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ANALYSIS OF BLUE SPRING DISCHARGE DATA TO DETERMINE A MINIMUM FLOW REGIME

Analysis of Blue Spring Discharge Data

to

Determine a Minimum Flow Regime

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In Cooperation with the

Blue Spring Minimum Flow Interagency Working Group

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EXECUTIVE SUMMARY

Blue Spring, located near Orange City, in Volusia County, Florida, is a first magnitude spring, and is one of only three large, natural warm-water winter refuges for West Indian manatees in north Florida. Because manatee population recovery and growth depend on maintaining the availability of reliable winter warm-water habitats, Blue Spring run has been designated as critical habitat for the Florida Manatee by the United States Fish and Wildlife Service (*USFWS*). The St. Johns River Water Management District (*SJRWMD*), pursuant to its statutory responsibilities, is developing minimum flows for Blue Spring. For this purpose, SJRWMD developed a set of objectives and strategies, and formed the Blue Spring Minimum Flow Interagency Working Group (*MFIWG*). This group, which consists of experts from various participating organizations, including the Florida Department of Environmental Protection (*FDEP*), Florida Fish and Wildlife Conservation Commission (*FFWCC*), and SJRWMD, has assisted in the formulation of recommended minimum flows that increase incrementally over time – referred to as a minimum flow regime -- at the spring. USFWS and Save the Manatee Club, Inc. also participated in the MFIWG, however, primarily in reviewing and commenting on draft recommendations. The research efforts that support the recommended minimum flow regime are based on the analysis of the vast daily database of Blue Spring State Park (*BSSP*), as well as period of record (*POR*) spring discharge, river stage and river temperature data, collected and compiled by the U.S. Geological Survey (*USGS*) and SJRWMD. This report presents methodologies, findings, and recommendations concerning the establishment of a minimum flow regime for Blue Spring (*Blue Spring MFR*) designed to protect the use of Blue Spring as a refuge to accommodate the expansion of the West Indian manatee population in the St. Johns River. Based on additional analyses contained in a separate report, the recommended Blue Spring MFR will protect all of the applicable values that SJRWMD must consider in establishing a minimum flow regime for Blue Spring.

Manatee Physiology and Habitat Analysis

Manatees seek refuge in the warmer waters of the Blue Spring run when the temperature of the river drops below 66°- 68° Fahrenheit (°*F*) or 19°- 20° Celsius (°*C*). The spring water remains at a nearly constant temperature of 73.4°F (23°C) all year. Manatees typically begin aggregating in the run in November and leave in March, which is referred to as the "manatee season." In this report, each manatee season is identified by the year in which it starts. For example, the 2000 manatee season refers to the period of November 1, 2000, through March 31, 2001.

In general, prolonged exposure to cold (66° - 68°F) river water wedges penetrating into the spring run for longer than 4-7 days could result in catastrophic losses to the manatee population. Given the typical long life span of manatees, catastrophic conditions are thus defined as 50-year extreme hydrologic events lasting 3 or more days. These extreme events correspond to simultaneous occurrence of cold river water conditions with low spring discharges.

Analysis of BSSP's daily database indicates that: (a) manatee usage of the run as a warm-water refuge has markedly increased over the last two decades, (b) the manatees aggregate in zones immediately up-gradient of a cold water intrusion, and (c) spring run zones closest to the cold/warm-water interface have the capacity to accommodate all the manatees currently using the run as a winter refuge. These findings were further supported by a series of detailed supplementary investigations to assess the ranges of individual manatee habitat water depths and velocities, as well as their aggregation tendencies in the past two decades.

Blue Spring Warm-water Capacities

The "actual" carrying capacity of the spring as a manatee winter refuge is measured in terms of *the useable warm-water length* (UWWL), which is conservatively defined as the portion of the run with a bottom temperature greater than 68°F and a centerline water depth greater than or equal to 5 feet (*ft*). In contrast, the "required" carrying capacity of the spring needed to accommodate the manatee population is measured in terms of *the equivalent warm-water length* (*EWWL*), which is calculated for each manatee season by dividing the maximum daily manatee count per season by the maximum observed spread for the same season. Supporting analyses were conducted in order to ensure that the computed EWWLs are: (a) representative measures of river conditions during periods of below average temperatures; and (b) reliable measures of the required manatee carrying capacity of the spring run.

Hydrology/Hydrodynamics of Blue Spring

The available POR spring discharge data, generally collected once every two months, from March 7, 1932 to June 7,2006 were analyzed. This analysis indicated that: (a) the long term mean discharge during the manatee season is higher than the long term mean discharge; and (b) the spring flow regime is influenced by climatic factors. Given the absence of any statistically significant anthropogenic effects and/or discernable inconsistencies in the measured Blue Spring discharges, the entire POR discharge data were used in the subsequent analyses.

A three-dimensional hydrodynamic computer model, based on Environmental Fluid Dynamics Code (EFDC), was developed and calibrated for estimating the simultaneous occurrence of extreme river stage, colder river temperature, and lower spring discharge. This model is capable of calculating the useable warm-water length (i.e., the manatee carrying capacity of the spring) under extreme hydraulic and thermal conditions.

Blue Spring Extreme (Catastrophic) Conditions

The extreme conditions that reduce the useable warm-water length include: (a) simultaneous occurrence of high river stage, low river temperature, and low spring discharge, which lengthens the cold water intrusion from the river into the spring; and (b) simultaneous occurrence of low river stage, low river temperature, and low spring discharge which makes a significant portion of the run inaccessible to manatees. Using 1000 statistically simulated daily Blue Spring discharge sequences, along with available POR daily river stage and temperature time series, extreme river and spring conditions were determined.

Minimum Flow Computational Process

Based upon the analyses of manatee habitat, Blue Spring hydrodynamics, and catastrophic conditions, a framework for the minimum flow computations was developed. This process is based on the principle that the minimum flow must provide an adequate refuge under catastrophic conditions during manatee seasons. For this purpose, catastrophic conditions are defined as 50-year extreme events lasting for 3 or more days, whereas adequate refuge is defined as the condition when the spring run's actual manatee carrying capacity (i.e., the useable warm-water length) equals or exceeds the required manatee carrying capacity (i.e., the target EWWL).

Using the available data, EWWLs were forecasted and utilized to calculate the minimum long term mean flows that would provide the minimum length of useable warm water refuge necessary to accommodate the anticipated manatee population during any manatee season, under catastrophic conditions. For this purpose, the projected manatee maximum counts and maximum manatee spreads are mathematically extrapolated based on continuous exponential growth.

Based on the exponential growth of manatee usage of the spring run, the temporal pattern of the required minimum long term mean flows was determined. This pattern was then used to develop a phased minimum long term mean flow regime. This regime consists of five-year periods for which minimum long term mean flows are established. The computational process is data-driven, and thus, should be periodically reassessed at least once every five years.

Recommendations

A number of recommendations are provided as summarized below:

- Recommended Minimum Flow Regime: A phased Blue Spring MFR, consisting of five-year periods, is recommended. The sequence of recommended minimum long term mean flows is as follows:

Period	Recommended Minimum Long Term Mean Flow (cfs)
(Effective Date) to March 31, 2009	133
April 1, 2009 to March 31, 2014	137
April 1, 2014 to March 31, 2019	142
April 1, 2019 to March 31, 2024	148
After March 31, 2024	157

- Data Updates: Given the data-driven nature of the computational process for calculating the minimum long term mean flow, the BSSP daily observations, as well as daily and instantaneous spring discharge measurements should continue. This data along with other new relevant information should be used to periodically verify the minimum flow computational assumptions.

- Model Improvements: SJRWMD should complete the following planned model enhancements: (a) calibration of the EFDC model based on validated instantaneous spring discharge measurements, and (b) development of a transient groundwater flow model in order to assess the impacts of short term changes in groundwater flow conditions on the spring discharge.

- MFR Uncertainty: The recommended Blue Spring MFR is the result of a series of computational procedures, each associated with various degrees of uncertainty. Implementation of the MFR should be accomplished with significant consideration given to the uncertainties associated with the computed minimum long term flows and associated target dates to achieve the stated goals.

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1. INTRODUCTION

1.1 Overview

Blue Spring ("the spring"), located near Orange City, in Volusia County, Florida, (Figure 1-1) is a first magnitude spring with a long term mean discharge of approximately 157 cubic feet per second (*cfs*) or 101 million gallons per day (*mgd*). The spring run and surrounding lands were purchased by the State of Florida in 1972 and now comprise the 2,600 acre Blue Spring State Park.

The spring run ("the run") is one of only three large, natural warm-water winter refuges for the Florida subspecies of the West Indian manatee (*Trichechus manatus latirostris*) in north Florida. The other two refuges are springs associated with the Crystal and Homosassa rivers located on the west coast of Florida. Manatees are a sub-tropical to tropical species, therefore, the availability of reliable, warm-water winter refuges is essential to the survival of these populations in the northern portion of their winter range (i.e., Florida and south Georgia). Some manatees use artificial warm-water sources, primarily power plant discharges, as winter refuges. However, due to the occasional and/or permanent shutdown of such power plants, their discharges are unreliable. In contrast, springs provide reliable continuous sources of natural warm water.

On March 11, 1967, the West Indian Manatee was designated as an endangered species throughout its entire North American range, due to concern that the species was in danger of extinction. Additionally, the Endangered Species Act of 1973 provided a means whereby the ecosystem upon which endangered species depend may be designated as critical habitat. Because manatee population recovery and growth depend on maintaining the availability of reliable winter warm-water habitats, Blue Spring, from its point of origin to its confluence with the St. Johns River, was designated as critical habitat for the Florida manatee by the United States Fish and Wildlife Service (*USFWS*).

The St. Johns River Water Management District (*SJRWMD*), pursuant to its responsibilities to establish minimum flows and levels (*MFL*) for surface and ground water systems (373.042, Florida Statutes [*FS*]), is developing a minimum flow regime for Blue Spring. Blue

Spring was prioritized for the establishment of MFLs in compliance with a January 1995 Settlement Agreement between SJRWMD and Concerned Citizens of Putnam County for Responsible Government, Inc. and Citizens for Water, Inc. The minimum flow will represent the limit at which further withdrawals from the Upper Floridan aquifer in and near the Blue Spring groundwater basin would be significantly harmful to the water resources and ecology of the area. Declining discharges from Blue Spring could threaten its use as a reliable warm-water winter refuge for manatees. The adequate protection of manatee habitat is currently the controlling factor in establishing a minimum flow for Blue Spring.

SJRWMD formed the Blue Spring Minimum Flow Interagency Working Group (*MFIWG*), a group of experts from various organizations to assist in the formulation of a recommended minimum flow regime for the spring. MFIWG participants include:

- Blue Spring State Park (*BSSP*)
- Florida Department of Environmental Protection (*FDEP*)
- Florida Fish and Wildlife Conservation Commission (*FWCC*)
- SJRWMD

USFWS and Save the Manatee Club, Inc. also participated in the MFIWG, primarily by reviewing and commenting on draft recommendations.

1.2 Research Team

The MFIWG research teams are as follows:

- Manatee Habitat Analysis
    - Kent Smith, FWC
    - J.B. Miller, FDEP
    - Richard Harris, Blue Spring State Park, FDEP
- Hydrodynamic and Hydrologic Analysis
    - Pete Sucsy, SJRWMD
    - G. B. (Sonny) Hall, SJRWMD
    - Bill Osburn, SJRWMD
- Statistical Analysis
    - Shahrokh Rouhani, NewFields
    - Mike Wild, NewFields

Work performed by the research teams has been made possible by the efforts of the BSSP Ranger, Wayne Hartley, who has documented manatee usage of the spring since 1978.

This report summarizes methodologies and findings from all three research teams, evaluates minimum flow projections relative to current conditions, reflects feedback from the MFIWG, and proposes future actions and efforts. Additionally, Dr. Graham Worthy, Hubbs Professor of Marine Mammalogy and Director of the Physiological Ecology and Bioenergetics Laboratory, University of Central Florida, was contracted by SJRWMD to perform the following services:

- Provide scientific peer review of recommended minimum flow regime for Blue Spring; and
- Provide expertise regarding manatee biology and life history, ecology, physiology and thermoregulation, and habitat requirements.

2. BLUE SPRING MINIMUM FLOW OBJECTIVE

Manatees seek refuge in the warmer waters of the run when the temperature of the river drops below 66° - 68° Fahrenheit (°*F*) or 19°- 20° Celsius (°*C*). The spring water remains at a nearly constant temperature of 73.4°F (23°C) all year. Manatees typically begin aggregating in the run in November and leave in March (hereinafter referred to as "manatee season"). In this report, each manatee season is identified by the year in which it starts. For example, the 2000 manatee season refers to the period of November 1, 2000 through March 31, 2001.

During manatee seasons, manatees use the run as a resting area, returning to the river during the warmer period of the day to feed. Manatees generally aggregate just upstream of the interface between the warmer spring water and the colder river water. Figure 2-1 depicts the physical features of the run.

When the temperature of the run exceeds that of the river, the colder (denser and dark) river water intrudes into the spring run beneath the warmer (lighter and clear) spring water. The length of this cold-water intrusion is determined by the stage and temperature of the river and the magnitude of the spring discharge. Higher river stage, colder river temperature, and to a lesser extent, lower spring discharge all lengthen the cold-water intrusion into the run. The longer the cold-water intrusion, the shorter the length of the run that can be used by the manatee as a warm-water refuge.

Another unfavorable condition is created when lower river stage, colder river temperature, and to a lesser extent, lower spring discharge shorten the length of the accessible warm-water portion of the run. Under this condition, only a portion of the warm-water length of the run may be adequately deep to accommodate manatees.

In an effort to manage spring discharge and establish a minimum flow regime, SJRWMD developed a minimum flow objective and strategies for the spring, as follows:

Objective

Develop a recommended minimum flow that protects, from significant harm the water resources and ecology relevant to Blue Spring and the Blue Spring run, from the upper spring pool to its confluence with the St. Johns River.

Strategies

1. Develop a recommended minimum flow that will protect the use of Blue Spring as a refuge, measured as useable length (length of Blue Spring run for which bottom temperature exceeds 68°F and water depth exceeds 5 feet), to accommodate expansion of the West Indian manatee population.
2. Evaluate the following values from Rule 62-40.473, *F.A.C.*, to determine which of those values are relevant to Blue Spring:
    a. Recreation in and on the water (62.40.473 (1) (a), *F.A.C.*)
    b. Fish and wildlife habitats and the passage of fish, other than that related to the refuge of the West Indian manatee (62.40.473 (1) (b), *F.A.C.*)
    c. Estuarine resources (62.40.473 (1) (c), *F.A.C.*)
    d. Transfer of detrital material (62.40.473 (1) (d), *F.A.C.*)
    e. Maintenance of freshwater storage and supply (62.40.473 (1) (e), *F.A.C.*)
    f. Aesthetic and scenic attributes (62.40.473 (1) (f), *F.A.C.*)
    g. Filtration and absorption of nutrients and other pollutants (62.40.473 (1) (g), *F.A.C.*)
    h. Sediment loads (62.40.473 (1) (h), *F.A.C.*)
    i. Water quality (62.40.473 (1) (i), *F.A.C.*)
    j. Navigation (62.40.473 (1) (j), *F.A.C.*)
3. Consider the relevant values in establishing the minimum flow for Blue Spring.

This report implements Strategy 1 since it focuses on the development of a recommended minimum flow regime that will protect the use of Blue Spring as a warm-water refuge to accommodate expansion of the West Indian manatee population (Blue Spring MFR). Strategies 2 and 3 have been implemented through the preparation of a separate report entitled, "Human Use and Ecological Evaluation of the Recommended Minimum Flow Regime for Blue Spring and Blue Spring Run, Volusia County" (WSI 2006).

Implementation of these three strategies has led to the conclusion that the phased Blue Spring MFR recommended in this report will protect the relevant values in 62-40.473, *F.A.C*. If actual growth in manatee usage differs from the projections used in this report, the minimum flow could be amended only after all of the relevant values in Sections 62-40.473 and 40C-8.011, *F.A.C*., are considered to determine whether an amendment is warranted.

3. METHODOLOGY AND ANALYSIS

The Blue Spring minimum flow analysis in this report included the following analytical components:

- Quantitative analysis of manatee distribution in Blue Spring
- Analysis of measured Blue Spring discharges
- Hydrodynamic modeling of Blue Spring
- Statistical simulations
- Determining extreme daily hydrodynamic combinations
- Minimum flow computations
- Computed minimum flow under catastrophic conditions

The methods and analyses performed for each component are detailed in the following sections.

3.1 Manatee Distribution in Blue Spring

Since 1978, BSSP rangers have meticulously tracked individual manatees' presence within the run, as well as air and water temperatures. Daily surveys are performed during manatee seasons. An example of a BSSP daily survey sheet is provided as Figure 3.1-1. Figure 3.1-2 depicts a BSSP manatee survey in progress.

BSSP surveys are usually conducted in the morning, when the manatees are in greatest attendance. The reported river temperatures and intrusion lengths also reflect morning conditions. The BSSP daily observation sheet divides the run into 22 zones with a series of landmarks along the run, referred to as "transects" (Figure 3.1-1). Visual observation of the extent of cold-water intrusion is also made and noted. Such observation is possible because the intruding river water is highly colored, whereas the overlying spring water is clear. The results of the daily manatee season surveys ("the BSSP database") were compiled and tabulated in a Microsoft Access database. Items were compiled as follows:

- Daily air and water temperature
- Survey starting and ending time

- Cold water intrusion length[1]
- Total number of manatees
- Manatee counts per zone

The BSSP database provides a unique basis to assess the manatee distribution over the run during the last two decades.

The following sections are based on the findings of FDEP's "*Manatee Use of the Blue Spring Run, Blue Spring State Park, Volusia County, Florida,"* dated November 29, 2000 (Smith *et al.* 2000), as well as additional and updated analyses of the BSSP database by NewFields.

3.1.1 Manatee Physiology

Manatees are tropical aquatic herbivores and are adapted to warm shallow waters. Concomitantly, the species exhibits a high degree of thermal conductance (i.e., poor insulation) with relatively low metabolic rates. Research indicates that adult and juvenile manatees possess metabolic rates that are 25-30% of predicted values (Gallivan and Best 1980; Best 1981; Gallivan *et al*. 1983; Irvine 1983; Miculka and Worthy 1994; Miculka and Worthy 1995). The result of these physiological characteristics is an inability to withstand cold conditions and, therefore, the need to offset these metabolic insufficiencies by relocating to thermal refuges, either natural springs or the warm water effluent from power plants or coastal industries (*e.g.*, Reynolds and Wilcox 1985). Blue Spring Run is the primary warm-water refuge in the St. Johns River.

This response to cold weather conditions is apparently a learned response. Females introduce their calves to warm-water refuges during the prolonged period of maternal dependence common to the species (Worthy 2003). It has been suggested that juveniles appear to be most at risk during cold winters, partially due to their inexperience with using these warm-water refuges (O'Shea *et al*. 1985). The concept that manatees learn the locations of appropriate refuges is significant because the potential loss of a refuge can affect generations of manatees (Worthy 2003).

[1] The cold water intrusion length, also known as "the dark water," is conservatively recorded as the total length of all fully and partially intruded zones.

The temperature at which cold exposure becomes critical to manatees is dependent on body size, degree of insulation, and surface area relationships (Worthy 2003). Miculka and Worthy (1994 and 1995) collected metabolic rate data from 13 manatees, ranging in mass from 275 to 1400 pounds (lb). Manatees weighing more than 660 lb exhibit the standard mammalian response to cold temperatures by increasing their metabolism. In general, this response occurred at water temperatures of approximately 66° - 68°F, and individual animals increased their metabolic output by almost 100% when temperatures dropped to 59°F. These data suggest that animals of this size are capable of dealing with cold, for at least some period of time, paralleling what is observed in the wild (Worthy 2003).

Younger and/or smaller animals (< 660 lbs) proved to be more susceptible to cold exposure due to an apparent inability to increase their metabolic rate at low temperatures. Exposure to cold water (61°F) did not cause an increase in metabolic heat production (Miculka and Worthy 1995). These smaller animals became lethargic and began holding their pectoral flippers close to their body in an apparent attempt to conserve body heat (Worthy *et al*. 2000). Exposure to cold St. Johns River water intrusions into Blue Spring Run that occlude preferred habitat for longer than 4-7 days could result in catastrophic losses to the manatee population (Worthy *et. al*. 2000).

3.1.2 Manatee Preferred Habitat[2]

Smith *et al.* (2000) analyzed the aggregate distribution of the manatees along Blue Spring Run over the past two decades. Using the approach suggested by these authors, the updated analysis of BSSP database indicates that 90% of all observed manatees were aggregated within the first ten spring run zones, i.e., canoe beach (*CB*) to Zone 9 (see Figure 3.1-3), which were viewed as the preferred manatee habitat area. Smith *et al.* (2000) recommended that a model of spring flow dynamics be based on protecting the preferred manatee habitat area from cold water intrusions on a frequency that is based on the long life span of the manatee (i.e., over 50 years).

The maximum daily manatee counts per season has increased since 1978 (Figure 3.1-4). This has resulted in more frequent observation of large numbers of manatees along the

[2] The preferred manatee habitat is referred to as the zones along the spring run immediately upstream of the cold-warm water interface where manatees usually aggregate.

spring run. For example, of the 91 surveys demonstrating manatee total counts of 80 or above, all but four are from the recent seven manatee seasons (1999-2005).

A comprehensive analysis of manatee resting and navigational preferences was conducted using all the available BSSP survey data (Season 1978-2005). For this purpose, the measured centerline bathymetric elevations of the spring run were used to plot the number of observed manatees versus the centerline water depth within each spring run zone where they were observed. In these calculations, the presence of a bathymetric hump between Transects 9 and 10 (also referred to as the swimming area hump) was considered. To reflect the effect of this navigational constraint, bottom elevations of Zone 10 and higher were equated to that of the swimming area hump. The resulting Figure 3.1-5 shows a symmetric distribution with a mean water depth of 7 to 8 feet (*ft*), ranging from 3 to 13 ft. These findings were further confirmed through supplementary analyses including: manatee location preferences with respect to cold water intrusions; detailed individual manatee water depth and velocity habitat analyses; as well as manatee surface aggregation density trends. The results of these analyses are presented in Appendix A.

Based upon the previously described manatee physiology and habitat studies, the following main conclusions were applied in developing the Blue Spring MFR:

- Preserve the thermal and hydraulic integrity of the preferred manatee habitat area.
    - In response to this conclusion, in subsequent analyses, spatial preferences of manatees are quantified in order to ensure the availability of similar adequate warm-water refuge habitat under future catastrophic extreme events.
- Base critical minimum flow periods on a 4- to 7-day critical duration[3] with a critical return period (frequency) that is based on the long life span of the manatee (i.e., over 50-years).
    - In response to this conclusion, in all subsequent analyses, 3-day, 50-year events are considered as catastrophic extreme events. The 3-day duration is selected due to the fact that a protective minimum flow regime under 3-day events is bound to be adequate under 4- to 7-day extreme events.

[3] In this investigation, for the sake of conservatism, a 3-day critical duration is used. This approach ensures that extreme conditions of longer durations, such as those associated with 4- to 7-day periods, are encompassed in determining the severity of a critical condition.

3.1.3 "Actual" Manatee Carrying Capacity

Manatees use the run as a winter warm-water refuge from the colder waters of the St. Johns River, when the river temperature drops below 65º - 68ºF (Section 3.1.1). During such periods, manatees require sufficient warm water depth to navigate and rest along the spring run. However, cold water from the river intrudes into the run under certain hydraulic conditions. Higher river stage, colder river temperature and lower spring discharge all lengthen the cold water intrusion into the run and thereby reduce the ***useable warm water length*** (*UWWL*) for the manatees. The useable warm water is also reduced when lower river stage, colder river temperature and lower spring discharge occur simultaneously. Under this condition, cold-water intrusion is not lengthened, but shallow depths in the upper portions of the run make these areas less accessible to manatees.

UWWL is the measure of the "actual" manatee carrying capacity of the run, as expressed in terms of the length of the run which contains adequately deep warm-water for manatee navigation and resting. The range of acceptable warm water depths was determined through an analysis of the period of record (*POR*) data, as represented in the histogram on Figure 3.1-5. This figure indicates that 95% of manatees were observed within zones with centerline water depths of 5 ft or greater. To preserve the conservative nature of this analysis, the lower 5th-percentile depths (i.e. depths between 3 to 5 ft) were ignored, and thus, only spring segments with centerline warm water depths of 5 ft or more were considered as useable warm water habitat.

Additionally, the minimum spring bottom water temperature was determined to be 68ºF. This temperature is the upper range of cold temperatures that cause manatees to begin taking refuge within the spring run (Section 3.1.1). Therefore, UWWL is defined as the segment of spring run with bottom temperatures equal to or greater than 68ºF and a centerline water depth of 5 ft or more. The 68ºF bottom temperature and the 5-foot depth limit are conservative criteria that are selected in order to ensure the protective nature of the computed useable warm-water lengths.

A more precise depth constraint would consider lateral variations of depth in the run and the depth preference of manatees when resting in these shallower side-bank areas. Presently, however, the bathymetric data, which consist primarily of a centerline survey down the run, do not adequately represent the lateral depth variation to justify applying this additional constraint.

3.1.4 "Required" Manatee Carrying Capacity

To determine the required manatee carrying capacity, a measure of aggregation density of manatees was needed. Heretofore, the extent of aggregation areas are only available as hand-drawn shapes on the not-to-scale map of the run as depicted on the BSSP field survey sheets (e.g., Figure 3.1-1). To avoid reliance on such approximations, the aggregation density in any spring run zone was defined in terms of two accurately observed quantities: (1) the number of observed manatees in a given spring run zone as counted during the BSSP daily surveys; and (2) the fixed length of each spring run zone as enumerated on the third column of Table 3.1-1. The resulting ratio of these two quantities yields the number of manatees per foot of the run in a given spring run zone, which is referred to as ***manatee spread*** (manatee/ft). During each season the highest observed manatee spread calculated along the run represents the aggregation tendency of manatees during that season.

The ratio of the maximum daily manatee count in a season and the maximum manatee spread calculated for the same season is defined as the ***equivalent warm-water length*** (*EWWL*) of that season. EWWL is a measure of the "required" manatee carrying capacity of the run, i.e. the minimum warm-water length needed to protect and accommodate manatees seeking refuge, in a given season. Using the POR BSSP data, EWWL for each season was then computed as follows:

- Surveys from each year were tabulated according to the maximum number of manatees present per spring run zone. The manatee spread for each spring run zone for each manatee season was calculated as the ratio of the maximum daily count in that zone during the given season over the length of that zone. As an example, the 1995 season manatee spreads for spring run zone are listed in Table 3.1-1.

- The maximum manatee spread among all the spring run zones was identified during each manatee season. For example, the maximum manatee spread for the 1995 season was 0.41 manatees per ft along Zone 6 (Table 3.1-1).

- EWWL for each manatee season was then calculated by dividing the maximum daily manatee count per season by the maximum manatee spread for the same season. For example, the 1995 season had a maximum daily manatee count of 71 (Figure 3.1-4). The EWWL of 173 ft was calculated by dividing the maximum daily count for 1995 (71 manatees) by the maximum manatee spread for 1995 (0.41 manatees per ft, Table 3.1-2).

This procedure highlights the fact that EWWL is dependent on the number and distribution of observed manatees, and thus, is not directly driven by either water depths or spring discharge rates. The computed EWWL values for the 1978-2005 seasons are scattered around the mean EWWL of 171 feet with a standard deviation of ±40 feet (Table 3.1-2 and Figure 3.1-6).

The MFIWG identified several issues concerning the calculation and application of EWWLs and requested that these issues be evaluated to determine their effect on predicting the required manatee carrying capacity. Additional analyses were performed to:

- Evaluate the effect of computing EWWL using average daily manatee counts and average manatee spread vs. maximum daily counts and maximum manatee spread.
- Determine if EWWLs are dependent on water temperature of the St. Johns River (i.e., manatee season climate).
- Determine if the computed EWWL values adequately represent cold river conditions during the manatee season.

The results of these extensive analyses further confirmed the reliability of the computed EWWL as an appropriate measure of the required manatee carrying capacity of the spring run (Appendix B).

3.2 Analysis of Measured Blue Spring Discharges

Available POR spring flow measurements include: (a) bi-monthly (once every two months) instantaneous discharge measurements, collected by USGS from 1932 to 2006 (except for 1981-82); and (b) SJRWMD bi-monthly instantaneous discharge measurements made from 1983 to 1996[4]. The number of measurements in each year ranged from two (2) to 23. The

[4] Since November 1999, USGS has installed continuous flow measurement devices within the run. The measurement procedure and the resulting continuous data, however, are still under review.

median number of yearly measurements is eight (8). Based on these discharge measurements, as well as other spring discharges and precipitation data, William Osburn of SJRWMD conducted a number of investigations, including:

- *"Sample Trend Analysis for The Water 2020 Area I Work Group Ground Water Modeling Subgroup,"* March 1998.
- "*Blue Spring, Volusia County, Florida; Seasonal Spring Discharge Statistics,*" July 2001a
- "*Relationship between Discharge at Blue Spring, Volusia County and nearby springs*," October 2001b.
- "*Blue Spring, Volusia County, Florida; Seasonal Spring Discharge Statistics*," 2003a
- "*Relationship between Discharge at Blue Spring, Volusia County, and Rainfall,*" March 2003b.
- "*Blue Spring, Volusia County, Florida; Seasonal Spring Discharge Statistics*," 2006a
- "*Relationship between Discharge at Blue Spring, Volusia County and nearby springs,*" 2006b. In progress.

The following discussion summarizes the results of these analyses.

Periodic assessments of measured spring discharge data were made in order to quantify the differences during various seasons (Osburn, 2001a, 2003a, and 2006a). The investigated periods presented in this document include the manatee season (November through March), non-manatee season (April through October), as well as the POR (March 7, 1932 to June 7, 2006). Table 3.2-1 demonstrates a statistical summary of discharge from the spring during various seasons[5,6]. Figure 3.2-1 illustrates the box plots and frequency distributions of POR measurements during various seasons. This figure clearly demonstrates a consistent difference between discharge rates during the manatee and non-manatee seasons. This difference is further confirmed through the inter-annual analysis of spring discharges using locally weighted scatter plot smoothing (*LOESS*) graphs (Cleveland, 1993) that indicate that throughout the POR, the discharges during manatee seasons consistently exceeded those measured during the non-manatee seasons (Figure 3.2-2).

[5] The listed statistics are likely affected by the uneven distribution of the available data throughout the investigated period. This means that the years with more flow measurements have a greater influence on these statistics. This effect is reduced when the simulated daily values are used to compute discharge statistics (Table 3.4-4).

A statistical test was performed to determine if discharge differences between the manatee and non-manatee seasons were significant. For this purpose, the two-sample t-test was utilized to compare the mean discharge rates during the manatee versus non-manatee seasons (Helsel and Hirsch 1995, page 125). This statistical test indicated that the long term mean discharge during manatee seasons was significantly different from the long term mean discharge during non-manatee months (Table 3.2-2).

The main findings of the analysis of POR seasonal Blue Spring discharge data were:

- the differences between seasonal discharges were statistically significant; and
- the long term mean discharge was approximately five (5) cfs lower than the long term mean discharge during the manatee season.

The influence of climatic and anthropogenic factors on the spring have been investigated by SJRWMD (Osburn 2001b, 2003b, 2006b; Williams 2006; and Williams and Osburn, personal communication, 2006). . Of special interest is the observed decline in spring discharge, culminating in 1990, which coincides with the end of the multi-decadal dry period of 1970-1990, as discussed by Enfield *et al.* (2001). The influence of regional climatic factors on hydrologic variables in Central Florida is further confirmed by Basso and Schultz (2003), McCabe *et al.* (2004), and Kelly (2004). In summary, given the absence of any statistically significant anthropogenic effects and/or discernable inconsistencies in the measured Blue Spring discharges, the entire POR discharge data were used in the subsequent analyses.

3.3 Hydrodynamics of Blue Spring

SJRWMD developed a three-dimensional hydrodynamic computer model to simulate the simultaneous occurrence of extreme river stage, colder river temperature, and lower spring discharge. The model was calibrated using 18 observed intrusion events for which the input parameters were simultaneously observed. The model simulates both intrusion length and useable warm-water lengths. The following sections discuss the hydraulics of the spring

[6] The lowest listed discharge of 63 cfs, reported by USGS on November 6,1935, was discarded due to its anomalous (outlier) nature. This value was nearly 5 standard deviations less than the mean discharge value.

and the river; and development, calibration, sensitivity assessment, and applicability of the model.

3.3.1 Characteristics of Blue Spring Run Hydraulics

3.3.1.1 Spring Run Bathymetry

Bottom elevations for Blue Spring run were obtained from two primary sources: (a) a bathymetric survey by Post, Buckley, Schuh, and Jernigan, Inc. (PBS&J), Winter Park, FL, on June 9, 1995, and (b) a supplemental survey by SJRWMD staff at the mouth of the spring run on May 17, 1996. The survey by PBS&J consisted of a centerline survey and eight lateral cross-sections (Figure 3.3-1). A disproportionate number of lateral cross-sections were made in the upper, shallower end of the run because it was thought that this reach might be a hydraulic control. The centerline survey contained 50 measurements at 50-ft intervals. Elevation measurements for the lateral cross-sections had a 5-ft spacing. All elevations were reported relative to National Geodetic Vertical Datum of 1929 (*NGVD29*).

The supplemental bathymetric survey by SJRWMD staff consisted of 334 observations of bottom elevation along 13 transects (Figure 3.3-1 -purple). This survey was performed with a resource-grade GPS (Trimble Pathfinder Pro XL) with real-time correction for horizontal positioning and soundings were measured with an Innerspace 448 fathometer, field checked with a surveying rod. The horizontal and vertical measurements were correlated using event marks on the fathometer and time stamps in the GPS data files. Horizontal accuracy was 3.3 to 9.8 ft (1 to 3 m) at 95% confidence interval and vertical accuracy was 1.2 in (3 centimeters [*cm*]) at 68% confidence interval (personal communication, Roy Wegner, SJRWMD Division of Surveying, 1997). A reference water level at the mouth of the run was determined from a staff gauge leveled to NGVD29, which was then used to adjust bottom elevations to NGVD29.

The measured lateral cross-sections show that bottom elevations range from about –2 ft to –8 ft NGVD29 from Cross-Section 1 to Cross-Section 8 (Figures 3.3-2 and 3.3-3). Figure 3.3-4 shows the centerline profile. Supplementary SJRWMD measurements were incorporated into the numerical model. This additional bathymetric detail near the mouth of the spring run, where cold water intrusions occur most frequently, was essential for model calibration.

3.3.1.2 Stage-Discharge Relationship

The surface water slope along the run is relatively small compared to the stage variability of the adjacent river. Even a large spring flow of 212 cfs results in a slope of only 0.0007 inches per ft or about a 1.5 inches of rise over the 2133 ft length of the run. By contrast the stage of the river in winter ranges over 6 ft. As a result, the stage of the run is primarily controlled by the river, and not by the discharge of the spring.

3.3.1.3 Two-Layer Flow

During winter, the water of the river can be colder and denser than the water exiting the run. The temperature of the spring water remains a nearly constant 71.6 to 73.4ºF throughout the year, whereas the temperature of the river water can drop below 50ºF during extremely cold periods. When the temperature of the run exceeds that of the river, the warmer (less dense) spring water flows over the colder (denser) river water and a two-layer flow condition results.

Mixing between the two water masses is small because the velocity of the outflowing spring water is relatively low. The kinetic energy of the flow is not sufficient to overcome the resistance to mixing provided by the density stratification. The lack of mixing is visually observable because the river water is naturally colored from dissolved organic compounds, whereas the spring water is clear. The resultant two-layer flow condition is called an arrested thermal wedge, where the denser river water intrudes into the spring run beneath the less dense spring water.

The hydraulics of this type of two-layer flow condition were theoretically analyzed by Stommel and Farmer (1952) and Officer (1976). These analyses show that the length of intrusion of the underlying denser water is determined by the river stage, the outflowing discharge, and the difference in density between the upper and lower layers. Higher river stage, lower discharge, and increased density difference between the fluid layers all lengthen the intrusion of the denser lower layer under the upper layer.

Within the run, the difference in density is primarily governed by river temperature because the spring water temperature is nearly constant. Lowering river temperature increases the density difference between the layers. Differences in mineral content also contribute slightly to the density difference between the river and spring waters. The dissolved mineral content of the spring is about 0.2 parts per thousand (*ppt*) greater than that of the river. This difference in weight of dissolved minerals is only significant for calculating the density difference between the water masses when the river temperature is within a few degrees Fahrenheit of the spring temperature.

3.3.1.4 An Empirical Equation of Intrusion Length

An empirical equation to estimate the length of intrusion of a denser bottom layer under a lighter surface layer was developed by Keulegan (1966) from flume experiments at the U.S. Army Waterways Experiment Station. The equation was developed for a rectangular channel of constant depth. The equation is presented here in order to show the general relationship between intrusion length and the primary factors known to affect intrusion length, i.e. flow velocity, river stage (depth) and density difference.

The form of the empirical equation is simplified by definition of two numbers: the densimetric velocity[7] (V_Δ) and the densimetric Reynolds number[8] (*Re*). Let,

ρ_1 = the density of the upper layer

ρ_2 = the density of the lower layer

$\Delta\rho = \rho_2 - \rho_1$

ρ_m = average density

H = the depth of the channel

g = gravitational acceleration[9]

υ = kinematic viscosity[10] of the lower layer

then,

V_Δ = Densimetric velocity = $\sqrt{gH \dfrac{\Delta\rho}{\rho_m}}$ (1)

Re = Densimetric Reynolds number = $V_\Delta(\dfrac{H}{\upsilon})$. (2)

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[7] Densimetric velocity – A useful scaling factor for comparing density currents. Physically, the speed of propagation of a long internal wave at the interface of two fluids of different densities.
[8] Reynolds Number – A dimensionless scaling factor relating the relative importance of inertial and viscous forces in fluid flow.
[9] Gravitational acceleration – The downward acceleration on an object produced by the earth's gravity in accordance with Newton's Law of gravitational force.
[10] Kinematic Viscosity – A ratio of fluid viscosity to fluid density.

The intrusion length (L) is then calculated as:

$$L = HA\left(\frac{2V_r}{V_\Delta}\right)^{-\frac{5}{2}} \qquad (3)$$

Where V_r = outflowing velocity and

$$A = \frac{0.88}{280(\mathrm{Re})^{-1} + 0.148(\mathrm{Re})^{-\frac{1}{4}}} \qquad (4)$$

Both the densimetric velocity and the densimetric Reynolds number increase with increasing depth and density difference. An increase in either of these parameters would expand the intrusion length. Decreasing river velocity (V_r) also increases intrusion length.

Figure 3.3-5 shows the relationship between intrusion length and outflowing velocity for a channel with similar dimensions to the run based on Equation (3). This figure compares V_r/V_Δ, the ratio of outflowing velocity and densimetric velocity, with L/H as the ratio of intrusion length and water depth. The values were calculated for a channel width of 100 ft, water depth of 5 ft, bottom to surface temperature difference of 23ºF, and variable discharge of 50 to 210 cfs to be similar in characteristics to Blue Spring Run. Note that declining velocity (discharge) results in an exponentially increasing intrusion length relative to depth, with the steepest part of the curve occurring for outflowing velocities below 60% of the densimetric velocity.

3.3.1.5 Intrusion Length Compared with Observed Variables

A direct comparison of observed intrusion length with each of the primary variables (i.e., river stage, river temperature, and spring discharge) upon which it depends illustrates the complexity of these relationships for the real system (Figures 3.3-6 through 3.3-8, respectively). In these figures, the intrusion lengths are represented by the number of transects in which they have been observed. Spring run transects are approximately 100 feet apart (Figure 3.1-1).

A comparison of observed daily river stage at DeLand with intrusion length (Figure 3.3-6) shows that large intrusions tend to occur at higher river stage, as expected. Note, however, that high river stage does not necessarily result in a large intrusion; and the largest observed intrusion to date occurred at a moderate river stage.

Larger observed intrusions tend to occur at colder river temperatures (Figure 3.3-7). However, similar to the river stage relationship with intrusion, the coldest river temperatures do not necessarily produce the largest intrusions.

Intrusion length was expected to be inversely correlated with spring discharge, i.e. as spring discharge decreases, cold water intrusion into the spring run increases, and vice versa. To assess this hypothesis, observed intrusion lengths were compared with observed spring discharges (Figure 3.3-8). Fewer points are shown on this plot as compared to the previous two plots because the bi-monthly sampling of discharge observations provides fewer observations for comparison with intrusion length. Although intrusion length should vary inversely with discharge, no such relationship is discernible (Figure 3.3-8) because of masking by river stage and river temperature effects.

The relationships between intrusion length and observed river stage, river temperature, and spring discharge illustrate the complexity of predicting intrusion for a given combination of variables. The numerical modeling approach, described in the following section, provides a predictive tool that can incorporate the combined effects of the hydraulic variables on the spring's hydrodynamics.

3.3.2 Numerical Model of Spring Flow

Evaluation of the reliability of the spring run as a thermal refuge under catastrophic conditions requires estimation of cold river water intrusion lengths under relatively infrequent combinations of relevant forcing parameters (i.e., river temperature, river stage, and spring discharge). Extreme combinations of interest, however, are not covered by the existing data, although more than 20 years of observed cold water intrusion lengths are available. In other words, some type of predictive model is required to estimate cold-water intrusion length under conditions that have not yet been observed. Empirical regression models, analytic models, and computational fluid-dynamics models were considered. Each of these models has advantages and disadvantages. For example, regression models are simple and data driven; however, they are not useful for predictions under extreme combinations that are beyond the range of observed data.

Analytic models, such as the empirical equation (3), are useful for examining the fundamental relationships between intrusion length and forcing parameters under highly idealized conditions. However, analytical models cannot account for variation of channel width and depth and turbulent mixing processes between the layers that could occur at higher flows or lower density stratification. In contrast, computational fluid- dynamics models are specifically designed to incorporate complex hydrodynamic variations. These computational models are based on fundamental physical equations of motion that allow predictions beyond the observed range of available data. Such features made computational fluid-dynamics models best suited for estimating cold-water intrusion lengths at the spring run under extreme hydrothermal combinations.

These considerations led to the selection of a numerical three-dimensional flow model, Environmental Fluid Dynamics Code (*EFDC*; Hamrick 1992a). EFDC was selected for its coupled momentum dynamics with density gradients (baroclinic flow calculation[11]) and robust turbulence closure scheme that predicts the extent of vertical mass and momentum exchange.

3.3.2.1 Description of EFDC Model

EFDC solves finite-difference forms of the hydrostatic Navier-Stokes equations[12], together with a continuity equation[13], 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[14]. 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). Jin *et al.* (2000) provide a useful overview of the model formulation. EFDC has been successfully applied in other areas of Florida where stratified flows are important, for example, Turkey Creek near Melbourne (Zarillo and Surak 1994; Mostafa and Hamrick 1993) and the estuarine portion of the St. Johns River (Sucsy and Morris 2001).

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[11] Baroclinic flow calculations – Calculations that account for fluid flow caused by density differences.
[12] Navier-Stokes equations – The fundamental partial-differential equations that describe the flow of incompressible fluids.
[13] Continuity equation – The equation that expresses a conservation law by equating a net flux over a surface with a loss or gain of material within the surface.
[14] Sigma grid – A vertical grid scheme where the total, time-dependent water depth is divided into a fixed number of equal intervals that change in length and volume as water level rises and falls.

3.3.2.2 Model Grid of Blue Spring Run

A curvilinear, orthogonal grid[15] (Figure 3.3-9) was applied to the run and a portion of the adjacent river. The model grid contained 4050 cells (405 horizontal cells of 10 vertical layers each). Horizontal cell widths ranged from 9.8 ft within the run to 262 ft within the river. Five cells across the width of the run were used to simulate the shape of the cross-sectional depth profiles of the run. Vertical cell thickness depends on depth and ranged from 0.79 to 17.72 inches.

3.3.2.3 Model Bathymetry and Geometry

The model grid was developed from shoreline data obtained from bathymetric surveys of the run, as discussed in Section 3.3.1.1, and a digitized shoreline of the river from a *Le Systeme Pour l'Observation de la Terre* (*SPOT*) satellite image of 33 x 33 ft (10 x 10 m) resolution. The model contains a value of depth at the center of each cell. Depths were obtained from two sources, i.e. PBS&J and SJRWMD bathymetric surveys of the run, as discussed in Section 3.3.1.1.

3.3.2.4 Model Boundary Conditions

External forces to the EFDC model were specified at three model boundaries: (a) the upstream boundary of the river, (b) the downstream boundary of the river, and (c) the spring boil. Parameters specified at the upstream, open river boundary were river discharge, water temperature, and salinity. River stage was specified at the downstream, open model boundary. Parameters specified at the spring boil, a specified inflow boundary, were discharge, water temperature, and salinity.

Salinity was a constant 0.5 Practical Salinity Scale 1978 (psu, Lewis 1980) at the upstream river boundary and a constant 0.7 psu at the head of the spring for all model runs. Temperature at the spring boil was a constant 72.5ºF. Other model forcing parameters (river stage, river temperature, river discharge and spring discharge) varied among model runs to simulate the river conditions for each specific scenario.

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[15] Orthogonal grid – A two-dimensional set of cells organized in rows and columns where each cell is defined by possibly curved lines that intersect at right angles. An orthogonal grid is used here to represent the geometry of Blue Spring Run.

River stage and river discharge were obtained from a USGS gauge located near DeLand approximately 6.5 miles downstream of Blue Spring (Figure 3.3-10)[16]. River temperature was taken from observations made by BSSP during daily manatee surveys.

3.3.2.5 Steady-State Calculation of Intrusion Length

The model was used to calculate a steady-state value of cold-water intrusion length given a specified set of river stage, river temperature, and spring discharge. Although EFDC is capable of dynamic simulation, the sampling interval of spring discharge (bi-monthly) and river temperature (daily) did not support that approach. Model tests showed that the response time of the intrusion to perturbations of the forcing parameters is relatively rapid, generally less than 6 hours (hr). The rapid response time justified the appropriateness of the steady-state approach. The model was run for a 12-hr period for each set of conditions to ensure steady-state conditions had been reached.

3.3.2.6 Air-Water Surface Heat Exchange

The temperature model of the spring does not include air-water surface heat exchange. This simplification was made because the transit time of a parcel of water through the spring run is short relative to the possible rate of temperature increase by solar radiation. Transit time in the spring run is about 2 hours (hr), based on velocity estimates, and only about 1 hr for surface water, based on numerical simulation; whereas, the maximum rate of temperature rise on a clear winter day at noon is only 0.7ºF hr^{-1}. (This estimate is based on the spring run receiving 500 Watts per square meter [$W\ m^{-2}$] of solar irradiance with no losses). When sensible heat loss, long-wave radiation, and evaporation are considered the estimate for temperature rise becomes negligible.

Similarly, a maximum rate of temperature decline, assuming an air temperature near freezing and no additional sources of heat, is 1.3ºF hr^{-1}. Such a loss could affect intrusion length estimates slightly during extremely cold events, but the effect would be to lessen the intrusion by decreasing the density difference between the lower and upper fluid layers. Neglecting air-water surface heat exchange, then, is a conservative choice from the viewpoint of manatee protection.

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[16] Observed daily discharge at DeLand was transferred directly to the upstream model boundary. Daily stage observed at DeLand was adjusted using a linear regression relationship (Sucsy *et al.* 1998) with a regression coefficient (r^2) of 0.981.

3.3.2.7 Observed Data

The data used to calibrate the EFDC model for intrusion length were obtained from USGS, FDEP, and SJRWMD (Table 3.3-1). River stage and river discharge were taken from a USGS station near DeLand, 6.5 miles downstream of Blue Spring. River stage at DeLand was adjusted to Blue Spring by linear regression (Sucsy *et al*., 1998). As noted in Section 3.1, river temperature and cold-water intrusion are routinely observed by BSSP during daily manatee counts.

3.3.2.8 Model Calibration

Model calibration was based on observed intrusion events that were coincident (within a day) with a spring discharge measurement by USGS. This restriction was to limit the calibration to periods of known discharge because the discharge data have an unknown daily variability. There were 18 calibration events. Table 3.3-2 shows the parameters used for each event and also compares observed and simulated intrusion length and spring run stage.

Observed intrusion length is reported as a range because observations are recorded by zone. The beginning and end of each zone are defined by specific transects. The location of each transect is from a reference point taken as the center of model cell (10,16) at Universal Transverse Mercator (*UTM*) coordinate (466,708 m, 3,201,730 m) near the mouth of the spring run. The distance to the first 10 transects are 89, 194, 312, 404, 495, 571, 682, 761, 889, and 968 feet[17]. So, a reported intrusion extending to Zone 1 would lie between Transect 1 and Transect 2, which are 89 and 194 ft, respectively, from the reference point near the mouth of the run. In this case, the observed intrusion length would have a range from 89 to 194 ft, as measured from the designated reference point.

Intrusion length was calculated as the upstream extent of cold river water. The upstream edge of the intrusion was operationally defined as the point where the bottom temperature equaled ($0.8T_{spring} + 0.2T_{river}$), where T_{spring} is the temperature of the spring water and T_{river} is the temperature of the river. This location was determined by linearly interpolating between cell nodes.

[17] Transect 10 is located within the swimming area.

A single discrete observation of river temperature at one horizontal and vertical location is not a precise measurement of average river temperature. Average river temperature used for the calibration events, then, was allowed to vary by 0.9ºF (0.5ºC) from the discrete observations made by the BSSP rangers. Allowing for this variability in river temperature resulted in five of the calibration events having slightly different river temperature from that directly observed by the ranger. This slight adjustment is well within the accuracy of the observation relative to the single observation's representation of river temperature at the appropriate temporal-scale that affects intrusion length.

The selection of observed intrusion length also followed a critical evaluation of the data based on surrounding observations. Occasionally a longer intrusion length was selected when such an intrusion was reported just prior to or following an event and other conditions were similar. Selecting a longer intrusion when similar conditions indicate no clear choice is conservative from the view point of manatee protection. Table 3.3-3 lists the rationale for selection of an intrusion length when different from that reported by the BSSP ranger on the specific date.

The EFDC model was calibrated by first adjusting the number of vertical (sigma) layers until the numerical solution was unaffected by an additional increase. Ten vertical layers were established as sufficient. Finally, the bottom roughness coefficient was adjusted globally to provide the best match for the twelve calibration scenarios (Table 3.3-2). The final bottom roughness coefficient was 0.02 meters.

Simulated intrusion lengths fell consistently within the range of observed intrusion lengths (Table 3.3-2) indicating the satisfactory precision of the simulated values of intrusion lengths.

3.3.2.9 Model Sensitivity

The sensitivity of perturbations to the model boundary conditions on simulated intrusion length was calculated using the calibration event of January 24, 1992 (Table 3.3-2). This event was selected for the sensitivity tests because it represents a fairly large observed intrusion that occurred for a relatively low stage.

The sensitivity analysis was performed by varying each of the boundary parameters (river stage, river temperature, river salinity, river discharge, and spring discharge) by ±10% and recalculating the intrusion length. These results were then used to calculate a condition number as described by Chapra (1997). The condition number defines a transfer function between the relative error of the parameter and the relative error of the intrusion length, $\Delta L/L = C_{Nk}*(\Delta K/K)$, where L is intrusion length, K is the parameter, and C_{Nk} is the condition number for parameter K.

Results of the sensitivity tests show that simulated intrusion length is most sensitive to spring discharge and river temperature, and relatively insensitive to river stage, river salinity, and river discharge.

3.3.3 River Stage and Useable Warm-Water Length

River stage controls the portions of the run that have sufficient water depth, and also affects the intrusion length. So an increase in river stage can either increase or decrease useable warm-water length. Figure 3.3-11 illustrates the relationship between intrusion length and useable warm-water length over a range of river stage. River temperature and spring discharge were held constant in Figure 3.3-11 at 60ºF and 150 cfs, respectively. This figure represents three lines all of which are functions of the river stage:

- The solid line shows the length of run having water depth greater than or equal to 5 ft. This length represents the potential useable habitat in the absence of cold-water intrusion. With respect to water depth, the full length of the run is available at a river stage greater than about 3 ft NGVD29. At low stage the potential available run length is quite restricted.
- The dashed line shows the intrusion length. This length is not useable as a manatee refuge because of its low temperature
- The dotted line shows useable warm-water length, which is the difference between the length of potential useable habitat and the intrusion length.

Useable warm-water length increases with increasing stage despite a corresponding increase in intrusion length. This occurs because the increase in river stage makes upstream areas of the run deeper (i.e. their maximum centerline depths exceed 5 ft) and, therefore, more accessible to manatees. Above a stage of 3 ft, however, the increase in intrusion length begins to diminish the useable warm-water length (Figure 3.3-11).

3.4 Statistical Simulations of Daily Discharge Sequences

As discussed previously, spring discharge measurements are generally available on a bi-monthly basis. Although collected since the 1930s, such a set of instantaneous measurements is inadequate to determine manatee season extreme combinations that last for 3 or more days ($\geq$ 3 day durations). In response to these deficiencies, a statistical procedure was applied to simulate daily discharge sequences consistent with POR conditions at the spring. The simulated values were designed to mimic daily discharge patterns, including extreme conditions that can last up to 3 days.[18]

Statistical procedures to augment limited or sparse time series have been commonly used in water resources since the 1960s (Hufschmidt and Fiering 1966, and Fiering and Jackson 1971). These procedures are aimed at generating adequately long time series that have the same statistical properties as the original data. For example the simulated data should have the same mean, standard deviation, and autocorrelations as the original data. Such generated data would then allow assessing the statistical properties of the investigated variables under a variety of extreme conditions.

In this investigation, the following computational tasks were performed in order to generate yearly sequences of daily manatee-season spring discharges:

- **Computation of Daily Spring Discharges:** Daily spring discharges were required for this analysis to define the autocorrelation between daily values of discharge for different time lags. Because the measured discharge data for Blue Spring were collected on a bi-monthly basis, these data are inadequate for defining the variability of discharge at daily time scales. Therefore, the EFDC model was used in a "back-calculation" mode to estimate spring discharges for those days when observed values of river temperature, river stage, and cold-water intrusion length were available. Model boundary conditions to EFDC were specified using observed values of river stage, temperature, and intrusion lengths, and an initial trial for spring discharge. The model was then run to steady-state and the resulting simulated

[18] The daily simulated discharges were intended to simulate 3-day events. These simulations were not intended to generate statistical features of inter-seasonal or multi-decadal discharge patterns. Statistical simulation of inter-seasonal or multidecadal discharge patterns requires the use of discharge values, each representative of a specific season or multi-decadal period.

intrusion length was compared against the observed intrusion length. If the simulated intrusion fell outside the two transect boundaries bounding the observed intrusion, then the spring discharge was adjusted, either up or down as appropriate, and the model re-run. This procedure was repeated iteratively for all days of observed cold-water intrusions, thus producing a set of 589 daily spring EFDC-estimated discharge values within the period 1981-1999. As depicted on Figure 3.4-1, the EFDC-estimated value not only matched the magnitude and temporal pattern of measured discharges, but also filled the discharge data gap for days when river temperature, river stage, and cold-water intrusion length were available, but discharge data was not. These estimated values include a large number of consecutive daily spring discharges which allow the computation of their autocorrelations for any time lag between one to 150 days.

- **Standardization of EFDC-Estimated Spring Discharges:** The POR instantaneous measured spring discharge values are normally distributed, as displayed on Figure 3.4-2. However, as shown on this figure, measurements during specific periods have deviated from central tendencies of the pooled measured data. Given the long-duration of POR measured data and to maintain monthly characteristics of the EFDC-estimated daily discharges, the observed POR instantaneous spring discharge measurements were used to compute the average and standard deviation of spring discharges for each month of the manatee seasons, as listed in Table 3.4-1. These monthly statistics were then used to standardize each EFDC-estimated daily flow.[19,20] For example, spring discharges during the months of December had an average value of 167 cfs (or 166.58) with a standard deviation of 16 cfs (or 16.46 cfs), as listed in Table 3.4-1. So the standardized values of discharges in that month were computed as the ratio of the difference between the measured value and its monthly mean value divided by its monthly standard deviation. For example, the discharge rate of 170.91 cfs on December 3, 1996 (Table 3.3-2), is transformed into

[19] Standardized computed daily flow is defined as the difference between the computed discharge and its corresponding monthly average discharge divided by its corresponding monthly discharge standard deviation.

[20] The daily discharge data used in the simulation are EFDC-estimated discharge values. However, due to the much longer POR of measured data, the standardization is based on monthly averages and standard deviations of measured values. This resulted in a set of standardized values with a mean of 0.0 and variance of 1.3. The higher-than-unit variance is mainly due to the higher fluctuation

its dimensionless standardized value of 0.26 = (170.91 – 166.58)/16.46. This means that the discharge on that given day was 0.26 standard deviations higher than the monthly average value. This approach is intended to preserve the monthly characteristics of the simulated discharge values, and not as a substitute for normal-score transformation.[21]

- **Temporal Correlation of Standardized Computed Spring Discharges:** At this stage the autocorrelation of standardized spring discharges was calculated using the variogram[22] analysis based on temporal lags between any pair of spring discharges in days (Issaks and Srivastava 1989). For this purpose, differences between all pairs of standardized spring discharges were computed and listed with respect to their corresponding time lags in days. Subsequently, all computed differences were grouped according to their time lags. For example, all differences associated with a 1-day lag were grouped together. This process was repeated for all time lags ranging from 1 to 120 days[23]. The difference in each time lag was then used to calculate the average one-half squared difference in that lag. This value was referred to as the sample variogram. The resulting set of sample variograms for time lags ranging from 1 to 120 days is shown on Figure 3.4-3. This figure also displays the visually-fitted variogram model, shown as the solid red line. The fitted variogram model indicates that the computed standardized discharges show a degree of correlation for a period of up to 21 days. The resulting nugget effect is attributed to EFDC-estimation uncertainties and diurnal fluctuations of discharge data. Standardized discharges that are more than 21 days apart appear to be uncorrelated with respect to each other.

- **Simulating 1000 Yearly Sequences of Daily Discharges:** The simulated yearly sequences were intended to represent possible realizations of future occurrences. Therefore, an unconditional simulation process was chosen. Using the above

of daily EFDC-estimated discharges when compared to less-fluctuating bi-monthly instantaneous discharge measurements.

[21] Due to the normality of measured data (Figure 3.4-2), normal-score transformation was not performed.

[22] Using the U.S. Environmental Protection Agency (Englund and Sparks 1988) definition, the variogram in this investigation is the plot of variance (one half the mean difference) of paired standardized computed spring discharges as a function of their temporal distances in days.

variogram, 1000, 365-day sequences of daily standardized spring discharges were simulated unconditionally using the geostatistical software ISATIS™. The *Sequential Gaussian Simulation* (SGS) method was selected for unconditional simulation purposes. For each yearly sequence, SGS simulated standardized discharges at randomly selected days and iteratively added them as conditioning data. These iterations continued until all 365 days in the sequence had simulated discharges. This process was then repeated 1000 times.[24] 1000, 365-day sequences were simulated in order to generate a statistically significant number of distributions to ensure that the resulting values are representative of the complete range of variations of the spring discharges. For consistency, from each 365-day sequence, the middle 150 daily values were selected to represent the 5-month manatee season. An example is shown on Figure 3.4-4. In this investigation, the simulations are performed such that pooled values are statistically similar to the original standardized data, i.e. having similar mean values, variances, and variograms. However, consistent with multi-year deviations displayed by instantaneous measured discharges (Figure 3.4-2), individual simulated yearly sequences were allowed to deviate from the statistical properties of the pooled data.

- **Back-Transformation of Simulated Values:** The selected sequence of 150 daily standardized values from each of the 1000 simulations was back-transformed to daily discharge by adding the product of each simulated value and its corresponding monthly standard deviation of measured spring discharge to the monthly average spring discharge. POR monthly averages and standard deviations are given in Table 3.4-1. For example, a simulated value of 0.10 in a given day in December is transformed into 168 cfs = (0.10x16.46 + 166.58).

- **Statistical Confirmation of Simulated Values:** The simulated daily spring discharge time series are suitable for further analysis, if they are statistically similar to the available measured and EFDC-estimated discharge values. For this purpose, statistical properties and histograms of pooled simulated 1-day and 3-day running averages were computed and compared to those of the measured manatee-season

[23] Time lags greater than 120 days included small number of pairs, and thus, were not considered in the variogram analysis.

and the EFDC-estimated discharges. These results are listed in Table 3.4-2 and displayed on Figure 3.4-5, respectively, which demonstrate the statistical similarity of the simulated, measured and EFDC-estimated discharges. Especially, similarity of central tendencies (i.e. mean and median values) as well as standard deviations and percentiles are noteworthy. Further review of Table 3.4-2 indicates the wider range of simulated values when compared to the minimum and maximum of measured or estimated discharges. This wider coverage allows the exploration of extreme conditions beyond those observed or estimated heretofore.

- **Computation of 1-Day and 3-Day Extreme Spring Discharges:** Using the 1000 simulated daily spring discharge time series previously described, 1-day and 3-day running averages were computed for each manatee season. Within each simulated manatee season, the lowest 1-day and 3-day discharges were determined. The resulting 1000-year long time series were then ranked in order to compute their corresponding percentiles[25]. For this purpose, the computed percentile (CP) of each ranked value was defined based on the Weibull formula (Helsel and Hirsch 1995, page 23) as its rank divided by number of simulated seasons plus one (i.e., 1001). The computed minimum spring discharge percentiles are listed in Table 3.4-3. Their statistical properties are summarized in Table 3.4-4. As suggested by the hydrologic data analyses described in Section 3.2, Table 3.4-4 also includes the long term mean discharge rate, which was calculated by adjusting the mean manatee-seasonal flow by approximately 5 cfs. As explained in Section 3.2, the computation of the long term mean discharge is supported by the POR LOESS graphs and the statistical test that indicate consistent differences between discharge measurements during the manatee versus non-manatee seasons.

As noted, the above unconditionally simulated values are statistically representative of the available manatee-season spring discharge regime for the following reasons: (a) the simulated values have similar monthly averages and standard deviations as the POR manatee-season measured discharges (Table 3.4-1); (b) the pooled simulated values have similar autocorrelation (variogram) structure as the POR data (Figure 3.4-1); (c) the pooled

[24] Srivastava (1994) and Deutsch and Journel (1992, Chapter V) provide concise descriptions of the simulation process.

simulated, measured, and EFDC-estimated discharges have similar statistical properties (Table 3.4-2); and (d) the pooled simulated, measured, and EFDC-estimated discharges display similar distributions (Figure 3.4-5).[26] In addition to statistical similarity to the POR data, the simulated values offer a unique advantage due to their vast abundance. This advantage is related to the wide range of simulated discharges, which results in extreme low flow values consistent with the statistical properties of the POR manatee-season dataset. Because the simulated discharges are representative of the POR, their low values provide a conservative basis to determine extreme spring discharge conditions, as discussed in subsequent sections.

3.5 Extreme Daily Hydrodynamic Combinations

As noted, the spring's winter refuge diminishes as the length of useable warm-water decreases. The useable warm-water length can reach its minimum levels if a series of simultaneous extreme conditions occur. These unfavorable conditions include:

- High river stage, low river temperature, and low spring discharge: Under this extreme combination the increasing intrusion length substantially reduces the length of winter refuge.
- Low river stage, low river temperature, and low spring discharge: Under this extreme combination the overall depth of the run decreases, and thus, makes a significant portion of the run inaccessible to manatees.

In this investigation both of these unfavorable conditions were considered in the computational process. The first step in this process was to define the duration and the frequency of occurrence (referred to as the return period) of the extreme condition. An extreme event can last over many days. In general, shorter extreme events entail less favorable conditions than those associated with longer durations. In this investigation, extreme events associated with durations of ≥ 3 days were especially of interest (Section 3.1.1). The magnitude of an extreme event is also related to its return period. Rarer extreme events, associated with longer return periods, result in less favorable, more extreme conditions.

[25] The computed percentile is the probability of not exceeding the stated minimum discharge for the given duration in any one season.

[26] As noted, consistent with multi-year deviations displayed by instantaneous measured discharges, individual simulated yearly sequences are allowed to deviate from the statistical properties of the pooled data.

After defining the desired duration and return period, river and spring conditions that could result in such an extreme condition were identified. To demonstrate this process, consider the case of the 2-year, 1-day extreme condition. This 1-day extreme condition is expected to occur once every two years. To identify river conditions that could result in such an extreme condition, the observed (measured) data (Table 3.5-1) were used to determine the lowest and highest 1-day river stages, as well as lowest 1-day river temperature in any given year. The time series of these annual extreme values were then used to determine their cumulative probabilities (i.e., frequency or recurrence interval) of various minimum/maximum stage and minimum temperature values, as listed on Table 3.5-1. For spring discharges, using the 1000-year statistically simulated daily discharges, the 1-day minimum discharge percentiles from Table 3.4-2 were used to complete Table 3.5-1. For this purpose, the lowest 1-day spring discharge during each simulated season were identified and ranked in an ascending order. The percentile of each simulated lowest 1-day spring discharge was then calculated as its rank divided by the total number of simulated seasons.

Values in Table 3.5-1 represent the extreme levels which would occur with given likelihoods during each manatee season. For example, as listed in Table 3.5-1, the chances of having a minimum 1-day spring discharge equal to or less than 66.5 cfs in any given season is 1%, while the chances of having a maximum 1-day river stage of 3.4 ft or higher in any given season is 20%.

The probability of a given combination of these extreme events depends on the correlation among them. There is no discernable correlation among contemporaneous measured river stage, temperature and spring discharge[27] (Figure 3.5-1). The absence of correlation between these variables is due to the fact that the river stage at DeLand is strongly influenced by ocean water level. Figure 3.5-2 compares daily stage at DeLand and Mayport (the mouth of the river located 142 river miles from DeLand) during 1981 when the lowest annual river flow on record (743 cfs) occurred. This figure clearly indicates that even during drought conditions, the DeLand river stage is primarily controlled by ocean water level and local winds. Ocean water level could affect Blue Spring discharge by secondarily altering

[27] In this figure, contemporaneous estimated spring discharges were used. These estimates were generated by SJRWMD based on a regression model of observed air temperatures. The model

the head difference between the potentiometric surface of the aquifer and the St. Johns River. However, a comparison of Mayport stage with Blue Spring discharge shows that the effect of ocean water level on spring discharge is likely insignificant. Mayport stage and Blue Spring discharge are uncorrelated for the period 1932-2000 (Figure 3.5-3). These results further confirm that the assumption of independence between daily St. Johns River stage and Blue Spring discharge is reasonable.

Under such conditions, the probability of the simultaneous occurrence of a given combination (known as their joint probability) is the product of their corresponding cumulative probabilities. This is a standard process to compute joint probabilities for mutually independent variables (Helsel and Hirsch 1995, page 379).

As an example, combinations of daily extreme values with a joint probability of 50% (i.e., a 2-year return period) were determined (Table 3.5-2). Note that the cumulative probabilities of each combination yield a joint probability of 50%. For example consider the first cited combination:

- Probability (low spring discharge < 1.81-year low spring discharge of 103.2 cfs) = 55% or 0.55
- Probability (low river temperature < 1.05-year low river temperature of 66.2°F) = 95% or 0.95
- Probability (low river stage < 1.04-year low river stage of 1.1 ft) = 96% or 0.96
- The simultaneous occurrence of these independent event would yield a joint probability of 50% (0.55x0.95x0.96 = 0.50 or 50%).

To ensure an adequate coverage of the ranges of river and spring combinations that can result in the desired extreme event, multiple combinations were determined. In this example, Table 3.5-1 provided the necessary percentiles of the 1-day events. Eighteen (18) combinations, covering the range of river stages, temperatures and spring discharges that could result in a 1-day, 2-year extreme condition were determined (Table 3.5-2). The first nine (9) combinations are associated with the extreme 1-day low river stage, low river temperature and low spring discharge, whereas the other 9 combinations are associated with the extreme 1-day high river stage, low river temperature and low spring discharge combinations. Each of these 1-day extreme combinations have a joint probability of 50%

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evaluation proved highly reliable results with a regression coefficient of 99% (Peter Sucsy, personal communication, 2001).

per season (or a 2-year return period). These extreme combinations provide an adequate coverage of the potential range of variations of the investigated hydraulic variables.

In the next step, these combinations were used as input into the EFDC model in order to determine the combination that yields the most limiting useable warm-water length. As indicated in Table 3.5-2, all low river stage combinations proved to be more stringent than their corresponding high river stage combinations. Furthermore, the most stringent combination involves the occurrence of an 80% or 1.25-year, one-day minimum spring discharge, yielding a useable warm-water length of 694 ft. These results demonstrate that under present conditions, the most conservative, minimum 1-day, 2-year warm-water length would be 694 ft (Table 3.5-2).

This computational process can be applied to any duration, or joint return period as long as the corresponding percentiles of the extreme event for the given duration are computed. As suggested in the FDEP investigation (Smith *et al.* 2000), one of the durations of concern is extreme combinations that last for 4 to 7 days. For such a range of durations, the 3-day is the limiting (conservative) duration, and thus, the percentiles of 3-day extreme events were computed. For this purpose, 3-day running averages of river stages and temperatures based on available daily observed (measured) values were calculated. Then the lowest and highest 3-day river stages, as well as the lowest 3-day river temperature in any given year were determined. The time series of these annual extreme values were then used to determine the cumulative probabilities of 3-day minimum/maximum stage and minimum temperature values (Table 3.5-3). For spring discharges, the 3-day minimum discharge percentiles from Table 3.4-3 were used to complete the 3-day percentile table (Table 3.5-3). As discussed in the subsequent section, the resulting 3-day percentile table was then used to determine extreme catastrophic conditions.

4. MINIMUM FLOW DETERMINATION FOR MANATEE HABITAT PROTECTION

The following discussion presents a computational process for calculation of minimum flows. This process was performed consistent with the stated Blue Spring minimum flow strategy of developing a minimum flow regime that will protect the use of Blue Spring as a warm-water refuge for the West Indian Manatee (Strategy 1). The minimum flow computations are based on the following principles:

- The minimum flow must provide an adequate refuge under catastrophic conditions during manatee seasons.
- Consistent with the FDEP findings (Smith *et al.* 2000), catastrophic conditions are defined as 50-year extreme events lasting for 3 or more days.
- An adequate winter refuge is defined as a condition for which the forecasted equivalent warm-water length or EWWL (i.e. the required capacity) is less than or equal to the useable warm-water length or UWWL (i.e. the actual capacity).

Given these minimum flow principles, a series of computations was conducted in order to determine the spring flow regime that would provide UWWLs greater than or equal to the forecasted EWWLs under catastrophic conditions. For this purpose, the following computational steps were implemented. This process can be repeated as new information, including manatee use data and spring discharge measurements, becomes available.

4.1 Computational Step 1. Determining the Required Manatee Carrying Capacity

The computed EWWLs (Table 3.1-2) represent the minimum lengths of useable warm water that were needed to accommodate the observed manatee populations during manatee seasons from 1978 to 2005. Forecasts of future EWWLs were made by investigating the two factors that control EWWL: (1) maximum daily count (manatees), and (2) maximum manatee spread (manatees/ft), as listed in Table 3.1-2. Figures 4.1-1 and 4.1-2 display the time series of these two variables, respectively. These figures indicate maximum daily counts and maximum manatee spreads display strong, statistically-significant exponential trends. The statistical curve estimation results are also included on each figure, respectively.

To ensure that the forecasted EWWLs are sufficiently protective, the following considerations were made:

- **Forecasting Maximum Daily Counts:** The 90% confidence interval of projected maximum daily counts in future seasons is shown on Figure 4.1-3. This confidence interval was generated using the 5% lower confidence limit and the 95% upper confidence limit of the estimated growth rate. In all the subsequent forecasting computations, the 95% upper confidence limit of the estimated growth rate was used. This conservative choice was justified by two facts: (a) the unique use of the spring run as a natural warm-water manatee refuge; and (b) the expected, but still unknown, increase in manatee use of the spring run as a winter refuge because of the closure of other artificial warm-water refuges along the St. Johns River.

- **Forecasting Maximum Manatee Spread:** The expansion of the manatee spread along the run will ultimately be constrained by the geometry of the run. This physical constraint is demonstrated on Figure 4.1-4, which displays the cross-section of the run along the segments that would contain adequately deep warm water under catastrophic conditions. Based on knowledge about the size of adult manatees along with the observed maximum surface area of 28 square feet per manatee, the number of adult manatees that can be accommodated (fully submerged) along the critical segment of the run[28] was calculated (Figure 4.1-4). This resulted in a manatee spread ceiling of 1.73 manatees/ft. As shown on Figure 4.1-4, a significant portion of the width of the run was assumed to remain vacant in order to allow free movement of manatees during catastrophic conditions. For this purpose, the width of the vacancy is selected to allow full rotation of adult manatees, which is a necessary component of their movement along the spring run. Such lateral coverages of the run by manatees have been observed during high aggregation days, where almost the entire width of the run is occupied by manatees. In all

[28] The critical segment was identified as the narrowest section of the spring run upstream of the cold-warm water interface under the 50-year, 3-day extreme event which are Zones 5 through 7.

subsequent forecasting computations, the exponential growth curve of the maximum manatee spread with a ceiling of 1.73 manatees/ft was used (Figure 4.1-5).

Based on these results, the forecasting of the required carrying capacity or EWWL was conducted by estimating the ratio of the projected maximum daily count and maximum manatee spread for any given season (Table 4.1-1).

The projected maximum manatee counts and spreads in Table 4.1-1 are mathematically extrapolated using the available data and assuming exponential growths. These projected values are not meant to be estimates of the total St. Johns River manatee population size, but rather are forecasts of the manatee usage along the spring run. Specifically, the projected values are intended to estimate how many manatees could theoretically aggregate in the spring run under a given set of hydrological and meteorological conditions. However, it is recommended that these projections be re-evaluated at least once every five years as new data are collected in order to ensure the reliability of the recommended Blue Spring MFR.

4.2 Computational Step 2. Determining the Relationship Between Flow Regime and Minimum Useable Warm Water Lengths Under Catastrophic Conditions

Consistent with the previously stated minimum flow principles (see introduction to Section 4), extreme 50-year river/spring combinations were determined based on the 3-day percentile values that are listed in Table 3.5-3. The resulting extreme 50-year combinations for both low-stage/low-temperature/low-discharge and high-stage/low-temperature/low-discharge combinations are listed in Table 4.2-1. The 3-day, 50-year combinations were then used as input into the EFDC model in order to determine the combination that yielded the most stringent useable warm water length. Among the computed useable warm-water lengths, the minimum length was determined to be 348 ft (Table 4.2-1).

These calculations were repeated in order to compute the minimum useable warm-water lengths under catastrophic conditions as the spring flow was incrementally reduced. For this purpose, it was assumed that any reduction in the spring flow would result in the same amount of reduction of the minimum spring discharge percentiles. In statistical terms, this assumption implies that a change in the flow would result in a uniform shift of the entire distribution of the spring discharge values. For example, a 1 cfs reduction in the flow would reduce all the 3-day minimum spring discharge rates by 1 cfs (see Table 3.5-3, second column). From a hydraulic point of view, however, this assumption is conservative, because processes that affect the mean discharge levels usually would have more limited impact on lower discharge levels. This is mainly due to the fact that the mean conditions at the spring are driven by regional conditions, whereas extreme catastrophic conditions are commonly associated with localized climatic events. Therefore, the regional processes that impact the mean conditions at Blue Spring may have relatively little to no effect during localized extreme conditions at the spring. This implies that the magnitude of a reduction among extreme discharge rates is likely to be smaller than such reductions among mean flow rates. In this investigation, the assumption of the uniform flow reduction is pursued although reductions under low flow conditions are expected to be lower than those associated with average flow conditions.

The calculated minimum useable warm-water lengths under catastrophic conditions as a function of the reduced flow regimes are listed in Table 4.2-2 and depicted on Figure 4.2-1. These results represent flow regimes with their corresponding minimum long term mean flows (computed in terms of its reduced long term mean discharge rates) and flow reduction values.

4.3 Step 3. Determining the Minimum Flow Regime Based on the Target EWWL

Utilizing the information provided in Sections 4.1 and 4.2, the minimum flow regime was defined as the condition when the catastrophic minimum warm-water length is equal to the target EWWL at each season. This is a protective condition under which the catastrophic "actual" manatee carrying capacity is equal to the "required" manatee carrying capacity. This equation yielded the minimum long term mean flows during future seasons which will adequately provide the minimum length of useable warm water refuge needed to accommodate the anticipated increasing manatee populations under catastrophic conditions (Table 4.3-1 and Figure 4.3-1).

Based on the computed minimum long term mean flows, a phased Blue Spring MFR, composed of five-year periods, was developed (Figure 4.3-2). Specific durations of these periods and the recommended minimum long term mean flows are listed in Table 4.3-2.

4.4 Robustness of the MF Regime

Per USFWS suggestions, the robustness of the results of the MF computational process with respect to extreme historical conditions was assessed. For this purpose, the MF regime under a variety of extreme conditions was assessed. The results indicated that the recommended Blue Spring MFR yields conditions that are equally protective of the manatee winter refuge as those currently offered by the existing spring flow regime. The detailed explanations of the analyses are provided in Appendix C.

4.5 Periodic Re-evaluation of the MF Regime

The above minimum flow computational process is data-driven, and thus, is recommended to be periodically reassessed. As better, more definitive information concerning spring/river hydraulics, spring/groundwater interaction, climatic trends, manatee physiology, and other related factors becomes available, these data should be used in re-evaluations of the MF regime. These periodic re-evaluations are especially important whenever new data warrant a re-calculation of the projected EWWLs (Section 4.3). Furthermore, upon the availability of reliable continuous spring discharge data or further refinement of the EFDC model, the relationship between the reduced flow regime and catastrophic minimum warm-water length (Section 4.2) should be reaffirmed. Any re-evaluation would need to include a re-assessment of all relevant environmental values (62-40.473, 40C-8.011(3), *F.A.C.*) in light of all new data.

For this purpose, the continuation of the BSSP manatee season daily surveys at Blue Spring is essential. Based on the data collected during each season, maximum daily count and maximum aggregation length density should be computed according to the procedure described in Section 3.1.4. This process involves the following steps:

- Based on the survey results of the entire manatee season, determine: (1) the maximum number of manatees observed along the run during any survey, and (2) maximum number of manatees observed in any zone during any survey.
- Compute the highest manatee spread in each zone by dividing the maximum number of manatees observed in that zone by its respective length.
- Among the computed zone-specific manatee spreads, determine the maximum manatee spread (number of manatees per ft) in any zone.

At this stage, the updated maximum manatee daily count and maximum spread time series should be subjected to trend analyses in order to quantify their temporal trends, as discussed in Section 4.1. The projected EWWL will be the ratio of the forecasted maximum manatee daily count and maximum spread for any given season in the future. Given the current exponential patterns of maximum manatee daily count and maximum spread time series, special attention must be paid to the relative magnitudes of the fitted growth rates. Specifically, the projected EWWL should be adjusted upward, if the maximum daily counts show a higher growth rate than currently estimated (i.e., a more rapid expansion of manatee use), and/or if the maximum manatee spread shows a lower growth rate than currently estimated (i.e., a less rapid increase in the expansion of dense aggregation areas).

Periodic reevaluations are strongly recommended to verify the predicted EWWLs.

5. POTENTIAL IMPACTS ON WATER USE

This section discusses the implications of the findings of the Blue Spring minimum flow analysis on the future of consumptive use permits for groundwater withdrawals. In general, groundwater withdrawals from the Floridan aquifer in the area of Blue Spring reduce aquifer potentiometric pressures, and therefore, affect Blue Spring discharges. SJRWMD has assessed the future projected groundwater withdrawals on Blue Spring discharges using the Volusia Regional Groundwater Flow model (Williams 2006). In this assessment, groundwater withdrawals within the model domain for 1995 were estimated at 127.6 mgd, and are projected to reach 171.3 mgd by 2020, i.e. a 40% increase. This projected increase is due to the anticipated rise in public water supply demands. Subsequent to the projections to the year 2020, additional model simulations were performed to assess the impacts to the year 2025. Findings of these model simulations indicated that, based upon projected groundwater pumping for the year 2025, the mean annual simulated spring flow at Blue Spring is projected to decline by approximately 4% from 1995 pumping conditions to the projected 2025 pumping conditions (i.e., a change from 150 cfs to 144 cfs, respectively).

Existing spring flow conditions (i.e., 2005 season) provide adequate winter manatee refuge, even during extreme catastrophic conditions. However, with the projected expansion of the St. Johns River manatee population, the spring's manatee carrying capacity will ultimately be exceeded under extreme river stage, temperature, and spring flow combinations. Once the carrying capacity is exceeded, some manatees will be physically excluded from the warm-water refuge, resulting in prolonged exposure to cold water and possible death. Concomitant reductions in spring flow associated with groundwater withdrawals could further limit the availability of reliable warm water habitat by causing the spring's manatee carrying capacity to be exceeded sooner than in the absence of such groundwater withdrawals.

The establishment of a Blue Spring MFR will impact the ability of water suppliers to increase groundwater withdrawals to meet projected demands. Based on the provisions of sections 373.219 and 373.223, *FS*, SJRWMD is specifically authorized to administer and enforce permitting programs to regulate the consumptive use of water. In part, SJRWMD has implemented these permitting programs through Chapter 40C-2, *F.A.C*. Section 40C-2.301 (4)(l), *F.A.C.,* requires an applicant for a consumptive use permit to provide reasonable assurance that the proposed water use will not cause water levels or flows to fall below the minimum limits set forth in Chapter 40C-8, *F.A.C*. Section 40C-2.301(5)(a)5, *F.A.C*., requires SJRWMD to deny a consumptive use permit if the proposed water use will cause the rate of flow of a surface water course to be lowered below any established minimum flow. To date, SJRWMD has established by rule in Chapter 40C-8, *F.A.C*., over one hundred minimum flows and levels and, as required by Chapter 40C-2, *F.A.C*., has utilized the relevant minimum flows and levels in its permitting decisions. Compliance with these permitting criteria with regard to the Blue Spring MFR can be determined by using the required minimum long term mean flow as the required spring discharge in SJRWMD's calibrated steady state groundwater flow model.

Reduction in Blue Spring discharge is not the only factor that contributes to the regional water supply development limitations. Wetland and lake impacts are also a concern and may be a greater limitation than the recommended minimum spring flow regime. SJRWMD groundwater evaluations (Burger 2002) indicate that wetland drawdown limits are currently more constraining on future groundwater development in the Blue Spring area than the recommended Blue Spring MFR.

6. RECOMMENDATIONS

Based on the efforts of MFIWG, the following recommendations are provided:

- SJRWMD should adopt a phased minimum flow regime for Blue Spring (Table 4.3-2) to accommodate the anticipated increase in the West Indian Manatee population.
- The MF computational process is data-driven, and thus, should be verified periodically (at least once every five years) based on the most current data. This information can then be used by SJRWMD to evaluate whether an amendment to the applicable provision of Chapter 40C-8, *F.A.C*., is warranted.
- The BSSP manatee season daily surveys of manatee occurrence and intrusion length should continue and be included in a database maintained by SJRWMD. The MFIWG should periodically review the BSSP observation procedures to explore the opportunities for further improving the consistency and accuracy of the reported measures.
- Daily (continuous) spring discharge measurements should be collected and maintained in the appropriate database (USGS or SJRWMD). Collection of daily discharge data will provide valuable information to further understand the spring hydraulics.
- Instantaneous (manual) spring discharge measurements consistent with those being collected by USGS should be continued on at least a bi-monthly basis.
- The Blue Spring hydrodynamic model (EFDC) should be refined to improve the temporal resolution of the model as USGS daily spring flow data become available.
- SJRWMD should complete the following planned model enhancements: (a) calibration of the EFDC based on validated instantaneous spring discharge measurements, and (b) development of a transient groundwater flow model in order to assess the impacts of short term changes in groundwater flow conditions on the spring discharge.

The recommended Blue Spring MFR is the result of a series of computational procedures, each associated with various degrees of uncertainty. Although every effort was made to apply conservative assumptions based on the best available information, the parameters of the recommended flow regime are prone to uncertainty. Among primary sources of uncertainty are projected manatee counts and spreads, as well the assumed spring discharge statistical trends and properties. For example, as displayed on Figure 4.3-1, the annual manatee growth rate was conservatively set at 7.02%. A one (1) percent ± deviation from this assumed value would yield significant variations in the timing and magnitude of the recommended MFR, as displayed on Figure 6-1.

Furthermore, actions taken to implement the recommended MFR in relation to District water supply planning and permitting activities also entail additional uncertainties associated with the regional groundwater models developed for these purposes. For example, the groundwater models rely on the spring discharge data for purposes of calibration and that flow is modeled based on an assumed hydrogeologic connection between the aquifer and the spring. Under such conditions, the phased implementation of the recommended MFR should be accomplished with significant consideration given to the uncertainties associated with the computed minimum long term flows and associated target dates to achieve the stated goals.

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8. GLOSSARY

The following standard abbreviations for units of measurement and other scientific/technical acronyms and terms are found throughout this document:

Arrested thermal wedge	Stationary, wedge-like extent of colder water intrusion into a warmer water body
Baroclinic flow calculation	Calculations that account for fluid flow caused by density differences
BSSP	Blue Spring State Park
CB	Canoe beach, segment of Blue Spring Run located near the confluence of the spring run and the St. Johns River
cfs	Cubic feet per second, measure of flow velocity
°C	Degrees Celsius, scale of temperature measurement
cm	Centimeter, measure of length
c.v.	Coefficient of variation is an attribute of a distribution, defined as its standard deviation divided by its mean
Densimetric velocity	A useful scaling factor for comparing density currents. Physically, the speed of propagation of a long internal wave at the interface of two fluids of different densities
Double mass analysis	A plot of the cumulated values of one variable against the cumulated values of another or against the computed values of the same variable for a concurrent period of time
EFDC	Environmental Fluid Dynamic Code model
EWWL	Equivalent warm-water length (required manatee carrying capacity); a measure, in feet, of the minimum warm-water length required to protect the projected manatee population seeking winter refuge in any given year
Fathometer	Sonic depth finder used for determining depth of water or a submerged object by means of sound wave
°F	Degrees Fahrenheit, scale of temperature measurement
F.A.C.	Florida Administrative Code
FDEP	Florida Department of Environmental Protection
FS	Florida Statutes
ft	Feet
FWCC	Florida Fish and Wildlife Conservation Commission

Gravitational acceleration	The downward acceleration on an object produced by the earth's gravity in accordance with Newton's Law of gravitational force.
GPS	Global Positioning System, worldwide satellite location system
hr	Hour
Intrusion length	Length, in feet, of penetration of St. Johns River water into Blue Spring Run. Intrusion length is determined by the stage and temperature of the river and the magnitude of the spring flow
Kinematic viscosity	A ratio of fluid viscosity to fluid density.
LOESS	Locally weighted scatter plot smoothing routine
Long term	At least a 30 year continuous period (40C-8.021(6), *F.A.C.*)
m	Meters
Manatee aggregation area	In this report, portions of Blue Spring Run where aggregated groups of manatees are observed by BSSP rangers
Manatee habitat	In this report, locations along Blue Spring Run where manatees are observed by BSSP rangers
Manatee season	Winter months of November through March
Manatee spread	In this report, number of manatees per foot of Blue Spring Run length; calculated as the ratio of the number of manatees in a spring run zone to the length of the spring run zone in feet
Manatee aggregation surface density	In this report, number of aggregated manatees per square foot of the aggregation area; calculated as the ratio of the number of observed aggregated manatees in a given area to the surface area of that aggregation area in square feet
MFIWG	Minimum flow interagency working group
MFL	Minimum flows and levels
MFR	Minimum flow regime
mgd	Million gallons per day, measure of flow velocity
$m^3 s^{-1}$	Cubic meters per second, measure of flow velocity
NGVD	National Geodetic Vertical Datum
PBS&J	Post, Buckley, Schuh and Jernigan, Inc.
POR	Period of record, all time-series measurements of some factor, such as water levels records from 1930 to 2001.
ppt	Parts per thousand, measure of concentration of a substance
Reynolds number	A dimensionless scaling factor relating the relative importance of inertial and viscous forces in fluid flow
SJRWMD	St. Johns River Water Management District
SMCI	Save the Manatee Club, Inc.

Transect	Invisible lines crossing Blue Spring Run, perpendicular to the direction of flow and located by landmarks along the run channel, which divide the Run into 22 segments or zones
Useable warm-water length	The length of the Blue Spring Run in feet for which bottom water temperature exceeds 68°F and water depth exceeds 5.0 ft
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
UTM	Universal Transverse Mercator, map coordinate system
Variogram	Plot of variance of paired investigated values (e.g., paired standardized computed spring discharges) as a function of their separation distances (e.g., temporal distances in days.)
$W\ m^{-2}$	Watts per square meter, measure of energy

APPENDIX A. SUPPLEMENTARY MANATEE HABITAT ANALYSIS

Manatee and Cold Water Intrusion Analysis

The following analyses compare observed manatee aggregation areas with respect to locations of observed cold water intrusions. At the time of the analysis, there were 924 surveys where both cold water intrusion and manatee counts per spring run zone were made (November 1981 through March 2000). The number of investigated surveys for various spring run zone cold water intrusion lengths is listed in Table A-1.

Using these surveys, manatee observations per spring run zone were summarized under various cold water intrusion lengths. Figures A-1 through A-7 depict manatee locations for seven intrusion lengths ranging from 0 to 571 ft. Based on these summarizations, two key observations were made:

- Manatees prefer spring run zones immediately upstream of the cold water intrusion.
- Spring run zones closest to the cold/warm-water interface, such as Zones 1 through 4, have the capacity to accommodate all the animals currently using the run as a winter refuge on a daily basis (Table A-2).

Manatee Habitat Water Depth Analysis

At the time of the analysis, the available BSSP observation surveys during highest manatee attendance dates were used to assess the range of water depths where manatees were observed. These dates are listed on Table A-3[1]. The location of observed manatees on the survey sheets was determined, as shown in the example on Figure A-8. As depicted on Figure A-9, the observed locations were then transposed over the Blue Spring geographic information system (GIS) database, where water depths during each investigated date had been computed using the Blue Spring hydrodynamic model[2]. This process allowed the determination of water depth at all locations where manatees had been observed on any given date. In locations where more than one manatee was observed, average, minimum and maximum depths were determined. The resulting depths were combined by weighting

[1] Note that the BSSP electronic manatee attendance data sets not only include days with BSSP survey sheets, but also those days when only manatee counts are provided in spreadsheets.
[2] A detailed discussion concerning the Blue Spring hydrodynamic model is provided in Section 3.3 of the report.

them consistent with the number of observed manatees at each location. The histograms of average, minimum, and maximum water depths are displayed on Figures A-10 through A-12, respectively. The main findings of the analysis are:

- During high attendance dates, individual manatees have been observed mostly in shallow waters along the north bank of the spring run.
- During high attendance dates, manatee habitat depths ranged from 2.7 to 10.2 ft[3].
- During high attendance dates, average observed manatee habitat depth was 5.4 ft.

Manatee Habitat Water Velocity Analysis

Similar to the previous analysis, the investigated surveys were used to assess the range of water velocities where manatees have been observed. For this purpose, the locations of observed manatees on the survey sheets were transposed over the Blue Spring GIS database, where water velocities during each investigated date had been computed using the Blue Spring hydrodynamic model. In all observed locations, average surface, mid-depth, and bottom water velocities were calculated. The resulting velocities from various locations were then weighted consistent with the number of observed manatees at those locations. The histograms of average surface, mid-depth, and bottom velocities are displayed on Figures A-13 through A-15, respectively. The range of computed manatee habitat water velocities during highest attendance dates are listed below by their mean and standard deviations:

- Surface water velocity: 0.38 ± 0.38 ft/sec
- Mid-depth water velocity: 0.29 ± 0.28 ft/sec
- Bottom water velocity: 0.09 ± 0.09 ft/sec

Manatee Aggregation Surface Density Trends

Manatees have shown a strong tendency to aggregate in the vicinity of the cold/warm-water interface. An example of such an aggregation is shown on Figure A-16. The manatee aggregation behavior in the last two decades was assessed by analyzing the BSSP observation surveys during coldest river dates and highest manatee attendance in each manatee season, available at the time of the analysis.

[3] These water depths correspond to individual locations of observed manatees. The water depths used in the definition of the useable warm-water length in Section 3.1.3 of the report, in contrast, correspond to the centerline water depth of the zone in which manatees are observed.

For each selected date, aggregation surface density within each manatee aggregation area with more than three (3) manatees was calculated (Figure A-17). The shaded manatee aggregation areas drawn by the BSSP rangers on the daily field survey sheets were delineated on the GIS image of the spring run. This allowed the computation of delineated manatee aggregation areas in square feet, which along with their corresponding number of reported manatees, were used to calculate manatee aggregation area-specific aggregation surface densities for the coldest river dates (Figure A-18 and Table A-4) and the highest attendance days in each season (Figure A-19 and Table A-5).

The observed mean and standard deviations of the computed aggregation surface densities were further analyzed in order to investigate whether they display any significant correlation or trend. In this investigation, a correlation with a significance level of less than 5% is considered as a statistically significant correlation at a 95% confidence level. For this purpose, non-parametric Kendall's tau correlation coefficients (Helsel and Hirsch 1995, p. 212) were computed. This non-parametric, rank-based procedure can be applied to any paired set of numbers regardless of their statistical distributions. The resulting correlations and their significances are listed in Table A-6 and indicate that, during both highest attendance and coldest river dates:

- Mean and standard deviations of aggregation densities did not display any statistically significant temporal trends, i.e. the aggregation densities fluctuated around a more or less constant value; and
- Mean and standard deviations of aggregation surface densities displayed significant correlations, i.e., days with higher manatee attendance tended to have aggregation areas with a wider range of manatee aggregation surface densities.

Given the relative stability of observed manatee aggregation densities in the last two decades, the increase in the use of the run has mainly been accommodated by the expansion of locations containing dense aggregations of manatees. The expansion in dense aggregations of manatees is exemplified by comparing two BSSP field survey sheets (Figure A-20). The top survey sheet represents January 15, 1999 when a total number of 33 manatees were observed, while the bottom survey sheet represents March 1, 2002, when 78 manatees were observed. As shown on this figure, during January 15, 1999, manatees generally aggregated along the north bank of the run. On March 1, 2002, however, the larger number of manatees aggregated by dispersing over a larger portion of the width of the run. Note that in both cases, the manatee aggregation areas were most commonly observed in the vicinity of the cold/warm-water interface.

While the above method based on surface area of aggregation areas does provide a measure of manatee aggregation surface density, at present, the extent of aggregation areas are only available as hand-drawn shapes on the not-to-scale map of the run as depicted on the BSSP field survey sheets (e.g., Figure A-20). To avoid reliance on such approximations, the manatee aggregations in any spring run zone was defined in terms of the manatee spread (i.e., manatees per unit length of each zone), as discussed in Section 3.1.4 of the report. Figure 4.1-2 of the report displays the highest manatee spreads observed in any zone during each season from 1978 to 2005. The depicted trend in this figure represents the capacity of the run to accommodate the rising number of manatees over the last two decades.

APPENDIX B. EWWL SENSITIVITY ANALYSES

The MFIWG identified several issues concerning the calculation and application of EWWLs and requested that these issues be evaluated to determine their effect on predicting the required manatee carrying capacity. Additional analyses were performed to:

- Evaluate the effect of computing EWWL using average daily manatee counts and average manatee spread vs. maximum daily counts and maximum manatee spread.
- Determine if EWWLs are dependent on water temperature of the St. Johns River (i.e., manatee season climate).
- Determine if the computed EWWL values adequately represent cold river conditions during the manatee season.

The results of these analyses are presented in the following sections.

Computing EWWLs - Average vs. Maximum Daily Manatee Counts and Spreads

Analyses were completed to evaluate the appropriateness of using maximum manatee counts and maximum manatee spread to compute EWWLs. For this purpose, average manatee spreads were calculated based on manatee counts in various spring run zones during each season. However, the calculation of average manatee spread encountered a problem because most of the spring run zones (i.e., Zones 9 and higher) are usually empty during daily manatee surveys. Using zero manatee spread values from these empty zones, artificially lowers the computed average manatee spread, and thus, yields incorrect measures of the manatee aggregation surface density. In response to this problem, average manatee spread in each season was computed in three different ways:

- Using computed manatee spreads from all spring run zones (i.e., including zero spreads from spring run zones with zero observed manatees);
- Using computed manatee spreads from spring run zones with at least one (1) observed manatee; and
- Using computed manatee spreads from spring run zones with at least five (5) observed manatees.

The computation of alternative EWWLs was based on the following combinations:

- EWWLs as the ratio of average daily manatee counts over three different calculations of average manatee spread, i.e., average spreads based on: (a) spreads from all spring run zones, including zones with zero manatees; (b) spreads from spring run zones with ≥ 1 manatee observed; and (c) spreads from spring zones with ≥ 5 manatees observed, respectively; and

- EWWLs as the ratio of maximum daily manatee counts and three different calculations of average manatee spread i.e., average spreads based on: (a) spreads from all spring run zones, including zones with zero manatees; (b) spreads from spring run zones with ≥ 1 manatee observed; and (c) spreads from spring zones with ≥ 5 manatees observed, respectively.

EWWL Calculations using Average Daily Manatee Counts and Average Spreads: The calculation of EWWL for each season computed as the ratios of average daily manatee counts and three different calculations of average manatee spread showed inconsistent results (Table B-1). Average-based EWWLs computed using average spread for all spring run zones (including numerous zero spreads from spring run zones with zero observed manatees) resulted in a large number of the computed EWWLs (Table B-1) exceeding the existing carrying capacity of the run under catastrophic conditions (i.e., 348 feet, Table 4.2-1). This means that in the event of a 3-day catastrophic event, there should be manatee losses due to inadequate warm-water refuge along the spring run. Such results imply that there was an elevated likelihood of catastrophic manatee losses during the past two decades. In reality, the hallmark of this period has been the observed exponential growth of manatee use. Similar results were also observed for EWWLs computed using average manatee spread derived from all spring run zones with ≥1 manatee present (i.e. seasons 1992, 1997 and 2002 as highlighted in Table B-1). The contradiction between the predicted higher likelihood of catastrophic losses versus the observed exponential growth in manatee use was the rationale for disregarding the computed EWWLs based on average manatee spread, or using spreads from all spring run zones, including those with no or 1 observed manatee.

The average-based EWWLs computed with average manatee spread based on data from spring run zones populated by at least 5 (five) manatees did not indicate any higher likelihood of catastrophic losses during the past two decades. These latter EWWLs were similar to the previously computed maximum-based EWWLs. Statistical comparisons of these two sets of computed EWWLs using the Paired Two Sample for

Mean Test (Helsel and Hirsch 1995, p. 147) indicated that they were statistically indistinguishable (Table B-2).

EWWL Calculations with Maximum Daily Counts and Average Spreads: Table B-3 lists the results of computations where maximum daily manatee counts and three different measures of average manatee spread were used to calculate EWWLs. The computed EWWLs in most years in the past two decades were higher than the existing carrying capacity of the spring run under catastrophic conditions (i.e., 348 feet, as listed in Table 4.2-1 of the report). As noted above, such results implied a higher likelihood of catastrophic losses during the past two decades, which was in contrast to the observed exponential growth in manatee use during the same period. As a result, these computed EWWLs were also disregarded.

In summary, the above results indicate that the average manatee spreads are generally inappropriate measures of manatee aggregation densities during a given season. The use of average manatee spread values generally yields results that are inconsistent with the observed exponential growth of manatee use during the past two decades. EWWLs computed based on average manatee spread for spring run zones populated with at least 5 (five) manatees, however, proved to be statistically indistinguishable from the previously computed maximum-based EWWLs. These findings support the use of maximum-based EWWLs as an appropriate and conservative measure of the required manatee carrying capacity of the spring run.

Manatee Season Climate Effects

Based on the available information at the time of the analysis, the relationship of EWWL to manatee season climates was investigated. In this study climatic conditions were represented by average, minimum, and maximum manatee-season St. Johns River temperatures (Table B-4). Plots of EWWL time series during below-average (<66.3°F) and above-average (>66.3°F) temperatures are provided on Figure B-1. These time series were tested for their temporal trends and dependence on seasonal river temperatures using Kendall's tau correlations (Helsel and Hirsch 1995, p. 212; Table B-5). The results indicate that:

- EWWL values during cold and warm seasons do not display statistically significant temporal trends at 95% confidence levels, i.e. EWWL values fluctuate around more or less constant values; and
- EWWL values during cold and warm seasons do not display statistically significant correlations at 95% confidence levels with average, minimum, or maximum river temperatures, i.e. EWWL fluctuations are independent of river temperature.

These findings support the use of the EWWL values computed based on the extensive combined daily manatee surveys in all subsequent analyses.

Cold River Condition Effects

A further analysis was conducted to ensure that the computed EWWL values adequately represented cold St. Johns River conditions during the manatee season. For this purpose, only manatee surveys during days when the river temperature was below 65°F ("cold-river-day") were used in the calculations of manatee season EWWLs. Tabular and graphical comparisons of the "cold-river-day" vs. "all-days" EWWLs show very similar trends (Table B-6 and Figure B-2). These sets of computed EWWL values were compared using the non-parametric Wilcoxon Signed Rank test (Helsel and Hirsch 1995, p. 118). The results indicate that EWWLs based on "cold-river-days" data were statistically indistinguishable from those computed based on the complete set of available daily manatee surveys (Table B-6). These findings support the use of the EWWL values computed based on the extensive combined daily manatee surveys in all subsequent analyses.

APPENDIX C. MINIMUM FLOW REGIME UNDER EXTREME CONDITIONS

Per USFWS' suggestion, the recommended Blue Spring MFR was assessed under a number of extreme historical conditions. These extreme combinations were utilized in order to determine the potential impact of the recommended Blue Spring MFR on the useable warm water length (i.e., the actual carrying capacity of the run). For this purpose, extreme hydraulic and thermal parameters (i.e., low river stage, low river temperature, and low spring discharge) were determined under three scenarios, as listed below:

- **Synthetic extreme conditions:** These conditions assume simultaneous occurrence of the lowest observed values of river stage, river temperature, and spring discharge during the investigated period regardless of time differences between actual occurrences of individual parameter values.

- **Observed extreme conditions:** These conditions represent the most extreme combinations of concurrently observed parameters.

- **Estimated extreme conditions:** These conditions represent the most extreme combination of concurrently estimated and/or observed parameters. This approach was used because, for many days, measured river temperature and spring discharge were unavailable. To fill such data gaps, river temperatures were estimated based on available air temperatures, and spring discharges were computed based on the observed dark water intrusions using the Blue Spring EFDC model.

Under each extreme condition, the length of useable warm water length was computed. In addition, the same length was calculated when the spring discharge was reduced by 25 cfs (POR long term mean discharge is 157 cfs – 25 cfs = minimum long term mean discharge of 132 cfs). This reduction represents a conservative estimate of the potential impact of the recommended Blue Spring MFR. The results are discussed in the following sections.

Synthetic Extreme Conditions

A synthetic extreme combination of lowest river stage, river temperature, and spring flow was generated using the available data at the time of the analysis. In addition, the same combination was determined based on the data records of the preceding 25 years. The worst observations and the likelihood of their occurrence (computed in terms of annual cumulative probabilities) are listed in Table C-1. Given the rarity of these measurements, their simultaneous occurrence yielded very extreme conditions with return periods exceeding 1,000 years. Specifically, the following was noted:

- The simultaneous occurrence of extreme conditions resulted in a 26,144-year return period (Table C-1). Using the values for the POR (preceding 25-years), yielded a 1,006-year return period. Both of these combinations represent very extreme conditions.

- Furthermore, the POR (25 years) minimum spring discharge was assumed to be representative of the 3-day extreme condition. This is a conservative assumption because: (a) the instantaneous discharge measurements are much more variable than the 3-day average discharge rates; and (b) the POR minimum spring discharge was observed during a non-manatee month, and non-manatee months are known to have lower discharges than those occurring during the manatee months.

Based on the observed extreme conditions (Table C-1), two combinations were formed, one representing the entire period of record values and another limited to the preceding 25 years (i.e., the 26,114-year versus the 1,006-year combination). The useable warm-water lengths were calculated for both of these combinations, yielding 100 ft and 0 ft, respectively. The 1,006-year combination proved to be more stringent, when the entire warm-water length of the spring run has a depth less than 5 ft. These results further support the Blue Spring minimum flow approach (Sections 4.1 through 4.3 of the report), in which a wide range of combinations with the same return periods was investigated before the most stringent combination was determined.

Based on the more stringent 1,006-year extreme combination, the useable warm-water lengths under the current spring flow regime and the recommended Blue Spring MFR were calculated to be 0 ft. This result indicates that under extreme combinations both the current flow regime and the recommended Blue Spring MFR would provide comparable useable warm-water lengths. Specifically, the recommended Blue Spring MFR does not create a condition substantially different from that occurring under the current flow regime.

Observed Extreme Conditions

Using the period of record data at the time of the analysis, all the dates for which concurrent measurements of river stage, river temperature and spring discharge occurred were identified. Due to the bimonthly nature of spring discharge measurements, as well as discontinuation of river temperature measurements, the number of such dates when concurrent measurements were available was limited to only 128 dates. Among these dates, the day in which the lowest useable warm-water length occurred was January 25, 1977, when river stage = 0.68 ft, river temperature = 49.6 °F, and spring discharge = 147 cfs. The return period of this combination was computed as a 1-day 26-year event, or a 3-day 30-year event. The computed useable warm-water length for this date was 584 ft, while under the recommended Blue Spring MFR, as described in Section 4.3 of the report, the useable warm-water length for this date would be 448 ft. As these computed lengths indicate, under both the current flow regime and the recommended Blue Spring MFR, the resulting useable warm-water length far exceeds the projected required warm-water lengths (EWWLs), as listed in Table 4.1-1 of the report.

Estimated Extreme Conditions

As noted above, the data gaps for river temperature and spring discharges were addressed by using measured air temperature and dark water intrusion lengths, respectively. This expanded database yielded nearly 6,000 days for which concurrent values of 3-day river stage, 3-day river temperature and 1 or 3-day dark water intrusion were available. Among these days, the smallest useable warm-water length (UWWL), 627 ft, occurred on December 30, 1993, when 3-day river stage = 0.42 ft, 3-day river temperature = 56.2 °F, and spring discharge = 149 cfs. The return period of this 3-day combination was computed as a once in 5-year event. This computed useable warm-water length (627 ft) would be reduced to approximately 546 feet under the proposed minimum flow reduction. Again, these results indicate that under both the current flow regime and the recommended Blue Spring MFR, the resulting useable warm water length during December 30, 1993 would have far exceeded the projected required useable warm-water lengths (EWWLs) under catastrophic conditions, as listed in Table 4.1-1 of the report.

Tables

Table 3.1-1
Spring Run Zone Manatee Spread
1995 Season

Transect Zone	Maximum Daily Manatee Count	Zone Length (ft)	Manatee Spread (manatee/ft)
Canoe Beach	7		
ZONE 1	8	89	0.09
ZONE 2	29	105	0.28
ZONE 3	22	118	0.19
ZONE 4	33	92	0.36
ZONE 5	32	92	0.35
ZONE 6	31	75	0.41
ZONE 7	10	112	0.09
ZONE 8	15	79	0.19
ZONE 9	4	128	0.03
ZONE 10	4	79	0.05
ZONE 11	10	66	0.15
ZONE 12	1	98	0.01
ZONE 13	6	82	0.07
ZONE 14	13	56	0.23
ZONE 15	5	112	0.05
ZONE 16	2	190	0.01
ZONE 17	1	115	0.01
ZONE 18		157	0.00
ZONE 19		138	0.00
Head-Spring		105	0.00

Table 3.1-2
Computed Equivalent Warm Water Lengths (EWWLs)

Season	Maximum Daily Manatee Count	Maximum Manatee Spread (manatee/ft)	EWWL (ft)
1978	28	0.16	171
1979	24	0.20	122
1980	34	0.24	142
1981	27	0.18	152
1982	33	0.25	132
1983	30	0.23	131
1984	31	0.29	108
1985	45	0.28	159
1986	38	0.23	166
1987	47	0.32	149
1988	53	0.28	187
1989	57	0.30	187
1990	55	0.43	128
1991	67	0.44	154
1992	67	0.32	207
1993	80	0.34	237
1994	74	0.27	272
1995	71	0.41	173
1996	72	0.49	148
1997	86	0.45	192
1998	86	0.61	141
1999	112	0.54	206
2000	95	0.64	148
2001	97	0.69	141
2002	123	0.56	220
2003	128	0.67	192
2004	130	0.53	244
2005	182	1.00	182

Table 3.2-1
Statistical Summary of POR Blue Spring Instantaneous Discharge Measurements

Long Term Discharge (cfs)						
Season	Period[1]	Minimum[2]	Mean	Median	Maximum	Count
All	1932 - 2006	87	157	159	218	659
Manatee Months	1932 - 2006	87	163	164	218	256
Non-manatee Months	1932 - 2006	97	153	154	199	403

[1] First Measurement on March 7, 1932; Last Measurement on June 7, 2006
[2] The lowest listed discharge of 63 cfs, reported by USGS on November 6, 1935, was discarded due to its anomalous (outlier) nature. This value was nearly 5 standard deviations less than the mean discharge value.

Table 3.2-2
Two-Sample t-Test for Comparison of POR Blue Spring Instantaneous Discharge Measurements During Manatee and Non-Manatee Seasons

Comparison of Long Term Mean Seasonal Discharges Two-Sample t-Test: Assuming Equal Variances		
	Non-Manatee Measurements	**Manatee Measurements**
Mean	153 cfs	163 cfs
Standard Deviation	18 cfs	19 cfs
No. of Measurements	403	256
p(T<=t) two-tail	<0.0001	
Test Result: p<5% (Reject the null hypothesis)	**Significantly Different Mean Discharges**	

Table 3.3-1
Summary of Available Data Used for Model Boundary Conditions and Calibration

Data Type	Collecting Agency	Location	Period of Record	Comment on Accuracy
River stage	USGS	S.R. 44 about 5 miles west of DeLand	1932-present	Generally accurate to 0.01 foot
River Discharge	USGS	S.R. 44 about 5 miles west of DeLand	1945-present	Generally accurate to 15% of true value
River Temperature	USGS	S.R. 44 about 5 miles west of DeLand	1931-1980s	Temperature readings ceased in 1980s. Time series was extended by estimating values based on air temperature reading at the same station which also ceased in 2001.
Blue Spring Discharge	USGS/SJRWMD	Blue Spring run about 800 ft from St. Johns River	1932-present	Generally accurate to 10% of true value
Spring Run/River Temperature	BSSP	Near mouth of Blue Spring Run	1981-present	Ranger reports observed temperature to 0.5 C. It is not known how representative this measurement is of the mean river temperature.
Cold-Water Intrusion Length	BSSP	Blue Spring Run	1981-present	Ranger estimates intrusion length by visual observation and reports to nearest transect spaced at approx. 100-ft intervals.

Table 3.3-2
Observed Cold-Water Intrusion Events
Used for Model Calibration

Date*	T_{river} (°F)	Q_{spring} (cfs)	Q_{river} (cfs)	H_{bndry} (ft)	Obs L (ft)	Sim L (ft)	Obs H (ft)	Sim H (ft)
12/3/96	66.2	170.9	2454.3	1.4	89-194	89	1.5	1.5
2/11/91	66.2	125.9	1218.3	1.2	89-194	157	1.2	1.2
3/17/99	65.8	162.9	1084.1	0.9	89-194	92	1.0	1.0
1/21/99	65.3	165.9	1423.1	0.8	89-194	85	0.8	0.8
1/10/90	64.4	144.9	2295.4	0.9	89-194	125	1.0	1.0
1/5/83	68.0	166.9	759.2	1.8	89-194	92	1.8	1.8
12/9/90	64.4	142.9	1793.9	1.6	194-312	194	1.5	1.5
3/3/94	64.4	132.9	2164.7	1.4	194-312	256	1.4	1.4
12/21/86	65.3	151.9	1031.2	1.7	89-194	161	1.7	1.7
2/17/87	63.5	145.9	2482.5	1.6	194-312	256	1.7	1.7
12/14/92	60.8	149.9	4491.9	1.7	312-404	328	1.9	1.9
1/18/94	60.8	137.9	1387.8	0.9	194-312	256	0.9	0.9
3/2/98	66.0	164.9	9672.3	4.5	404-495	427	4.8	4.8
11/23/87	61.7	168.9	4841.5	2.3	312-404	328	2.4	2.4
3/21/88	62.6	118.9	4131.7	1.7	312-404	394	1.8	1.8
12/14/88	60.8	150.9	2758.0	2.0	312-404	358	2.0	2.0
1/24/92	56.3	156.9	2140.0	1.0	312-404	312	1.0	1.0
1/31/95	57.2	173.9	5791.4	2.4	404-495	446	2.6	2.6

*These events occurred within one day of a measurement of spring discharge

The columns listed above are:

(a) Date,
(b) T_{river}, river temperature in degrees Fahrenheit,
(c) Q_{spring}, Blue Spring discharge in cfs,
(d) Q_{river}, St. Johns River discharge in cfs,
(e) H_{bndry}, specified stage of downstream model boundary in ft,
(f) Obs L, observed intrusion length in feet (intrusions recorded as Transect *n* would lie between Transects *n* and *n+1*, e.g., an intrusion recorded as Transect 1 lies between Transect 1 and 2 that are 89 and 194 ft from the mouth of the run),
(g) Sim L, simulated steady-state intrusion length in ft,
(h) Obs H, observed stage of Blue Spring Run in ft, and
(i) Sim H, simulated stage in Blue Spring Run in ft.

Table 3.3-3
Selection of Intrusion Length Rationale

Date	Selection of Intrusion Length
12/9/90	Intrusion reported to transect 1, but intrusion reached transect 2 on previous day when observed river temperature was higher. Conservative approach was to use intrusion to transect 2.
3/3/94	Intrusion reported to transect 1, but intrusion reached transect 2 on successive four days under similar conditions. Conservative approach was to use intrusion to transect 2.
12/21/86	Intrusion reported to transect 2, but on all other days over the period 12/19-12/26 the intrusion was either to transect 1 or there was no intrusion at all. Selected transect 1 as representative of intrusion length for this period.
12/14/92	Intrusion reported to transect 2, but intrusion reached transect 3 on next day at a higher river temperature. Conservative approach was to use intrusion to transect 3.
3/2/98	Intrusion reported to transect 2, but intrusion reached transect 4 on next day at a similar river temperature. Conservative approach was to use intrusion to transect 4.
1/31/95	Intrusion reported to transect 3, but intrusion reached transect 4 from 1/18-1/29 under similar conditions. Conservative approach was to use intrusion to transect 4.

Table 3.3-4
Calculated Condition Numbers at ±10% Parameter Variation

Spring Discharge	River Temperature	River Stage	River Salinity	River Discharge
1.73	1.06	0.20	0.11	0.00

Table 3.4-1
Observed POR Monthly Spring Flow Statistics

Month	Long Term Mean Spring Flow (cfs)	Standard Deviation (cfs)
November	161	23
December	167	16
January	165	20
February	161	18
March	159	18

Table 3.4-2
Statistical Comparison of EFDC-Estimated and Measured Spring Discharges During Manatee Seasons (1932-2005) and Simulated Manatee-Season 1-Day and 3-Day Discharges

Parameters	Measured Discharge (cfs)	EFDC-Estimated Discharge (cfs)	1000-Year Simulated Discharge (cfs)	
			1-Day	3-Day
Sample Size	256	593	150,000	149,998
Mean	163	163	164	164
Median	164	162	164	164
Std. Deviation	19	21	21	16
Minimum	87	107	46	79
Maximum	218	251	269	237
Percentiles				
5%	127	132	130	138
25%	151	148	151	154
75%	174	176	177	174
95%	194	200	197	189

Table 3.4-3
Computed Percentiles of Minimum Spring Discharge
During Manatee Seasons Using Simulated Values

(CP is the computed probability of not-exceeding the stated minimum discharge for the given duration in any one year)

CP (%)	**Table 3.4-3 Minimum Spring Discharge (cfs)**	
	1-Day	**3-Day**
1	66.5	89.5
2	71.0	91.9
3	73.8	93.9
4	76.6	95.8
5	77.8	97.7
6	79.6	99.6
7	81.4	100.3
8	82.9	101.4
9	83.9	102.0
10	84.9	102.5
11	85.4	103.4
12	86.2	104.3
13	87.2	105.0
14	87.7	105.8
15	88.5	106.5
16	89.0	106.8
17	90.0	107.6
18	90.5	108.2
19	91.1	108.6
20	91.5	109.2
21	92.0	109.5
22	92.3	110.3
23	92.8	110.7
24	93.0	111.0
25	93.3	111.6
26	93.8	112.2
27	94.2	112.7
28	94.5	113.1
29	94.8	113.4
30	95.3	113.7
31	95.8	113.9
32	96.0	114.2
33	96.3	114.6
34	96.8	114.8
35	97.3	115.1
36	97.8	115.4

CP (%)	Table 3.4-3 Minimum Spring Discharge (cfs)	
	1-Day	3-Day
37	98.1	115.8
38	98.3	116.0
39	98.6	116.2
40	98.8	116.4
41	99.1	116.6
42	99.3	117.0
43	99.8	117.4
44	100.2	117.5
45	100.4	117.8
46	100.9	118.1
47	101.2	118.4
48	101.4	118.7
49	101.9	119.0
50	102.0	119.2
51	102.2	119.5
52	102.4	119.6
53	102.7	119.7
54	103.0	120.1
55	103.2	120.3
56	103.4	120.4
57	103.4	120.6
58	103.9	120.8
59	104.3	121.0
60	104.6	121.3
61	104.9	121.7
62	105.4	121.9
63	106.1	122.1
64	106.2	122.4
65	106.4	122.5
66	106.7	122.9
67	106.9	123.1
68	107.4	123.3
69	107.7	123.5
70	108.2	123.9
71	108.6	124.1
72	108.8	124.3
73	109.2	124.6
74	109.7	124.9
75	109.8	125.1
76	110.2	125.4
77	110.5	125.7
78	110.9	125.9
79	111.2	126.1

CP (%)	Table 3.4-3 Minimum Spring Discharge (cfs)	
	1-Day	**3-Day**
80	111.5	126.3
81	111.7	126.6
82	112.0	126.8
83	112.5	127.2
84	112.9	127.6
85	113.2	127.8
86	113.9	128.1
87	114.2	128.5
88	114.6	128.8
89	115.0	129.0
90	115.5	129.4
91	116.1	130.0
92	116.5	130.5
93	117.0	131.2
94	117.8	131.8
95	118.3	132.3
96	118.6	132.9
97	119.6	133.6
98	120.8	134.2
99	123.2	136.3

Table 3.4-4
Statistical Properties of POR Flow Regime
During Manatee Season Using the Simulated Daily Discharges
(cfs)

Long Term Mean Discharge =	156.1	cfs
Long Term Mean Manatee-Seasonal Discharge =	161.8	cfs
Return Period	Min 3-Day	Min 1-Day
2 Year	102.0	119.2
10 Year	84.9	102.5
50 Year	71.0	91.9

Table 3.5-1

Percentiles of Manatee Season 1-Day Extreme Values Calculated Either Using Log Pearson Type III (LPIII) and Non-Parametric Ranking (NP)

(CP is the cumulative probability of not-exceeding the stated minimum value or exceeding the stated maximum value in any one year)

Table 3.5-1							
Min 1-Day Spring Discharge (Based on 1000 Year Simulations) (NP)		Min 1-Day Temp (Based on Observed Data) (LPIII)		Deland Min 1-Day Stage (Based on Observed Data) (NP)		Deland Max 1-Day Stage (Based on Observed Data) (LPIII)	
CP[1] (%)	Min Discharge (cfs)	CP (%)	Min Temp (°F)	CP (%)	Min Stage (ft)	CP (%)	Max Stage (ft)
1	66.5	1	46.2	1	-1.0	1	5.9
2	71.0	2	47.2	2	-1.0	2	5.3
3	73.8	3	48.1	3	-1.0	3	5.0
4	76.6	4	49.1	4	-0.8	4	4.7
5	77.8	5	50.1	5	-0.5	5	4.6
6	79.6	6	50.4	6	-0.4	6	4.5
7	81.4	7	50.8	7	-0.4	7	4.3
8	82.9	8	51.2	8	-0.4	8	4.2
9	83.9	9	51.6	9	-0.4	9	4.1
10	84.9	10	52.0	10	-0.3	10	4.0
11	85.4	11	52.3	11	-0.3	11	3.9
12	86.2	12	52.5	12	-0.3	12	3.8
13	87.2	13	52.7	13	-0.3	13	3.8
14	87.7	14	53.0	14	-0.3	14	3.7
15	88.5	15	53.2	15	-0.2	15	3.7
16	89.0	16	53.4	16	-0.1	16	3.6
17	90.0	17	53.7	17	-0.1	17	3.5
18	90.5	18	53.9	18	-0.1	18	3.5
19	91.1	19	54.2	19	-0.1	19	3.4
20	91.5	20	54.4	20	-0.1	20	3.4
21	92.0	21	54.5	21	-0.1	21	3.3
22	92.3	22	54.7	22	-0.1	22	3.3
23	92.8	23	54.8	23	-0.1	23	3.3
24	93.0	24	55.0	24	-0.1	24	3.2
25	93.3	25	55.1	25	-0.1	25	3.2
26	93.8	26	55.2	26	0.0	26	3.2
27	94.2	27	55.4	27	0.0	27	3.1
28	94.5	28	55.5	28	0.0	28	3.1
29	94.8	29	55.7	29	0.0	29	3.1
30	95.3	30	55.8	30	0.0	30	3.0

[1] CP: Cumulative Probability

Table 3.5-1							
Min 1-Day Spring Discharge (Based on 1000 Year Simulations) (NP)		Min 1-Day Temp (Based on Observed Data) (LPIII)		Deland Min 1-Day Stage (Based on Observed Data) (NP)		Deland Max 1-Day Stage (Based on Observed Data) (LPIII)	
CP[1] (%)	Min Discharge (cfs)	CP (%)	Min Temp (°F)	CP (%)	Min Stage (ft)	CP (%)	Max Stage (ft)
31	95.8	31	55.9	31	0.0	31	3.0
32	96.0	32	56.1	32	0.0	32	3.0
33	96.3	33	56.2	33	0.1	33	3.0
34	96.8	34	56.4	34	0.1	34	2.9
35	97.3	35	56.5	35	0.1	35	2.9
36	97.8	36	56.7	36	0.1	36	2.9
37	98.1	37	56.8	37	0.1	37	2.8
38	98.3	38	56.9	38	0.1	38	2.8
39	98.6	39	57.1	39	0.1	39	2.8
40	98.8	40	57.2	40	0.1	40	2.8
41	99.1	41	57.4	41	0.1	41	2.7
42	99.3	42	57.5	42	0.1	42	2.7
43	99.8	43	57.7	43	0.1	43	2.7
44	100.2	44	57.8	44	0.1	44	2.6
45	100.4	45	58.0	45	0.1	45	2.6
46	100.9	46	58.1	46	0.1	46	2.6
47	101.2	47	58.3	47	0.1	47	2.6
48	101.4	48	58.4	48	0.1	48	2.5
49	101.9	49	58.6	49	0.1	49	2.5
50	102.0	50	58.7	50	0.2	50	2.5
51	102.2	51	58.8	51	0.2	51	2.5
52	102.4	52	59.0	52	0.3	52	2.4
53	102.7	53	59.1	53	0.3	53	2.4
54	103.0	54	59.2	54	0.3	54	2.4
55	103.2	55	59.3	55	0.3	55	2.4
56	103.4	56	59.5	56	0.3	56	2.3
57	103.4	57	59.6	57	0.3	57	2.3
58	103.9	58	59.7	58	0.3	58	2.3
59	104.3	59	59.9	59	0.3	59	2.3
60	104.6	60	60.0	60	0.3	60	2.3
61	104.9	61	60.1	61	0.3	61	2.2
62	105.4	62	60.3	62	0.3	62	2.2
63	106.1	63	60.4	63	0.3	63	2.2
64	106.2	64	60.5	64	0.3	64	2.2
65	106.4	65	60.7	65	0.3	65	2.2
66	106.7	66	60.8	66	0.4	66	2.1
67	106.9	67	60.9	67	0.4	67	2.1
68	107.4	68	61.1	68	0.4	68	2.1
69	107.7	69	61.2	69	0.4	69	2.1

Table 3.5-1							
Min 1-Day Spring Discharge (Based on 1000 Year Simulations) (NP)		Min 1-Day Temp (Based on Observed Data) (LPIII)		Deland Min 1-Day Stage (Based on Observed Data) (NP)		Deland Max 1-Day Stage (Based on Observed Data) (LPIII)	
CP[1] (%)	Min Discharge (cfs)	CP (%)	Min Temp (°F)	CP (%)	Min Stage (ft)	CP (%)	Max Stage (ft)
70	108.2	70	61.3	70	0.4	70	2.0
71	108.6	71	61.5	71	0.4	71	2.0
72	108.8	72	61.6	72	0.4	72	2.0
73	109.2	73	61.7	73	0.4	73	2.0
74	109.7	74	61.9	74	0.4	74	2.0
75	109.8	75	62.0	75	0.4	75	2.0
76	110.2	76	62.1	76	0.4	76	1.9
77	110.5	77	62.3	77	0.5	77	1.9
78	110.9	78	62.4	78	0.5	78	1.9
79	111.2	79	62.5	79	0.5	79	1.9
80	111.5	80	62.7	80	0.6	80	1.9
81	111.7	81	62.9	81	0.6	81	1.8
82	112.0	82	63.1	82	0.6	82	1.8
83	112.5	83	63.2	83	0.6	83	1.8
84	112.9	84	63.4	84	0.6	84	1.8
85	113.2	85	63.6	85	0.7	85	1.7
86	113.9	86	63.8	86	0.8	86	1.7
87	114.2	87	64.0	87	0.8	87	1.7
88	114.6	88	64.2	88	0.8	88	1.6
89	115.0	89	64.4	89	0.9	89	1.6
90	115.5	90	64.6	90	0.9	90	1.6
91	116.1	91	64.9	91	0.9	91	1.6
92	116.5	92	65.2	92	1.0	92	1.5
93	117.0	93	65.5	93	1.0	93	1.5
94	117.8	94	65.9	94	1.0	94	1.5
95	118.3	95	66.2	95	1.1	95	1.4
96	118.6	96	66.5	96	1.1	96	1.3
97	119.6	97	67.1	97	1.1	97	1.3
98	120.8	98	67.7	98	1.2	98	1.2
99	123.2	99	68.7	99	1.2	99	1.1

Table 3.5-2
Useable Warm Water Lengths Under 2-Year, 1-Day Combinations of Extreme Values

Lowest St. Johns River Stage						
50% Joint Probability Combinations			Min Discharge (cfs)	Min River Temp (°F)	Deland Min Stage (ft)	Useable Warm Water Length (ft)
Min Discharge CP	Min River Temp CP	Deland Min Stage CP				
55%	95%	96%	103.2	66.2	1.1	979.0
60%	90%	93%	104.6	64.6	1.0	904.0
70%	80%	89%	108.2	62.7	0.9	832.0
80%	70%	89%	111.5	61.3	0.9	803.0
80%	80%	78%	111.5	62.7	0.5	694.0
90%	60%	93%	115.5	60.0	1.0	770.0
90%	90%	62%	115.5	64.6	0.3	794.0
95%	55%	96%	118.3	59.3	1.1	743.0
95%	95%	55%	118.3	66.2	0.3	903.0

Highest St. Johns River Stage						
50% Joint Probability Combinations			Min Discharge (cfs)	Min Temp (°F)	Deland Max Stage (ft)	Useable Warm Water Length (ft)
Min Discharge CP	Min River Temp CP	Max Stage CP				
55%	95%	96%	103.2	66.2	1.4	1165.0
60%	90%	93%	104.6	64.6	1.5	1172.0
70%	80%	89%	108.2	62.7	1.6	1197.0
80%	70%	89%	111.5	61.3	1.6	1112.0
80%	80%	78%	111.5	62.7	1.9	1232.0
90%	60%	93%	115.5	60.0	1.5	992.0
90%	90%	62%	115.5	64.6	2.2	1459.0
95%	55%	96%	118.3	59.3	1.4	929.0
95%	95%	55%	118.3	66.2	2.4	1528.0

Table 3.5-3
Percentiles of Manatee Season 3-Day Extreme Values Calculated Either Using Log Pearson Type III (LPIII) and Non-Parametric Ranking (NP)

(CP is the probability of not-exceeding the stated minimum value or exceeding the stated maximum value in any one year)

Table 3.5-3							
Min 3-Day Spring Discharge (Based on 1000 Year Simulations) (NP)		Min 3-Day Temp (Based on Observed Data) (LPIII)		Deland Min 3-Day Stage (Based on Observed Data) (NP)		Deland Max 3-Day Stage (Based on Observed Data) (LPIII)	
CP[2] (%)	Min Discharge (cfs)	CP (%)	Min Temp (°F)	CP (%)	Min Stage (ft)	CP (%)	Max Stage (ft)
1	89.5	1	46.8	1	-1.0	1	5.9
2	91.9	2	47.7	2	-0.9	2	5.3
3	93.9	3	48.6	3	-0.6	3	5.0
4	95.8	4	49.6	4	-0.4	4	4.7
5	97.7	5	50.5	5	-0.4	5	4.6
6	99.6	6	50.9	6	-0.4	6	4.4
7	100.3	7	51.3	7	-0.3	7	4.3
8	101.4	8	51.6	8	-0.3	8	4.2
9	102.0	9	52.0	9	-0.3	9	4.0
10	102.5	10	52.4	10	-0.3	10	3.9
11	103.4	11	52.7	11	-0.2	11	3.9
12	104.3	12	52.9	12	-0.2	12	3.8
13	105.0	13	53.1	13	-0.2	13	3.7
14	105.8	14	53.3	14	-0.2	14	3.7
15	106.5	15	53.6	15	-0.1	15	3.6
16	106.8	16	53.8	16	-0.1	16	3.5
17	107.6	17	54.0	17	-0.1	17	3.5
18	108.2	18	54.3	18	-0.1	18	3.4
19	108.6	19	54.5	19	-0.1	19	3.4
20	109.2	20	54.7	20	-0.1	20	3.3
21	109.5	21	54.9	21	-0.1	21	3.3
22	110.3	22	55.0	22	-0.1	22	3.3
23	110.7	23	55.2	23	-0.1	23	3.2
24	111.0	24	55.3	24	0.0	24	3.2
25	111.6	25	55.4	25	0.0	25	3.2
26	112.2	26	55.6	26	0.0	26	3.1
27	112.7	27	55.7	27	0.0	27	3.1
28	113.1	28	55.9	28	0.0	28	3.1
29	113.4	29	56.0	29	0.0	29	3.0
30	113.7	30	56.1	30	0.1	30	3.0

[2] CP: Cumulative Probability

Table 3.5-3							
Min 3-Day Spring Discharge (Based on 1000 Year Simulations) (NP)		Min 3-Day Temp (Based on Observed Data) (LPIII)		Deland Min 3-Day Stage (Based on Observed Data) (NP)		Deland Max 3-Day Stage (Based on Observed Data) (LPIII)	
CP[2] (%)	Min Discharge (cfs)	CP (%)	Min Temp (°F)	CP (%)	Min Stage (ft)	CP (%)	Max Stage (ft)
31	113.9	31	56.3	31	0.1	31	3.0
32	114.2	32	56.4	32	0.1	32	2.9
33	114.6	33	56.6	33	0.1	33	2.9
34	114.8	34	56.7	34	0.1	34	2.9
35	115.1	35	56.9	35	0.1	35	2.8
36	115.4	36	57.0	36	0.1	36	2.8
37	115.8	37	57.1	37	0.1	37	2.8
38	116.0	38	57.3	38	0.1	38	2.8
39	116.2	39	57.4	39	0.1	39	2.7
40	116.4	40	57.6	40	0.1	40	2.7
41	116.6	41	57.7	41	0.1	41	2.7
42	117.0	42	57.9	42	0.1	42	2.6
43	117.4	43	58.0	43	0.1	43	2.6
44	117.5	44	58.2	44	0.1	44	2.6
45	117.8	45	58.3	45	0.2	45	2.6
46	118.1	46	58.5	46	0.2	46	2.5
47	118.4	47	58.6	47	0.2	47	2.5
48	118.7	48	58.8	48	0.2	48	2.5
49	119.0	49	58.9	49	0.2	49	2.5
50	119.2	50	59.1	50	0.2	50	2.4
51	119.5	51	59.2	51	0.2	51	2.4
52	119.6	52	59.3	52	0.3	52	2.4
53	119.7	53	59.5	53	0.3	53	2.4
54	120.1	54	59.6	54	0.3	54	2.3
55	120.3	55	59.7	55	0.3	55	2.3
56	120.4	56	59.9	56	0.3	56	2.3
57	120.6	57	60.0	57	0.3	57	2.3
58	120.8	58	60.1	58	0.3	58	2.3
59	121.0	59	60.3	59	0.3	59	2.2
60	121.3	60	60.4	60	0.3	60	2.2
61	121.7	61	60.5	61	0.3	61	2.2
62	121.9	62	60.7	62	0.3	62	2.2
63	122.1	63	60.8	63	0.4	63	2.1
64	122.4	64	60.9	64	0.4	64	2.1
65	122.5	65	61.1	65	0.4	65	2.1
66	122.9	66	61.2	66	0.4	66	2.1
67	123.1	67	61.4	67	0.4	67	2.1
68	123.3	68	61.5	68	0.4	68	2.0
69	123.5	69	61.6	69	0.4	69	2.0

Table 3.5-3							
Min 3-Day Spring Discharge (Based on 1000 Year Simulations) (NP)		Min 3-Day Temp (Based on Observed Data) (LPIII)		Deland Min 3-Day Stage (Based on Observed Data) (NP)		Deland Max 3-Day Stage (Based on Observed Data) (LPIII)	
CP[2] (%)	Min Discharge (cfs)	CP (%)	Min Temp (°F)	CP (%)	Min Stage (ft)	CP (%)	Max Stage (ft)
70	123.9	70	61.8	70	0.5	70	2.0
71	124.1	71	61.9	71	0.5	71	2.0
72	124.3	72	62.1	72	0.5	72	2.0
73	124.6	73	62.2	73	0.5	73	1.9
74	124.9	74	62.3	74	0.5	74	1.9
75	125.1	75	62.5	75	0.5	75	1.9
76	125.4	76	62.6	76	0.5	76	1.9
77	125.7	77	62.8	77	0.5	77	1.9
78	125.9	78	62.9	78	0.5	78	1.9
79	126.1	79	63.0	79	0.5	79	1.8
80	126.3	80	63.2	80	0.6	80	1.8
81	126.6	81	63.4	81	0.6	81	1.8
82	126.8	82	63.6	82	0.6	82	1.8
83	127.2	83	63.8	83	0.7	83	1.7
84	127.6	84	64.0	84	0.7	84	1.7
85	127.8	85	64.2	85	0.8	85	1.7
86	128.1	86	64.4	86	0.9	86	1.7
87	128.5	87	64.6	87	0.9	87	1.6
88	128.8	88	64.8	88	0.9	88	1.6
89	129.0	89	65.0	89	0.9	89	1.6
90	129.4	90	65.2	90	0.9	90	1.6
91	130.0	91	65.6	91	0.9	91	1.5
92	130.5	92	65.9	92	1.0	92	1.5
93	131.2	93	66.3	93	1.1	93	1.5
94	131.8	94	66.6	94	1.1	94	1.4
95	132.3	95	67.0	95	1.1	95	1.4
96	132.9	96	67.4	96	1.1	96	1.3
97	133.6	97	68.0	97	1.2	97	1.2
98	134.2	98	68.7	98	1.3	98	1.2
99	136.3	99	69.8	99	1.3	99	1.1

Table 4.1-1
Projected EWWLs

Season	Projected Max Count (manatees)	Projected Spread (manatees/ft)	Projected EWWL (ft)
2006	158	0.74	214
2007	169	0.78	218
2008	182	0.82	223
2009	195	0.86	227
2010	209	0.90	232
2011	224	0.95	237
2012	240	0.99	242
2013	258	1.04	247
2014	277	1.10	252
2015	297	1.15	258
2016	318	1.21	263
2017	342	1.27	268
2018	366	1.34	274
2019	393	1.40	280
2020	422	1.48	286
2021	452	1.55	292
2022	485	1.63	298
2023	520	1.71	304
2024	558	1.73	322
2025	599	1.73	345
≥2026	642	1.73	345

Table 4.2-1
Flow Regime
Useable Warm Water Lengths Under Catastrophic Conditions
(50-Year, 3-Day Combinations of Extreme Values)

Lowest St. Johns River Stage						
2% Joint Probability Combinations			Min Discharge (cfs)	Min River Temp (°F)	Deland Min Stage (ft)	Useable Warm Water Length (ft)
Min Discharge CP	Min River Temp CP	Deland Min Stage CP				
5%	90%	44%	97.7	65.2	0.1	602.0
10%	80%	25%	102.5	63.2	0.0	470.0
20%	20%	50%	109.2	54.7	0.2	368.0
20%	70%	14%	109.2	61.8	-0.2	393.0
30%	30%	22%	113.7	56.1	-0.1	375.0
30%	60%	11%	113.7	60.4	-0.2	387.0
40%	40%	13%	116.4	57.6	-0.2	364.0
40%	50%	10%	116.4	59.1	-0.3	387.0
50%	40%	10%	119.2	57.6	-0.3	373.0
50%	50%	8%	119.2	59.1	-0.3	393.0
60%	30%	11%	121.3	56.1	-0.2	360.0
60%	60%	6%	121.3	60.4	-0.4	498.0
70%	20%	14%	123.9	54.7	-0.2	348.0
70%	70%	4%	123.9	61.8	-0.4	603.0
80%	10%	25%	126.3	52.4	0.0	411.0
80%	80%	3%	126.3	63.2	-0.6	480.0
90%	5%	44%	129.4	50.5	0.1	418.0

Table 4.2-1 (continued)

Highest St. Johns River Stage						
2% Joint Probability Combinations			Min Discharge (cfs)	Min Temp (°F)	Deland Max Stage (ft)	Useable Warm Water Length (ft)
Min Discharge CP	Min River Temp CP	Max Stage CP				
5%	90%	44%	97.7	65.2	2.6	1292
10%	80%	25%	102.5	63.2	3.2	1285
20%	20%	50%	109.2	54.7	2.5	1075
20%	70%	14%	109.2	61.8	3.7	1262
30%	30%	22%	113.7	56.1	3.3	1246
30%	60%	11%	113.7	60.4	3.9	1252
40%	40%	13%	116.4	57.6	3.8	993
40%	50%	10%	116.4	59.1	4.0	1246
50%	40%	10%	119.2	57.6	4.0	993
50%	50%	8%	119.2	59.1	4.2	986
60%	30%	11%	121.3	56.1	3.9	977
60%	60%	6%	121.3	60.4	4.6	996
70%	20%	14%	123.9	54.7	3.7	980
70%	70%	4%	123.9	61.8	4.7	1249
80%	10%	25%	126.3	52.4	3.2	1252
80%	80%	3%	126.3	63.2	5.0	1256
90%	5%	44%	129.4	50.5	2.6	1082

Table 4.2-2
Reduced Flow Regimes
Minimum Useable Warm Water Lengths Under Catastrophic Conditions
(50-Year, 3-Day Combinations of Extreme Values)

(Reduction in flow regime is calculated with respect to the current flow regime)

Table 4.2-2		
Flow Regime Long Term Mean Discharge (cfs)	Flow Regime Reduction (cfs)	Minimum Useable Warm Water Length (ft)
156.6	0	348
155.6	1	344
154.6	2	340
153.6	3	336
152.6	4	332
151.6	5	328
150.6	6	323
149.6	7	319
148.6	8	314
147.6	9	309
146.6	10	305
145.6	11	300
144.6	12	294
143.6	13	289
142.6	14	284
141.6	15	279
140.6	16	273
139.6	17	267
138.6	18	262
137.6	19	256
136.6	20	250
135.6	21	244
134.6	22	237
133.6	23	231
132.6	24	225
131.6	25	218
130.6	26	211
129.6	27	205
128.6	28	198
127.6	29	191
126.6	30	183
125.6	31	176
124.6	32	169
123.6	33	161
122.6	34	154
121.6	35	146
120.6	36	138
119.6	37	130

Table 4.2-2		
Flow Regime Long Term Mean Discharge (cfs)	Flow Regime Reduction (cfs)	Minimum Useable Warm Water Length (ft)
118.6	38	122
117.6	39	114
116.6	40	106
115.6	41	97
114.6	42	89
113.6	43	80
112.6	44	72
111.6	45	63
110.6	46	54
109.6	47	45
108.6	48	36
107.6	49	26
106.6	50	17
105.6	51	7

Table 4.3-1
Projected Minimum Long Term Mean Flows

Season	**Projected Max Count (manatees)**	**Projected Spread (manatees/ft)**	**Projected EWWL (ft)**	**Recommended Long Term Mean Flow (cfs)**
2006	158	0.7385	214	131
2007	169	0.7759	218	132
2008	182	0.8153	223	**133**
2009	195	0.8566	227	133
2010	209	0.9000	232	134
2011	224	0.9456	237	135
2012	240	0.9935	242	136
2013	258	1.0439	247	**137**
2014	277	1.0968	252	138
2015	297	1.1523	258	139
2016	318	1.2107	263	140
2017	342	1.2721	268	141
2018	366	1.3365	274	**142**
2019	393	1.4043	280	143
2020	422	1.4754	286	144
2021	452	1.5502	292	145
2022	485	1.6288	298	146
2023	520	1.7113	304	**148**
2024	558	1.7330	322	152
2025	599	1.7330	345	157
2026	642	1.7330	345	157

Table 4.3-2
Recommended Phased Minimum Long Term Mean Flow Regime

Duration	**Recommended Long Term Mean Flow (cfs)**
(Effective Date) to March 31, 2009	133
April 1, 2009 to March 31, 2014	137
April 1, 2014 to March 31, 2019	142
April 1, 2019 to March 31, 2024	148
After March 31, 2024	157

Appendix A

Table A-1
Number of Manatee Surveys
Per Spring Run Zone Cold Water Intrusion Lengths

Spring Run Zone	Spring Run Zone Length (ft)	No. of Manatee Surveys[1] Per Spring Run Zone
0 = CB[2]	0	241
Zone 1	89	261
Zone 2	194	173
Zone 3	312	124
Zone 4	404	102
Zone 5	495	22
Zone 6	571	1

[1] 924 surveys with both intrusion length and manatee counts recorded
[2] CB – Canoe beach

Table A-2
Manatee Distribution Per Spring Run Zone for
Given Cold Water Intrusion Lengths

Zone	CB	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Boil
Cold Water Intrusion Length = 0 feet																					
Max	19	18	22	12	13	14	11	8	4	3	7	10	2	2		1			1	1	1
Average	4	4	6	3	3	3	3	3	2	2	3	3	1	2		1			1	1	1
Min	1	1	1	1	1	1	1	1	1	1	1	1	2	1		1			1	1	1
Cold Water Intrusion Length = 89 feet																					
Max	20	32	45	21	20	30	18	9	7	7	3	9	6	3	2	1	2	3	3		3
Average	4	7	11	6	5	5	4	3	2	2	2	3	2	2	2	1	2	2	3		2
Min	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	3		1
Cold Water Intrusion Length = 194 feet																					
Max	8	9	57	39	22	23	14	12	7	7	11	12	5	6	10	1	2	3		3	1
Average	2	2	12	10	7	6	4	3	2	3	3	3	2	2	6	1	1	3		3	1
Min	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3		3	1
Cold Water Intrusion Length = 312 feet																					
Max	7	8	31	42	56	29	16	20	15	7	14	10	17	6	4	4	2	9	2	2	1
Average	3	2	5	7	12	8	5	4	3	2	3	3	3	2	2	2	2	5	2	2	1
Min	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	2	2	1
Cold Water Intrusion Length = 404 feet																					
Max	9	5	7	13	47	32	18	14	16	15	7	20	9	12	5	7	4	10	5	2	1
Average	2	2	2	3	11	11	6	5	4	3	2	4	3	3	2	2	2	3	3	2	1
Min	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Cold Water Intrusion Length = 495 feet																					
Max	2	3	1	2	4	27	31	18	18	7	24	10	6	10	13	5	3	19	4	3	4
Average	2	2	1	1	2	14	11	8	9	2	5	4	3	5	5	4	2	5	3	3	2
Min	1	1	1	1	1	2	1	2	1	1	1	1	1	1	1	1	1	1	2	2	1
Cold Water Intrusion Length = 571 feet																					
Only survey						1	10	8	12	2					1	4		1			

Table A-3
Investigated Highest Manatee Attendance Dates
with Surveyed Sheet

Date	Manatee Daily Total
12/15/1997	86
1/8/1999	86
2/1/2000	89
2/7/2000	87
12/21/2000	94
12/29/2000	86
1/1/2001	86
1/2/2001	92
1/5/2001	92
1/24/2001	95
1/5/2002	97

Table A-4
Calculated Manatee Aggregation Surface Densities
During Coldest Days per Season

Manatee Aggregation Surface Density during Coldest Days			
Manatee Season	**Calculated Manatee Aggregation Surface Density (manatees/sq. ft)**		
	Mean	**Std Dev**	**C.V.**
1981	0.008	0.000	5%
1985	0.005	0.002	35%
1986	0.004		
1987	0.005	0.002	35%
1988	0.006	0.003	45%
1989	0.007	0.004	57%
1990	0.005	0.001	17%
1991	0.008	0.005	55%
1992	0.011	0.005	46%
1993	0.008	0.004	54%
1994	0.006	0.002	34%
1995	0.009	0.004	47%
1996	0.007	0.004	59%
1997	0.006	0.003	46%
1999	0.011	0.005	50%
2000	0.008	0.003	39%
2001	0.006	0.003	60%
Overall	**0.007**	**0.003**	**48%**
C.V. = Coefficient of Variation			

Note: In the 1986 coldest day only one aggregation area was identified on the daily survey sheet. Daily survey sheets for coldest days in 1982-1984 were unavailable.

Table A-5
Calculated Manatee Aggregation Surface Densities during Highest Attendance Days per Season

Manatee Aggregation Surface Density during Max Attendance Days			
Manatee Season	**Calculated Manatee Aggregation Surface Density(manatee/sq. ft)**		
	Mean	**Std Dev**	**C.V.**
1981	0.004		
1982	0.007	0.003	49%
1984	0.012	0.005	41%
1985	0.010	0.004	41%
1986	0.006	0.002	24%
1987	0.007	0.004	54%
1988	0.008	0.002	24%
1989	0.016	0.009	57%
1990	0.009	0.007	77%
1991	0.018	0.006	33%
1992	0.013	0.006	48%
1993	0.010	0.004	42%
1994	0.009	0.004	47%
1995	0.009	0.004	40%
1996	0.009	0.005	58%
1997	0.017	0.010	62%
1998	0.010	0.005	53%
2000	0.016	0.009	59%
Overall	**0.012**	**0.007**	**59%**
C.V. = Coefficient of Variation			

Note: In the 1981 highest attendance day only one aggregation area was identified on the daily survey sheet. Daily survey sheets for highest attendance days during 1983 and 1999 were unavailable.

Table A-6
Statistical Analyses of Seasonal Manatee Aggregation Surface Densities

Manatee Aggregation Density during Coldest Days
Non-Parametric Correlations (Kendall's tau_b)

		SEASON	MEAN	STDEV
SEASON	Correlation Coefficient	1.000	0.307	0.289
	Sig. (2-tailed)	.	0.101	0.139
	N	17	17	16
MEAN	Correlation Coefficient	0.307	1.000	0.654
	Sig. (2-tailed)	0.101	.	0.002
	N	17	17	16
STDEV	Correlation Coefficient	0.289	0.654	1.000
	Sig. (2-tailed)	0.139	0.002	.
	N	16	16	16

Manatee Aggregation Density during Max Attendance Days
Non-Parametric Correlations (Kendall's tau_b)

		SEASON	MEAN	STDEV
SEASON	Correlation Coefficient	1.000	0.299	0.329
	Sig. (2-tailed)	.	0.104	0.077
	N	17	17	17
MEAN	Correlation Coefficient	0.299	1.000	0.702
	Sig. (2-tailed)	0.104	.	0.000
	N	17	17	17
STDEV	Correlation Coefficient	0.329	0.702	1.000
	Sig. (2-tailed)	0.077	0.000	.
	N	17	17	17

Appendix B

Table B-1
EWWL Based on Average Daily Counts and Average Spreads

Manatee Season	Average-based Manatee Spread (manatee/ft)			Average Daily Count (manatees)	Average-based EWWLs (ft)			EWWL based on Max Count & Max Spread (ft)
	All Spring Run Zones	Spring Run Zones ≥1 Manatee	Spring Run Zones ≥5 Manatees		All Spring Run Zones	Spring Run Zones ≥1 Manatee	Spring Run Zones ≥5 Manatees	
1978	0.05	0.06	0.09	17.2	**370**	271	199	171
1979	0.05	0.08	0.10	13.8	276	172	134	122
1980	0.04	0.10	0.14	16.7	**377**	170	116	142
1981	0.04	0.07	0.10	11.6	260	175	117	152
1982	0.03	0.09	0.15	17.1	**524**	182	112	132
1983	0.03	0.10	0.14	13.4	**535**	136	95	131
1984	0.05	0.09	0.17	15.1	294	165	88	108
1985	0.04	0.09	0.17	16.3	**447**	179	94	159
1986	0.04	0.07	0.13	15.8	**379**	229	125	166
1987	0.05	0.10	0.13	22.3	**415**	235	175	149
1988	0.05	0.09	0.14	19.5	**421**	205	139	187
1989	0.05	0.10	0.18	21.7	**415**	227	122	187
1990	0.08	0.10	0.14	23.8	315	249	169	128
1991	0.06	0.09	0.14	29.1	**454**	324	209	154
1992	0.06	0.08	0.13	31.1	**492**	**371**	247	207
1993	0.07	0.18	0.18	38.1	**512**	212	212	237
1994	0.08	0.11	0.15	33.6	**442**	295	220	272
1995	0.09	0.13	0.23	31.7	342	244	136	173
1996	0.13	0.15	0.20	30.5	237	205	153	148
1997	0.06	0.10	0.19	36.5	**609**	**361**	196	192
1998	0.09	0.15	0.21	32.1	347	216	152	141
1999	0.11	0.18	0.22	44.2	**421**	247	199	206
2000	0.09	0.14	0.20	37.1	**403**	267	187	148
2001	0.11	0.15	0.21	35.1	306	230	166	141
2002	0.07	0.15	0.23	62.5	**851**	**409**	276	220
2003	0.17	0.22	0.24	55.1	326	254	226	192
2004	0.09	0.15	0.22	42.6	**485**	285	193	244

Bolded = Seasons with EWWLs in excess of the Current Flow Regime EWWL (348 ft - Table 4.2-1)

Table B-2

Paired Samples Test of Maximum-based EWWLs versus Average-based EWWLs

Paired EWWL Differences (ft)					
Mean	Std. Deviation	Std. Error Mean	t	Degrees of freedom	Significance (2-tailed)
5.6	37.9	7.3	0.77	26	45%

Conclusion: Paired differences are not statistically significant.

Table B-3
EWWLs based on Maximum Daily Count and Average Spreads

Manatee Season	Max Daily Manatee Count (manatees)	Average Manatee Spread (all data) (manatees/ft)	Resulting EWWL (ft)	Average Manatee Spread (>0 manatees/zone)) (manatees/ft)	Resulting EWWL (ft)	Average Manatee Spread (>5 manatees/zone) (manatees/ft)	Resulting EWWL (ft)
1978	28	0.05	**603**	0.06	**442**	0.09	324
1979	24	0.05	**478**	0.08	298	0.10	232
1980	34	0.04	**768**	0.10	347	0.14	236
1981	27	0.04	**604**	0.07	**406**	0.10	271
1982	33	0.03	**1010**	0.09	**351**	0.15	217
1983	30	0.03	**1198**	0.10	304	0.14	212
1984	31	0.05	**604**	0.09	340	0.17	182
1985	45	0.04	**1236**	0.09	**494**	0.17	261
1986	38	0.04	**910**	0.07	**550**	0.13	299
1987	47	0.05	**873**	0.10	**494**	0.13	**368**
1988	53	0.05	**1147**	0.09	**558**	0.14	**379**
1989	57	0.05	**1090**	0.10	**596**	0.18	321
1990	55	0.08	**727**	0.10	**575**	0.14	**391**
1991	67	0.06	**1048**	0.09	**748**	0.14	**483**
1992	67	0.06	**1058**	0.08	**798**	0.13	**531**
1993	80	0.07	**1074**	0.18	**446**	0.18	**446**
1994	74	0.08	**973**	0.11	**649**	0.15	**486**
1995	71	0.09	**767**	0.13	**548**	0.23	305
1996	72	0.13	**558**	0.15	**482**	0.20	**361**
1997	86	0.06	**1435**	0.10	**850**	0.19	**462**
1998	86	0.09	**932**	0.15	**578**	0.21	**407**
1999	112	0.11	**1065**	0.18	**626**	0.22	**505**
2000	95	0.09	**1033**	0.14	**684**	0.20	**479**
2001	97	0.11	**847**	0.15	**636**	0.21	**460**
2002	123	0.07	**1676**	0.15	**805**	0.23	**544**
2003	128	0.17	**757**	0.22	**589**	0.24	**524**
2004	130	0.09	**1481**	0.15	**871**	0.22	**589**

Bolded = Seasons with EWWLs in excess of the Current Flow Regime EWWL (348 ft - Table 4.2-1)

Table B-4
EWWL and River Temperatures per Season

Manatee Season	EWWL (ft)	Seasonal River Temperature (°F)		
		Average	Max	Min
1978	171	65.1	76.2	53.5
1979	122	65.6	76.8	55.6
1980	142	61.3	77.1	47.0
1981	152	68.9	82.8	58.3
1982	132	65.9	76.0	55.4
1983	131	66.8	76.2	55.8
1984	108	65.7	82.4	51.3
1985	159	67.0	82.5	53.6
1986	166	68.1	79.0	57.9
1987	149	64.1	74.0	55.2
1988	187	67.7	74.9	56.6
1989	187	65.7	73.7	49.2
1990	128	67.5	75.1	60.1
1991	154	65.2	76.0	53.8
1992	207	66.0	78.1	60.7
1993	237	66.2	77.8	55.6
1994	272	67.6	78.1	55.4
1995	173	64.9	79.3	55.1
1996	148	68.8	78.6	57.5
1997	192	66.4	75.9	60.1
1998	141	69.0	77.4	58.9
1999	206	66.9	76.1	57.2
2000	148	65.2	74.3	55.8
Mean	**165**	**66.3**	**77.3**	**55.6**

Table B-5
Statistical Analysis of Seasonal EWWL versus River Temperature

Non-Parametric Correlations (Kendall's Tau)
EWWL versus Time and Seasonal River Temperature

EWWL-Cold Season	Season	Avg River Temp	Max River Temp	Min River Temp
Kendall's Tau	0.36	0.18	-0.05	0.08
Significance (2-tailed)	10%	41%	84%	73%
EWWL-Warm Season	Season	Avg River Temp	Max River Temp	Min River Temp
Kendall's Tau	0.27	-0.24	0.05	-0.26
Significance (2-tailed)	24%	31%	82%	27%

Note: Significance levels greater than 5% imply absence of significant correlation.

Table B-6
Cold-days EWWL versus All-days EWWL per Season

Manatee Season	EWWL (ft) All Days	EWWL (ft) Cold River Days
1978	171	171
1979	122	122
1980	142	142
1981	152	213
1982	132	132
1983	131	131
1984	108	108
1985	159	159
1986	166	149
1987	149	160
1988	187	187
1989	187	187
1990	128	128
1991	154	154
1992	207	212
1993	237	237
1994	272	272
1995	173	168
1996	148	148
1997	192	176
1998	141	141
1999	206	206
2000	148	146

Test Statistics (Wilcoxon Signed Ranks Test)	
EWWL-Cold River Days versus EWWL-All Days	
Z	-0.084666751
Asymp. Sig. (2-tailed)	0.93252633

Note: Significance greater than 5% (0.05) implies absence of significant difference between the two variables.

Appendix C

Table C-1
Worst Observed River/Spring Conditions

Hydraulic Measure	Parameter Value	Annual Cumulative Probability (%)
Period of Record Minimum 3-day River Stage (2/14/52)	-1.0067 ft	1%
Preceding 25-year Minimum 3-day River Stage (2/5/82)	-0.0067 ft	26%
Period of Record/Preceding 25-year Minimum 3-day River Temperature (12/28/89)	51.4°F	8.5%
Period of Record/Preceding 25 year Minimum Spring Discharge (9/28/00)	97 cfs	4.5%

Data Source	Annual Cumulative Probability (%)			Joint Cumulative Probability (%)	Return Period (years)
	Min Stage (ft)	Min Temperature (°F)	Min Spring Discharge (cfs)		
Period of Record	1.00%	8.50%	4.50%	0.0038%	26,144
Proceeding 25-year Period	26.00%	8.50%	4.50%	0.0995%	1,006

Notes:

Joint cumulative probability is calculated as the product of individual annual cumulative probabilities.
Return period in years is the inverse of the joint cumulative probability.

Figures

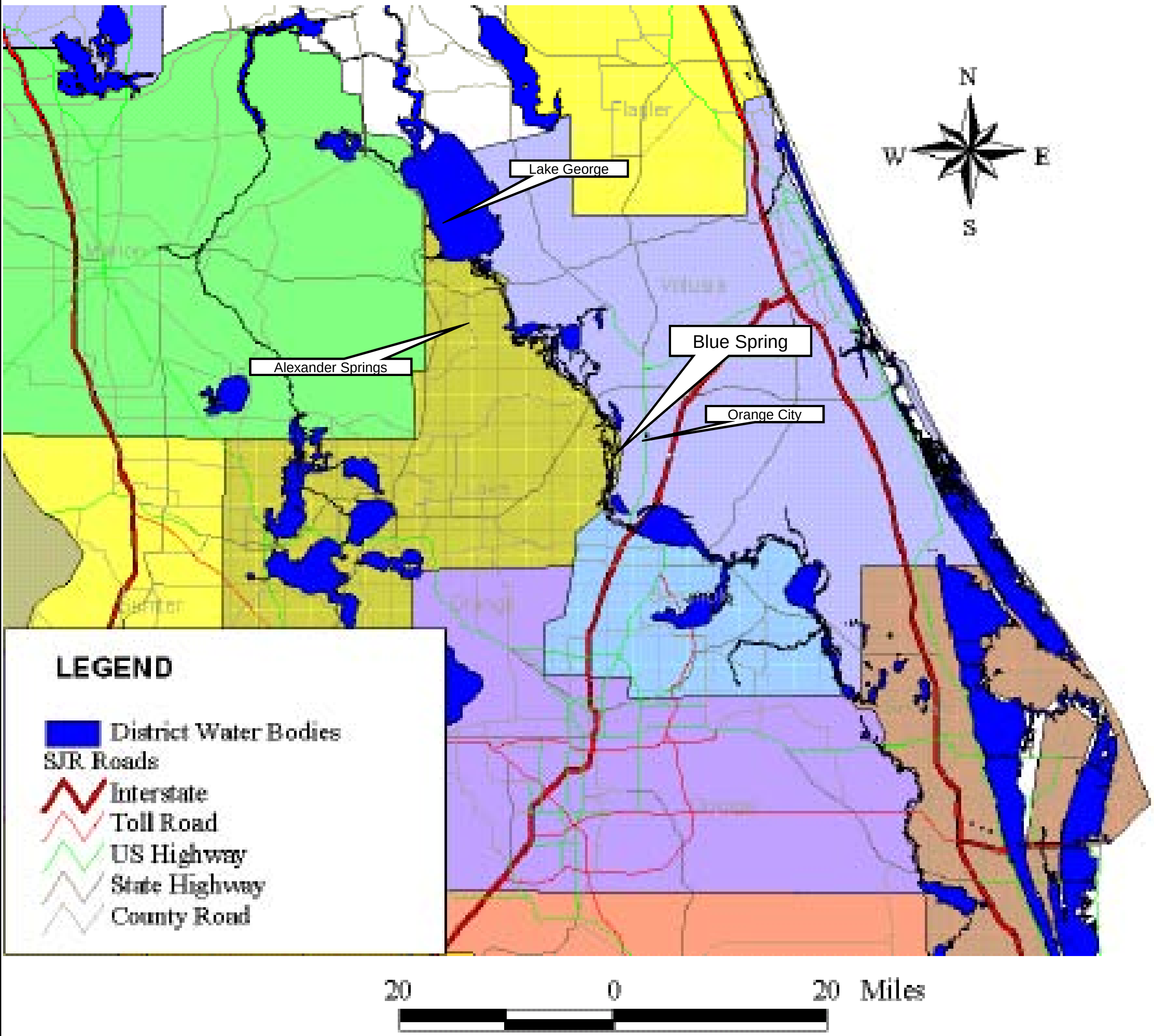


Figure 1-1. Location Map of Blue Spring Run

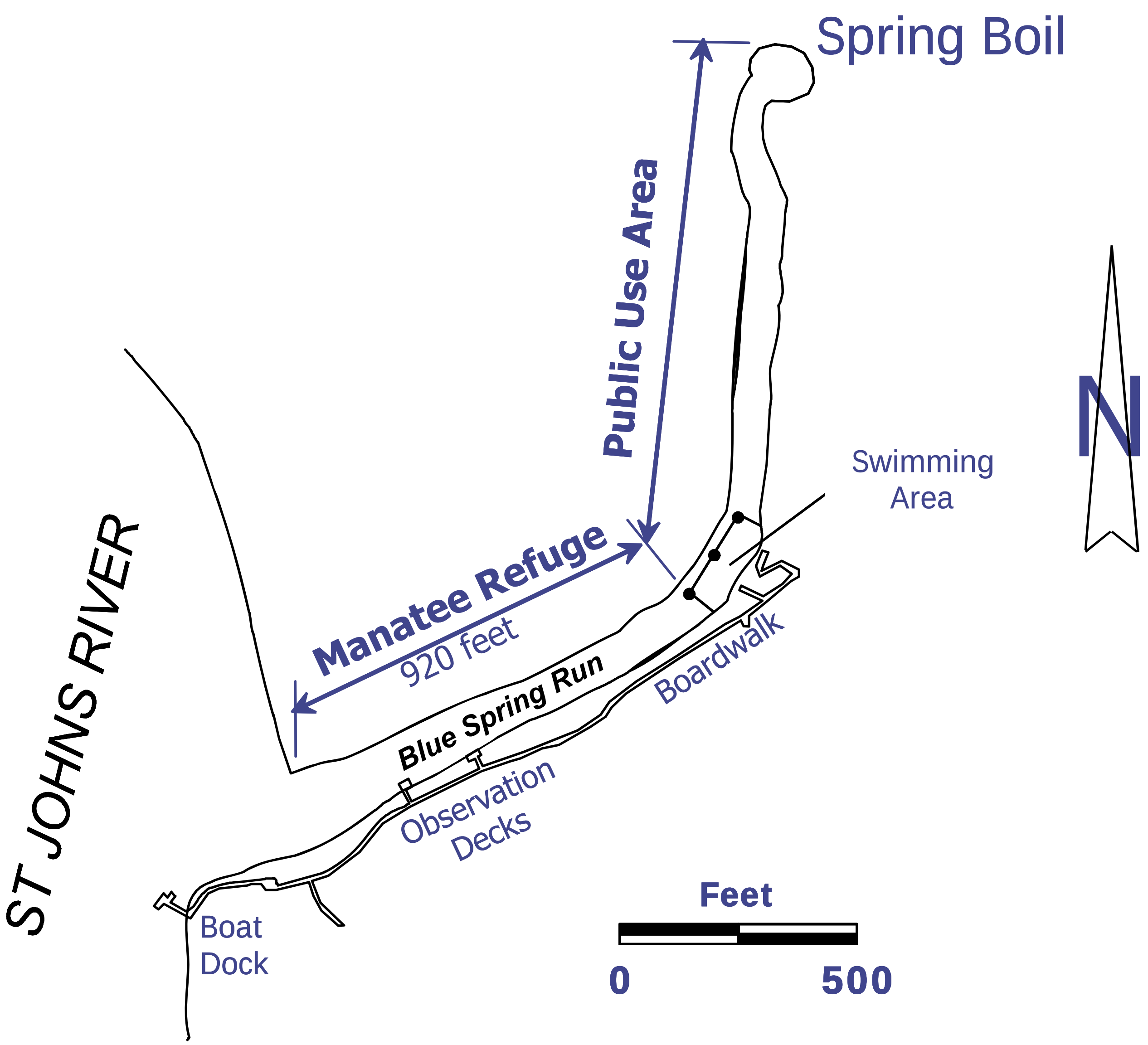


Figure 2-1. Blue Spring Run Schematic

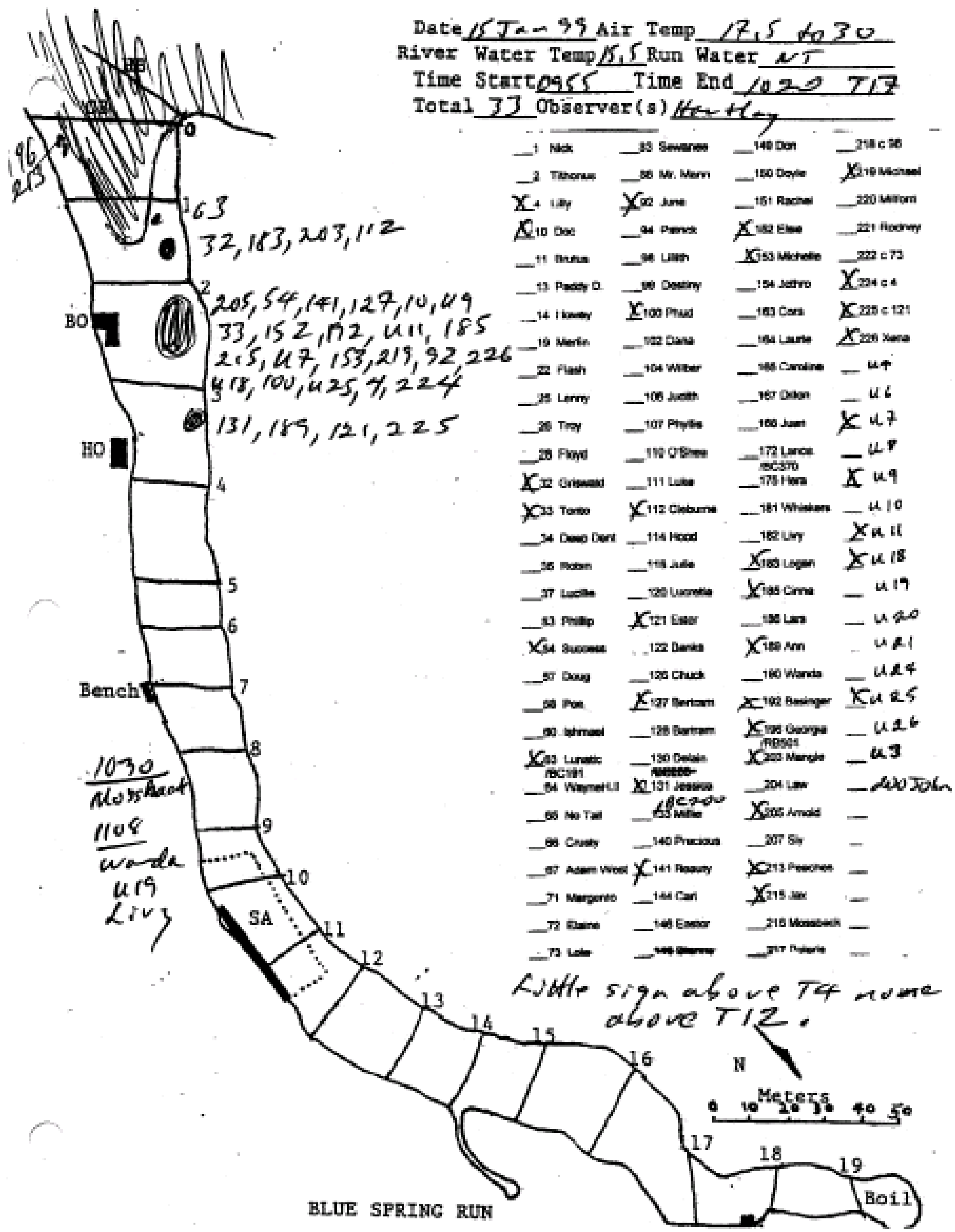


Figure 3.1-1. Example of BSSP Manatee Survey Sheet

Figure 3.1-2. Blue Spring State Park Manatee Survey in Progress

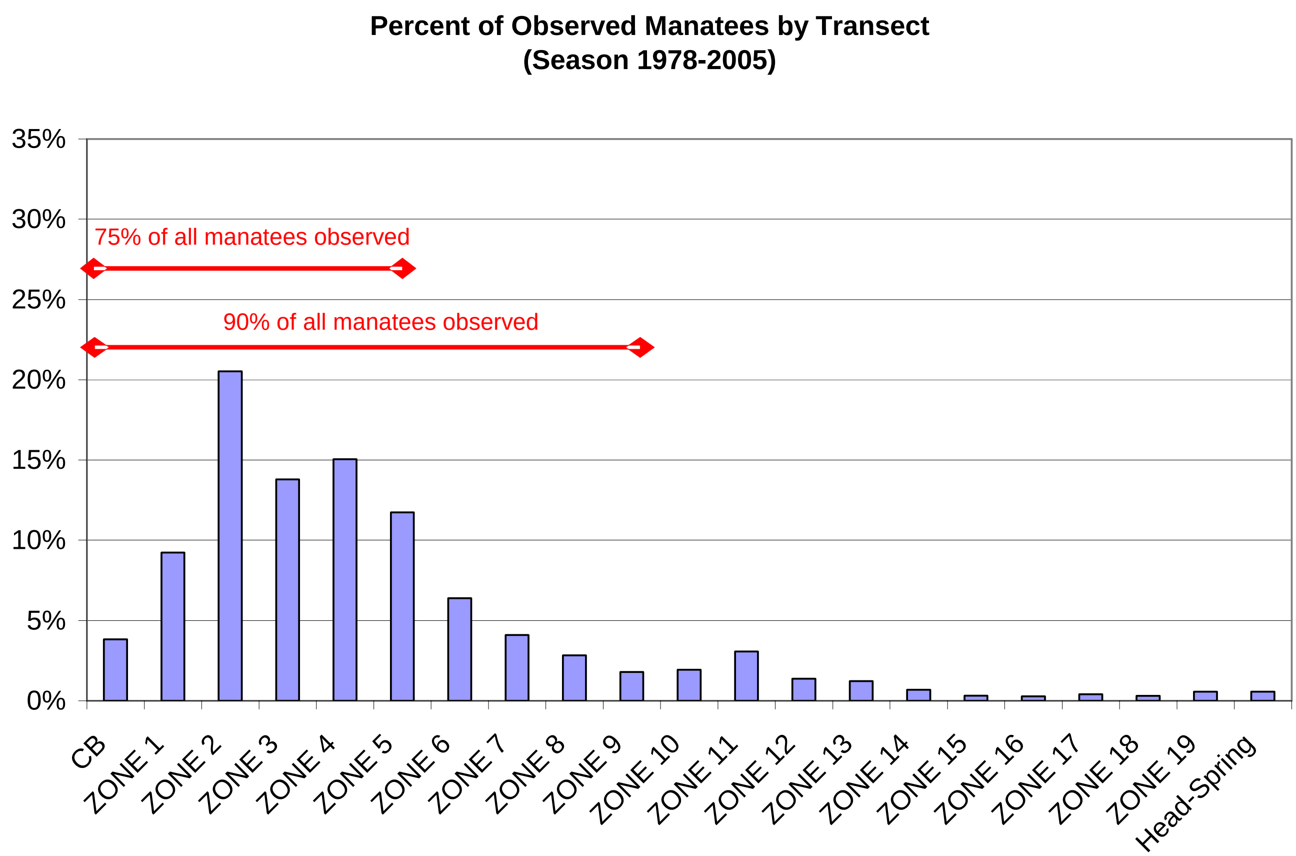
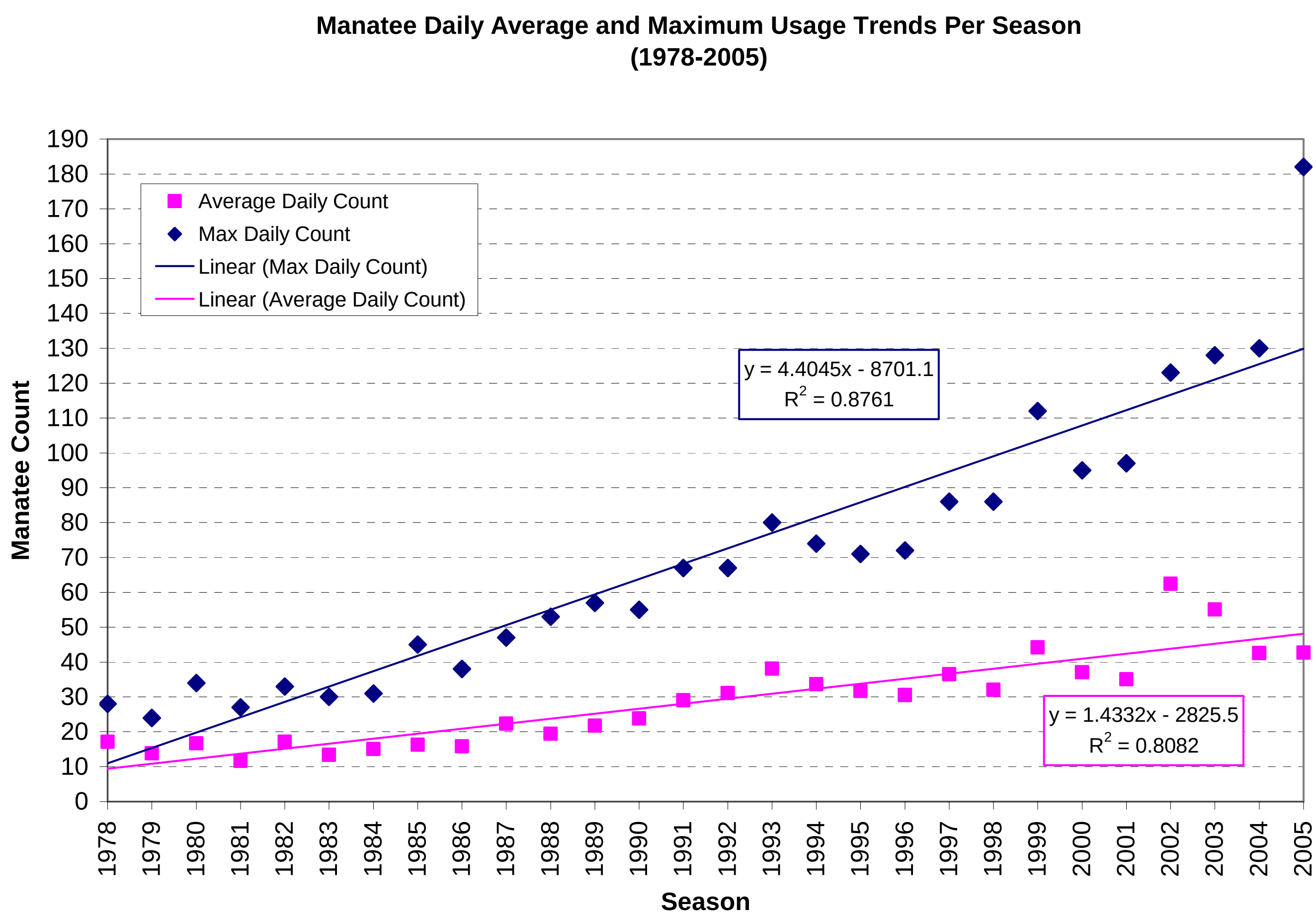
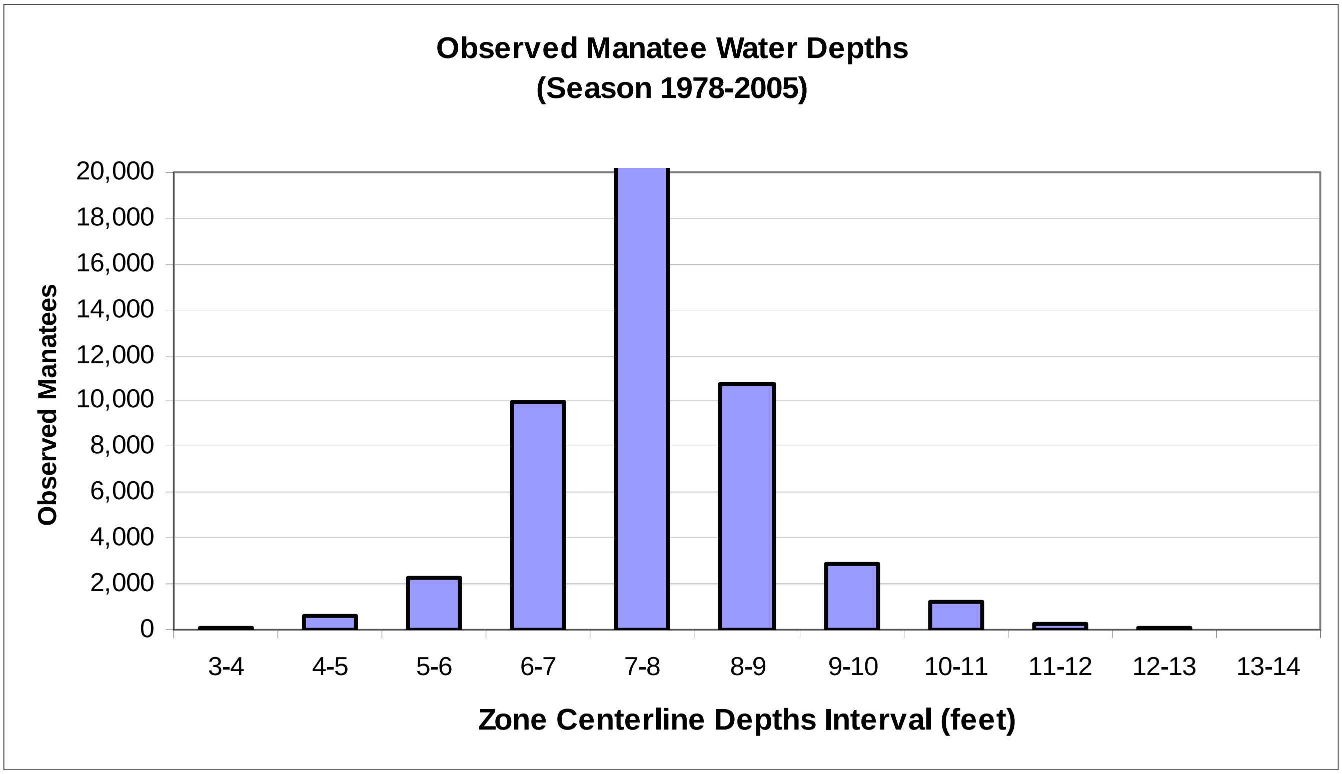


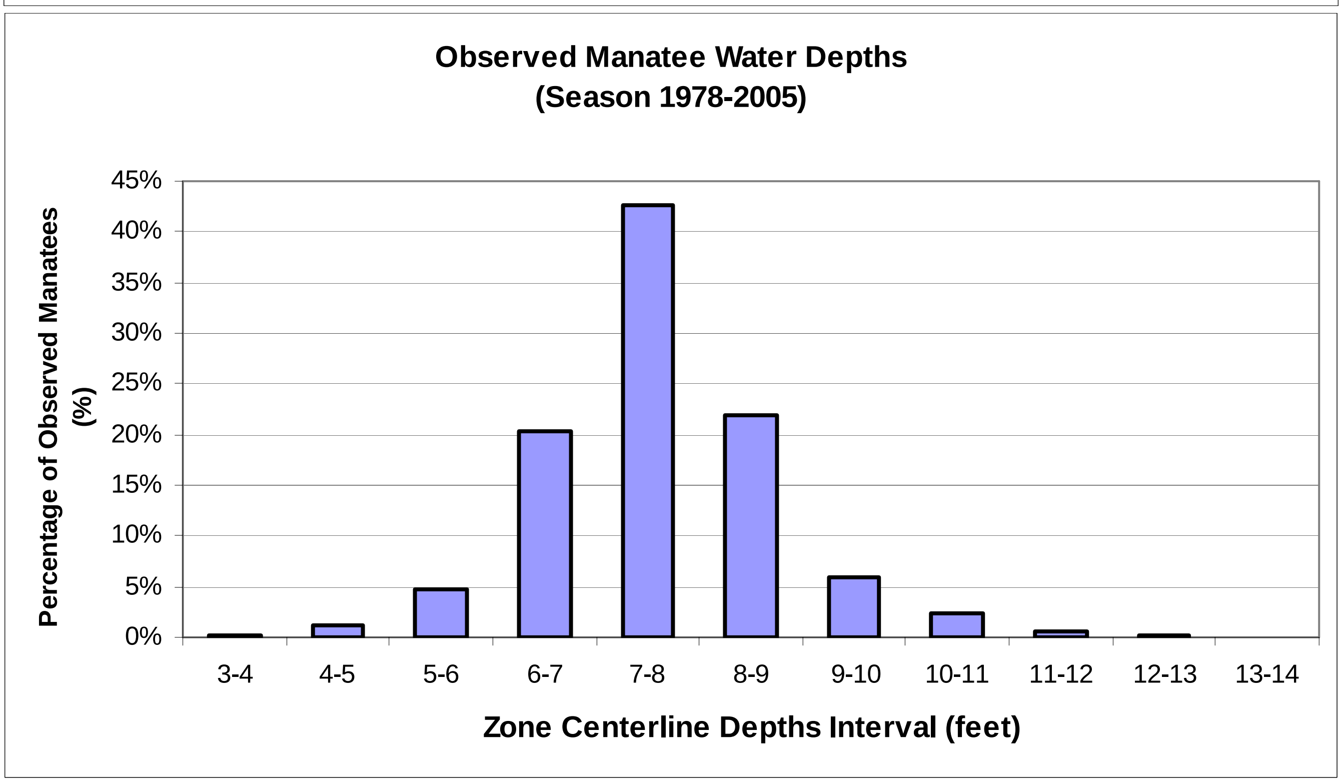
Figure 3.1-3. Percent of the Total Number of Manatees Observed by Blue Spring Run Zone for the 1978 – 2005 Manatee Seasons



Season	Avg. Daily Count	Max Daily Count	Season	Avg. Daily Count	Max Daily Count
1978	17	28	**1992**	31	67
1979	14	24	**1993**	38	80
1980	17	34	**1994**	34	74
1981	12	27	**1995**	32	71
1982	17	33	**1996**	31	72
1983	13	30	**1997**	36	86
1984	15	31	**1998**	32	86
1985	16	45	**1999**	44	112
1986	16	38	**2000**	37	95
1987	22	47	**2001**	35	97
1988	19	53	**2002**	62	123
1989	22	57	**2003**	55	128
1990	24	55	**2004**	43	130
1991	29	67	**2005**	43	182

Figure 3.1-4. Trends in Manatee Average Daily and Maximum Daily Counts per Manatee Season (1978-2005)





(Each interval includes all measured values greater than its lower bound and less than or equal to its upper bound)

Figure 3.1-5. Occurrence of the Number and Percentage of Observed Manatees by Blue Spring Run zone Centerline Water Depth Interval for Manatee Seasons (1978-2005)

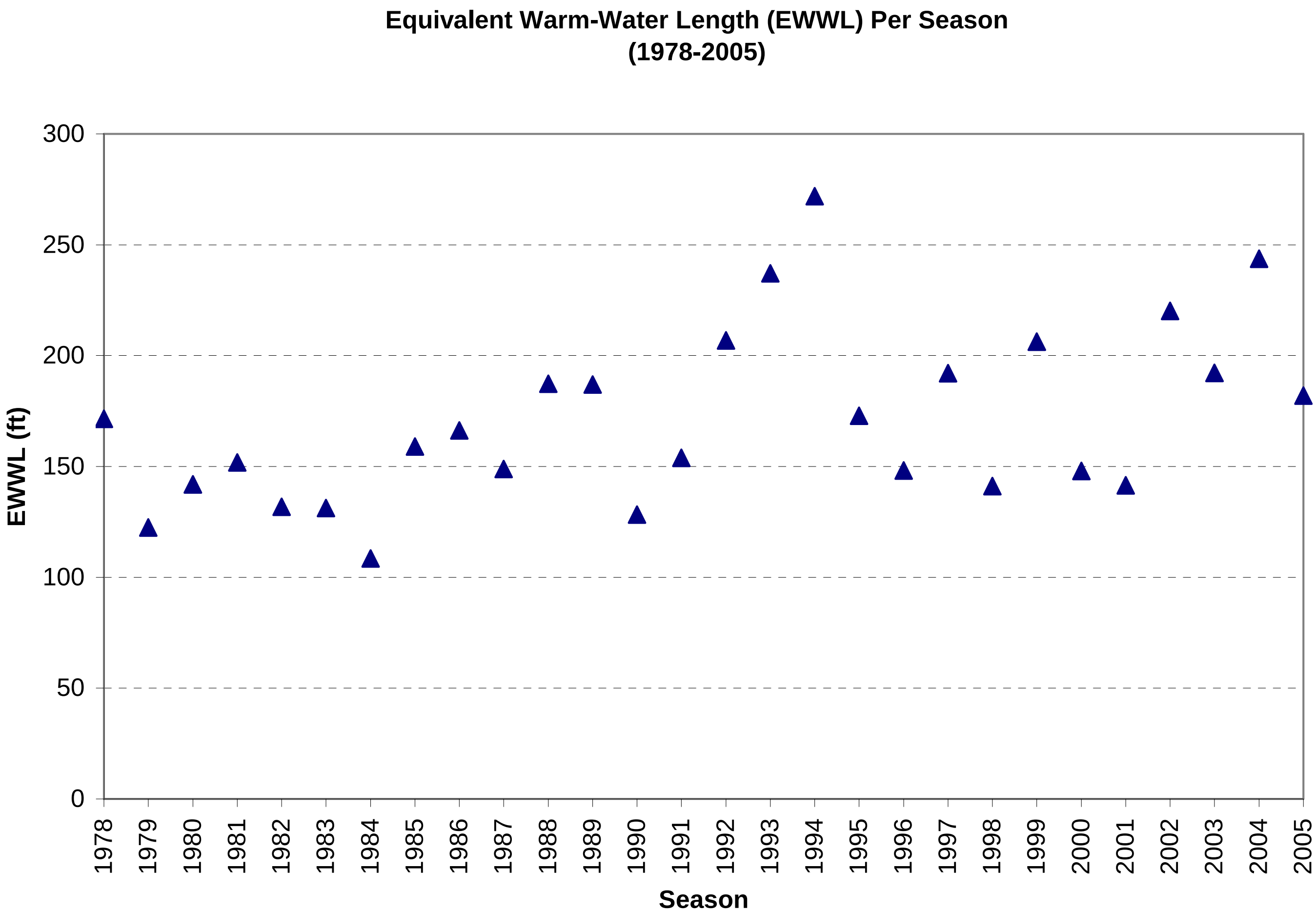
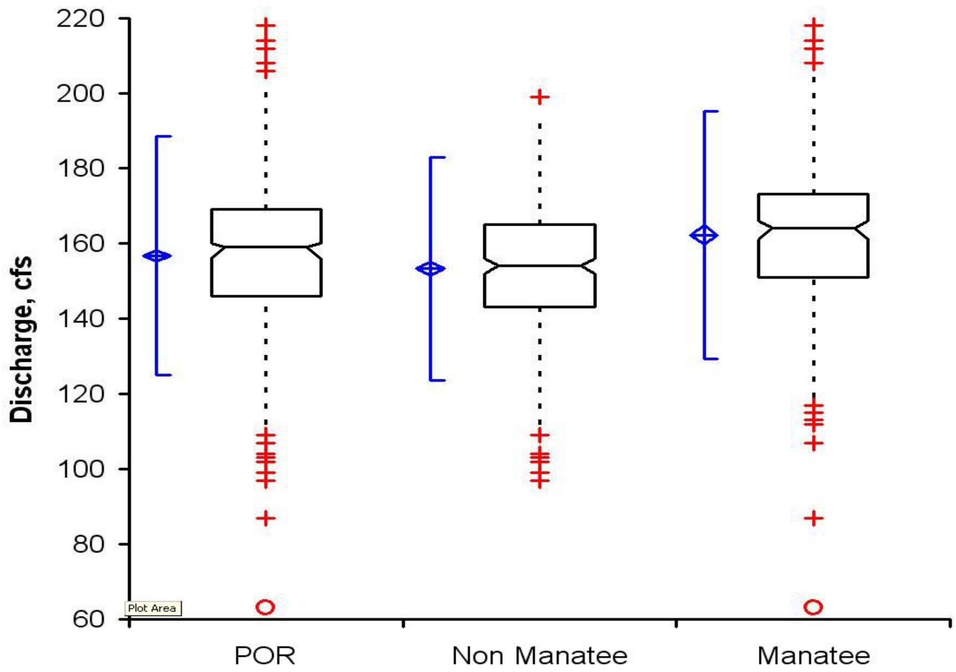
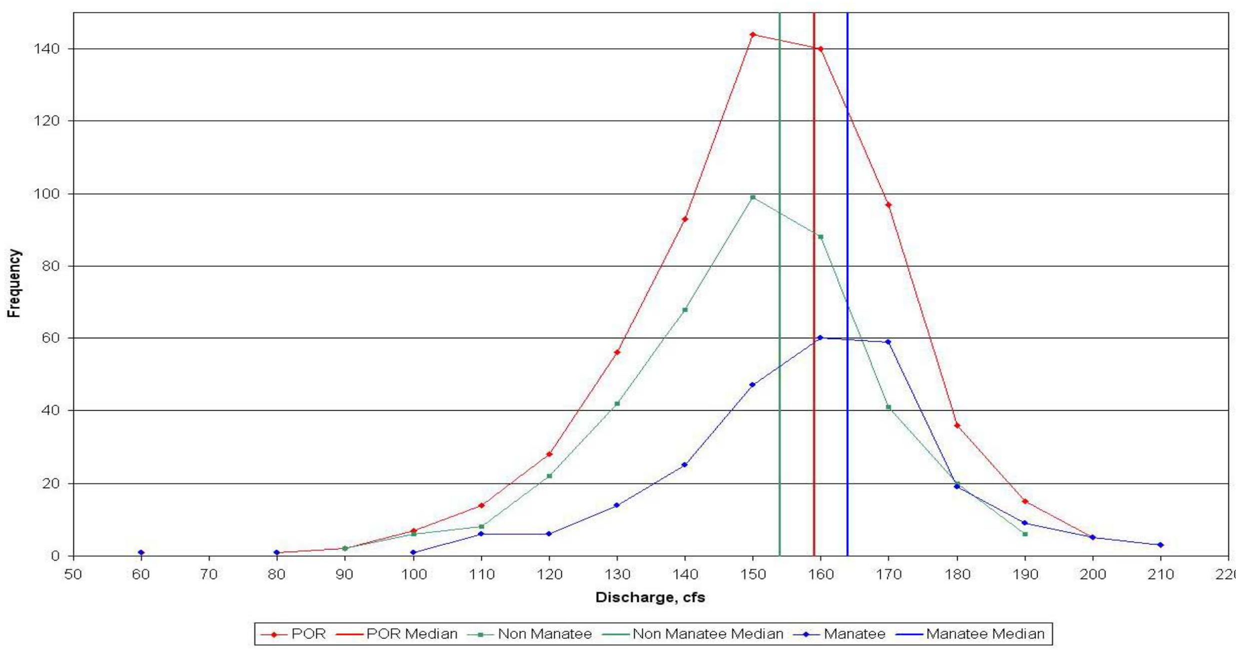


Figure 3.1-6. Plot of Equivalent Warm-Water Length (EWWL) by Manatee Season (1978-2005)



Box plots of Blue Spring instantaneous discharge measurements.
The middle line in the box indicates the median



POR Frequency distribution of Blue Spring instantaneous discharge measurements.

Figure 3.2-1. POR Box Plots and Frequency Distributions of Seasonal Blue Spring Discharge Measurements: March 1932 – June 2006 (Source: Osburn, 2006a)

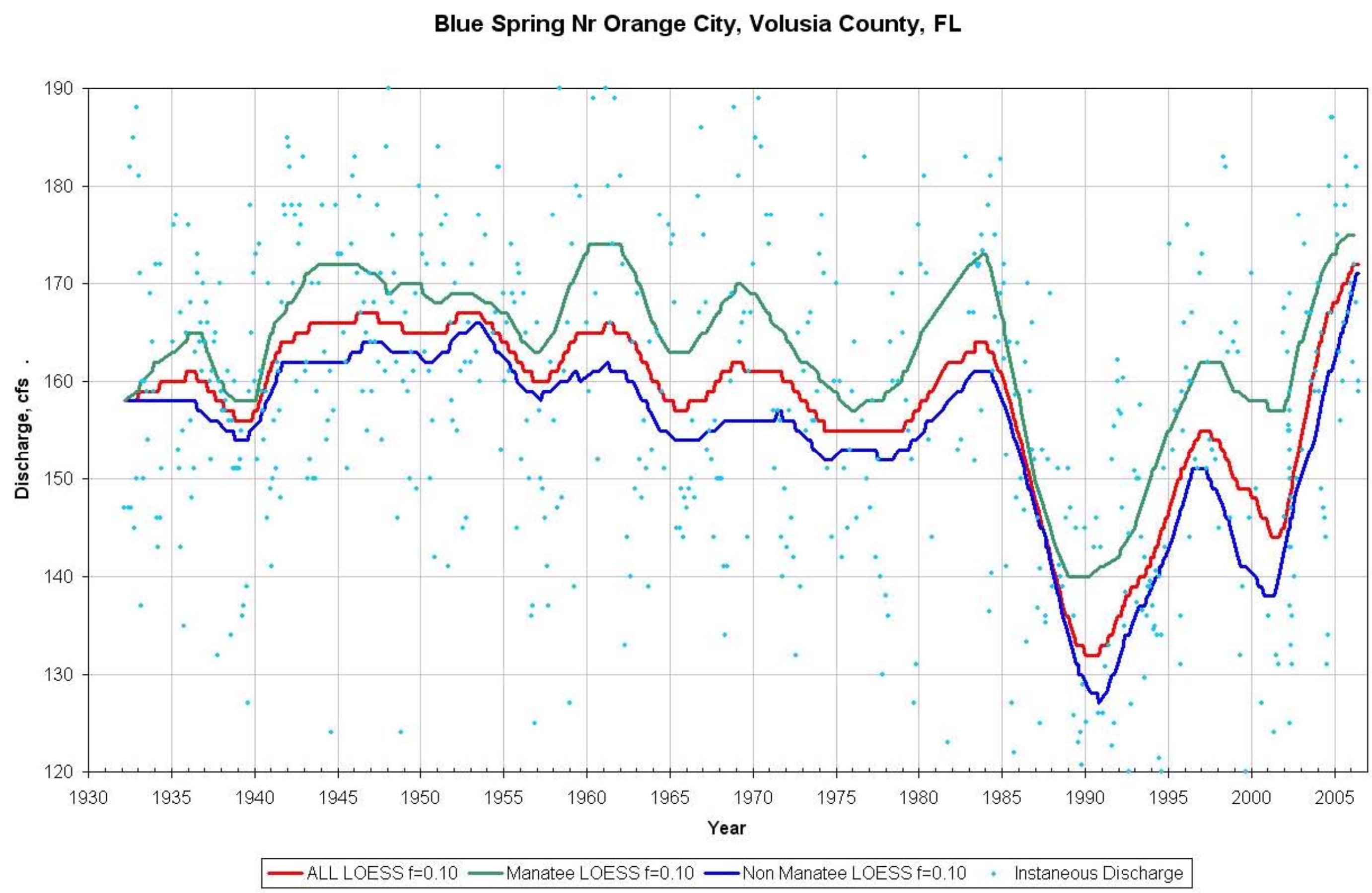


Figure 3.2-2. Locally Weighted Scatter Plot Smoothing (LOESS) Graphs of Blue Spring All, Manatee Season and Non Manatee Season Discharge (Source: Osburn, 2006a)

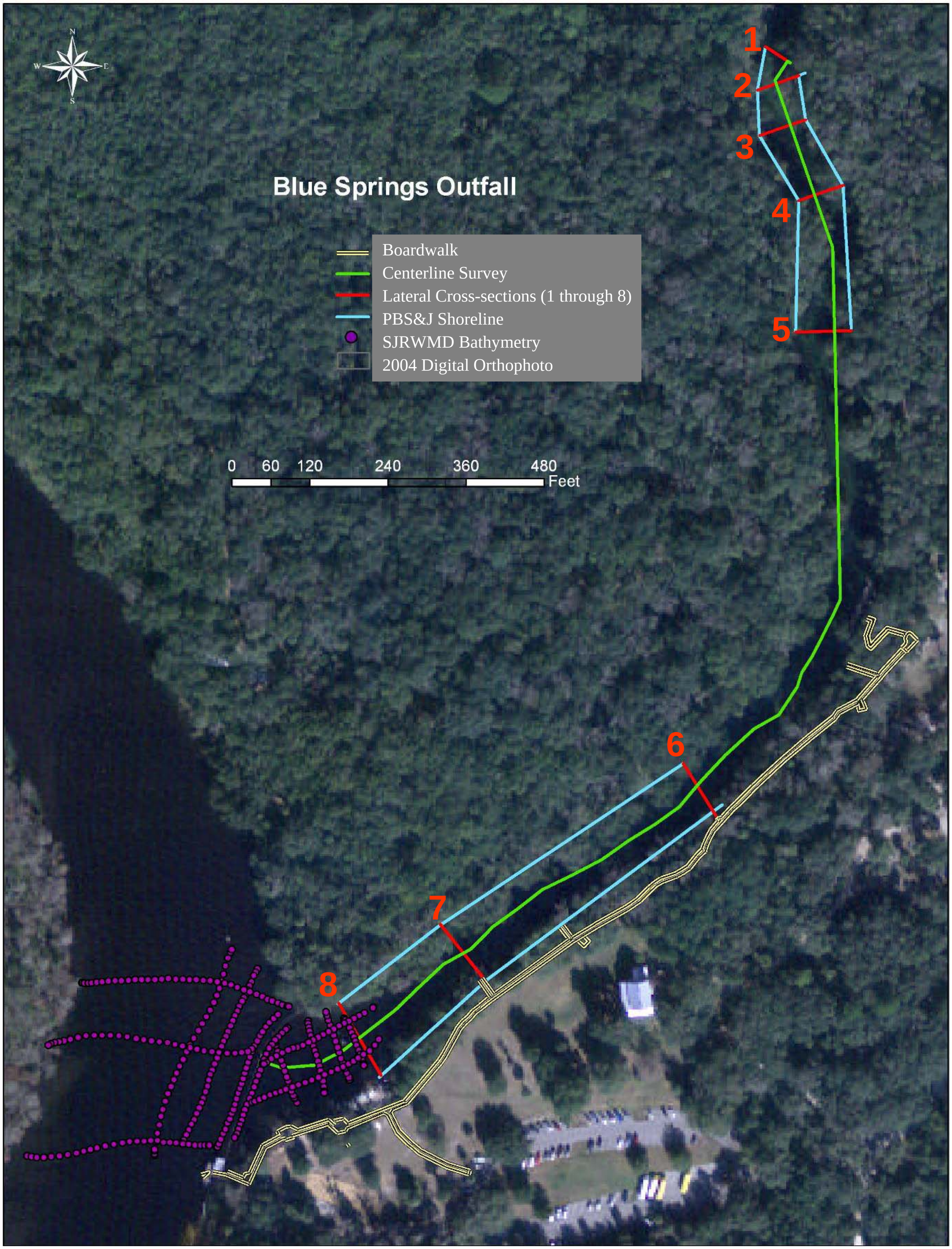


Figure 3.3-1. Locations of Observed Bathymetry in and near Blue Spring Run.

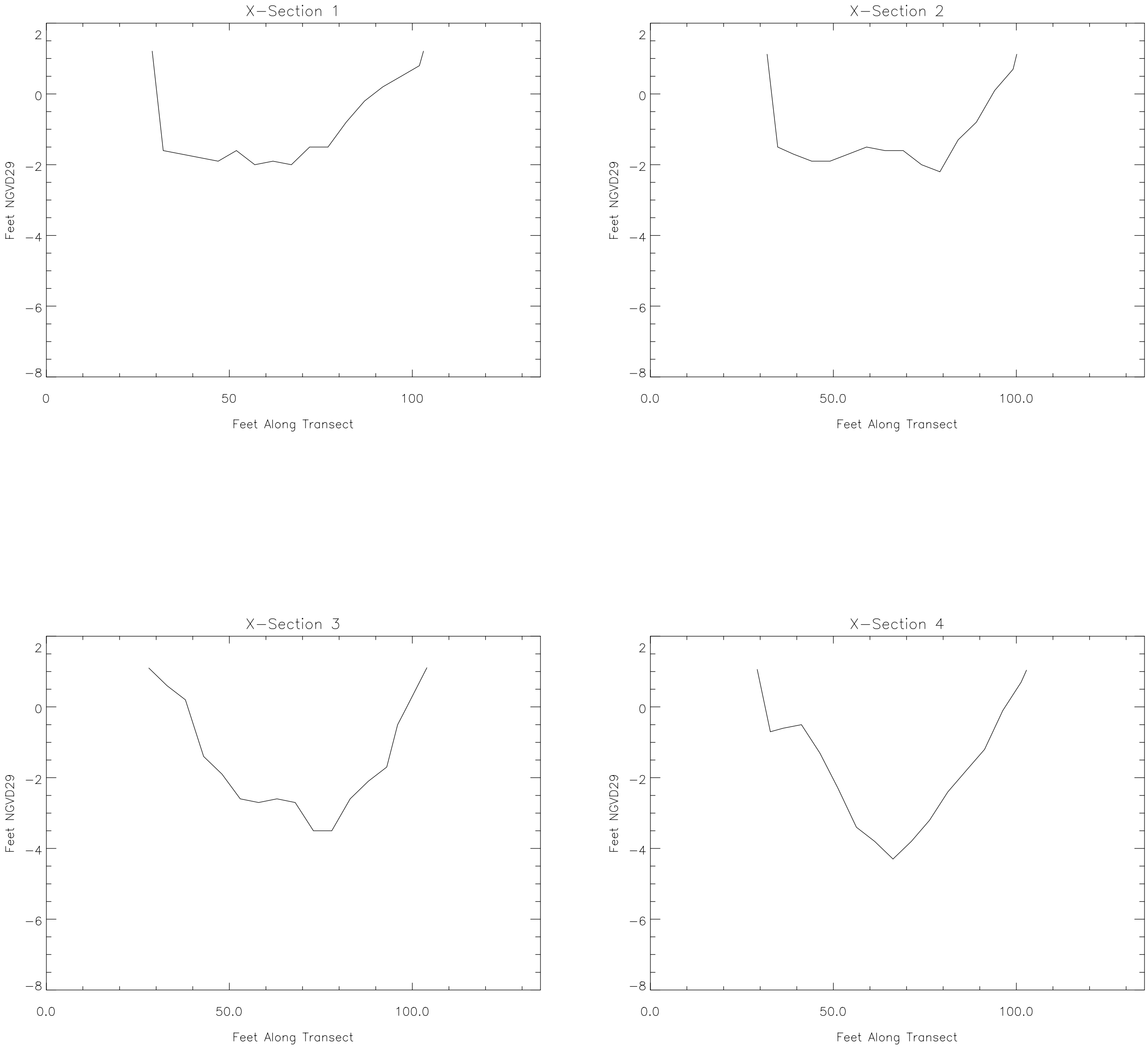


Figure 3.3-2. Lateral Cross-Sections 1 though 4 within Blue Spring Run.
(Source: Post, Buckley, Schuh, and Jernigan, 1995.)

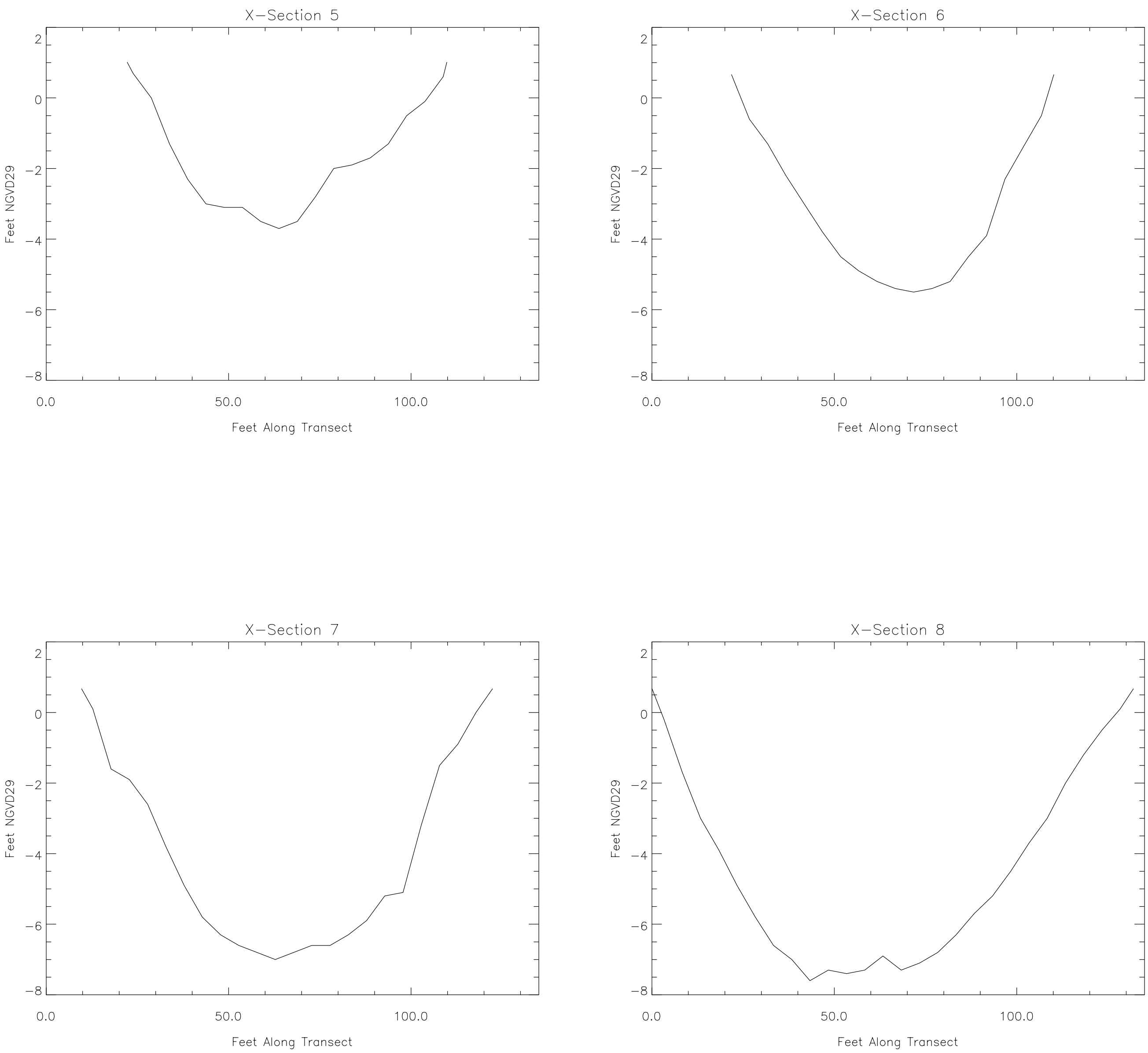


Figure 3.3-3. Lateral Cross-Sections 5 though 8 within Blue Spring Run. (Source: Post, Buckley, Schuh, and Jernigan, 1995.)

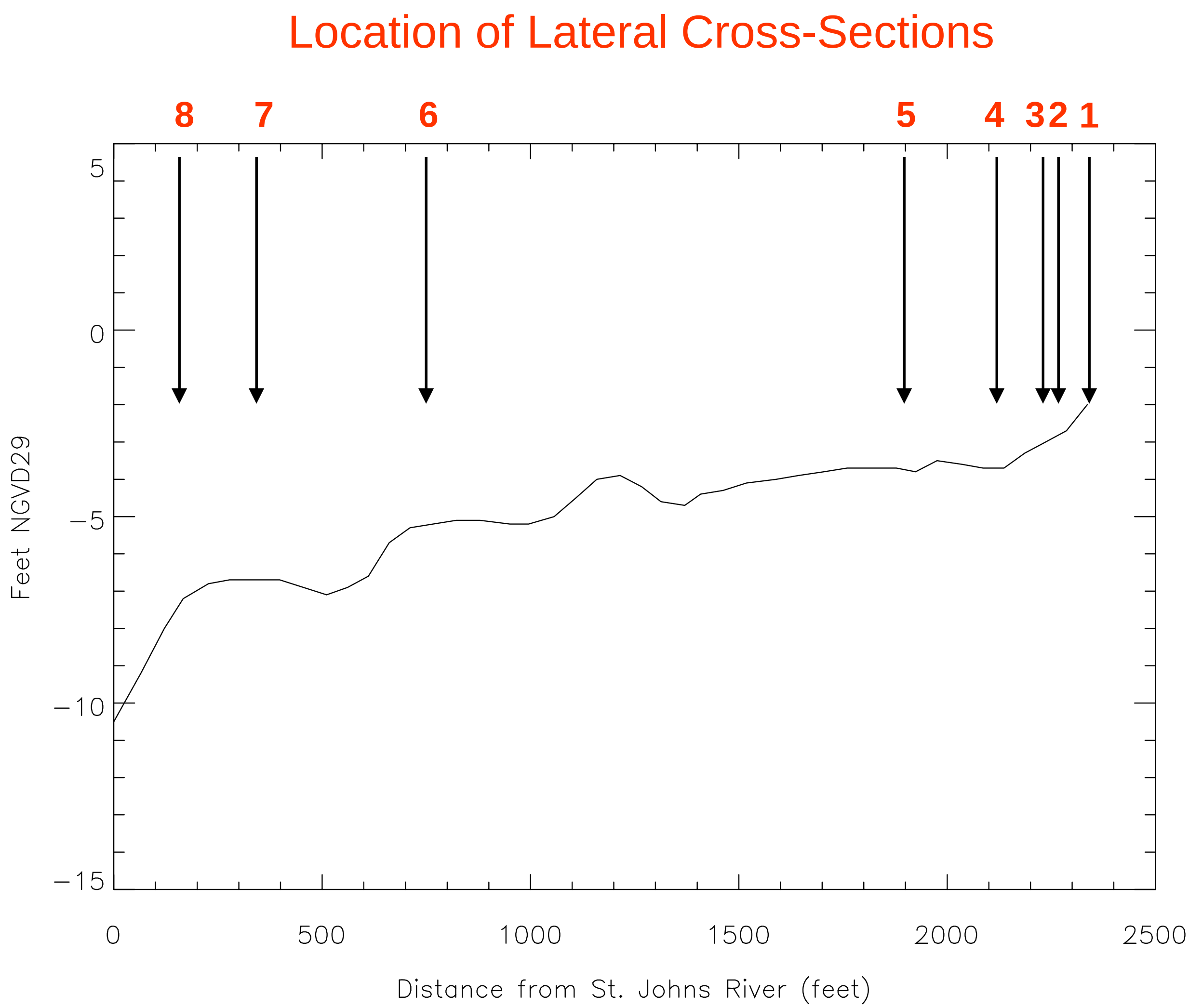


Figure 3.3-4. Centerline bottom elevation for Blue Spring Run.
(Source: Post, Buckley, Schuh, and Jernigan, 1995.)
The arrows show the locations of the 8 lateral transects, numbered from right to left.

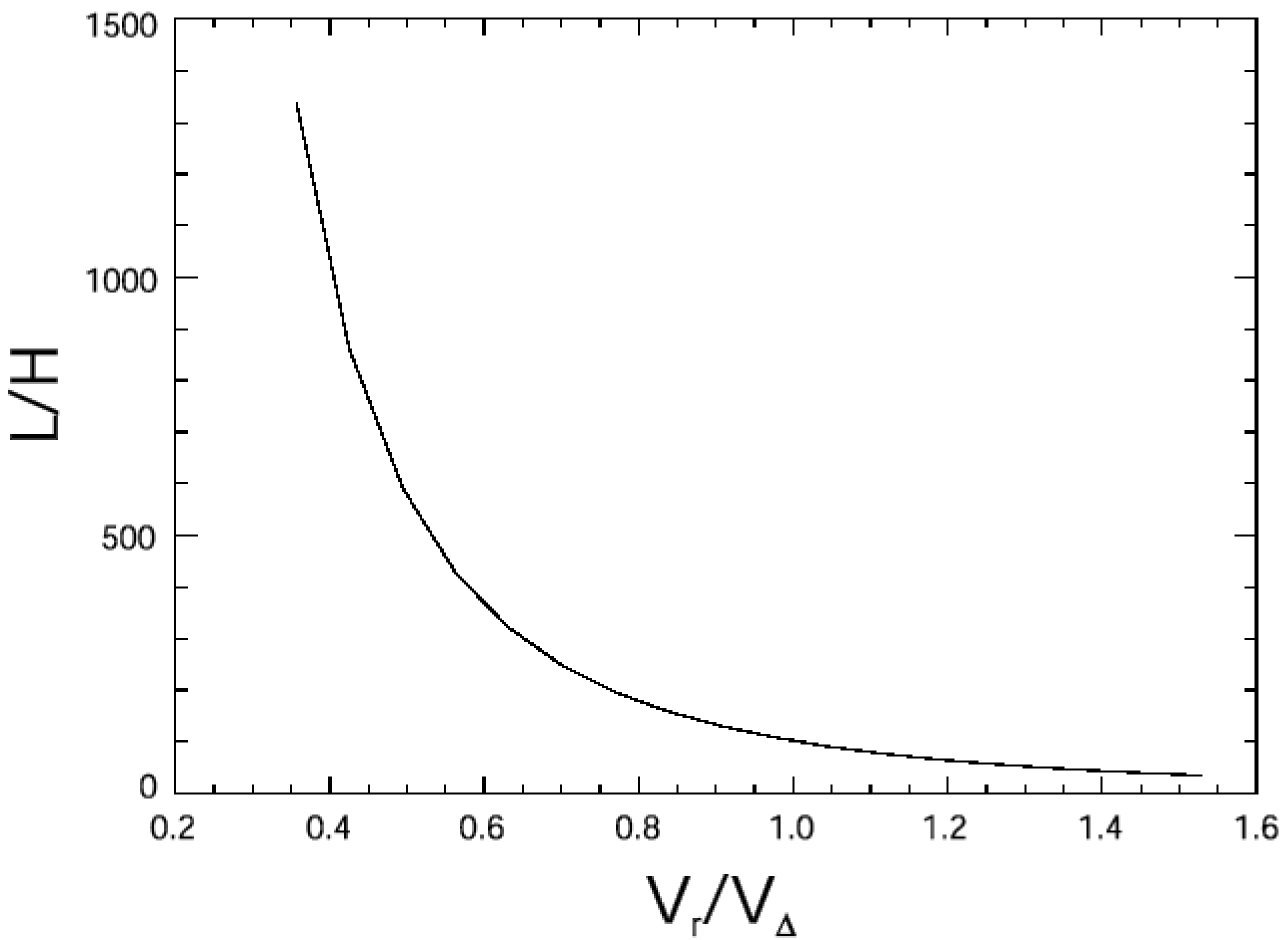


Figure 3.3-5. Relationship between V_r/V_Δ, the ratio of outflowing velocity and densimetric velocity, and (L/H), the ratio of intrusion length and depth for a channel similar in characteristics to Blue Spring Run. The values were calculated for a 100 ft wide by 5 ft deep channel with a temperature difference of 23 F. This figure illustrates the characteristic of the relationship between intrusion length and flow that would be expected for Blue Spring.

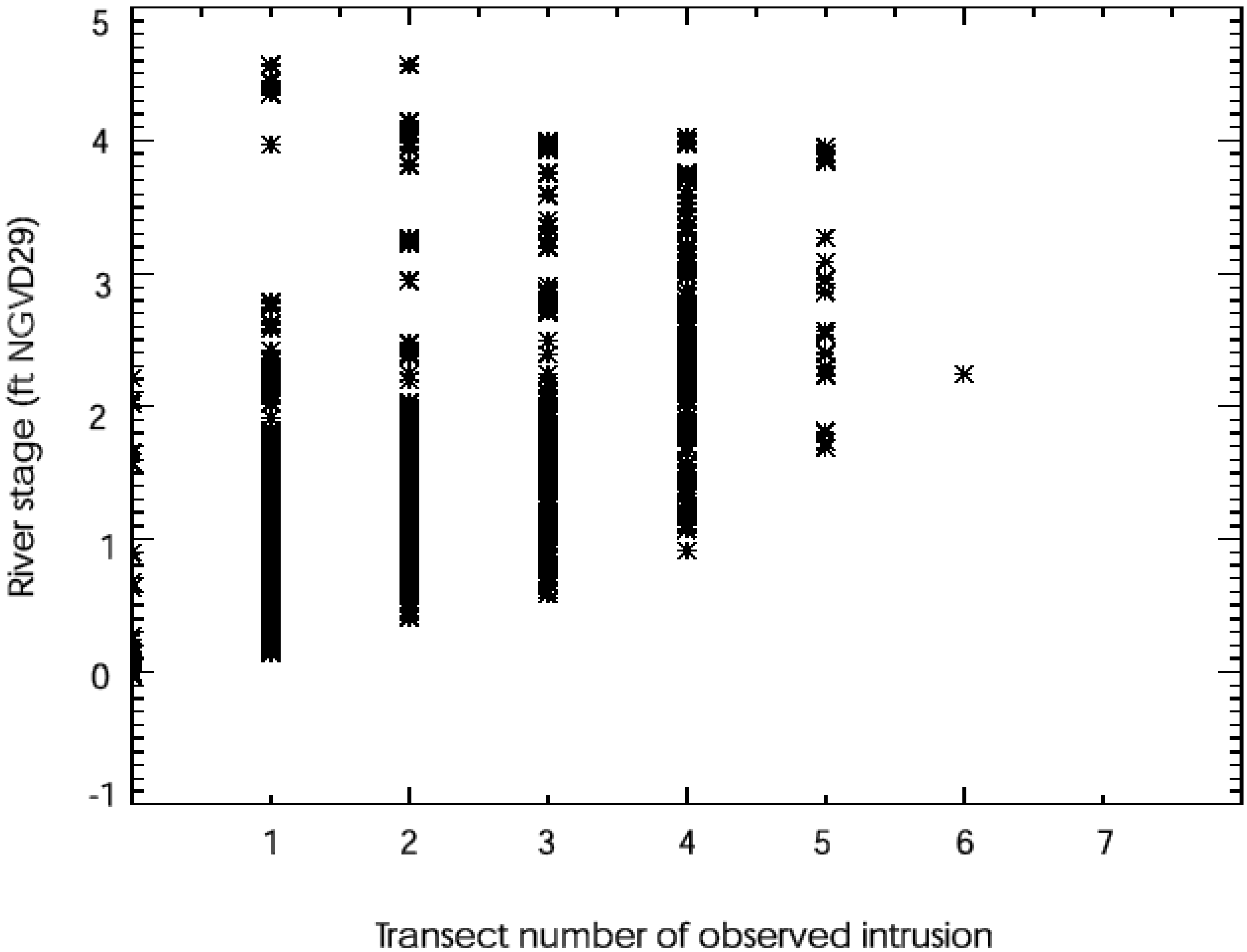


Figure 3.3-6. Transect number of observed intrusion compared with observed river stage. Larger intrusions tend to occur at higher river stage, as expected, but high river stages don't necessarily result in large intrusions.

Note: St. Johns River stage is measured at DeLand at SR44 Crossing

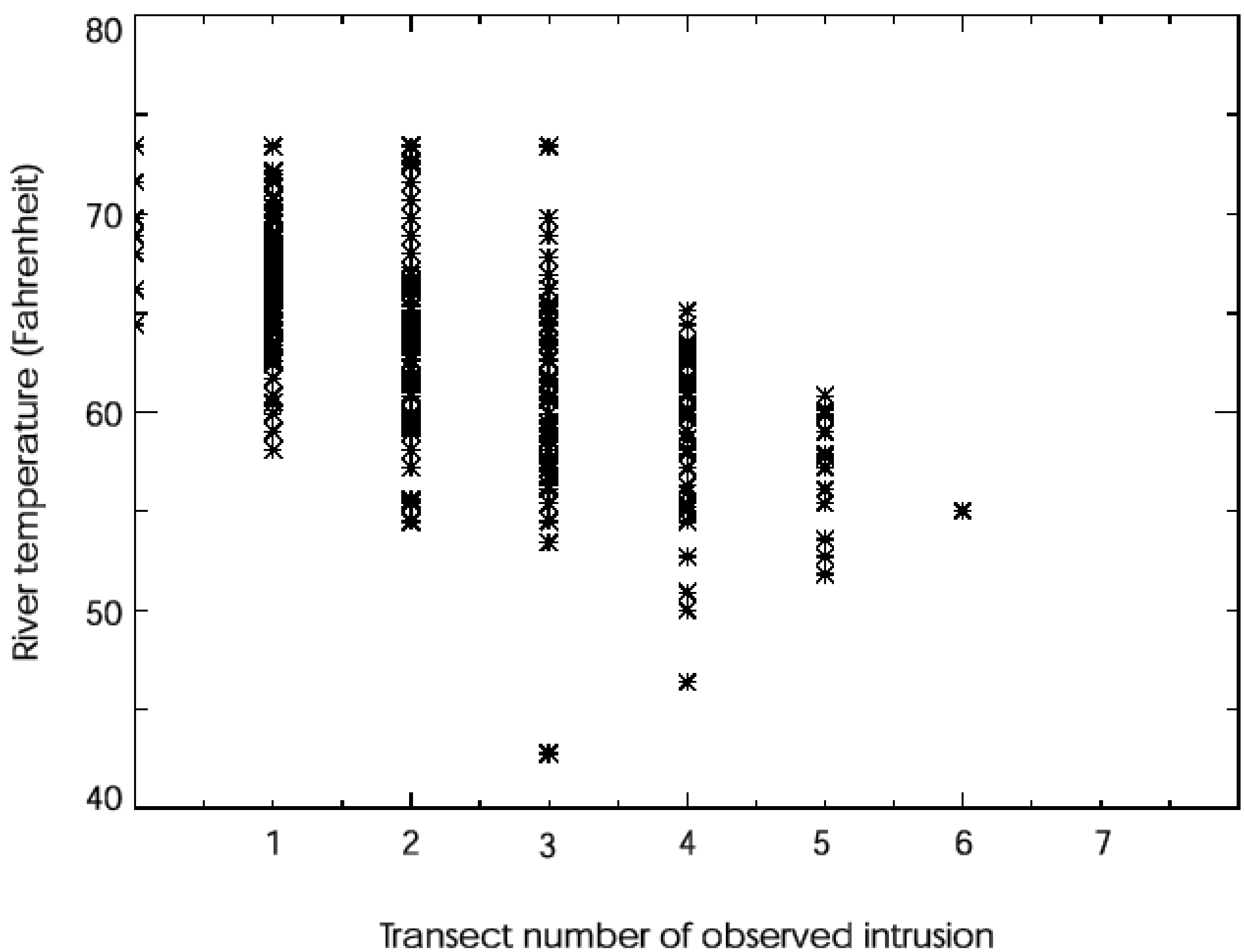


Figure 3.3-7. Transect number of observed intrusion compared with observed river temperature. Larger intrusions tend to occur at colder river temperatures because of the increased density difference between the river water and spring water.

Note: River temperature is the observed temperature reported during the daily morning manatee survey.

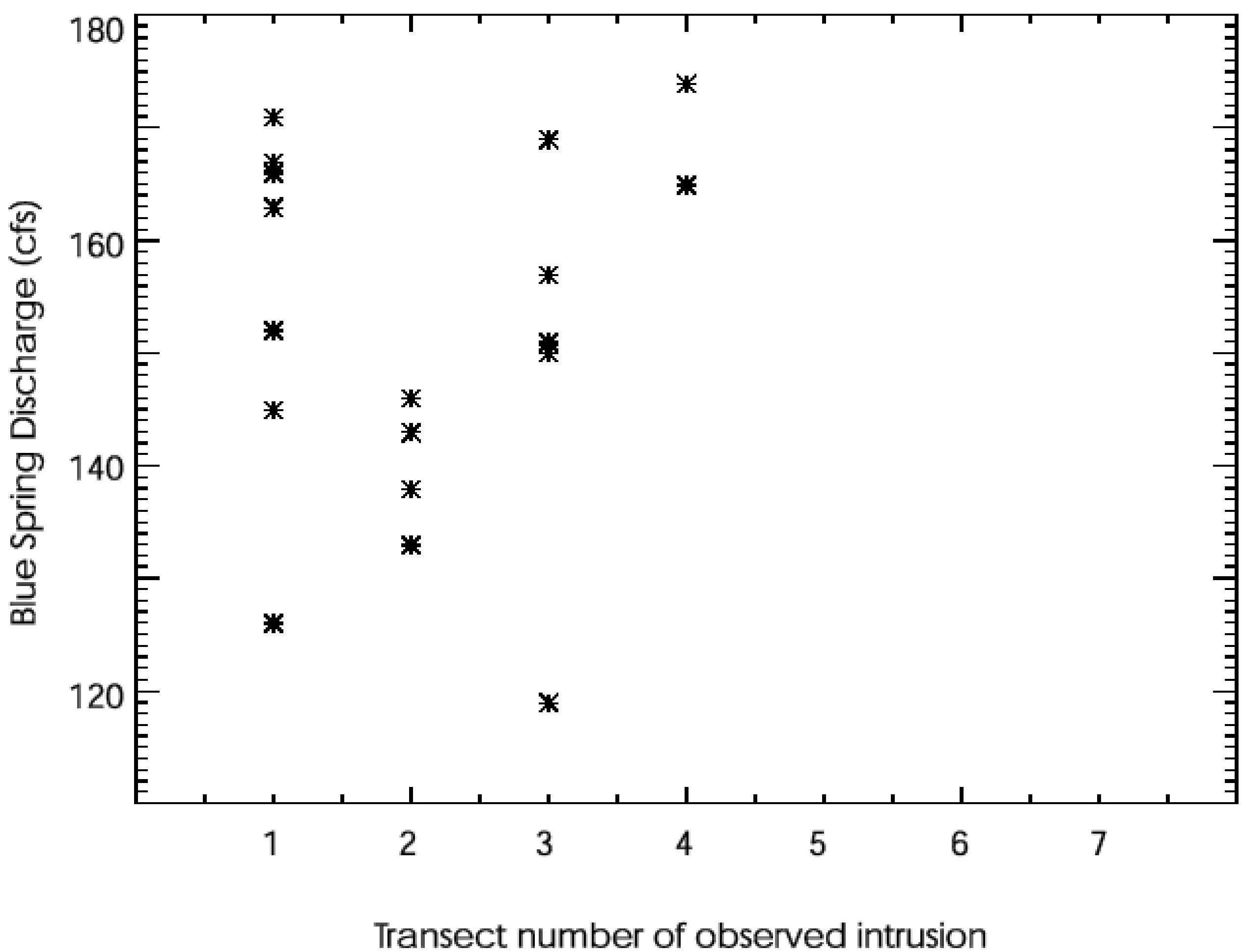


Figure 3.3-8. Transect number of observed intrusion compared with observed discharge from Blue Spring. Although discharge affects intrusion length, no relationship is discernible here because of masking by river stage and temperature.

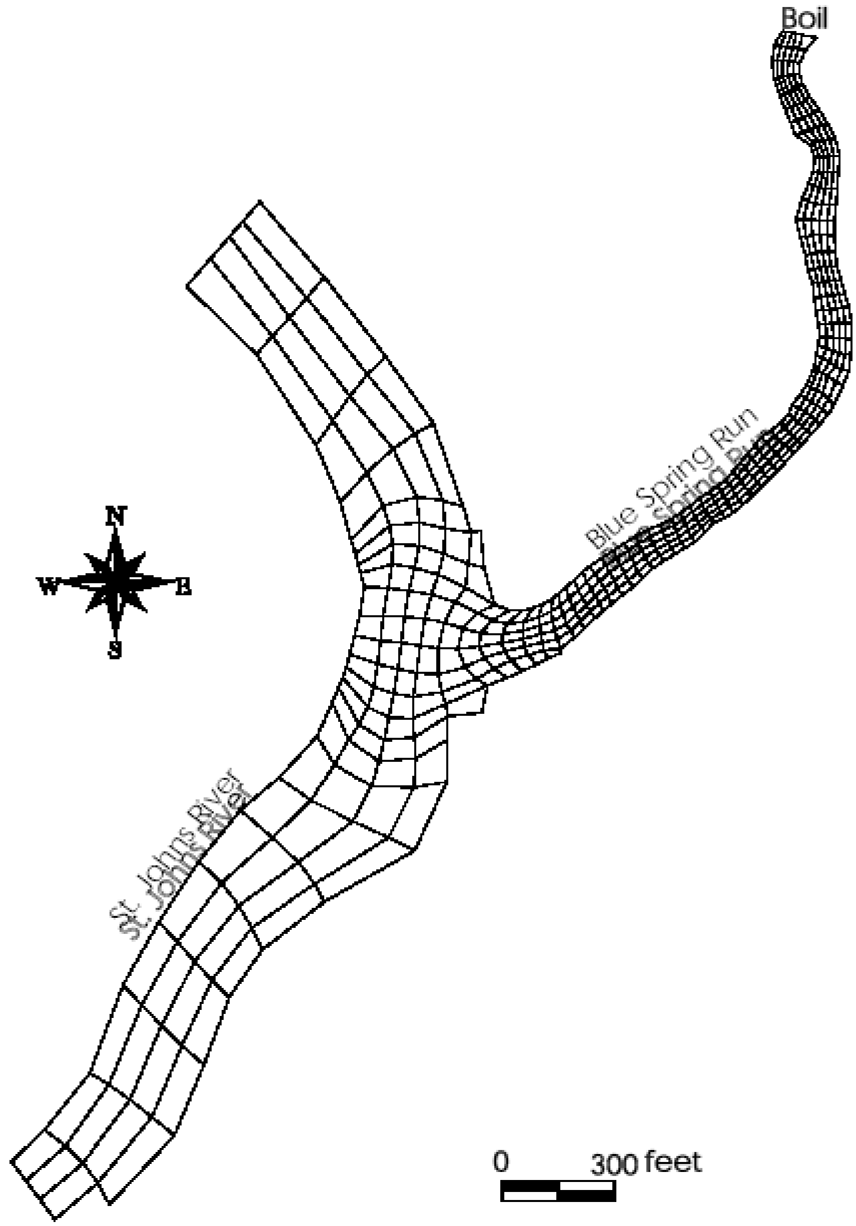


Figure 3.3-9. Model grid of Blue Spring Run and adjacent portion of St. Johns River.

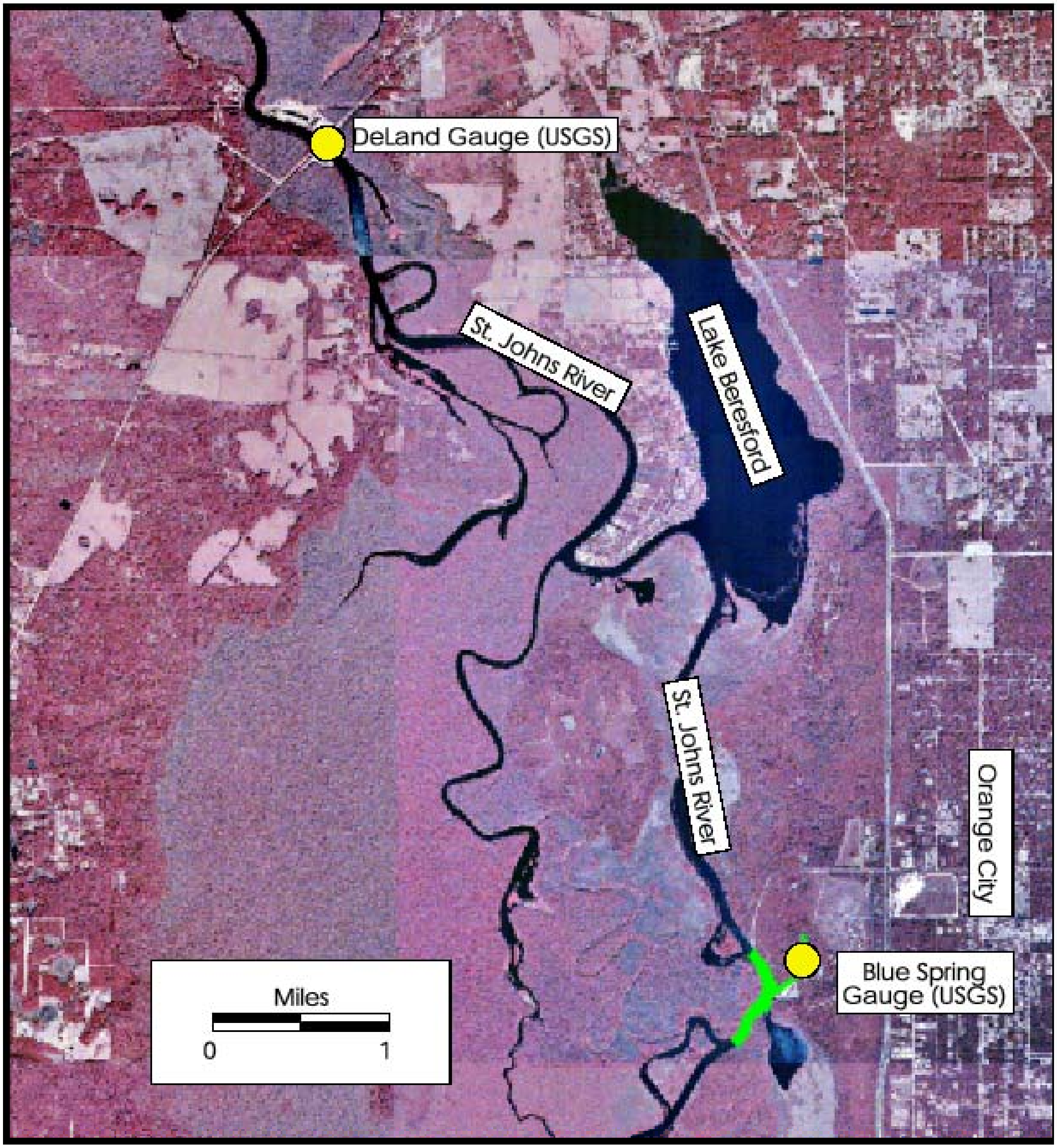


Figure 3.3-10. Overview of model grid (denoted in green) and locations of stations used to provide model boundary conditions (denoted as yellow circles). A USGS gauge near DeLand provided daily river discharge and stage for forcing at the model upstream and downstream open boundaries, respectively. Observations made in and near Blue Spring Run by USGS and BSSP were used to set discharge and temperature for the Blue Spring inflow boundary, and river temperature at the upstream open boundary.

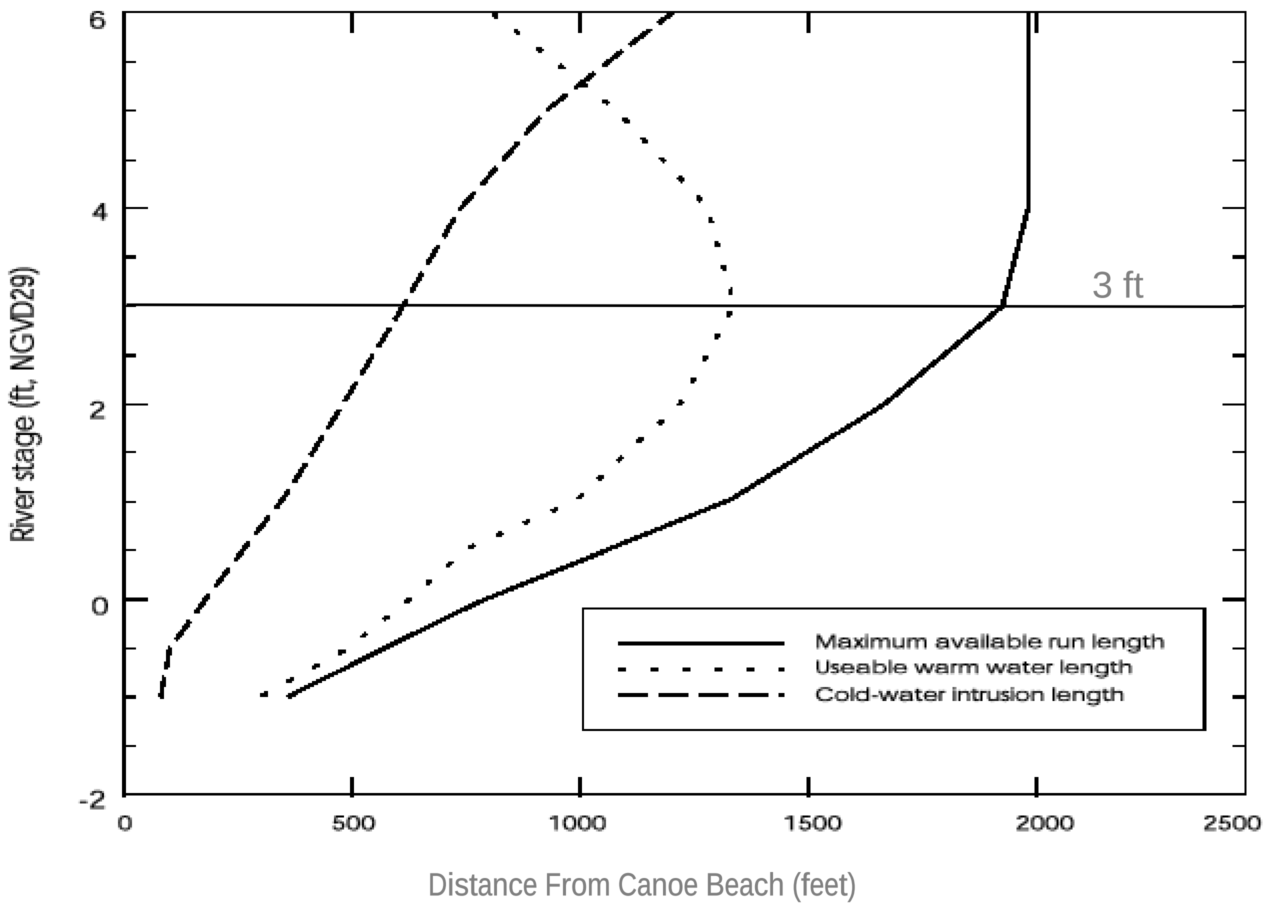


Figure 3.3-11. Relationship between cold-water intrusion and useable warm water length for river stage ranging from -1.0 to 6.0 ft NGVD29.
Useable warm water length is reduced by large intrusions, as typically occur at high stage, or reduction of channel depth, as occur at low stage.

Note: Cold-water intrusion and warm water length were calculated, for the sake of illustration, using a river temperature of 60F and spring discharge of 150 cfs. Selecting different values of temperature and discharge would change the absolute values of cold-water intrusion and, hence, useable warm water length, but the curve of warm water length would retain its characteristic shape.

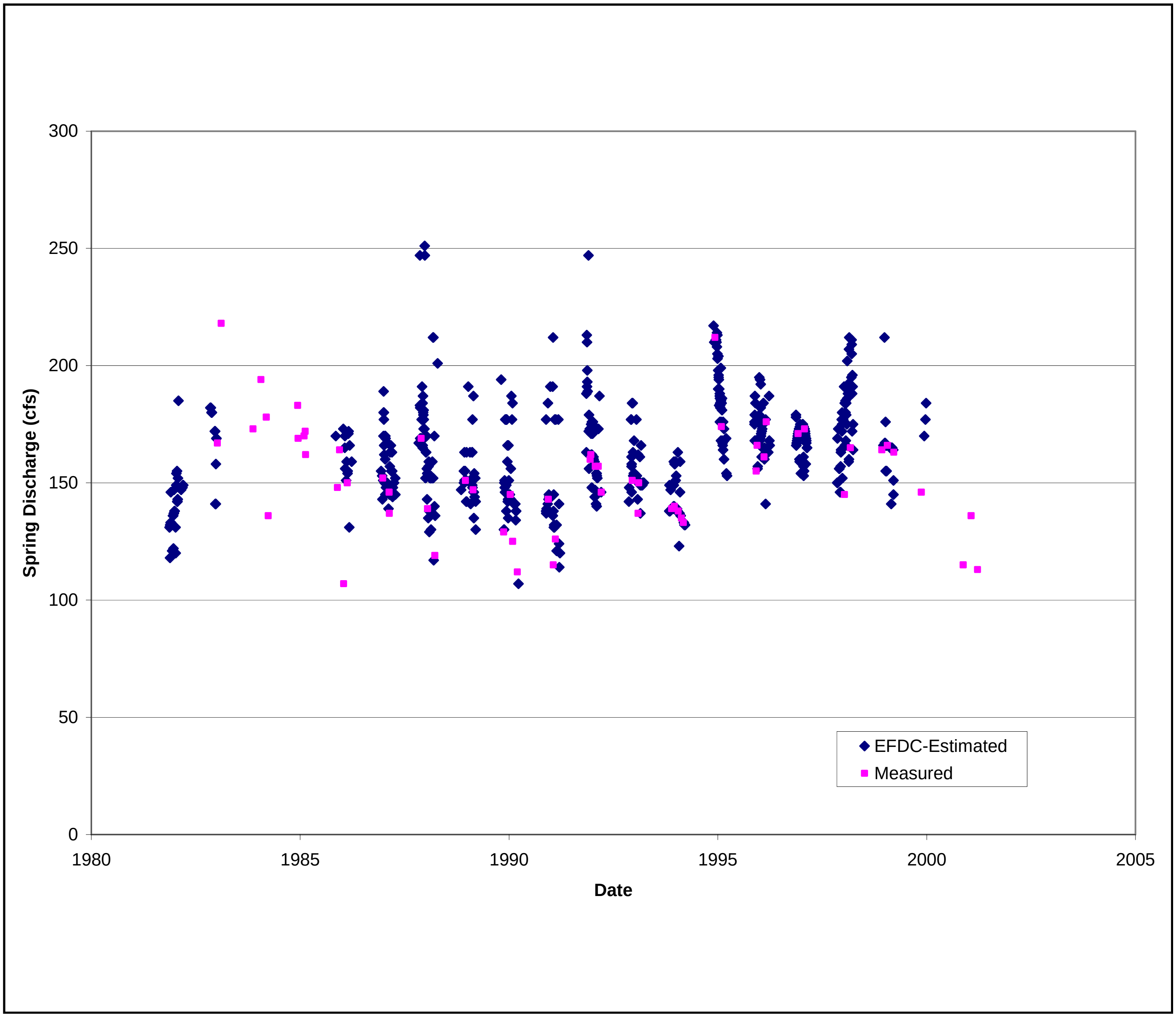


Figure 3.4-1. EFDC-Estimated versus Measured Spring Discharges during Manatee Seasons 1981-1999

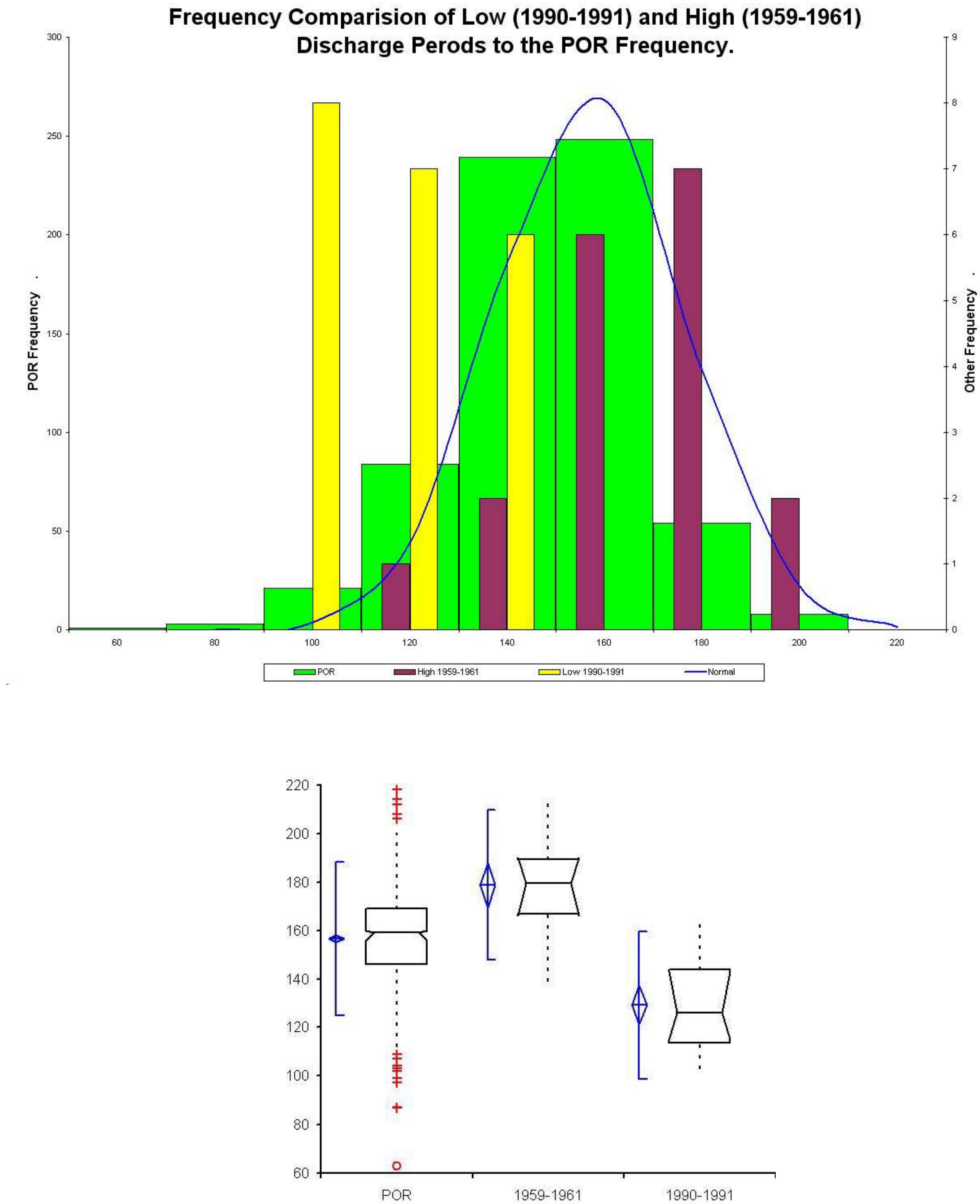


Figure 3.4-2. Comparison of Discharge Histograms and Box Plots during POR (March 1932 to June 2006) to Low (1990-1991) and High (1959-1961) Periods
(Source: Osburn, personal communication, 2006)

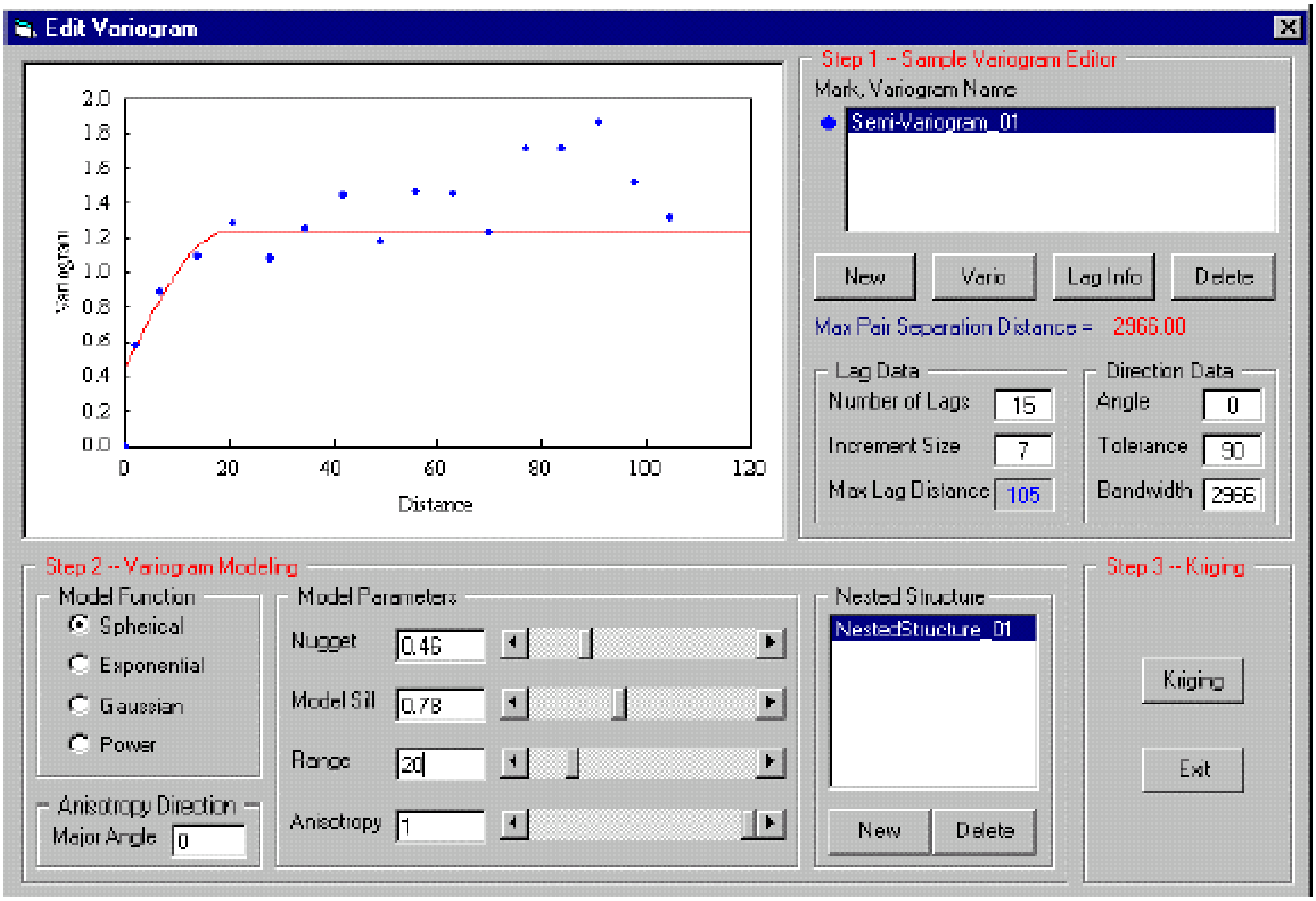


Figure 3.4-3. Variogram of Standardized Computed Spring Discharges

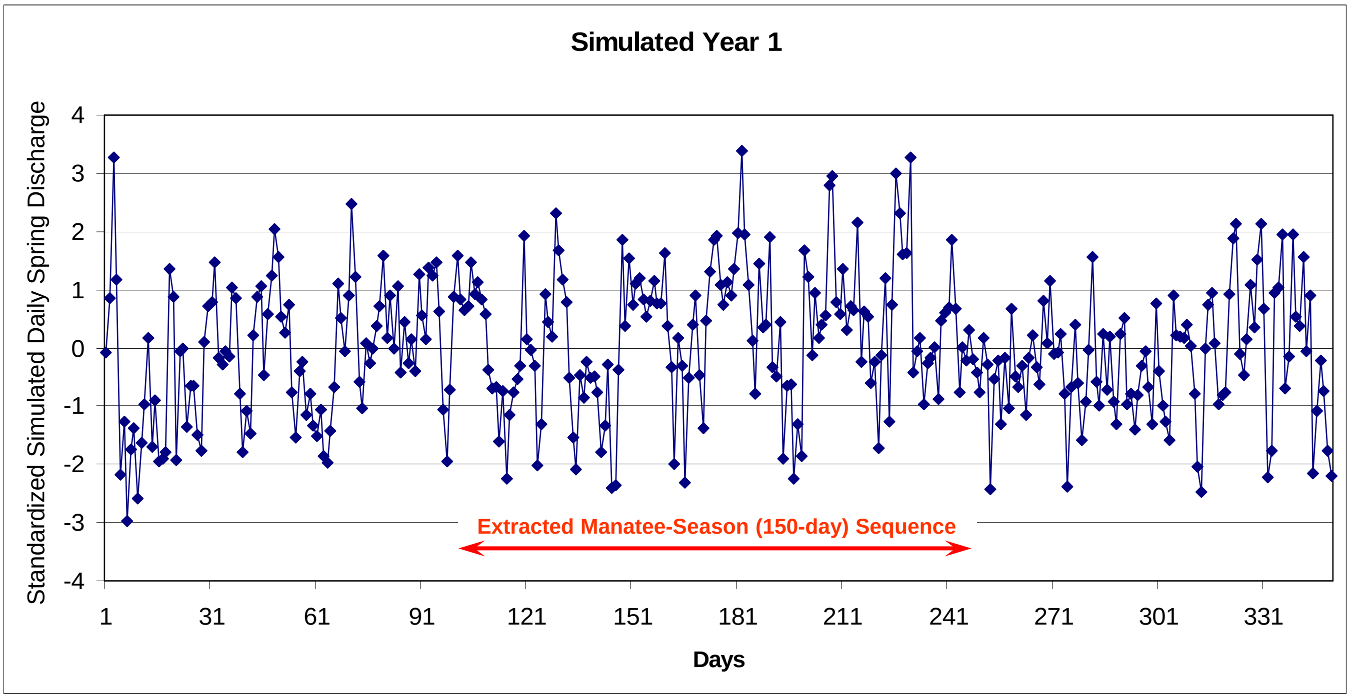


Figure 3.4-4. Example of an Extracted Manatee-Season Sequence from a Simulated Year of Standardized Daily Spring Discharges

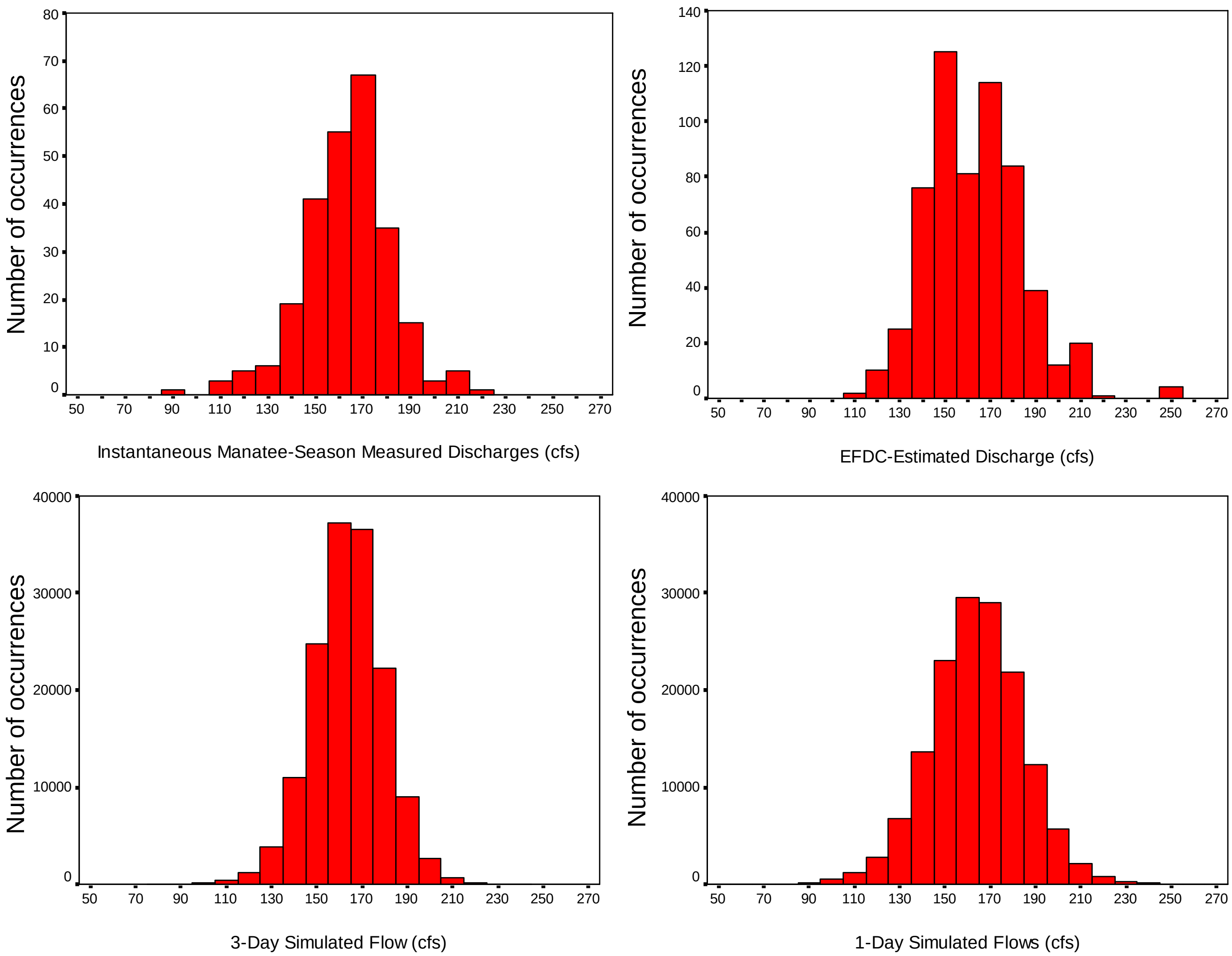


Figure 3.4-5. Histograms of EFDC-Estimated and Measured Spring Discharges During Manatee Seasons (1932-2005) versus Histograms of Simulated Manatee-Season 1-Day and 3-Day Discharges

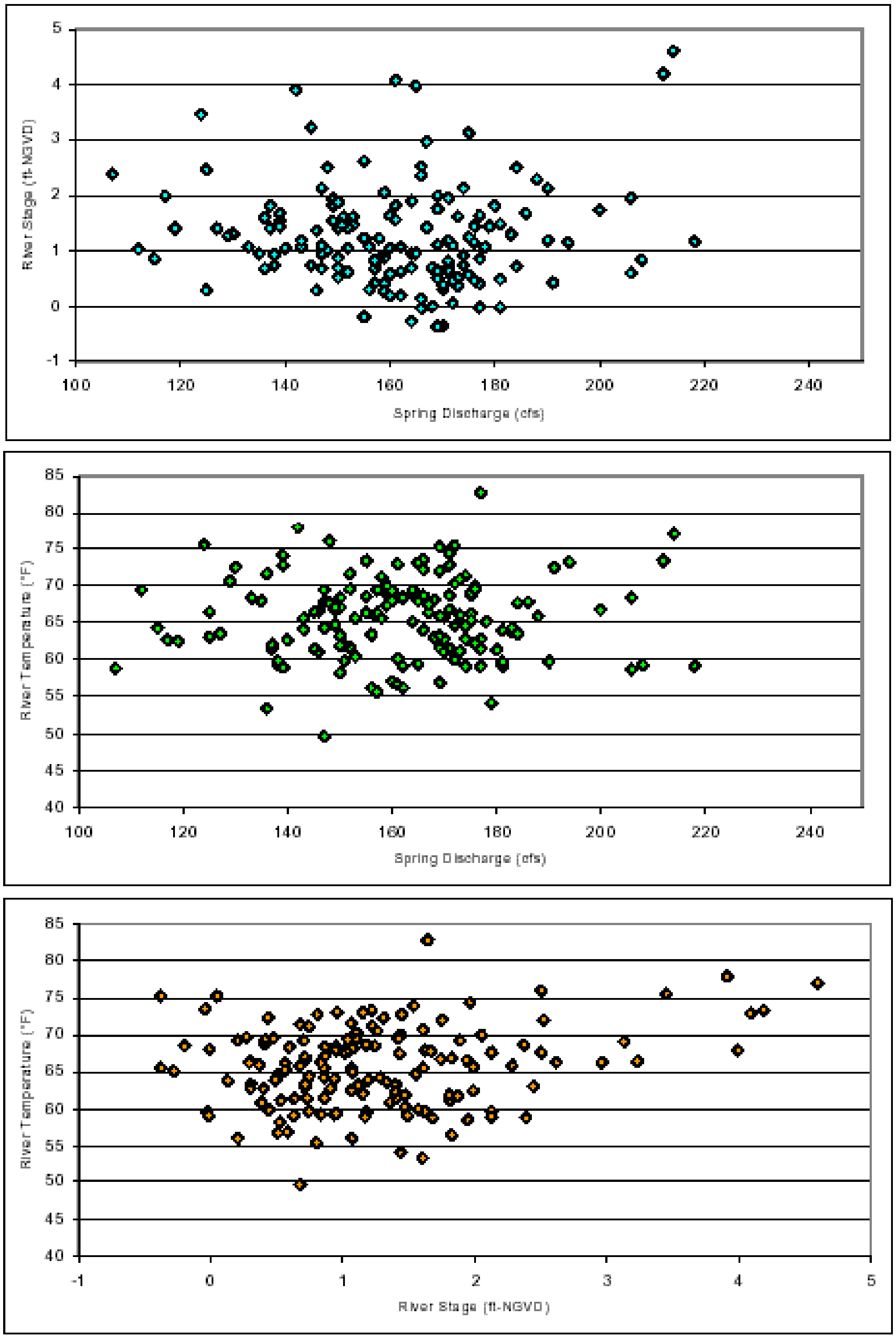


Figure 3.5-1 River Stage, River Temperature and Blue Spring Discharge Scatter Plots

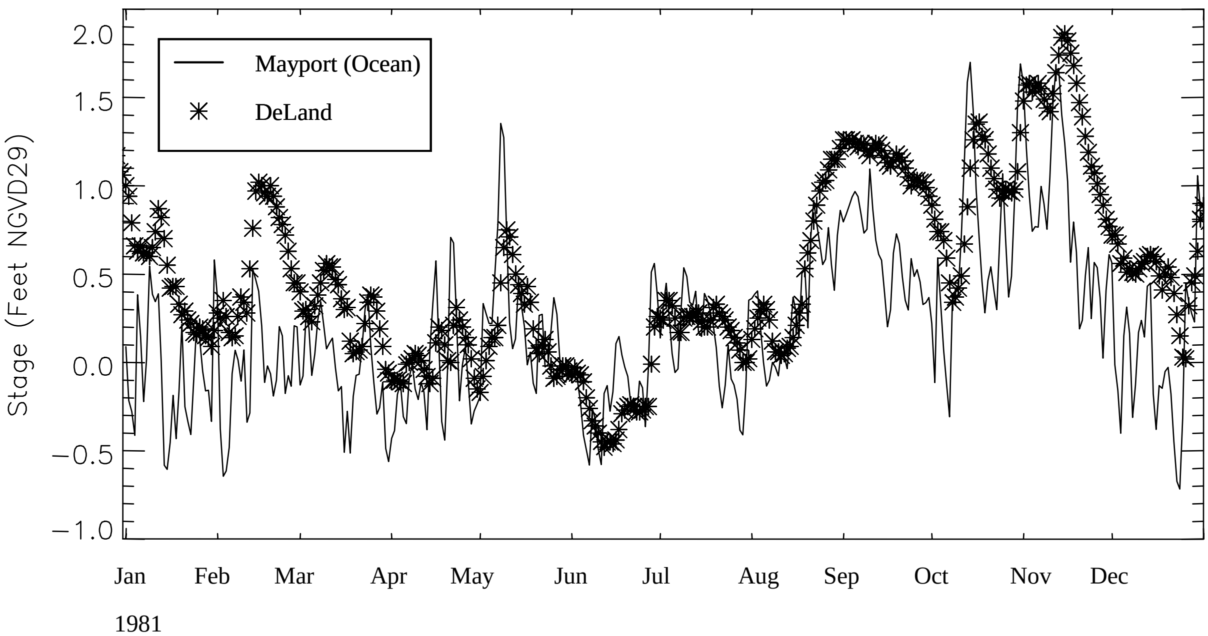


Figure 3.5-2 Daily stage at Mayport (Ocean) and DeLand at St. Johns River mile 142 during the drought year of 1981

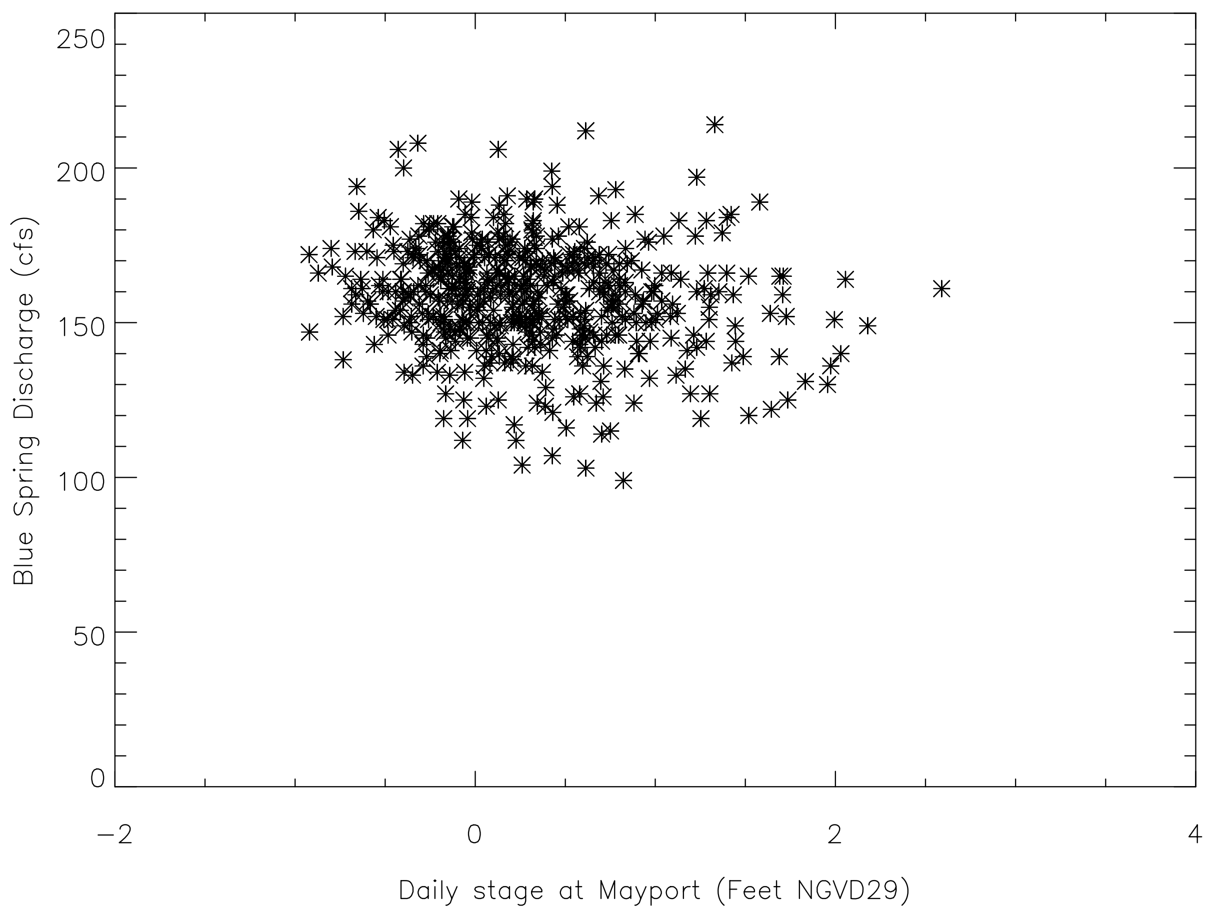
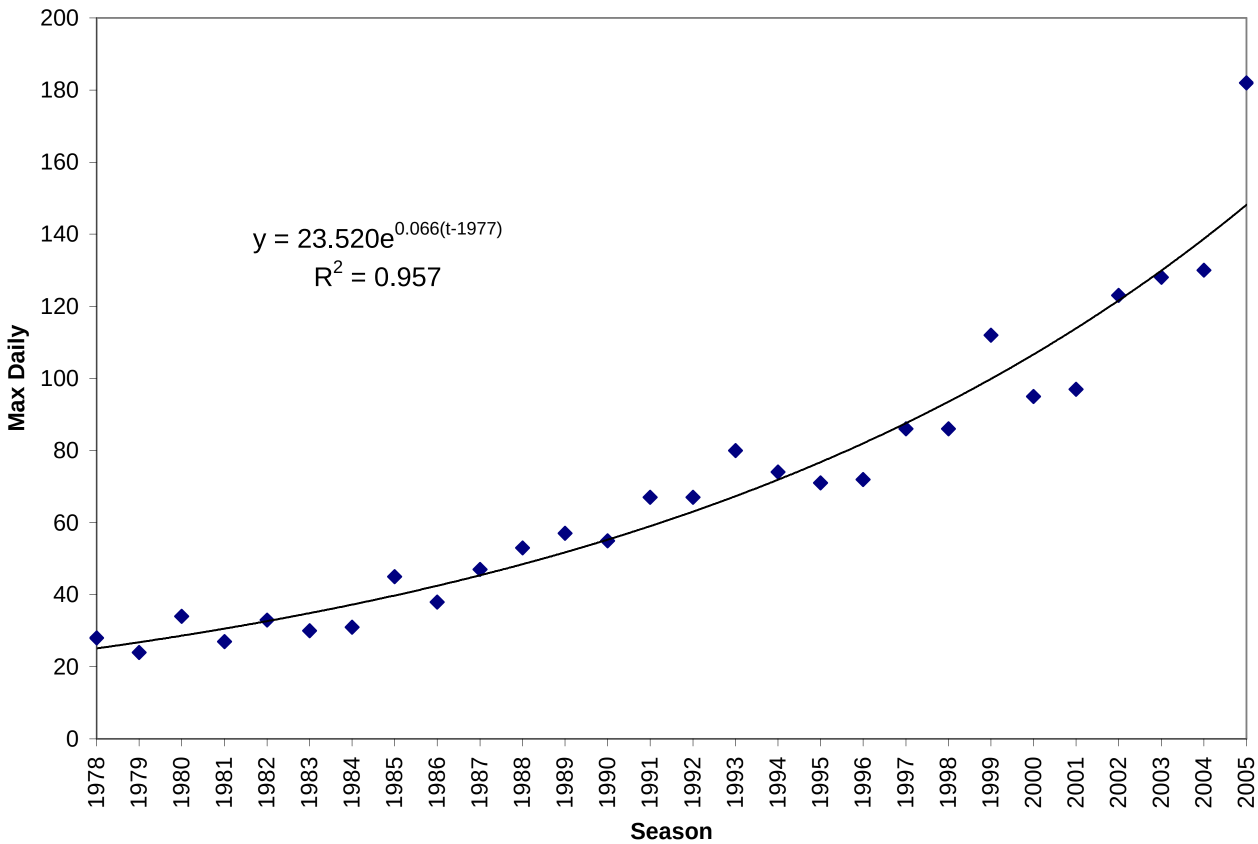


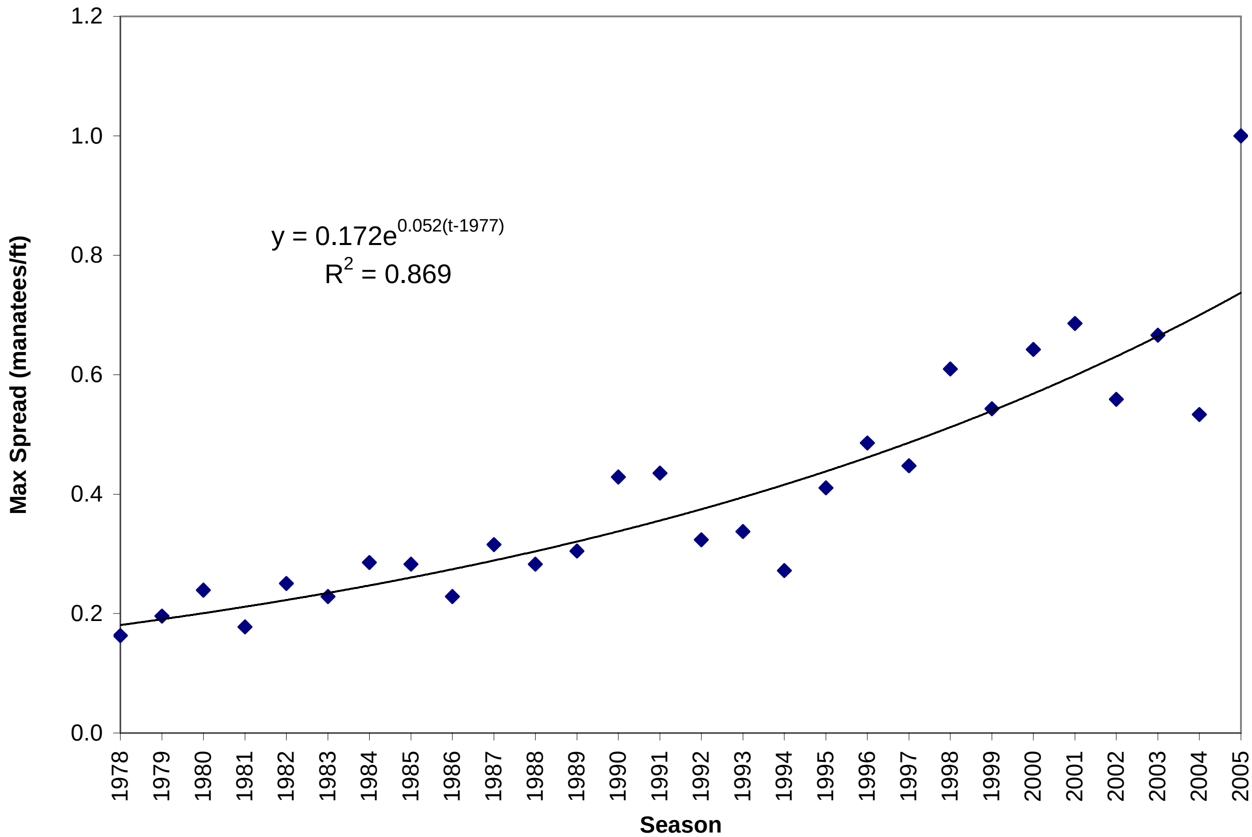
Figure 3.5-3 Mayport (Ocean) Stage and Blue Spring Discharge Scatter Plot



Model	R2	degrees of freedom	F-statistics	Significance	Fitted Coefficients	
					b0	b1
Linear	0.876	26	183.79	0.00%	6.564	4.405
Logarithmic	0.627	26	43.73	0.00%	-17.585	36.300
Power	0.806	26	107.76	0.00%	14.684	0.587
Exponential	**0.957**	**26**	**582.99**	**0.00%**	**23.520**	**0.066**

Notes:
Any significance value less than 5% implies a significant trend at 95% confidence.
Selected model is highlighted.

Figure 4.1-1. Maximum Daily Count Trend Analysis (1978-2005 Manatee Seasons)



Model	R2	degrees of freedom	F-statistics	Significance	Fitted Coefficients	
					b0	b1
Linear	0.781	26	92.72	0.00%	0.101	0.021
Logarithmic	0.570	26	34.52	0.00%	-0.018	0.174
Power	0.740	26	73.9	0.00%	0.118	0.468
Exponential	**0.869**	**26**	**172.45**	**0.00%**	**0.172**	**0.052**

Notes:
Any significance value less than 5% implies a significant trend at 95% confidence.
Selected model is highlighted.

Figure 4.1-2. Maximum Spread Trend Analysis (1978-2005 Manatee Seasons)

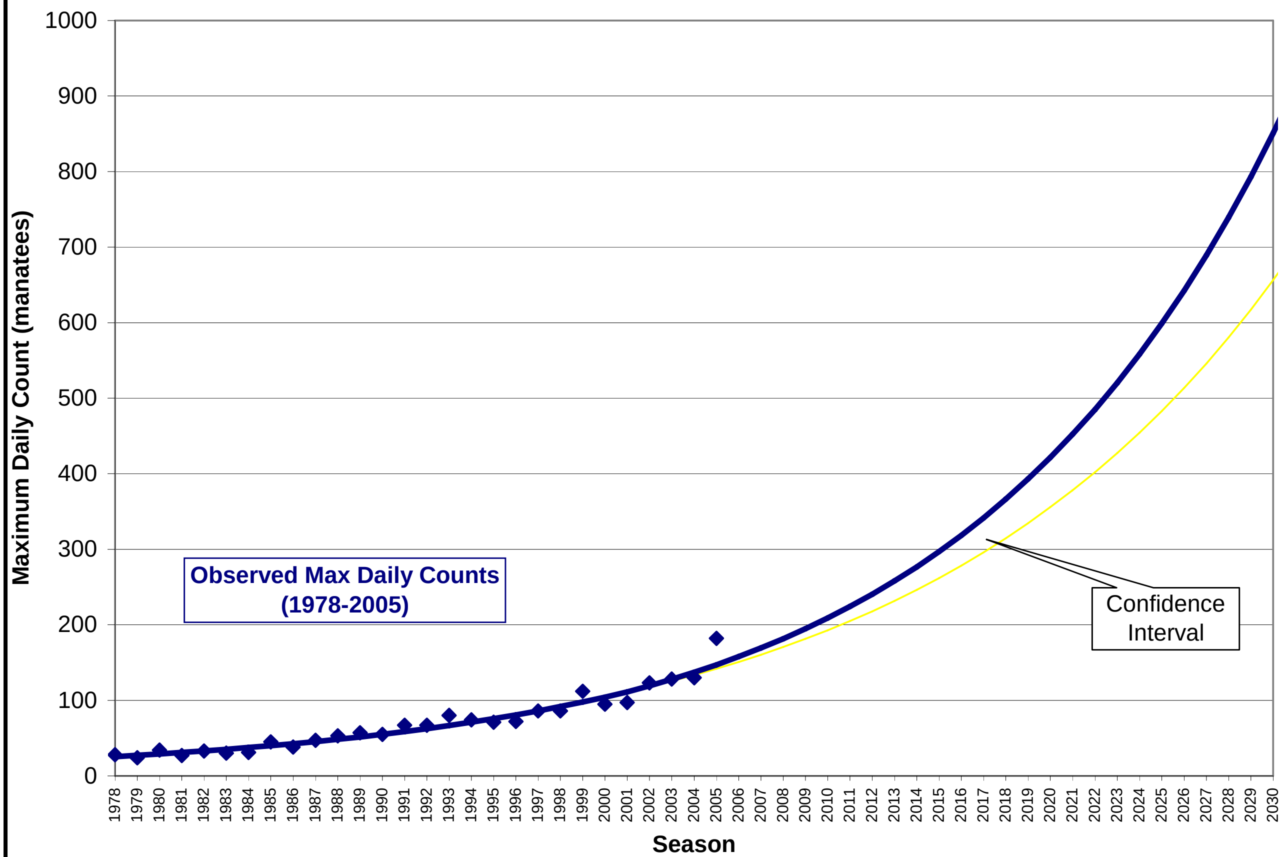
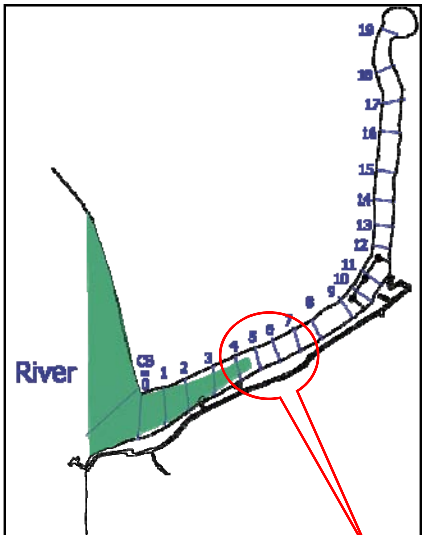
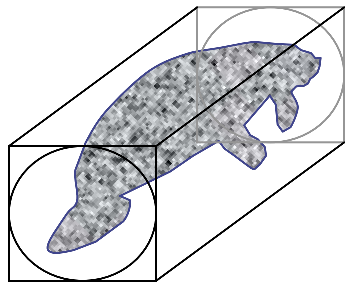


Figure 4.1-3. Predicted Future Maximum Daily Manatee Counts at Blue Spring

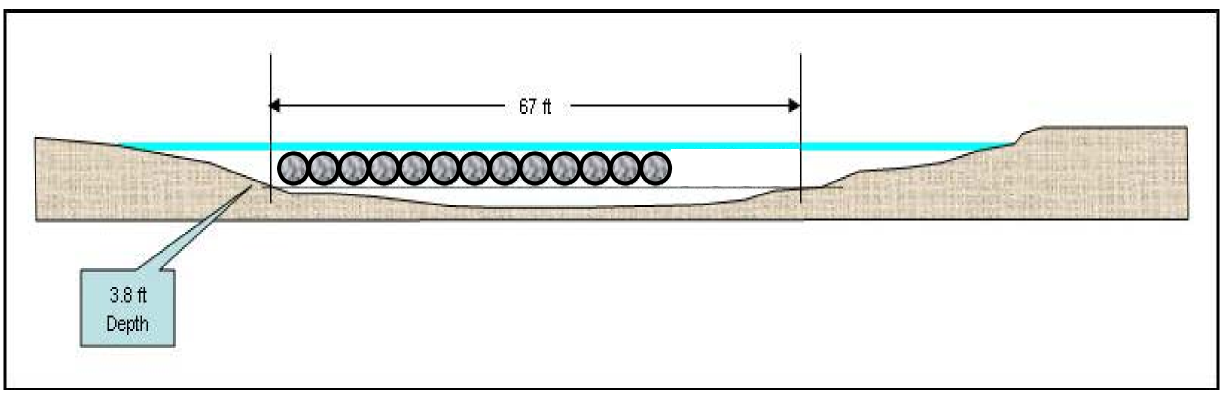




Manatee Space
Observed **7.5'x3.8'x3.8'**

Segments with adequately deep warm water under catastrophic conditions

Critical Segment Cross Section with Manatees



Manatee Space
Observed **7.5'x3.8'x3.8'**

Spread Ceiling Under Catastrophic Condition
= **13** manatee across the run / 7.5' = **1.73** manatees/ft

Figure 4.1-4. Physical Constraints to Manatee Spread within the Blue Spring Run

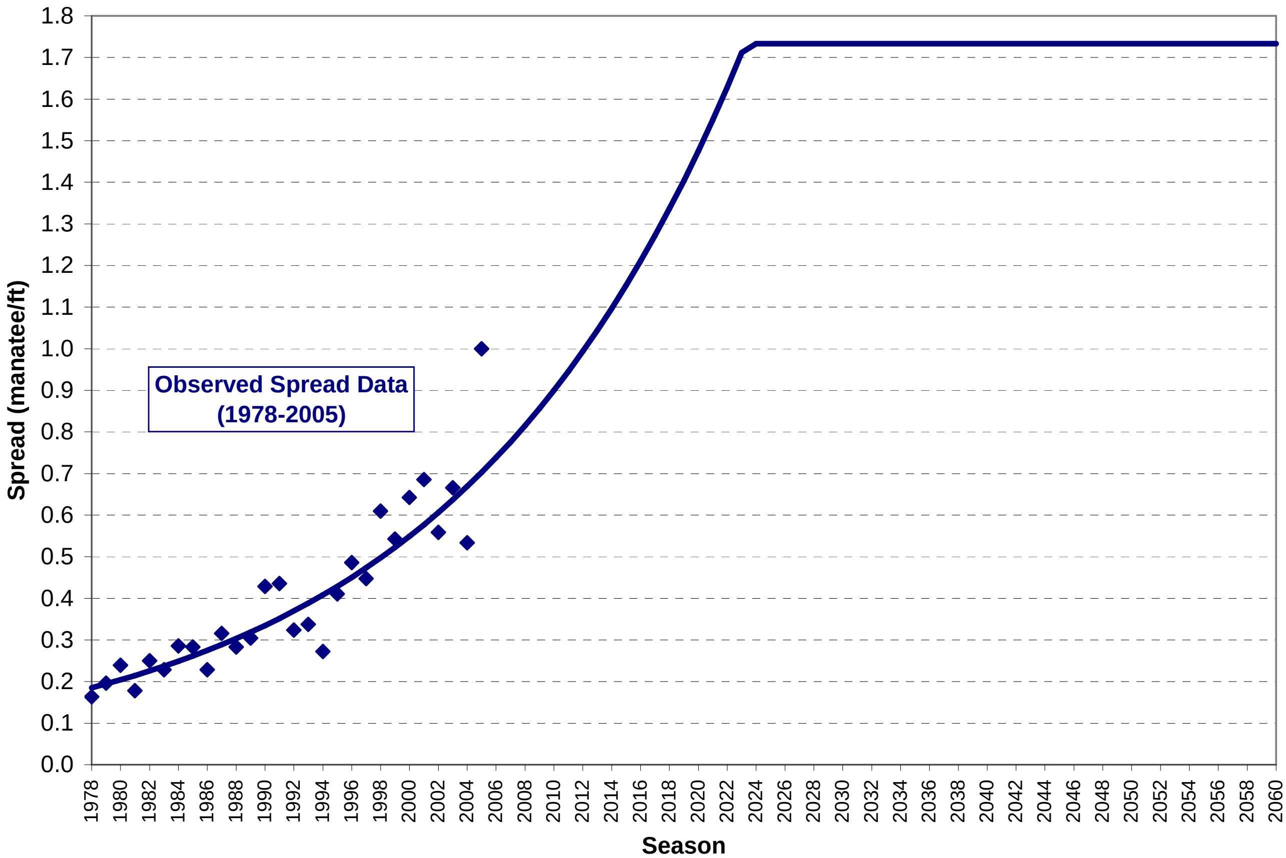


Figure 4.1-5. Projected Maximum Manatee Spread with a Ceiling at 1.73 manatee/ft

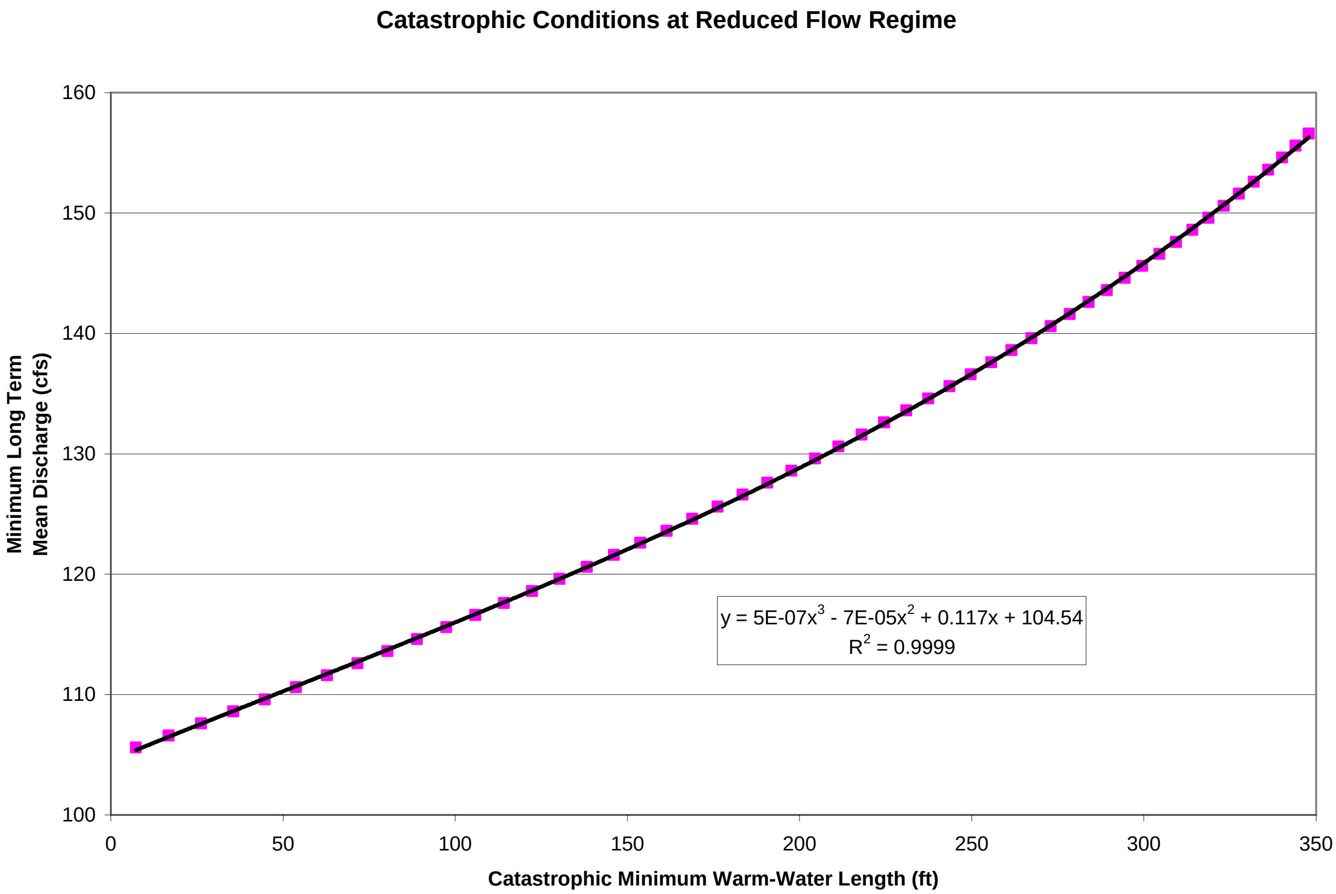


Figure 4.2-1. Minimum Useable Warm-Water Length under Catastrophic Conditions at Reduced Spring Discharge Regimes

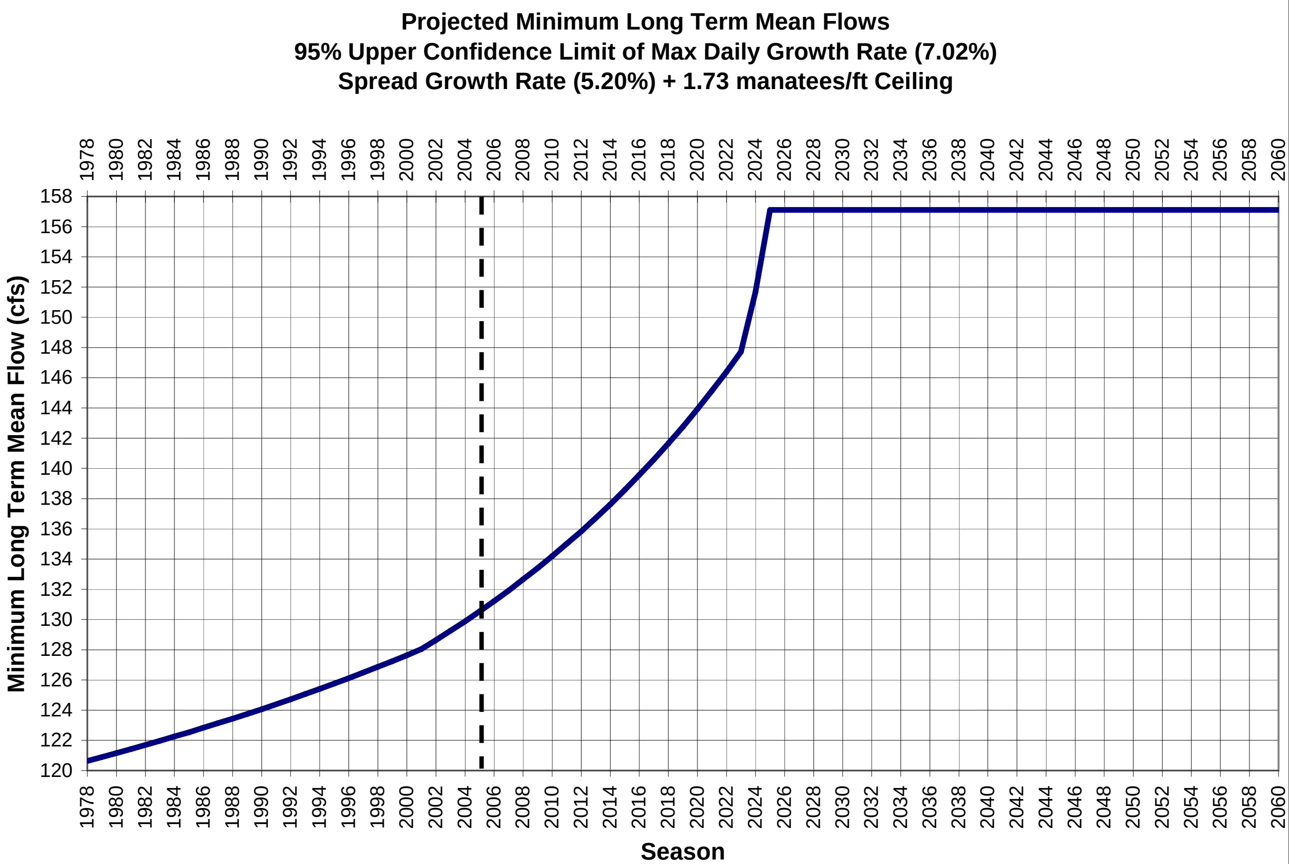


Figure 4.3-1. Projected Blue Spring Minimum Long Term Mean Flows (based on a manatee max daily attendance growth rate of 7.02% per annum and a manatee spread growth rate of 5.20% per annum with a spread ceiling at 1.73 manatees/ft)

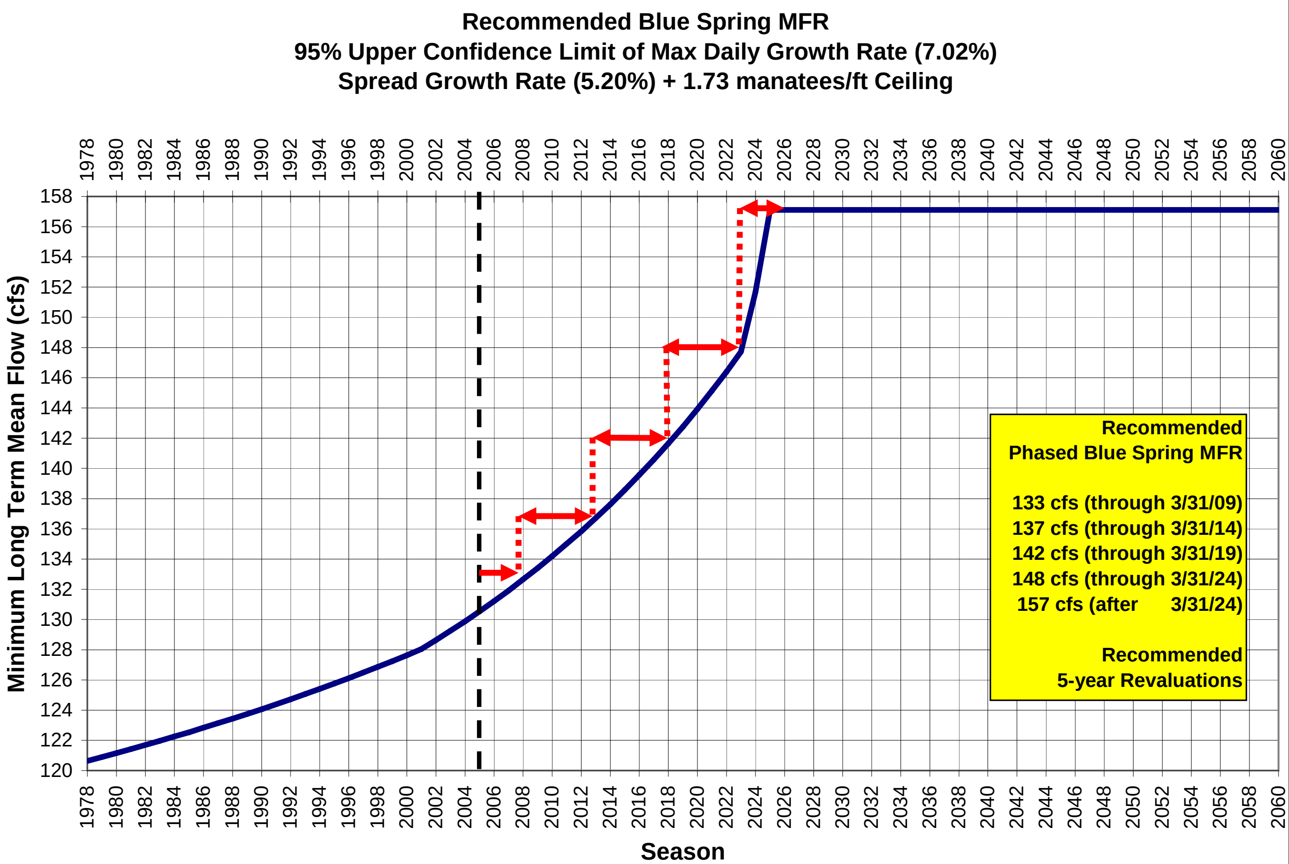


Figure 4.3-2. Recommended Phased Blue Spring MFR (based on a manatee max daily attendance growth rate of 7.02% per annum and a manatee spread growth rate of 5.20% per annum with a spread ceiling at 1.73 manatees/ft)

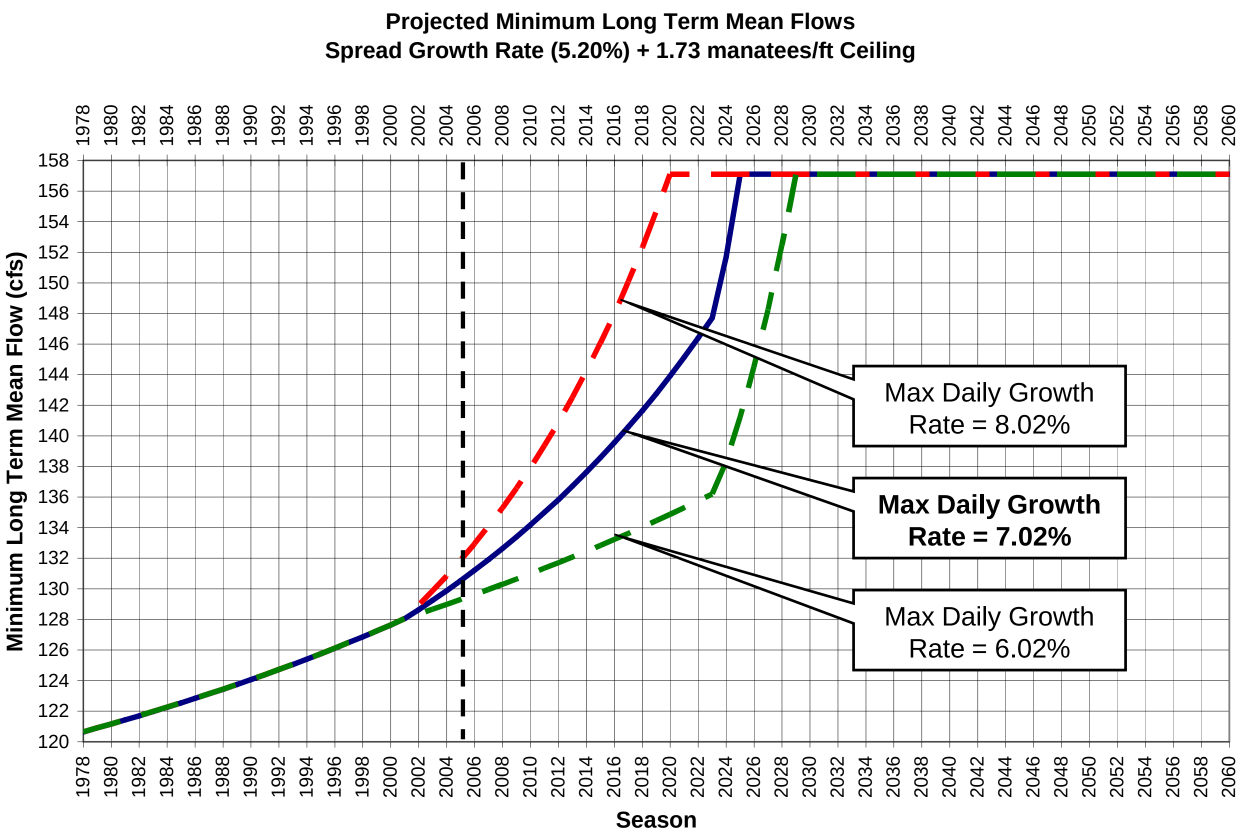
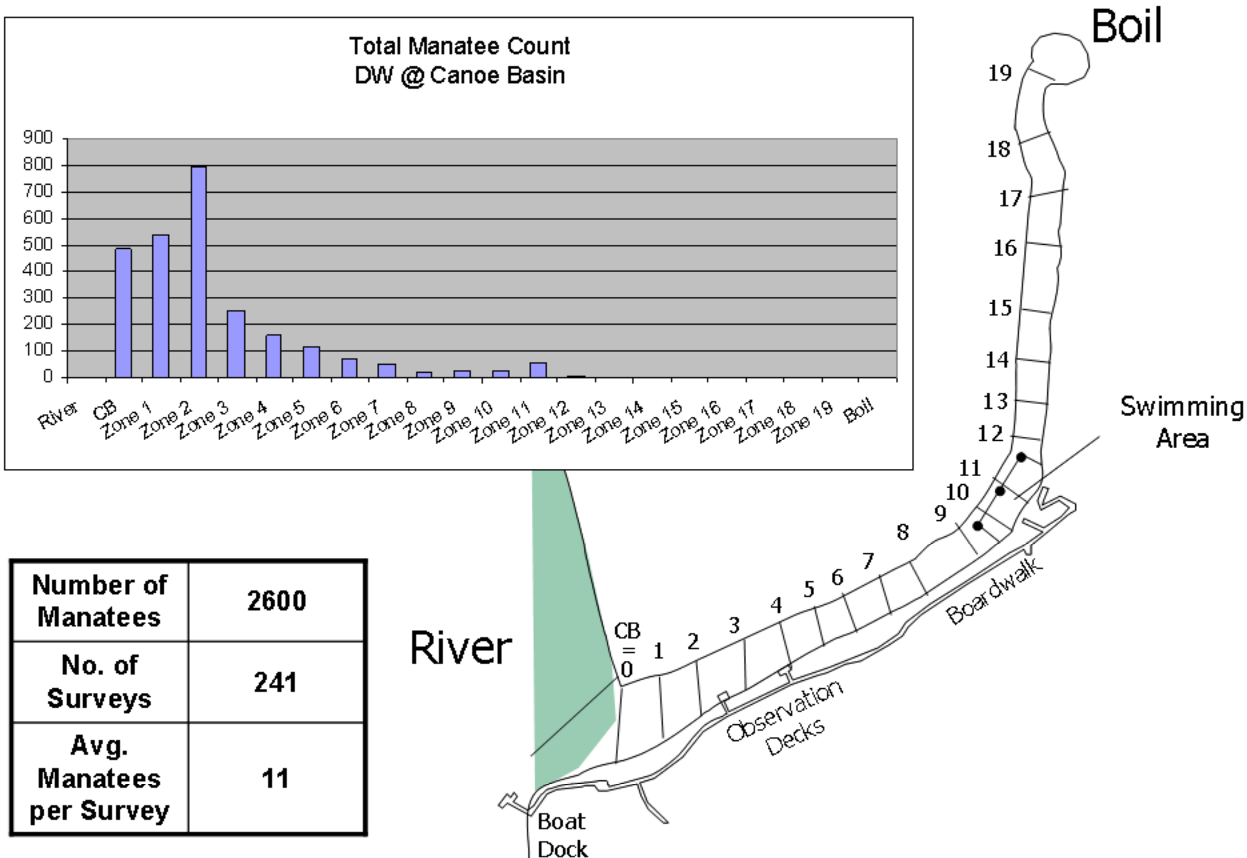


Figure 6-1. Sensitivity of Projected Blue Spring Minimum Long Term Mean Flows (based on manatee max daily attendance growth rates of 7.02% ± 1% per annum and a manatee spread growth rate of 5.20% per annum with a spread ceiling at 1.73 manatees/ft)

Appendix A

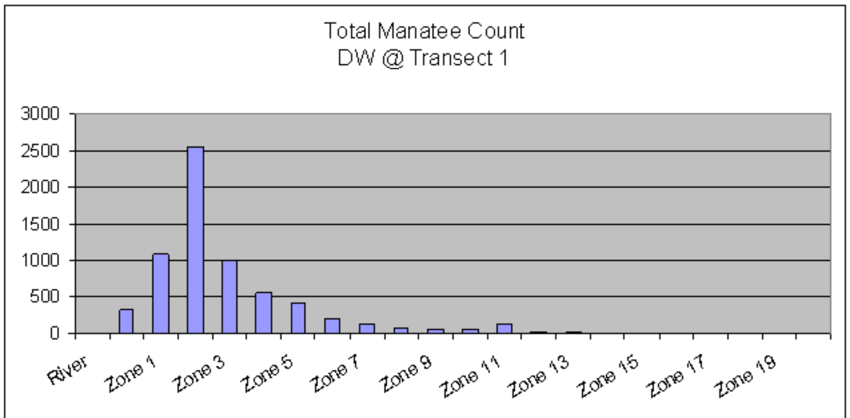


Number of Manatees	2600
No. of Surveys	241
Avg. Manatees per Survey	11

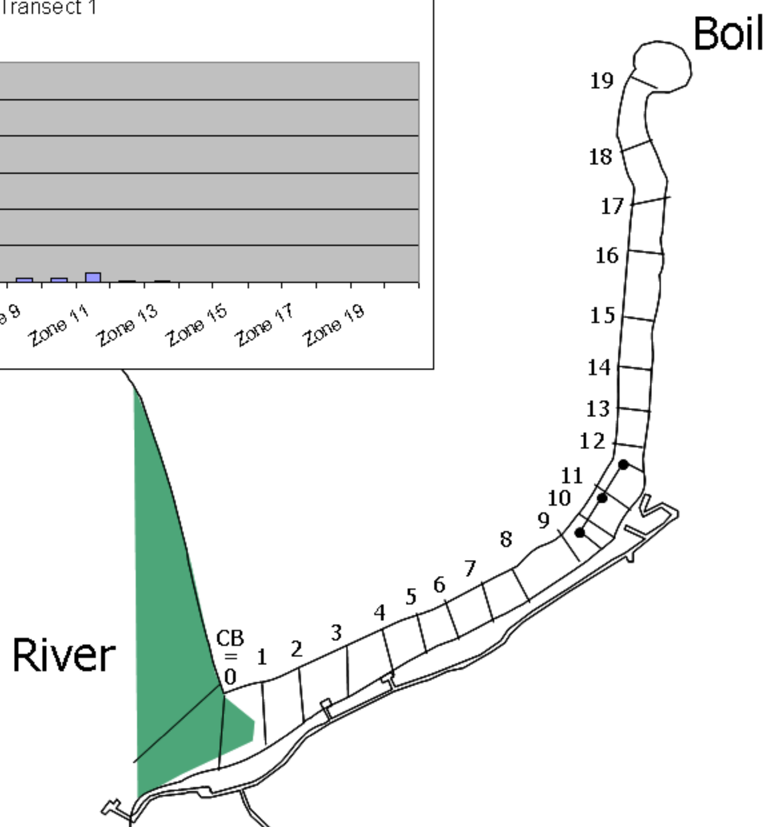
	CB	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Boil
Max	19	18	22	12	13	14	11	8	4	3	7	10	2	2		1			1	1	1
Avg	4	4	6	3	3	3	3	3	2	2	3	3	1	2		1			1	1	1
Min	1	1	1	1	1	1	1	1	1	1	1	1	2	1		1			1	1	1

Figure A-1. Distribution of Total Manatee Counts for Manatee Season 1978-2001 with a 0-ft River Intrusion (intrusion at Canoe Beach)

CB = Canoe Beach



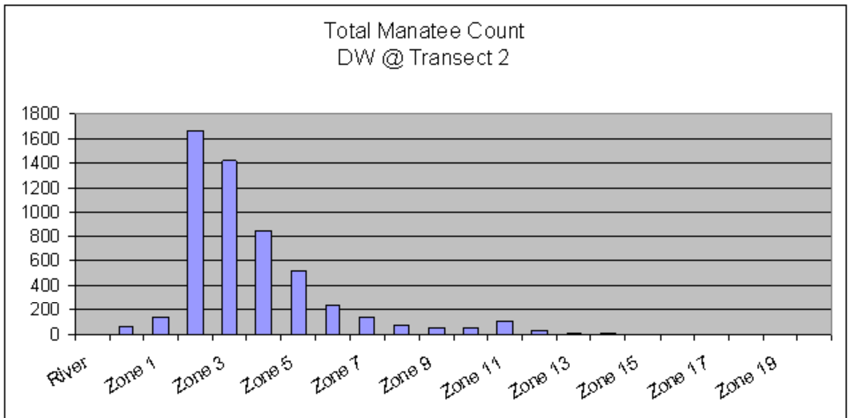
Number of Manatees	**6620**
No. of Surveys	**261**
Avg. Manatees per Survey	**25**



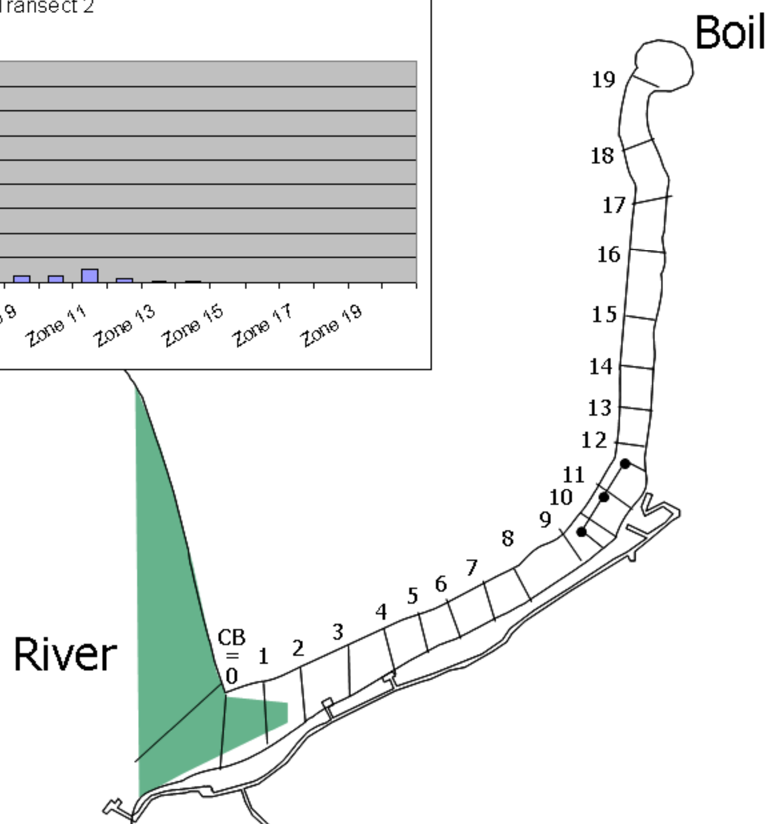
	CB	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Boil
Max	20	32	45	21	20	30	18	9	7	7	3	9	6	3	2	1	2	3	3		3
Avg	4	7	11	6	5	5	4	3	2	2	2	3	2	2	2	1	2	2	3		2
Min	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	3		1

Figure A-2. Distribution of Total Manatee Counts for Manatee Season 1978-2001 with a 89-ft River Intrusion

CB = Canoe Beach



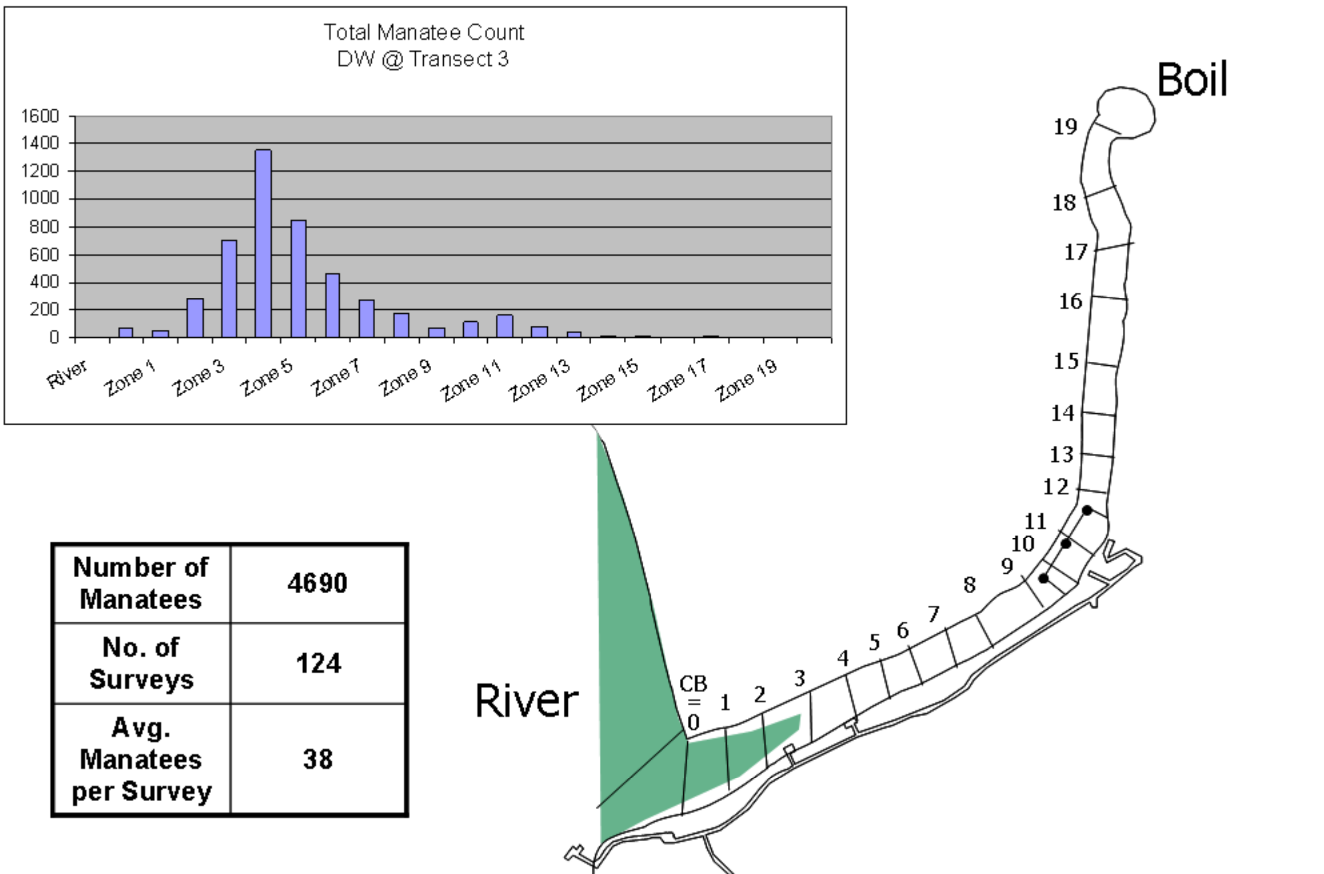
Number of Manatees	5430
No. of Surveys	173
Avg. Manatees per Survey	31



	CB	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Boil
Max	8	9	57	39	22	23	14	12	7	7	11	12	5	6	10	1	2	3		3	1
Avg	2	2	12	10	7	6	4	3	2	3	3	3	2	2	6	1	1	3		3	1
Min	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3		3	1

Figure A-3. Distribution of Total Manatee Counts for Manatee Season 1978-2001 with a 194-ft River Intrusion

CB = Canoe Beach

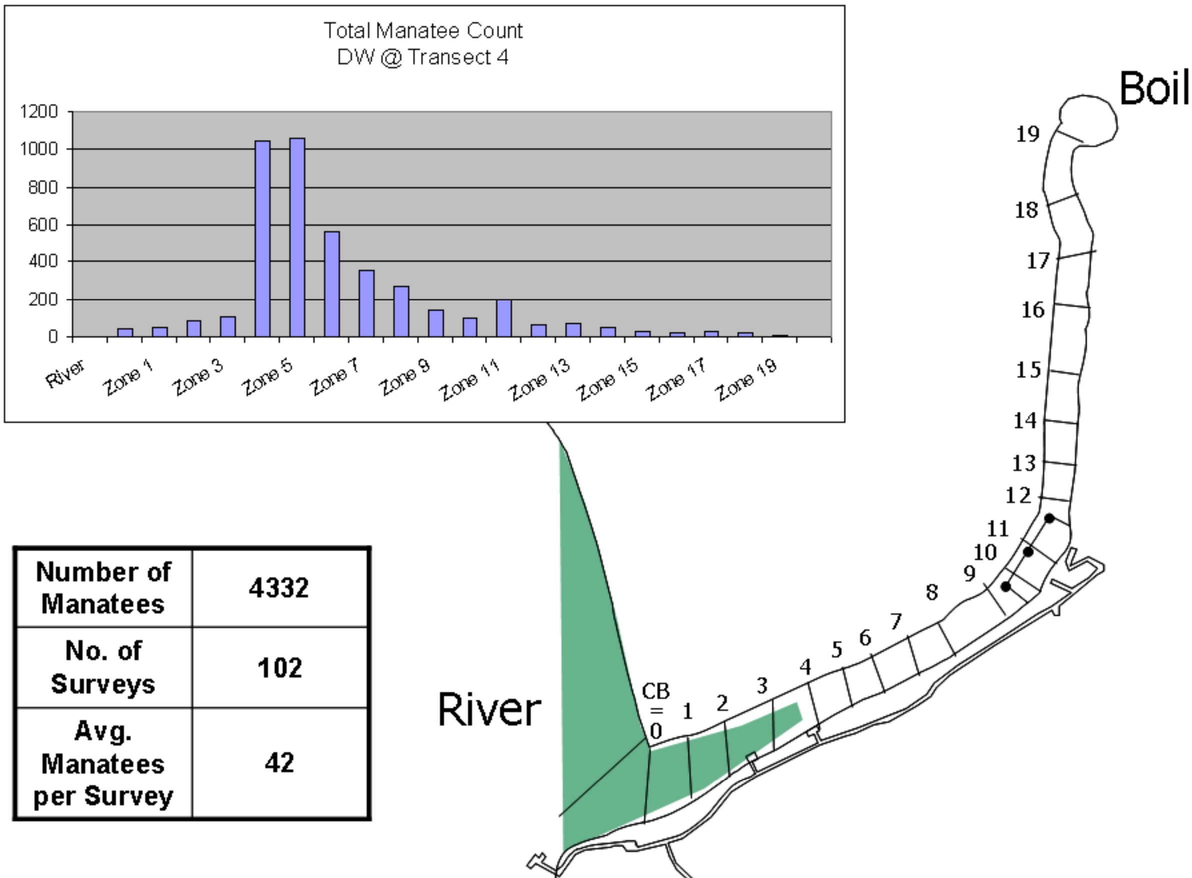


Number of Manatees	4690
No. of Surveys	124
Avg. Manatees per Survey	38

	CB	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Boil
Max	7	8	31	42	56	29	16	20	15	7	14	10	17	6	4	4	2	9	2	2	1
Avg	3	2	5	7	12	8	5	4	3	2	3	3	3	2	2	2	2	5	2	2	1
Min	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	2	2	1

Figure A-4. Distribution of Total Manatee Counts for Manatee Season 1978-2001 with a 312-ft River Intrusion

CB = Canoe Beach

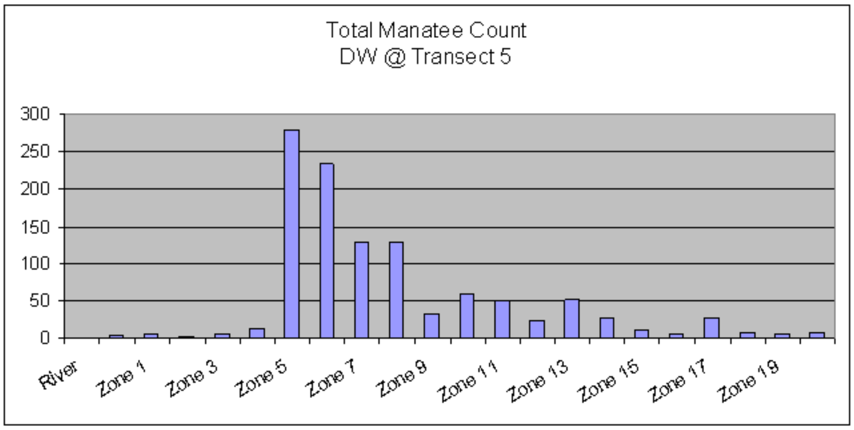


Number of Manatees	4332
No. of Surveys	102
Avg. Manatees per Survey	42

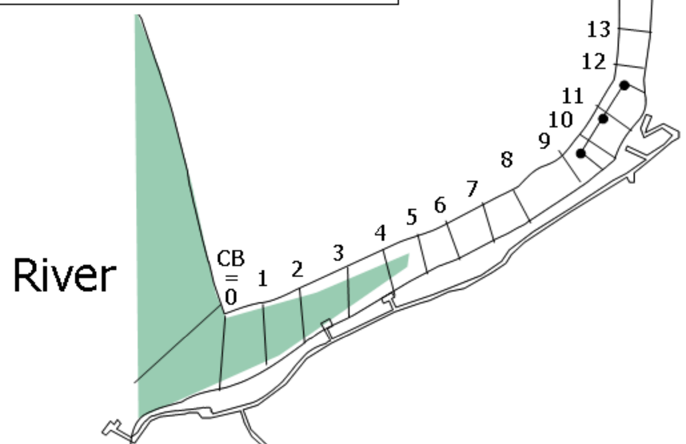
	CB	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Boil
Max	9	5	7	13	47	32	18	14	16	15	7	20	9	12	5	7	4	10	5	2	1
Avg	2	2	2	3	11	11	6	5	4	3	2	4	3	3	2	2	2	3	3	2	1
Min	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Figure A-5. Distribution of Total Manatee Counts for Manatee Season 1978-2001 with a 404-ft River Intrusion

CB = Canoe Beach



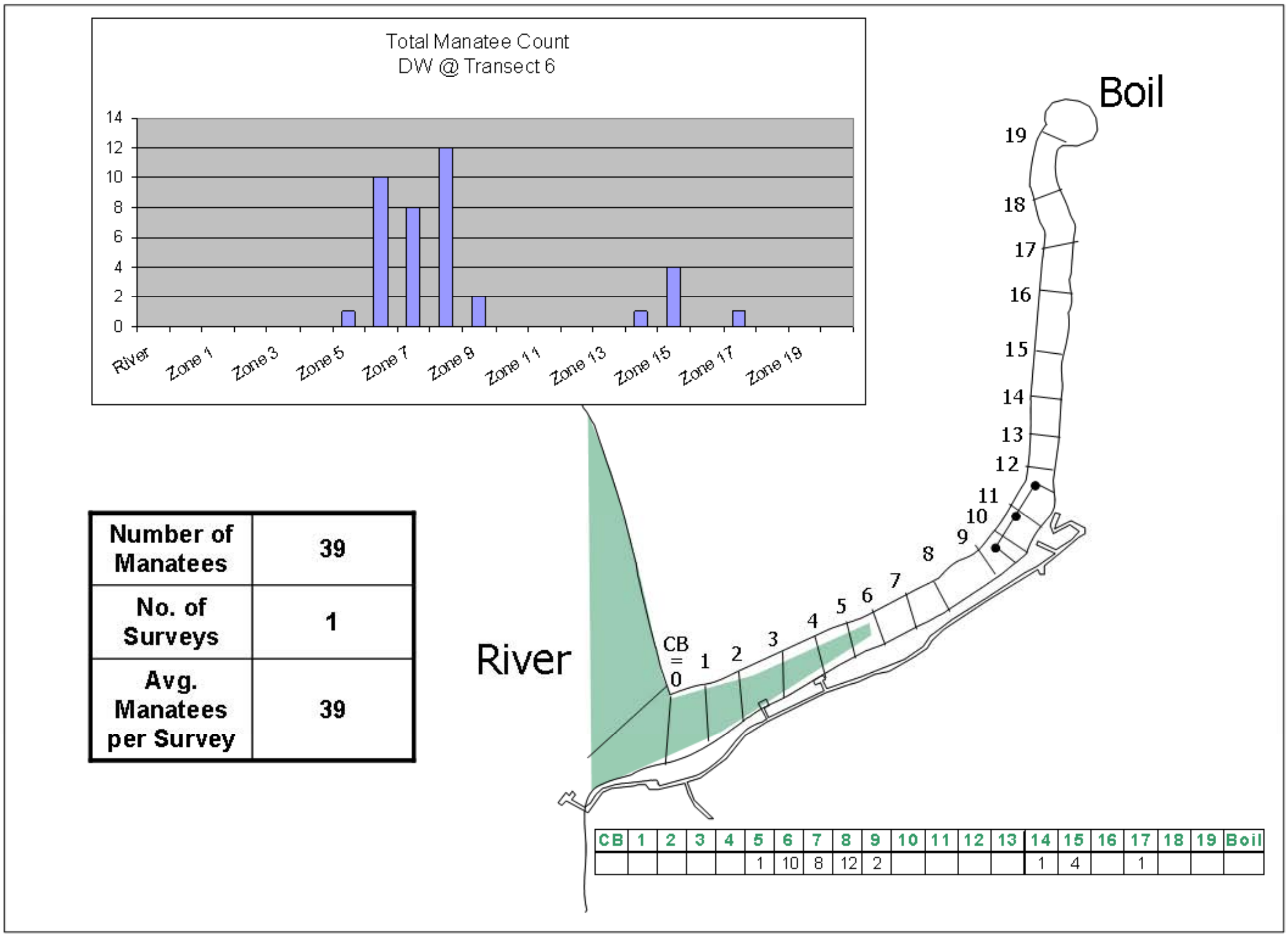
Number of Manatees	1110
No. of Surveys	22
Avg. Manatees per Survey	50



	CB	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Boil
Max	2	3	1	2	4	27	31	18	18	7	24	10	6	10	13	5	3	19	4	3	4
Avg	2	2	1	1	2	14	11	8	9	2	5	4	3	5	5	4	2	5	3	3	2
Min	1	1	1	1	1	2	1	2	1	1	1	1	1	1	1	1	1	1	2	2	1

Figure A-6. Distribution of Total Manatee Counts for Manatee Season 1978-2001 with a 495-ft River Intrusion

CB = Canoe Beach



Number of Manatees	39
No. of Surveys	1
Avg. Manatees per Survey	39

CB	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Boil
					1	10	8	12	2					1	4		1			

Figure A-7. Distribution of Total Manatee Counts for Manatee Season 1978-2001 with a 571-ft River Intrusion

CB = Canoe Beach

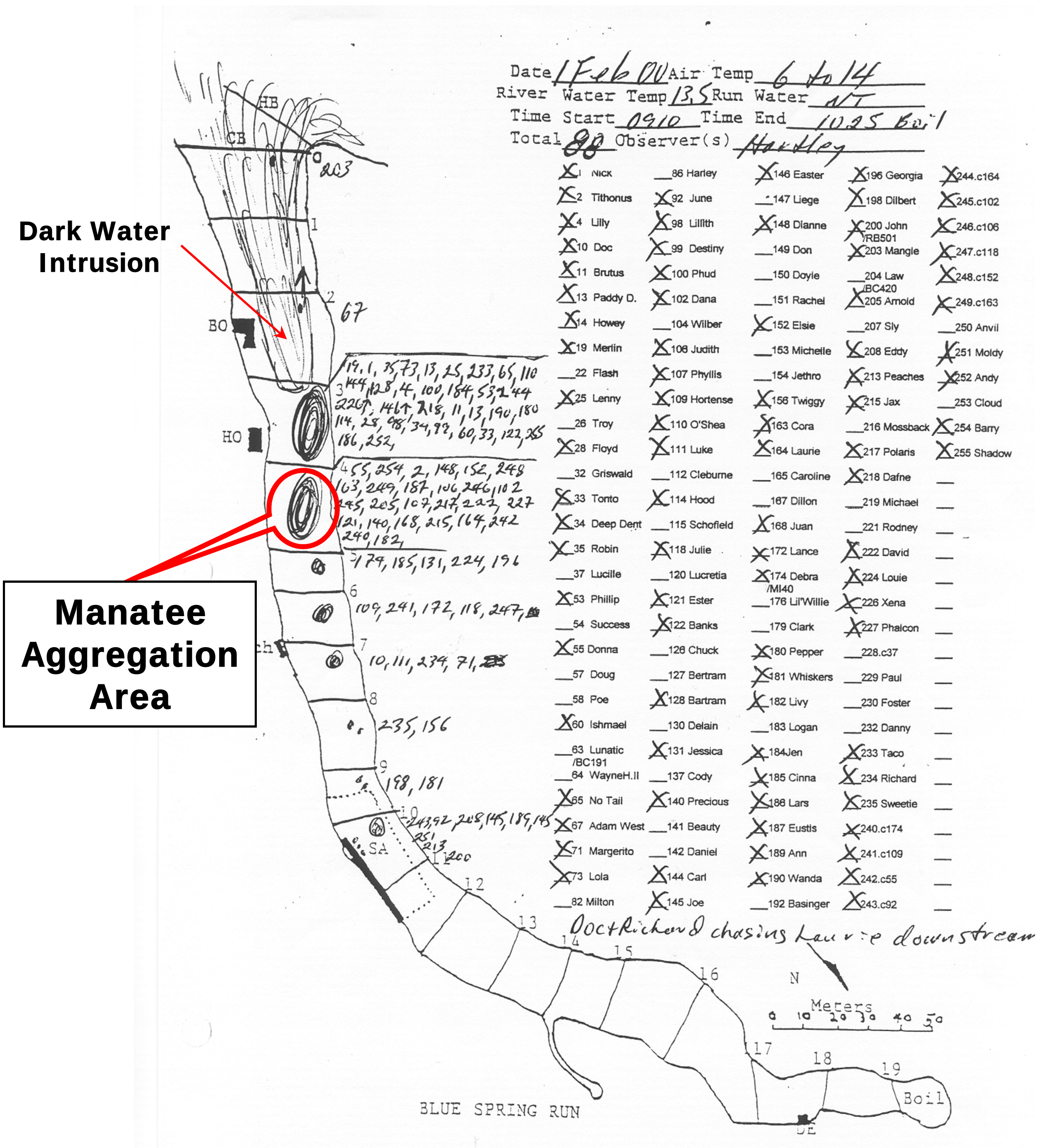


Figure A-8. Example of a Manatee Aggregation Area Recorded on a Daily Blue Spring Manatee Survey Sheet

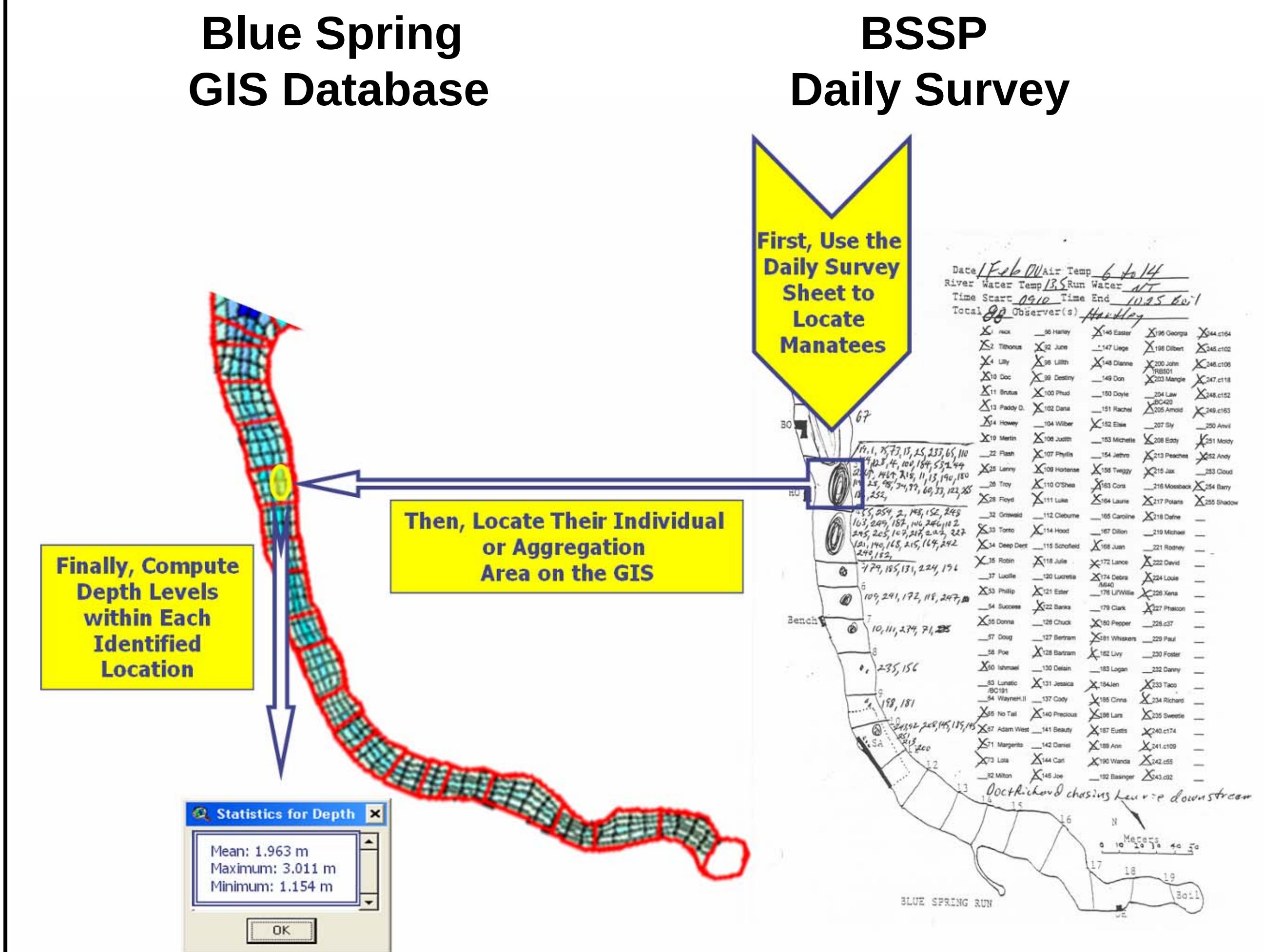


Figure A-9. Process of Computing Manatee Habitat Water Depths

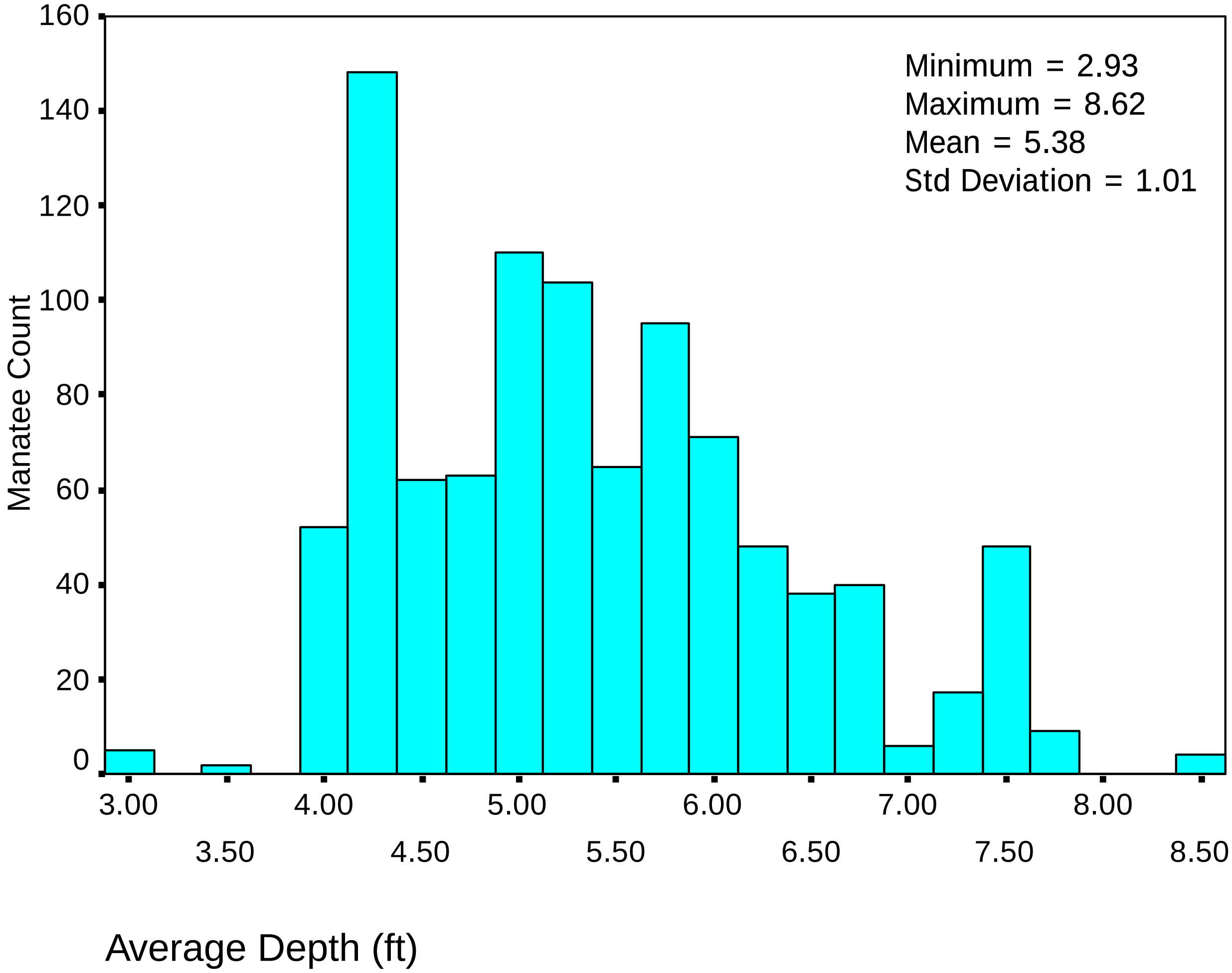


Figure A-10. Histogram of Average Manatee Habitat Water Depths

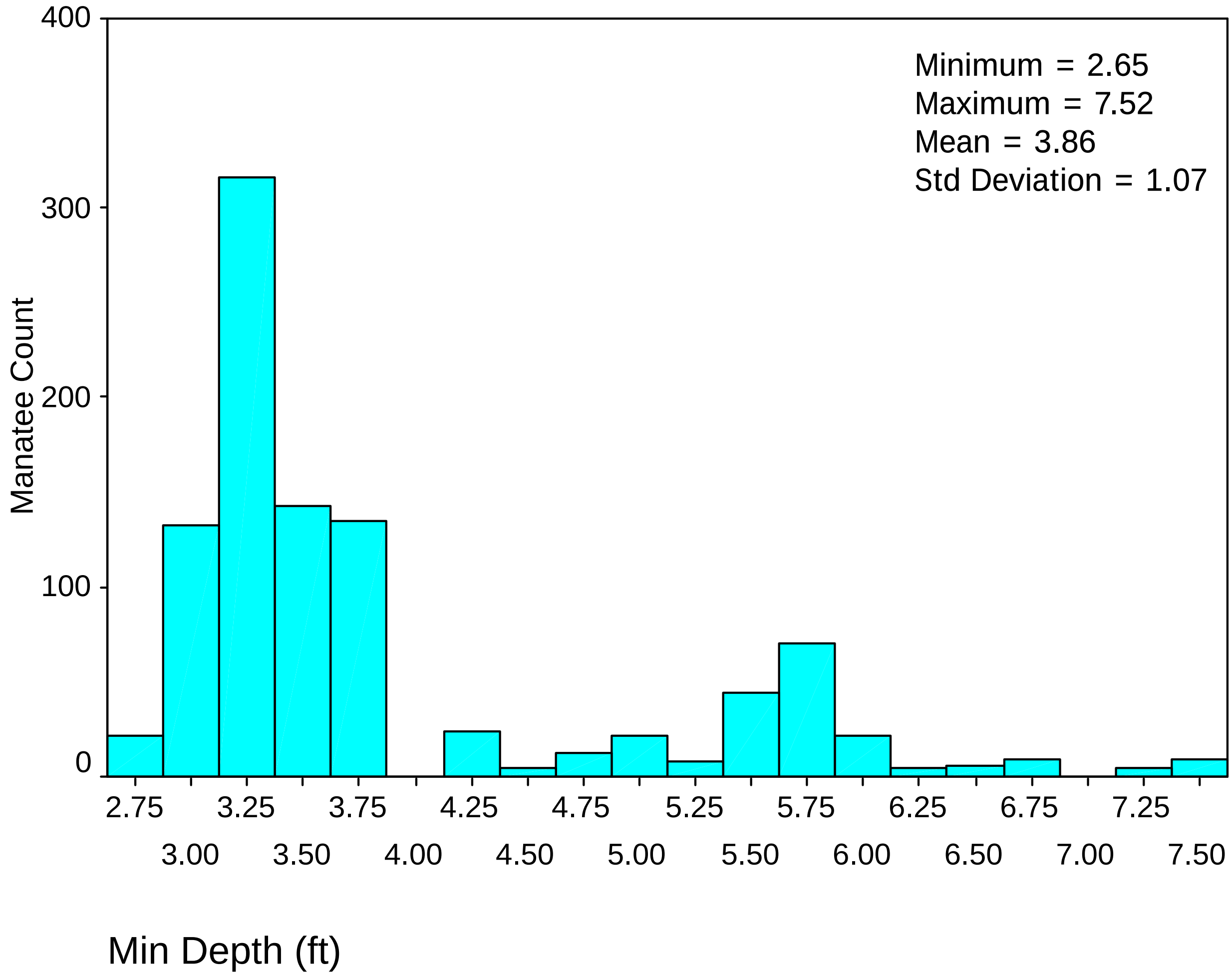


Figure A-11. Histogram of Minimum Manatee Habitat Water Depths

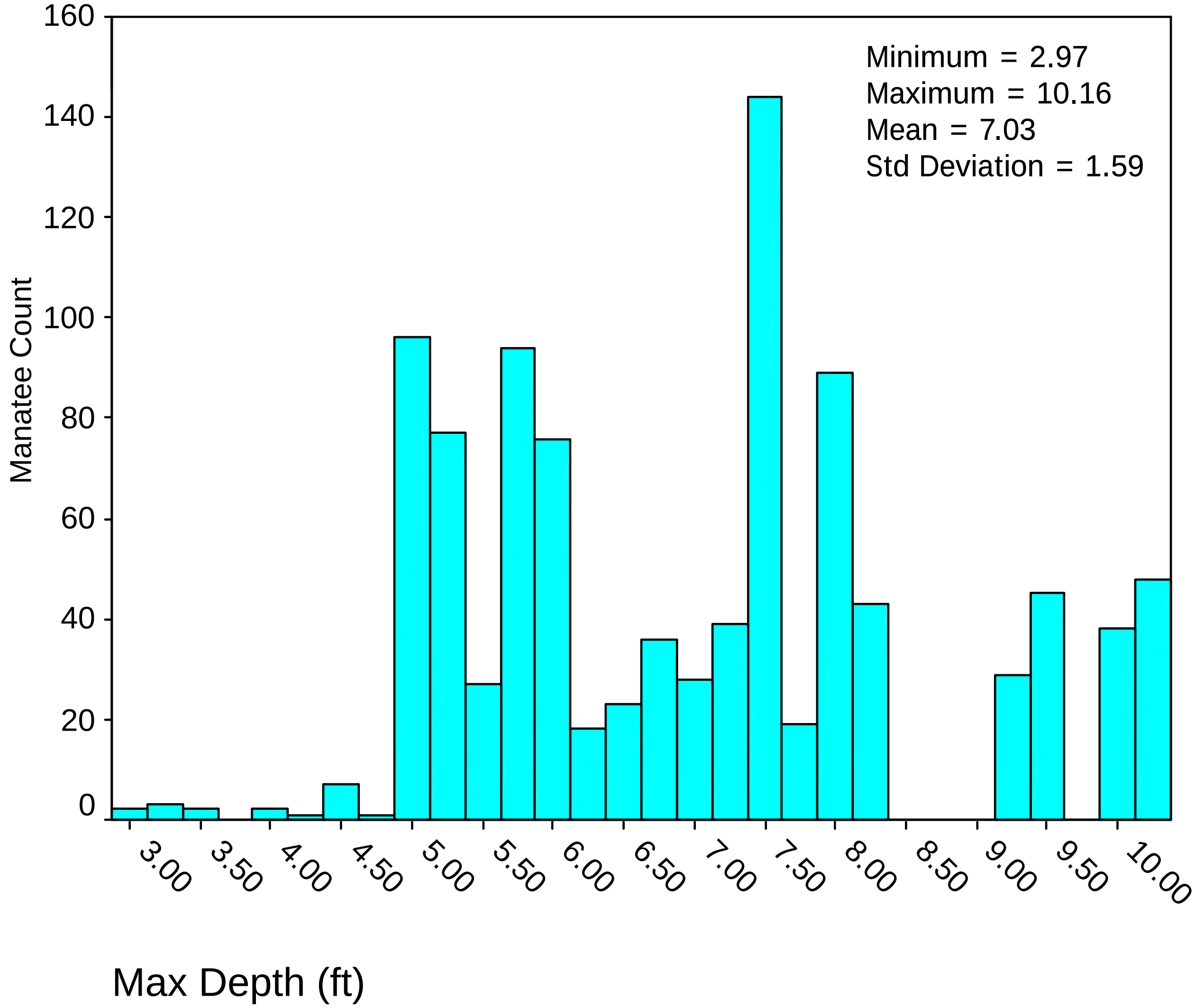


Figure A-12. Histogram of Maximum Manatee Habitat Water Depths

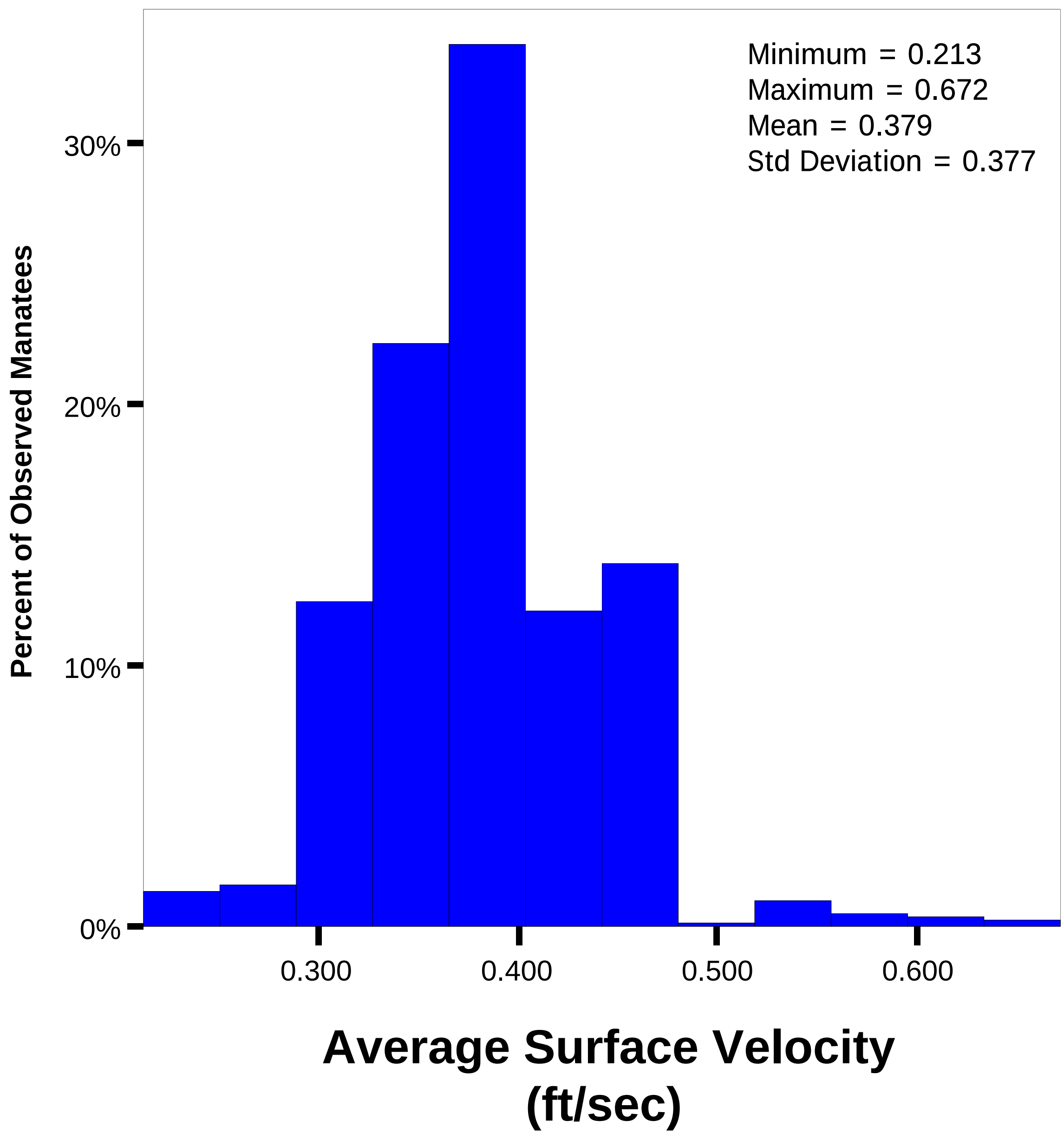


Figure A-13. Histogram of Average Manatee Habitat Surface Water Velocity

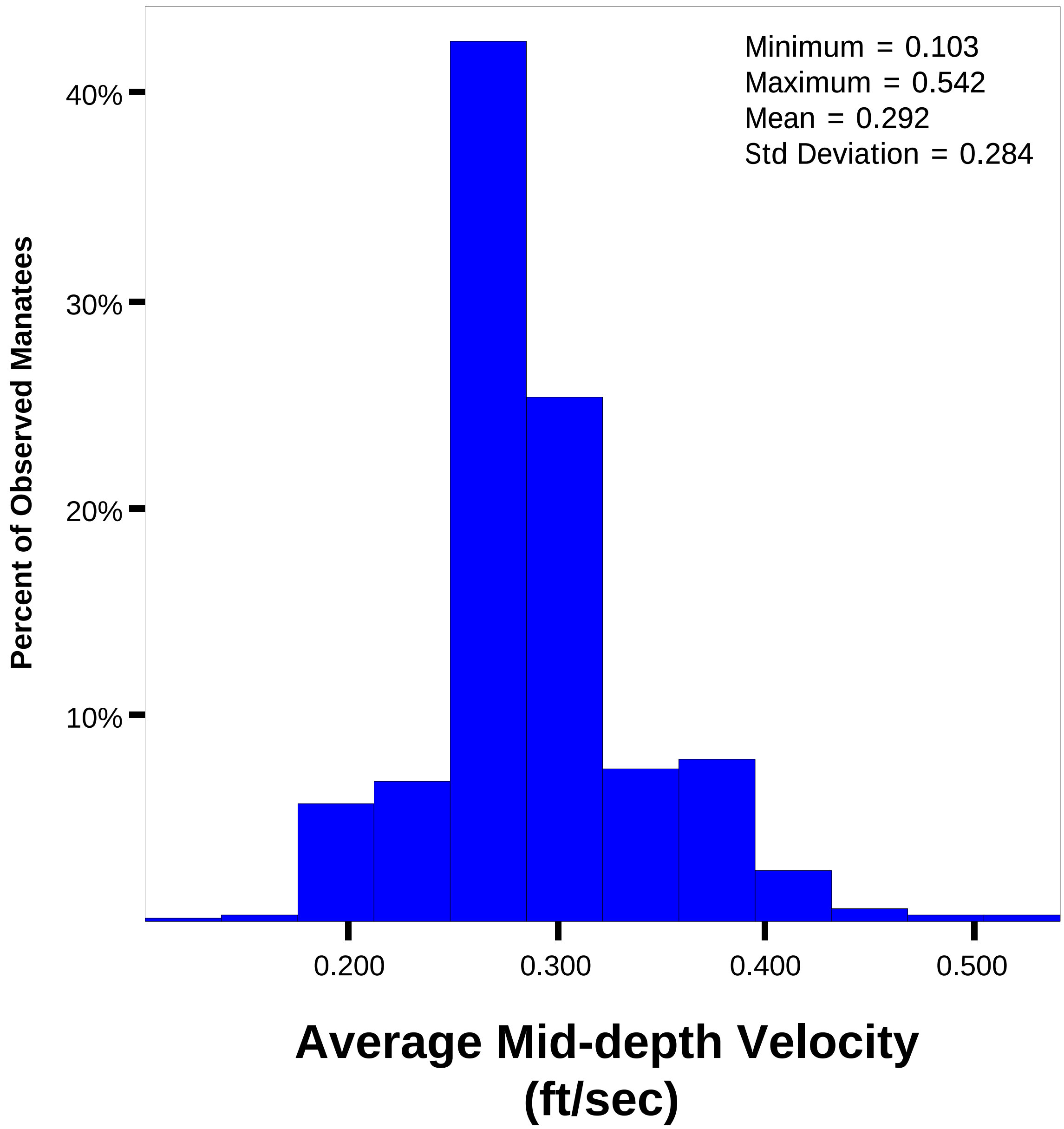


Figure A-14. Histogram of Average Manatee Habitat Mid-depth Water Velocity

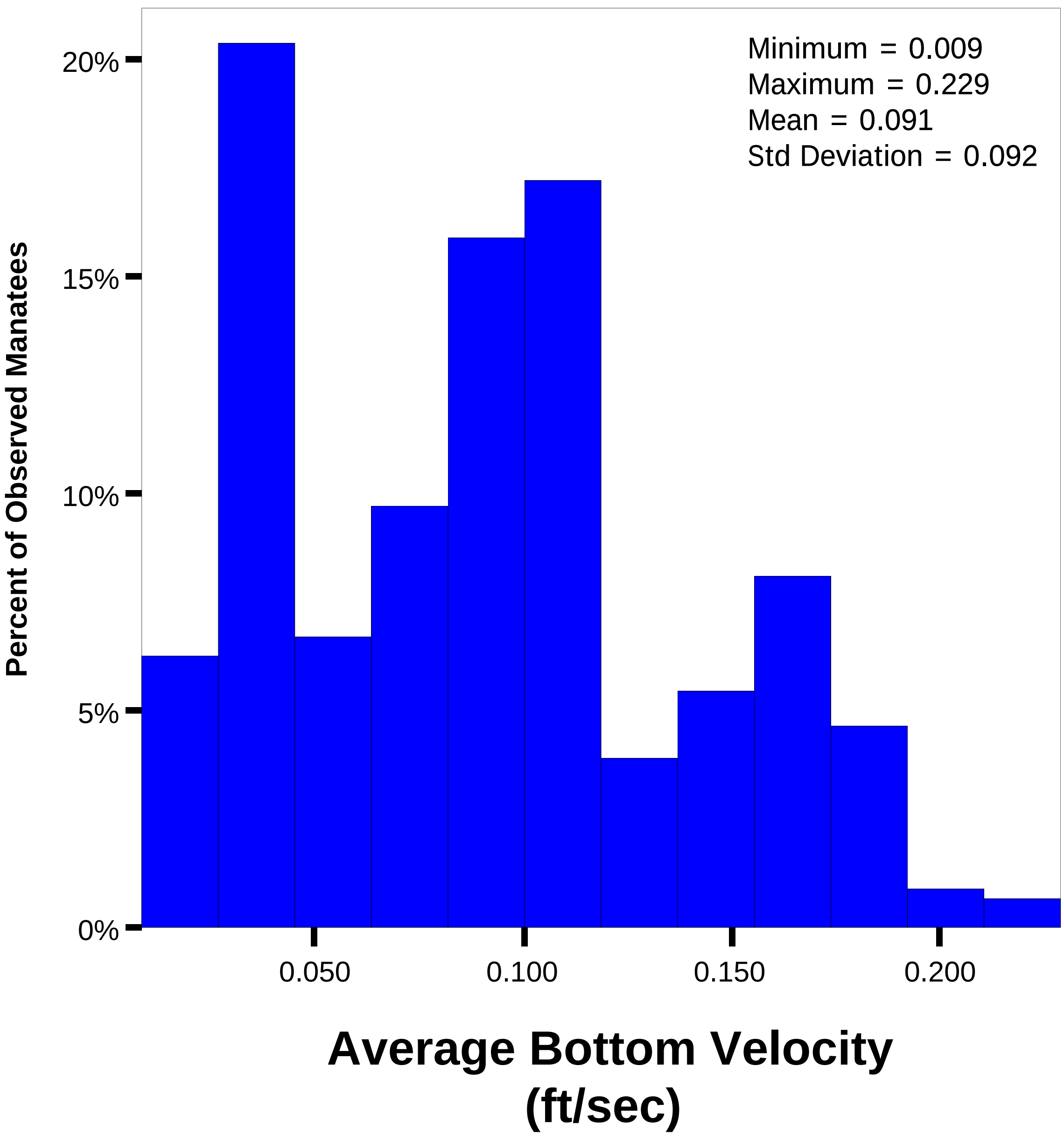


Figure A-15. Histogram of Average Manatee Bottom Water Velocity

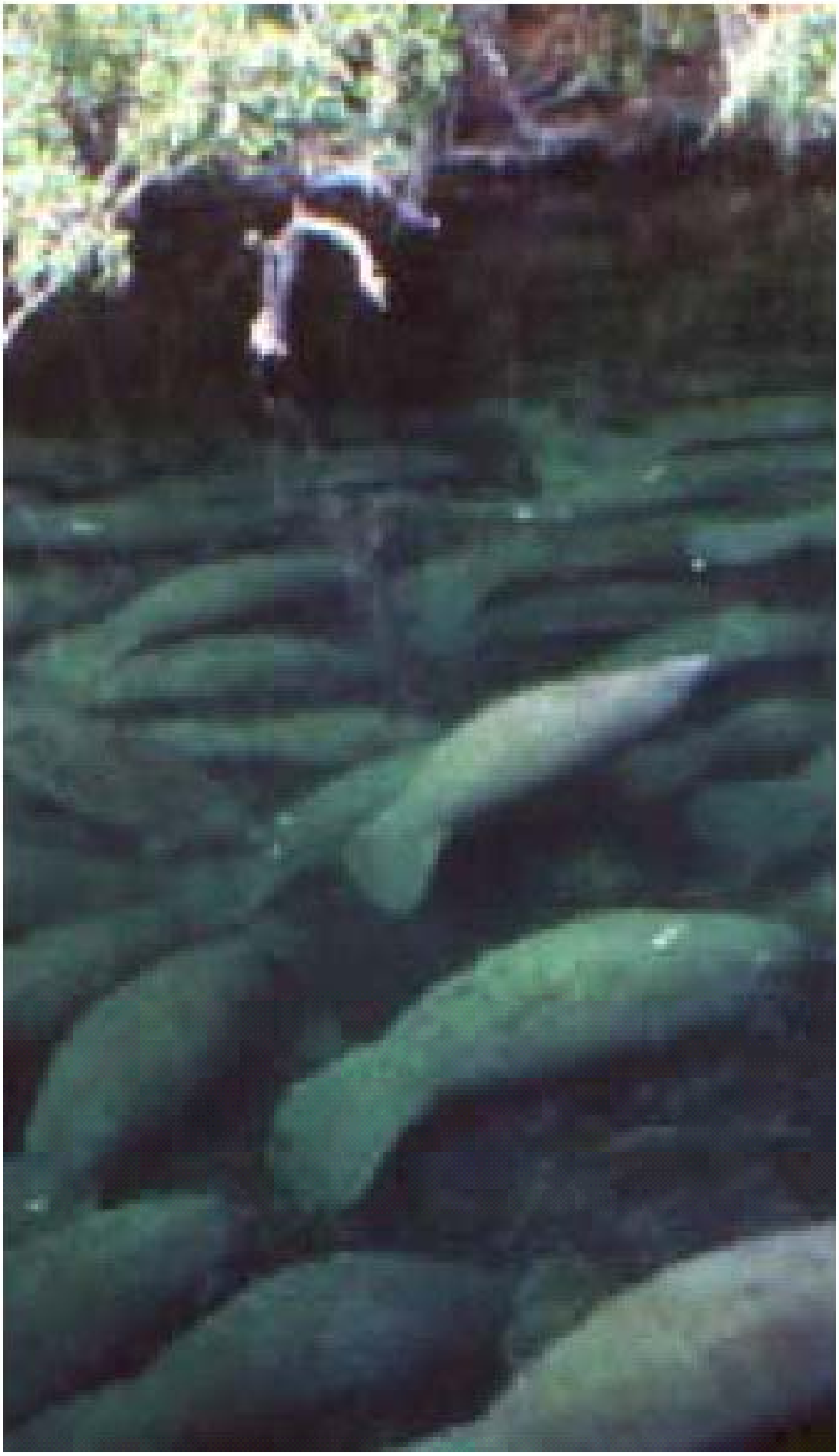


Figure A-16. Manatee Aggregation in Blue Spring Run

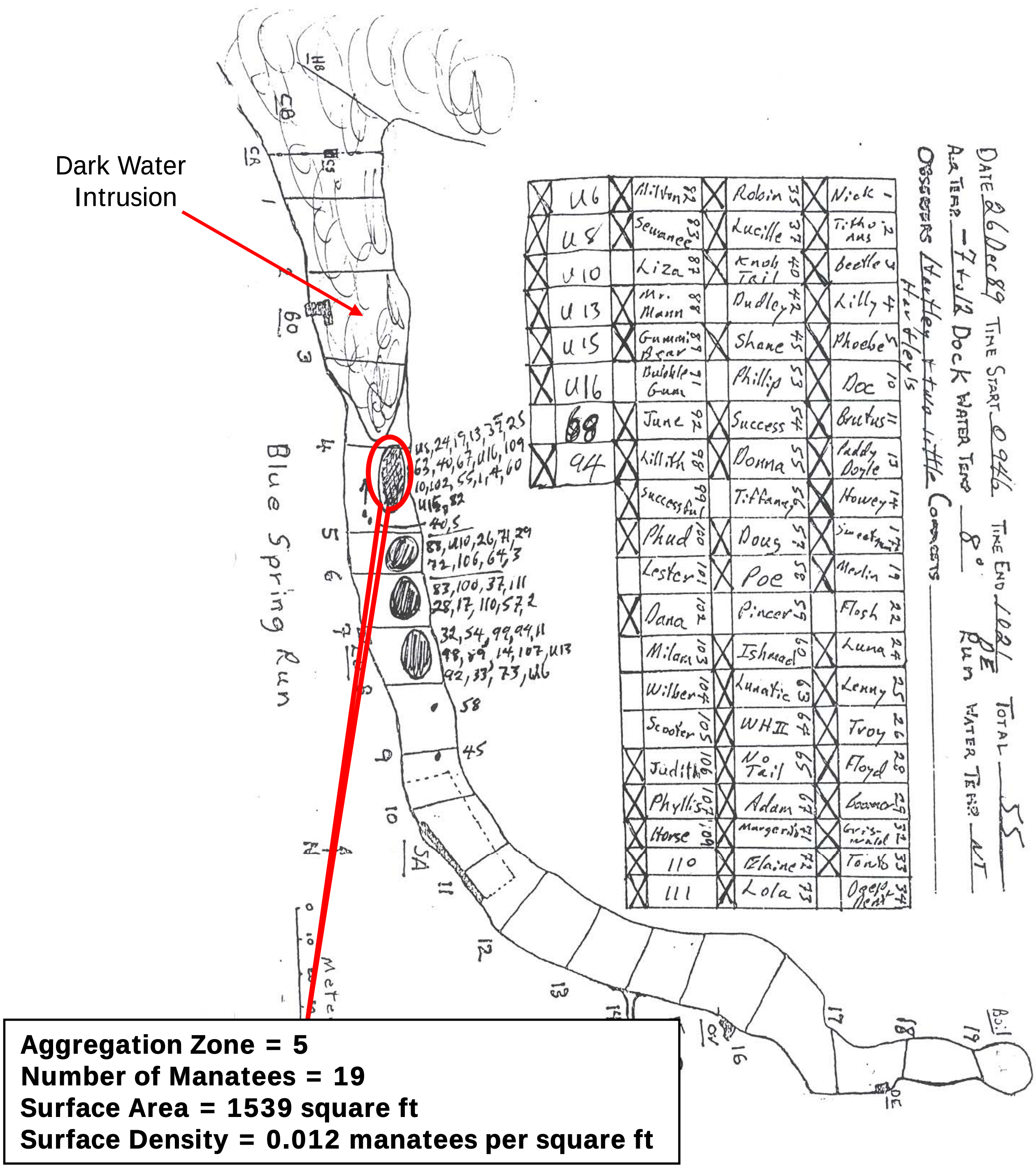


Figure A-17. Example of a Manatee Aggregation Surface Density Calculation

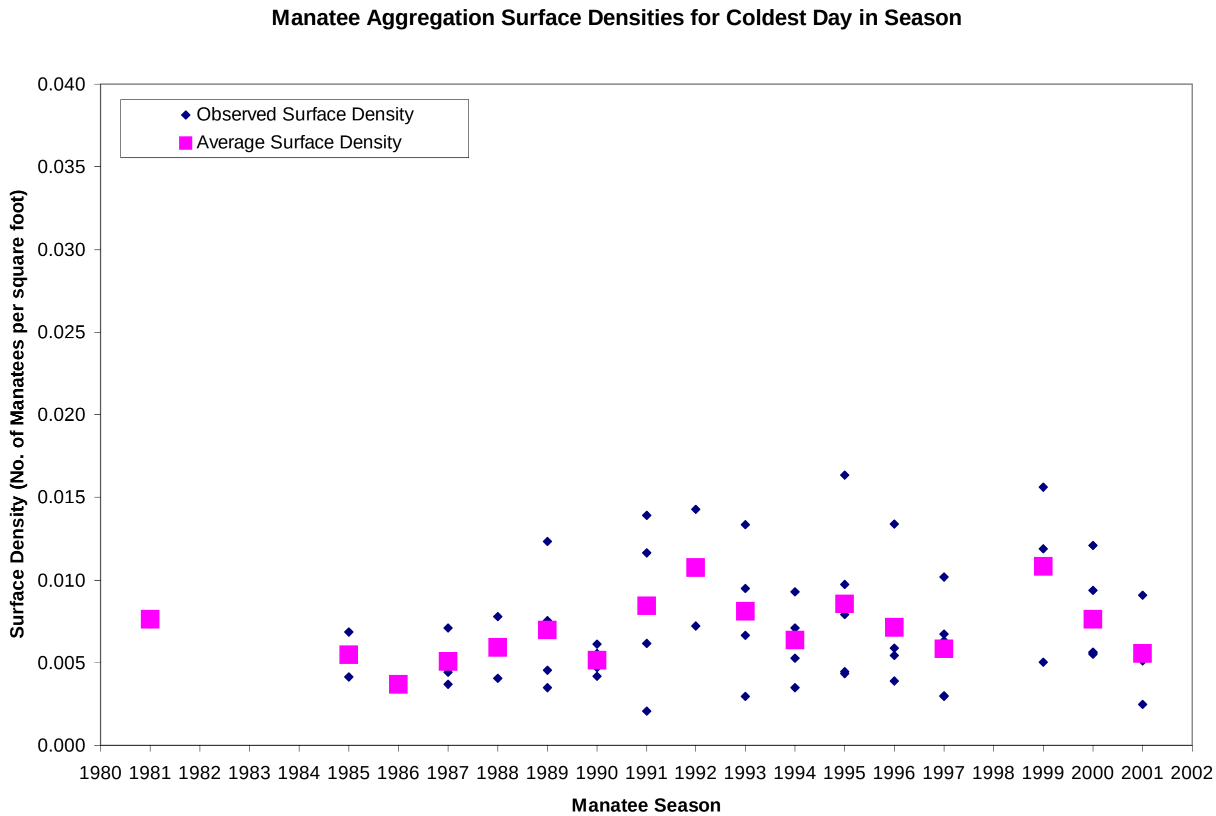


Figure A-18. Computed Manatee Aggregation Surface Densities during Coldest Days Per Manatee Season (1981-2001)

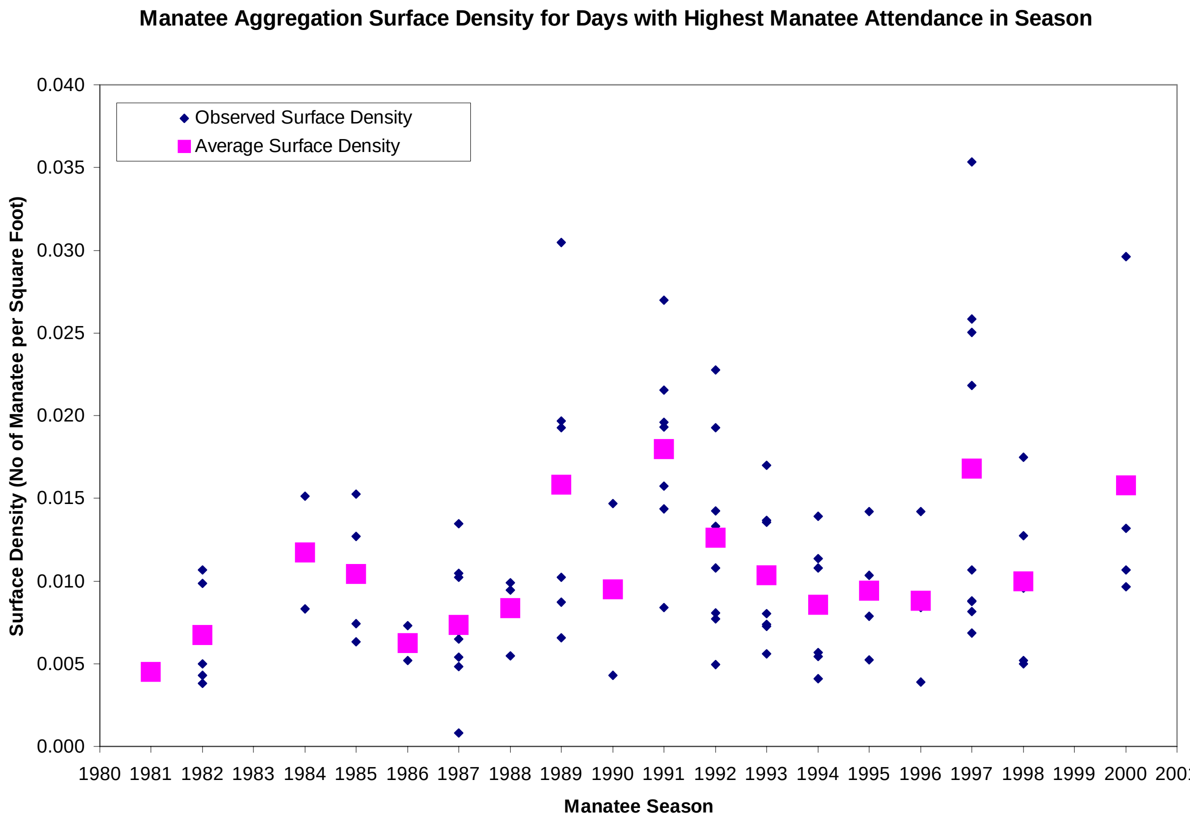
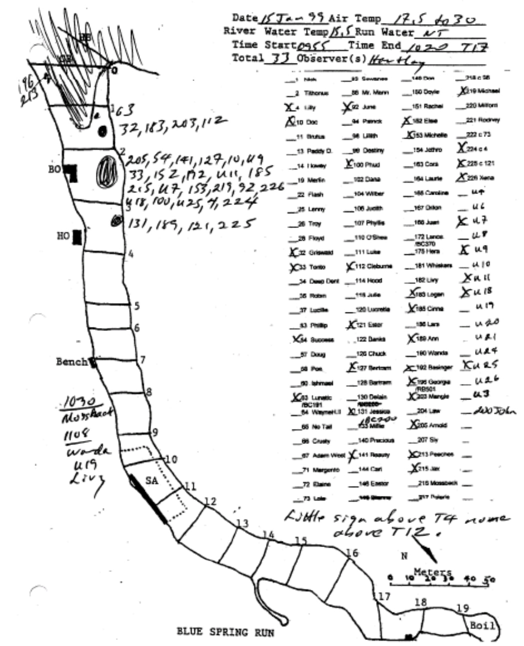


Figure A-19. Computed Manatee Aggregation Surface Densities during Highest Attendance Days per Manatee Season (1981-2001)

1/15/1999



3/1/2002

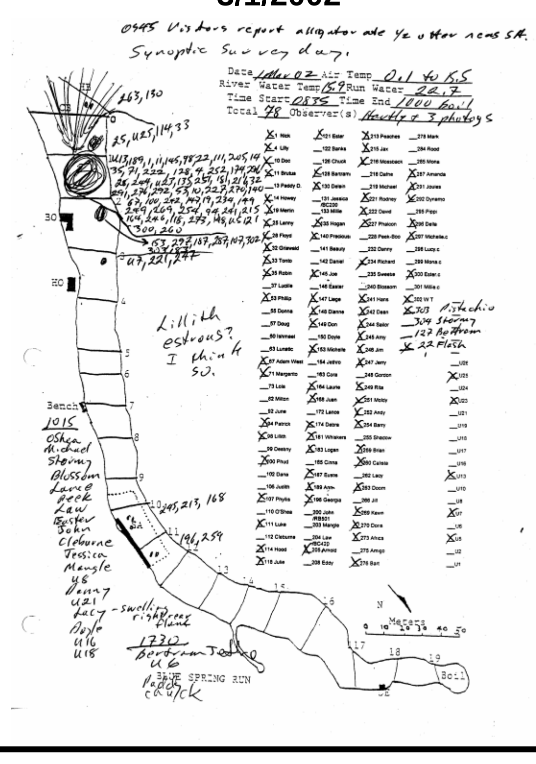


Figure A-20. Examples of BSSP Daily Manatee Survey Sheets

Appendix B

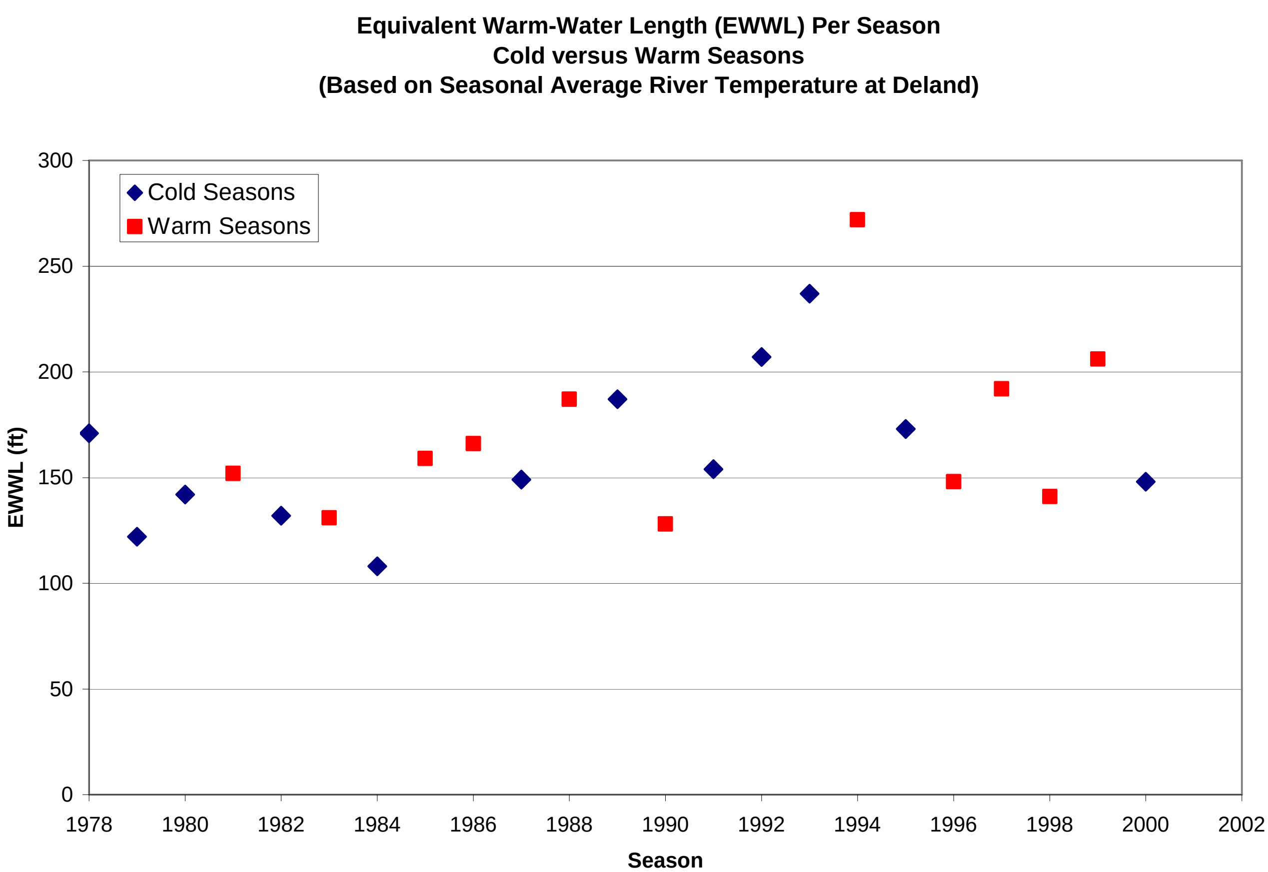


Figure B-1. Plot of Equivalent Warm-Water Length (EWWL) per Manatee Season (1978-2000) – Cold versus Warm Seasons

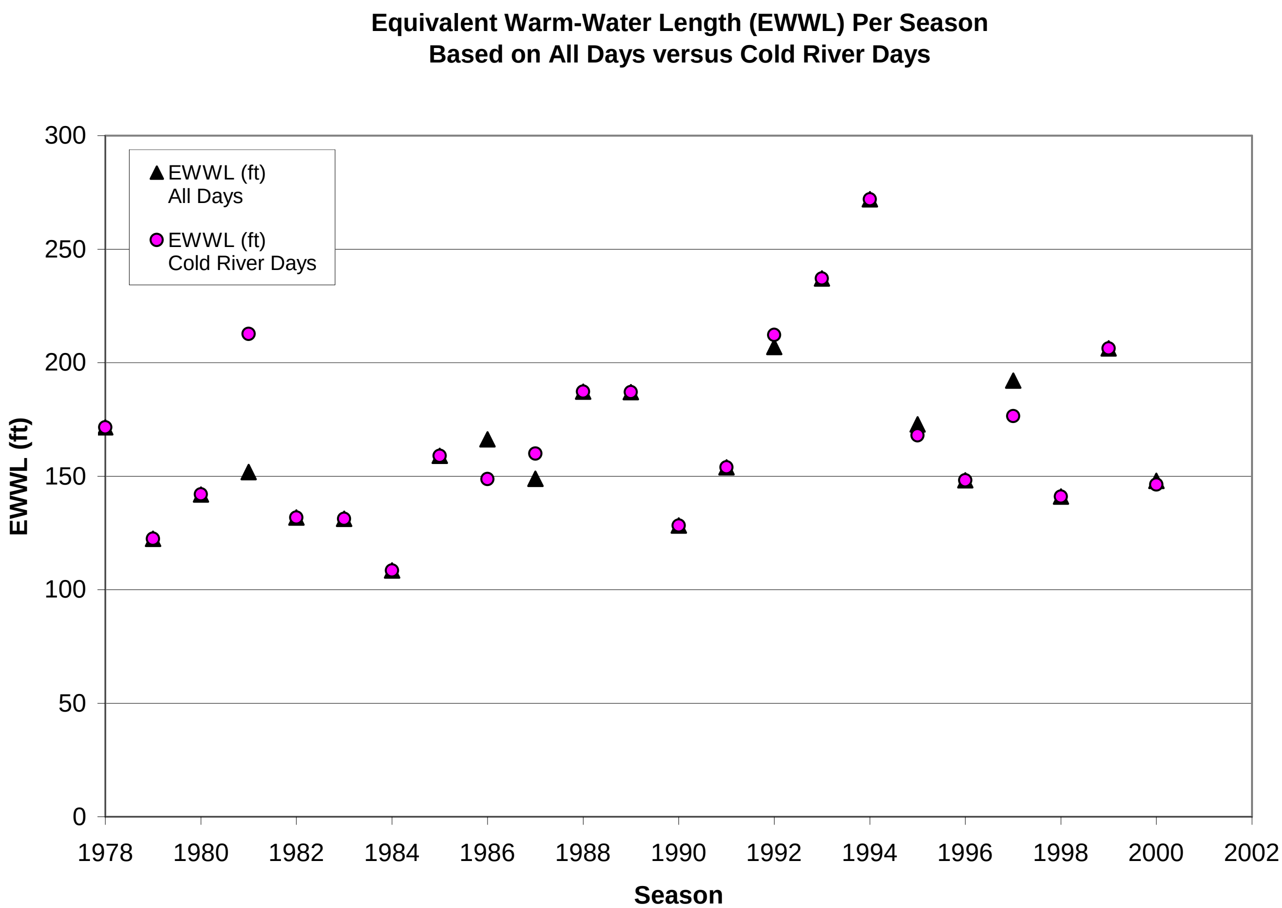


Figure B-2. Plot of Equivalent Warm-Water Length (EWWL) per Manatee Season (1978-2001) – All Days versus Cold River Days