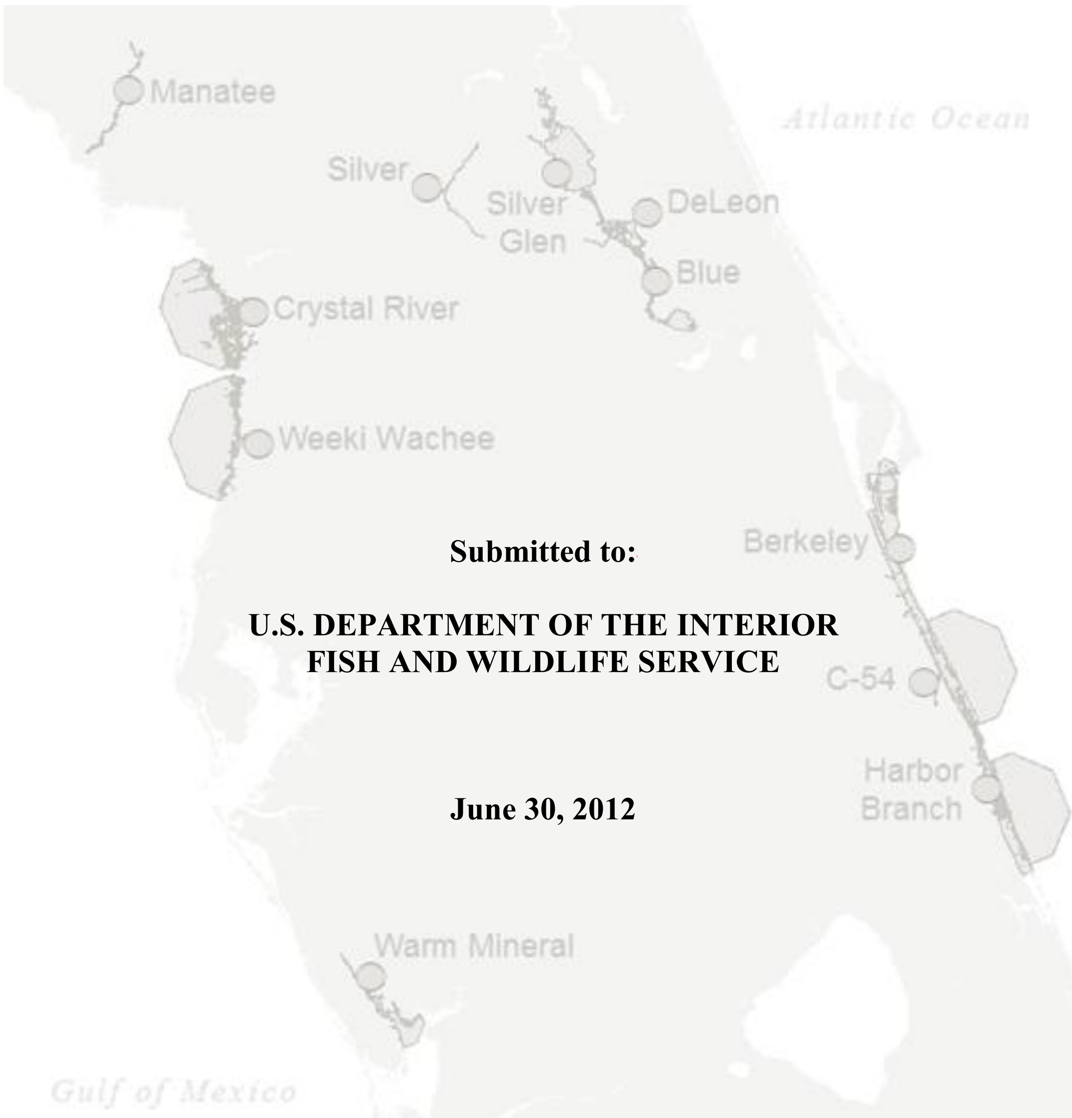
Final Report

Carrying Capacity Assessment of Manatee Forage and Warm-water Associated with Eleven Florida Sites



Submitted to:

U.S. DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

June 30, 2012

Submitted by:

Innovative Health Applications, LLC
6141 North Courtenay Parkway, Suite A
Merritt Island, FL 32953

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Submitted to:

U.S. DEPARTMENT OF THE INTERIOR
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Jacksonville, Florida

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EXECUTIVE SUMMARY

The availability of reliable, warm-water winter refuges is essential to manatee survival within the subtropical climate of Florida. The U. S. Fish and Wildlife Service (USFWS) is mandated to increase knowledge related to the current and future conditions of multiple designated manatee warm water sites across Florida. This effort is one of the actions identified in the Florida Manatee Recovery Plan (USFWS 2001). This report represents the first significant effort by USFWS to assemble and integrate site specific information for numerous manatee warm water sites and to estimate each site's current potential to support manatees during the winter. The estimates represent only two components of capacity: 1) warm water extent (Site-K), and 2) available forage (Forage-K). It was not meant to, nor does it take into account manatee behaviors or human disturbances at these sites.

The USFWS plans to integrate or consider the results of this effort relative to their customized demographic model (Manatee Core Biological Model) which may better enable managers to assess the current status of the Florida manatee population (Runge 2003, Runge et al. 2007, Runge et al. 2007a). Previous estimates of warm-water habitat carrying capacity were derived from expert opinion and this effort offers a quantitative evaluation of a subset of designated sites in Florida.

While considerable information was available for some sites, the project was challenged by data gaps that will not be filled for years to come in some cases and/or were constrained by funding. All assessments were based on existing information with the exception of confirmatory sampling of water temperatures in winter 2011-12 for a few springs. The hydrologists, modelers and biologists on the team reviewed source material, collated data, reviewed metadata, interviewed numerous local experts and discussed parameters and uncertainties. Site-K estimates for some locations may not equate to warm water K due to lack of detailed thermal data under varying temperature scenarios (extensive or intense cold events). The current extent of freshwater forage was not known for some sites. In addition, the reader is reminded that the resulting estimates were based on parameters and current conditions that could change in the near or distant future (i.e. recent changes in the forage base in the Indian River Lagoon occurred unexpectedly over a matter of months after three decades of stability).

Probably the most important product of this effort was the development of a model to produce estimates. Monte Carlo Simulations (MCS) were performed on both Site- and Forage-K in order to incorporate the uncertainties and inherent variability of each parameter's inputs. The MCS used 10,000 trials and the output of the model provided a probabilistic range of estimates for Site-K and Forage-K. In addition, the simulated, limiting capacity for each site was calculated. The limiting capacity or "Limiting-K" was computed by taking the lesser of the Forage-K and Site-K capacity for each trial. The resulting probabilistic range of estimates for Limiting-K was provided along with Forage-K and Site-K in the output of the model. Oracle Crystal Ball, Fusion Edition was used for the MCS. The model allows for new inputs (i.e., forage extent, warm water delineations, biomass values, manatee consumption rates, manatee dimensions, etc.). The model and structure of the simulation were reproduced with the public domain statistical software, R (http://www.r-project.org/). The R-script for this effort is available within the report.

Combined, the eleven sites demonstrate a potential capacity (Limiting-K) at the 50th percentile of 18,789 manatees (13,684 to 25,551 for the 10th and 90th percentiles, respectively). Recent information regarding relative abundance of manatees observed across Florida suggests there may currently be about 5,000 manatees. Combining the 50th percentile values for all eleven sites for Site-K yields capacity for over 90,000 manatees (see Results section tables). That same estimate for Forage-K for the eleven sites combined totals over 50,000 manatees.

Regardless of the percentile chosen, the study indicates that warm water does not appear to be a current constraint to manatees at most sites. In some areas, forage is a current issue or likely future issue. Far larger numbers of manatees can be accommodated spatially than can be supported by the local vegetation. These estimated capacities should not be used to reduce protection of the warm-water sites around the state. Alternatively, they offer insight to the long asked question of capacity and provide USFWS with insight as they move forward with the Manatee Recovery Actions.

The eleven sites analyzed in this report just begin to scratch the surface of determining manatee carrying capacity regionally or for the entire state of Florida. The process followed here could be replicated or use modified input parameters to determine carrying capacity limitations at other warm-water sites throughout the state. Site-specific carrying capacity estimates would need to be translated into regional estimates for inclusion in the Manatee Core Biological Model. With the quantitative calculations at these eleven study sites, we have exceeded the current recognized carrying capacity estimates for the Upper St. Johns, Atlantic, and Northwest regions (Runge 2004). Further work to expand and refine carrying capacity estimation throughout the state will be necessary to enhance results from the current modeling efforts to determine an accurate status of Florida manatee population.

INTRODUCTION

The U. S. Fish and Wildlife Service (USFWS) is mandated to increase knowledge related to the current and future conditions of multiple designated sites across the state of Florida. Manatees are a sub-tropical species, and therefore, the availability of reliable, warm-water winter refuges is essential to their survival. The purpose of this project is to fulfill the USFWS need to estimate the forage and warm-water carrying capacity of sites designated as manatee refuges. This effort is one of the actions identified in the Florida Manatee Recovery Plan (USFWS 2001). In addition, the USFWS plans to integrate or consider the results of this effort relative to a customized demographic model (Manatee Core Biological Model) which may better enable managers to assess the current status of the Florida manatee population (Runge 2003, Runge et al. 2007, Runge et al. 2007a).

There has been general agreement among manatee scientists that warm water is likely to be the limiting resource to manatee population growth (Runge 2004). Previous estimates of warm-water habitat carrying capacity were derived from expert opinion. The broad, region-wide estimates were as follows: Northwest region = 1200 manatees (range 750-3000); Atlantic region = 2000 manatees (1200-5000); Southwest region = 2400 manatees (1500-3000); and Upper St. Johns region = 325 manatees (150-500) (Runge 2004). This project was intended to support refinement of broad, region-wide estimates by performing site-specific estimates using a more quantitative approach. For this purpose, manatee carrying capacity (K) information was developed for two parameters associated with K. We estimated Site K by considering volumetric warm-water constraints and estimated Forage K based on manatee accessible forage. This effort included Monte Carlo simulation (MCS) models developed for each site in order to provide a probability distribution of K estimates.

Study Site Selection Background

USFWS' original request for carrying capacity (Site K and Forage K) estimation included the following sites: Sebastian River (C-54 canal), Berkeley Canal, Blue Spring (Volusia), De Leon Springs, Coral Gables Waterway, Turkey Point Canal, Crystal River, Weeki Wachee River System, Warm Mineral Springs, and Matlacha Isles. Four additional sites were selected from a list of “optional” sites, including: St. Johns River Region - Silver Glen Springs; Atlantic Region - Harbor Branch Canal; Northwest Region - Manatee/Fanning Springs; and the Southwest Region - Port of the Islands.

The first year of this effort (2010) reported findings for the Sebastian River C-54 Canal, Berkeley Canal, and Harbor Branch Canal. After further review and discussion, USFWS determined that the remaining assessments (2011) should be conducted only for natural spring sites, to include the following locations: Blue Spring (Volusia), De Leon Springs, Weeki Wachee Springs, Warm Mineral Springs, Silver Glen Springs, Manatee Springs, Crystal River, and Silver Springs. The assessments were based on existing information with the exception of a small effort of water temperature sampling in winter 2011-12 for springs with data gaps.

This final report combines the findings for all eleven sites assessed during 2010 and 2011. It includes edits elicited from USFWS in January and February and consideration of comments provided by the Florida Fish and Wildlife Conservation Commission in June 2012.

OBJECTIVES

Originally, the objectives for the second phase of this USFWS project were to estimate the existing K for six Florida sites: Blue Spring, Silver Glen Spring, Warm Mineral Spring, Port of the Islands, Coral Gables Waterway and Crystal River. A third phase was to follow during which the five remaining sites would be evaluated. However, in early FY11 USFWS assessed the Recovery Actions requirements and schedule, and adjusted this scope of work which set the project on temporary hold. The adjustment included: 1) fast-tracking the project to end in March of 2012 (originally December 2012), 2) adding uncertainty estimates to parameter inputs in order to perform site specific MCSs, 3) performing rapid field assessments of temperatures for sites with severe data gaps, and 4) removing three sites from consideration.

Therefore, in 2011 a probabilistic range of K estimates was calculated for the following eight sites: Blue Spring, De Leon Springs, Silver Glen Spring, Silver Spring, Manatee Springs, Warm Mineral Springs, Weeki Wachee Springs, and the Kings Bay/Crystal River system. MCS's were also performed for the original 2010 sites (Sebastian River C-54 Canal, Berkeley Canal, and Harbor Branch Canal) and results are presented herein in order to provide a consistent approach for the K estimates.

As stated in our August 2010 report, carrying capacity generally refers to numerous environmental variables interacting with an organism. However, in this case, "carrying capacity" is related to two specific parameters: 1) accessible warm-water (often considered as greater than or equal to the 20 ºC thermal plume) supporting manatees at each site (Site-K); and 2) forage accessible to manatees within a 30 km distance of each designated warm-water site (Forage-K).

METHODS

Site-K and Forage-K carrying capacities were estimated consistent with assumptions outlined by the USFWS and associated focus groups (i.e. Manatee Recovery Team Habitat Working Group, Warm Water Task Force, etc.), including priorities identified by state and federal managers for refining the current estimates of carrying capacity. We also utilized assumptions outlined in the St. Johns River Water Management District's (SJRWMD) recent Blue Spring MFL Report (Rouhani *et al.* 2007) and output from the USFWS report "Assimilation Efficiencies of Captive West Indian Manatees Consuming Seagrass" (Worthy 2008).

Monte Carlo Simulation

Monte Carlo methods are a class of calculations that use a repeated random sampling of variables in order to compute a range of probable results. Monte Carlo analysis was coined by Metropolis and Ulam (1949) in reference to games of chance which were popular in the casinos of Monte Carlo. Their analytical process simulated the outcomes of multiple games over and over, relying on a large number of trials (or simulations) to define the outcome's probability distribution.

The steps in a MCS are best summarized by Wittwer (2004):

1. Create a parametric model: $y=f(x_1, x_2, \ldots, w_q)$.
2. Generate a set of random inputs: $x_{i1}, x_{i2}, \ldots, x_{iq}$.
3. Simulate the model and store the results as y_i.
4. Repeat steps 2 and 3 for $i = 1$ to n.
5. Analyze the results using such tools as histograms, summary statistics, and confidence intervals.

MCS's were performed on both Site- and Forage-K in order to incorporate the uncertainties and inherent variability of each parameter's inputs. When possible, triangular or uniform parametric models were used for each input in order to clearly present the minimum, maximum and likely values of an input.

The MCS used 10,000 trials and the output of the model provided a probabilistic range of estimates for Site-K and Forage-K. In addition, the simulated, limiting capacity for each site was calculated. The limiting capacity or "Limiting-K" was computed by taking the lesser of the Forage-K and Site-K capacity for each trial. The resulting probabilistic range of estimates for Limiting-K was provided along with Forage-K and Site-K in the output of the model. Oracle Crystal Ball, Fusion Edition was used for the MCS. In order to aid in the evaluation of the MCS used in this effort, the models and structure of the simulation were reproduced with the public domain statistical software, R (http://www.r-project.org/). Simulation results were presented in increments of 10% from the 0th to 100th percentile. These percentiles represent the probability of a forecast value being less than or equal to the value that corresponds to the percentile. The 0th percentile represents the smallest value in the data set range, while the 100th percentile represents the largest.

Data Acquisition

General data calls began in 2010 with the original larger site list and continued through February 2011, when the project scope underwent adjustments after which data calls began again in late summer of 2011. As mentioned above, short-term water temperature data collection occurred in winter 2011/2012, to augment certain data deficient sites. In some cases, existing datasets appeared adequate and convincing for determining warm water extents, however, temperature and bathymetry data were lacking in some river segments. Therefore, to support improving confidence in designating the warm-water site extent (to calculate Site-K) we performed some site specific sampling. Our estimates are based on existing data, literature, maps, plans, and knowledge from experts that have collected quantifiable, volumetric assessments of each area. Those sources are found in the literature cited and significant sources are referenced in the calculation spreadsheets.

Site-K

The objective of Site-K analyses was to define the usable volume of the warm-water site and estimate the number of manatees that can be accommodated. This estimate is referred to as the Site-K, which often requires: a) water temperature measurements, b) bathymetric information, c) warm-water surface area calculations under extreme hydro-climatic conditions, and d) physical characteristics of a typical manatee.

One of the few sites with significant data already available is Blue Spring, in Volusia County. The St. Johns River Water Management District (SJRWMD) implemented a quantitative procedure to determine the minimum flow regime for Blue Spring (Rouhani *et al.* 2007). The research efforts that supported the recommended minimum flow regime were based on the analysis of the daily manatee observation database of Blue Spring State Park, as well as period of record spring discharge, river stage and river temperature data, collected and compiled by the U.S. Geological Survey (USGS) and SJRWMD. An important element of this analysis was the development of a quantitative process to define the manatee carrying capacity of the Blue Spring run. This procedure was constructed on the basis of manatee physiology and habitat analysis.

In the case of Blue Spring (Rouhani *et al*., 2007), the carrying capacity of the spring as a manatee winter refuge was measured in terms of the useable warm-water length under extreme hydraulic and thermal conditions, which is conservatively defined as the portion of the run with a bottom temperature greater than 68 F (20 C) and a centerline water depth greater than or equal to1.5 m (5 ft). In this analysis, 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. Methods used in this study are consistent with those developed in the Blue Spring analysis.

Water temperature measurements

Warm-water surface areas were estimated based on transects or maps of temperature profiles from probes or thermal imagery, when available, in order to delineate areas with water temperature at or in excess of 20°C. In situations where these data were unavailable or limited, we also considered known manatee winter aggregation data (aerial surveys, ground based observations from local experts, etc.) to demarcate the estimated outer extent of a particular thermal refuge.

Bathymetry

Bathymetry can further refine the spatial extent of areas of adequate depth, i.e. more than 1.2 m (4 ft) of warm water, which allows full submergence of typical manatees. Available bathymetric data ranged from detailed surveys at specific points in time to a few point measurements by local biologists. The MCS included a site-specific depth limiting factor to address bathymetric variability within each site's warm water area.

Analysis of Extreme Conditions

The 2010 effort included a procedure to compute the statistical properties of the annual minimum 3-day water level[1] at the sites. This calculation was originally used for the Blue Spring site as

[1] A 3-day critical duration was first used in Rouhani *et al*. (2007) for the sake of conservatism in order to ensure 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.

detailed in Rouhani *et al.* (2007) which had negligible tidal influence and detailed bathymetric, hydrologic, and manatee aggregation data. However, with the addition of MCS and the fact that many of the 2011 sites had strong tidal influences and relatively limited data, extreme conditions were addressed by determining useable warm water areas within each refuge where water depths were greater than or equal to 1.2 m. These areas were estimated using available bathymetric surveys or field observations. The warm water areas were then discounted using a depth limiting factor. This factor was estimated using real-time water level data that can be linked to bathymetric measurements and/or field observations.

Physical Characteristics of Manatees

Physical dimensions of manatees were reviewed and approved by USFWS for use in 2010 and characterized by a typical volume of an adult manatee of 2.3m x 1.2m x 1.2m (7.5ft x 3.8ft x 3.8ft). It was assumed that manatees seeking refuge will form a single layer, "shoulder-to-shoulder" configuration. While manatee behavior can be complicated and varied, this conservative assumption was corroborated by historical observations at aggregation sites and more recently during very high density events observed at the three pilot sites during the unprecedented winter of 2010 (J. Provancha, personal observation).

With the addition of MCS, this assessment used a range of sizes for manatees rather than an average size employed in the 2010 Report. Variables for length and width, as well as a length buffer (spacing between manatees), were used in the model.

Consistent with Rouhani *et al*. (2007), the Site-K of a warm-water refuge site was conservatively estimated based on the following assumptions:

- Size and buffer spacing of a visiting manatee were estimated using the distributions shown in Appendix 1a. These distributions are currently assumed to be non-site specific. (In the 2010 Report we limited the size of an average adult manatee as a space of 2.3m x 1.2m x 1.2m).
- The estimated Site-K represents only the volume of warm water that can be occupied by one layer of fully submerged adult manatees.
- Any portion of the investigated water body with a depth of warm water less than 1.2 m is considered as unsuitable as a warm-water refuge.
- Additional capacities associated with partially submerged adult or younger manatees, as well as vertical stacking of manatees are not included in the estimated Site-K.
- The estimated Site-K is further reduced to allow free movement of manatees along the land-bound edges of a site. This portion, or vacant area, is conservatively estimated as the length of a typical manatee in order to allow for full rotation (nose to tail) in order to enter or leave a refuge.

Each of the 2011 warm water sites is unique in terms of shape, depth, degree of tidal influence and available warm water area. However, in order to maintain a consistent process to estimate Site-K, the warm water areas were calculated using two basic methods:

- Simulate a useable area for approximately rectangular refuges based on variable warm water length and average width. Vacant space for entry and exit into the refuge, as described above, was subtracted from the useable area. Finally, a depth limiting factor was multiplied by this area to address shallow (less than 1.2 m) portions of the refuge. This method was used on most of the sites.
- Simulate useable areas for non-rectangular refuge sites using GIS-calculated warm water areas and perimeters. Crystal River, Silver Glen Springs, and the 2010 site, Harbor Branch, have non-rectangular areas. Crystal River and Silver Glen Springs also have more than one defined warm water area within their respective site boundaries that vary in size and historical usage. GIS-calculated warm water areas were used to approximate useable area. Vacant space for entry and exit into the useable areas was estimated using the GIS-calculated perimeter times the simulated length of a manatee. One-half of the perimeter was used in the vacant space calculation for partially land-bound areas (Crystal River and Silver Glen Springs). As with the rectangular areas, a depth limiting factor was multiplied by the useable areas to account for less than 1.2m (4ft) portions.

Blue Spring already had a comprehensive analysis of usable warm water lengths based on flow, temperature and water level models as well as decades of daily manatee aggregation data. Ranges of warm water lengths based on extreme hydraulic and thermal events were entered directly into the model.

The simulated warm water surface area calculated using the procedures described above was then divided by the simulated surface area of a manatee to determine the holding capacity of the refuge.

Forage-K

Forage-K is defined by the quantity of available forage found within 30 km of the warm-water site. Required data include: a) areal extent of vegetation, b) percent coverage of vegetation within the delineated areal extent, c) average biomass in kg/m^2, d) growth rate during the winter season, and e) consumption rate for manatees in kg/day. These estimates were often produced based on available information from various agencies (i.e. water management districts, county governments, FWC research and monitoring groups, USGS, academic institutions, etc.).

In 2010, we utilized explicit information from the Worthy (2008) assimilation efficiency report on the daily food intake rate. However, we used 800 kg as the likely body weight (instead of the 1000 kg used by Worthy). We believe the 1000 kg average value is large based on our field observations, general knowledge, and the manatee dimensions used to calculate Site-K. Others may suggest even lower values be used. However, the MCS takes into account a range of body weights, from average juvenile, average adult to large adult. We utilized a likely 13% of body mass as “intake” recommended by Worthy (2008) for adults in cold periods. As with body weight, intake was varied in the MCS. Distributions used for these and other parameter inputs are described in the Results section and provided in Appendix 1a. New “likely” values can be changed in future runs of our model as supplied to the USFWS as part of this report deliverable.

Maps of vegetation (forage) data within 30 km of the site were developed using available vegetation data to quantify square meters of forage. In some cases partial maps were already available. Discussions with local experts enabled us to elicit a range of certainty values for these acreages for use in the MCS. Using these data, we determined how many manatees could be sustained on the available forage. The sustainability timeframe (120 days, December through March) was determined by the USFWS Habitat Working Group. For Forage-K we used the following calculation (developed within the same working group):

$K = (A*B*G)/(C)$, where:

A = forage availability within 30 km of the site, in m^2;
B = forage biomass (ranges determined from literature), in kg/m^2;
G = vegetative growth rate(ranges determined from measurements and expert opinions), in days;
C = consumption rate (modified as described above from Worthy 2008), in % biomass/day.

Available forage or submerged aquatic vegetation (SAV) within a 30 km swimming distance from a warm-water site was calculated using a geographic information system (GIS) developed by M. Gimond previously during the Manatee Habitat Checklist process (Provancha *et al.* 2009).

Forage availability for each site (parameter A in the aforementioned equation) was estimated in one of three ways depending on how SAV was characterized in a GIS. For sites where polygons were characterized as SAV presence or absence (these sites include Harbor Branch, C-54 and Berkeley) all areas identified as having SAV were summed then multiplied by an estimated percent cover producing a *weighted* SAV area. Uncertainty around the estimated percent cover was parameterized in the MCS using a triangular distribution. For example, if total SAV area covered 1000 m^2 and estimated percent cover for all areas was 50% with an uncertainty of +/-10%, a weighted minimum and maximum SAV area of 450 m^2 and 550 m^2, respectively, (with a peak probability at 500 m^2) were used in the MCS.

For sites where SAV polygons were characterized by a single percent coverage value (these sites include Blue Spring, DeLeon, Silver Glen and Silver Spring), each polygon area was multiplied by the percent coverage (formulated as a fraction) then summed to produce a *weighted* SAV area. An overall uncertainty value was then applied to the weighted SAV areal value. For example, if all 30% SAV coverage polygons summed to 500 m^2 and all 70% SAV coverage polygons summed to 1000 m^2 , the weighted SAV area was calculated from (0.3 * 500) + (0.7 * 1000) or 850 m^2. If the uncertainty of the entire SAV coverage was 20%, weighted SAV area values ranging from 680 m^2 and 1020 m^2 (with a peak probability at 850 m^2) were used in the MCS (following a triangular distribution).

For sites where SAV polygons were characterized by a range of percent coverage values (these include Weeki Wachee, Crystal River and Warm Mineral), polygons within each percent coverage category were summed and the percent coverage range was used to define the minimum and maximum weighted SAV area values in the MCS. For example, if all polygons in the 10% to 50% coverage category summed to 500 m^2 and all polygons in the 75% to 100%

coverage category summed to 1000 m^2, the minimum weighted SAV area value used in the MCS was calculated from (0.1 * 500) + (.75 * 1000) or 800 m^2 and the maximum weighted SAV area value used in the MCS was calculated from (0.5 * 500) + (1.0 * 1000) or 1250 m^2; the peak weighted SAV area value was then computed by taking the average between the minimum and maximum values or (800 + 1250) / 2 = 1025 m^2 in this example.

Based on extensive literature reviews conducted by the USFWS Manatee Habitat Working Group in 2006, a range of biomass (winter season, wet weight) estimates for mixed SAV beds, referred to as B(1) and B(2) were selected to apply to the SAV acreages. Discussions with experts (P. Carlson/FWC, K. Smith/FWC, Tom Fraser/UF, Jud Kenworthy/NOAA, and P. Hall/FWC in 2011 and Mar. 2012, resulted in our decision to use a conservative range of growth rates for winter SAV (0.0052 to 0.01 kg/d). These estimates were applied as the lower and upper end of the MCS input. These outcomes were then multiplied by G (vegetative growth) to yield an adjusted winter site forage biomass. This latter value was then divided by a manatee daily winter consumption rate (C) to yield Forage-K.

GIS Analyses

GIS analyses were performed to identify site-specific vegetation coverage areas and warm water areas. Some GIS datasets were compiled previously for the USFWS Habitat Checklist Assessments: Middle St. Johns River Springs (Provancha *et al.* 2009), Crystal River Complex, Florida (Habitat Working Group, revised by Taylor *et al*.2009), and Sarasota County checklist assessment (Taylor *et al*. 2010).

GIS files for vegetation coverage within the Middle St John's basins did not exist in 2008 during the Checklist effort. Therefore acreages of forage were not available and values represented in those reports were minimum estimates of forage within the 30 km swim distances. Freshwater vegetation in many areas has still not been adequately mapped. However, recent data collected by FWC, SJRWMD, and US Army Corps for invasive plant monitoring provided presence absence data that allowed some inferences to be developed. We requested the FWC team help determine relative percent cover along the St. Johns River within the areas of our study and we converted those to create acreages of forage. Warm water areas were delineated for each of the springs based on zones exceeding a depth of 1.2 m, documented usage, site surveys and, in the absence of any of these factors, visible extent.

STUDY AREAS

The study sites are located along the central west coast of Florida, central Florida along the St. Johns and Ocklawaha Rivers, and east coastal Florida within the Indian River Lagoon (Figure 1). Several of the USFWS Manatee Habitat Checklist Reports prepared in 2007- 2010 provided supporting background information for these sites.

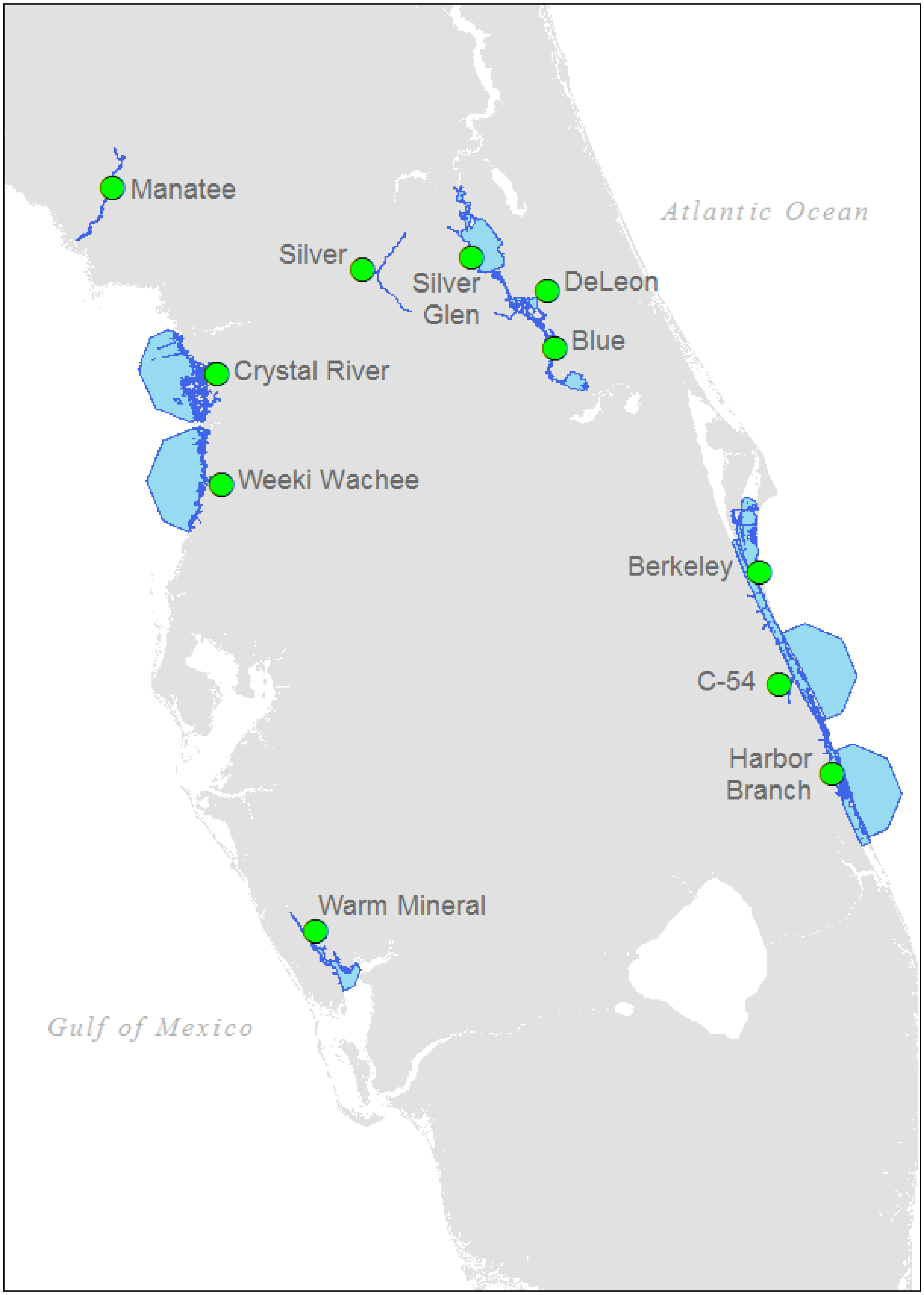

Figure 1. Locations of the eleven Florida warm water sites assessed.

Blue Spring

Blue Spring is a first magnitude spring in Volusia County within Blue Spring State Park. This is the only warm water site within the St. Johns system that has been designated as a primary site by the Warm Water Task Force and Habitat Working Group. Blue Spring has a circular spring pool with a depth of 6.1 m. Algae are the only aquatic vegetation currently documented in the spring and spring run. The spring run flows southwest 320 m to the St. Johns River. The long-term (1932 to 2012) mean discharge of the spring is 156 cfs (USGS, National Water Information System: http://waterdata.usgs.gov/fl/nwis/measurements?site_no=02235500&agency_cd=USGS&format=brief_list; accessed April 28, 2012). Maximum daily manatee counts per season have increased at a rate of about 7% since 1978. Smith *et al.* (2000) approximated the seasonal daily average number of manatees has tripled since the 1970s, indicating the importance of this habitat to the local and regional manatee population. The recent high count was 317 (January 2010) manatees documented in this run (Blue Springs State Park Ranger's log, December 2011).

Figure BS- 1. Map of the warm water extent for the Blue Springs site currently available to manatees.

According to Rouhani *et al.* (2007), the "actual" carrying capacity of this spring as a manatee winter refuge is measured in terms of the useable warm-water length (UWWL), which was conservatively defined as the portion of the run with a bottom temperature greater than 68 F (20C) and a centerline water depth greater than or equal to 1.5 m (5 ft). 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 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. A UWWL of 106 m was calculated for these simultaneous extreme events and summarized along with other variations in Rouhani *et al.* (2007). Figure BS-1 indicates our current estimation of the warm water extent for this site with a total area of 2306 m^2 and a likely length of 107 m. Synoptic measurements show that this area can extend to greater lengths during favorable, non-extreme periods. However, Rouhani *et al.* (2007) did not calculate a physical (Site-K) capacity of manatees but, instead, determined the number of manatees per foot of UWWL during extreme (50 year) river stage and spring flow conditions. Using this value of 1.73 manatees/ft multiplied by the UWWL of 348 ft (106 m), the site capacity was calculated to be approximately 600 adult manatees. Please refer to the Results section of this report for additional discussion of the 1.73 manatees/ft and corresponding capacity compared to the simulated capacity from the MCS.

According to various sources within the St. Johns River Water Management District, there is essentially no native SAV within the Blue Spring run. Data provided by Robert Mattson (SJRWMD) and Kelli Gladding/FDEP (April 2011) yielded vegetation distribution and composition within the St. Johns River up and downstream of this site. The shoreline data, collated for the USFWS 2009 Habitat Checklist, were integrated with recent FDEP vegetation presence-absence data. We then worked with FDEP to estimate percent cover along the extent of their collection sites. Figure BS-2 displays the vegetation outside of the run estimated for the St. Johns River within the 30 km manatee swim distance for this site. The vegetative data extended over 33,819,484 m^2 (8,356 ac) but was weighted using the percent cover estimates from FDEP resulting in a total of 7,851,962 m^2 (1940 ac). Using techniques outlined in the Forage-K sub-section of the Methods section, a weighted SAV area coverage value of 7,851,962 m^2 (1,940 ac) was computed with min/max values (as used in the MCS) ranging from 6,281,570 m^2 (1,552 ac) to 9,422,355 m^2 (2,328 ac).

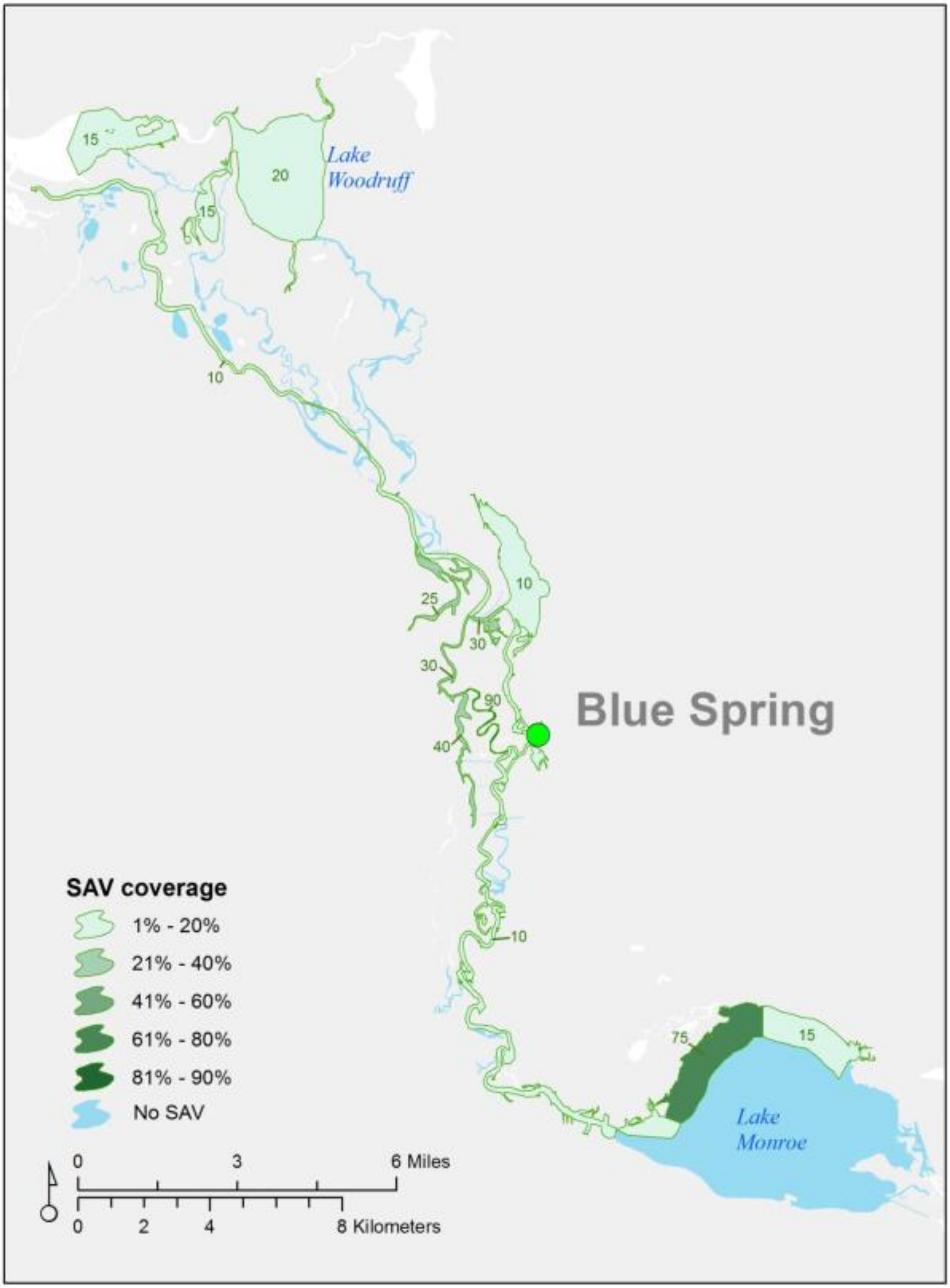

Figure BS-2. Map of the Blue Spring site displaying the 30 km manatee swim extent and estimated SAV coverage.

De Leon Springs

De Leon Springs is a second magnitude spring in Volusia County within De Leon Springs State Park. Mean discharge from the spring from 1929-2000 is 27.2 cfs (Scott *et al.* 2004). The spring has a circular pool with a maximum depth of 8.5 m. A concrete wall encircles the pool, and the spring flows through a concrete weir and then down a 1 m drop into the spring run, such that manatees cannot access the spring pool. The thermally-buffered run flows 0.4 km into Spring Garden Lake; Spring Garden Creek then flows 4 km to Lake Woodruff. However recent work has shown that the thermal quality relative to manatees is limited to a very small area as indicated by Figure DS-1. Measurements and in-water work (Monica Ross/ Sea2Shore Alliance, pers. Comm., Nov. 2011) suggests that the refuge is quite small. Based on this information, we estimated a useable warm water area of 8591m^2 (2.1 ac).

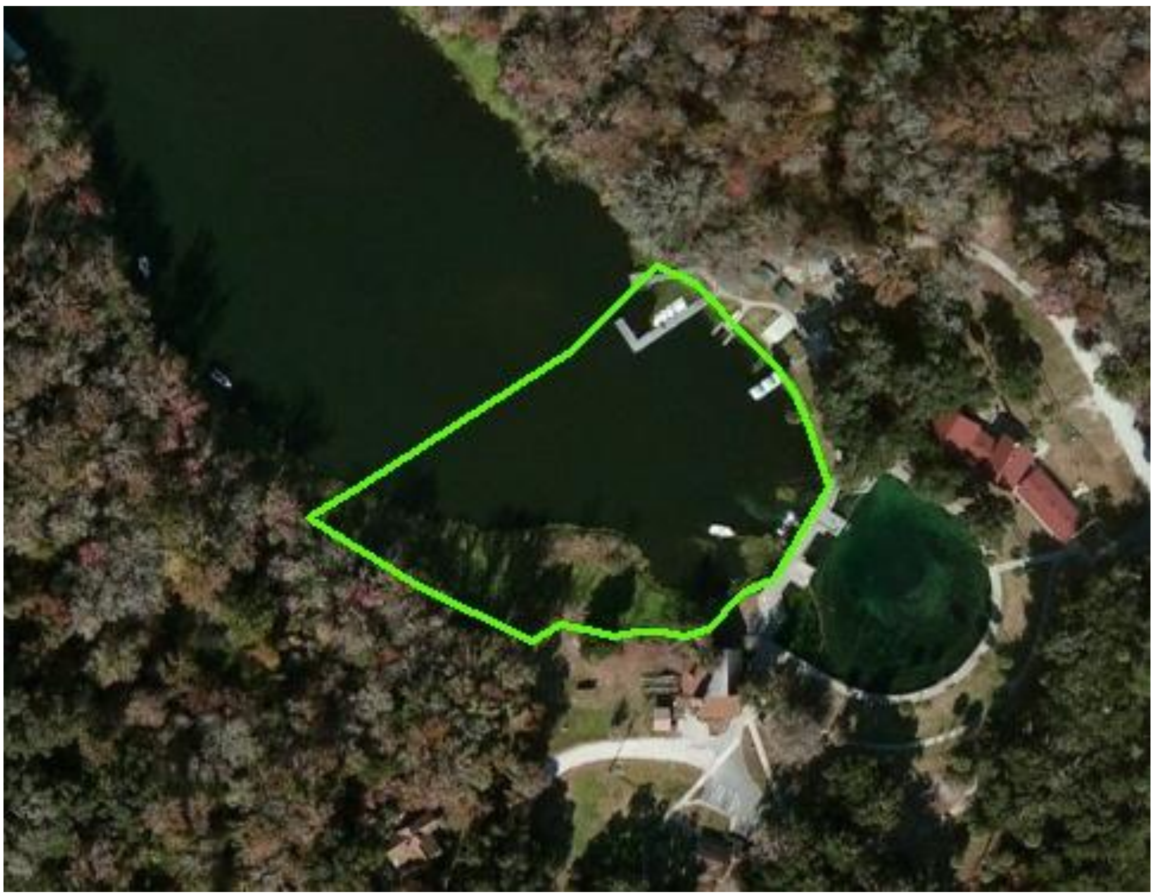

Figure DS-1. Map of the warm water extent for De Leon Springs site currently available to manatees.

The lower portion of the polygon shown in Figure DS-1 has floating vegetation on the south western shore and did not have warm water when sampled (Ross 2010). However, manatees have been observed in this portion of the area during winter surveys (J. Reid/USGS, M.

Ross/Sea2Shore, pers. comm.). The potential further limitation of the useable area is addressed in the MCS and described in the Results section.

Until recently, this spring system was reportedly used by very small numbers (less than 10) of manatees during the cold season. A high winter count of 25 manatees was documented here during the winter of 2006. Photo identification efforts have documented some individuals known to also over-winter at Blue Spring.

Algae are the only vegetation present in the spring pool, but this source is not available to manatees. Manatees do have access to the spring run and its abundant submersed and floating vegetation. In addition to the spring run, forage is found downstream of the run as estimated for the St. Johns River within the 30 km extent for this site, Figure DS-2. Submerged plants common to this system are *Chara, Hydrilla, Vallisneria, Najas, Potamogeton,* and *Spyrogira*. Detailed sampling within the spring pool and run by Wetland Solutions (2010) indicate that percent cover of SAV for De Leon Springs was about 20%. While these data are of interest and supportive, they do not cover the broad area needed to assess forage within the full manatee swim distance.

As described earlier for Blue Spring, estimates were developed by integrating presence-absence data with percent coverage data collected in 2007 and 2010 supplied by FDEP (Kelli Gladding, April 2011). Using techniques outlined in the Forage-K sub-section of the Methods section, a weighted SAV area coverage value of 4,238,072 m^2 (1,047 ac) was computed with min/max values (as used in the MCS) ranging from 3,390,457 m^2 (838 ac) to 5,085,686 m^2 (1,257 ac).

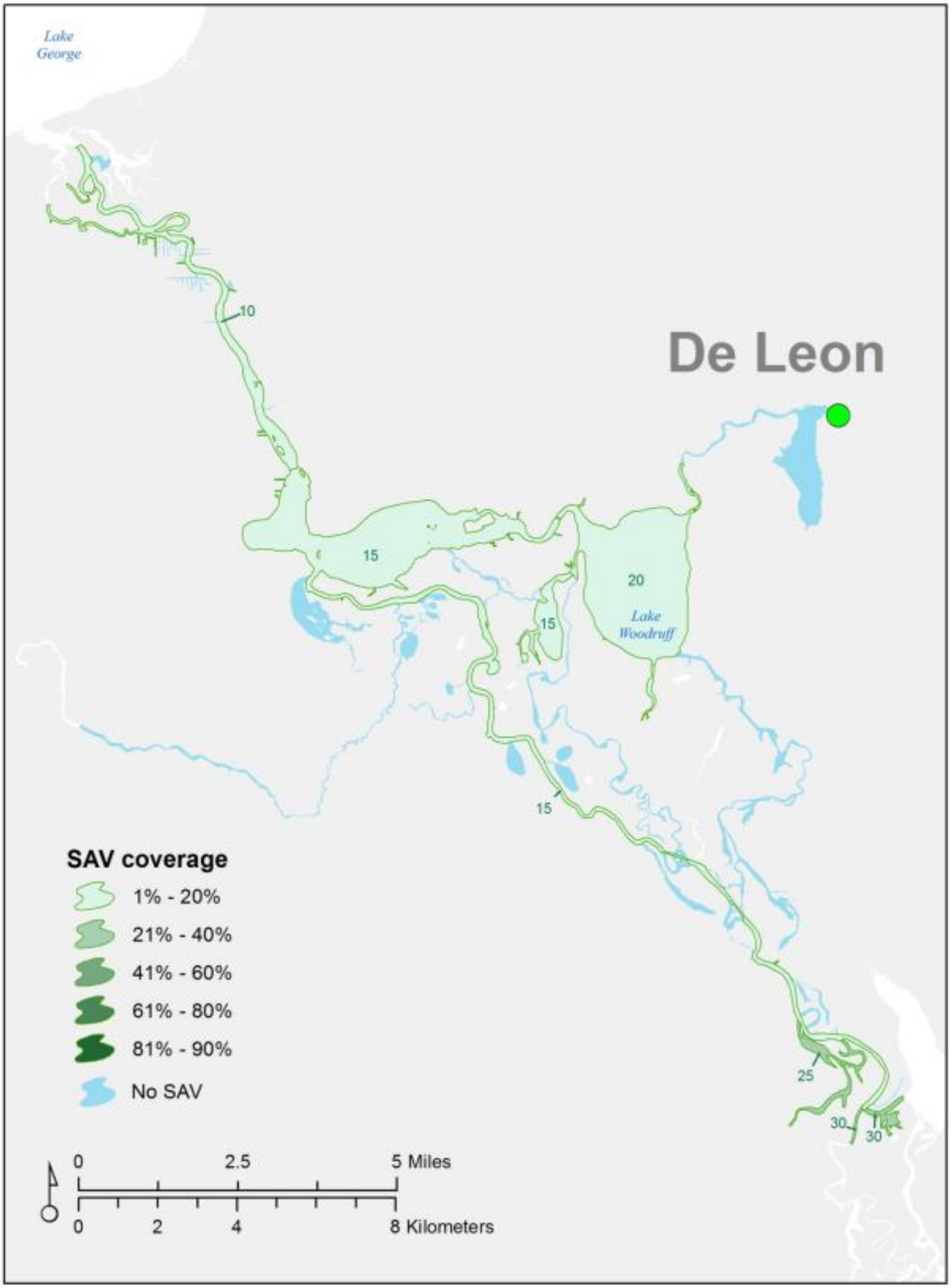

Figure DS-2. Map of the De Leon Springs site displaying the 30 km manatee swim extent and estimated SAV coverage.

Silver Glen Springs

A first magnitude spring in Marion County within the Ocala National Forest and the Silver Glen Springs Recreation Area, Silver Glen Springs has a large spring pool with two vents and a water depth of 4-5 m. Discharge in 2001 was 109 cfs (Scott *et al*. 2004). The spring run flows east 1.2 km to the St. Johns River. Small numbers of manatees (less than ten) have been documented using the lower portion of the spring system during cold weather, (M. Ross/Sea2Shore Alliance and R Mezich/FWC, Nov and Dec 2011, pers. comm.). The spring pool is closed to boat traffic, however the spring run is heavily used by recreational boaters, especially during holidays in the warm season. Figure SGS-1 shows the extent of the warm water areas within the spring run. These areas have depths greater than 1.2 m according to bathymetric information provided by WSI. A cold water intrusion length of 200 m from Lake George into the spring run is assumed based on observed cold water intrusion at the nearby Blue Spring site. With this assumed cold water intrusion, the four easternmost polygons shown in Figure SGS-1 were not included as part of the useable warm water area.

Figure SGS-1. Map of the warm water extent for the Silver Glen Springs site currently available to manatees.

The vegetation map for within the run comes from recent work by Wetland Solutions, Inc. (WSI 2011) as shown in Figure SGS-2 and indicates 40,866 m^2 (approximately 10 ac) of SAV available. Transect sampling by SJRWMD indicated 14 and 15 acres within the run and spring in 2003 and 2008, respectively. Reports from SJRWMD indicate the dominant species are *Vallisneria*, *Eleocharis* and *Hydrilla*. Percent cover for Silver Glen run and pool was 57% and 40%, respectively (R. Mattson/SJRWMD, March 2011).

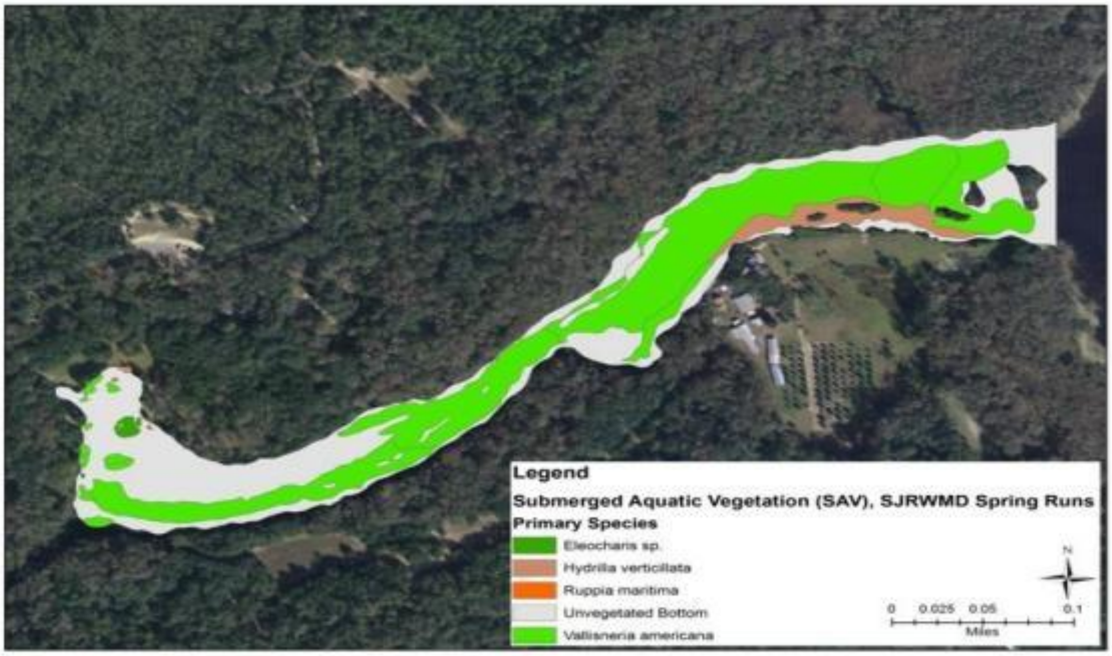

Figure SGS-2. The extent of SAV within the Silver Glen Springs run (courtesy Wetland Solutions, Inc. 2011).

However, vegetation in the spring run and pool only represent a fraction of the vegetation within the 30 km swim distance area (Figure SGS-3). Using data from FDEP mapping (K. Gladding, Feb 2011) and techniques outlined in the Forage-K sub-section of the Methods section, a weighted SAV area coverage value of 11,131,303 m^2 (2,751 ac) was computed with min/max values (as used in the MCS) ranging from 8,905,042 m^2 (2,200 ac) to 13,357,563 m^2 (3,301 ac).

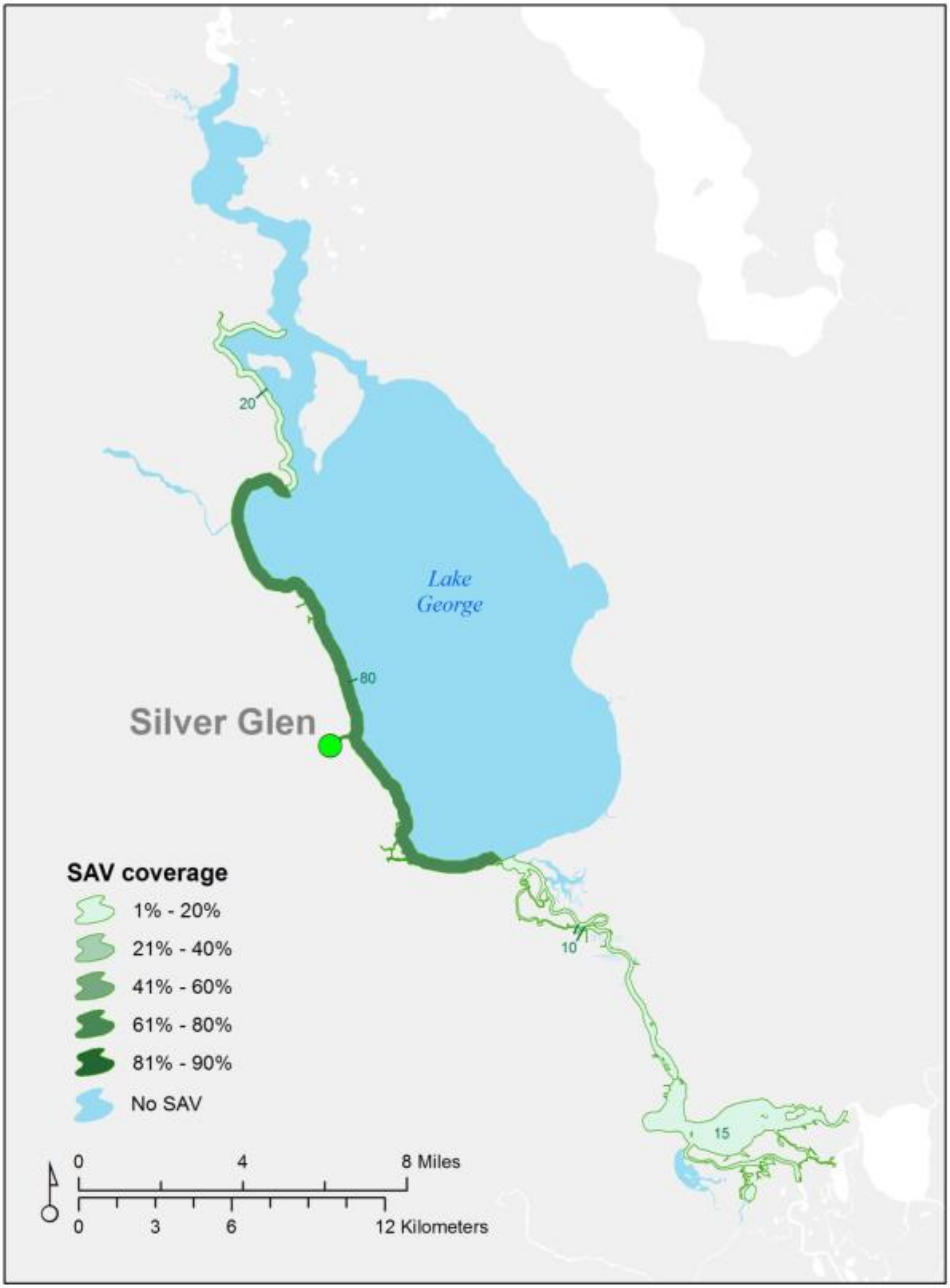

Figure SGS-3. Map of the Silver Glen Springs site displaying the 30 km manatee swim extent and estimated SAV coverage.

Silver Springs

The Silver Springs Group, located in Marion County, forms the headwaters of the Silver River, which flows 8 km eastward to the Ocklawaha River. Silver Springs is the largest inland spring in Florida, with many small springs and vents that flow within 1 km of the main spring. Flows from the individual springs are combined, yielding an average flow of 820 cfs for the period 1932 to 1974. The Main Spring at Silver Springs has a pool that measures 91 m by 56 m with a depth over the vent opening of 10 m (Scott *et al*. 2004). Information on manatee use of the spring system is scarce. Sally Leib (FDEP, Dec 2011, pers. comm.) described groups of no more than five manatees using this site. The estimated extent of the warm water area for Silver Springs is shown in Figure SS-1. This area is based on visible extent from our site reconnaissance and temperature gathering effort from January through March 2012. Bathymetry and documented manatee usage are not available to further refine the useable area. The usable area within this extent was addressed with the MCS in the Results section.

Figure SS-1. Map of the warm water extent for the Silver Springs site currently available to manatees.

Vegetation in Silver Springs pool and run is similar to other springs in the region,, including *Chara, Hydrilla, Vallisneria, Najas, Potamogeton, Sagittaria* and *Spyrogira.* And like other Springs, *Lyngbya* is a common, undesirable invasive. However, these data represent a fraction of the requisite area in the 30 km swim distance area. We did not locate adequate SAV maps for this river but our field observations in January and March of 2012 found vast quantities of eel grass and *Chara* covering the majority (60 to 80%) of the bottom of this river offering extensive forage (Figure SS-2). Wetland Solutions, Inc. (WSI 2011) quantified SAV coverage within the run as 75% cover. Based on these recent observations we applied 75% SAV coverage to our model for the entire river. Interviews with rangers and local biologists indicate no adequate estimates of vegetation within the adjoining Ocklawaha River where tannins are high and assumed to inhibit SAV growth. Using recent observations and techniques outlined in the Forage-K sub-section of the Methods section, a weighted SAV area coverage value of 182,302 m^2 (45 ac) was computed with min/max values (as used in the MCS) ranging from 154,957 m^2 (38 ac) to 109,647 m^2 (52 ac). A confidence of ± 15% was applied.

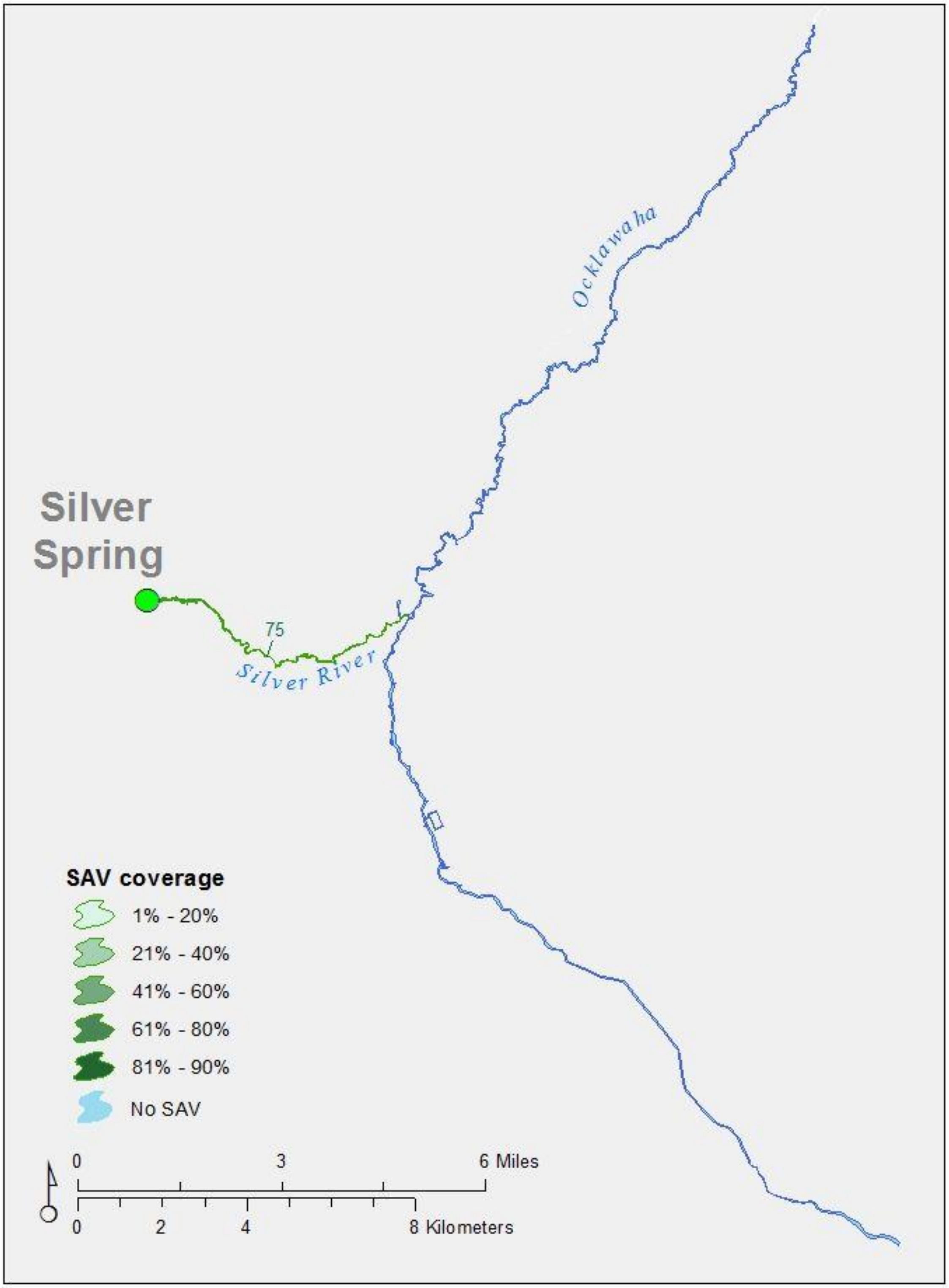

Figure SS-2. Map of the Silver Springs site displaying the 30 km manatee swim extent and estimated SAV coverage.

Manatee Springs

Manatee Springs is a first magnitude spring along the south shore of the Suwannee River in Levy County, within the FDEP Manatee Spring State Park. Manatee Springs is considered a secondary warm-water site by the Warm Water Task Force (WWTF). Manatee Springs has a pool that measures 18 m by 23 m and has a maximum depth of 7.6m . The spring boil temperature is typically 22 to 23 C. The short spring run flows south 365 m to the Suwannee River. Flow from the spring on 23 October 2002 was recorded at 154 cfs (Scott *et al*. 2004). The shoreline surrounding the spring pool and run is forested, with a recreation area for park visitors. The Suwannee River Water Management District (SRWMD) has recently established minimum flows and levels for the Lower Suwannee River, including Manatee Springs. Strong consideration was given to providing “acceptable refuge for manatees during cold months as well as for fish passage and wildlife habitat in general” (Farrell *et al*. 2005).

The extent of the plume is highly variable and dependent on fluctuation in the Suwannee water levels. Our first estimate of the plume was based on expert opinion and observations of manatees at this site over the last decade, Figure MS-1. Since 2000, manatees in Manatee Springs tend to aggregate east of the protection zone float line/buoys. Although there were no temperature data available downstream of the spring, the warm water was assumed by Park rangers not to extend beyond this point in the winter.

Figure MS-1. Manatee Springs depiction of the spring representing the thermal refuge component based on expert opinion and manatee distributions.

The site is quite small and the numbers of manatees using it are low. Increasing use of the spring by manatees has been documented in recent years. Powell and Rathbun (1984) suggested that Manatee Springs had been little used by manatees over the past century, but use began increasing in the 1970's as small numbers of manatees were observed in the spring in the spring and fall. Park staff has been documenting manatee sightings since 1993, with an average of 43 sightings per month (many of which may be repeat sightings of the same individuals). Photo-identification indicates that 21 individuals use the spring on a regular basis (Langtimm *et al*. 2003). However, most of these individuals also use Crystal River and Homosassa Springs as warm-water refuges during the winter. Some of the same manatees also utilize Fanning Spring to the north. In winter of 2010, a maximum of only nine manatees were observed at one time at Manatee Springs (Sally Leib/FDEP, Dec 2011, Larry Steed/ FDEP, Dec 2011).

Bathymetric data for this site enabled us to determine yet another configuration and estimation of warm water extent as shown in Figure MS-2. The variations in useable warm water area as well as tidal impacts for this site are addressed further in the Results section.

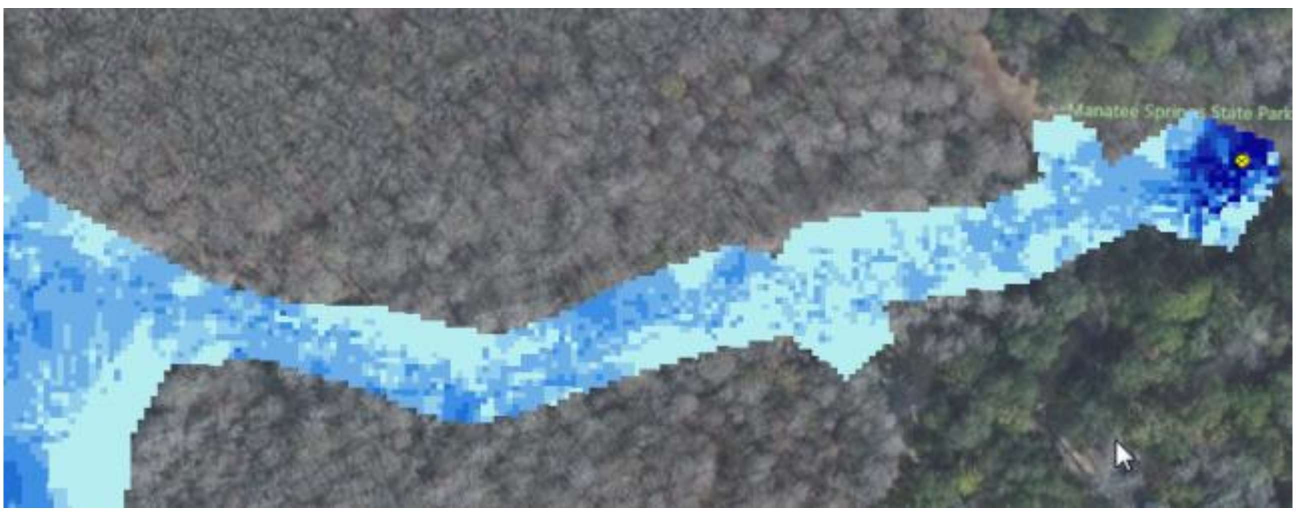

Figure MS-2. Manatee Springs depiction of the spring representing the thermal refuge component based bathymetric zones greater than 1.2 m (dark blue). (Bathymetry courtesy Harley Means/*Florida Geological Survey, FDEP*).

Water temperatures were collected during our site reconnaissance in early December 2011when ambient air temperature was 23.3 C. Collections occurred along a transect from the boil down to the Suwannee. This resulted in a general trend of warm water (greater than 20 C) extending west from the boil, which was 22 C. This warm water plume extended inside the run west until about 100 m east of the Suwannee and Manatee Springs run interface, where temperatures dropped by 4 C. Temperatures within the nearby Suwannee were 17- 18 C during this event. Also of note is the fact that the Suwannee water levels are typically low in winter and therefore the colder river waters generally would not penetrate the spring run itself.

In 2009, WSI sampled this spring run and described very small amounts of *Cabomba*, *Hydrilla*, *Naja*, *Nuphar* and *Sagittaria*. While they indicated percent coverage of 80% for filamentous algae and vascular plants, SAV is essentially no longer found in the Manatee Spring and run and is extremely limited downstream in the Suwannee River (H. Means/FDEP, pers.comm., Dec 2011; J. Provancha, personal observation, Dec 2011). Studies by Estevez *et al*. (2000) described a variety of SAV species along the lower Suwannee, however, those sites were limited to the portion beyond our 30 km manatee swim extent. They mentioned that while some SAV was found north of their study sites, the SAV beds were discontinuous patches. While there may be small pockets of vegetation up and down the Suwannee, they are not mapped and experts suggest the area is extremely stressed. Local rangers and FDEP concur that *Lyngbya* has taken over much of the spring area and river. Experts agree that while manatees may occasionally be observed consuming *Lyngbya*, it is incidental to foraging on other plants and is otherwise avoided by manatees (C. Beck/ USGS, Sirenia, and K. Smith/ FDEP pers. comm., Dec. 2011). The majority of vegetation disappeared by about 2001, with some years of improvement noticed (2003 and 2004), however, the majority of the area has been denuded due to floods and pollutant loads in the system (S. Leib, FDEP, Dec. 2011).

Manatee biologists suggested that manatees are able to forage on shoreline vegetation and marsh grasses in the Suwannee (J. Reid/USGS, pers. comm.., Dec 2011). However, experts agree that it should not be considered a typical food item for this assessment (C. Beck/USGS, pers. comm., Jan. 2012). Recall that our protocol does not include estimations of forage associated with marsh grasses bank vegetation, etc., and therefore this habitat and habit is not included in the current assessment.

In summary, vegetation for manatees is essentially not available in the vicinity of the spring but found out in the Gulf of Mexico, over 34 km away. Those SAV beds are considered stressed as well (Charbonneau and Carlson, 2011).

Figure MS-3. Map of the Manatee Springs site displaying the 30 km manatee swim extent and estimated SAV coverage.

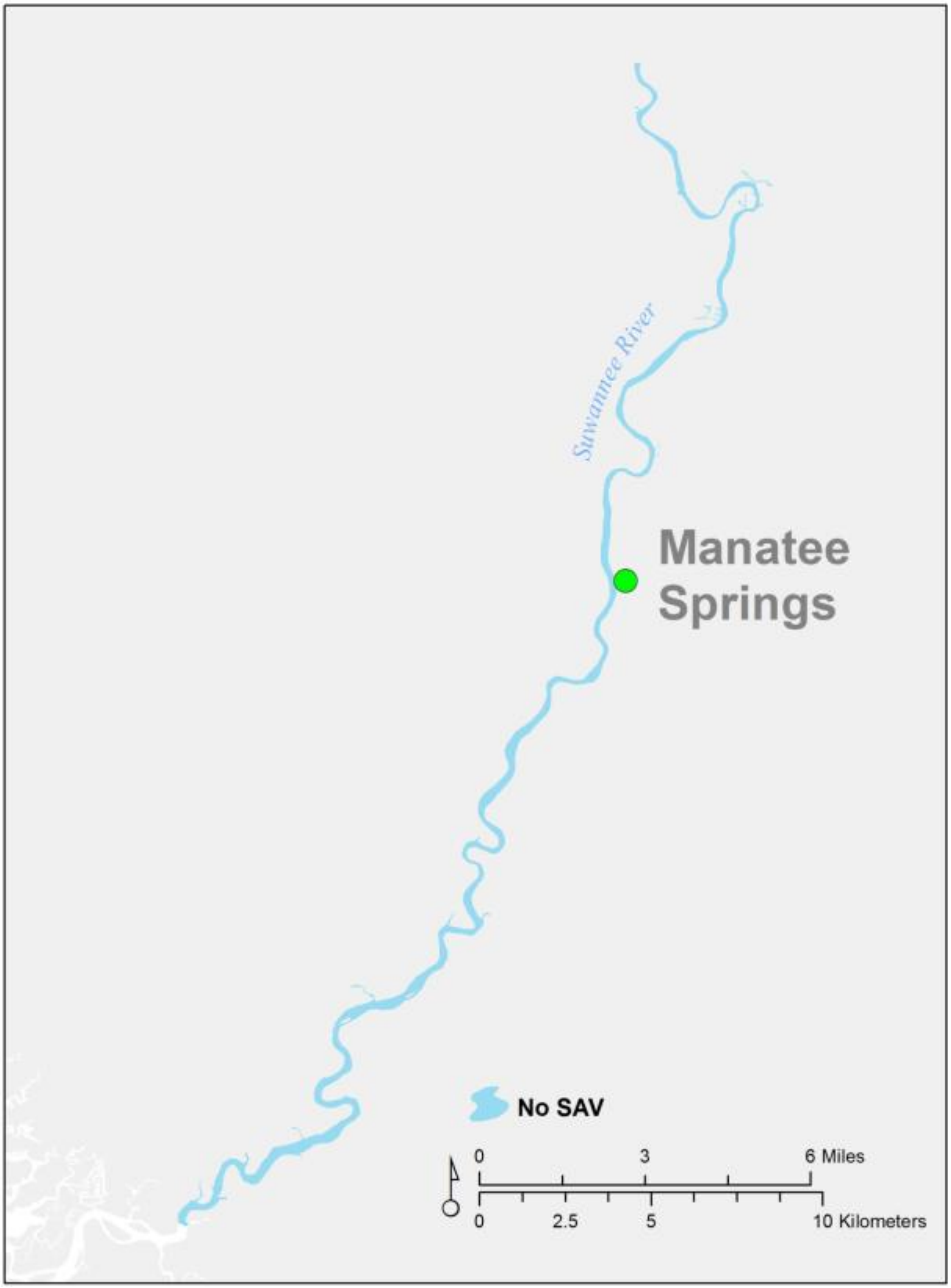

Figure MS-3. Map of the Manatee Springs site displaying the 30 km manatee swim extent and estimated SAV coverage.

Weeki Wachee Springs Complex

Weeki Wachee Spring, formerly owned by the Southeast Florida Water Management District (SWFWMD) and leased to the City of Weeki Wachee, was recently transferred to the FDEP State Park system. Buccaneer Bay, a water park developed along the banks of the spring boil, is open to the public from March through September each year. Downstream of the spring pool the Weeki Wachee River is highly developed into residential properties, including canal systems with concrete seawalls. Portions of the south shoreline of the run still remain forested and are located within the SWFWMD Weeki Wachee Preserve. A portion of the river is on the southern boundary of the Chassahowitzka Wildlife Management Area**.** The river is idle speed/no wake east of Roger's Park, 8 km downstream from the spring pool. The SWFWMD has conducted sediment removal projects in the upper reaches of the river in recent years, likely improving access to manatees.
Weeki Wachee Springs includes the main, primary spring at the headwaters of the Weeki Wachee River, as well as smaller thermal refuges including Mud and Jenkins Springs. It is a first magnitude spring in Hernando County with a spring pool that measures 50 m by 64 m and has a maximum depth of 13.7 m over the spring vent. Average flow from 1917 – 2012 was 173 cfs (USGS, National Water Information System: Web Interface; http://waterdata.usgs.gov/fl/nwis/measurements?site_no=02310500&agency_cd=USGS&format=brief_list; accessed April 29, 2012). The spring run, the Weeki Wachee River, flows approximately 8 km west to the Gulf of Mexico. The spring pool and adjacent areas have been extensively developed into a tourist attraction that conducts underwater mermaid shows. The Weeki Wachee/Mud Spring/Jenkins Creek Springs complex is included as a primary warm-water site on the WWTF list of "Important Manatee Warm-Water Sites".

Hartman (1974) commented that manatees were never seen in the shallow Weeki Wachee River. While manatee use of the spring has not been systematically surveyed, it appears to be increasing. A high count of 22 manatees was documented in the river system on 1 March 1999 (Taylor *et al.* 2010). Staff at the Weeki Wachee Theme Park are said to observe small numbers of manatees in the spring pool during the winter months. We observed five animals within the Spring pool during our site reconnaissance on 15 January 2012. Although small in number, manatees distribute themselves along the full length of the 8 km- river/run. In 2011, our interviews with Park staff report that on cold days, 6 to 7 manatees can be observed in the area and up to 15 seen at Hospital Hole and Roger's Park, downstream (T. Brewer/Weeki Wachee State Park and Eric Pitard/Kayak Shack, pers. comm.). Our site visit of the full run on 15 January 2012, resulted in sightings of 6 manatees just upstream of Hospital Hole.

Studies, local experts and T. Brewer (Weeki Wachee State Park) indicate that the entire length of the run provides warm water in winter, Figure WWS-1. Unpublished temperature transect data (courtesy C. Zajac SWFWMD), collected between 2005 and 2011, provided intermittent winter measurements along the length of the river. The temperatures remained above 23 C during all winter and fall sample periods. Several small spring outflows along the way are, in part, responsible for this large warm water "extent". To increase certainties for our hydrology team, additional temperature measurements were made at several sites downstream of the Spring using continuous loggers deployed from January to March 2012. It was confirmed that adequate warm water penetrates the entire length of the river. The estimated extent of the warm water area for Weeki Wachee Springs is shown in Figure WWS-1. In the absence of bathymetric data, and after our site visits in January and March 2012, we determined that the entire width was not adequately deep and only a narrow portion of the river/run had depths that tended to be 1.2m or greater. We estimated that approximately 10% or 1.2 to 1.5 m (4 to 5 ft) of the, on average, 15.2 m (50 ft) width of the river was useable and that warm water extends to a maximum length of 9350 m. The variability of the useable area and the extent of warm water at this site is addressed with the MCS in the Results section.

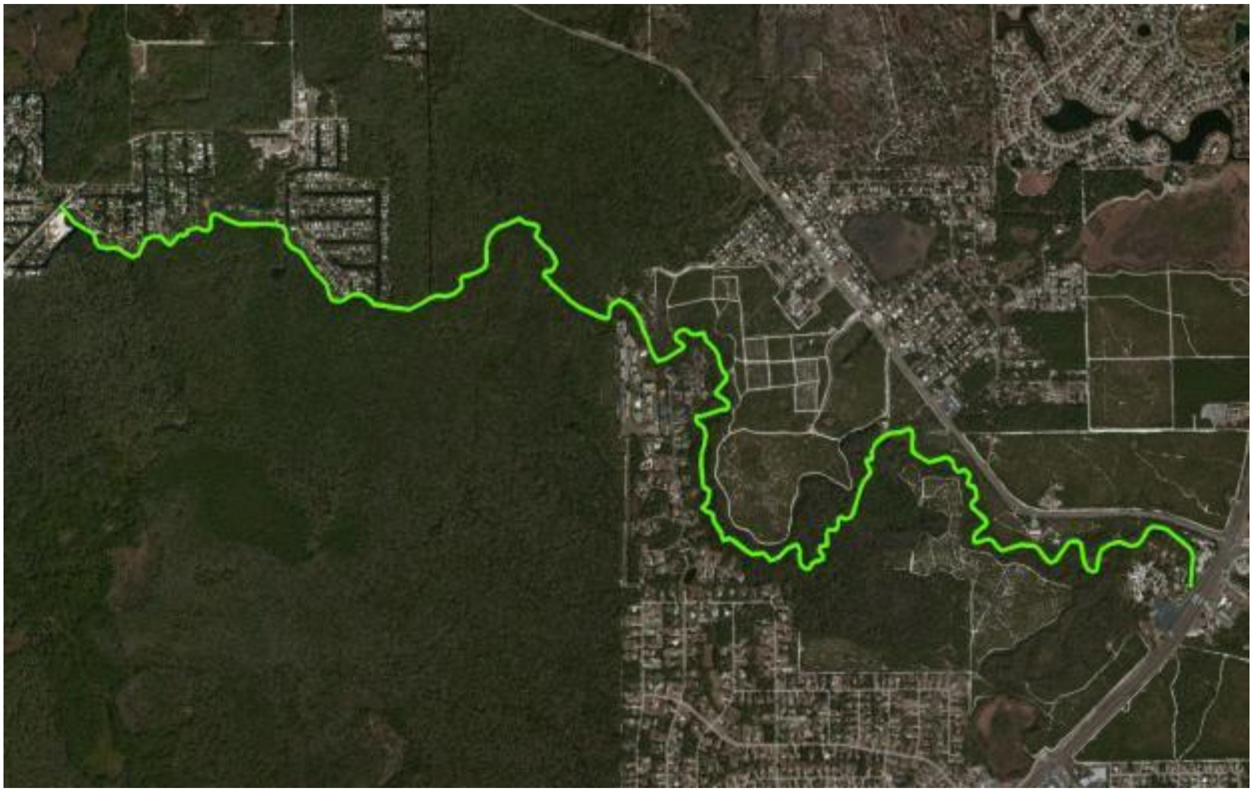

Figure WWS-1. Map of the warm water extent for the Weeki Wachee Springs site currently available to manatees.

In 2011, SAV was reported as very limited along the entire river/run. The Weeki Wachee "run" is reported to support *Hydrilla, Chara, Sagittaria, Spirogyra* and *Vallisneria* (WSI 2011). When SAV was found in the area, WSI reported a 43% coverage. *Lyngbya* has also taken hold in this run to a large degree. While SAV was probably abundant several decades ago, some losses were due to purposeful removal by managers related to entertainment aesthetics in past years and other losses are due to the impacts of recreational activities involving large numbers of people treading within the beds (C. Zajac/SWFWMD, pers. comm.). The SWFWMD reports some sampling and two seasons of SAV planting efforts to increase vegetation, however these efforts failed for several reasons. Our observations made by kayaking the entire river, showed essentially no adequate SAV for Weeki Wachee manatees. There were two small (approximately 12 m^2) patches of eelgrass; one just outside the spring boil, and the other downriver just upstream from Hospital Hole.

As shown in Figure WWS-2, the primary food source is in the coastal seagrass meadows. Those SAV species along the coast are comprised of *Thallasia testudinium*, *Syringodium filiforme*, *Halodule wrightii*, *Halophila engelmanni* and *Ruppia maritima*. The coastal SAV meadows within our 30 km extent were described by Charbonneau and Kolasa (2011) as stable in terms of overall coverage and species composition over the last decade. They mentioned that SAV appears to be converting from continuous beds to patchy ones and as such were a cause for concern. The 2007 SAV mapping efforts for this area indicated percent coverage results in three categories: dense SAV (75% - 100%), sparse-medium SAV (10% - 75%) and patchy SAV (10% - 50%). The classification used in the 2007 SAV GIS layer had overlapping SAV ranges. These were not modified for our simulations. Using techniques outlined in the Forage-K sub-section of the Methods section, a weighted SAV area coverage value of 380,299,801 m^2 (93,974 ac) was computed with min/max values (as used in the MCS) ranging from 284,522,000 m^2 (70,300 ac) to 476,077,000 m^2 (117,641 ac).

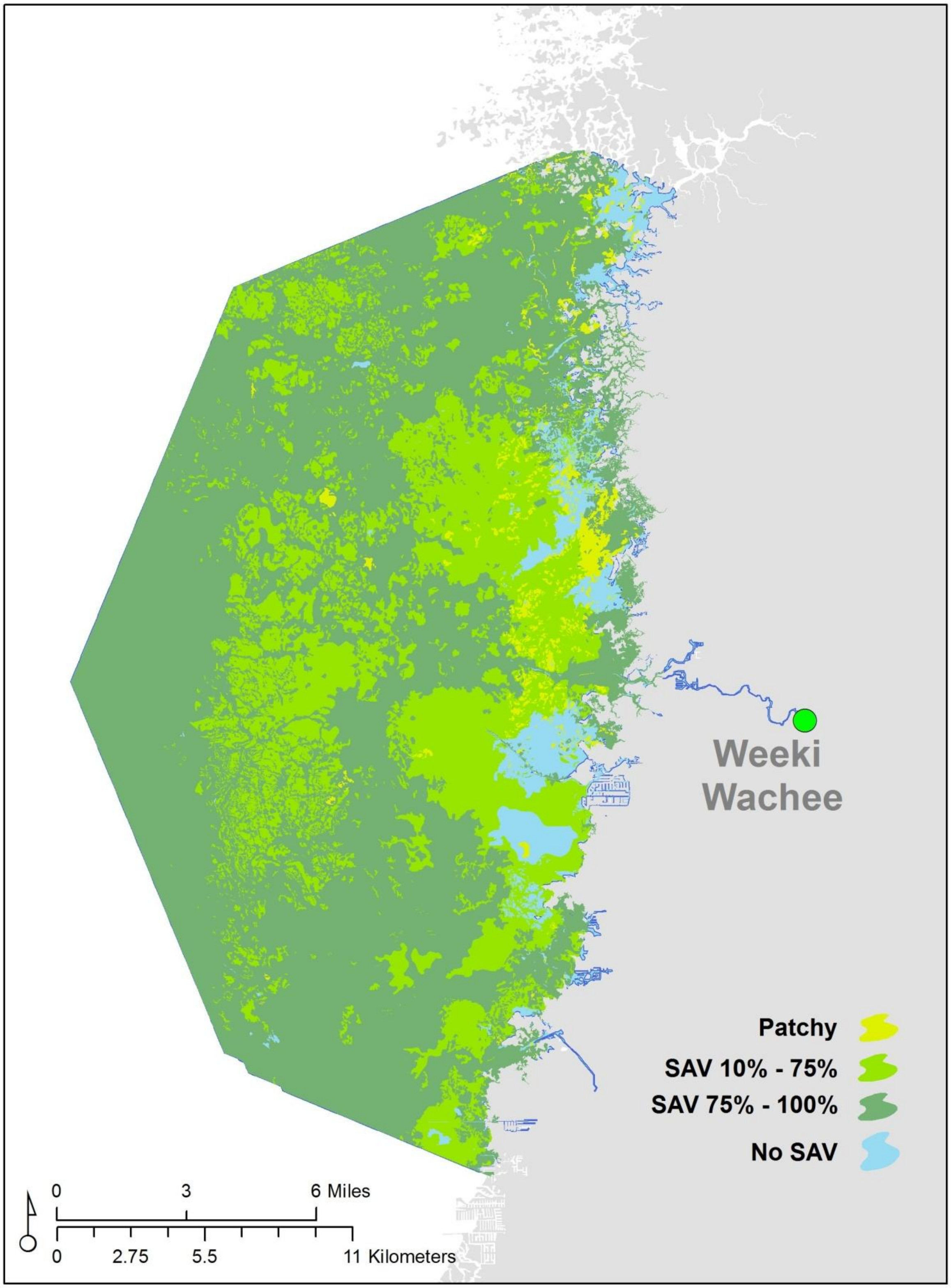

Figure WWS-2. Map of the Weeki Wachee Spring site displaying the 30 km manatee swim extent and estimated SAV coverage.

Warm Mineral Spring

Warm Mineral Spring is a second magnitude spring located in Sarasota County with a spring pool that measures 76 m by 96 m and is reported to have a maximum depth of 70m (Scott *et al*. 2004). The very narrow and shallow spring run, Salt Creek, flows southwest 3.7 km to the Myakka River. The average flow from 1942 – 1974 was 9.7 cfs (Scott *et al*. 2004). Warm Mineral Springs is listed as a primary warm-water site on the WWTF list. This spring was privately owned and operated as a spa and recreation area for many years, until the City of North Port partially purchased the spring in December 2010. The spring is still operated as a spa and recreation area through a 30 month lease. No swimmers or boaters are allowed in the run from 15 November through 15 March of each year.

Manatees do not have direct access to the spring itself due to rocks blocking the pool and a very shallow water depth in the run to approximately 700-1000 m south of the spring boil. However, in 2011 FWC removed some barriers within the run improving, somewhat, access along this habitat (R. Mezich/FWC, pers. comm., 2011). Manatees are seen in aggregations along the neighborhoods near the end of Santa Rosa Street, Dorado Street and at several points south, including the Corsica Basin. FWC biologist have monitored manatees using the area for several years and developed manatee photo identifications here. They have observed manatees approximately 1 km south of the Highway 41 bridge in winter near the Myakka River. Manatee use of the spring run has increased significantly in the past ten years. FWC staff documented a high count of 147 manatees in the spring run in November 2002. Approximately 70 manatees were observed on one day at one of the aggregation areas in the run during an extreme cold event in January 2010 (D. Boyd/FWC, pers. comm., Dec 2011). Initial interviews, literature searches, and estimations suggested that the warm water extent may include the area north of Highway 41 including some of the basins and canals as depicted in Figure WM-1.

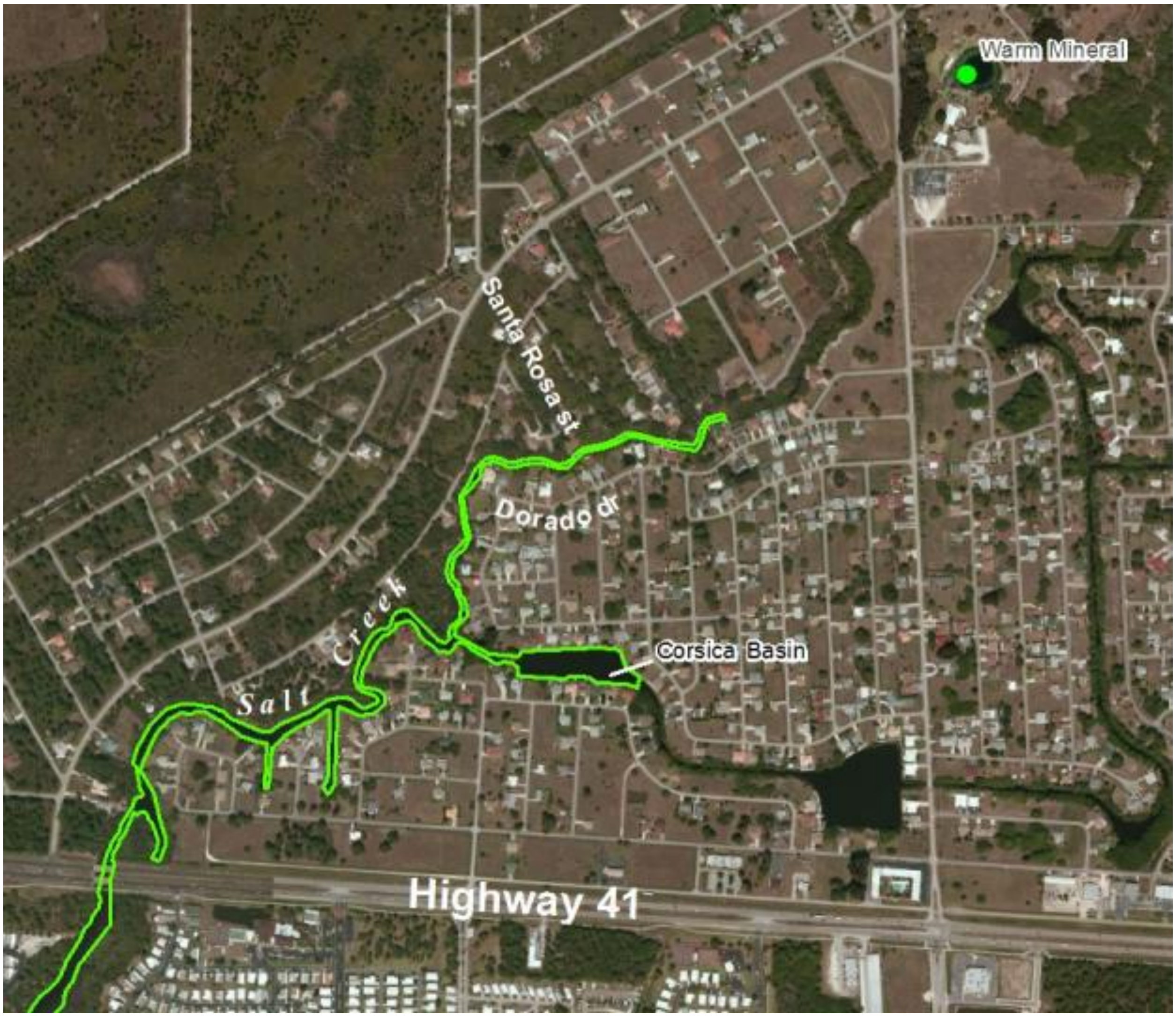

Figure WM-1. Initial estimate of warm water extent for the Warm Mineral Springs site in southwest Florida.

Our reconnaissance in late December 2011 estimated the limits of warm water approximately 300 to 350 meters south of the Sebastian Street. Low flow rates from the Spring as compared to the tidal waters entering Salt Creek indicate that the downstream influence of warm water from Salt Creek is much smaller than originally perceived. Transducers deployed during our site reconnaissance demonstrated that tidal influences over two feet were observed at the upstream end of the refuge near Sebastian Street. Temperature recordings from transducers at the end of Sanibel Street and Sebastian Street showed a difference of approximately 5.4 C (24.8 and 19.4 C, respectively). We also reviewed unpublished transducer results from FWC (S. Koslovsky/FWC). FWC has been monitoring temperatures in Salt Creek near Santa Rosa Street and Corsica Basin. The Salt Creek transducer showed that cold water from Myakka River dropped temperatures in the refuge below 20 C during a cold front with air temperatures less than 10 C (January 12-16, 2011). Winter season (November – March) water temperatures collected since 1998 at this location in Salt Creek fell below 20 C 2.6% of the time compared to over 19% for Corsica Basin. Based on our survey and the FWC transducer data, an alternative warm water depiction was developed. This depiction is approximately 2700 m^2, as illustrated in Figure WM-2. Less than half of this area has depths greater than 1.2 m. This portion of the warm water area was accounted for in the MCS using a depth limiting factor. The length of the refuge was also varied in the MCS due to the results from the FWC transducers and low water level conditions. These variations are presented in the Results section.

Figure WM-2. Revised warm water extent for Warm Mineral Springs.

Figure WM-3. Map of the Warm Mineral site displaying the 30 km manatee swim extent and estimated SAV coverage.

As with many areas, bank vegetation exists in various conditions and types but is not evaluated as forage for this study. No SAV is found along the refuge or run, where alkalinity/sulfur content from this spring is high. The nearest SAV is downstream, mainly in Charlotte Harbor. The SAV distribution came from the Sarasota County checklist assessment (Taylor *et al.* 2010) and can be found online http://ocean.floridamarine.org/mrgis_ims/Description_Layers_Marine.htm#seagrass and is shown in Figure WM-3. This polygon GIS data set represents a compilation of statewide seagrass data from various s source agencies and scales. The data were mapped from sources ranging in date from 1987 to 2007. Not all data in the compilation were mapped from photography; some were the results of field measurements. The original source data sets were not all classified in the same manner; some used the Florida Land Use Cover and Forms Classification System (FLUCCS) codes 9113 for discontinuous seagrass and 9116 for continuous seagrass; some defined only presence and absence of seagrass; and some defined varying degrees of seagrass percent cover. In order to merge all of these data sources into one compilation data set, the Florida Fish and Wildlife Research Institute (FWRI) reclassified the various source data attribute schemes into two categories, "continuous" and "discontinuous" seagrass. In areas where studies overlap, the most recent study where a given area has been interpreted is represented in this data set.

More recently, Perry et al. (2011) reported of a mapping project for 2008 in the northern Charlotte Harbor. They report that SAV within the Charlotte Harbor area is stable or increasing. The areal extent of the beds in 2008 appears to match the above 2007 map, but the SAV is described as patchy. This patchiness in the northern portion was reaffirmed by experts in 2012 (P. Carlson/FWC, Feb 2012, pers. comm.). Perry et al. (2011) described SAV species similar to other Florida coastal areas: *Halodule wrightii*, *Syringodium filiforme*, *Thalassia testudinium*, *Halophila engelmanni*, *Halophila dicipens*, and *Ruppia maritima*. The disparate and patchy SAV beds within the Myakka River are represented by a single species, *Halodule wrightii* (Stearns 2007). Using techniques outline in the Forage-K sub-section of the Methods section and recent SAV mapping efforts for the region (SWFWMD, 2010), a weighted SAV area coverage value of 1,771,351 m² (438 ac) was computed with min/max values ranging from 708,540 m² (175 ac) to 2,834,161 m² (700 ac).

Kings Bay/Crystal River System

Crystal River flows north-northwest for about 11 km to the Gulf of Mexico from its headwaters located in Kings Bay, Citrus County. Kings Bay is about 165 hectares (ha) (408 ac) in size and contains about 30 fresh, warm water springs which remain about 22 C year-round. The Kings Bay Springs group is the second largest spring system in Florida and is collectively considered a first magnitude spring. The springs are distributed over a large area, approximately 2 km long by 1km wide (Buckingham 1990), rather than a single, large discharge point. King Spring or Tarpon Hole is the main (largest) warm water source utilized by the northwest manatee subpopulation. This spring is followed in relative use by Gator Hole, Magnolia Spring, Wine Jug Spring, Three Sisters Springs, and Hunter Springs (J. Kleen/USFWS pers. comm., Dec 2011). Crystal River National Wildlife Refuge is located in Kings Bay and is comprised of 32 ha (80 ac). The Refuge also manages and enforces seven manatee sanctuaries in Kings Bay totaling 16 ha (40 ac). The warm water sources within Kings Bay comprise 7 ha (17.4 ac) and are outlined in Figure CR-1.

The Kings Bay Springs (also known as Crystal River Springs) discharge approximately 975 cfs (Jones *et al.* 1998) into Kings Bay. This discharge is derived from a mixture of fresh and brackish water vents located throughout the bay which is between 1 to 3 m deep. All the springs within Kings Bay are tidally influenced which can cause up to 2 m of variation in depth (Hoyer *et al*. 1997; Champion and Starks 2001). Fresh-water springs are mostly clustered on the eastern side of Kings Bay, while brackish-water springs occur in the central and western portions of the bay. Discharge measurements taken at Kings Bay in 2000 and 2001 indicate that spring flow is only 75 percent of its historic average. Ground water discharging at the Kings Bay Springs may be fresh or brackish, depending on tides and water levels in the Floridan aquifer. Ground water in the springs is largely derived from the drainage basin bounded by the Withlacoochee River and a line in south-central Citrus County. Water in the Floridan aquifer to the north of this line will discharge near the Kings Bay Springs while water south of the line will discharge near Homosassa Springs. Water that is discharging from the Kings Bay Springs entered the Floridan aquifer system within the last 50 years (Jones and Upchurch 1994).

Each winter, manatees within the spring system eat the aquatic plants down to bare sand with regrowth occurring every summer provided there is no salt water intrusion from hurricanes and tropical storms. A peak of 651 manatees was counted in the Crystal River complex in January 2010 during a statewide synoptic manatee survey that coincided with an unprecedented ten day freeze (J. Kleen/USFWS, pers. comm.), with about 566 manatees found within the four springs in the central portion of Kings Bay. Over 500 manatees were observed here again in December of 2010 during a significant cold snap. USFWS reports that 90 to 95% of the manatees were highly associated with the King Spring, Three Sisters Spring, Gator Hole canals, and Hunter Spring. These four areas were also considered the most utilized based on long term observations of USGS (Sirenia) biologists (J. Reid and B. Bonde, pers. comm. Dec, 2011).

King Spring (Tarpon Hole), is located at the south end of Kings Bay, south of undeveloped Banana Island which is part of Crystal River National Wildlife Refuge. The spring vent is approximately 61 m in diameter and 9 m deep and discharges water at a rate of 42 cfs into Kings Bay. A split in the limestone rock creates two caverns which go down another 9 m. Water from the vent is clear. Mullet Spring, also known as Tarpon Hole II, is adjacent to King Spring on the south side of Banana Island.

Gator Hole, Magnolia Spring and Wine Jug Spring are located on the east side of Kings Bay on a residentially developed horseshoe-shaped canal. Gator Hole is located on the north side of the canal and is approximately 6 m deep and forms a circle. Gator Hole once had an extensive cave system with rock spires, but it collapsed around 1963. Magnolia Spring is located on the east side of this horseshoe-shaped canal near the main channel which leads to Three Sisters Spring. The spring vent is in limestone and a boil is visible at low tide. Gator Hole and Magnolia Spring have winter counts of approximately 60 manatees. Wine Jug Spring is located on the west side of the canal and its importance to manatees has increased in the last decade with

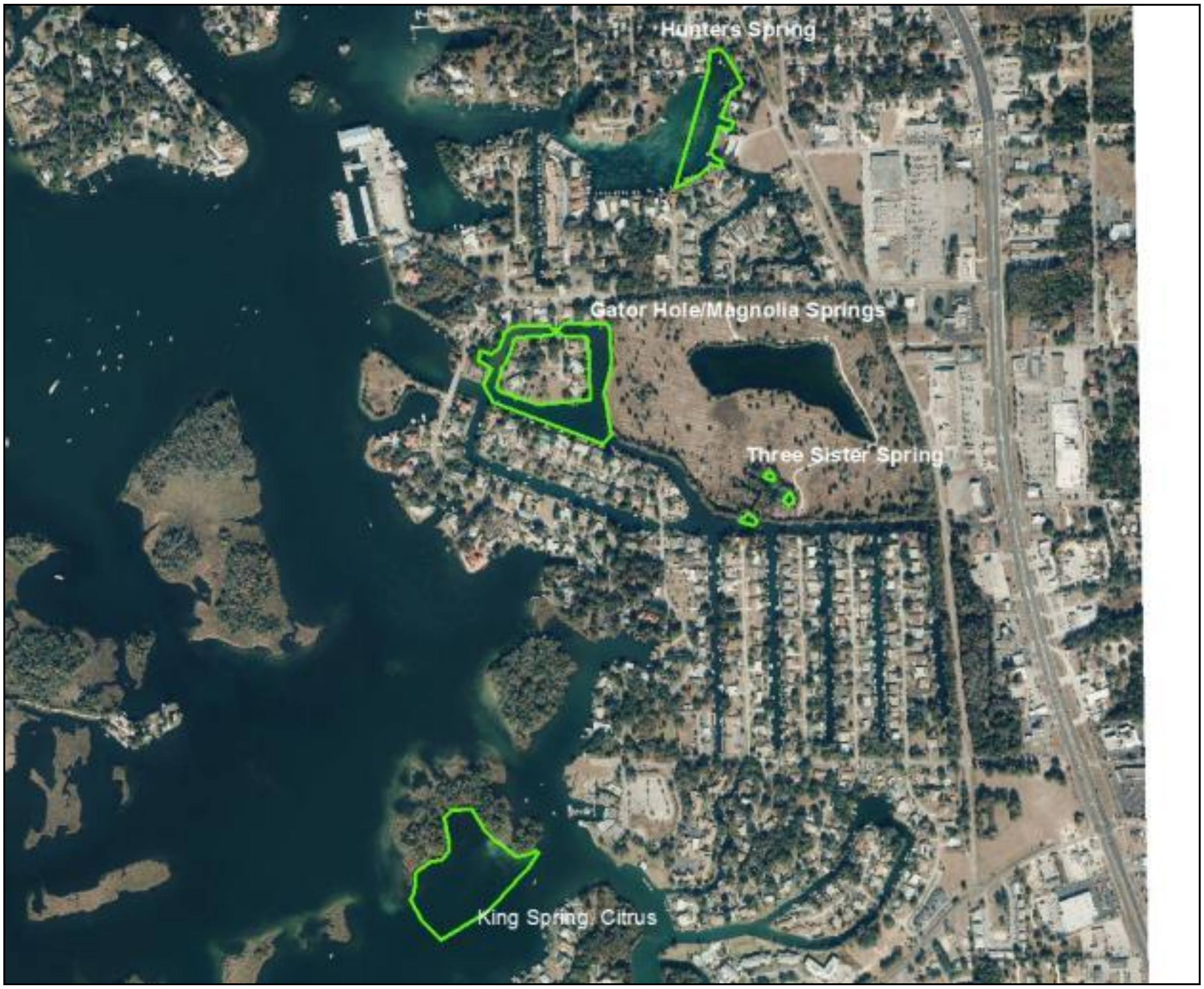

Figure CR-1. Primary thermal refuges of the Crystal River, Kings Bay area.

winter manatee numbers increasing from a couple of manatees to over 30 utilizing this spring alone.

Three Sisters Spring is located in the central eastern portion of Kings Bay. Large numbers of manatees have been observed on very cold mornings utilizing Three Sisters Spring . Three Sisters is a complex of three spring areas with several large and small vents and sand boils. A 30 m spring run, that is 3 m wide and 0.9-1.5 m deep, leads to an opening that contains the group of three springs which run in roughly a north-south line. A stormwater improvement project is ongoing at Three Sisters Springs whereby a wetland treatment system will be constructed on property acquired by the City of Crystal River, the SWFWMD and will be managed by the USFWS. Stormwater from over 40 ha (100 ac) of commercial and residential lands will be intercepted by this system, thereby improving quality prior to discharge to Kings Bay. The purchase of the property was complete 28 July 2010.

Hunter Spring, the northernmost spring, is an approximately 12m by 9m oval pool surrounded by trees which shade the spring. Small limestone openings are found near the northern side of the pool at a depth of about 4m. The pool is bowl-shaped and is about 3m deep, with a mild boil on the surface.

Kings Bay contains relatively clear spring-fed waters but can turn green with abundant suspended algal growth. Crystal River's waters are a darker green, but since the river is relatively shallow, the bottom is usually visible. SWFWMD studies over the last decade indicate that Kings Bay has experienced a 50% decrease in water clarity (SWFWMDa 2011, Hoyer et al. 1997), mostly attributed to increases in microscopic algae in the water column. Reduction in light penetration impacts the growth of vascular plants which provide natural forage for manatees. An abundance of aquatic vegetation is present including native species, such as tapegrass (*Vallisneria americana*), southern naiad (*Najas guadalupensis*), and pondweed (*Potomogeton sp.*). Non-native invasive plants include *Hydrilla verticillata* and *Myriophyllum spicatum*. Vegetation downstream, in the Gulf of Mexico, includes *Syringodium filiforme, Halodule,wrightii and Thalassia testudinium (*T. Fraser/University of Florida, pers. comm., Dec 2011). Submerged aquatic vegetation coverages displayed in Figure CR-2 are for seagrass only, and represent minimum estimates of available forage within the designated swim distance (30 km). In Kings Bay freshwater vegetation has been monitored over the last decade (Jacoby et al 2007, Hauxwell et al. 2003), however it is agreed that the freshwater vegetation there represents less than 1% of the forage available for manatees within this study area (T. Fraser/University of Florida, pers. comm., Dec 2011).

2007 SAV mapping efforts for this area indicated percent coverage results in three categories: dense SAV (75% - 100%), sparse-medium SAV (10% - 75%) and patchy SAV (10% - 50%). However, the 2007 SAV map did not cover the northern extent of the 30km swim distance. Earlier SAV coverage was used to fill in the void. Using techniques outlined in the Forage-K sub-section of the Methods section, a weighted SAV area coverage value of 247,331,322 m^2 (61,116 ac) was computed with min/max values (as used in the MCS) ranging from 192,918,431 m^2 (47,671 ac) to 301,744,212 m^2 (74,563 ac).

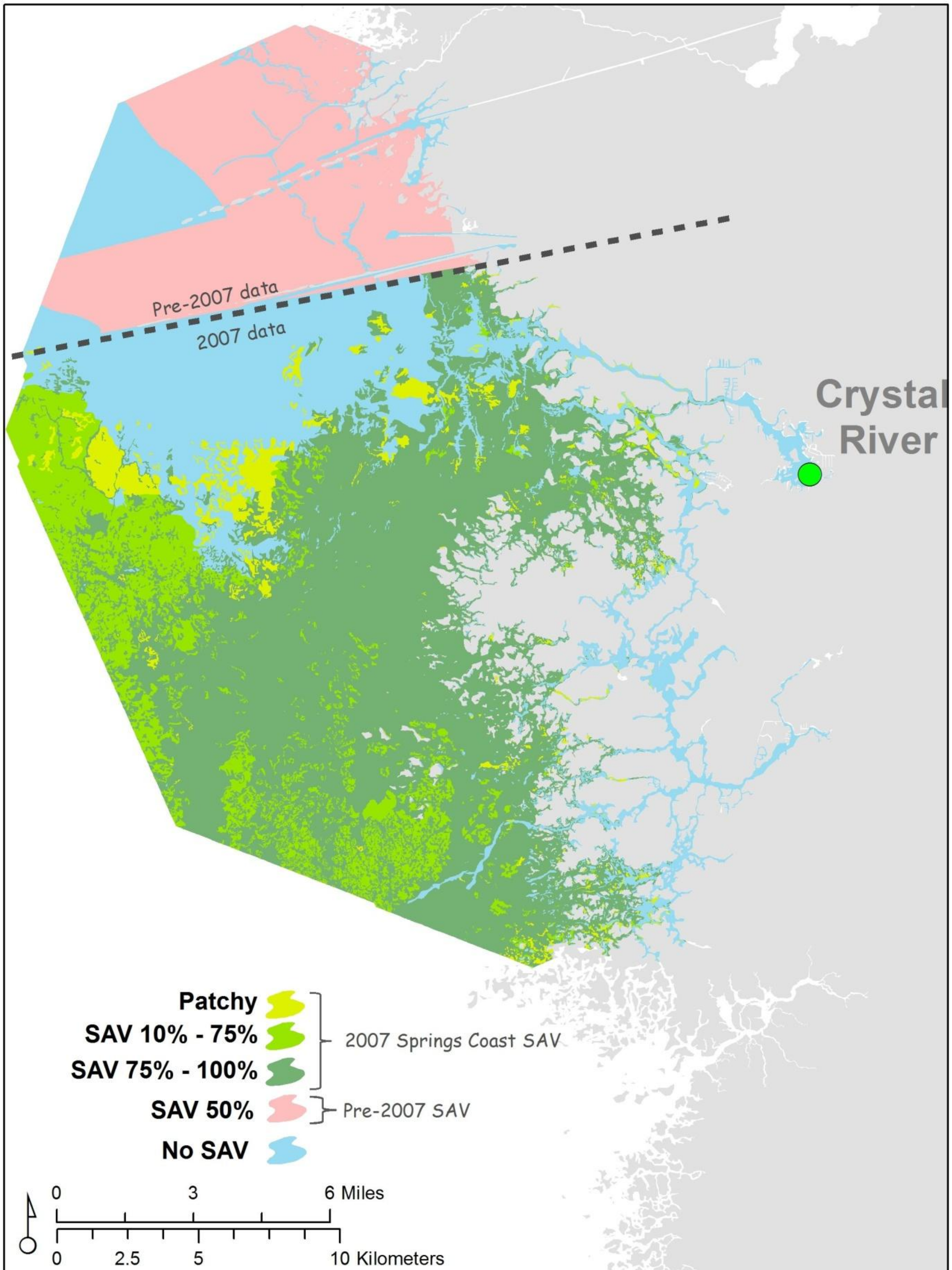

Figure CR -2. Map of the Crystal River sites displaying the 30 km manatee swim extent and estimated SAV coverage.

C-54 Canal

Sebastian River and C-54 Canal are near the town of Fellsmere, bordering Brevard and Indian River Counties and listed as a secondary warm-water source for manatees (FWC unpublished data). Prior to the development of power plants (FPL and Reliant) in the northern Indian River Lagoon (IRL), Sebastian River was reported to be the northern limit of the manatee winter range along the east coast of Florida. The canal is considered of marginal quality as a warm water site by manatee experts at FWC. The river is accessed from the IRL just southwest of the Sebastian Inlet where salinities measured near the water surface decrease from 26 parts per thousand (ppt) to about 4 ppt as one travels westerly to the C-54 Canal. Our review of provisional data collected by FWC on 1 March 2010 (C. Deutsch/FWC, temperature and salinity profiles with depth) demonstrates a noticeable salinity stratification or halocline in the canal with salinities greater than 20 ppt at the bottom and 4-14 ppt at the surface to mid-level depths.

The C-54 Canal is a relatively large site with a layer of sediment covering the benthos (A. Spellman/FWC, pers. comm., Nov 2008). The water near the spillway structure is opaque with tannins obscuring visibility. An initial review of SJRWMD water quality datasets and discussions with Lori Morris and Ralph Brown (SJRWMD) identified similar near-surface temperatures in the canal as compared to the open waters of the Sebastian River as well as minimal temperature stratification in the winter. However, our analysis of SJRWMD data demonstrate temperature differences between the water surface and the bottom ranging from 4-5C during extreme cold weather events.

Recently received temperature data (C. Deutsch, FWC, continuous temperature data loggers, November 2009 to February 2010) corroborates the presence of a thermocline at C-54 Canal and underlines the usefulness of continuously collected versus discrete data during extreme events. Although the data are provisional and have yet to be validated by the FWC, our review indicates water temperatures at the bottom of the canal are between 3 to 5 C warmer than at the surface, and in agreement with the SJRWMD described above. Temperature and salinity differences with depth are indicative of the influx of groundwater into this deep, man-made canal.

The FWC profile data collected on March 1, 2010 demonstrate that the canal ranges in depth from 3 to 4.5 m (10-15 ft). Warmer temperatures were recorded at the canal bottom near the spillway structure; however, 762 m downstream of the structure the warmer temperatures were at the surface. This change further confirms the influx and mixing of warmer groundwater into the canal. An extreme low water analysis was performed to determine if the canal depth can be a limiting factor at C-54.

In addition to the SRJWMD and provisional FWC data, we relied on expert opinion and discussions with FWC manatee aerial survey staff, local rescue staff, and our own data to determine the extent of the warm-water site at the C-54 Canal (Figure C54-1). This extent was best described by the distribution of animals on winter aerial surveys. Aerial surveys conducted by Mote Marine Laboratory for the FWC in the winter of 2010 (J. Provancha and J. Reynolds unpublished) provided insight for the C-54 Canal and other sites during the unprecedented cold period between January and March 2010. Over 660 manatees were observed on December 12, 2010 in C54 canal while only 23 were sighted within the Sebastian River that day. Animal distributions during the coldest days became the discriminator of the refuge boundary. While warm waters might in fact be found downstream of the C-54 Canal itself, manatees were not seen in those waters during extremely cold (air) temperature periods. Depth profiles near the edges of the canal demonstrate depths less than 1.2 m but most of the canal is greater than 1.2 m. Variations in useable warm water area in terms of length and depth of the canal are addressed by the MCS in the Results section.

Figure C54-1.   Map of the warm water extent for the C54 site currently available to manatees.

Fresh water is abundant from the C-54 spillway but is greatly affected by wind and precipitation events. Vegetation (Hyacinth/*Eichhornia*) can be seen in large quantities flowing east over the spillway when westerly winds dominate. This vegetation source influences visitation by manatees. Historical flows of freshwater from the C-54 Canal were much higher but have been redirected over the last decade (R. Day/IRLNEP, pers. comm., Dec 2008). The shoreline vegetation is "accessible" to manatees, but no data are available to indicate level of use. We assume that manatees have limited forage within the system and that the seagrass beds to the east are the primary vegetation source (Figure C54-2). Using techniques outlined in the Forage-K sub-section of the Methods section and a 10% coverage estimate (Lori Morris/SJRWMD, pers. comm., Mar 2012), a weighted SAV area coverage value of 2,772,468 m² (685 ac) was computed with min/max values (as used in the MCS) ranging from 2,495,221 m² (617 ac) to 3,049,715 m² (754 ac).

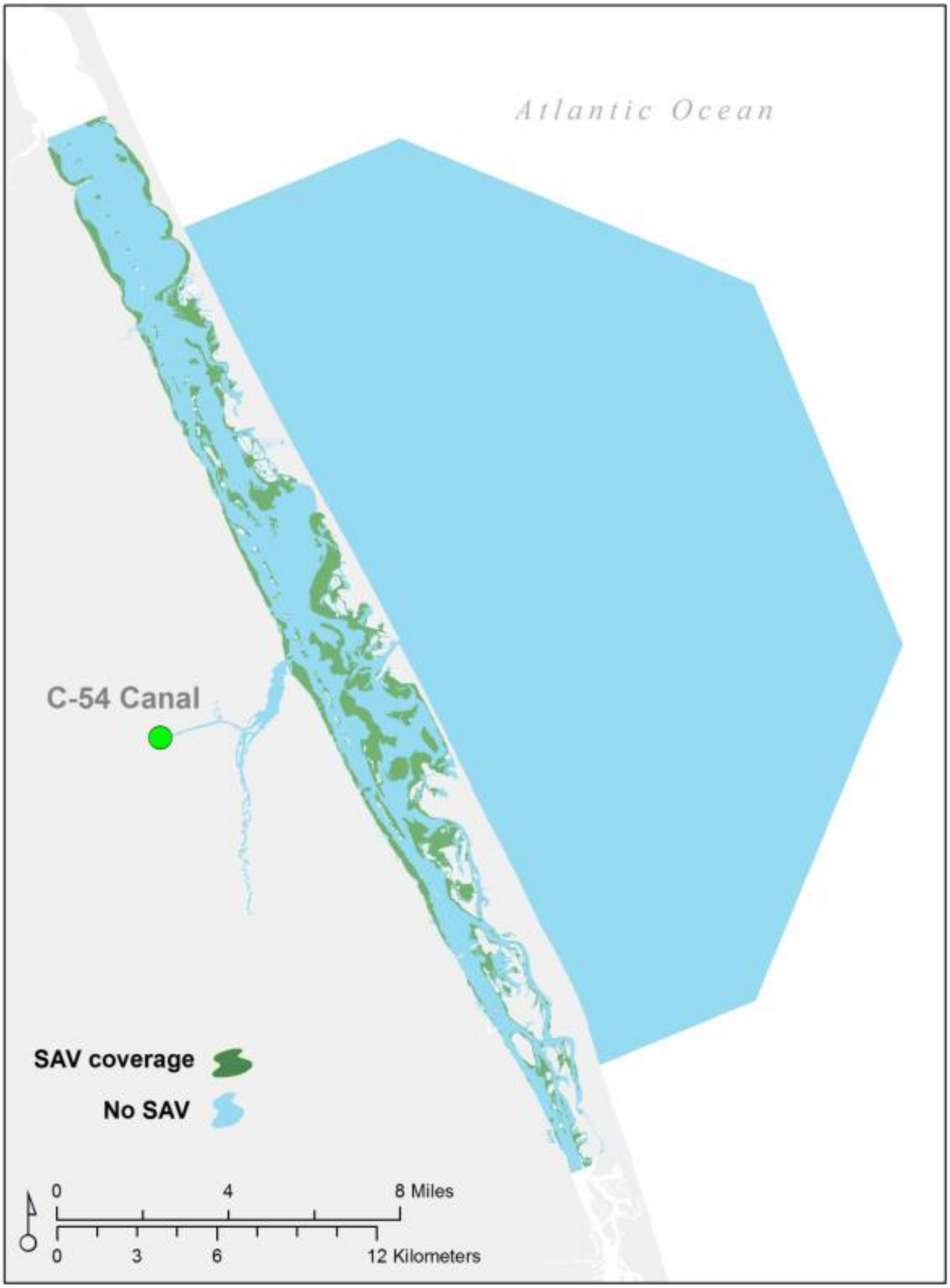

Figure C54-2. Map of C-54 Canal site displaying the 30 km manatee swim extent and estimated SAV coverage. (Maps courtesy Provancha *et al.* 2009 and 2010 Habitat Checklists).

Berkeley Canal

Berkeley Canal is part of a network of residential canals that connects with the southern Banana River on the central east coast of Florida. It has been known as a warm-water aggregation site for over a decade. In spite of all the human "influences" associated with this canal, manatees sometimes gather in large numbers (aerial counts of up to 140, February 2011, J. Provancha, pers. observervation). FWC indicates that there is significant sedimentation within the canal that creates a warmer layer at the bottom (C. Deutsch pers. Comm., April 2010). As with the C-54 site, FWC staff collected detailed temperature profiles on January 29, 2010 and deployed continuous temperature data loggers within the Berkeley Canal. This provisional dataset indicates an east-west thermocline bisecting the Berkeley Canal at the South Patrick Drive overpass (Figure BK-1). The temperatures in the Berkeley Canal are approximately 3 C warmer, on average, than the canal west of the overpass. The length of this site is approximately 300 m.

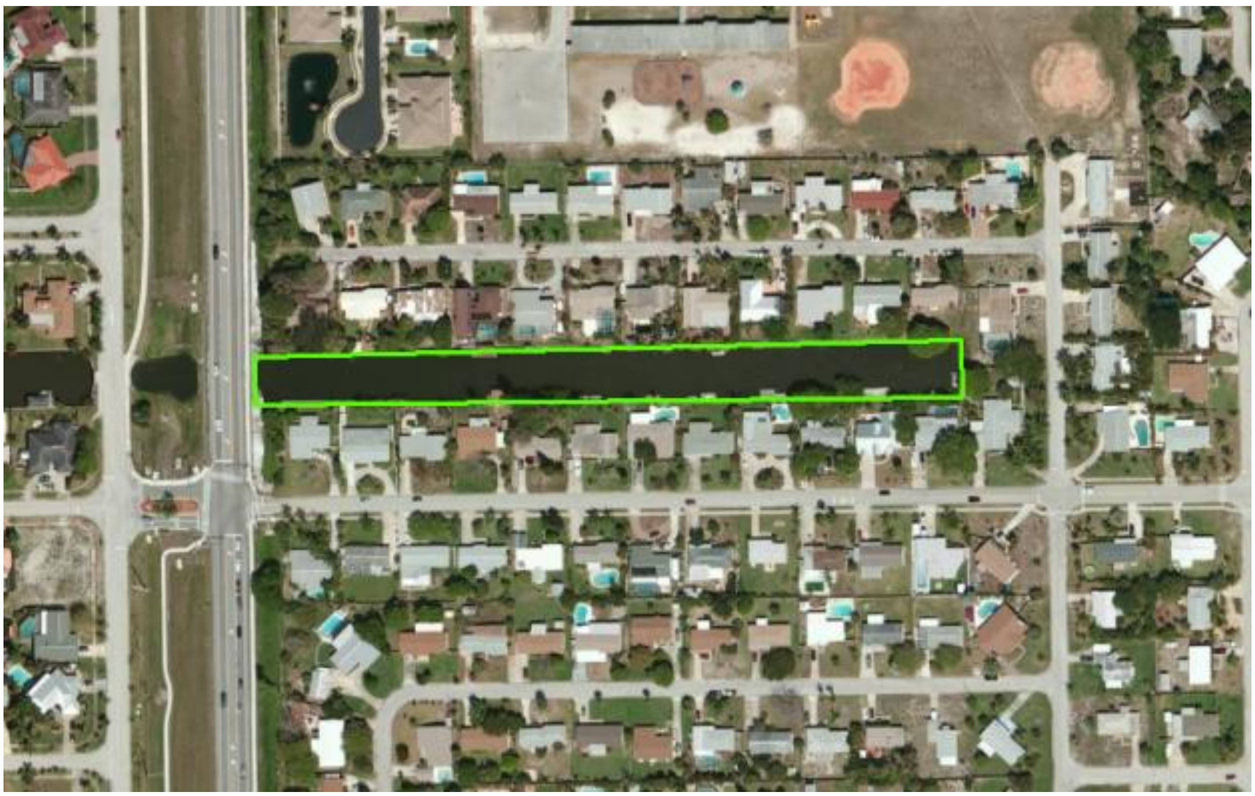

Figure BK-1. Map of the warm water extent for the Berkeley Canal site currently available to manatees.

Continuous temperature data from November 2009 to March 2010 demonstrate that surface to bottom water temperature differences within the canal range from 3 to over 10 C on extreme events (C. Deutsch/FWC, pers. comm., April 2010). However, on 29 January, the date of the temperature profile collection effort, the temperature difference between the surface and bottom of the canal was less than 2 C. These temperature differences could be indicative of warm groundwater influx into the canal near its bottom working in combination with a warm sediment layer described by FWC staff. Daily average temperatures at the bottom of the canal remained above 20 C during most of the unprecedented 2010 winter season except for 14 days. Salinity within the Berkeley Canal ranged from 14 to 19 ppt during the 29 January 2010 survey while salinities west of the overpass ranged from 22 to 24 ppt. Lower salinities in Berkeley Canal could be the result of groundwater influx or surface water runoff. FWC indicated that their bottom temperatures may have been sediment temperatures, suggesting a need to gather more detailed water column profiles in the future.

The data as well as discussions with A. Spellman and C. Deutsch (FWC) clearly indicate that the warm water extent of this refuge is east of the South Patrick Drive overpass. The FWC profile data demonstrates that the canal ranges in depth from 1.2 to 1.5 m (4 to 5 ft) in the center portion of the canal although FWC staff and others identify that the depth in the canal could be as deep as 2.1 m (7 ft). Depth profiles near the edges of the canal and along the eastern and western ends demonstrate depths less than 1.2 m. Variations in useable warm water area in terms of length and depth of the canal are addressed by the MCS in the Results section.

The lateral extent of the warm-water refuge of Berkeley Canal (east of the overpass) corroborates the distribution of manatees seen in historical and recent ground and aerial surveys. Aerial surveys in the winters of 2010- 2012 also support this “manatee use based” delineation, in addition to yielding the highest numbers of manatees to date, seen within this portion of the canal. Over 100 manatees were sighted several times there in winters of 2011 and 2012, with a high count of 140 on 15 February 2011 (K. Scolardi/Mote Marine Lab, pers. Comm., Mar 2012). The extent of SAV within 30 km of the site is shown in Figure BK-2.

Using techniques outlined in the Forage-K sub-section of the Methods section and a 10% coverage (Lori Morris/SJRWMD, pers. comm., Mar 2012), a weighted SAV area coverage value of 5,597,311 m² (1,383 ac) was computed with min/max values (as used in the MCS) ranging from 5,037,580m² (1,245 ac) to 6,157,043 m² (1,521 ac).

Figure BK-2. Map of the Berkeley Canal site displaying the 30 km manatee swim extent and estimated SAV coverage. (Maps courtesy Provancha *et al.* 2009 and 2010 Habitat Checklists).

Harbor Branch Canal

Harbor Branch Canal is located in the southern Indian River in St Lucie County and is listed as a secondary warm-water site according to the USFWS warm water task force. As described in the 2009 Checklist (Provancha *et al.* 2010), this site supports several manatees on a regular basis but there is little information about the numbers or patterns of manatee usage at this site (D. Hanisak and M. Mazzoil/Harbor Branch Oceanographic Institution – Florida Atlantic University (HBOI), pers. comm., January 2009 and March 2010; C. Hudak/FWC, pers. comm., March 2010). The site is not part of the FWC synoptic surveys but has been surveyed during the Florida Power and Light (FPL) annual winter surveys on several occasions (Reynolds 2006). The observed numbers of manatees range from zero to 13 animals (J. Reynolds/Mote Marine Laboratory (MML), pers. comm., March 2010).

The canal is about 1100 m in length and 50 m wide. It primarily supports ship and submarine docking activities for HBOI. There is no long term historical water temperature monitoring at this site (D. Hanisak of HBOI, personal communication, November 2009). The temperature differences between adjacent waters and this canal are based on intermittent samples provided to us by C. Hudak of FWC. A minor temperature difference of about 1 C was found. However, as shown by the C-54 Canal and Berkeley Canal sites, temperature differences may be greater at the bottom of the canal than at the surface.

Given the limited temperature information for this canal, we cannot determine if this site is a viable warm water refuge. Hudak's data from winter of 1999- 2000 showed a water temperature drop below 20 C at a point within the canal when air temperatures dropped to 10 C. However, it is believed that this site can provide shelter from high winds and waves during cold fronts (Figure HB-1). The benthic sediments may also provide a source of warming to experienced manatees. Therefore, for the purposes of this report we "assumed" that this site is a viable refuge. Additional sampling of this site by HBOI may be performed in the future offering better insight into the true quality of this site.

Animals can easily enter and exit the canal through the opening to the Indian River and the Intracoastal waterway (ICW). Large seagrass flats (primarily *Halodule* and *Syringodium)* are present along the ICW just outside of the canal (Figure HB-2). Boat traffic within the canal is limited to HBOI and traffic is slow speed. A bathymetry map was provided in April 2010 by M. Mazzoil (HBOI).

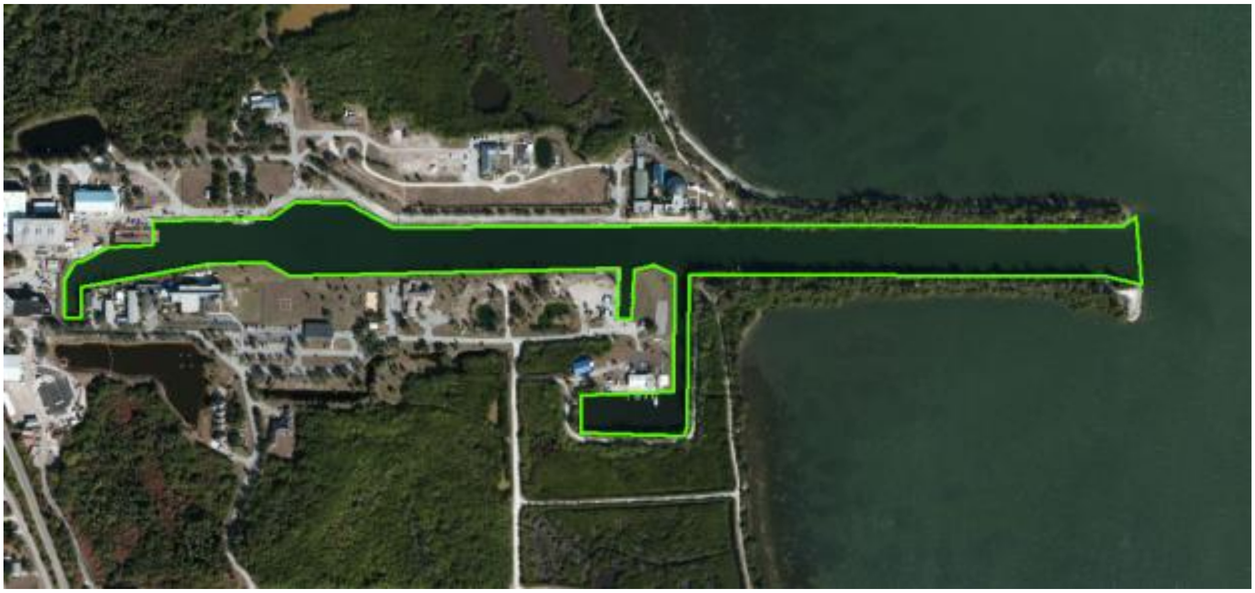

Figure HB-1. Map of the warm water extent for the Harbor Branch Canal site currently available to manatees.

The extent of seagrass within 30km of the site is shown in Figure HB-2. Using techniques outlined in the Forage-K sub-section of the Methods section and a 10% coverage (Lori Morris/SJRWMD, pers. comm., Mar 2012), a weighted SAV area coverage value of 3,591,844 m^2 (887 ac) was computed with min/max values (as used in the MCS) ranging from 3,232,660 m^2 (799 ac) to 3,951,029 m^2 (976 ac).

Figure HB-2. Map of the Harbor Branch Canal site displaying the 30 km manatee swim extent and estimated SAV coverage. (Maps courtesy Provancha *et al.* 2009 and 2010 Habitat Checklists).

RESULTS

As mentioned previously, the data compiled for each site were entered into a MCS model spreadsheet which uses Oracle Crystal Ball to perform the simulations. The MCS also included non-site specific data regarding manatee size, manatee spacing, manatee consumption, and SAV winter growth rates and forage biomass. Parameter inputs to the model mostly used triangular distributions in order to easily adjust values and simplify the simulation process. Parameter inputs with only a minimum and maximum value reflect uniform distributions.

Table 1, demonstrates the non-site specific parameter inputs to the MCS. The cells colored light blue indicate distribution input limits. The minimum and maximum values used for the non-site specific parameters reflect reasonable rather than extreme limits. For instance, the minimum, likely and maximum manatee lengths were calculated from measured values of manatees that died of cold stress in 2010 which was an extreme, cold weather event.[2] While we expect to find smaller and larger animals in Florida waters, we used this sample from 2010 to help determine likely ranges during the winter season. These values can be easily adjusted and within our program provided to the Service.

Our rationale and justification for each of the non-site specific input limits are described in Table 2. The green cells are simulation cells which randomly select a value within each parameter input's distribution and the yellow cells are calculation cells. For instance, Calculated Area of a manatee is the length plus the length buffer times the width. Distribution graphs for each parameter input (green cells) are provided in Appendix 1a. The parameters inputs and MCS model setup were reproduced in the public domain statistical software, R. The R script is provided as Appendix 2.

Table 1. Non-Site Specific Parameters

Manatee Parameters	Simulated Value	Units	Assumption Distribution Inputs		
			Min	Likely	Max
Length	2.30	m	1.5	2.4	4
Length Buffer	0.30	m	0.18	0.3	0.35
Width	1.10	m	1	1.16	1.25
Calculated Area	2.86	m^2			
Avg Body Wt	800	kg	500	800	1200
Consumption (C)	13%	%bm/day	12%	13%	14%
SAV Biomass Factors			Min	Likely	Max
Winter Growth Rate (G)	0.0052	120 dys	0.0052	NA	0.01
Forage Biomass	1.20	kg/m^2	0.785	NA	1.62

[2] http://myfwc.com/research/manatee/rescue-mortality-response/mortality-statistics/

Table 2. Rationale for Non-Site Specific Parameters used in this assessment. Each input value can be adjusted within the model for future assessments based on new information.

MANATEE PARAMETERS	MIN	LIKELY	MAX	RATIONALE
Length (m)	1.5	2.4	4	2010 cold stress mortality statistics[3]
Length Buffer (m)	0.18	0.3	0.35	Expert opinion
Width (m)	1	1.16	1.25	Expert opinion
Avg Body Wt (kg)	500	800	1200	Range of average sizes
Consumption (%bm/day)	12%	13%	14%	Worthy 2008
SAV Winter Growth Rate(/day)	0.005	NA	0.01	Expert opinion, see Methods
Forage Biomass (kg/m^2)	0.785	NA	1.62	Hanisak (2001) & Morris: minimum; Dawes et al, mixed beds: maximum; expert opinion

NA – Not available. A likely amount was not used for this parameter. A uniform instead of a triangular distribution was used which has only a minimum and maximum value.

The MCS model for site specific parameter inputs for Site-K and Forage-K was initially constructed and tested using the three previously investigated sites from our 2010 effort (C-54 Canal, Berkeley Canal and Harbor Branch Canal). The model parameter inputs for all sites are shown in Tables 3a and 3b. Distribution graphs for each parameter input shown these Tables are provided in Appendix 1b.

As described in the Methods section, the MCS used 10,000 trials of the combination of inputs shown in Tables 1, 3a and 3b. It should be noted that the capacity results for the 2010 sites differ from the reported values in the 2010 Report because of the incorporation of MCS. The MCS assumed variations in non-site specific data presented in Table 1 as well as site specific inputs for warm water lengths, depth and SAV percent cover. A brief summary of our analysis of the 2010 Sites from the 2010 Report is presented along with MCS results.

[3] http://atoll.floridamarine.org/data/Zips/custom/Manatee/Manatee_Mortality_201012_wmerc.zip

Table 3a. Site Specific Parameters for Site-K for each sites. Green cells are simulation cells which randomly select a value within each parameter input's distribution and the yellow cells are calculation cells

Site-K - dimensions							Length Distribution Inputs (m)			Depth Distribution Inputs		
Site Name	Variable Warm Water Length (m)	Average Width (m)	Calculated Perimeter [L/W] (m)	Depth Limited Fraction	GIS Surface Area (m^2)	Useable Area (m^2)	Min	Likely	Max	Min	Likely	Max
Blue Spring	117.0	20.0	274	NA	2306	1802	95	107	118	NA	NA	NA
Crystal River	NA	NA	3213.2	30%	70737	46929	NA	NA	NA	24%	30%	36%
De Leon Springs	60.0	50.0	220	20%	8591	2179	30	60	344	10%	20%	30%
Manatee Springs	65.0	20.0	170	10%	4989	901	25	65	95	5%	10%	20%
Silver Glen Springs	NA	NA	1644.3	5%	21597	18721	NA	NA	NA	3%	5%	10%
Silver Springs	7000.0	30.0	14060	40%	245339	106680	6000	7000	8000	20%	40%	60%
Warm Mineral Springs	300.0	13.7	627	50%	2669	1365	250	300	350	40%	60%	80%
Weeki Wachee	8000.0	15.2	16030	90%	17800	8512	2000	8000	9350	88%	90%	92%
C-54	600.0	60.0	1320	3%	159307	32243	300	600	2200	2%	3%	5%
Berkeley	290.0	22.0	624	5%	6769	4794	280	290	300	3%	5%	10%
Harbor Branch	NA	NA	3500	20%	84597	61237	NA	NA	NA	10%	20%	30%

Table 3b. Site Specific Parameters for Forage-K. Green cells are simulation cells which randomly select a value within each parameter input's distribution and the yellow cells are calculation cells

Forage-K - SAV							
				SAV Confidence Factors			
Site Name	Total GIS SAV Area (m^2)	Weighted SAV Area (m^2)	SAV Cover Confidence	Min	Likely	Max	A - adjusted area (m^2)
Blue Spring	33,819,484	7,851,962	1.00	0.80	1.00	1.20	7851962
Crystal River	353,561,300	247,331,322	1.00	0.78	1.00	1.22	247331322
De Leon Springs	25,285,987	4,238,071	1.00	0.80	1.00	1.20	4238071
Manatee Springs	0	0		NA	NA	NA	NA
Silver Glen Springs	26,849,850	11,131,302	1.00	0.80	1.00	1.20	11131302
Silver Springs	243,069	182,302	1.00	0.85	1.00	1.15	182302
Warm Mineral Springs	5,149,969	1,771,351	1.00	0.40	1.00	1.60	1771351
Weeki Wachee	519,346,858	380,299,801	1.00	0.75	1.00	1.25	380299801
C-54	27,724,681	2,772,468	1.00	0.90	1.00	1.10	2772468
Berkeley	55,973,114	5,597,311	1.00	0.90	1.00	1.10	5597311
Harbor Branch	35,918,445	3,591,845	1.00	0.90	1.00	1.10	3591845

The output of the MCS is shown in Table 4 and Figures ALL-1 and ALL-2, providing comparison of capacities among sites. As mentioned in the Monte Carlo Simulation sub-section of the Methods section, the lesser of Site-K and Forage-K is determined for each of the 10,000 trials. The result of this calculation, Limiting-K, will have its own frequency distribution. However, if either Site-K or Forage-K equals Limiting-K in Table 4, then that capacity is always limiting. For example, Forage-K is always limiting for De Leon Springs and Site-K is always limiting for Weeki Wachee.

Table 4. Median (50th percentile) simulation results for Limiting K, Site-K and Forage-K.

Site Name	Limiting K	Site-K	Forage-K
Blue Spring	456	491	646
Crystal River	13725	14336	20388
De Leon Springs	349	1445	349
Manatee Springs	0	243	0
Silver Glen Springs	917	5638	917
Silver Springs	15	31827	15
Warm Mineral Springs	141	308	143
Weeki Wachee	1953	1953	31266
C-54	230	15713	230
Berkeley	464	1414	464
Harbor Branch	298	18598	298

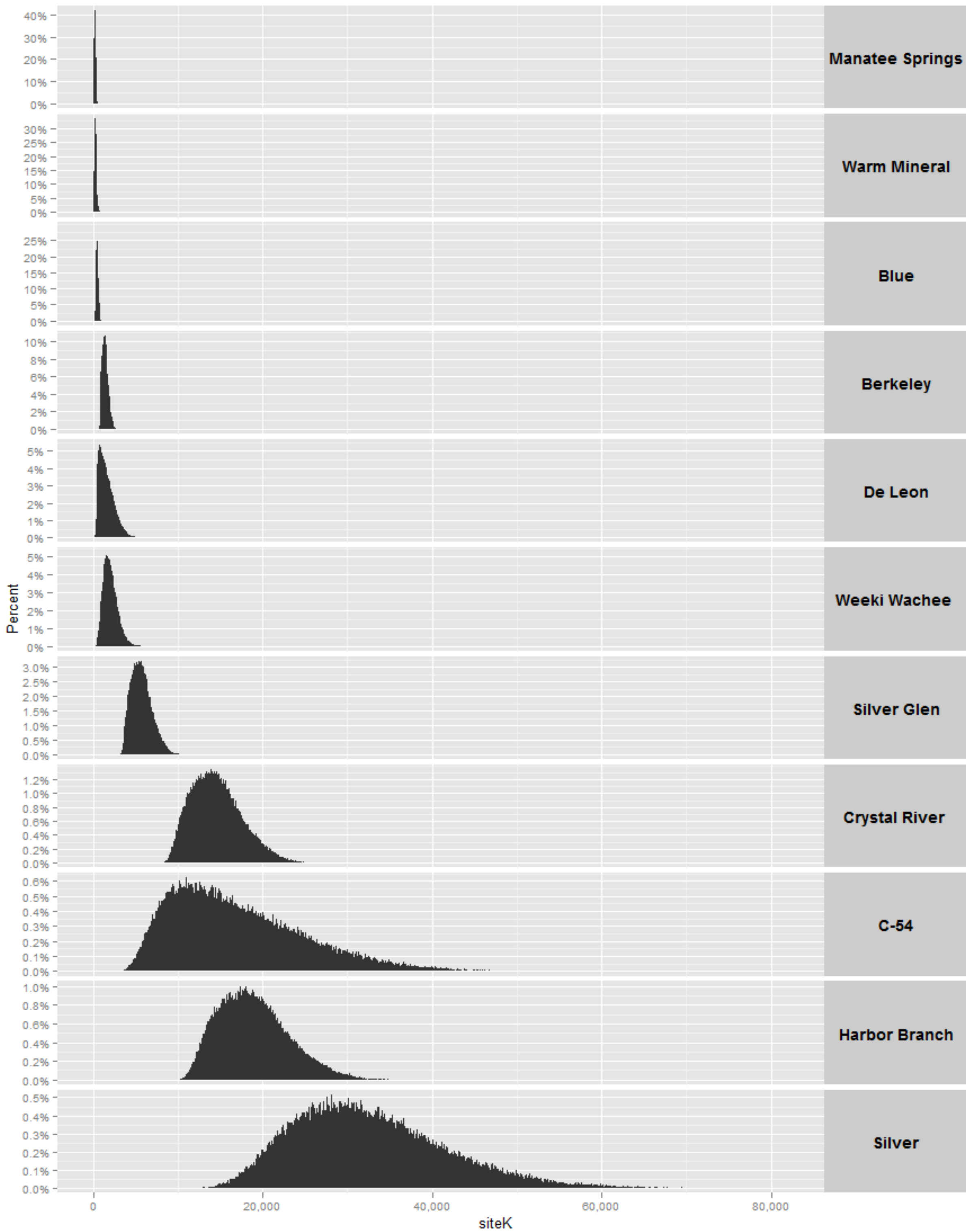

Figure ALL-1. MCS simulation results. Site-K manatee carrying capacity frequency distribution for each site.

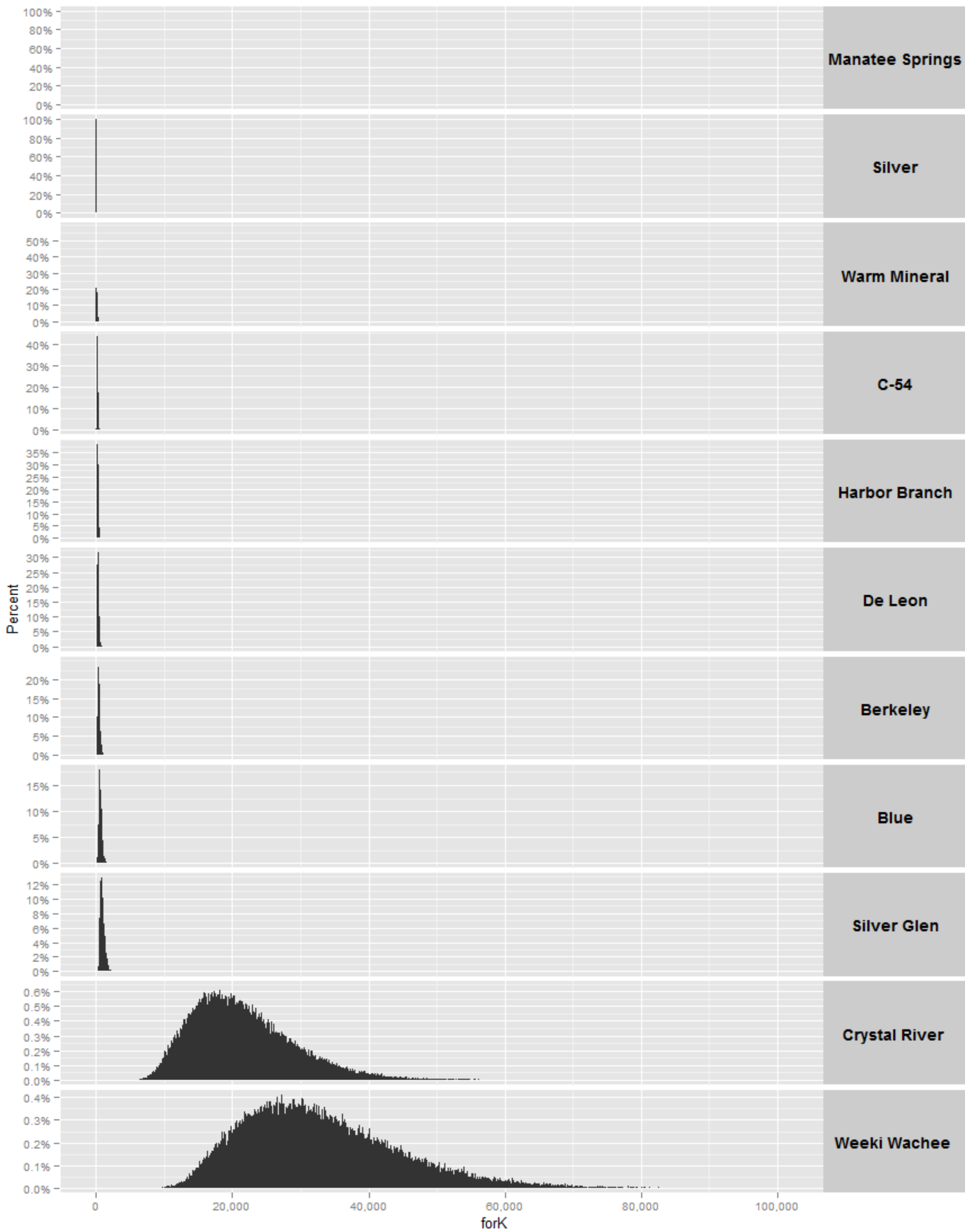

Figure ALL-2. MCS simulation results. Forage-K manatee carrying capacity frequency distribution for each site.

The general trend is that warm water (Site-K) exceeds Forage-K for most sites. The frequency distributions for each site (Figures ALL-1 and ALL-2) provide a visual display of the range in the capacity simulated output. Crystal River, C54 Canal, Harbor Branch, and Silver Springs have the largest warm water capacities while Crystal River and Weeki Wachee have the greatest forage capacities.

Site specific parameter inputs and simulation results for each site are discussed in the following sections. The forecasted output of the MCS, as shown by Site-K, Forage-K and Limiting-K percentile distributions, are provided for all sites.

Blue Spring

Site-K

Rouhani *et al.* (2007) performed a detailed analysis of flow, temperature and water levels for Blue Spring. In addition, Blue Spring State Park rangers have documented manatee usage of the spring run since 1978, identifying both position and quantity of manatees within the run. The useable warm-water length (UWWL) during extreme (50 return year) conditions was determined to be 107 m (348 ft). A manatees/ft estimate was calculated by taking the observed space of an average adult manatee (2.3m x 1.2m) and identifying a critical portion of the run, identified as zones 5 through 7 (See Figure BSR-1.) that had sufficient depth to serve as a refuge during extreme conditions.

We understand that manatees can get to the boil but only under high water level days. This area is therefore not part of the current model. Manatees can also be east of Zone 5 during lower level days. Within this area, it was assumed by Rouhani *et al.* (2007, see Figure 4.1-4) that 13 manatees can fit, shoulder to shoulder while still allowing space for entry and exit. This equates to 1.73 manatees/ft (13 manatees/7.5 ft [2.3m] observed length of an adult manatee = 1.73). The capacity is then determined by taking 1.73 manatees/ft and multiplying by the UWWL of 106m during the extreme event to reach a total of 602 manatees. Since our effort included MCS, a range of values for the UWWL were assumed due to the variability of flow and water level estimates. Consequently, we used 106 m as the likely warm water length with minimum and maximum values of ± 10% along with a fixed width of 20 m.

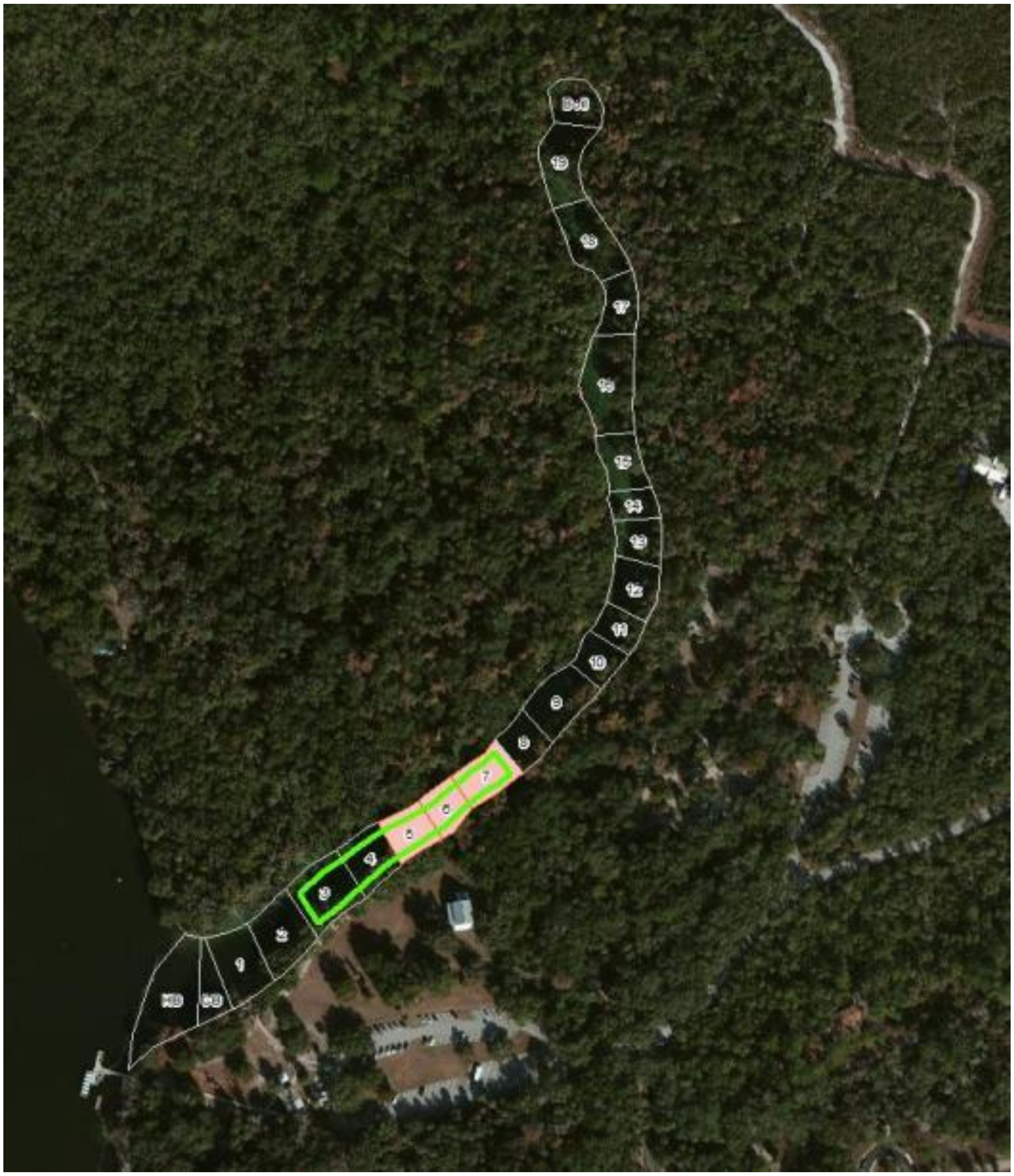

Figure BSR-1. Critical portion of the Blue Spring run providing refuge for wintering manatees.

Forage-K

A weighted SAV area of 7,851,962 m^2 for Blue Spring was provided by interpolation of data from Kelli Gladding /FDEP. This area was varied by ± 20% in the MCS based on Ms. Gladding's confidence in the assessment and weighting technique. The extent of forage within 30 km of the site was shown previously in Figure BS-2. Simulated Site-K, Forage-K and Limiting-K for Blue Spring are shown in Table BSR-1 below. Complete simulation results are provided in Appendix 1b.

Table BSR-1. Capacity Simulations, Blue Spring

PERCENTILES	SITE-K	FORAGE-K	LIMITING-K
0%	242	213	213
10%	340	408	329
20%	384	479	366
30%	420	535	396
40%	456	591	426
50%	491	646	456
60%	523	709	486
70%	559	781	519
80%	605	869	558
90%	674	1000	614
100%	1008	1819	933

Site-K was determined to be the limiting factor for Blue spring. However, the values of Forage- and Site-K are similar; the Limiting-K values calculated were less than 10% lower than Forage-K.

DeLeon Springs

Site-K

Useable warm water at De Leon Springs was limited to a small zone just downgradient of an overflow weir based on conversations with information from Monica Ross/Sea2Shore Alliance. Due to a lack of temperature and depth data as well as synoptic data, the MCS values for this site were set to be highly variable. Based on information from Ms. Ross, the likely length was 60 m but was allowed to range from 30 to 344 m with the longer length the distance from the weir to the lake. It was also assumed that depth would be likely limited to 20% of the simulated area ± 10%.

Forage-K

A weighted SAV area of 4,238,071 m^2 for De Leon Springs was provided by interpolation of data from Kelli Gladding/FDEP. This area was varied by ± 20% in the MCS based on Ms. Gladding's confidence in the assessment and weighting technique. The extent of forage within 30 km of the site was shown previously in Figure DS-2. Simulated Site-K, Forage-K and Limiting-K for Crystal River are shown in Table DS-1 below. Complete simulation results are provided in Appendix 1b.

The simulation results for De Leon Springs suggest that the warm water capacity of De Leon Springs exceeds forage capacity by approximately one order of magnitude using our current assumptions and that Forage-K is almost always limiting. Consequently, the simulated values for Limiting-K are equal to or slightly lower than Forage-K.

Table DS-1. Capacity Simulations, De Leon Springs

PERCENTILES	SITE-K	FORAGE-K	LIMITING-K
0%	253	122	122
10%	647	221	221
20%	831	259	258
30%	1018	290	289
40%	1221	320	319
50%	1445	349	349
60%	1693	383	382
70%	1998	420	419
80%	2355	468	464
90%	2894	538	533
100%	6194	1059	1059

Silver Glen Springs

Site-K

The Silver Glen Springs warm water area was estimated using bathymetric survey data and limited to portions of the run greater than 1.2 m (shown in Figure SGS-1). It was also assumed that cold water from Lake George intrudes into the run approximately 200 m and further limits the available warm water area. The total warm water area was estimated to be 21,597 m^2. Water level measurements from a USGS gage within the run were evaluated but proved to be inclusive due to the limited period of record (2003 to present) and no clearly defined relationship to the bathymetric survey. Consequently, a depth limiting factor of 3 to 10% was used to account for variability in water depth and additional cold water intrusion. Vacant area allowed for entry and exit was limited to only ½ of the perimeter of these areas since most of the warm water areas are only bound by land on one side.

Forage-K

A weighted SAV area of 11,131,302 m^2 for Silver Glen Springs was provided by interpolation of data from Kelli Gladding /FDEP. This area was varied by ± 20% in the MCS based on Ms. Gladding's confidence in the assessment and weighting technique. The extent of forage within 30 km of the site was shown previously in Figure SGS-2. Simulated Site-K, Forage-K and Limiting-K for Silver Glen Springs are shown in Table SGS-1 below. Complete simulation results are provided in Appendix 1b.

Table SGS-1. Capacity Simulations, Silver Glen Springs

PERCENTILES	SITE-K	FORAGE-K	LIMITING-K
0%	3296	307	307
10%	4254	580	580
20%	4663	678	678
30%	5012	760	760
40%	5330	841	841
50%	5638	917	917
60%	5957	1003	1003
70%	6296	1103	1103
80%	6719	1224	1224
90%	7383	1413	1413
100%	10237	2754	2754

Forage-K, as shown in Table SGS-1, is clearly the limiting factor for Silver Glen Springs with values 5 to 10 times less than Site-K.

Silver Springs

Site-K

The useable warm water area and length for Silver Spring is vast based on our 14 January and 5 March 2012 site reconnaissance and transducer data deployment. Our observations also show that most of Silver Springs and Silver River has adequate depth to serve as a manatee refuge. Based on this survey, we estimated a likely length of 7000 m with a maximum of 8000 m (approximate length to Ocklawaha River) and a width of 30 m. It was assumed based on our visual survey of the entire Silver River that the useable depth was likely 60% of this area ± 20%. Because of this large area, simulated Site-K values were very large as demonstrated by Table SS-1.

Forage-K

Vast quantities of SAV (*Vallisneria*) were evident on both of our field visits to Silver River in 2012. The mapped SAV extent within a 30 km swim distance encompassed an area of 243,069 m^2 with a weighted SAV coverage of 182,302 m^2 based on 75% coverage of the river bottom. Confidence limits in the MCS were set to +/- 15% (J. Provancha, pers. observation, Jan. and Mar. 2012). Forage within the Ocklawaha portion of the 30 km buffer was zero at the time of this assessment. Forage-K, as shown in Table SS-1, is over 2,000 times less than Site-K. Complete simulation results are provided in Appendix 1b.

Table SS-1. Capacity Simulations, Silver Springs

PERCENTILES	SITE-K	FORAGE-K	LIMITING-K
0%	12800	5	5
10%	22268	10	10
20%	25138	11	11
30%	27340	12	12
40%	29630	14	14
50%	31827	15	15
60%	34160	16	16
70%	36743	18	18
80%	39847	20	20
90%	44759	23	23
100%	71504	43	43

Manatee Springs

Site-K

Useable warm water area at Manatee Springs was limited to near the boil due to shallow water throughout the spring. A significant tidal fluctuation as measured by a water level recorder near the boil is demonstrated by Figure MS-4.

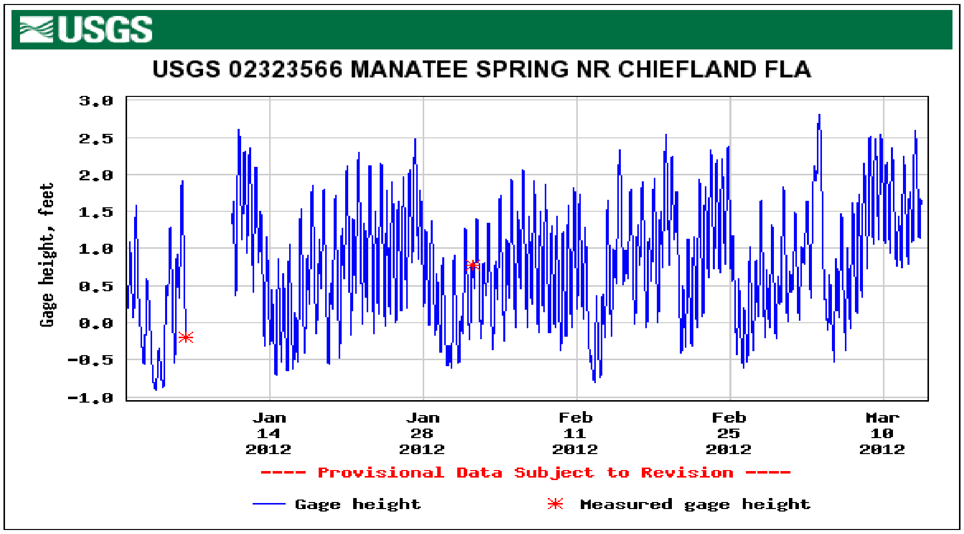

Figure MS-4. Manatee Springs water levels from USGS Gage 02323566

Based on this information, coupled with bathymetric data and information on manatee aggregation in the Spring, we estimated the useable area was limited to a likely length of 65 m with minimum and maximum lengths of 25 (adjacent to the boil) and 95 m (length of greater than 1.2 m depth area).

Forage-K

As discussed earlier, our study assumption was that manatees use submersed aquatic vegetation as the primary support forage, eliminating estimations associated with marsh grasses and overhanging bank vegetation. Following this assumption, the distance to the nearest forage (local and coastal sources) from Manatee Springs eliminates this site as a viable winter refuge. The distance violates the 30 km criteria from the refuge site to forage. Specific manatees observed at Manatee Springs have been observed many times at Crystal River Kings Bay and Homosassa Springs in winter (Sally Leib/FDEP, Susan Butler/USGS, pers. comm., Dec 2011). Manatee Springs, while it has visitation, the overall quality may be such that manatees must utilize other sites to be adequately supported in severe winters. As mentioned earlier some manatee experts (J. Reid/USGS) have reported manatees in the Suwannee foraging on marsh grasses and bank vegetation. We recognize this caveat and mention it herein for consideration of data that might support future assessments of these habitats relative to manatee sustenance. Only Site-K is represented in Table MS-1. However, based on our current assumptions, Forage-K is zero and thus suggests that this site is not a viable refuge. Complete simulation results are provided in Appendix 1b.

Table MS-1. Capacity Simulations, Manatee Springs

PERCENTILES	SITE-K	FORAGE-K	LIMITING-K
0%	62	0	0
10%	149	0	0
20%	177	0	0
30%	200	0	0
40%	221	0	0
50%	243	0	0
60%	267	0	0
70%	293	0	0
80%	328	0	0
90%	376	0	0
100%	695	0	0

Weeki Wachee Springs Complex

Site-K

The estimation of useable warm water from the Weeki Wachee system was complicated by the presence of multiple springs within the river/run. The system is warm for its full extent but a lack of adequate bathymetric data further complicated our estimates. Therefore, our surveys of the river/run in January and March 2012 were used to estimate a likely of 8000 m and minimum and maximum lengths of 2000 and 9350 m. We also estimated an average river width of 15.2 m and only a small portion of that width, 1.5 m (10% ± 2%), has depths greater than the required 1.2 m.

While we know that a few manatees do travel all the way to the boil, the relatively short minimum distance was selected to account for the low probability that animals would make the trek all the way to the main boil in the park and distribute themselves over the entire length of the river.

This assumption is substantiated by Applied Technology and Management (ATM) (2007)[4] assessment on withdrawal impacts to the river in which they state that, "Manatees tend to congregate just above the interface of the cooler and warmer waters, and move upstream as cooler waters intrude further into the system."

Forage-K

There is essentially no forage found within the Weeki Wachee River in recent years nor during our site visit. The GIS delineated weighted SAV area was 380,299,801 m^2 for the Weeki Wachee Springs (represented primarily by the coastal seagrasses) with min/max range of +/- 25% estimated from the range of percent coverage values within each mapped category (see explanation in the Methods section). Simulated Site-K, Forage-K and Limiting-K for Weeki Wachee are shown in Table WWS-1 below.

Table WWS-1. Capacity Simulations, Weeki Wachee Springs

PERCENTILES	SITE-K	FORAGE-K	LIMITING-K
0%	347	9417	347
10%	1093	19601	1093
20%	1346	23033	1346
30%	1560	25936	1560
40%	1758	28555	1758
50%	1953	31266	1953
60%	2167	34300	2167
70%	2424	37873	2424
80%	2718	42019	2718
90%	3168	48469	3168
100%	5605	105644	5605

Based on our current assumptions, Site-K is always the limiting capacity for Weeki Wachee. This is mostly due to shallow depths in the warm water portions of the river. ATM (2007) calculated a capacity of approximately 1770 manatees[5] based on critical flow conditions during cold periods which is closest to our 40% simulated result for Site-K.

Warm Mineral Springs

Site-K

Our reconnaissance of Warm Mineral Springs in December 2011 was used to estimate the extent of this refuge which had low spring flow rates, shallow depths and a strong tidal

[4] ATM (2007) calculated their capacity based on a habitat size of 27,500 m2 and a manatee density of 0.006 manatee/ft2. However, it should be noted that we could not find a justification for 0.006 manatee/ft2 in their report. The closest value was 0.007 manatee/ft2 which was derived from the mean density of observed manatees in Blue Spring during the coldest days. If we used this density and the habitat size of 27,500 m2, the calculated capacity would be 2072 manatees which is closest to our 50% value.

component. Based on this information and synoptic aggregation data, we estimated that the extent of the warm refuge was likely of 300 m with a minimum of 250 m and a maximum of 350 m. An average width of 13.7 m and a useable depth of 40% ± 20% were used in the MCS based on our survey.

Forage-K
The GIS delineated weighted SAV area was 1,771,351 m^2 for the Warm Mineral Springs area with a min/max range of +/- 60% estimated from the range of percent coverage values within each mapped category (see explanation in the Methods section). Simulated Site-K, Forage-K and Limiting-K for Warm Mineral Springs are shown in Table WM-1 below. Complete simulation results are provided in Appendix 1b.

Table WM-1. Capacity Simulations, Warm Mineral Springs

PERCENTILES	SITE-K	FORAGE-K	LIMITING-K
0%	80	25	25
10%	186	81	81
20%	219	99	98
30%	249	113	113
40%	278	128	127
50%	308	143	141
60%	340	160	156
70%	376	178	173
80%	422	204	195
90%	490	239	228
100%	922	505	472

The Forage-K results compared to the Site-K, indicated that forage is almost always the limiting factor for this refuge. However, we feel that the useable warm area could be much smaller due to the relatively low flow rates of Warm Mineral Spring compared to other springs looked at as part of this effort. Also, as detailed earlier, FWC’s transducer located in the upstream portion of the refuge demonstrates that water temperatures can drop below 20 C during extreme cold weather events. Consequently, Warm Mineral Springs may not be a reliable winter refuge if flow rates from the spring diminish in the future.

Kings Bay/Crystal River System

Site-K
As detailed earlier in this report, 90 to 95% of manatees visiting the Kings Bay/Crystal River system of springs during winter months are highly associated with the King Spring, Three Sisters Spring, Gator Hole canals, and Hunter Spring refuge areas in Crystal River. Each of these areas is tidally influence with up to 1.8 m fluctuations in depth. This tidal fluctuation is up to 1.5 m during the winter season according to a nearby USGS gage (Station ID: 02310742) which is 1000 to 1600 m downstream of the refuge areas. Low tide deviations from the 1988 NGVD datum are, on average, 0.5 m during winter with 10% of low tides greater than 0.7 m.

Given the large fluctuations in water level and the absence of detailed bathymetry, it was assumed that 30% ("depth limited fraction") of the delineated refuge areas will be less than 1.2 m during low tide. This percentage was varied ± 20% in the MCS (24% to 36%). Also, portions of the Three Sisters Spring area were deemed too shallow to serve as a refuge. These shallow areas most likely serve as high water pathways to the deeper, warm water areas. The total area of the four refuges is approximately 70,700 m^2, 7 hc (17 ac) and was left constant in the MCS. Useable area was varied in the MCS based on the depth limited fraction. As described in the Methods section of this report, a vacant area allowing for entry and exit was limited to only ½ of the perimeter of these areas since most refuge areas are only bounded by land on one side.

Forage-K

The extent of forage within 30 km of the site was shown previously in Figure CR-2. The GIS delineated weighted SAV area was 247,331,322 m^2 for the Crystal River area (represented primarily by the coastal seagrasses) with min/max range of +/- 22% estimated from the range of percent coverage values within each mapped categories (see explanation in the Methods section). Simulated Site-K, Forage-K and Limiting-K for Crystal River are shown in Table CR-1 below. Complete simulation results are provided in Appendix 1b.

Table CR-1. Capacity Simulations, Crystal River/Kings Bay

PERCENTILES	SITE-K	FORAGE-K	LIMITING-K
0%	8437	6683	6683
10%	10947	12820	10595
20%	11952	14990	11516
30%	12794	16909	12291
40%	13585	18580	13007
50%	14336	20388	13725
60%	15116	22361	14454
70%	15985	24534	15261
80%	17041	27254	16250
90%	18672	31423	17691
100%	26018	57842	24726

These results suggest that the forage capacity at Crystal River exceeds the warm water capacity using our current assumptions and that Site-K is always limiting.

C-54 Canal

Site-K[5]

The dominant influence of tides (high frequency variations) within the estuary is limited to within 5.6 km from an inlet (T. Cera/SJRWMD, pers. comm., March 2010). Outside of this

[5] Our 2010 Report had assumed that if manatees aggregated within a particular refuge, then that refuge was adequately warmer than surrounding water bodies. Consequently, the analysis performed in the 2010 effort determined only extreme hydraulic (i.e. low water level) conditions at each Site. Our current effort includes MCS analysis which estimates variability of useable warm water area by applying constraints on depth (which accounts for low water level conditions), length and area (see Methods section). Therefore, both the extreme hydraulic analysis and the MCS analysis are presented for the 2010 Sites: C-54, Berkeley and Harbor Branch.

radius, climate conditions, such as wind and seasonal temperature (low frequency variations) dominate water level fluctuations and patterns. The analysis is initiated at the C-54 site, which is closest to an ocean inlet and subject to the most extreme water level fluctuations as compared to Harbor Branch Canal and Berkeley Canal. A continuous water stage recorder maintained by the USGS Florida Water Science Center was 3.9 km downstream of the C-54 site (Station ID: 02251210). This USGS station has 24 years of daily data through April 2012 as well as 15 minute interval water levels.

The 20-year minimum 3-day water level deviation from the calculated long-term seasonal mean water level at the C-54 Canal site is approximately 0.3 m. This means that even under a 20-year extreme condition, the water level at the C-54 site falls to between 2.7 to 4.3 m, which is significantly higher than the required 1.2 m (4 ft). Consequently, the Site-K at the C-54 Canal site is unaffected by the above computed extreme low water level conditions.

As mentioned earlier, MCS analysis was employed for the 2010 sites in order to produce a consistent assessment of capacity compared to the 2011 sites. Consequently, the extreme water level analysis for the 2011 effort accounted for using a depth limiting factor in the MCS. Since the canal is uniformly deep, a small limiting factor range (2-5%) was used to address the edges of the canal. Also, the MCS assumed that length of warm water in the refuge could also be limiting due to encroachment of tidal waters from Sebastian River and Indian River Lagoon. The lengths used in the MCS are shown in Table 3a and were based on unpublished FWC temperature transducer results (C. Deutsch/FWC) and synoptic measurements. Based on this limited data, we determined that warmer waters are most likely near the canal gate up to 600 m away. However, manatee locations during synoptic and other surveys show that most manatees can be in the canal up to 2200 m from the gate.

Forage-K

The extent of forage within 30 km of the site was shown previously in Figure C54-2. The GIS delineated SAV area of 27,704,344 m^2 was initially 50% covered with a confidence interval of ± 15% in the MCS (Lori Morris/SJRWMD, pers. comm., February 2011). However, severe algal blooms caused a significant reduction in SAV within our areal extent for C54 (Lori Morris/SJRWMD, pers. comm., Mar 2012.). Therefore, we reduced the percent SAV cover to 10% with a confidence interval of ± 10% in the MCS. Simulated Site-K and Forage-K results for C-54 Canal are shown in Table C54-1 below. Complete results and distribution graphs are provided in Appendix 1b.

Table C54-1. Capacity Simulations for C-54 Canal

PERCENTILES	SITE-K	FORAGE-K	LIMITING-K
0%	3598	77	77
10%	8237	145	145
20%	10186	171	171
30%	11878	191	191
40%	13666	210	210
50%	15713	230	230
60%	17904	250	250
70%	20507	274	274
80%	23593	305	305
90%	28152	349	349
100%	56936	640	640

These results suggest that the warm water capacity at C-54 Canal exceeds the forage capacity using our current assumptions even with the additional limitations in place for length and depth in the MCS. These data suggest Forage-K capacity is always limiting for C-54 Canal.

Berkeley Canal

Site-K
Given the fact that the C-54 Canal site is the most prone to hydraulic fluctuations among the three 2010 pilot sites and was unaffected by the computed extreme low water level conditions, we concluded that Berkeley Canal would also be unaffected, resulting in similar computations. However, with inclusion of the MSC as well as depth and temperature data (C. Deutsch/FWC), we also accounted for less uniform depths throughout Berkeley Canal, especially near the western end of the canal which tended to be shallow, thus slightly shortening the canal length. Characteristics of Berkeley Canal are listed in Table 3a, and the extent of warm water was shown previously in Figure BK-1.

Forage-K
The extent of forage within 30 km of the site was shown previously in Figure BK-2. (Lori Morris/SJRWMD, pers. comm., Mar 2012). Simulated Site-K, Forage-K and Limiting-K for Berkeley Canal are shown in Table BK-1 below. Complete results and distribution graphs are provided in Appendix 1b. The GIS delineated SAV area of 55,930,173 m^2 was initially assumed to be 50% covered with a confidence interval of ± 15% (Lori Morris/SJRWMD, pers. comm., Feb 2011). Similar to C-54, we reduced the coverage to 10% with a confidence interval of ± 10% in the MCS due to recent significant impacts to SAV in the IRL (Lori Morris/SJRWMD, pers. comm., Mar. 2012). The simulated Site-K, Forage-K and Limiting-K for Berkeley Canal are shown in Table BK-1 below. Complete results and distribution graphs are provided in Appendix 1b.

Table BK-1. Capacity Simulations, Berkeley Canal

PERCENTILES	SITE-K	FORAGE-K	LIMITING-K
0%	736	166	166
10%	1000	294	294
20%	1121	344	344
30%	1223	385	385
40%	1322	424	424
50%	1414	464	464
60%	1509	506	506
70%	1610	555	555
80%	1738	615	615
90%	1936	706	706
100%	2836	1419	1419

These results suggest that the forage capacity is always limiting at Berkeley Canal. This is due to recent impacts to SAV in the IRL. Our 2010 Report determined that Forage-K and Site-K were similar, but Forage-K was still the limiting parameter in 2010, when SAV coverage was considerably larger than 2012.

Harbor Branch Canal

Site-K

Given the fact that the C-54 Canal site is the most prone to hydraulic fluctuations among the three 2010 IRL pilot sites and was unaffected by the computed extreme low water level conditions, we concluded that Harbor Branch Canal would also be unaffected, resulting in similar computations. Bathymetry (M. Mazzoil/HBOI) for the canal showed that parts of the canal had variable and shallow depths, especially within small branches and along the edges. Based on this information, we assumed approximately 20% ± 10% of the canal would not have greater than 1.2 m depths during low tide. We did not have adequate temperature data to limit the useable size of the canal. Synoptic measurements were also not conclusive. Therefore, we assumed the canal to be uniformly warm until such data is made available. Characteristics of Harbor Branch Canal are listed in Table 3a, and the extent of the site was previously depicted in Figure HB-1.

Forage-K

The extent of forage within 30 km of the site was shown previously in Figure HB-2. The GIS delineated SAV area of 35,918,445 m^2 was assumed 10% covered with a confidence interval of ± 10% in the MCS (Lori Morris/SJRWMD, pers. comm., Mar 2012). This decrease in SAV percent cover (from 50%, in our preliminary model, to 10%) was similar to the other IRL sites where water conditions in 2011 impacted the SAV at an unprecedented level. Simulated Site-K, Forage-K and Limiting-K for Berkeley Canal are shown in Table HB-1 below. Complete results and distribution graphs are provided in Appendix 1b.

Table HB-1. Capacity Simulations, Harbor Branch Canal

PERCENTILES	SITE-K	FORAGE-K	LIMITING-K
0%	10504	101	101
10%	13885	189	189
20%	15315	221	221
30%	16468	247	247
40%	17520	272	272
50%	18598	298	298
60%	19713	325	325
70%	20849	356	356
80%	22368	395	395
90%	24556	451	451
100%	35733	844	844

These results suggest that the warm water capacity at Harbor Branch Canal exceeds the forage capacity using our current assumptions and that Forage-K is always limiting.

DISCUSSION

Site-K and Forage-K carrying capacities were estimated consistent with assumptions outlined by the USFWS and associated focus groups (i.e. Manatee Recovery Team Habitat Working Group, Warm Water Task Force, etc.), including priorities identified by state and federal managers for refining the current estimates of carrying capacity. Our estimates are based on best available existing data, literature, maps, plans, and knowledge and opinion of recognized experts that have collected quantifiable, volumetric assessments of areas. We also augmented with short term water temperature collection. These sources were used to develop conservative parameter inputs for this process. However it is expected that in the future one or more of the input parameters and/or uncertainty surrounding parameter may need to be updated or modified as new data or opinions become available. For that reason the models and structure of the simulations were reproduced in the public domain statistical software, R, and provided to USFWS with this report to ensure the continued utility of this process of calculating manatee carrying capacity of warm water sites in Florida.

Our 2010 effort included a statistical analysis and incorporation of warm water capacity under extreme hydrological conditions. However, with the addition of MCS, we accounted for extreme conditions in this effort using estimated warm water areas greater than 1.2 m and a depth limiting factor. Lastly, we also incorporated manatee size and a refuge edge entry/exit buffer into the Site-K calculations. In order to incorporate the uncertainty and inherent variability of each parameter input, we developed ranges around the parameter for use in MCS calculations.

The outputs presented here should be considered conservative estimates for a variety of reasons. For example, the estimated Site-K represents only the volume of warm water that can be occupied by one layer of fully submerged adult manatees. Additional capacities associated with partially submerged adult or younger manatees, as well as vertical stacking of manatees are not included in the estimated Site-K.

As mentioned in the outset, not included in our analysis is manatee behavior, due to the lack of adequate insight at this point in time. The vagaries of manatee behavior should always be taken into account, as the availability of a warm-water site with adequate spatial and thermal capacity does not mean that manatees will find or use the site. This behavioral issue is left for future assessments after more is learned about manatee's warm water and forage site selection and fidelity under varying conditions, including density dependence. Human disturbance associated with specific sites was also not included in the analysis due to the lack of information about the effects of such and consensus on how to quantify this issue.

For Forage-K, our study assumption limited manatees to the use of submerged aquatic vegetation as the primary support forage, eliminating estimations associated with marsh grasses and overhanging bank vegetation. Collection of additional data for these low quality (but occasionally utilized) food sources might support future assessments of these habitats relative to manatee sustenance.

Limitations of existing data were noted in numerous areas:

- Continuous, long-term water temperature datasets were invaluable and should be considered for all important winter manatee habitats. Discrete temperature data collection was less useful for this analysis. We collected our own continuous temperature data at some sites in order to aid in our assessment of useable warm water area.
- Bathymetric surveys for warm water sites should be tied to nearby USGS real-time water level gages in order to assess extreme hydraulic conditions that may further limit useable warm water areas during catastrophic events.
- Biomass data vary in quality and currency. Invasive plant monitoring by state agencies has somewhat improved our knowledge of presence/absence of freshwater vegetation, but these areas have yet to be adequately mapped for this type of analysis. In addition, these systems are dynamic with changes sometimes occurring in very short time frames that could significantly alter estimates. An example of rapid change is the Indian River Lagoon SAV where an unprecedented algal bloom in 2011 reduced SAV extent by nearly 90%, all within a single year (L. Morris/SJRWMD, pers. comm., Mar. 2012; J. Provancha, pers. observ.). This is a SAV area that has been relatively stable or increasing over two decades and our original estimates (2010) generated a much higher value for SAV in that area than was ultimately reported herein. This dynamic will always be a challenge to incorporate.

Simulation results are presented as Site-K, Forage-K, and Limiting-K from 0 to 100 percent. These percentile results, provided in increments of 10%, represent the percent chance, or probability, of a forecast value being less than or equal to the value that corresponds to the percentile. The 0 and 100th percentile results represent the minimum and maximum possible values of the simulation. As mentioned in the Monte Carlo Simulation sub-section of the Methods section, Limiting-K is calculated as the lesser of Site-K and Forage-K and is determined for each of the 10,000 trials in the MCS. Therefore, Limiting-K will have its own frequency distribution. However, if either Site-K or Forage-K percentile results equals Limiting-K, then that capacity is always limiting under every simulated condition. Conversely, if Forage- and Site-K results are similar, Limiting-K results will have lowest percentile capacity values.

Our current study resulted in Forage-K as the limiting parameter for De Leon, Manatee, Silver Glen and Silver Springs as well as C-54 and Harbor Branch Canals. Due to the significant impacts to SAV in Indian River Lagoon mentioned above, Forage-K is always the limiting parameter for Berkeley Canal. Site-K is always the limiting parameter for Weeki Wachee due to shallow depths within the river/run. Forage-K is the limiting parameter for Warm Mineral Springs but not for every simulated condition. Finally, Blue Spring is the only warm water refuge where both Forage-K and Site-K can be limiting. However, Site-K is typically the limiting factor for Blue Spring.

All simulation outcomes are provided in the Results section and in Appendix 1a. Table 5 presents the Limiting-K results for all investigated sites providing an opportunity to compare and contrast sites, although this was not the intent of the study.

Table 5. Limiting-K Simulation Results for all eleven sites. The values represent the range in the numbers of manatees estimated to be supported at each site (probability percentiles).

Site Name	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Blue Spring	213	329	366	396	426	456	486	519	558	614	933
Crystal River	6683	10595	11516	12291	13007	13725	14454	15261	16250	17691	24726
De Leon Spg	122	221	258	289	319	349	382	419	464	533	1059
Manatee Spg	0	0	0	0	0	0	0	0	0	0	0
Silver Glen Spg	307	580	678	760	841	917	1003	1103	1224	1413	2754
Silver Springs	5	10	11	12	14	15	16	18	20	23	43
Warm Mineral Spg	25	81	98	113	127	141	156	173	195	228	472
Weeki Wachee	347	1093	1346	1560	1758	1953	2167	2424	2718	3168	5605
C-54	77	145	171	191	210	230	250	274	305	349	640
Berkeley	166	294	344	385	424	464	506	555	615	706	1419
Harbor Branch	101	189	221	247	272	298	325	356	395	451	844

Figures ALL 1 and ALL 2, provide a graphical summary of the status of sites to accompany Table 5. Forage-K was the limiting factor for all natural spring sites with the exception of Weeki Wachee Spring. However, the warm waters within the Weeki Wachee River offer no substantial forage to manatees. They must leave the site and rely on the nearby Gulf of Mexico SAV beds (i.e., they must move into the cooler waters to feed during prolonged cold periods).

The Site-K and Forage-K results for Blue Spring and Warm Mineral Springs tended to be similar, especially for Blue Spring. Additionally, based on recent manatee use numbers, these two springs are likely close to reaching the estimated carrying capacity during cold winters.

Manatee Springs (with a relatively small Site-K) was determined to have a Forage-K of zero (due to the lack of SAV within the 30 km swim distance). This constraint could eliminate the site as a "currently" viable winter refuge. In contrast, the Silver Spring site is quite large and had vast and healthy looking SAV beds within the Silver River. The forage is concentrated within the warm water boundary. This "within warm water site forage" is the exception to the majority of our sites. The portion of the 30 km extent beyond the Silver River (in the Ocklawaha River) is currently reported to have very low SAV coverage resulting in the Silver Spring site having a surprisingly low Forage-K (n=15 manatees at the 50^{th} percentile). Recall that this forage is to sustain animals for the duration of a 120 day winter.

Crystal River had by far the largest calculated capacity, with a 50^{th} percentile Limiting-K of nearly 14,000 manatees. This comparative finding of capacity dominance by Crystal River is substantiated by historical synoptic manatee counts and those during the extreme 2010 cold weather event. Crystal River had at least 10 times more observed manatees than any other site in this investigation with the exception of Blue Spring which was 2.6 times. The simulated Limiting-K for this site is also more than 10 times larger than almost every natural spring site.

Combined, these sites demonstrate a potential capacity (Limiting-K) at the 50^{th} percentile of 18,789 manatees (13,684 to 25,551 for the 10^{th} and 90^{th} percentiles, respectively). Recent information regarding relative abundance of manatees observed across Florida suggests there may currently be about 5,000 manatees. Combining the 50^{th} percentile values for all eleven sites for Site-K yields capacity for over 90,000 manatees (see Results section tables). That same estimate for Forage-K for the eleven sites combined totals over 50,000 manatees.

Regardless of the percentile chosen, the study indicates that warm water does not appear to be a current constraint to manatees at most sites. In some areas, forage is a current issue or likely future issue. Far larger numbers of manatees can be accommodated spatially than can be supported by the local vegetation. These estimated capacities should not be used to reduce protection of the warm-water sites around the state. Alternatively, they offer insight to the long asked question of capacity and provide USFWS with insight as they move forward with the Manatee Recovery Actions.

The eleven sites analyzed in this report just begin to scratch the surface of determining manatee carrying capacity regionally or for the entire state of Florida. The process followed here could be replicated or use modified input parameters to determine carrying capacity limitations at other warm-water sites throughout the state. Site-specific carrying capacity estimates would need to be translated into regional estimates for inclusion in the Manatee Core Biological Model. With the quantitative calculations at these eleven study sites, we have exceeded the current recognized carrying capacity estimates for the Upper St. Johns, Atlantic, and Northwest regions (Runge 2004). Further work to expand and refine carrying capacity estimation throughout the state will be necessary to enhance results from the current modeling efforts to determine an accurate status of Florida manatee population.

LIST OF INTERVIEWEES OR DATA SOURCES FOR FY 2010/2011 SITES

- Sally Leib/ Silver Springs State Park, Florida Dept of Environmental Protection
- Larry Steed/ Manatee Springs Park, Florida Dept of Environmental Protection
- Mark Williams/ Fanning Springs State Park ,Florida Dept of Environmental Protection
- Toby Brewer/ WeekiWachee Springs, Florida Dept of Environmental Protection
- Harley Means, P.G./ Florida Geological Survey, Dept of Environmental Protection
- Dr. Paul Hansard, P.G. / Florida Geological Survey, Dept of Environmental Protection
- Tom Greenhalgh/ Florida Geological Survey, Dept of Environmental Protection
- Chris Zajac/ Southwest Florida Water Management District
- Catherine Wolden/ Southwest Florida Water Management District
- Dr. Ernie Estevez/ Mote Marine Laboratory
- Dr. John Reynolds/Mote Marine Laboratory
- Robert Mattson/ St. Johns River Water Management District
- Lori Morris/ St. Johns River Water Management District
- Ralph Brown/ St. Johns River Water Management District
- Tim Cera/St. Johns River Water Management District
- Joyce Kleen/ US Fish and Wildlife Service
- Kent Smith/ Florida Fish and Wildlife Conservation Commission
- Ron Mezich/ Florida Fish and Wildlife Conservation Commission
- Kelli Gladding/ Florida Fish and Wildlife Conservation Commission
- Denise Boyd/ Florida Fish and Wildlife Conservation Commission
- Chip Deutsch/ Florida Fish and Wildlife Conservation Commission
- Christy Hudak/ Florida Fish and Wildlife Conservation Commission
- Ann Spellman/ Florida Fish and Wildlife Conservation Commission
- Dr. Paul Carlson/ Florida Fish and Wildlife Conservation Commission
- Dr. Penny Hall/ Florida Fish and Wildlife Conservation Commission
- Stacy Koslovsky /Florida Fish and Wildlife Conservation Commission
- Margie Barlas//Florida Fish and Wildlife Conservation Commission
- Bill Hilbrands/ Hydrogage, Inc
- Jim Reid/ Sirenia, US Geological Survey
- Cathy Beck/ Sirenia, US Geological Survey
- Dr. Bob Bonde/ Sirenia, US Geological Survey
- Susan Butler/ Sirenia, US Geological Survey
- Melissa Charbonneau/ St. Martins Marsh and Big Bend Seagrasses Aquatic Preserve. Florida Dept of Environmental Protection,
- Jonathan Brucker/ St. Martins Marsh and Big Bend Seagrasses Aquatic Preserve. Florida Dept of Environmental Protection
- Timothy Jones/ St. Martins Marsh and Big Bend Seagrasses Aquatic Preserve. Florida Dept of Environmental Protection
- Robert Day/Indian River Lagoon National Estuary Program
- Dr. Dennis Hanisak/Harbor Branch Oceanographic Institute - Florida Atlantic University
- Marilyn Mazzoil/Harbor Branch Oceanographic Institute - Florida Atlantic University
- Monica Ross/Sea2Shore Alliance

- Nicole Adimey/ US Fish and Wildlife Service
- Ron Clarke /Wetland Solutions, Inc.
- Dr. Tom Fraser/ Water Institute, University of Florida,
- Tim Harris/US Army Corps of Engineers, Palatka, Florida.
- Mr. Eric Pitard/Kayak Shack, Weeki Wachee, Florida
- Judy Ott/Charlotte Harbor National Estuary Program
- Dr. Judson Kenworthy/NOAA

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APPENDIX

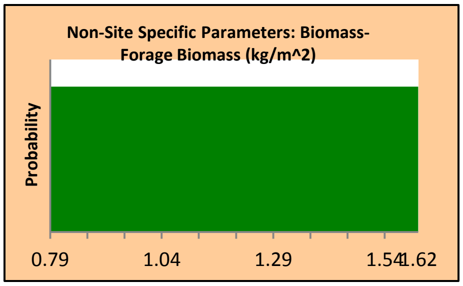
Appendix Section 1a.

Distribution Curves for Assessments

Assumption: Non-Site Specific Parameters: Biomass- Forage Biomass (kg/m^2)

Uniform distribution with parameters:

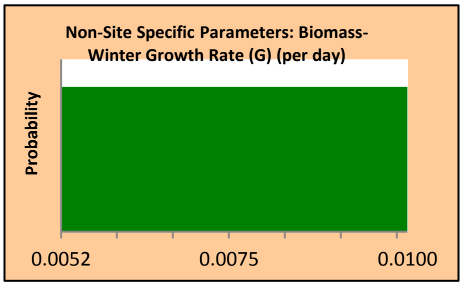
Minimum	0.79
Maximum	1.62



Assumption: Non-Site Specific Parameters: Biomass- Winter Growth Rate (G) (per day)

Uniform distribution with parameters:

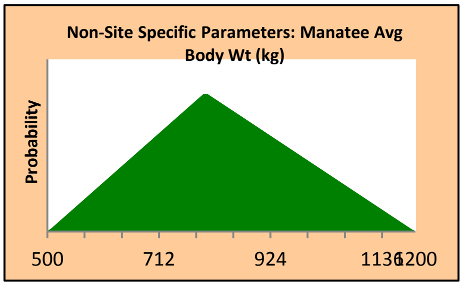
Minimum	0.0052
Maximum	0.0100



Assumption: Non-Site Specific Parameters: Manatee Avg Body Wt (kg)

Triangular distribution with parameters:

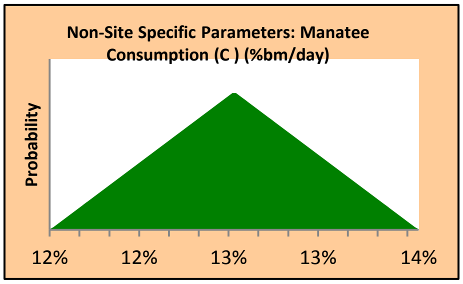
Minimum	500
Likeliest	800
Maximum	1200



Assumption: Non-Site Specific Parameters: Manatee Consumption (C) (%bm/day)

Triangular distribution with parameters:

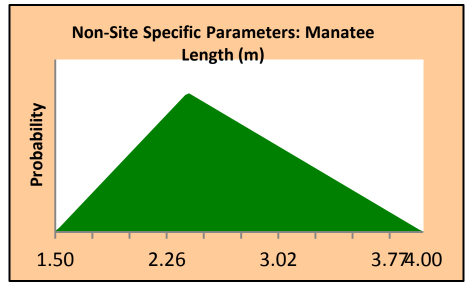
Minimum	12%
Likeliest	13%
Maximum	14%



Assumption: Non-Site Specific Parameters: Manatee Length (m)

Triangular distribution with parameters:

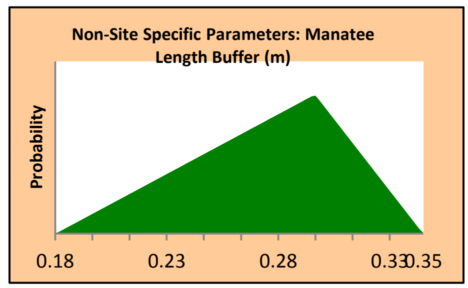
Minimum	1.50
Likeliest	2.40
Maximum	4.00



Assumption: Non-Site Specific Parameters: Manatee Length Buffer (m)

Triangular distribution with parameters:

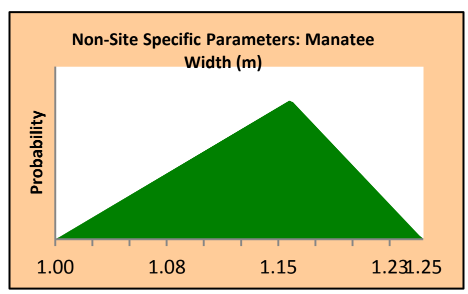
Minimum	0.18
Likeliest	0.30
Maximum	0.35



Assumption: Non-Site Specific Parameters: Manatee Width (m)

Triangular distribution with parameters:

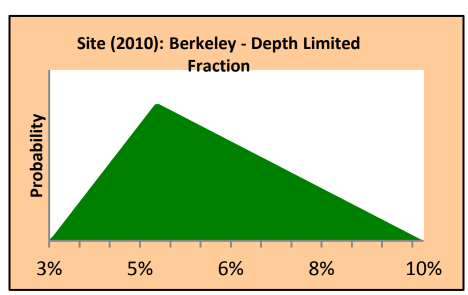
Minimum	1.00
Likeliest	1.16
Maximum	1.25



Assumption: Site (2010): Berkeley - Depth Limited Fraction

Triangular distribution with parameters:

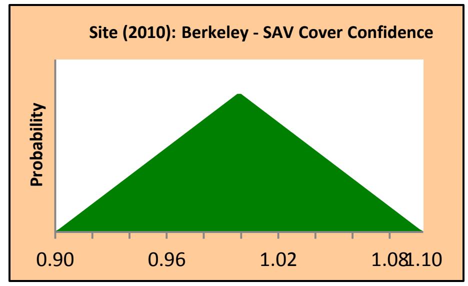
Minimum	3%
Likeliest	5%
Maximum	10%



Assumption: Site (2010): Berkeley - SAV Cover Confidence

Triangular distribution with parameters:

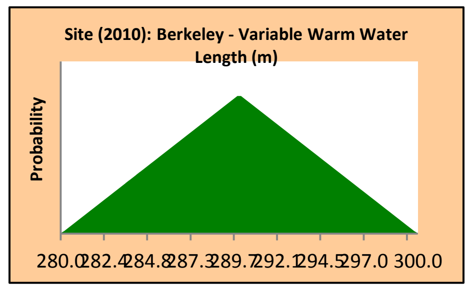
Minimum	0.90
Likeliest	1.00
Maximum	1.10



Assumption: Site (2010): Berkeley - Variable Warm Water Length (m)

Triangular distribution with parameters:

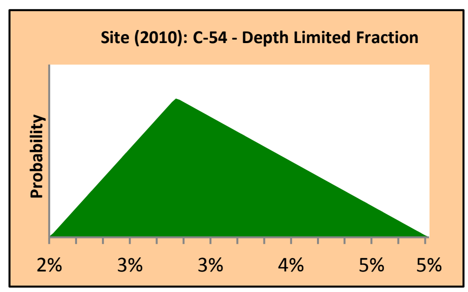
Minimum	280.0
Likeliest	290.0
Maximum	300.0



Assumption: Site (2010): C-54 - Depth Limited Fraction

Triangular distribution with parameters:

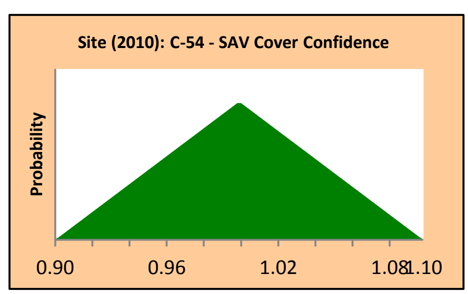
Minimum	2%
Likeliest	3%
Maximum	5%



Assumption: Site (2010): C-54 - SAV Cover Confidence

Triangular distribution with parameters:

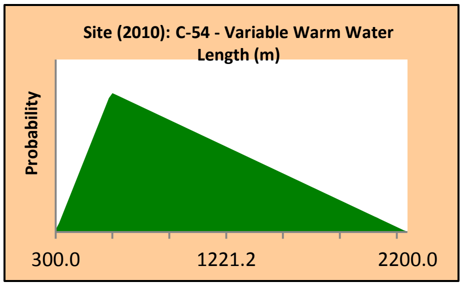
Minimum	0.90
Likeliest	1.00
Maximum	1.10



Assumption: Site (2010): C-54 - Variable Warm Water Length (m)

Triangular distribution with parameters:

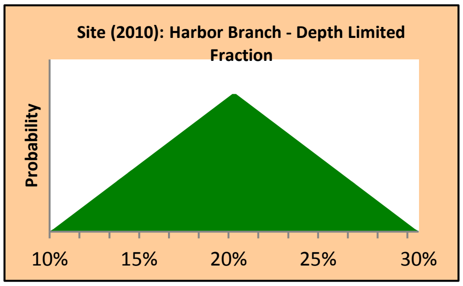
Minimum	300.0
Likeliest	600.0
Maximum	2200.0



Assumption: Site (2010): Harbor Branch - Depth Limited Fraction

Triangular distribution with parameters:

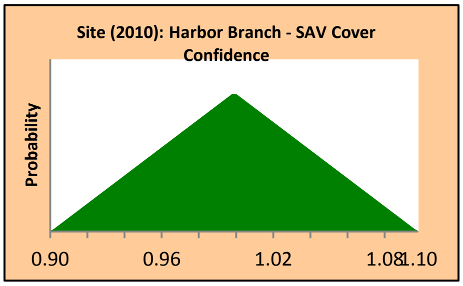
Minimum	10%
Likeliest	20%
Maximum	30%



Assumption: Site (2010): Harbor Branch - SAV Cover Confidence

Triangular distribution with parameters:

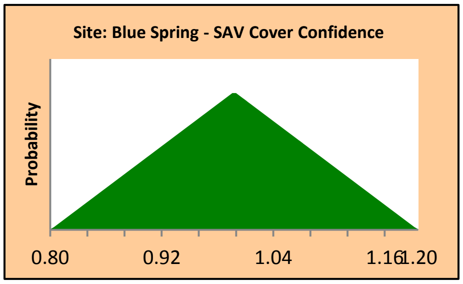
Minimum	0.90
Likeliest	1.00
Maximum	1.10



Assumption: Site: Blue Spring - SAV Cover Confidence

Triangular distribution with parameters:

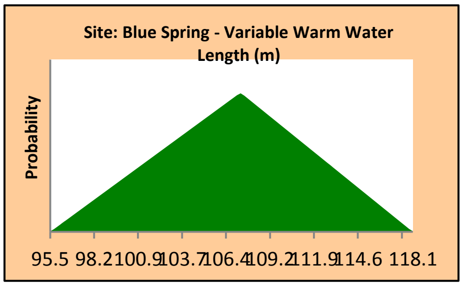
Minimum	0.80
Likeliest	1.00
Maximum	1.20



Assumption: Site: Blue Spring - Variable Warm Water Length (m)

Triangular distribution with parameters:

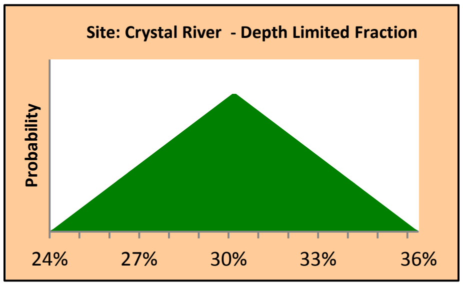
Minimum	95.5
Likeliest	107.3
Maximum	118.1



Assumption: Site: Crystal River - Depth Limited Fraction

Triangular distribution with parameters:

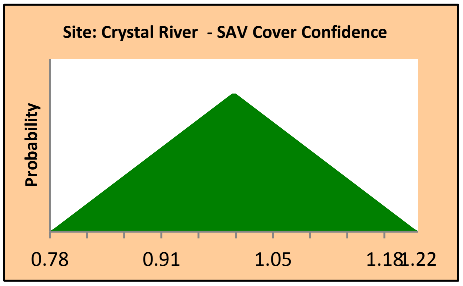
Minimum	24%
Likeliest	30%
Maximum	36%



Assumption: Site: Crystal River - SAV Cover Confidence

Triangular distribution with parameters:

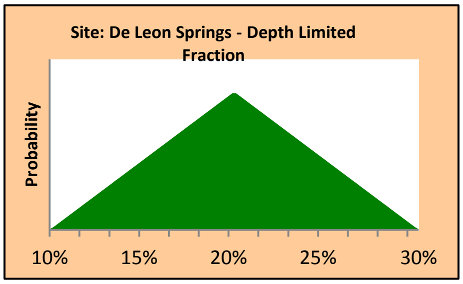
Minimum	0.78
Likeliest	1.00
Maximum	1.22



Assumption: Site: De Leon Springs - Depth Limited Fraction

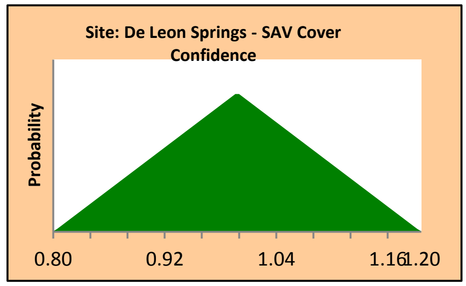
Triangular distribution with parameters:

Minimum	10%
Likeliest	20%
Maximum	30%



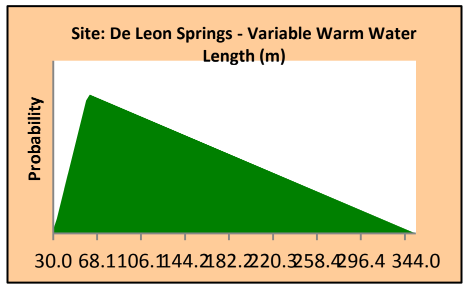
Assumption: Site: De Leon Springs - SAV Cover Confidence

Triangular distribution with parameters:	
Minimum	0.80
Likeliest	1.00
Maximum	1.20



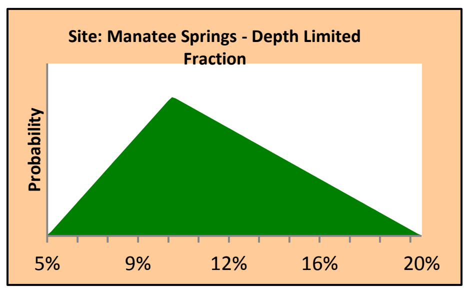
Assumption: Site: De Leon Springs - Variable Warm Water Length (m)

Triangular distribution with parameters:	
Minimum	30.0
Likeliest	60.0
Maximum	344.0



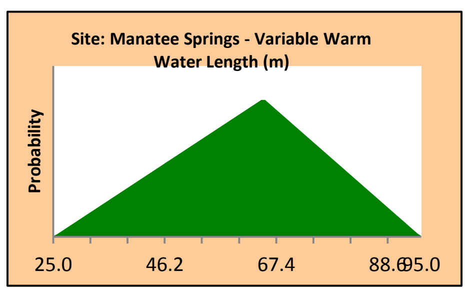
Assumption: Site: Manatee Springs - Depth Limited Fraction

Triangular distribution with parameters:	
Minimum	5%
Likeliest	10%
Maximum	20%



Assumption: Site: Manatee Springs - Variable Warm Water Length (m)

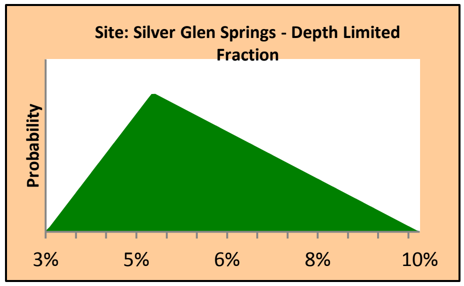
Triangular distribution with parameters:	
Minimum	25.0
Likeliest	65.0
Maximum	95.0



Assumption: Site: Silver Glen Springs - Depth Limited Fraction

Triangular distribution with parameters:

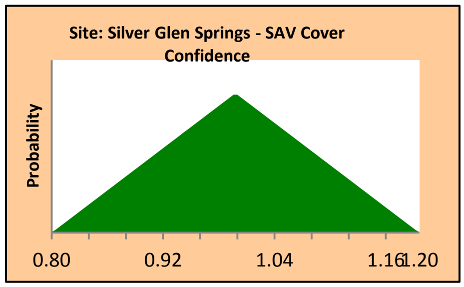
Minimum	3%
Likeliest	5%
Maximum	10%



Assumption: Site: Silver Glen Springs - SAV Cover Confidence

Triangular distribution with parameters:

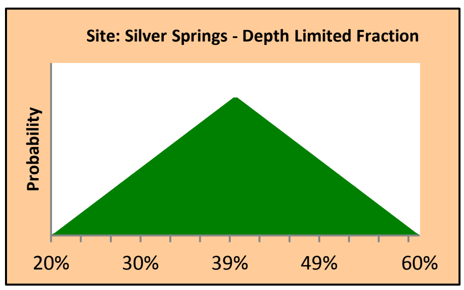
Minimum	0.80
Likeliest	1.00
Maximum	1.20



Assumption: Site: Silver Springs - Depth Limited Fraction

Triangular distribution with parameters:

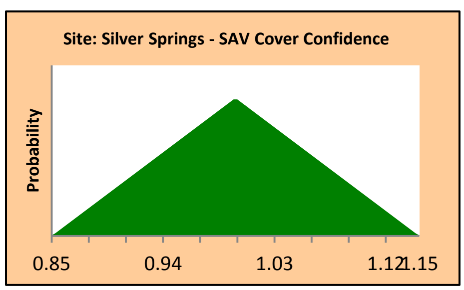
Minimum	20%
Likeliest	40%
Maximum	60%



Assumption: Site: Silver Springs - SAV Cover Confidence

Triangular distribution with parameters:

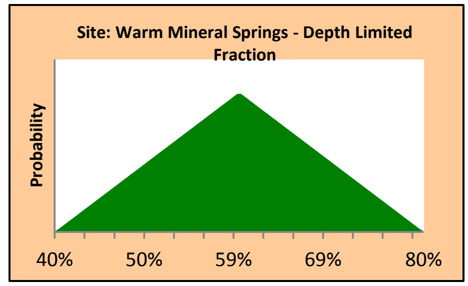
Minimum	0.85
Likeliest	1.00
Maximum	1.15



Assumption: Site: Warm Mineral Springs - Depth Limited Fraction

Triangular distribution with parameters:

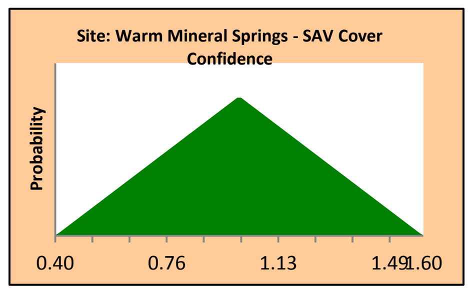
Minimum	40%
Likeliest	60%
Maximum	80%



Assumption: Site: Warm Mineral Springs - SAV Cover Confidence

Triangular distribution with parameters:

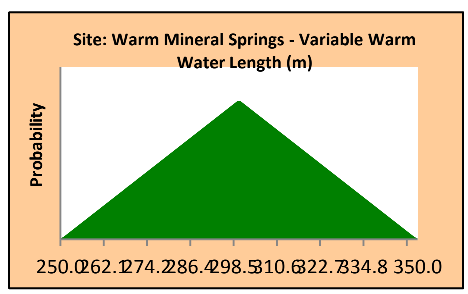
Minimum	0.40
Likeliest	1.00
Maximum	1.60



Assumption: Site: Warm Mineral Springs - Variable Warm Water Length (m)

Triangular distribution with parameters:

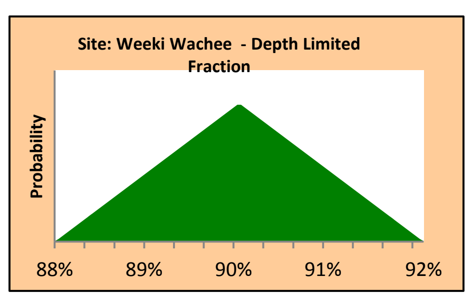
Minimum	250.0
Likeliest	300.0
Maximum	350.0



Assumption: Site: Weeki Wachee - Depth Limited Fraction

Triangular distribution with parameters:

Minimum	88%
Likeliest	90%

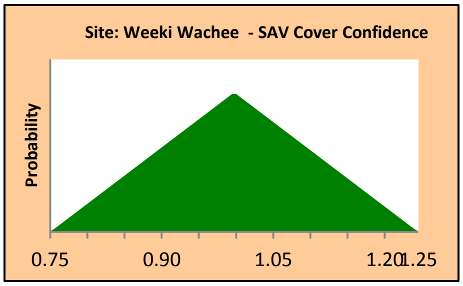


Maximum 92%

Assumption: Site: Weeki Wachee - SAV Cover Confidence

Triangular distribution with parameters:

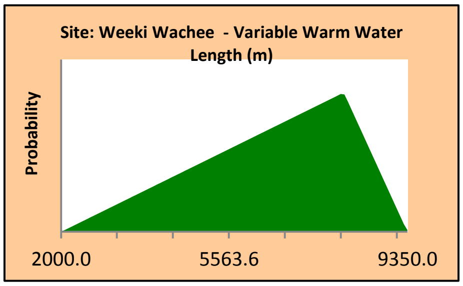
Minimum	0.75
Likeliest	1.00
Maximum	1.25



Assumption: Site: Weeki Wachee - Variable Warm Water Length (m)

Triangular distribution with parameters:

Minimum	2000.0
Likeliest	8000.0
Maximum	9350.0



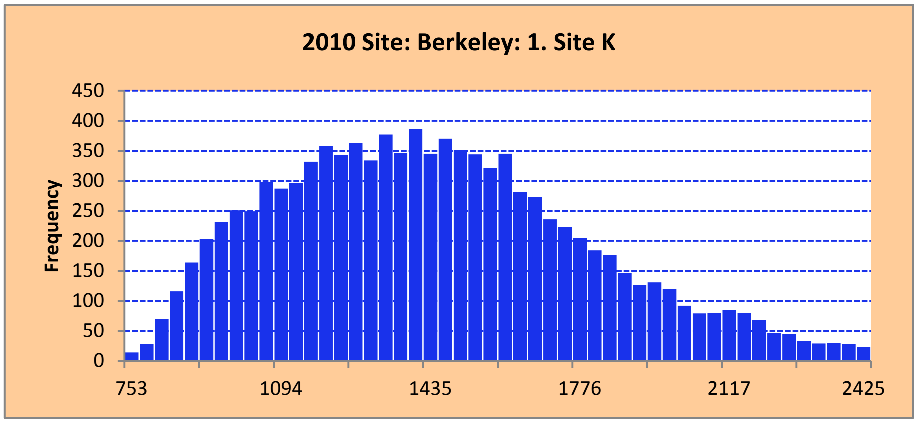
Appendix Section 1b.

Forecasts for Site-K and Forage-K at Eleven Sites

Forecasts

Forecast: 2010 Site: Berkeley: 1. Site-K

Summary:
Entire range is from 736 to 2836
Base case is 1676
After 10,000 trials, the std. error of the mean is 4



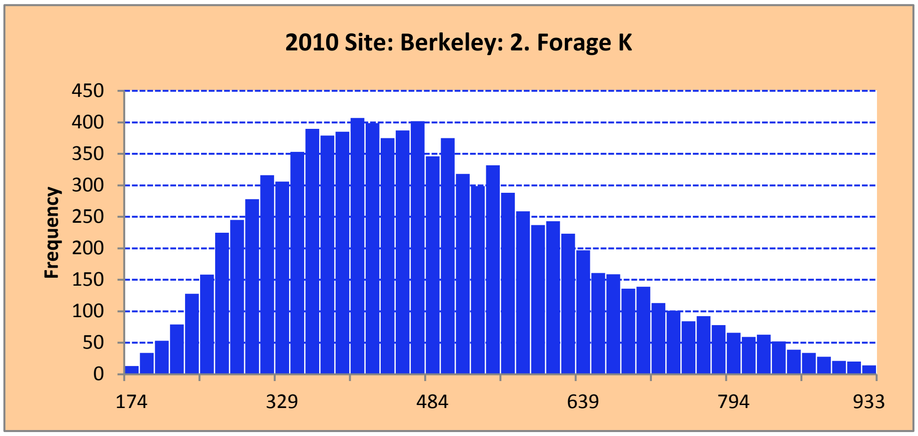
Statistics:	Forecast values
Trials	10,000
Mean	1445
Median	1414
Mode	---
Standard Deviation	356
Variance	126707
Skewness	0.5104
Kurtosis	2.90
Coeff. of Variability	0.2463
Minimum	736
Maximum	2836
Range Width	2101
Mean Std. Error	4

Forecast: 2010 Site: Berkeley: 1. Site-K (cont'd)

Percentiles:	Forecast values
0%	736
10%	1000
20%	1121
30%	1223
40%	1322
50%	1414
60%	1509
70%	1610
80%	1738
90%	1936
100%	2836

Forecast: 2010 Site: Berkeley: 2. Forage-K

Summary:
Entire range is from 166 to 1419
Base case is 296
After 10,000 trials, the std. error of the mean is 2



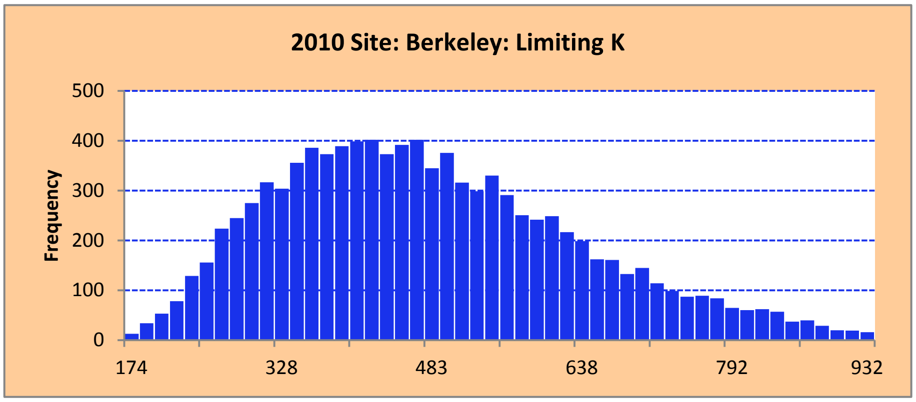
Statistics:	Forecast values
Trials	10,000
Mean	486
Median	464
Mode	---
Standard Deviation	163
Variance	26456
Skewness	0.7629
Kurtosis	3.64
Coeff. of Variability	0.3349
Minimum	166
Maximum	1419
Range Width	1253
Mean Std. Error	2

Forecast: 2010 Site: Berkeley: 2. Forage-K (cont'd)

Percentiles:	Forecast values
0%	166
10%	294
20%	344
30%	385
40%	424
50%	464
60%	506
70%	555
80%	615
90%	706
100%	1419

Forecast: 2010 Site: Berkeley: Limiting K

Summary:
Entire range is from 166 to 1419
Base case is 296
After 10,000 trials, the std. error of the mean is 2



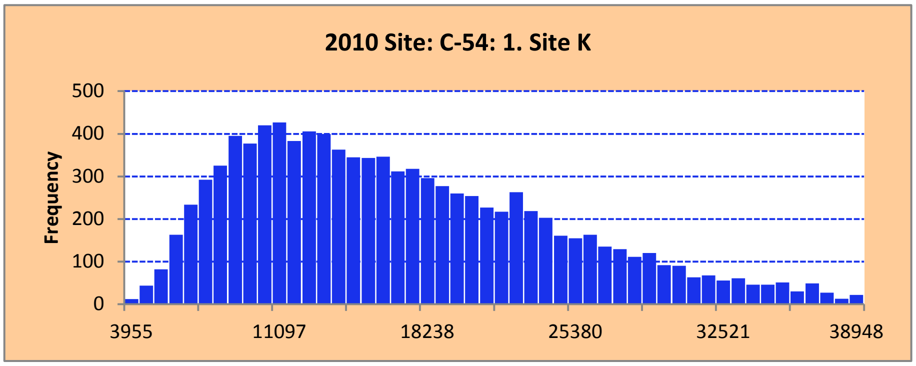
Statistics:	Forecast values
Trials	10,000
Mean	485
Median	464
Mode	---
Standard Deviation	162
Variance	26288
Skewness	0.7441
Kurtosis	3.57
Coeff. of Variability	0.3340
Minimum	166
Maximum	1419
Range Width	1253
Mean Std. Error	2

Forecast: 2010 Site: Berkeley: Limiting K (cont'd)

Percentiles:	Forecast values
0%	166
10%	294
20%	344
30%	385
40%	424
50%	464
60%	506
70%	555
80%	615
90%	706
100%	1419

Forecast: 2010 Site: C-54: 1. Site-K

Summary:
Entire range is from 3598 to 56936
Base case is 11274
After 10,000 trials, the std. error of the mean is 79



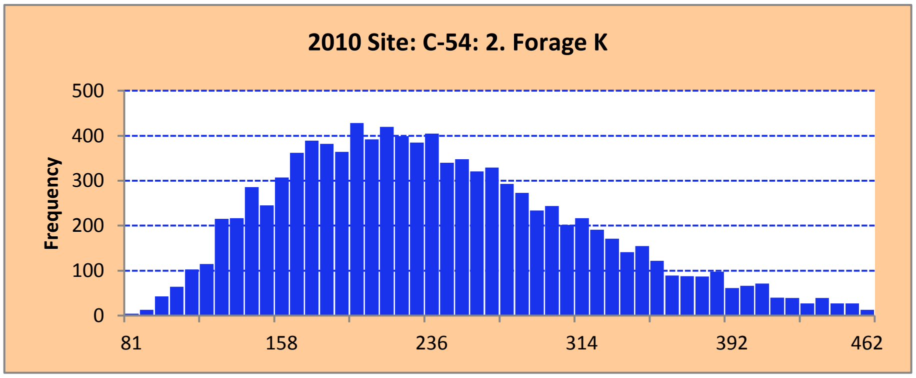
Statistics:	Forecast values
Trials	10,000
Mean	17176
Median	15714
Mode	---
Standard Deviation	7903
Variance	62465093
Skewness	0.8718
Kurtosis	3.57
Coeff. of Variability	0.4602
Minimum	3598
Maximum	56936
Range Width	53338
Mean Std. Error	79

Forecast: 2010 Site: C-54: 1. Site-K (cont'd)

Percentiles:	Forecast values
0%	3598
10%	8237
20%	10186
30%	11878
40%	13666
50%	15713
60%	17904
70%	20507
80%	23593
90%	28152
100%	56936

Forecast: 2010 Site: C-54: 2. Forage-K

Summary:
Entire range is from 77 to 640
Base case is 147
After 10,000 trials, the std. error of the mean is 1



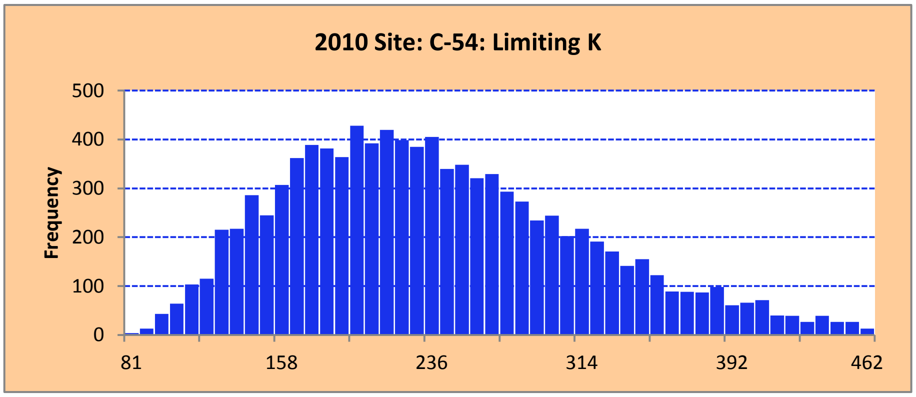
Statistics:	Forecast values
Trials	10,000
Mean	241
Median	230
Mode	---
Standard Deviation	80
Variance	6448
Skewness	0.7445
Kurtosis	3.53
Coeff. of Variability	0.3338
Minimum	77
Maximum	640
Range Width	564
Mean Std. Error	1

Forecast: 2010 Site: C-54: 2. Forage-K (cont'd)

Percentiles:	Forecast values
0%	77
10%	145
20%	171
30%	191
40%	210
50%	230
60%	250
70%	274
80%	305
90%	349
100%	640

Forecast: 2010 Site: C-54: Limiting K

Summary:
Entire range is from 77 to 640
Base case is 147
After 10,000 trials, the std. error of the mean is 1



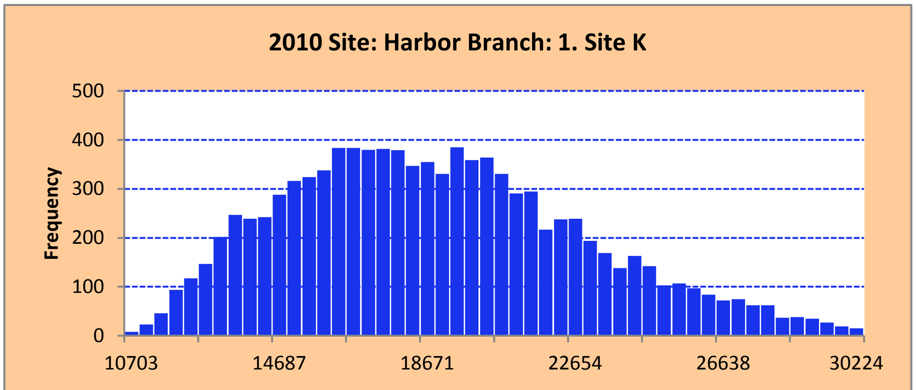
Statistics:	Forecast values
Trials	10,000
Mean	241
Median	230
Mode	---
Standard Deviation	80
Variance	6448
Skewness	0.7445
Kurtosis	3.53
Coeff. of Variability	0.3338
Minimum	77
Maximum	640
Range Width	564
Mean Std. Error	1

Forecast: 2010 Site: C-54: Limiting K (cont'd)

Percentiles:	Forecast values
0%	77
10%	145
20%	171
30%	191
40%	210
50%	230
60%	250
70%	274
80%	305
90%	349
100%	640

Forecast: 2010 Site: Harbor Branch: 1. Site-K

Summary:
Entire range is from 10504 to 35733
Base case is 21412
After 10,000 trials, the std. error of the mean is 41



Statistics:	Forecast values
Trials	10,000
Mean	18979
Median	18599
Mode	---
Standard Deviation	4087
Variance	16705042
Skewness	0.5279
Kurtosis	2.99
Coeff. of Variability	0.2154
Minimum	10504
Maximum	35733
Range Width	25229
Mean Std. Error	41

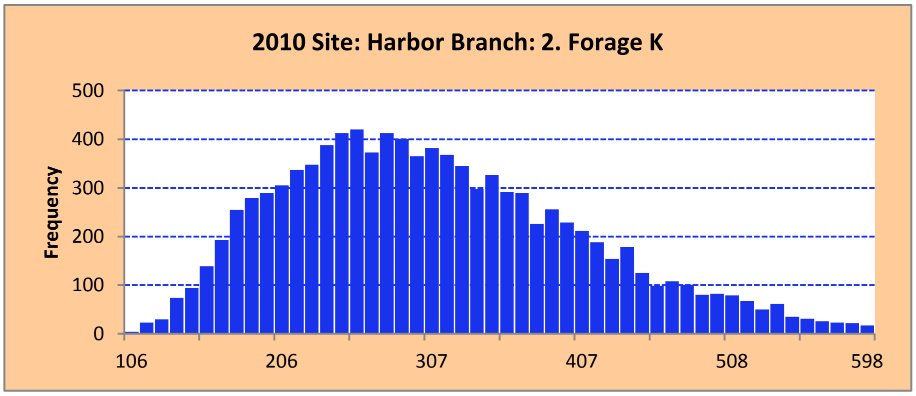
Forecast: 2010 Site: Harbor Branch: 1. Site-K (cont'd)

Percentiles:	Forecast values
0%	10504
10%	13885
20%	15315
30%	16468
40%	17520
50%	18598
60%	19713
70%	20849
80%	22368
90%	24556
100%	35733

Forecast: 2010 Site: Harbor Branch: 2. Forage-K

Summary:

Entire range is from 101 to 844
Base case is 190
After 10,000 trials, the std. error of the mean is 1



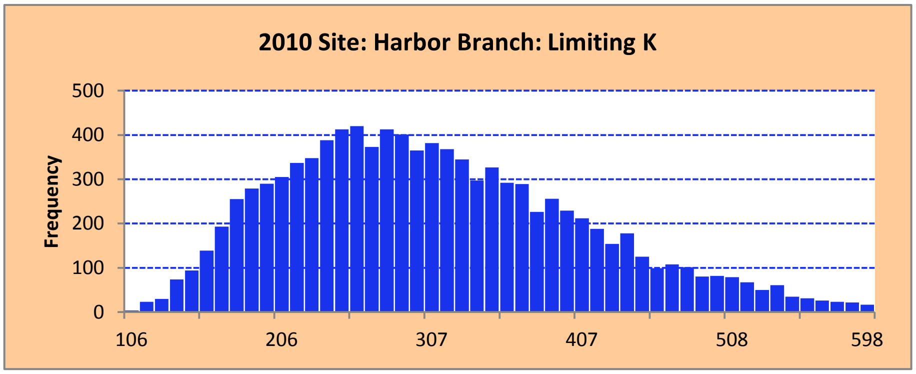
Statistics:	Forecast values
Trials	10,000
Mean	312
Median	298
Mode	---
Standard Deviation	104
Variance	10822
Skewness	0.7552
Kurtosis	3.63
Coeff. of Variability	0.3338
Minimum	101
Maximum	844
Range Width	743
Mean Std. Error	1

Forecast: 2010 Site: Harbor Branch: 2. Forage-K (cont'd)

Percentiles:	Forecast values
0%	101
10%	189
20%	221
30%	247
40%	272
50%	298
60%	325
70%	356
80%	395
90%	451
100%	844

Forecast: 2010 Site: Harbor Branch: Limiting K

Summary:
Entire range is from 101 to 844
Base case is 190
After 10,000 trials, the std. error of the mean is 1



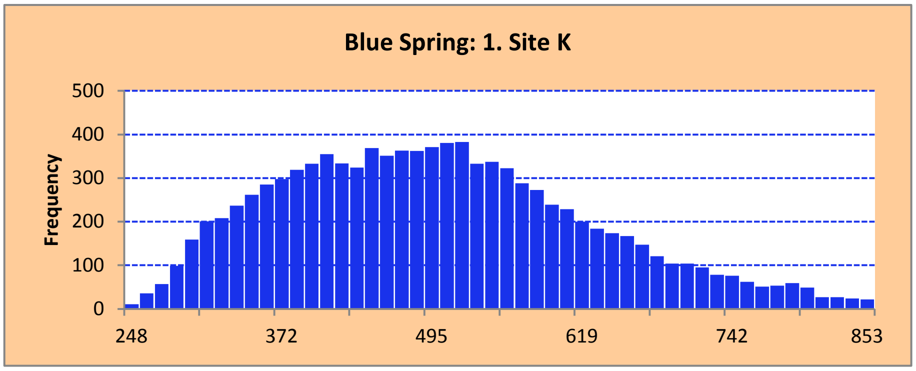
Statistics:	Forecast values
Trials	10,000
Mean	312
Median	298
Mode	---
Standard Deviation	104
Variance	10822
Skewness	0.7552
Kurtosis	3.63
Coeff. of Variability	0.3338
Minimum	101
Maximum	844
Range Width	743
Mean Std. Error	1

Forecast: 2010 Site: Harbor Branch: Limiting K (cont'd)

Percentiles:	Forecast values
0%	101
10%	189
20%	221
30%	247
40%	272
50%	298
60%	325
70%	356
80%	395
90%	451
100%	844

Forecast: Blue Spring: 1. Site-K

Summary:
Entire range is from 242 to 1008
Base case is 630
After 10,000 trials, the std. error of the mean is 1



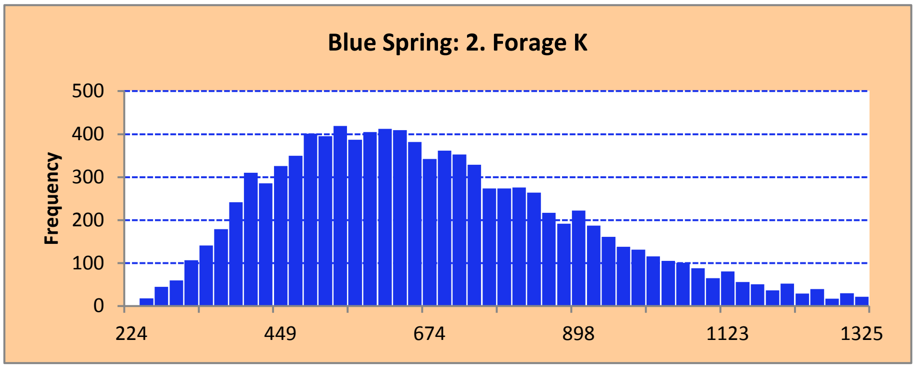
Statistics:	Forecast values
Trials	10,000
Mean	500
Median	491
Mode	---
Standard Deviation	128
Variance	16421
Skewness	0.5094
Kurtosis	2.90
Coeff. of Variability	0.2561
Minimum	242
Maximum	1008
Range Width	766
Mean Std. Error	1

Forecast: Blue Spring: 1. Site-K (cont'd)

Percentiles:	Forecast values
0%	242
10%	340
20%	384
30%	420
40%	456
50%	491
60%	523
70%	559
80%	605
90%	674
100%	1008

Forecast: Blue Spring: 2. Forage-K

Summary:
Entire range is from 213 to 1819
Base case is 416
After 10,000 trials, the std. error of the mean is 2



Statistics:	Forecast values
Trials	10,000
Mean	681
Median	646
Mode	---
Standard Deviation	234
Variance	54766
Skewness	0.7945
Kurtosis	3.64
Coeff. of Variability	0.3434
Minimum	213
Maximum	1819
Range Width	1606
Mean Std. Error	2

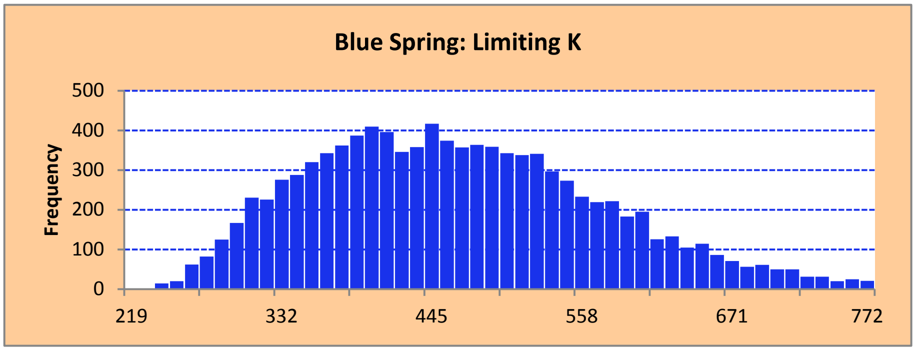
Forecast: Blue Spring: 2. Forage-K (cont'd)

Percentiles:	Forecast values
0%	213
10%	408
20%	479
30%	535
40%	591
50%	646
60%	709
70%	781
80%	869
90%	1000
100%	1819

Forecast: Blue Spring: Limiting K

Summary:
Entire range is from 213 to 933

Base case is 416
After 10,000 trials, the std. error of the mean is 1



Statistics:	Forecast values
Trials	10,000
Mean	466
Median	456
Mode	---
Standard Deviation	111
Variance	12425
Skewness	0.5491
Kurtosis	3.08
Coeff. of Variability	0.2392
Minimum	213
Maximum	933
Range Width	720
Mean Std. Error	1

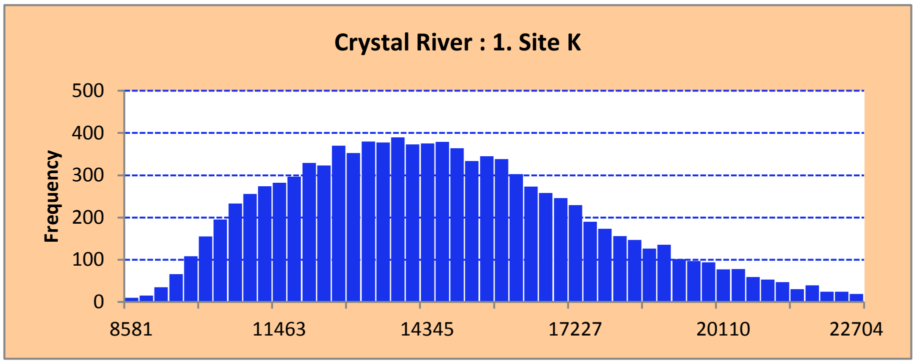
Forecast: Blue Spring: Limiting K (cont'd)

Percentiles:	Forecast values
0%	213
10%	329
20%	366
30%	396
40%	426
50%	456
60%	486
70%	519
80%	558
90%	614
100%	933

Forecast: Crystal River : 1. Site-K

Summary:
Entire range is from 8437 to 26018
Base case is 16409

After 10,000 trials, the std. error of the mean is 29



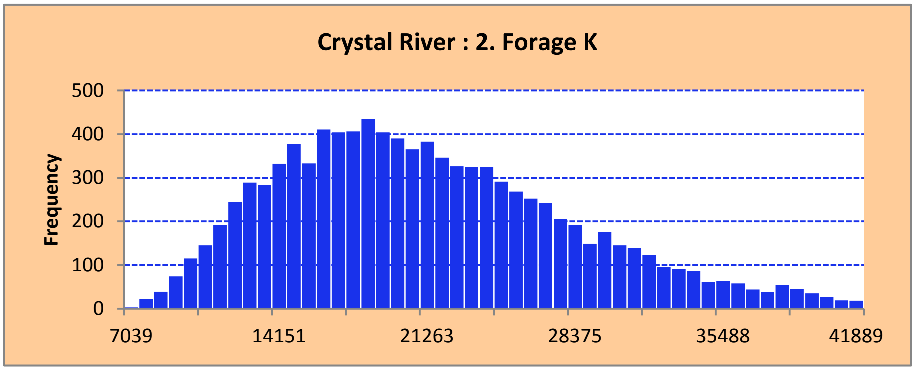
Statistics:	Forecast values
Trials	10,000
Mean	14613
Median	14336
Mode	---
Standard Deviation	2941
Variance	8649886
Skewness	0.5178
Kurtosis	2.93
Coeff. of Variability	0.2013
Minimum	8437
Maximum	26018
Range Width	17581
Mean Std. Error	29

Forecast: Crystal River : 1. Site-K (cont'd)

Percentiles:	Forecast values
0%	8437
10%	10947
20%	11952
30%	12794
40%	13585
50%	14336
60%	15116
70%	15985
80%	17041
90%	18672
100%	26018

Forecast: Crystal River : 2. Forage-K

Summary:
Entire range is from 6683 to 57842
Base case is 13089
After 10,000 trials, the std. error of the mean is 74



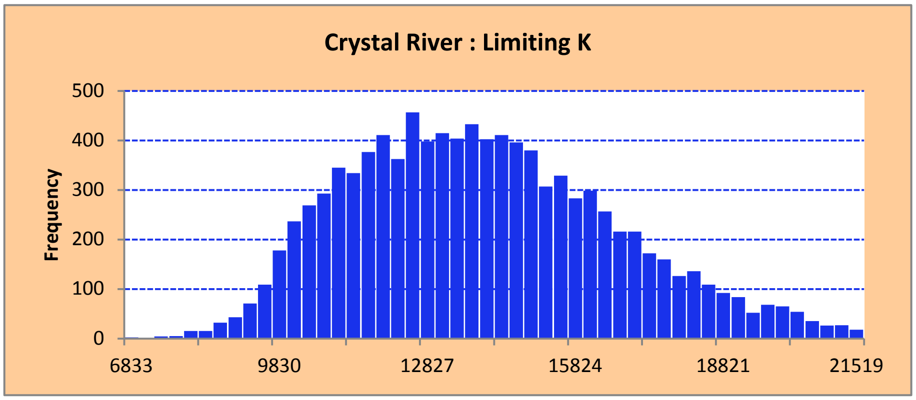
Statistics:	Forecast values
Trials	10,000
Mean	21467
Median	20390
Mode	---
Standard Deviation	7420
Variance	55063686
Skewness	0.8244
Kurtosis	3.83
Coeff. of Variability	0.3457
Minimum	6683
Maximum	57842
Range Width	51159
Mean Std. Error	74

Forecast: Crystal River : 2. Forage-K (cont'd)

Percentiles:	Forecast values
0%	6683
10%	12820
20%	14990
30%	16909
40%	18580
50%	20388
60%	22361
70%	24534
80%	27254
90%	31423
100%	57842

Forecast: Crystal River : Limiting K

Summary:
Entire range is from 6683 to 24726
Base case is 13089
After 10,000 trials, the std. error of the mean is 27



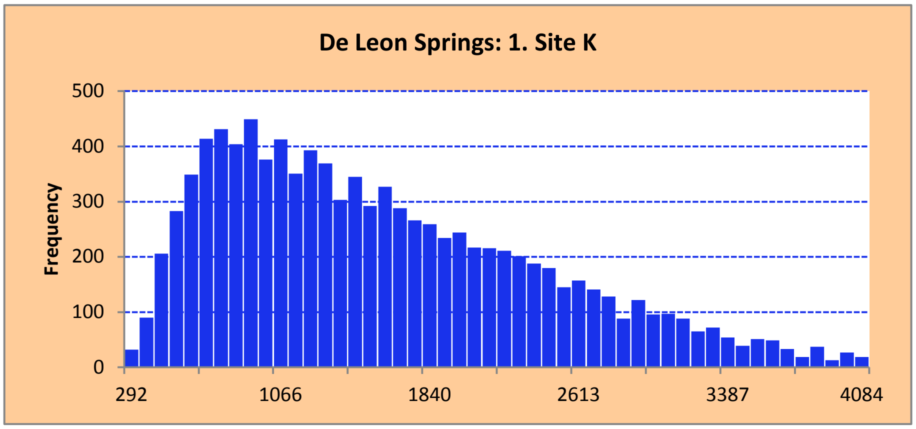
Statistics:	Forecast values
Trials	10,000
Mean	13973
Median	13725
Mode	---
Standard Deviation	2748
Variance	7553392
Skewness	0.5016
Kurtosis	3.00
Coeff. of Variability	0.1967
Minimum	6683
Maximum	24726
Range Width	18043
Mean Std. Error	27

Forecast: Crystal River : Limiting K (cont'd)

Percentiles:	Forecast values
0%	6683
10%	10595
20%	11516
30%	12291
40%	13007
50%	13725
60%	14454
70%	15261
80%	16250
90%	17691
100%	24726

Forecast: De Leon Springs: 1. Site-K

Summary:
Entire range is from 253 to 6194
Base case is 762
After 10,000 trials, the std. error of the mean is 9



Statistics:	Forecast values
Trials	10,000
Mean	1628
Median	1445
Mode	---
Standard Deviation	891
Variance	793498
Skewness	0.9553
Kurtosis	3.74
Coeff. of Variability	0.5471
Minimum	253
Maximum	6194
Range Width	5941
Mean Std. Error	9

Forecast: De Leon Springs: 1. Site-K (cont'd)

Percentiles:	Forecast values
0%	253
10%	647
20%	831
30%	1018
40%	1221
50%	1445
60%	1693
70%	1998
80%	2355
90%	2894
100%	6194

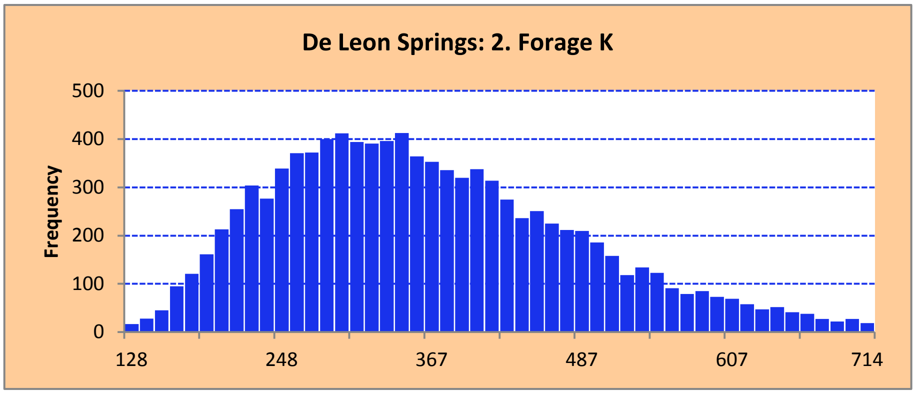
Forecast: De Leon Springs: 2. Forage-K

Summary:

Entire range is from 122 to 1059

Base case is 224

After 10,000 trials, the std. error of the mean is 1



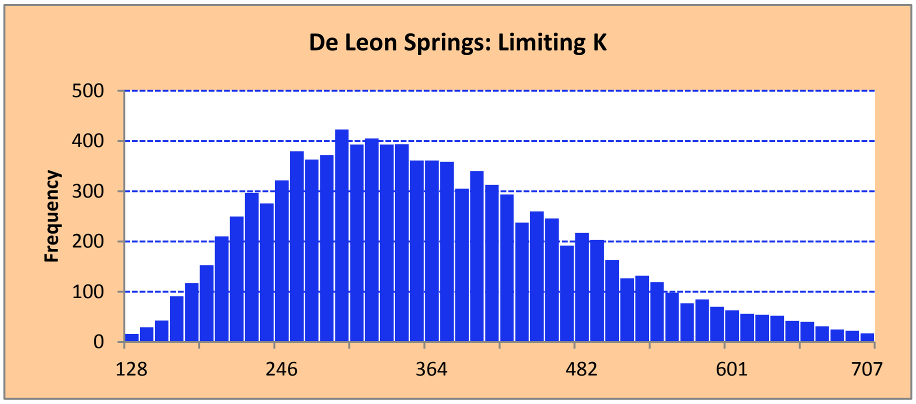
Statistics:	Forecast values
Trials	10,000
Mean	368
Median	349
Mode	---
Standard Deviation	126
Variance	15857
Skewness	0.7977
Kurtosis	3.73
Coeff. of Variability	0.3424
Minimum	122
Maximum	1059
Range Width	937
Mean Std. Error	1

Forecast: De Leon Springs: 2. Forage-K (cont'd)

Percentiles:	Forecast values
0%	122
10%	221
20%	259
30%	290
40%	320
50%	349
60%	383
70%	420
80%	468
90%	538
100%	1059

Forecast: De Leon Springs: Limiting K

Summary:
Entire range is from 122 to 1059
Base case is 224
After 10,000 trials, the std. error of the mean is 1



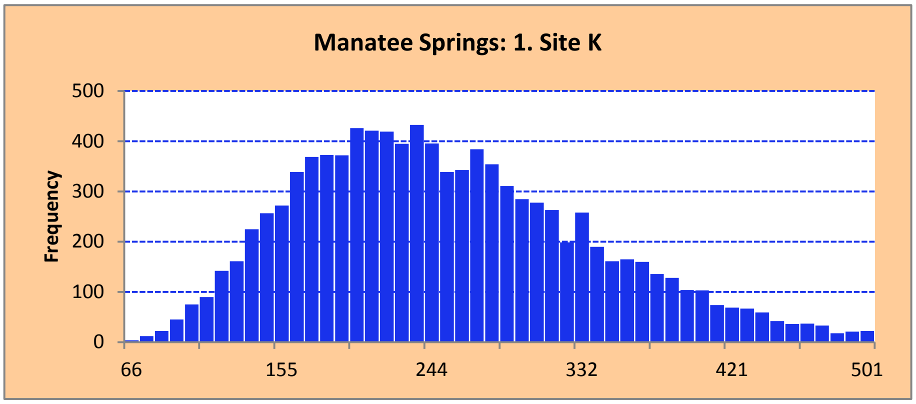
Statistics:	Forecast values
Trials	10,000
Mean	366
Median	349
Mode	---
Standard Deviation	124
Variance	15322
Skewness	0.7697
Kurtosis	3.67
Coeff. of Variability	0.3380
Minimum	122
Maximum	1059
Range Width	937
Mean Std. Error	1

Forecast: De Leon Springs: Limiting K (cont'd)

Percentiles:	Forecast values
0%	122
10%	221
20%	258
30%	289
40%	319
50%	349
60%	382
70%	419
80%	464
90%	533
100%	1059

Forecast: Manatee Springs: 1. Site-K

Summary:
Entire range is from 62 to 695
Base case is 315
After 10,000 trials, the std. error of the mean is 1



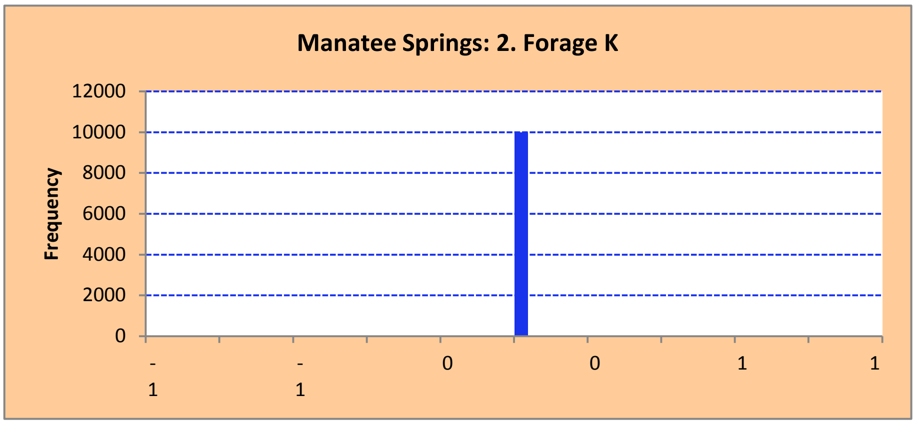
Statistics:	Forecast values
Trials	10,000
Mean	255
Median	243
Mode	---
Standard Deviation	90
Variance	8024
Skewness	0.7165
Kurtosis	3.53
Coeff. of Variability	0.3515
Minimum	62
Maximum	695
Range Width	633
Mean Std. Error	1

Forecast: Manatee Springs: 1. Site-K (cont'd)

Percentiles:	Forecast values
0%	62
10%	149
20%	177
30%	200
40%	221
50%	243
60%	267
70%	293
80%	328
90%	376
100%	695

Forecast: Manatee Springs: 2. Forage-K

Summary:
Entire range is from 0 to 0
Base case is 0
After 10,000 trials, the std. error of the mean is 0



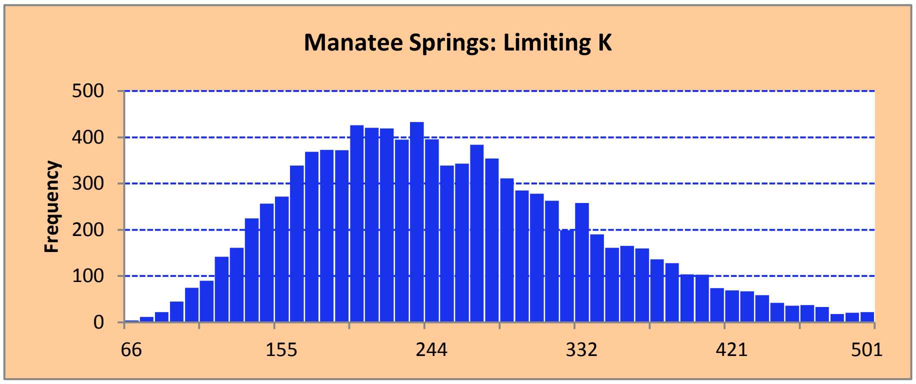
Statistics:	Forecast values
Trials	10,000
Mean	0
Median	0
Mode	0
Standard Deviation	0
Variance	0
Skewness	---
Kurtosis	---
Coeff. of Variability	---
Minimum	0
Maximum	0
Range Width	0
Mean Std. Error	0

Forecast: Manatee Springs: 2. Forage-K (cont'd)

Percentiles:	Forecast values
0%	0
10%	0
20%	0
30%	0
40%	0
50%	0
60%	0
70%	0
80%	0
90%	0
100%	0

Forecast: Manatee Springs: Limiting K

Summary:
Entire range is from 62 to 695
Base case is 315
After 10,000 trials, the std. error of the mean is 1



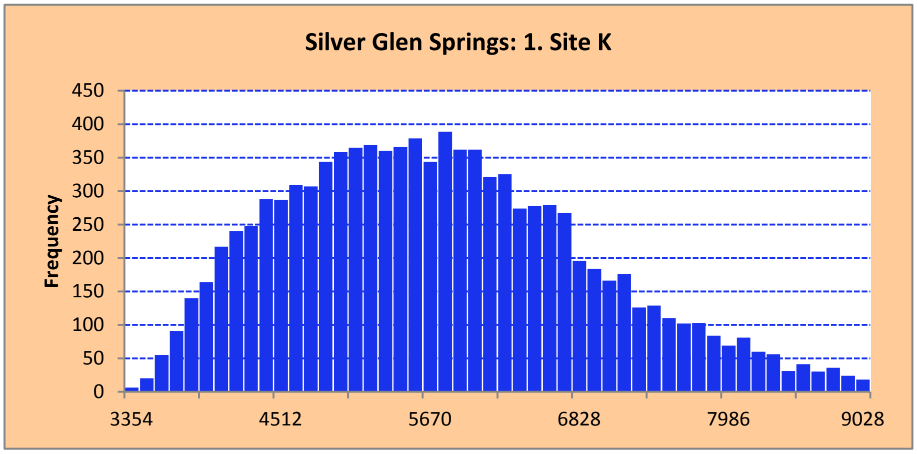
Statistics:	Forecast values
Trials	10,000
Mean	255
Median	243
Mode	---
Standard Deviation	90
Variance	8024
Skewness	0.7165
Kurtosis	3.53
Coeff. of Variability	0.3515
Minimum	62
Maximum	695
Range Width	633
Mean Std. Error	1

Forecast: Manatee Springs: Limiting K (cont'd)

Percentiles:	Forecast values
0%	62
10%	149
20%	177
30%	200
40%	221
50%	243
60%	267
70%	293
80%	328
90%	376
100%	695

Forecast: Silver Glen Springs: 1. Site-K

Summary:
Entire range is from 3296 to 10237
Base case is 6546
After 10,000 trials, the std. error of the mean is 12



Statistics:	Forecast values
Trials	10,000
Mean	5745
Median	5638
Mode	---
Standard Deviation	1193
Variance	1423852
Skewness	0.5088
Kurtosis	2.90
Coeff. of Variability	0.2077
Minimum	3296
Maximum	10237
Range Width	6941
Mean Std. Error	12

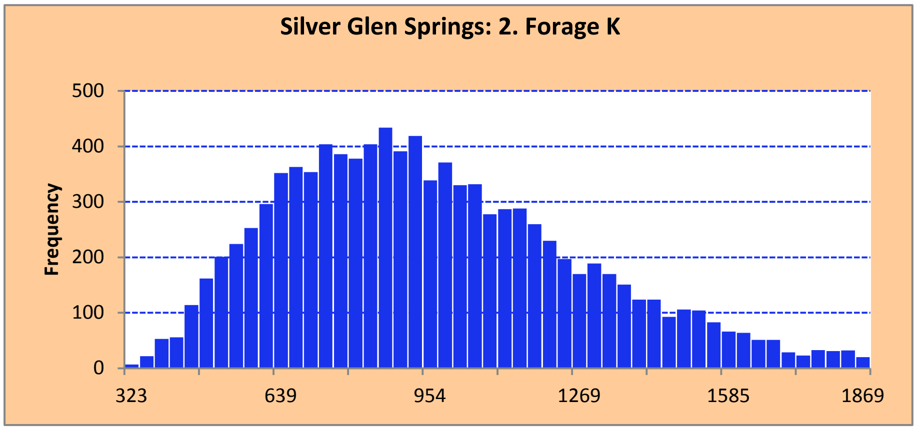
Forecast: Silver Glen Springs: 1. Site-K (cont'd)

Percentiles:	Forecast values
0%	3296
10%	4254
20%	4663
30%	5012
40%	5330
50%	5638
60%	5957
70%	6296
80%	6719
90%	7383

100%	10237

Forecast: Silver Glen Springs: 2. Forage-K

Summary:
Entire range is from 307 to 2754
Base case is 589
After 10,000 trials, the std. error of the mean is 3



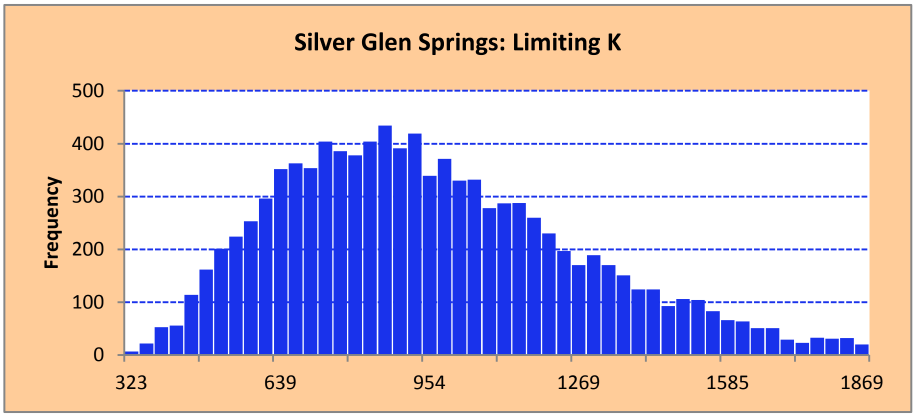
Statistics:	Forecast values
Trials	10,000
Mean	964
Median	917
Mode	---
Standard Deviation	329
Variance	107944
Skewness	0.7736
Kurtosis	3.67
Coeff. of Variability	0.3407
Minimum	307
Maximum	2754
Range Width	2446
Mean Std. Error	3

Forecast: Silver Glen Springs: 2. Forage-K (cont'd)

Percentiles:	Forecast values
0%	307
10%	580
20%	678
30%	760
40%	841
50%	917
60%	1003
70%	1103
80%	1224
90%	1413
100%	2754

Forecast: Silver Glen Springs: Limiting K

Summary:
Entire range is from 307 to 2754
Base case is 589
After 10,000 trials, the std. error of the mean is 3



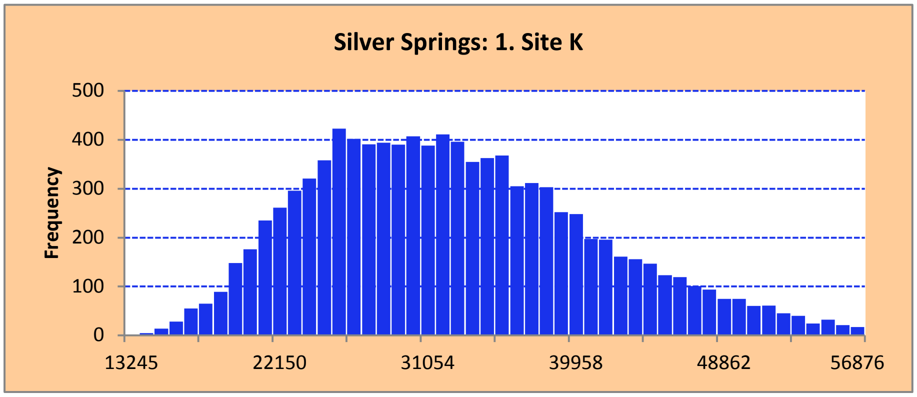
Statistics:	Forecast values
Trials	10,000
Mean	964
Median	917
Mode	---
Standard Deviation	329
Variance	107944
Skewness	0.7736
Kurtosis	3.67
Coeff. of Variability	0.3407
Minimum	307
Maximum	2754
Range Width	2446
Mean Std. Error	3

Forecast: Silver Glen Springs: Limiting K (cont'd)

Percentiles:	Forecast values
0%	307
10%	580
20%	678
30%	760
40%	841
50%	917
60%	1003
70%	1103
80%	1224
90%	1413
100%	2754

Forecast: Silver Springs: 1. Site-K

Summary:
Entire range is from 12800 to 71504
Base case is 37301
After 10,000 trials, the std. error of the mean is 88



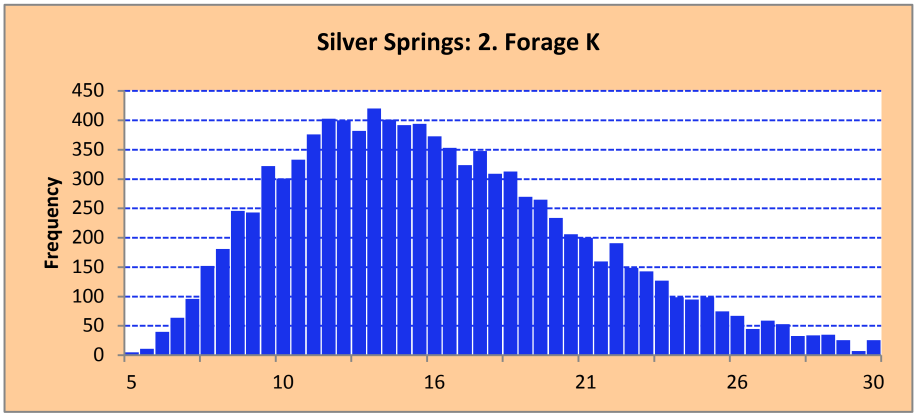
Statistics:	Forecast values
Trials	10,000
Mean	32801
Median	31827
Mode	---
Standard Deviation	8757
Variance	76689397
Skewness	0.6309
Kurtosis	3.28
Coeff. of Variability	0.2670
Minimum	12800
Maximum	71504
Range Width	58704
Mean Std. Error	88

Forecast: Silver Springs: 1. Site-K (cont'd)

Percentiles:	Forecast values
0%	12800
10%	22268
20%	25138
30%	27340
40%	29630
50%	31827
60%	34160
70%	36743
80%	39847
90%	44759
100%	71504

Forecast: Silver Springs: 2. Forage-K

Summary:
Entire range is from 5 to 43
Base case is 10
After 10,000 trials, the std. error of the mean is 0



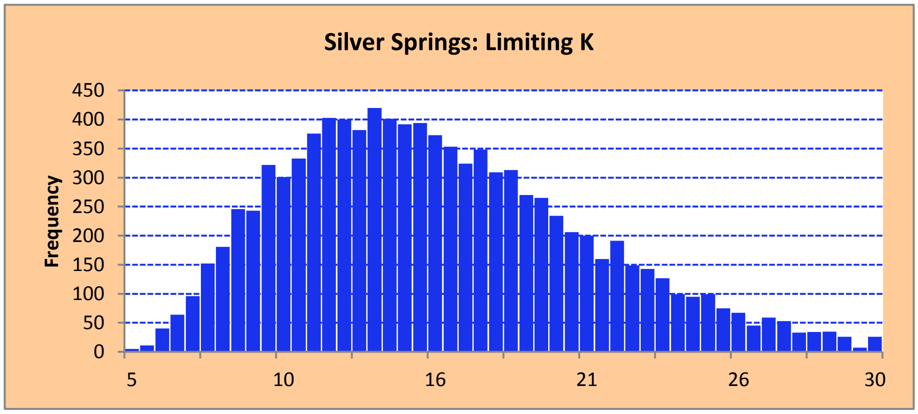
Statistics:	Forecast values
Trials	10,000
Mean	16
Median	15
Mode	---
Standard Deviation	5
Variance	28
Skewness	0.7623
Kurtosis	3.60
Coeff. of Variability	0.3370
Minimum	5
Maximum	43
Range Width	38
Mean Std. Error	0

Forecast: Silver Springs: 2. Forage-K (cont'd)

Percentiles:	Forecast values
0%	5
10%	10
20%	11
30%	12
40%	14
50%	15
60%	16
70%	18
80%	20
90%	23
100%	43

Forecast: Silver Springs: Limiting K

Summary:
Entire range is from 5 to 43
Base case is 10
After 10,000 trials, the std. error of the mean is 0



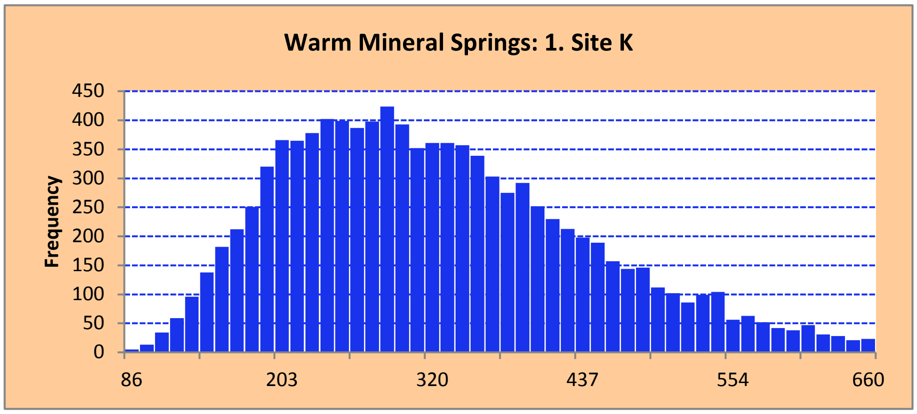
Statistics:	Forecast values
Trials	10,000
Mean	16
Median	15
Mode	---
Standard Deviation	5
Variance	28
Skewness	0.7623
Kurtosis	3.60
Coeff. of Variability	0.3370
Minimum	5
Maximum	43
Range Width	38
Mean Std. Error	0

Forecast: Silver Springs: Limiting K (cont'd)

Percentiles:	Forecast values
0%	5
10%	10
20%	11
30%	12
40%	14
50%	15
60%	16
70%	18
80%	20
90%	23
100%	43

Forecast: Warm Mineral Springs: 1. Site-K

Summary:
Entire range is from 80 to 922
Base case is 477
After 10,000 trials, the std. error of the mean is 1



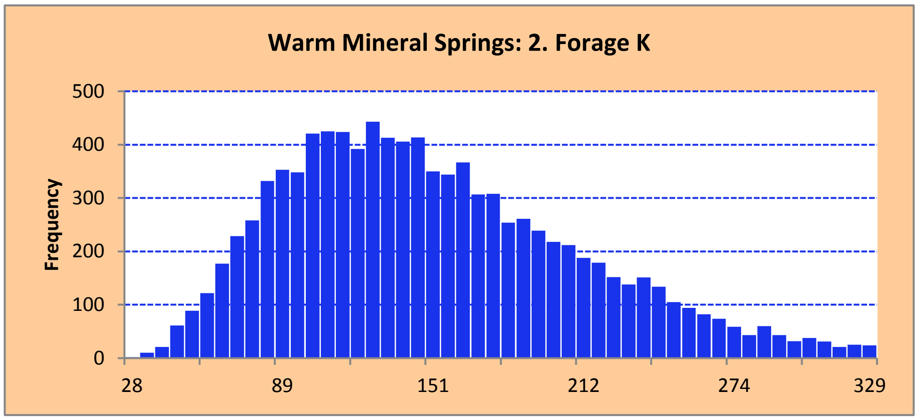
Statistics:	Forecast values
Trials	10,000
Mean	326
Median	308
Mode	---
Standard Deviation	121
Variance	14723
Skewness	0.7855
Kurtosis	3.63
Coeff. of Variability	0.3726
Minimum	80
Maximum	922
Range Width	842
Mean Std. Error	1

Forecast: Warm Mineral Springs: 1. Site-K (cont'd)

Percentiles:	Forecast values
0%	80
10%	186
20%	219
30%	249
40%	278
50%	308
60%	340
70%	376
80%	422
90%	490
100%	922

Forecast: Warm Mineral Springs: 2. Forage-K

Summary:
Entire range is from 25 to 505
Base case is 94
After 10,000 trials, the std. error of the mean is 1



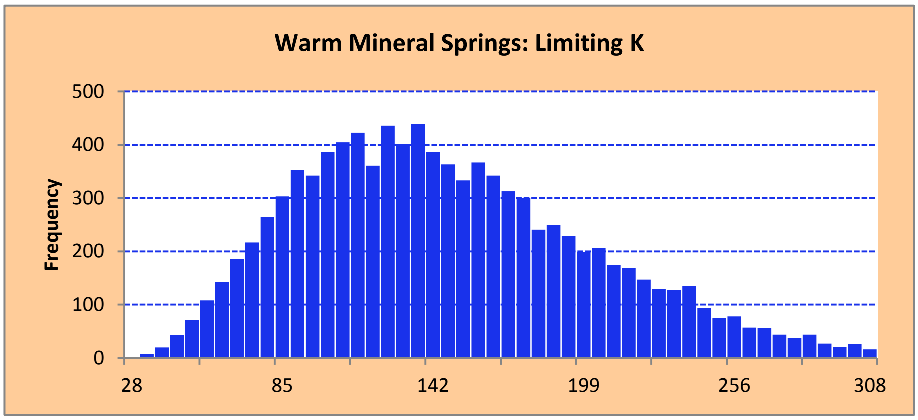
Statistics:	Forecast values
Trials	10,000
Mean	153
Median	143
Mode	---
Standard Deviation	64
Variance	4086
Skewness	0.9269
Kurtosis	4.15
Coeff. of Variability	0.4171
Minimum	25
Maximum	505
Range Width	480
Mean Std. Error	1

Forecast: Warm Mineral Springs: 2. Forage-K (cont'd)

Percentiles:	Forecast values
0%	25
10%	81
20%	99
30%	113
40%	128
50%	143
60%	160
70%	178
80%	204
90%	239
100%	505

Forecast: Warm Mineral Springs: Limiting K

Summary:
Entire range is from 25 to 472
Base case is 94
After 10,000 trials, the std. error of the mean is 1



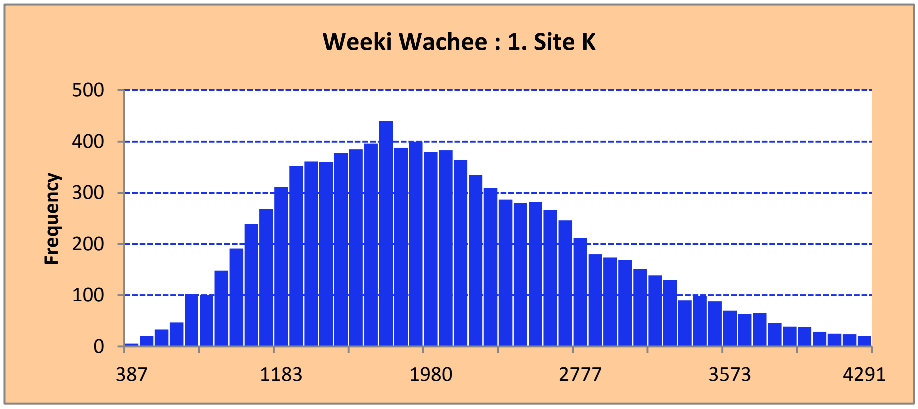
Statistics:	Forecast values
Trials	10,000
Mean	149
Median	141
Mode	---
Standard Deviation	58
Variance	3346
Skewness	0.7505
Kurtosis	3.68
Coeff. of Variability	0.3891
Minimum	25
Maximum	472
Range Width	447
Mean Std. Error	1

Forecast: Warm Mineral Springs: Limiting K (cont'd)

Percentiles:	Forecast values
0%	25
10%	81
20%	98
30%	113
40%	127
50%	141
60%	156
70%	173
80%	195
90%	228
100%	472

Forecast: Weeki Wachee : 1. Site-K

Summary:
Entire range is from 347 to 5605
Base case is 2976
After 10,000 trials, the std. error of the mean is 8



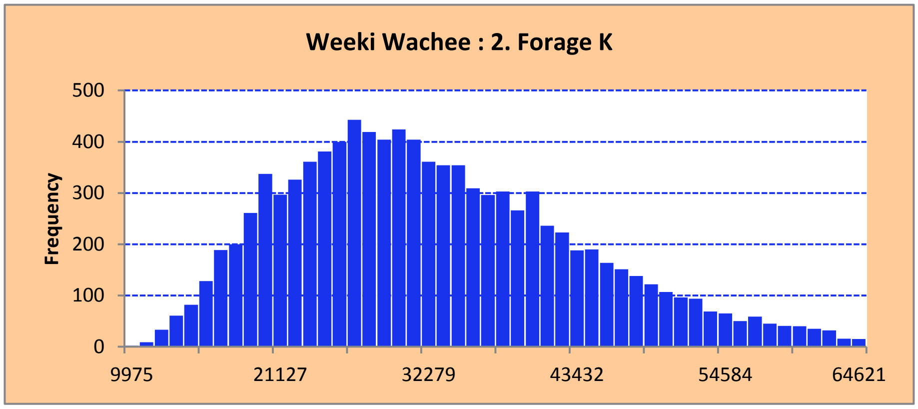
Statistics:	Forecast values
Trials	10,000
Mean	2060
Median	1953
Mode	---
Standard Deviation	811
Variance	657693
Skewness	0.6626
Kurtosis	3.32
Coeff. of Variability	0.3938
Minimum	347
Maximum	5605
Range Width	5258
Mean Std. Error	8

Forecast: Weeki Wachee : 1. Site-K (cont'd)

Percentiles:	Forecast values
0%	347
10%	1093
20%	1346
30%	1560
40%	1758
50%	1953
60%	2167
70%	2424
80%	2718
90%	3168
100%	5605

Forecast: Weeki Wachee : 2. Forage-K

Summary:
Entire range is from 9417 to 105644
Base case is 20126
After 10,000 trials, the std. error of the mean is 115



Statistics:	Forecast values
Trials	10,000
Mean	32990
Median	31268
Mode	---
Standard Deviation	11496
Variance	132155973
Skewness	0.8072
Kurtosis	3.81
Coeff. of Variability	0.3485
Minimum	9417
Maximum	105644
Range Width	96227
Mean Std. Error	115

Forecast: Weeki Wachee : 2. Forage-K (cont'd)

Percentiles:	Forecast values
0%	9417
10%	19601
20%	23033
30%	25936
40%	28555
50%	31266
60%	34300
70%	37873
80%	42019
90%	48469
100%	105644

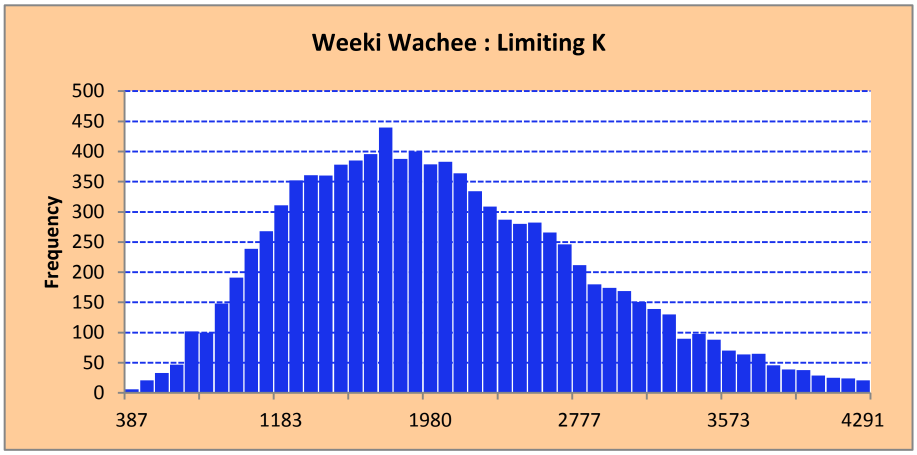
Forecast: Weeki Wachee : Limiting K

Summary:

Entire range is from 347 to 5605

Base case is 2976

After 10,000 trials, the std. error of the mean is 8



Statistics:	Forecast values
Trials	10,000
Mean	2060
Median	1953
Mode	---
Standard Deviation	811
Variance	657693
Skewness	0.6626
Kurtosis	3.32
Coeff. of Variability	0.3938
Minimum	347
Maximum	5605
Range Width	5258
Mean Std. Error	8

Forecast: Weeki Wachee : Limiting K (cont'd)

Percentiles:	Forecast values
0%	347
10%	1093
20%	1346
30%	1560
40%	1758
50%	1953
60%	2167
70%	2424
80%	2718
90%	3168
100%	5605

Appendix Section 2

Monte Carlo R Script

The R script can be run using R--a free data analysis program downloadable from http://www.r-project.org. To run the R code used in this project a comma delimited file (capacity.csv) needs to be present inside the directory where the R code resides. The file tabulates all site specific parameters. All non-site specific parameters are defined in the R code. The triangle library is needed to run the script. This library is freely available and can be installed from within the R programming environment.

Content of capacity.csv:

```
Site,lmin,lpeak,lmax,width,dmin,dpeak,dmax,Perimeter,Area, SAVarea ,SAVmin,SAVpeak,SAVmax,flag
Blue,95,107,118,20,0,0,0,NA,2306,7851962,0.8,1,1.2,0
Crystal River ,NA,NA,NA,NA,0.24,0.3,0.36,3213,70737,247331321,0.78,1,1.22,0.5
De Leon,30,60,344,50,0.1,0.2,0.3,NA,8591,4238071,0.8,1,1.2,0
Manatee Springs,25,65,95,20,0.05,0.1,0.2,NA,4989,0,1,1,1,0
Silver Glen,NA,NA,NA,NA,0.03,0.05,0.1,1644,21597,11131302,0.8,1,1.2,0.5
Silver,6000,7000,8000,30,0.2,0.4,0.6,NA,245339,182302,0.85,1,1.15,0
Warm Mineral,250,300,350,13.7,0.4,0.6,0.8,NA,2669,1771351,0.4,1,1.6,0
Weeki Wachee ,2000,8000,9350,15.2,0.88,0.9,0.92,NA,17800,380299800,0.75,1,1.25,0
C-54,300,600,2200,60,0.02,0.03,0.05,NA,159307,2772468,0.9,1,1.1,0
Berkeley,280,290,300,22,0.03,0.05,0.1,NA,6769,5597311,0.9,1,1.1,0
Harbor Branch,NA,NA,NA,NA,0.1,0.2,0.3,3500,84597,3591844,0.9,1,1.1,1
```

Most fields listed in the file should be self-explanatory. The *flag* field defines which method is to be used to compute siteK area. A *flag* value of 1 uses a site's length and width (along with the length's confidence intervals) whereas a *flag* value of 0 uses a site's area and perimeter .

Content of the MC R script:

```
library(triangle)
library(lattice)

# Number of simulations
n = 99999

# Open site specific data
inFile = read.csv("CapacityK.csv", header=T, na.strings = "NA")
attach(inFile)

# Manatee input parameters (non site specific)
m.length = rtriangle(n, 1.5, 4.0, 2.4)   # m
m.lbuf   = rtriangle(n, 0.18, 0.35, 0.3) # m
m.width  = rtriangle(n, 1, 1.25, 1.16)   # m
m.weight = rtriangle(n, 500, 1200, 800)  # kg
m.cons   = rtriangle(n, .12, .14, .13)   # Fraction consumption, C (bm/day)
m.area   = (m.length + m.lbuf) * m.width # m²

# Input SAV biomass factors (non site specific)
sav.grow = runif(n, 0.0052, 0.01) # Winter growth rate (per day)
bio.for  = runif(n, 0.785, 1.62)  # Forage Biomass (kg/m2)

# Location specific
siteK = matrix(nrow=n,ncol=length(Site))
forK  = matrix(nrow=n,ncol=length(Site))
colnames(siteK) = Site
colnames(forK)  = Site
```

```
# Start MC simulation
for (i in 1:length(Site)){
  z.lim    = rtriangle(n, dmin[i], dmax[i], dpeak[i]) # Depth limit fraction
  loc.len  = rtriangle(n, lmin[i], lmax[i], lpeak[i])
  loc.wid  = width[i]
  loc.peri = 2 * (loc.len + loc.wid)
  if (flag[i] == 1){
    loc.area = (1 - z.lim) * ( loc.len * loc.wid - (2 * m.length * loc.len))
  }else{
    loc.area = (1 - z.lim) * ( Area[i] - (m.length * Perimeter[i] * 0.5))
  }

  loc.sav  = SAVarea[i] * rtriangle(n, SAVmin[i], SAVmax[i], SAVpeak[i])

  # Add results to array
  siteK[,i] = loc.area / m.area
  forK[,i]  = loc.sav * bio.for * sav.grow / m.weight / m.cons

}
# This ends the MC simulation

### Get results ###

# Compute quantiles for all sites
siteK.qt = apply(siteK,2, function(x) quantile(x,  probs =
seq(0,100,10)/100,na.rm=T))
forK.qt = apply(forK,2, function(x) quantile(x,  probs =
seq(0,100,10)/100,na.rm=T))

# Output quantiles to comma delimited files
write.csv(siteK.qt, file="siteK.csv")
write.csv(forK.qt, file="forK.csv")

detach(inFile)
```