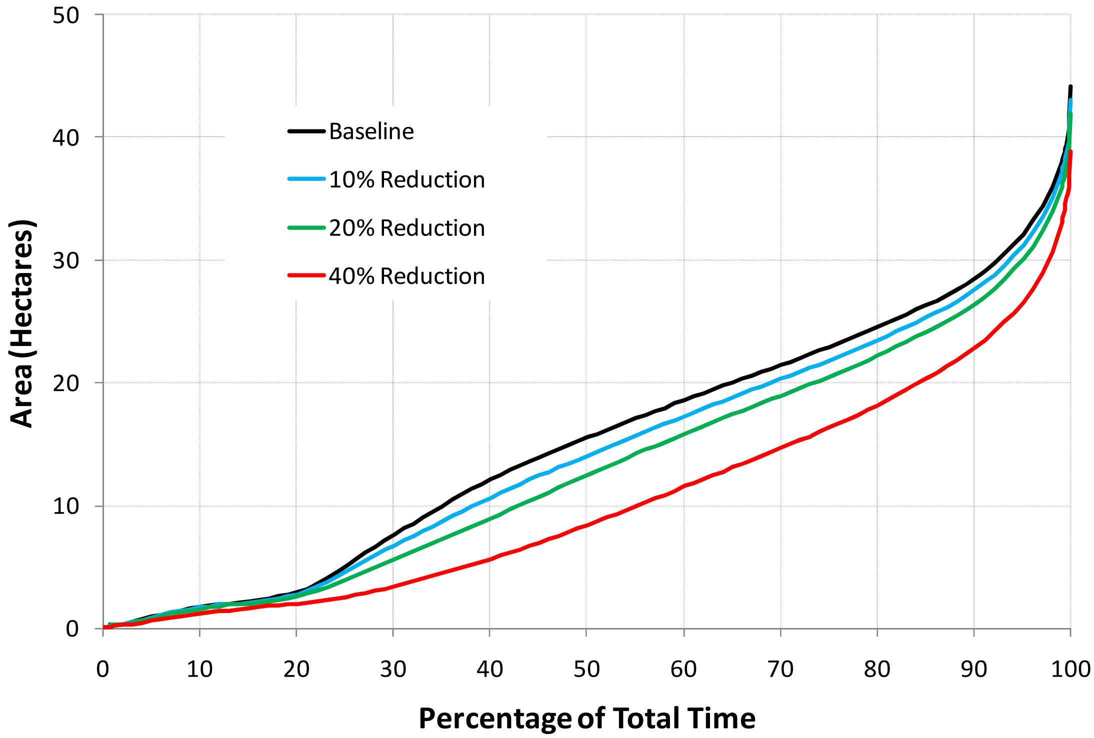


Figure 7-14 Area analysis CDF's: Salinity range 0 to 2 ppt.

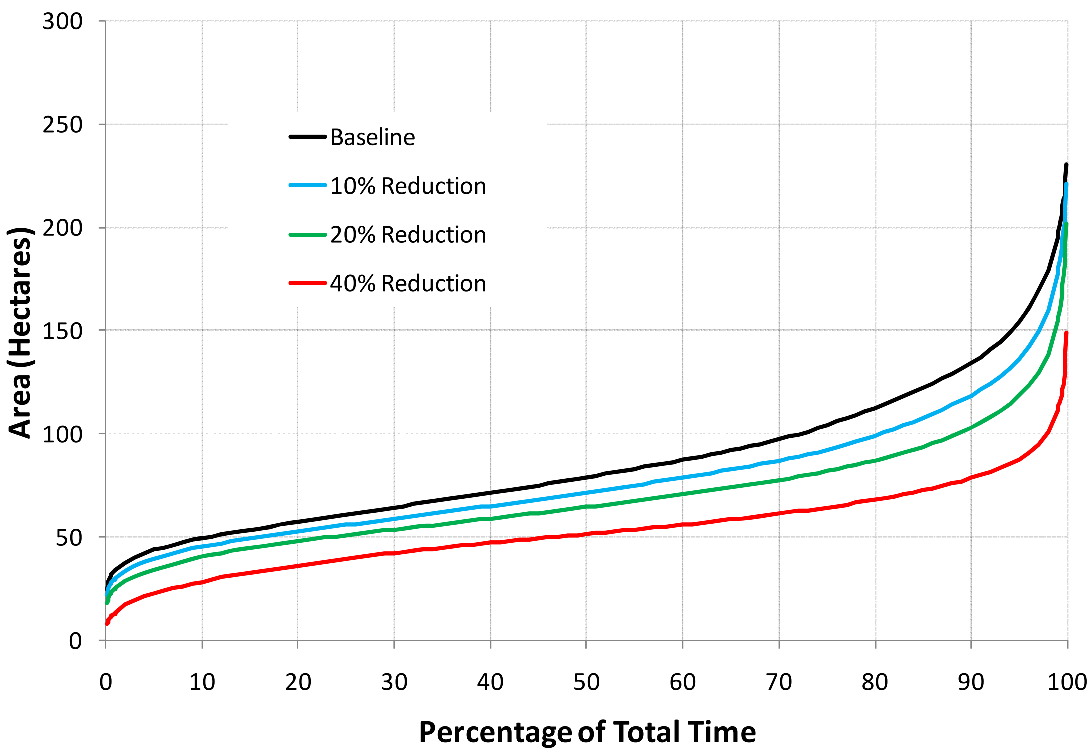


Figure 7-15 Area analysis CDF's: Salinity range 0 to 5 ppt.

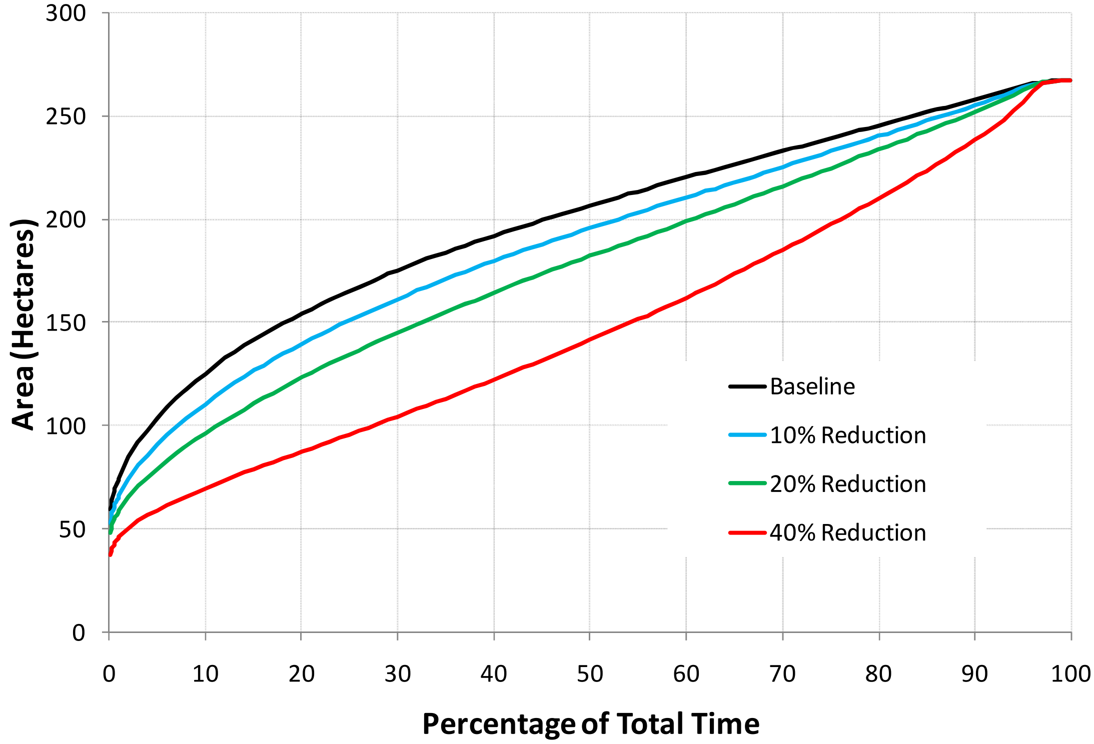


Figure 7-16 Area analysis CDF's: Salinity range 0 to 10 ppt.

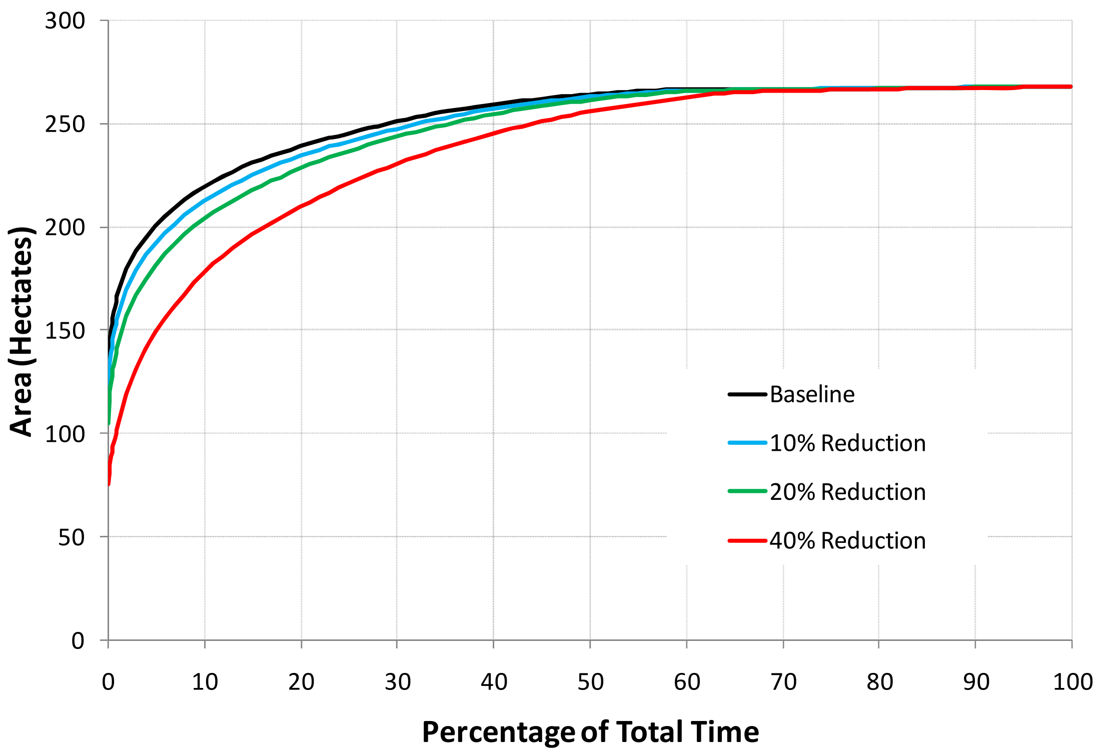


Figure 7-17 Area analysis CDF's: Salinity range 0 to 15 ppt.

Figures 7-18 to 7-21 show the resulting comparisons for shoreline lengths. The percentage of time shown in the X axis correlates to the cumulative time. As an example, for Figure 7-18 for the Baseline case, 40% of the time the shoreline length of 0-2 ppt salinity water is equal to or less than 3km.

As with the volume CDF's the 15% reduction of shoreline lengths (8.8 km) for the 0 to 15 ppt salinity range is not advisable (Figure 7-21). Figure 7-21 shows that for times greater than the 80 percentile level would require flow reductions for much more than 40%. A 15% reduction in shoreline length would require an unreasonable (and undesirable) reduction in flows. Therefore, the 0 to 15 ppt range is presented for completeness but was not included in the final MFL recommendations.

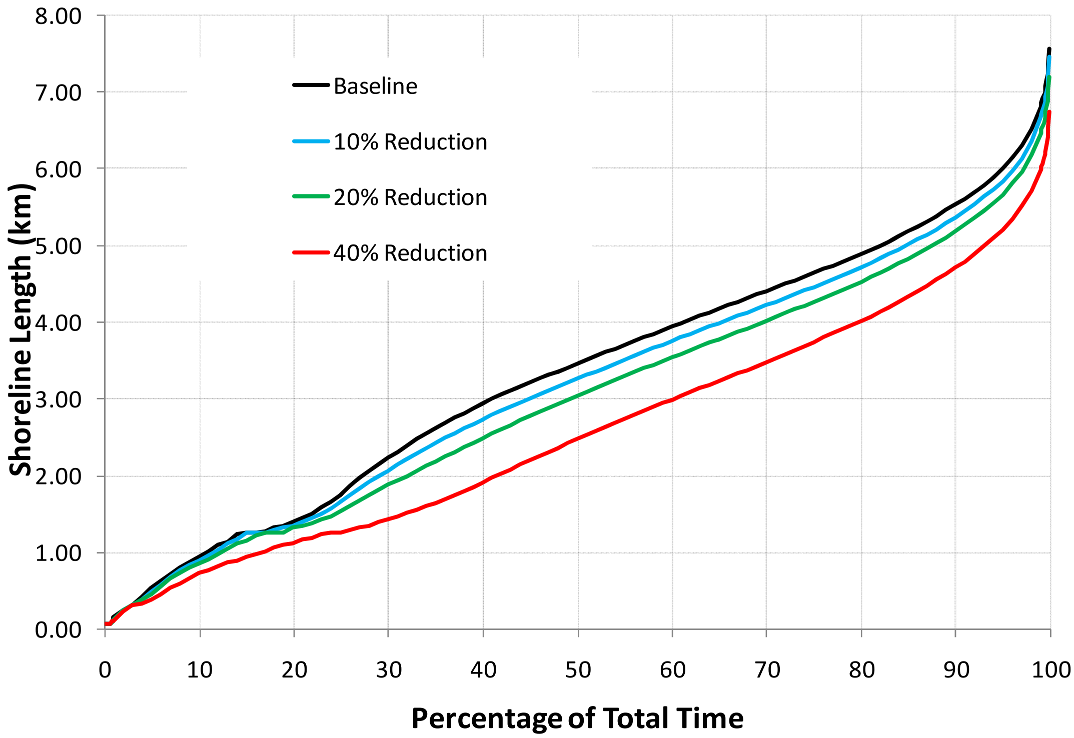


Figure 7-18 Shoreline length analysis CDF's: Salinity range 0 to 2 ppt.

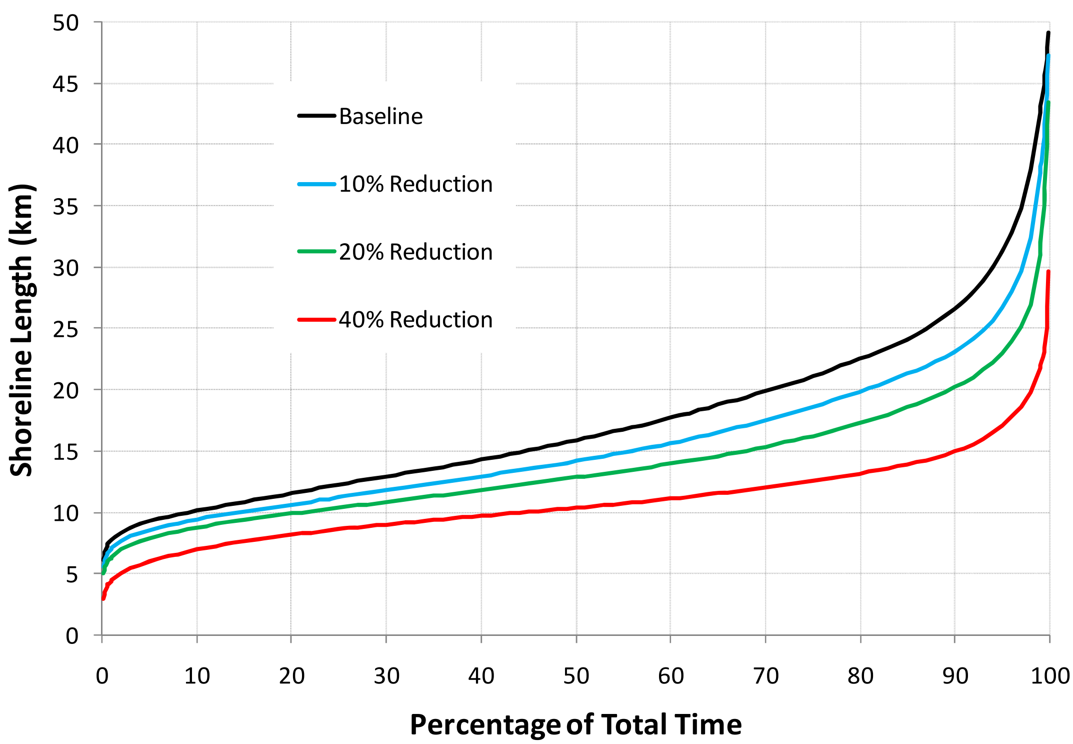


Figure 7-19 Shoreline length analysis CDF's: Salinity range 0 to 5 ppt.

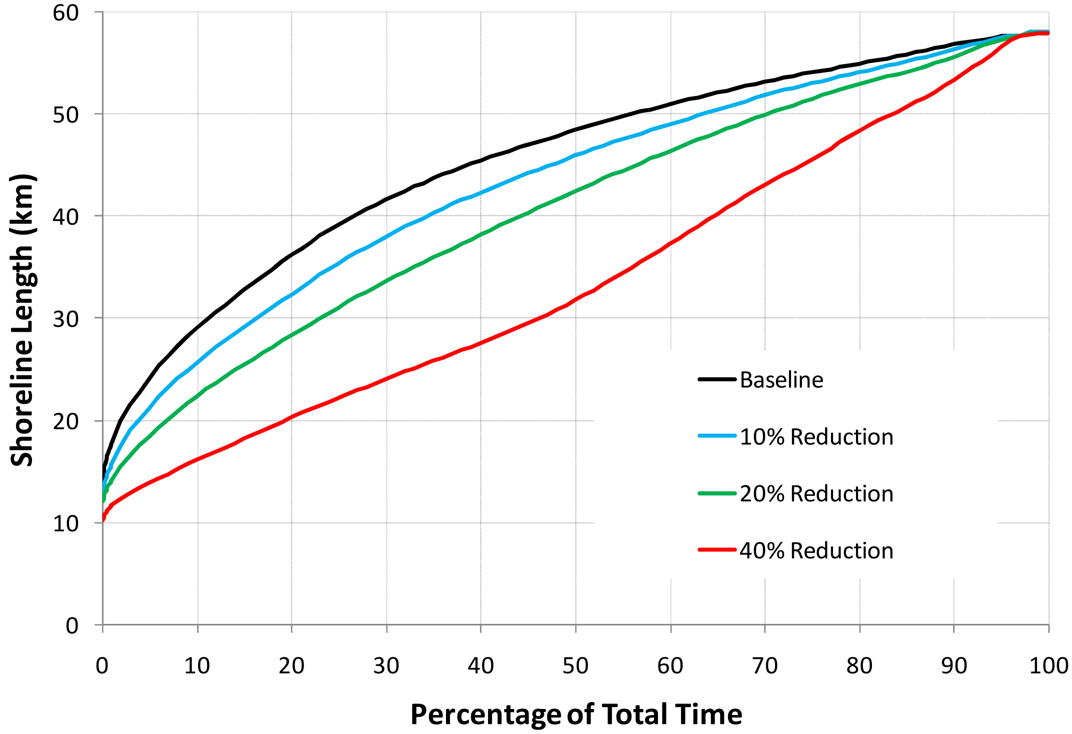


Figure 7-20 Shoreline length analysis CDF's: Salinity range 0 to 10 ppt.

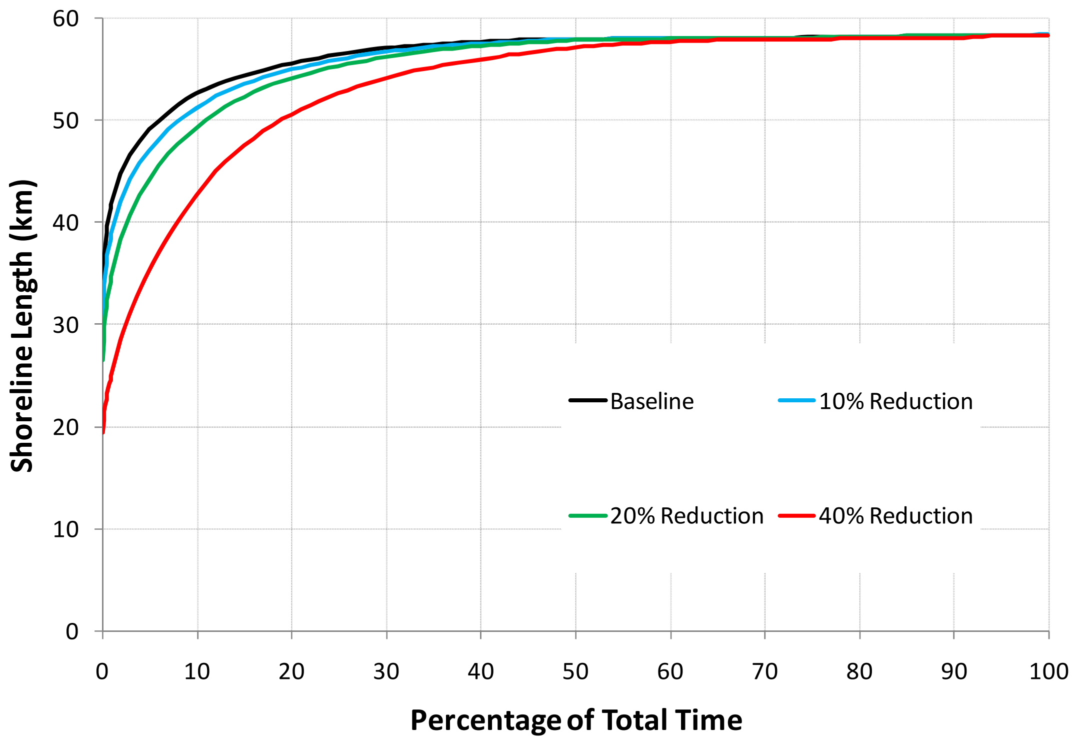
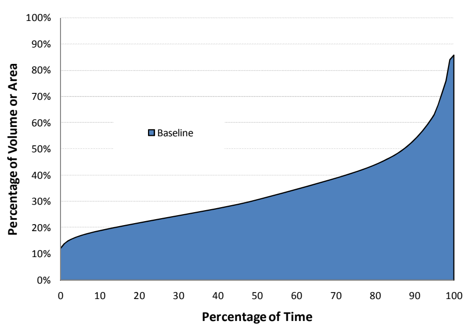


Figure 7-21 Shoreline length analysis CDF's: Salinity range 0 to 15 ppt.

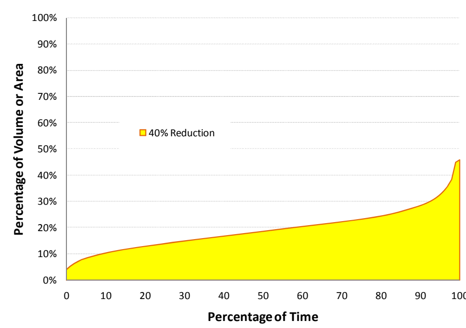
7.4 Determination of MFL for Salinity Reductions

To compute the change in volumes, areas and shoreline lengths between the baseline and the various flow reduction scenarios it is necessary to compute an integrated volume or area or shoreline length for each CDF. The approach used here is the same approach as used in the MFL for Dona Bay/Shaklet Creek (SWFWMD, 2007). Using the respective CDF's the area under the CDF curve (AUC) is computed for each scenario. These areas are then normalized to the Baseline scenario. The normalized total volume or area is then compared to the 15% maximum habitat loss criteria (or 85% of the Baseline volumes/areas remaining).

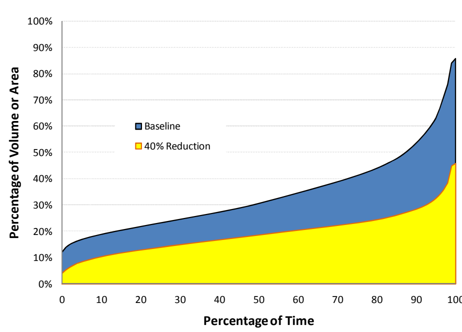
To illustrate the process consider the following schematic. In this example the normalized AUC for the 40% Reduction case is computed. First compute the AUC's for the Baseline case (shown in blue in Figure 4-22 (a)) and for the 40% Reduction case (shown in yellow in Figure 4-22 (b)). The difference in these volumes is shown as the blue area in Figure 4-22 (c). However, we want the complement (i.e. 1 - percent lost) or the volume remaining normalized to the Baseline case, as shown by the following equation.



(a) Baseline AUC.



(b) 40% Reduction AUC.



(c) Blue area represents the difference between the Baseline and 40% Reduction.

Figure 7-22 Area under the CDF curve (AUC) schematic.

$$AUC[40\%]_{Norm} = \frac{AUC_{40\%}}{AUC_{Baseline}}$$

A normalized AUC was then computed for each of the salinity and flow reduction combinations. Figures 7-23 to 7-34 provide bar charts for each salinity range for the volume, area and shoreline length AUC's. The volume summaries are shown in Figures 7-23 to 7-26 and the area summaries are shown in Figures 7-27 to 7-30 and the shoreline length summaries are shown in Figures 7-31 to 7-34. The minimum remaining habitat criteria (85% of the respective salinity range remaining) is also shown on each plot.

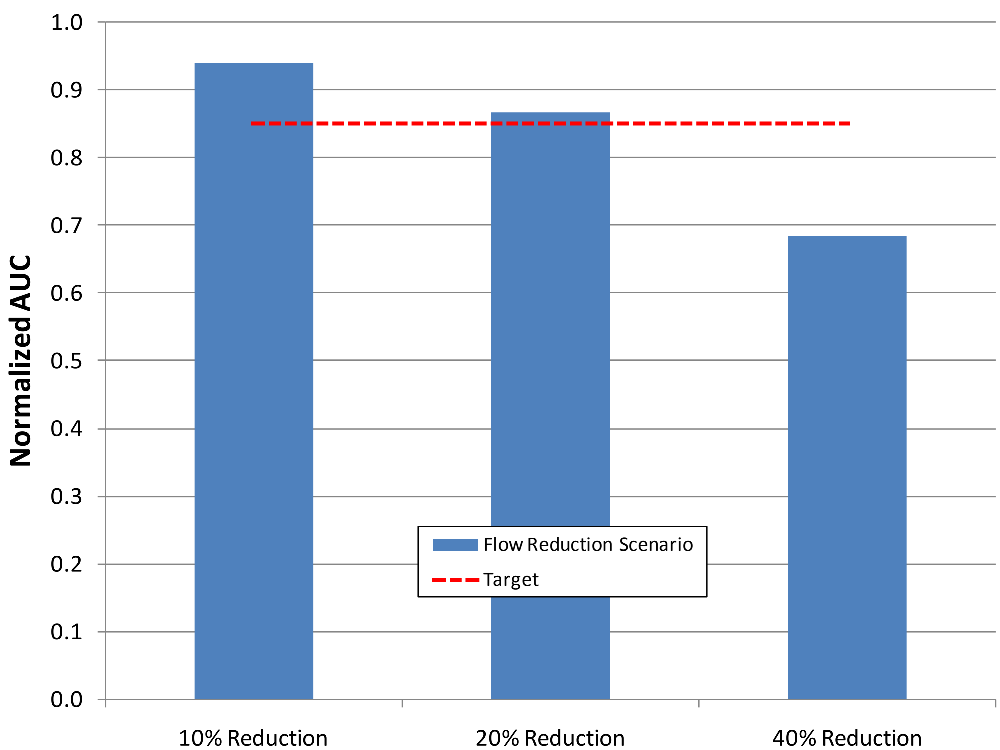


Figure 7-23 Summary of volumetric AUC analysis: Salinity range 0 to 2 ppt.

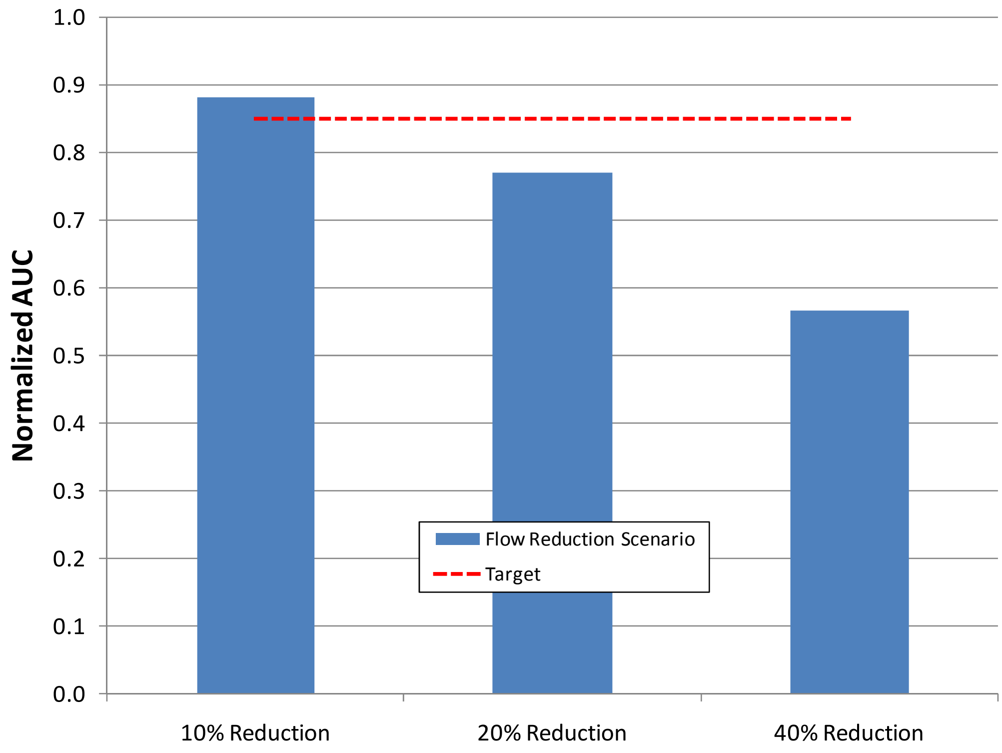


Figure 7-24 Summary of volumetric AUC analysis: Salinity range 0 to 5 ppt.

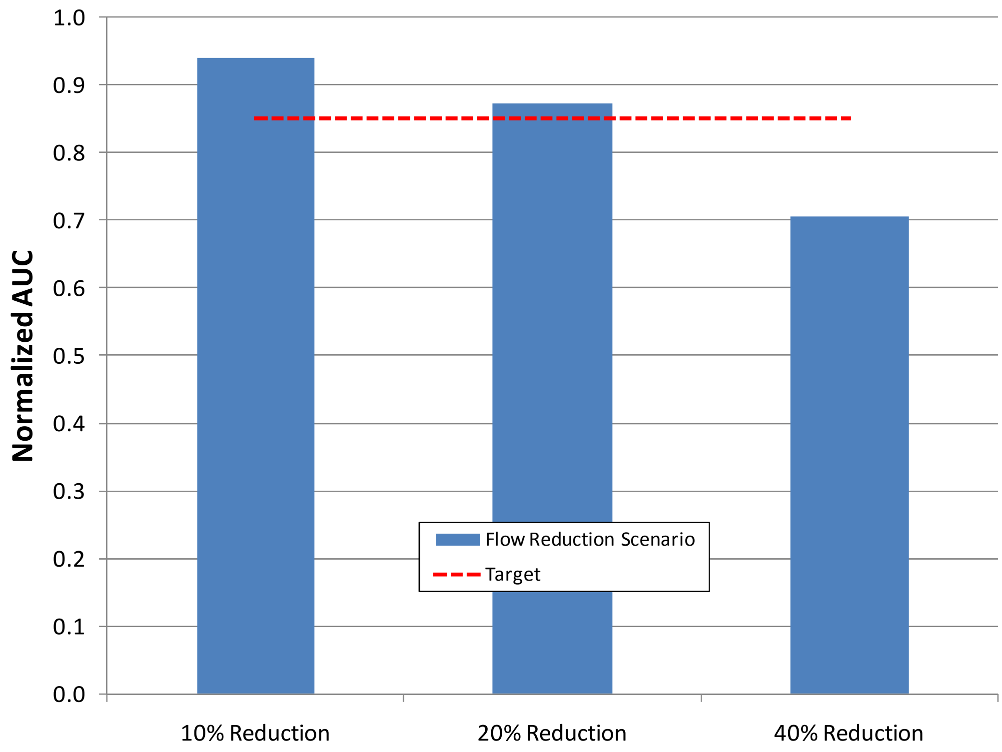


Figure 7-25 Summary of volumetric AUC analysis: Salinity range 0 to 10 ppt.

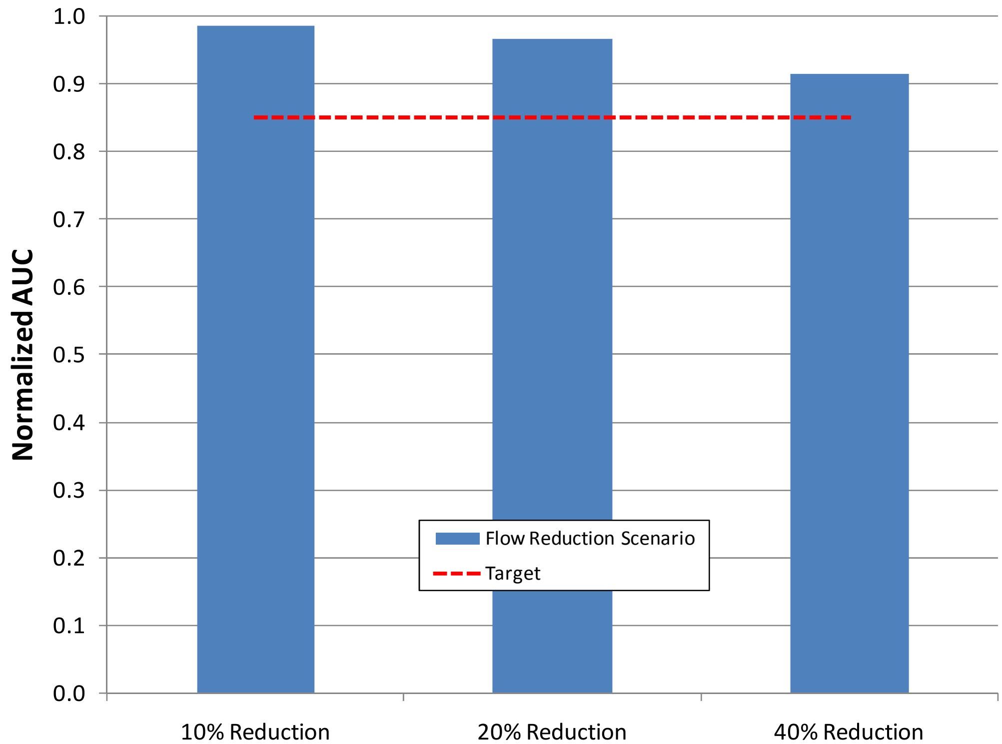


Figure 7-26 Summary of volumetric AUC analysis: Salinity range 0 to 15 ppt.

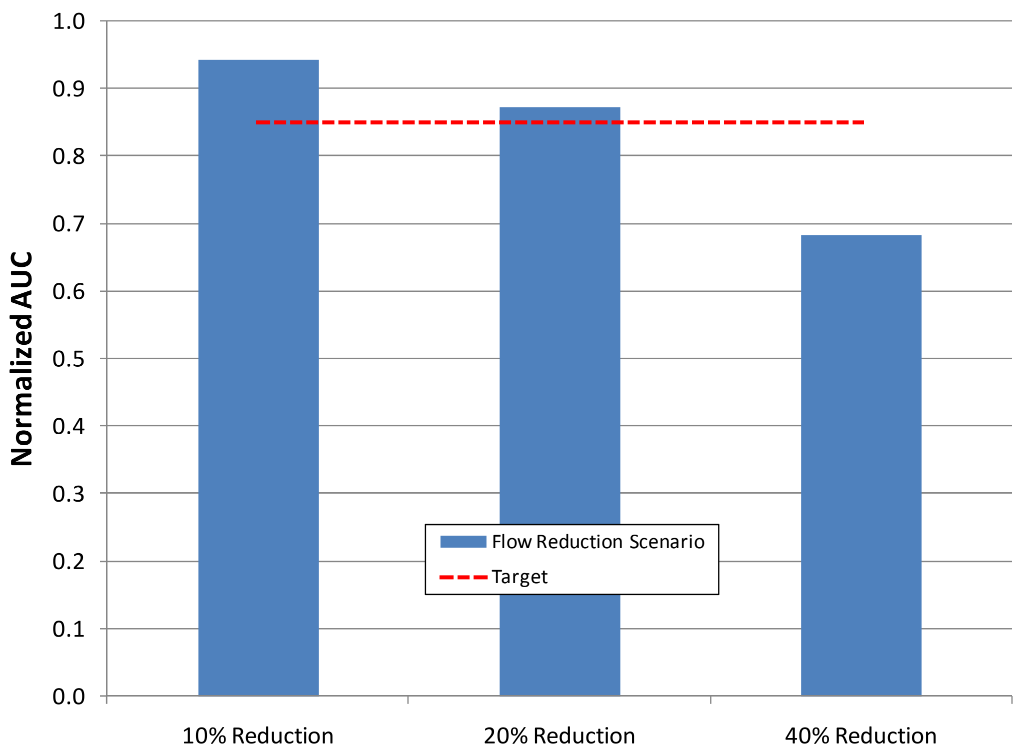


Figure 7-27 Summary of area AUC analysis: Salinity range 0 to 2 ppt.

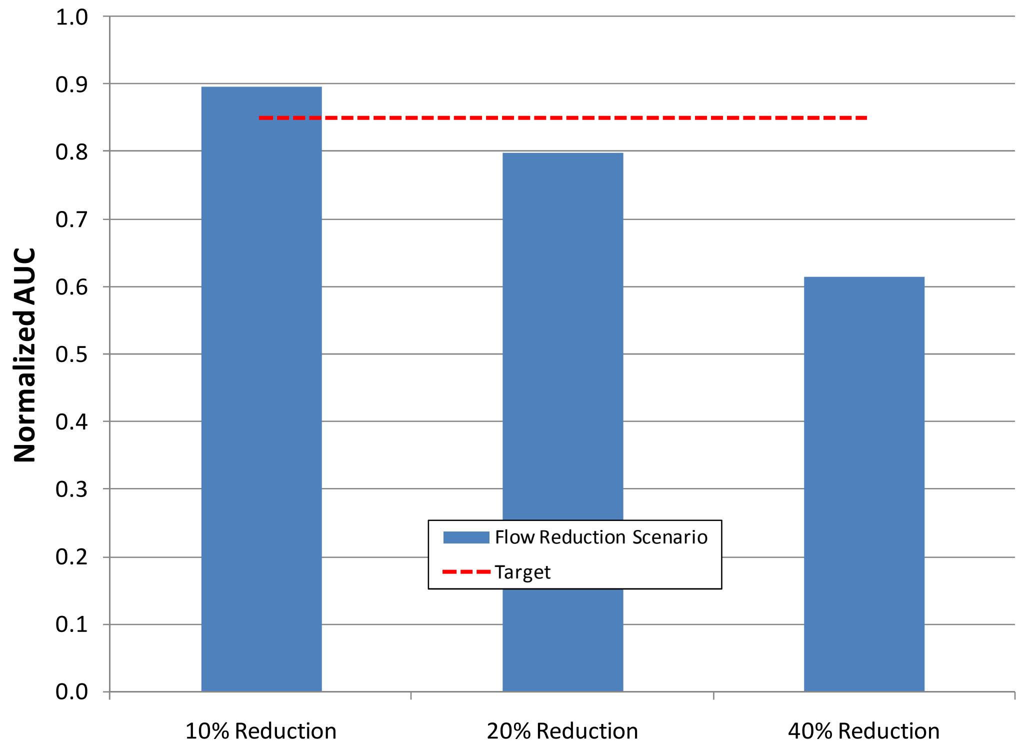


Figure 7-28 Summary of area AUC analysis: Salinity range 0 to 5 ppt.

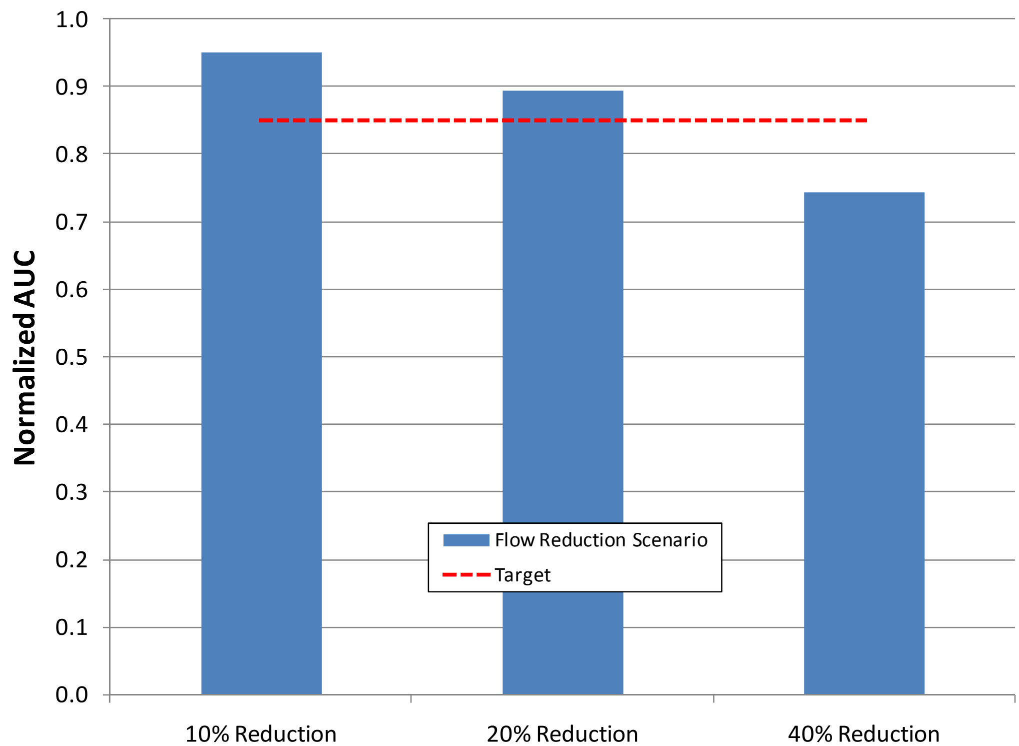


Figure 7-29 CDF's of areas for the 0 to 10 ppt salinity range.

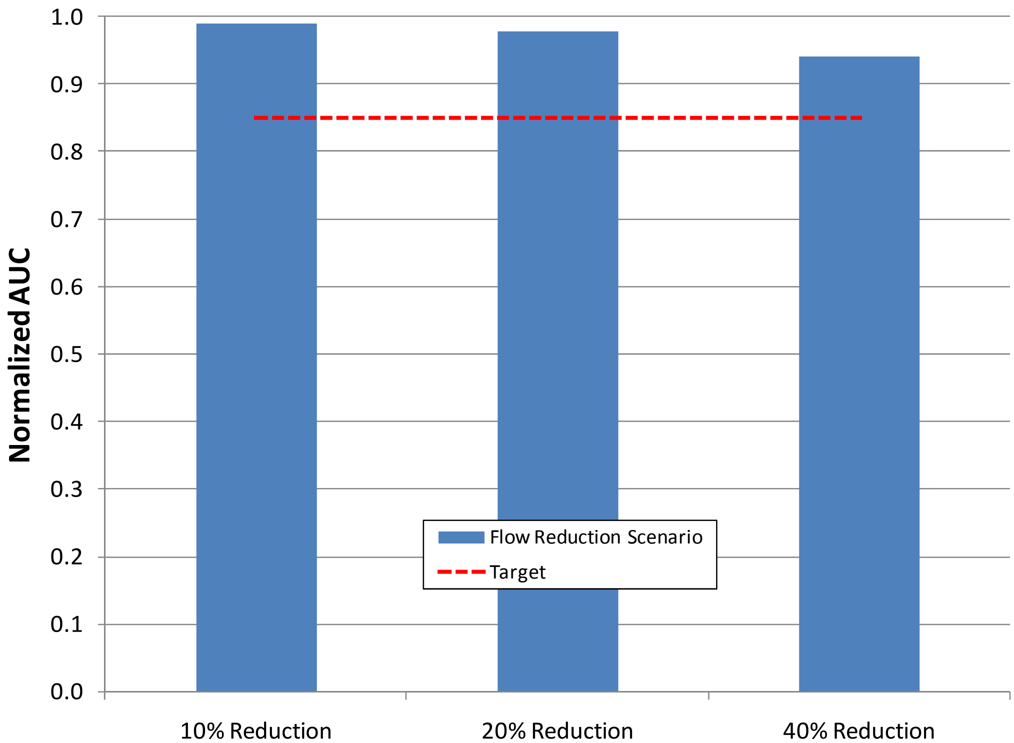


Figure 7-30 CDF's of areas for the 0 to 15 ppt salinity range.

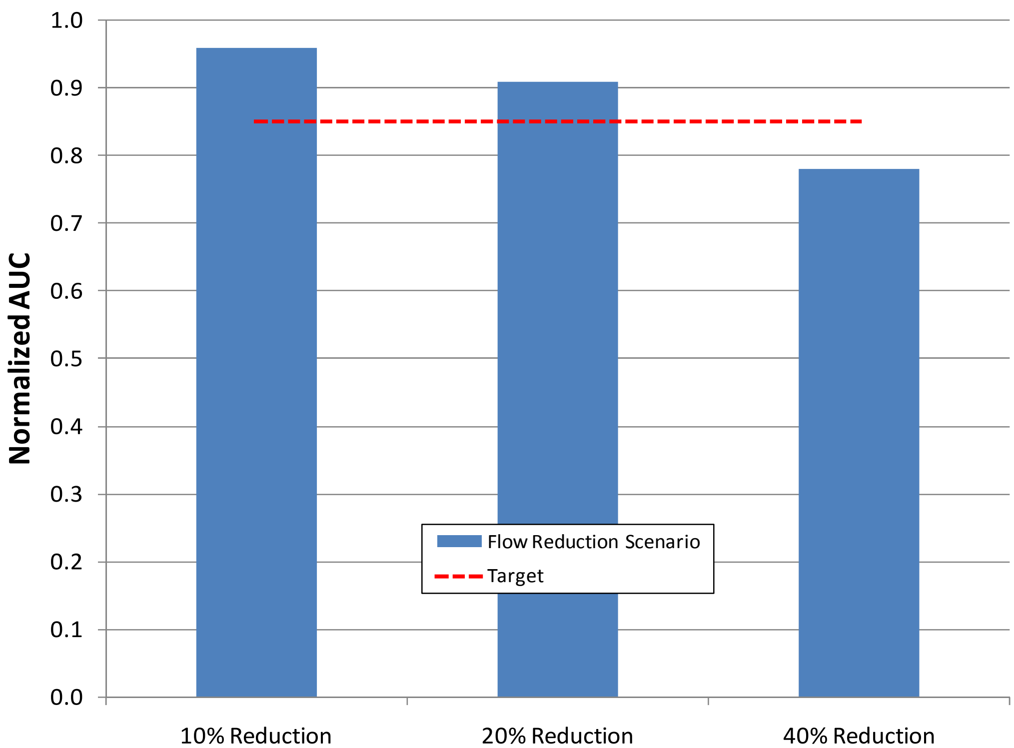


Figure 7-31 Summary of shoreline length AUC analysis: Salinity range 0 to 2 ppt.

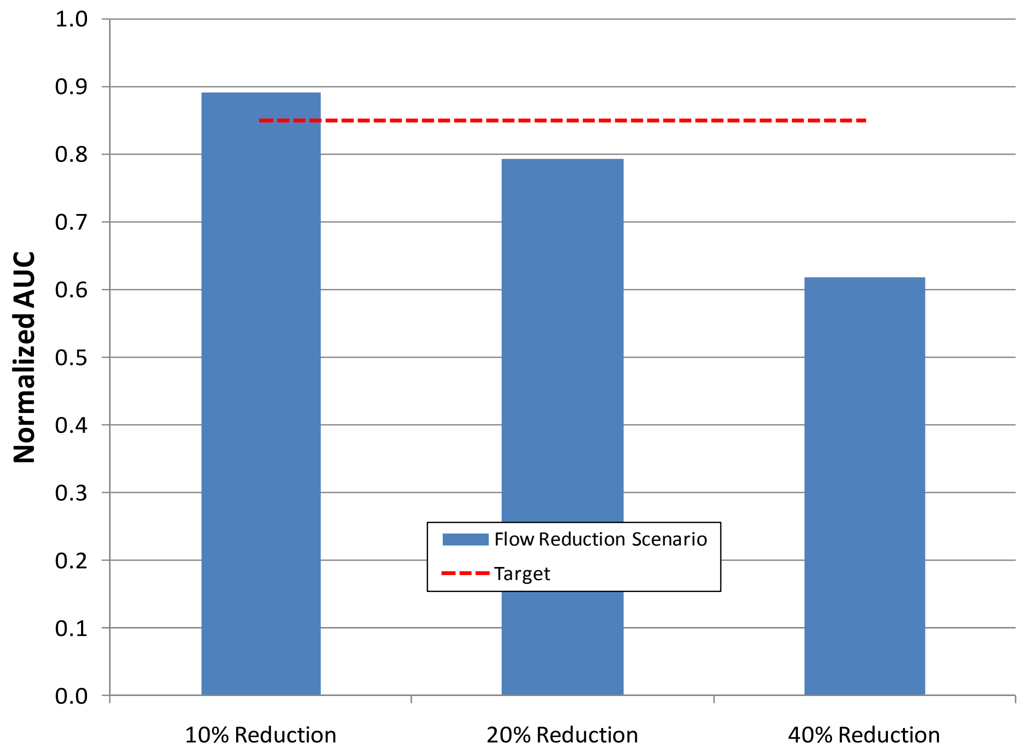


Figure 7-32 Summary of shoreline length AUC analysis: Salinity range 0 to 5 ppt.

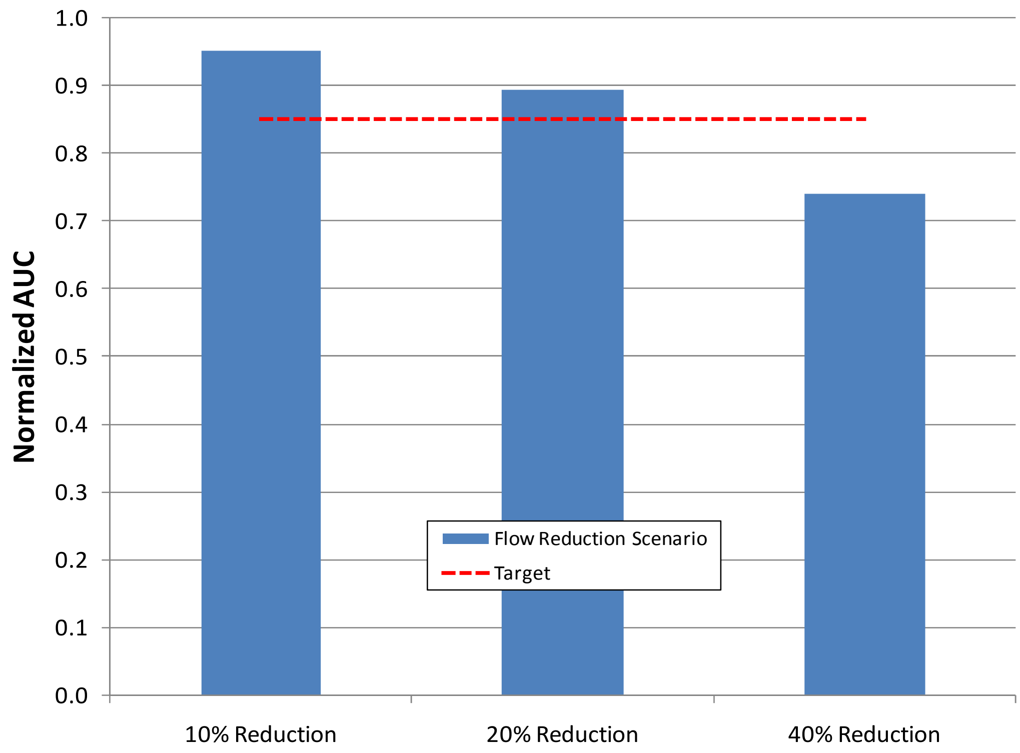


Figure 7-33 Summary of shoreline length AUC analysis: Salinity range 0 to 10 ppt.

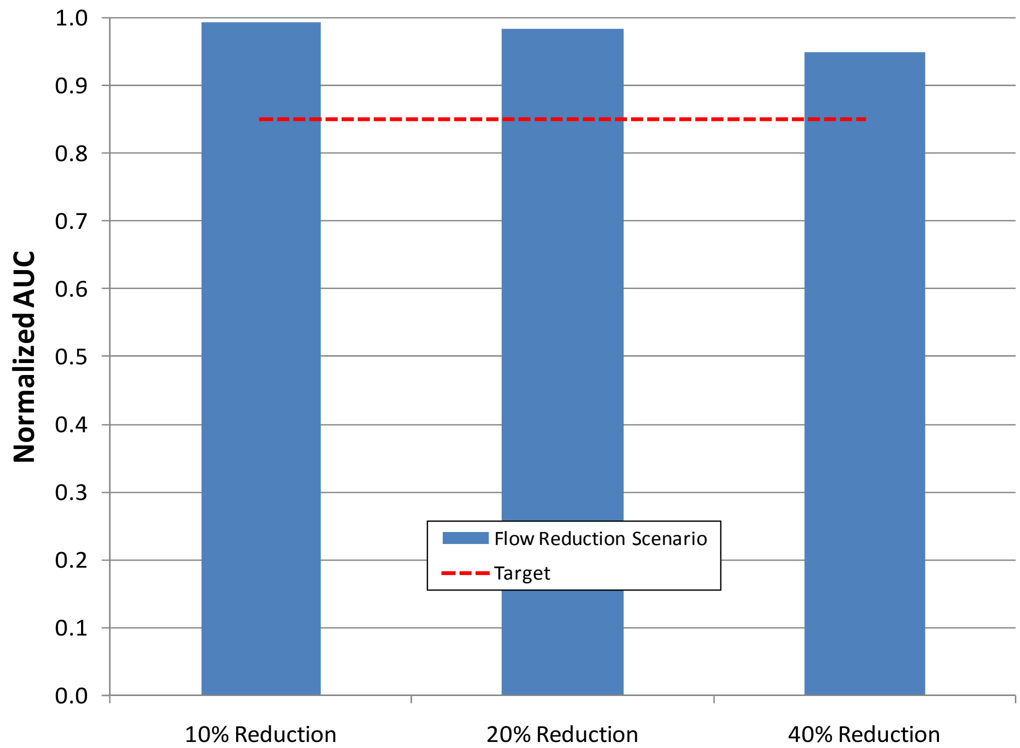


Figure 7-34 Summary of shoreline length AUC analysis: Salinity range 0 to 15 ppt.

These AUC's were used to estimate the percent reduction of flows required to reach the 15% habitat loss criteria. Table 7-1 provides a summary of these flow reductions.

Table 7-1 Flow Reductions based on a 15% loss of volume and/or area and/or shoreline length for the salinity ranges.

Salinity Range (ppt)	Flow Reductions Based on Volumes (%)	Flow Reductions Based on Areas (%)	Flow Reductions Based on Shoreline Lengths (%)
0 to 2	22%	23%	30%
0 to 5	13%	15%	13%
0 to 10	23%	26%	26%
0 to 15	> 40%	> 40%	> 40%

8 Conclusions and Recommendations

The impact on the Chassahowitzka River System due to reductions in spring discharge has been analyzed. The following are the main findings:

- For the “worst case” manatee season, no suitable manatee habitat was found.
- The Chassahowitzka River is not a good manatee refuge during very cold winters. The main problem for the manatee habitat was the shallow depths in the areas that have warm enough waters.
- The salinity regime is sensitive to the fresh water discharges.

An analysis of why the chronic and acute manatee habitat criteria were not being met was conducted. It was determined that the main issue for lack of suitable habitat were the shallow water depths. A detailed review of the measured depths and the model bathymetry was made. Given the model discretization, the model showed reasonable agreement with the data. However, from a review of the data it appears that there may be narrow deep channels that are not well resolved in the data and in the model in the upper reaches of the Chassahowitzka. Therefore, a recommendation would be to collect high resolution bathymetric data in the upper river sections, fill some data gaps lower in the system and then revise the hydrodynamic model, increasing the discretization in the upper reaches. This would allow a finer spatial resolution analysis of the manatee habitat in the upper most reaches of the Chassahowitzka River System.

With respect to salinity habitat protection, the maximum allowable habitat loss is 15% of either volume or area for any of the specified salinity ranges. An analysis has been conducted of the Chassahowitzka River System for salinity habitat protection. Based on these results it is recommended that the flow reduction not exceed 13%.

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Appendix A

Determining the 50Year Return Period Joint Probability

Table A-1- List of annual JP data, transform to logarithms

Year	Joint Probability (JP)	X Log10(JP)	$(X-X_{average})^2$	$(X-X_{average})^3$
1967	0.00252	-2.59833	0.09525	0.02940
1968	0.01524	-1.81715	1.18770	1.29437
1969	0.00518	-2.28539	0.38635	0.24014
1970	0.00021	-3.68612	0.60710	-0.47303
1971	0.00239	-2.62089	0.08184	0.02341
1972	0.00904	-2.04385	0.74495	0.64297
1973	0.00049	-3.30595	0.15919	-0.06351
1974	0.00225	-2.64785	0.06714	0.01740
1975	0.03873	-1.41193	2.23510	3.34154
1976	0.00323	-2.49035	0.17356	0.07231
1977	0.00027	-3.57481	0.44603	-0.29788
1978	0.00321	-2.49407	0.17048	0.07039
1979	0.00141	-2.85075	0.00316	0.00018
1980	0.00229	-2.63935	0.07162	0.01917
1981	0.00016	-3.80665	0.80944	-0.72824
1982	0.00022	-3.65262	0.55601	-0.41459
1983	0.01614	-1.79209	1.24294	1.38572
1984	0.00005	-4.30671	1.95930	-2.74253
1985	0.00015	-3.82922	0.85056	-0.78444
1986	0.00123	-2.90996	0.00001	0.00000
1987	0.00121	-2.91588	0.00008	0.00000
1988	0.00871	-2.06006	0.71724	0.60743
1989	0.00117	-2.93311	0.00068	-0.00002
1990	0.00001	-4.86886	3.84904	-7.55141
1991	0.00092	-3.03588	0.01662	-0.00214
1992	0.00031	-3.51075	0.36456	-0.22012
1993	0.00252	-2.59805	0.09543	0.02948
1994	0.00168	-2.77560	0.01726	0.00227
1995	0.00059	-3.22595	0.10176	-0.03246
1996	0.00065	-3.18500	0.07731	-0.02150
1997	0.00050	-3.30084	0.15514	-0.06111
1998	0.01092	-1.96197	0.89301	0.84389
1999	0.00545	-2.26383	0.41362	0.26601
2000	0.00402	-2.39596	0.26112	0.13343

Year	Joint Probability (JP)	X Log10(JP)	$(X-X_{average})^2$	$(X-X_{average})^3$
2001	0.00022	-3.65698	0.56253	-0.42191
2002	0.00002	-4.60865	2.89574	-4.92765
2003	0.00103	-2.98754	0.00649	-0.00052
2004	0.00043	-3.36408	0.20896	-0.09552
2005	0.00168	-2.77448	0.01755	0.00233
2006	0.10391	-0.98335	3.70027	7.11786
2007	0.00097	-3.01452	0.01157	-0.00124
N=41		Total=-119.1854	Total=26.21368	Total=-2.70014

USGS's Hydrology Subcommittee had recommended technique for fitting a log-pearson Type III distribution to annual extreme events. While this technique referred to flood flows it was felt that the approach was applicable to selecting an annual extreme event for the joint probabilities (JP). A detailed description of the technique was given in the bulletin #17B of the Hydrology Subcommittee. A similar procedure was applied here for fitting the log-pearson type III distribution to lowest *JP* annual series. The base 10 logarithms of the low threshold *JP* at selected exceedance probability *P* is computed by the equation:

$$Log(JP) = \overline{X} - KS \qquad \text{(A-1)}$$

Where $\overline{X}$ and S are defined below and *K* is a factor that is a function of the skew coefficient and selected exceedance probability.

$$\overline{X} = \frac{\sum X}{N} = \frac{-119.1854}{41} = -2.9070 \qquad \text{(A-2)}$$

$$S = \left[\frac{\sum\left(X-\overline{X}\right)^2}{(N-1)}\right]^{0.5} = \left(\frac{26.2137}{40}\right)^{0.5} = 0.8095 \qquad \text{(A-3)}$$

$$G = \frac{N\sum\left(X-\overline{X}\right)^3}{(N-1)(N-2)S^3} = \frac{(41)(-2.7001)}{(40)(39)(0.8095)^3} = -0.13377 \qquad \text{(A-4)}$$

In which

X = logarithm of annual JP
N = number of items in data set
$\overline{X}$ = mean logarithm
S = Standard deviation of logarithms

G = skew coefficient of logarithms

According to table of K values provided in bulletin #17B with the closest value of G=-0.1 and selected exceedance probability P=0.02 (50 years return period of JP), a value of K = 1.999 was obtained.

The base 10 logarithms of low threshold is computed from equation A-1

$Log(JP)$=-2.9070-(1.999)(0.8095)=-4.52522

And finally, the low threshold JP would be

JP=antilog(-4.52522)= 2.98E-05