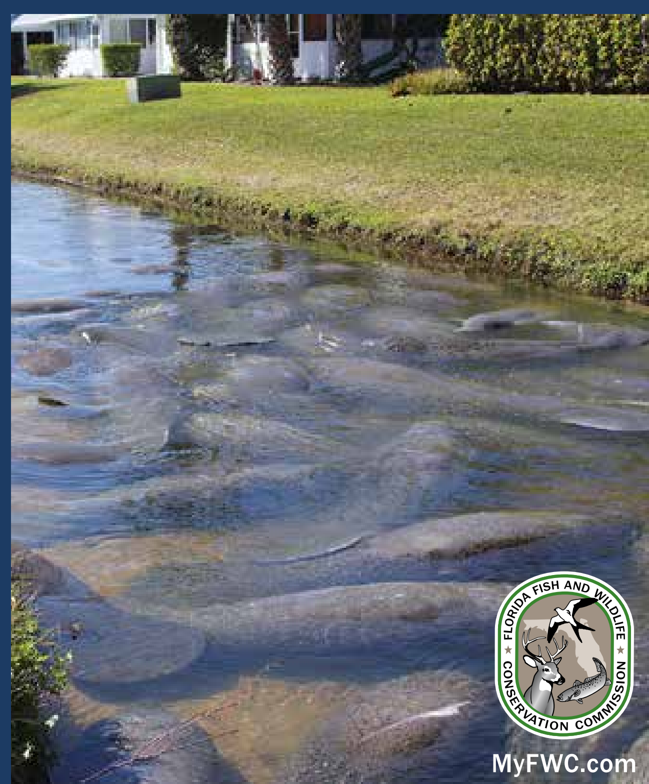
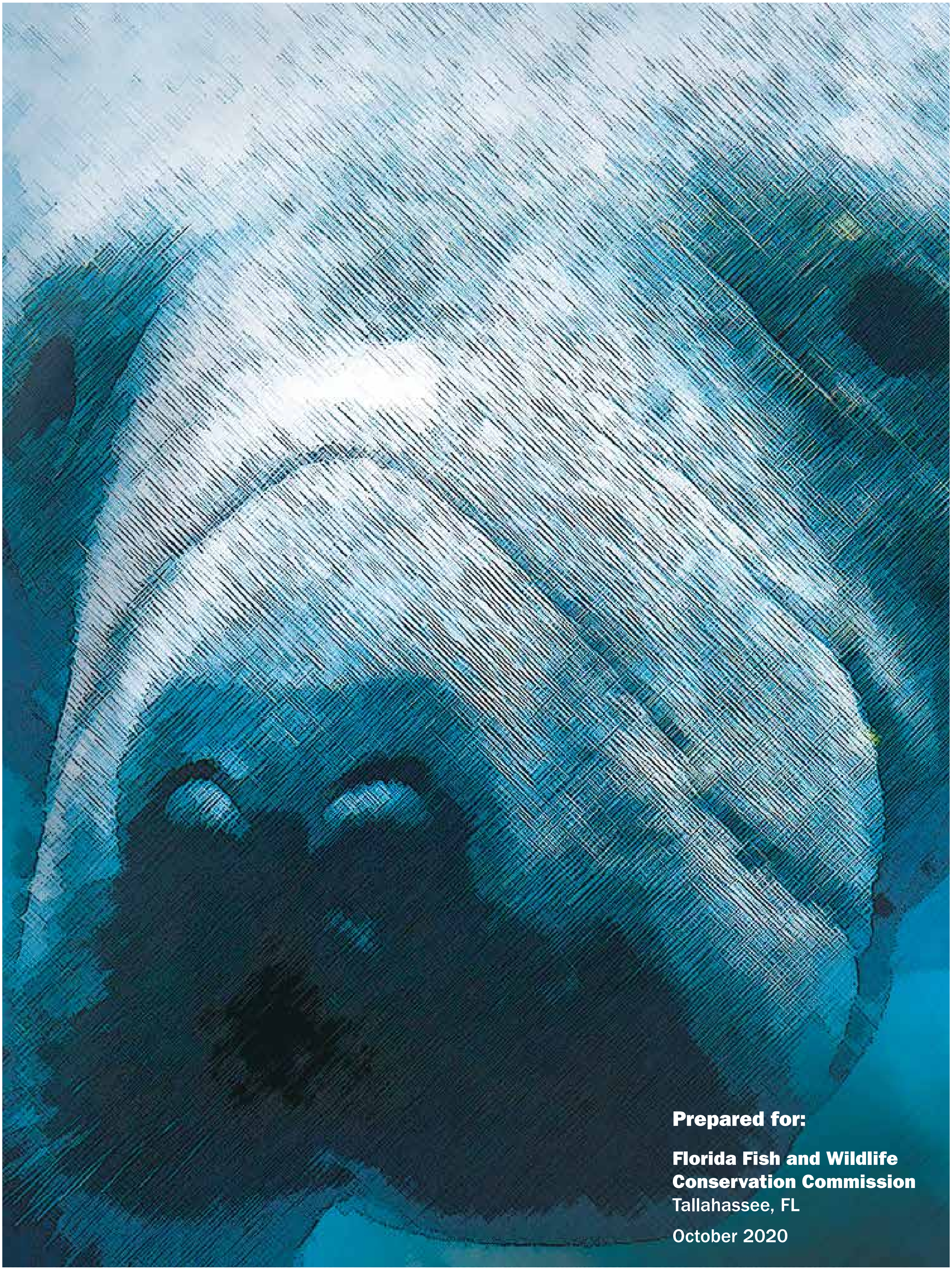
Florida Manatee
Warm-Water Habitat Action Plan





Prepared for:

Florida Fish and Wildlife Conservation Commission
Tallahassee, FL

October 2020

Florida Manatee Warm-Water Action Plan

Table of Contents

Cover Photo Credits:

Front cover: Left: Tampa Electric's Big Bend power plant, by Tampa Electric; Top right: Manatees at Idiot's Delight spring, by Ron Mezich, FWC; Bottom right: Manatees in the DeSoto Canal, by Dan Levine, FWC

Inside front cover: by Monica Ross, Clearwater Marine Aquarium Research Institute

Inside back cover: by Keith Ramos, USFWS

Back cover: Manatees at Wakulla Springs, by Terri Calleson, USFWS

Suggested citation:

Valade, J., R. Mezich, K. Smith, M. Merrill and T. Calleson (editors). 2020 update. Florida Manatee Warm-Water Action Plan. U.S. Fish & Wildlife Service and Florida Fish and Wildlife Conservation Commission. 43pp.

Executive Summary

The Florida Manatee Warm-Water Action Plan (WWAP) provides an overview and management goals aimed at addressing one of the most significant remaining threats to the continued existence of the Florida manatee, the loss of warm-water wintering habitat in the southeastern United States. Currently, over half of Florida manatees seek shelter from winter cold in the warm-water discharges of power plants. The rest of the population uses natural springs and thermal basins located in Florida. The power companies will likely phase out power plant discharges within the next 30 years, and human-caused impacts, such as flow reductions and other activities, threaten Florida's springs and thermal basins.

The Warm-Water Task Force (WWTF) developed an initial plan draft of this document in 2004. The WWTF, convened as a Florida Manatee Recovery Team subcommittee, included industry representatives, governmental agencies, and other stakeholders (Appendix C). The task force identified both short-term (<30 years) and long-term (>30 years) goals, as well as strategies for keeping manatees in the Florida landscape. The short-term goals seek to maintain the current winter range and distribution of manatees in Florida. The long-term goal was to identify and maintain a network of sustainable warm-water refugia with minimal dependence on technology and sufficient to ensure the recovery and persistence of the Florida manatee into the foreseeable future. Strategies for achieving these - goals included developing processes for retaining or replacing the existing primary warm-water habitat, maintaining natural spring flow rates, and maintaining or improving a sustainable warm-water network.

Manatees using spring-fed warm-water habitat in Kings Bay, Crystal River Photo Credit: J. Kleen, USFWS

The Florida Fish and Wildlife Conservation Commission (FWC) and the U.S. Fish and Wildlife Service (Service) worked jointly to develop this updated and revised version of the WWAP in 2019. It is intended to serve as a guidance document to support efforts to conserve, restore and protect the manatee's warm-water habitat in Florida. The magnitude of this undertaking is considerable and will require time and the combined efforts of numerous stakeholders. It will require significant funding. However, given the anticipated loss of power plant discharges over the next 30 years, the inherent site fidelity of manatees to specific warm-water locations and the difficulties associated with transitioning them to sustainable warm-water sites, we must begin now to avoid catastrophic losses of the Florida manatee population.

Warm-water refuges at the FPL Fort Myers Power Plant and Blue Spring. Photo Credit: Mote Marine Laboratory, Manatee Research Program

1. Introduction

For the Florida manatee *(Trichechus manatus latirostris)*, a tropical sub-species of the West Indian Manatee living at the northern limit of its range, the most critical factor to its long-term survival is the presence of warm-water habitat adequate to meet its wintering needs.

Historically, manatees relied upon natural springs, passive thermal basins (see Appendix B, Definitions), and warm ambient waters in southern Florida for shelter from cold winter temperatures (O'Shea 1988). During the 20th century, human activities significantly altered many of these historical refuges. Manatee access to many natural springs was blocked, spring flows were reduced or eliminated, surface sheet flows through the Everglades into coastal creeks at the southernmost tip of Florida were diverted, and many important feeding areas were lost or modified. At the same time, the construction of industrial plants discharging heated effluent into manatee accessible waterways created significant new sources of warm water. Some dredging and canal construction activities also created new passive thermal basins in areas not previously available to wintering manatees.

Manatees gathered at Warm Mineral Springs. Photo Credit: FWC.

Manatee responses to these changes varied. Most significantly, most of the Florida manatee population now seeks refuge during cold weather at industrial sites located throughout much of peninsular Florida. Natural springs characterized by adequate flows, manatee access, good sources of adjacent forage and limited human disturbance, also continue to attract manatees in increasing numbers. Springs that were dammed or otherwise blocked are either minimally used or are no longer accessible to manatees. Manatees continue to use passive thermal basins, at least for a temporary respite from cold weather, and have discovered and use newly created ones.

The current reliance of manatees on industrial warm-water sites and springs significantly affected by human activities has placed the very future of the Florida manatee directly in our hands. The continued thermal discharge of industrial plants hinges on operational and economic constraints beyond our control, and the loss of warm water at some or all these sites is an eventual certainty. Furthermore, natural spring flows continue to decline as human demands for groundwater increase (Florida Springs Task Force, 2000). Given that most of the Florida manatee population now relies on power plant outfalls and a handful of remaining natural springs for warm water, the protection and enhancement of natural sites and how we address the loss of industrial sites will set the course for the manatee's future. This plan identifies problems, alternative management options, recommendations and necessary actions to help ensure the recovery of the Florida manatee.

Manatees swimming in Wakulla Springs. Photo Credit: T. Calleson, USFWS

At present, there are 67 known primary and secondary warm-water sites used by manatees in Florida. These sites include 10 power plants, 23 springs and spring complexes, and 34 passive thermal basins (Appendix A). Each of these warm-water sources faces threats to varying degrees. There are four (4) threats categories: (1) diminished, unreliable or disrupted thermal flows; (2) elimination of flows; (3) preclusion of manatee access or use of particular refuges, and (4) human activities that disturb or otherwise adversely affect manatees while they are using warm-water refuges. Threats specific to each category of warm-water habitat are described below.

2. Types of Warm-Water Habitat

There are two functional types of warm-water habitats used by manatees to survive cold winter periods (Laist and Reynolds, 2005a): (1) “warm-water discharges” formed by the continuous flow of water at temperatures above ambient winter water temperatures, and (2) “passive warm-water habitat” (termed “thermal basins” by Laist and Reynolds 2005a), where thermoclines, haloclines, or other physical conditions slow local cooling processes, thereby retaining pockets of relatively warm water heated by solar radiation, groundwater seepage, decomposition of organic sediments, or other sources. Both functional types of warm-water habitat (also referred to generically as warm-water refugia) may be either natural or human-made in origin. Warm-water discharges used by manatees include natural artesian springs, outfalls from industrial facilities (primarily power plant cooling systems), wastewater treatment facilities and desalination plants. These warm-water discharges appear to be used by approximately two-thirds of all manatees, and more during exceptionally cold periods, as they provide the most reliable sources of warm-water habitat (Laist et al. 2013).

Most warm-water discharges used by manatees remain consistently above 20°C. Passive thermal basins include natural deep holes, dredged canals, and basins that typically lack warm-water inputs from discrete sources. Some passive sites include deeper, warmer, more saline water insulated by an upper layer (surface lens) of lighter freshwater that slows the cooling process. These sites can cool during intense or long periods of cold weather. Thus, most passive thermal basins capable of supporting large numbers of manatees occur in south and central Florida where temperatures are milder. Manatees use northern passive warm-water sites when winter temperatures are less extreme, for only short periods or as staging areas on their way to warmer refugia or warm weather sites in late winter. The temperatures of passive warm-water habitats and their ability to retain warm water during cold periods are poorly understood, and research on this topic is warranted.

Coastal and river water temperatures throughout mainland Florida, including the southernmost tip, routinely fall below the thermal tolerance levels of at least some manatees during winter periods. Patterns of cold-related manatee deaths suggest that warm-water springs are better able to sustain manatees in cold winter periods than either power plants or passive warm-water sites (Laist and Reynolds, 2005a, FWC Florida Fish and Wildlife Research Institute unpublished data). Springs that provide the main winter habitat for manatees have waters ranging from 21° to 23°C (70° to 73°F) or higher. Discharges at power plants are more variable, with some dropping to about 20°C (68°F) or lower during the coldest winter periods. In counties with major warm-water refuges provided by springs, cold- stress deaths are low. In counties where power plants provide the principal warm-water habitats, cold stress deaths are significantly higher between November and March (Laist et al. 2013). Cold stress deaths in southernmost Florida, where passive warm-water sites are the principal warm- water habitat, have averaged between about 5 to 10 percent of all deaths (FWRI, unpublished data).

Currently, there are 19 identified primary warm-water habitats where manatees are likely to be found during the coldest winter periods (See Appendix A); 15 are warm-water discharges (six power plants and nine

Aerial Survey over FPL Cape Canaveral Energy Center. Photo Credit: Mote Marine Laboratory, Manatee Research Program natural springs), and four are thermal basins. There also are numerous secondary warm-water habitats used by smaller numbers of manatees. These secondary sites are used principally as stopover sites by manatees caught in relatively mild cold periods, as staging areas in the spring and fall as they prepare for migration, or even as their main thermal habitat during mild winters. Florida manatees occur in at least four relatively discrete regional management units. These management units appear to maintain their discreteness due to strong winter site-fidelity to principal warm- water habitats, as well as to summer range fidelity, within each of their respective ranges (Deutsch et al. 2003). Manatee tracking and photo-identification studies show that there is relatively little movement between coasts or among the four currently defined regional management units (e.g., Weigle et al. 2001, Deutsch et al. 2003). Furthermore, most manatees do not use all known warm-water sites within their region. Therefore, the maintenance of a network of reliable warm-water habitats within the range of each management unit is a fundamental management need. Appendix A identifies the primary and important secondary habitats that form the current network of warm-water refuges for each of the four regional management units.

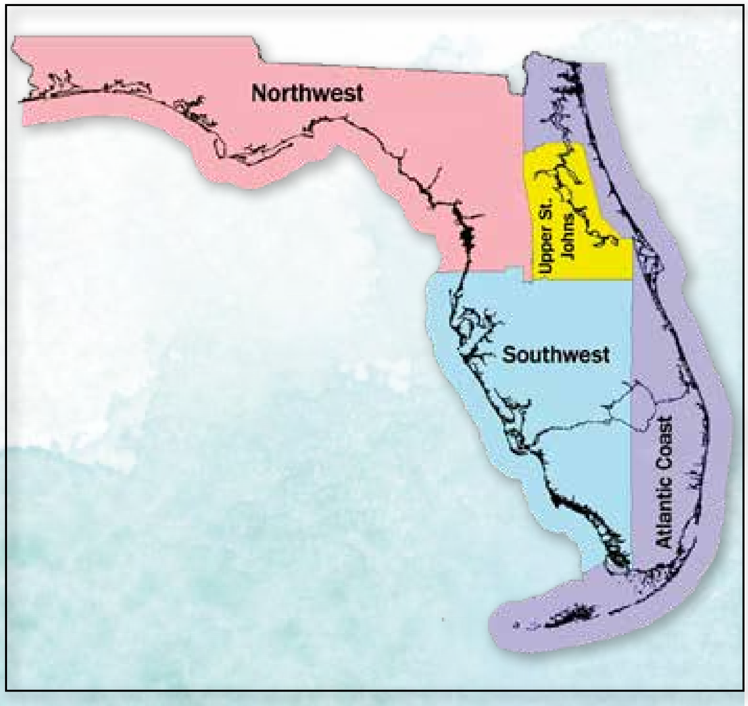
Springs and Spring Complexes

Natural springs, which presently provide primary and secondary warm-water manatee habitats, face an uncertain future (Laist and Reynolds 2005b). The threats to the springs' warm-water habitat used by manatees include: diminishing spring flows from human-caused groundwater withdrawals, obstructions that limit or preclude access, disturbance from recreational activities, loss of nearby forage resources, climatic variations and sea-level rise (Edwards 2013).

Groundwater withdrawals for residential, industrial and agricultural uses and development in groundwater recharge areas, have significantly reduced flow rates at many of Florida's springs. Left unchecked these declining spring flows would eventually reduce the size of thermal plumes to a point where they could no longer support large numbers of manatees. At Blue Spring in Volusia County, which currently provides the only major warm-water refuge for the Upper St. Johns River manatee management unit, average annual flow rates declined by 13 percent between the periods 1932-1975 and 1985-1994 (Sucsy et al. 1998). The District assessed the future projected groundwater withdrawals on Blue Spring discharges and predicted an estimated 4% decline in mean annual spring flow from 1995 to 2025 due to projected pumping conditions (i.e., a change from 150 cfs to 144 cfs, respectively). NewFields (2007) summarized the additional analysis of Blue Spring discharge data and found that climate (extended droughts) was an additional factor contributing to spring flow declines. Flow rates at Homosassa Springs, a principal warm-water refuge for the northwestern Florida manatee management unit, also may be declining. Its flow rates averaged 106 cubic feet per second (cfs) between 1931 and 1974, with a minimum rate of 80 cfs during that period (Scott et al. 2002). The main Homosassa Springs gage reports an average of 88 cfs for its full period of record from 1995 to 2017 and the SE Fork gage reports 60 cfs for its full 2012-2017 period of record (https://waterdata.usgs.gov).

Jenkins Spring, Hernando County. Photo Credit: USGS

Florida's five water management districts work to protect spring and river flow by collecting biological and hydrological information and using this information to develop and adopt Minimum Flows and Levels (MFL) regulations for individual rivers and springs. The Districts are required to develop and adopt MFLs per state statutes (Chapt. 376.042, F.S.). MFL's exist for several spring systems including Blue Spring and Homosassa Springs. In 2006, the St. Johns River Water Management District (SJRWMD) adopted a "phased" MFL for Blue Spring along the St. Johns River, which called for increases in the mean annual flow of the spring over 15 years to the long-term mean flow of 157 cfs. The primary focus of this MFL is to provide adequate warm-water habitat for the existing and future manatee population. The Blue Spring MFL prevention and recovery strategy calls for SJRWMD staff to work with water utilities and others in the Blue Spring region to reduce groundwater withdrawals via the use of reclaimed water, aquifer recharge, water supply projects and water conservation and regulatory measures.



Map showing manatee management units. USFWS (2001)

Today, only five springs systems are in use by large numbers of over-wintering manatees. Human modifications limit or preclude manatee use of other springs that might otherwise provide important warm-water habitat for manatees. Access constraints include locks, dams, fences, rock formations and silt-choked spring runs that prevent or restrict manatee access. For example, a downstream dam and lock restrict access to Rainbow Spring on the Withlacoochee River, and a long shallow spring run where rock, silt and sand deposits from human activity reduced the run's depths and limits access to Weeki Wachee Spring. At a time when critical power plant warm-water refuges will likely be lost, such existing restrictions on the availability of other warm-water habitats take on added significance and represent a substantial obstacle to the recovery and persistence of manatee populations dependent on natural warm-water habitats. Currently, several governmental and private organizations are developing and conducting restoration projects in spring systems that will improve access, restore aquatic vegetation and improve water quality for a variety of fish and wildlife species, including manatees.

Other significant threats to manatees using available warm- water habitats include vessel traffic and commercial and recreational water sports, particularly paddling (canoes, kayaks and paddleboards), swimming, fishing and diving, within or directly adjacent to warm- water habitats. Because of the limited number and size of warm-water habitats and the concentration of manatees using them, such activities can pose a risk of disturbance, injury and death for manatees. Existing management measures, such as boating speed zones and restrictions on human access, have been developed and help minimize these adverse effects. However, many secondary warm-water sites, some that hold the potential to be primary warm-water sites, continue to struggle with these critical management issues. The State of Florida Manatee Management Plan (FWC 2007) recognizes several crucial tasks to increase the availability of manatee warm-water habitat,

Manatee in Silver Glen Springs. Photo Credit: M. Ross, Clearwater Marine Aquarium Research Institute including identification of components of regional warm-water networks, establishment of protection measures where warranted, and implementation of restoration measures at springs and passive thermal basins. Additionally, the Florida Manatee Recovery Plan (U.S. Fish and Wildlife Service 2001) sets forth criteria to ensure a healthy, self-sustaining population of manatees in Florida, including adopting and maintaining minimum spring flows, protecting warm-water refuge sites, and protecting foraging habitat associated with warm-water refuge sites. As cited above, regulatory measures are in place to address commercial and recreational activities and reduce disturbances within important manatee warm-water habitat. At some locations, the construction of manatee viewing areas accommodates manatee viewing activities while minimizing interference with manatee use of the warm-water refuge. Table 1 provides additional information about spring systems that are important as manatee habitat.

Fanning Springs Restoration Project. Photo Credit: R. Mezich, FWC

King Spring/Banana Island Manatee Sanctuary. Photo Credit: J. Kleen, USFWS

Table 1. Spring systems currently providing primary warm-water manatee habitats

Region/Spring	County	Spring Magnitude	Minimum Flow & Level	Manatee Viewing Area	Management Notes
Blue Spring	Volusia	1	Yes	Yes	Spring run closed during winter
Salt Springs	Marion	2	No	No	Sand bars limit access; significant recreational activity
Silver Glen Springs	Marion & Lake	1	Yes	No	Significant recreational activity
Silver Springs	Marion	1	Yes	No	Rodman Dam and Buckman Lock limits access
Crystal River Springs Complex	Citrus	1	Yes	Yes	Significant recreational activity
Homosassa Springs	Citrus	1	Yes	Yes	Significant recreational activity
Wakulla Springs	Wakulla	1	No	Yes	
Weeki Wachee River Springs Complex	Hernando	1	Yes	Yes	Sand bars limit access
Warm Mineral Spring Creek/Salt Creek	Sarasota	3	No	No	Sand bars, weirs, and debris

Power Plants

Power plant outfalls built before 1972 form six primary warm-water sites and four secondary sites (Table 2) used by manatees. Since then, the Clean Water Act (CWA) regulations prohibit new facilities from discharging effluent substantially warmer than the receiving water bodies. The older, preexisting plants were granted variances, allowing them to continue discharging warm water. By the early 2000s, most of these older plants were approaching the end of their planned operational lives. However, starting in 2008, Florida Power and Light (FPL) began the process of repowering three of their Atlantic coast power plants. FPL completed repowering the Cape Canaveral Energy Center in 2013 with the Riviera Beach Energy Center completed in 2014 and the Port Everglades Energy Center in 2016. These changes by FPL provide a short-term level of security for industrial warm water used by manatees on the Atlantic coast. These new and more efficient plants produce a lesser volume of warm water, which shrink the area of warm-water refuges by as much as 25 percent. This lower heat output may result in these warm-water refuges becoming smaller and less dependable during extreme cold events. At this time, five of the six plants used as principal warm-water discharges for manatees have been repowered between 2003 and 2016 (i.e., FPL plants at Cape Canaveral, Riviera Beach, Port Everglades, Fort Myers and Lauderdale/Dania Beach) and two other locations are currently undergoing modernization (Tampa Electric Company (TECO) Big Bend and FPL Dania Beach Energy Center plants, both with expected completion in 2022). Also, two secondary plants (Duke Energy's Bartow and TECO's Bayside plants) were repowered in 2009. For these seven repowered plants, the continued availability of warm-water discharges seems likely over the next 20 years on the Gulf coast and 30 years on the Atlantic coast. The current situation at the seven repowered plants provides additional time for the state and federal wildlife agencies and the Florida power industry to develop long-term plans to reduce adverse effects to the recovering manatee population.

Manatees gathered at Riviera Beach Energy Center.
Photo Credit: M. Ross, Clearwater Marine Aquarium Research Institute

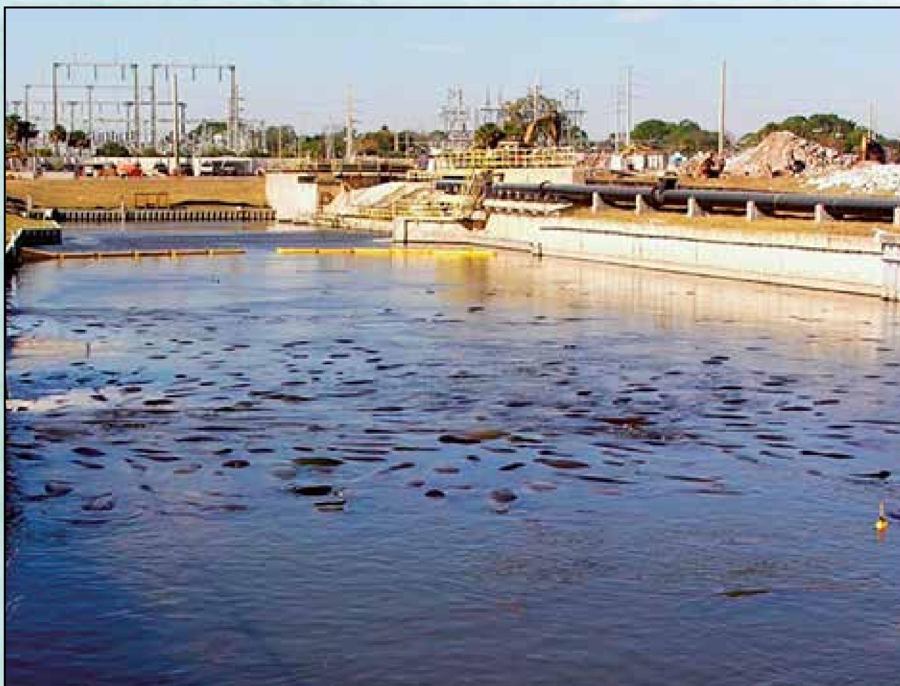
Precisely when individual power plants might change operations or be retired in the future is unclear. Such decisions involve proprietary economic forecasts made by individual utilities based on hard-to-predict factors, such as the future cost and availability of alternative fuels, competition with rival power companies, projected trends in electricity demand and the cost of renovation versus building new plants. Recent changes in federal environmental regulations governing Florida's electric utility industry, as well as increasing fuel prices, have complicated projections of changes in the industrial portion of the warm-water habitat networks. As previously noted, most of the primary industrial warm-water sites have been repowered. Other plants that have provided long-term secondary, and in some cases, primary industrial warm-water habitat have severely reduced operations or been retired (Jacksonville Electric Authority (JEA) Kennedy and Southside, OUC-Indian River, Henry D. King, Vero Beach and the Crystal River power plants). The two largest manatee regional populations (i.e., the Atlantic Coast and Southwest management units) rely most heavily on power plant outfalls for winter survival; closures in these regions will expose some manatees to more significant cold stress, as was documented during the winter of 2010, and may affect manatee behaviors (foraging, dispersal, etc.) during the winter months over the long term. Furthermore, modeling has shown that there is a high likelihood (nearly 50%) that populations in the Atlantic and Southwest regions will decline by at least 30% over the coming century, largely due to reductions in winter carrying capacity associated with loss of industrial warm-water habitat (Runge et al. 2017).

Manatees at Crystal River. Photo Credit: USGS

Near-term threats to manatees taking refuge at power plants include temporary power outages associated with mechanical failures, changes in operations due to economic considerations, construction activities affecting thermal discharges, oil, and chemical spills. Threats also include permanent or extended closures associated with corporate plans to close or re-power plants. Each site's National Pollution Discharge Elimination System (NPDES) permit addresses these threats as part of their permit's manatee protection plan. Notably, for primary manatee refuge plants, operators are required to operate during the winter within specific ambient water temperature thresholds. Permit conditions also require plant owners to notify regulatory agencies of plans to shut down plants.

Manatees attracted to thermal outfall at TECO Big Bend power plant. Photo Credit: Tampa Bay Electric Company

As with springs, both individuals and ecotour operators visit warm-water discharge areas to view manatees, and anglers target the discharges because they attract fish during winter months. These activities can create disturbances that deter manatees' use of warm-water habitat. The presence of seasonal "no entry" regulations designed to protect manatees and minimize disturbances, generally preclude boating and fishing activities within the warm-water refugia. Controlled opportunities for people wanting to view manatees are available at several observation facilities located around the state.



Manatee aggregation in the interim warm-water refuge created by temporary heaters at the Cape Canaveral Energy Center during repowering. Photo Credit: J. Valade, USFWS

Table 2. Existing and historic industrial facilities providing warm-water manatee habitat.

Region/Facility	Operational	County	Year Constructed	Repowered	Manatee Viewing Area	Notes
Atlantic Coast Region						
FPL Cape Canaveral Energy Center	Yes	Brevard	1965	2013	No	
FPL Fort Lauderdale Power Plant (aka Dania Beach Energy Center)	Yes	Broward	1926	1993	No	Repowering underway with expected completion in 2022
FPL Port Everglades Energy Center	Yes	Broward	1960	2016	No	
FPL Riviera Beach Energy Center	Yes	Palm Beach	1946	2014	Yes	
Ft. Pierce Utilities Henry D. King Electric Station	No	St. Lucie	1912	NA	Yes	Closed 2007
Jacksonville Electric Authority – Kennedy Power Plant	No	Duval	1912	NA	No	Closed 2007
Jacksonville Electric Authority – Northside Generating Station	No	Duval	1966	NA	No	Discharge relocated, 1970s
Jacksonville Electric Authority – Southside Power Plant	No	Duval	1947	NA	No	Closed 2001
Jefferson Smurfitt – Amelia Island Pulp Mill	No	Nassau	1938	NA	No	Discharge diffused 1997
Jefferson Smurfitt – Talleyrand Pulp Mill (former Alton Box Board Co.)	No	Duval	1938	NA	No	Closed 1998
Orlando Utilities Commission Indian River Power Plant (former Reliant Energy Power Plant)	No	Brevard	1960	NA	No	Closed 2010

Region/Facility	Operational	County	Year Constructed	Repowered	Manatee Viewing Area	Notes
Vero Beach Power Plant	No	Indian River	1961	NA	No	Plant to be removed
Northwest Region						
Duke Energy – Crystal River Power Plant	Yes	Citrus	1966	NA	No	Coal and nuclear units retired, new gas unit operating 2018
Sam O. Purdom Generating Station	Yes	Wakulla	1952	2000	No	Cooling Tower is used to eliminate thermal discharge
Southwest Region						
TECO Big Bend Power Station	Yes	Hillsborough	1969	NA	Yes	Repowering underway with expected completion in 2022
FPL Ft. Myers Power Plant	Yes	Lee	1958	2003	Yes	
Duke Energy Anclote Power Plant	Yes	Pasco	1974	NA	No	
TECO H.L. Culbreath Bayside Power Station	Yes	Hillsborough	1957	2009	No	
Duke Energy Bartow Power Plant	Yes	Pinellas	1958	2009	No	

Passive Thermal Basins and Other Warm-Water Features

Threats to passive thermal basins and other warm-water features used by manatees in winter include the loss of thermal capacity due to human activities such as development and restoration activities and changes to physical or hydrological features integral to individual thermal basins. Recreational activities also can cause disturbance to manatees using these sites. When feasible, efforts are made to protect thermal basins and address disturbance associated with human activities. Conservation efforts at these sites are often complicated, since the thermal properties of these warm-water sites are often not completely understood, and because many sites are in urban settings or adjacent to private properties, making it more challenging to minimize disturbances. Passive thermal basins are located primarily in the lower half of peninsular Florida (See Table 3 and Appendix A).

Table 3. Passive Thermal Basins providing primary warm-water habitat.

Region/Canals, thermal basins, other	County	Concerns	Suspected Attractant	Management Notes
Coral Gables Waterway	Miami-Dade	No	Groundwater seep	
DeSoto Canal	Brevard	Yes	Groundwater seep	Possible flow regime modifications, human interactions
Port of the Islands – Mitigation Site	Collier	No	Groundwater seep	Pools created in 2016; ongoing monitoring.
Port of the Islands – Port Canals	Collier	Yes	Thermocline due to halocline	Possible flow regime modifications, human interactions

3. Recommended Management Strategy

The Florida Manatee Recovery Plan (2001) identified the need to develop a "conceptual plan for a long-term network of warm-water refuges [Task 3.2.1(2)]." The WWTF reviewed and discussed relevant information on natural and manmade warm-water habitats used by manatees to survive winter and concluded that the construction and operation of industrial facilities discharging warm water into rivers, coastal lagoons and bays throughout Florida influenced the winter range of Florida manatees. Outfalls from these facilities have caused large numbers of manatees (600 to >1000 at several sites) to aggregate at sites where ambient water temperatures in winter routinely fall below 20°C (68°F).

Manatees in the DeSoto Canal. Photo Credit: B. Greer, FWC

Such temperatures can be lethal to manatees. Manatees exhibit a high degree of site fidelity to industrial, as well as natural, warm-water habitats that typically remain above 20°C (68°F). This behavior places a high percentage of manatees using industrial outfall facilities at risk of death due to cold stress, if their associated warm-water discharges are shut down or if warm-water availability becomes sporadic or unreliable. There is no assurance that the industrial production of warm water at these sites will continue.

Non-industrial sources of warm water also influence manatee distribution throughout Florida. Groundwater withdrawals within the recharge areas of natural springs used by manatees also place the species at risk, because of declining spring flows that can reduce the area in which manatees can thermoregulate. Other known warm-water refugia, such as passive thermal basins, also are critical to the recovery of the population and can lose their thermal properties as a result of changes in existing land management activities or coastal construction surrounding these areas.

Manatees at Wakulla Springs. Photo Credit: USGS

The essential nature of warm-water habitats for winter manatee survival necessitates a short-term management strategy (i.e., <30 years) to maintain a network of warm-water habitats for each of the four regional management areas in Florida. To this end, industrial sources serving as primary warm-water refugia from Brevard County south on the Atlantic Coast, and Tampa Bay south on the Gulf of Mexico Coast, should be retained or replaced unless adequate warm-water carrying capacity already exists at one or more functionally equivalent sources. Manatee site fidelity requires that the location of some of the alternate warm-water sites be at or near the existing warm- water source, such that a facility's closure is unlikely to significantly alter manatee distribution within their winter range. Flow rates at natural springs used by manatees as winter habitat, now and in the future, must be maintained at current levels or at levels that avoid significant harm. As part of the warm-water networks, passive thermal basins and other features known to provide thermal benefits to the manatee population also must be maintained or improved throughout the winter range of the manatee. The regional networks of warm-water habitats should be based on the current distribution of these features and should provide an overall configured habitat equivalent to that which exists at present.

Blue Spring, Volusia County. Photo Credit: T. Calleson, USFWS

Maintaining capacity at springs and passive thermal basins will be extremely important over the long-term for the manatees' survival as industrial warm-water habitat becomes less available.

In the long term (>30 years), the identification and maintenance of a reliable network of warm-water refugia with minimal dependence on technology and industrial warm water sources Is necessary for manatee recovery and persistence. Creation of new warm-water sources may be needed to achieve these aims in both the short- and long-term. One such non-technological option is to tap into warm saline or brackish groundwater to create an artificial spring or a groundwater-fed thermal basin; this idea has recently been carried out at Port of the Islands and is currently being monitored to determine thermal quality and manatee use. Preserving the existing winter range of the manatee is vital to meet this goal over the long-term. However, the current distribution of manatees will likely change as projected modifications to regional warm-water habitats become much less dependent on industrial warm-water sites with large thermal capacities.

4. Research & Monitoring

Continued research on manatee ecology, behavior, population biology, and health related to warm-water habitat is crucial for making informed management decisions. Future research and monitoring efforts on this subject will need to focus on a suite of questions that can be simply encapsulated as: How are manatees affected by changes in the availability and quality of warm-water habitat? These questions span spatial scales ranging from individual discharge sites to entire regional networks of thermal refuges. Site-specific issues, for example, include manatee response to temporary or permanent loss of thermal refuges (e.g., unplanned power plant shutdown), determining the appropriate ambient water temperature for triggering plant operation to avoid cold-related mortality or morbidity, and documenting the rate of manatee adoption of a newly created warm-water site. Efforts should be continued to identify passive thermal basins throughout the manatee's range in Florida, and to quantify the thermal quality of such sites, in order to provide a better understanding of regional warm-water networks. Manatee response to changes in warm-water habitat should be measured at both individual and population levels because understanding behavioral response (e.g., site fidelity) and physiological response (e.g., stress, energetics) helps provide the biological mechanisms driving changes in vital rates, distribution, and other population parameters. This is also essential for developing realistic simulation models.

Research and monitoring must also address questions of management importance over a wide span of temporal scales. Deutsch and Reynolds (2012) noted that "a combination of field experimentation, opportunistic studies, and simulation modeling is needed to evaluate behavioral and population response." Short-term issues may often be addressed through empirical studies and observations made over a period of several years. Knowledge of short-term effects is useful for contingency planning and prioritizing management actions. Long-term questions typically require some sort of modeling that relies on available scientific knowledge developed through such studies. Projecting the long-term effects on abundance and regional distribution of reduced carrying capacity, associated with eventual loss of industrial thermal effluents and diminished spring flows, was accomplished through a population viability analysis (Runge et al. 2017). This type of information is useful in evaluating population status and in state and federal imperiled species listing decisions. Even short-term issues can benefit from appropriate modeling efforts. There is an inherent inability to conduct replicated experiments to test the effects of various management actions on manatees (due to ethical, legal, logistical, and financial reasons), so we often must rely on modeling to simulate scenarios of interest to managers. Such efforts, for instance, might evaluate 'what-if' scenarios for various regimes of power plant operation (e.g., timing and warmth of thermal discharges) under different levels of winter severity, using projected changes in manatee energetics or mortality as potential metrics of interest.

Manatee Springs. Photo Credit: USGS

Recommended Management Strategy

Short-term Measures (<30 years) - Maintain the current winter range and distribution of manatees in Florida.

- Maintain a network of regional warm-water habitats based on the current distribution of these features occurring in each of the four currently recognized Florida manatee regional management units.
- Retain existing or replace lost primary warm-water refugia with one or more functionally equivalent sources of warm water unless adequate warm-water carrying capacity already exists.
- Identify alternate manmade warm-water sites at or near existing warm-water sources that are expected to be lost.
- Maintain flow rates at natural springs used by manatees at current levels or at levels that avoid significant harm to manatees.
- Maintain or improve passive thermal basins and other features known to provide thermal benefits to manatees.

Long-term Measures (>30 years) - Maintain a sustainable network of warm-water refugia.

- Identify and maintain a network of sustainable warm-water refugia with minimal dependence on technology and sufficient over the long-term to ensure the recovery and persistence of the Florida manatee pursuant to the habitat requirements for recovery under the Federal List of Threatened and Endangered Species.

5. Action Plan

A. Evaluate Management Strategies and implement Actions

We identified seven basic management strategies to achieve short-term and long-term goals for establishing a network of warm-water habitats to meet Florida manatee conservation goals. Conservation managers and partners can select from one or more of these strategies or others as the situation may dictate.

In some cases, further research is needed to determine the feasibility of an option. Information garnered from past, ongoing, and future research and monitoring efforts will be critical in delivering consistent, reliable, and safe warm-water habitats that will sustain the manatee population both regionally and statewide. The seven strategies, not listed in priority order, are discussed below.

1. Monitor manatee response and rescue.
2. Conserve, restore, protect, and enhance springs and other non-industrial warm-water habitats.

3. Maintain important industry-related warm-water discharges pending the development of alternative approaches for creating warm-water habitat.

4. Gradually decrease manatee dependence and use of specific industry-related warm-water discharges and minimize the resulting adverse effects to the manatee population as manatees adapt to new warm-water networks.

5. Develop warm-water habitats that are not industry-dependent.

6. Develop techniques to influence/control manatee use of warm-water habitats.

7. Prevent the creation of new artificial warm-water discharges that could become an attractive nuisance.

Manatees at Blue Spring. Photo Credit: M. Ross, Clearwater Marine Aquarium Research Institute

Strategy 1. Monitor Manatee Response and Rescue:

In some cases, when plans are made to retire an industrial facility used by manatees, the most appropriate action may be to do nothing other than monitor the effects of a plant's closure and attempt to rescue manatees that remain near the facility and show signs of cold stress. A monitoring plan is required to ensure steps are taken to identify the effects of the closure on manatee movements, distribution, and mortality. It also would include development of plans for rescuing distressed manatees and releasing them at appropriate locations. This might be a preferred option when other refuges are available nearby to support displaced animals (e.g., Henry D. King and Reliant Indian River power plants), when industry outfalls are in an area deemed inappropriate due to its cold northern geographic location (e.g., pulp mills in northeast Florida and Georgia), or when the associated discharge is a minor secondary refuge, considered to be a minimal component of the regional warm-water refuge network. Because of ingrained patterns of site fidelity, this option would likely be inappropriate in the case of a power plant retirement involving an associated outfall that is a principal warm-water habitat in a region.

Accomplishments:

1. Monitored manatee behavior when discharges at the Jefferson Smurfitt pulp mill at Amelia Island and the JEA Southside power plant sites were retired.

2. Many successful rescues with the existing statewide manatee rescue and rehabilitation program.

The primary research and monitoring tools for addressing questions related to manatee use of warm-water habitats include: (1) carcass salvage and necropsy to identify mortality trends, emerging threats, health surveillance, and severity of cold-related mortality events; (2) satellite-linked telemetry to understand movements, site fidelity, habitat use, and response to cold and other stressors; (3) aerial surveys to examine distribution, abundance, and habitat use at and surrounding warm-water sites; (4) photo-identification and genetic biopsy sampling to estimate adult survival and reproductive rates; (5) monitoring thermal quality of known and potential warm-water habitats; (6) integrated risk assessments to evaluate the effectiveness of management actions; (7) novel modeling approaches for assessing population growth and viability; (8) health assessments of captured manatees to measure body condition and physiological health; and (9) human dimensions surveys and related tools to characterize knowledge, attitudes, values, and expectations of the public with regard to manatees and warm water. Most of these research avenues have been guided by priorities identified in the Florida Manatee Recovery Plan (USFWS 2001) and the State of Florida's Manatee Management Plan (FWC 2007).

Priority Management Questions:

1. How does the population respond to the modification or loss of industrial warm-water habitat?
2. How is manatee health affected by modifications to warm-water network configuration?

Research Needs:

1. Investigate industrial warm-water discharges

Many industrial warm-water sites have provided generally reliable and safe warm-water habitat to the Florida manatee population over the past 50 years. Understanding the attributes found at these sites would be valuable in our efforts to create new sites or enhance existing warm-water sites. Investigations should examine: (1) the physical and thermal characteristics of the discharge basins, (2) manatee fine-scale use of the discharge basins in relation to thermal gradients, and (3) manatee attendance patterns at these warm-water sites in relation to ambient temperature, discharge temperature, and other factors.

2. Document manatee response to the loss of industrial warm-water discharges, including population impacts

Whenever feasible, research efforts should take advantage of opportunities to test hypotheses about manatee response to cessation of or interruption in industrial thermal discharges. Appropriate protocols and monitoring should be in place to reduce the risk of cold-related mortality and to rescue and translocate manatees, as needed. This will provide valuable information when devising future management actions to minimize the impacts of alterations in warm-water habitat.

Strategy 2. Conserve, restore, protect, and enhance springs and other non-industrial warm-water habitats:

This management option involves steps to maintain suitable flow rates at natural warm-water springs currently used by manatees and to restore access to spring systems that are now inaccessible or have had limited or no historical use by manatees. Restoration actions may include steps to eliminate obstructions impeding manatee use of warm-water springs, such as removing sediments that have silted in spring runs or removing barriers (e.g., dams, locks, or fences) that restrict manatee access to springs discharges. Where appropriate, protection measures, such as seasonal restrictions of public use, water withdrawal conditions and measures to protect aquatic and shoreline vegetation, can be developed with stakeholders to address warm-water habitat concerns. Protection zones can be adopted for areas significantly influenced by human activities that are impeding manatees' use of sites.

Ulele Springs Restoration Project. Photo Credit: R. Mezich, FWC

Spring flows may be reduced by extraction of groundwater for human use. Protection of spring flows involves working with the state's five Water Management Districts to: (1) monitor flow rates at springs used by manatees, (2) determine the minimum flow rate necessary to create thermal plumes adequate to support a desired number of manatees at essential springs and (3) implement measures that would ensure groundwater withdrawals do not decrease spring flow rates below identified minimum levels during periods of drought.

Accomplishments:

1. Restoration efforts completed at Florida springs that improved manatee habitat or access include Homosassa Springs, Three Sisters Springs, Chassahowitzka Spring, Weeki Wachee Springs, Ulele Spring, and Fanning Springs.

2. At Three Sisters Springs, removal of access impediments in the spring run and the stabilization of the shoreline improved manatee access and use. Additionally, Crystal River National Wildlife Refuge implemented projects (filtration marsh) to improve overall water quality at the springs.

Fanning Springs Restoration Project. Photo Credit: R. Mezich, FWC

3. Seasonal "No Entry" zones are in place at 12 warm-water sites (six passive thermal basins and six spring systems).

4. Minimum Flows and Levels are in place for Blue Spring in Volusia County, Sulphur Spring in Hillsborough County, Manatee and Fanning Springs in Levy County, Weeki Wachee Spring in Hernando County, the Homosassa and Chassahowitzka Rivers and the Crystal River/Kings Bay system in Citrus County, DeLeon Springs in Volusia County and Silver Glen Springs in Lake and Marion Counties.

Priority Management Questions:

1. What are the priority areas for the restoration and conservation of warm-water habitat?

2. What engineering and mitigation are necessary to enhance underutilized or inaccessible springs?

3. What is the warm-water and forage carrying capacity for regionally significant, non-industrial manatee warm-water sites?

4. What are the warm-water carrying capacity needs for a recovered manatee population?

5. What springs should be targeted for work to enhance or open them to manatee access?

6. How do we develop support from our stakeholders, partners, and the public for funding and implementing conservation strategies that may be necessary to address local warm-water manatee habitat management efforts?

Research Needs:

1. Investigate natural spring warm-water habitat.

Natural springs already support approximately 20 percent of the wintering manatee population and are the best choices because of dependability and minimal maintenance. Manatee access may be restricted by varying degrees due to human and natural causes. Additional research efforts are required to (1) identify other priority springs that could provide warm-water habitat for manatees, (2) identify the physical characteristics that are necessary for a spring to serve as primary warm-water habitat and (3) gain a better understanding of manatee use of spring systems, which may assist in the redistribution of manatees to new warm-water habitat.

2. Document manatee response to the restoration or protection of natural springs.

Given the resources required to restore spring systems or to establish protected zones for manatees in such systems, it is important to monitor manatee response to such efforts as well as any changes in the thermal or other physical characteristics (e.g., depth, current) of the warm-water site. Does manatee use increase after restoration that provides improved access to the site or reduced human disturbance? This information will be valuable when developing future restoration projects.

3. Assess habitat carrying capacity and manatee behavior for regionally significant non-industrial warm-water sites.

Carrying capacity (K) associated with warm-water sites is determined by the area and quality of warm water available to manatees at the site (thermal-based K) and by the amount and quality of forage available in the vicinity of the site (forage-based K). At different sites, and over different time periods, either of these components may become limiting. Behavior can also play a role in affecting the realized carrying capacity at a site, for example if manatees are deterred from some areas of the site by human activities or other factors. Evaluation of site-specific carrying capacity will require quantitative information on the site's thermal quality, the ambient temperature regime, and food availability (as distance to and quality of foraging grounds may affect cold exposure and body condition), and it will also need to consider behaviors that may modify site use. We also need information on how manatee health, body condition, and stress levels change as a local population approaches its environmental carrying capacity.

Strategy 3. Maintain important industry-related warm-water discharges pending the development of alternative approaches for creating warm-water habitat:

In some cases, when plans are made to retire an industrial facility used by manatees, an acceptable response may not yet be available because alternative actions lack development or completion. It may be necessary for wildlife agencies and power generating companies to work together to find viable solutions prior to changes in plant operations that would affect the plant's ability to continue to provide warm water habitat that may result in cold-stress related deaths. Deferring plant closure or supplying an alternative warm-water discharge until an acceptable management alternative is developed and implemented are two potential temporary actions.

Accomplishments:

1. Wildlife agencies generally support the repowering of existing power plants that provide primary warm-water. The repowering of these plants extends the life span of important warm-water sites, providing time to develop strategies to create replacement warm-water habitat. The goal is to provide warm-water habitat alternatives for manatees that will be displaced when the operations at these plants cease to provide reliable warm water during winter. Power plants that have been repowered since 2000 include FPL's Ft. Myers, Cape Canaveral, Riviera Beach, and Port Everglades energy centers, Duke Energy's Bartow plant and Tampa Bay Electric Company's Bayside power station. TECO Big Bend and FPL Dania Beach Energy Center are undergoing modernization (2019).

2. National Pollution Discharge Elimination System (NPDES) manatee power plant protection plans are in place for all primary industrial warm-water sites. These plans will be reviewed and updated.

3. Temporary heating systems provided manatee protection during repowering efforts.

Strategy 4. Gradually decrease manatee dependence and use of specific industry-related warm-water discharges and minimize the negative effects to the manatee population as manatees adapt to new warm-water networks:

This management option would involve efforts to gradually wean manatees off specific industrial discharges before the discharges close. Whether such an action is possible without causing cold-related manatee deaths is uncertain and requires additional research to evaluate its feasibility. The goal would be to move manatees away from the warm-water discharge area. For such an approach to succeed, nearby alternative sites would probably have to be known and acceptable to the animals. Decisions to use this approach would require a determination that other available warm-water habitats within the range of the affected manatees are sufficient to support the desired regional winter aggregation. Also, a dedicated rescue and rehabilitation program is necessary to minimize adverse effects as manatees adapt to new warm-water networks.

Jacksonville Electric Authority District II outfall manatee exclusion barrier. Photo Credit: T. Calleson, USFWS

Accomplishments:

1. Worked with partners to provide deterrents to manatees using marginal warm-water habitat (JEA Northside power plant and the JEA District 2 wastewater treatment outfall).

2. Many successful rescues with the existing statewide manatee rescue and rehabilitation program.

Priority Management Questions:

1. How do we best minimize manatee distress and mortality during warm-water transitions?

2. What might be altered or enhanced to shift manatees from industrial warm-water sites to natural or passive warm-water sites?

Research Needs:

1. Assess manatee movement and population impacts associated with past changes in thermal discharges at power plants and other industrial facilities.

Over the past 25 years, there have been many changes in the operation of thermal discharges created by power plants and other industrial facilities. This ranges from complete loss of the warm-water refuge (e.g., closure of Ft. Pierce power plant) to temporary suspension of discharges for varied periods of time. Repowering of several power plants on the east coast has included provision for a temporary heating system to provide thermal shelter for manatees in the event of cold weather. A wealth of data has been collected in a number of these cases by employing aerial surveys, satellite telemetry, water temperature monitoring, and ground-based visual observations of animal condition (e.g., Deutsch and Barlas 2016, Reynolds and Scolardi 2016). In addition, a long-standing carcass salvage and necropsy program provides spatial data on cold-related mortality, and rescues yield information on the occurrence of cold-related morbidity. A long-term database (Manatee Individual Photo-Identification System) of uniquely identifiable individuals provides information on survival and reproductive rates, as well as gross changes in movements and use of warm-water sites that may be associated with plant operational changes. Combining the findings from these complementary methods provides us with a 'weight-of-evidence' approach to better understand how manatees that experienced a major change at a particular warm-water site responded in terms of site fidelity and movements, and whether

FPL Cape Canaveral Energy Center temporary heating system. Photo Credit: J. Lorne that response resulted in permanent dispersal away from the aggregation site or temporary emigration to other warm-water sites, and how that may have affected survival.

2. Document manatee response to future management actions taken to reduce their dependence on industrial warm-water discharges, including population-level effects.

To maximize our learning of what actions may effectively lessen manatee reliance on industrial discharges while minimizing manatee morbidity and mortality, it will be crucial to monitor manatee response to such actions at the individual level and to document population impacts. That is, to characterize behavioral response (e.g., movements, site fidelity) of individuals and changes in population distribution and mortality. Appropriate operational protocols and monitoring of manatee response and temperatures must be established to reduce the risk of cold-related mortality and to rescue and translocate manatees, as needed. In addition, an individual-based model could be developed and run beforehand to predict how the proposed actions may increase risk to manatees (reduced body condition, cold mortality) and the action can be then modified to minimize this risk. These investigations will provide valuable information when the need arises to reduce manatee use of other industrial thermal effluents being planned for closure or diffusion.

Strategy 5. Develop non-industry dependent warm-water habitats:

This option involves establishing non-industry dependent warm-water discharges and thermal basins to maintain regional cold season networks. Whether such options are fiscally possible or technologically dependable are uncertain and require additional research to evaluate their feasibility.

This strategy includes enhancing existing or creating new thermal basins in coastal waters that take advantage of natural or created haloclines, or that could retain heat from solar radiation at levels that support manatees during cold winter periods. This would likely be the most appropriate option in southern Florida where winter temperatures are relatively mild. Such an option might enable coastal waters in southern Florida to support a greater number of manatees. Sites such as these also would involve undertaking studies to identify the best possible locations for new warm-water habitats. FPL and Reliant Energy supported some initial studies in this regard.

Other potential strategies include establishing new warm-water habitats using passive methods such as releasing warm saltwater from the aquifer, or active technologically based methods such as solar water heating or gas-fired water heaters. The feasibility of warming an adequate volume of ambient water to a requisite temperature (e.g., 20°C) within confined embayments that will minimize heat loss to adjacent water bodies must be assessed. Sources of warm water would be independent of industrial outfalls. Delegation of the discharge operations to a government agency or a nonprofit entity is a possibility. To the extent that such facilities are required to replace an industry outfall on a temporary or long-term basis, costs for establishing and maintaining equipment may need to be borne by the industries that initially attracted manatees to the area.

Port of the Islands Manatee Mitigation Feature. Photo Credit: H. Andreotta, SFWMD

Accomplishments:

1. Port of the Islands Manatee Mitigation Feature, developed to replace lost manatee warm-water habitat, was created by constructing a series of three 20-feet-deep pools that access the saline surficial aquifer.

Priority Management Questions:

1. What attributes make a good warm-water refuge?

2. How do we identify potential locations of new warm-water habitat?

3. How can we address human disturbance in areas where these threats deter manatee use of warm water habitat, impacting the suitability of potentially important warm-water manatee refuges?

Research Needs:

1. Identify and investigate thermal basins.
Thermal basins provide warm-water habitat throughout virtually all the manatees' winter range. However, these habitats are poorly understood and require further investigation to determine their potential as a component of the future regional warm-water habitat network that will support manatees. Thermal basins maintain warm water in a variety of ways and, therefore, their thermal quality and reliability also vary greatly among sites. Further studies are needed to: (1) identify thermal basins that may provide warm-water habitat to manatees, (2) assess the thermal quality of these sites, (3) determine the physical attributes that make these types of habitat attractive to manatees, and (4) document how manatees are using these sites.

2. Document manatee response to the enhancement of existing or creation of new thermal basins.
In some situations, it will be advantageous to replace lost warm-water sites with newly created or enhanced thermal basins. Such projects may be expensive, and may require considerable time for planning, permitting, possibly land acquisition, and implementation. Given the time and resources necessary to create such sites, and the potential precedent for replacing other lost warm-water habitat, it will be vital to monitor manatee response to such projects, as well as to determine the thermal characteristics of the new warm-water site. For example, how quickly do manatees find and adopt the site during cold weather, especially after the original warm-water source has disappeared? Manatee re-distribution among regional warm-water sites and cold-related mortality should be monitored. Such an effort is ongoing at Port of the Islands where a series of interconnected deep basins have been created—fed by warm, saline groundwater—to offset the anticipated loss of the main warm-water site due to a major hydrological restoration project.

3. Evaluate/assess alternative sources of warm-water and sites for thermal refuges.
Our preference is for manatees to have minimal dependence on warm-water produced by artificial or technological sources over the long-term. These alternate sources of warm water may play an integral role in the interim in maintaining sufficient warm-water habitat to support the manatee population during a period of transition. Some of the alternate warm-water habitats that require further investigation include (1) groundwater, (2) passive thermal basins, (3) oceanic currents and (4) solar and other technologies. Additionally, earlier investigations examined methodology to identify potential locations of new warm-water habitat. These investigations used a variety of information related to geography, human demographics, bathymetry, and existing manatee habitat. This area of research requires additional work to facilitate the development of an inventory of potential warm-water habitat available to test prototypes as well as to mitigate for the elimination of existing warm-water habitats.

4. Investigate Human Dimensions.
Research is needed to characterize and influence knowledge, attitudes, perceptions, and expectations of the public with regard to manatees and warm water, including actions needed to allow manatees to safely access these key habitats.

Strategy 6. Develop techniques to influence/control manatee use of warm-water habitat:

This strategy focuses on the manipulation of manatee behavior to alter their use of warm-water habitat. This could potentially involve luring manatees away from existing industrial warm-water sites to preferred alternative refuges. Manatees also may be encouraged to use particular warm-water refugia preferred by managers by releasing them at these sites. This approach would apply most readily to manatees released after a period of rehabilitation at oceanaria, but free-ranging manatees could theoretically be captured near a site about to be retired and translocated to a new site. This strategy is most likely to be successful if the site preferred by managers has habitat requisites (thermal quality, nearby forage) also preferred by manatees. Additionally, creating deterrents to non-preferred refuge locations could be used to alter manatee habitat use patterns.

Accomplishments:

1. Florida Power and Light's temporary heating systems used to provide warm-water habitat during repowering efforts for the Cape Canaveral and Port Everglades facilities provided valuable information related to manatee behavior during alterations to a primary warm-water habitat.

Priority Management Questions

1. Can we capitalize on attributes of manatee behavior to shift manatees from industrial to natural/passive warm-water sites?
2. What is the desired winter range for manatees on each coast over the long-term horizon?

Research Needs:

1. Develop models that link the configuration of warm-water networks to manatee distribution and population impacts.

Without mitigation, expected losses of industrial warm-water habitat are projected to cause a major change in long-term manatee distribution from the regions where manatees are currently most abundant and rely heavily on power plant effluents for warmth in winter (Southwest and Atlantic) to the regions where manatees primarily use natural springs in winter (Northwest and Upper St. Johns; Runge et al. 2017). Determining the desired winter range for manatees on each coast of Florida over the long-term horizon is crucial in order to provide an overall vision for guiding decisions on the warm-water management issues that will arise over time (e.g., where to place alternative warm-water sites). A number of factors will need to be considered in making this decision, including social and economic ones. What are the population implications under different warm-water network configurations that yield different winter distributions? A structured decision-making (SDM) approach could be taken to facilitate and inform this decision process. It would rely on models that translate different management options (that yield different winter distributions) into population-level effects.

2. Assess manatee physiological responses to temperature change.

Researchers studying this issue have made several important contributions, including information on manatee metabolic rates and variation in cold tolerance of individual manatees and age classes. Despite this, we do not have a good understanding of the (1) lethal effects of cold stress, (2) sub-lethal effects of manatees being subjected chronically to cold ambient waters, (3) general cold and heat tolerance ranges of manatees, or (4) cost/benefit relationships of travel between warm-water sites and foraging areas. Some of these physiological questions need to be addressed in controlled laboratory environments, whereas others can be tackled through analyses of cold-related mortality data (e.g., Hardy et al. in press). For many other questions that cannot be readily addressed empirically, simulation models could be employed to test the effects of different 'what if' scenarios of warm-water site operation, ambient temperature conditions, and foraging distance on manatee movements, habitat use, energetics, and mortality.

Strategy 7. Prevent creation of new artificial warm-water discharges that could become an attractive nuisance:

Wastewater and reverse osmosis discharge sites have been documented to attract small numbers of manatees during the winter months. These discharges provide relatively small amounts of water that is slightly warmer than ambient water temperatures. These sites in the northern and central portions of the manatee's winter range have proven inadequate in supporting manatees throughout the winter. Several of these sites have been monitored in northeast Florida, with multiple manatees rescued from one location due to symptoms related to cold stress. Avoiding the creation of these attractive nuisance sites through appropriate design and construction techniques can prevent costly rescues and unnecessary manatee deaths.

Accomplishments:

1. Worked with partners to prevent nuisance warm-water sites, including reverse osmosis discharges in cities of Palm Coast, Melbourne and St. Augustine along Florida's east coast.

Priority Management Questions:

1. How can we proactively identify and prevent the creation of artificial attractive nuisance warm-water sites?

B. Establish Dedicated Funding Sources

The required research, planning, and implementation of the most appropriate management actions that will lead to safe, reliable and sustainable warm-water sites for manatees will require substantial funding. At this point, there has not been any dedicated funding for the efforts. The multiple accomplishments that have contributed to the efforts thus far have come from multiple agencies (USFWS, FWC, USGS, MMC) and individual stakeholders (the Power Generating Industry and non-governmental organizations). Identification of dedicated funding sources is required to resolve this issue with minimal loss to the existing manatee population. The potential funding sources identified include legislative allocations, stakeholder contributions, regulatory compensation or mitigation efforts.

C. Adaptive Management

The best available information informed the drafting of these management recommendations. As additional information becomes available, management and research activities need to be flexible and adapt strategies that will best secure warm-water habitat during both the short-term and long-term.

D. Develop Outreach Efforts

Dedicated outreach efforts are necessary to inform the public of the threats to Florida manatee warm-water habitat and the potential solutions to mitigate future problems. Resolving this issue will require agreement between a multitude of stakeholders that eventually will be concerned about, affected by and involved in this issue. Threats to an already vulnerable species will continue without a concerted effort by all concerned parties.

6. Next Steps

This Florida Manatee Warm-Water Action Plan provides an overview and management goals that address one of the most significant remaining threats to the continued persistence of the Florida manatee, the loss of warm-water wintering habitat. Developing an overall management framework for addressing the numerous warm-water management issues will require the efforts of multiple stakeholders. There are biological aspects to consider, including understanding the effects on manatee population size and mortality that will result from

Wakulla Springs. Photo credit R. Mezich, FWC

different warm-water network configurations that will yield different winter distributions. There will also be socio-economic aspects to this issue, including impacts of changing manatee aggregations on boating and ecotourism. The challenges in implementing these warm-water action plan strategies around the state are due, in part, to regional differences in warm-water habitat and the diversity of stakeholders invested in this issue. The USFWS and FWC have discussed and planned several initial steps to continue to implement the strategies encompassed in this action plan.

Florida Power and Light agreed to host a workshop with selected stakeholders, where current information can be shared, and input can be received that will assist agencies and stakeholders in understanding the complexity of issues and upcoming challenges. From this workshop, the primary stakeholders will identify and outline recommendations for potential paths forward.

Following the stakeholder meeting and the assessment of the stakeholders' recommendations, the USFWS in coordination with FWC will determine whether to reconstitute a new Warm-Water Task Force or working group as the best opportunity to continue stakeholder involvement. Also, because the regional management units are diverse in the amount, availability, and existing and potential warm-water habitat types, local expertise will be critical to development of warm-water habitat networks within each management unit. To develop these regional networks, the agencies will form regional partnership teams that can provide the needed expertise and recommendations for individual network plans for warm-water habitat in each management unit.

APPENDIX A: Warm-Water Site List

Warm-Water Site	County	Refuge Classification	Thermal Quality	Refuge Manatee Use	Refuge Type	Protection
St. Johns River Management Unit						
Alexander Springs Run	Lake	Potential	Unknown	Unknown	First Magnitude	Slow Speed all year
Blue Spring	Volusia	Primary	High	Established	First Magnitude	Seasonal No Entry Zone
Bugg Spring	Lake	Secondary	Unknown	Unknown	Second Magnitude	Private Property
DeLeon Springs	Volusia	Secondary	Low	Unpredictable	Second Magnitude	None
Juniper Springs Run	Marion/ Lake	Potential	Unknown	Unknown	Second Magnitude	Slow Speed all year
Ocklawaha River Springs*	Putnam/ Marion	Potential	Unknown	Unknown	Spring Specific	None
Salt Springs	Marion	Primary	High	Established	Second Magnitude	None
Silver Glen Springs	Marion/ Lake	Primary	High	Established	First Magnitude	Slow Speed all year in Spring Creek
Silver Springs	Marion	Primary	High	Unpredictable	First Magnitude	None
Welaka Springs	Putnam	Secondary	Low	Established	Third Magnitude	None
Atlantic Coast Management Unit						
Banana River Marine Service Marina	Brevard	Secondary	Low	Established	PTB – Unknown	Slow Speed all year
Berkeley Canal	Brevard	Secondary	Medium	Established	PTB – Unknown	Slow Speed all year
Big Mud Creek	St. Lucie	Secondary	Unknown	Unpredictable	PTB – Unknown	Idle Speed all year

Warm-Water Site	County	Refuge Classification	Thermal Quality	Refuge Manatee Use	Refuge Type	Protection
Biscayne Canal – S28	Miami-Dade	Secondary	Unknown	Unpredictable	PTB – Unknown	Seasonal No Entry Zone
Black Point Park Marina	Miami-Dade	Secondary	Unknown	Unpredictable	PTB – Unknown	No Entry Zone all year
Brown St. Canal	Monroe	Secondary	Medium	Established	PTB – Unknown	None
Coral Gables Waterway	Miami-Dade	Primary	High	Established	PTB – Aquifer	Seasonal No Entry Zone/Idle Speed all year
DeSoto Canal	Brevard	Primary	Medium	Established	PTB – Aquifer	Slow Speed all year
Eau Gallie River – weir	Brevard	Secondary	Unknown	Unpredictable	PTB – Unknown	Slow Speed all year
FPL – Canaveral Energy Center	Brevard	Primary	Medium	Established	Power Plant	Seasonal No Entry Zone
FPL – Dania Beach Energy Center	Broward	Primary	Medium	Established	Power Plant	No Entry Zone all year
FPL – Port Everglades Energy Center	Broward	Primary	Medium	Established	Power Plant	No Entry Zone all year
FPL – Riviera Beach Energy Center	Palm Beach	Primary	Medium	Established	Power Plant	Seasonal Motorboats Prohibited
Harbor Branch	St. Lucie	Secondary	Unknown	Unpredictable	PTB – Unknown	No Entry Zone all year/Idle Speed all year
Holiday Cove	Brevard	Secondary	Unknown	Unpredictable	PTB – Unknown	Slow Speed all year

Warm-Water Site	County	Refuge Classification	Thermal Quality	Refuge Manatee Use	Refuge Type	Protection
Atlantic Coast Management Unit						
Little River – S27 Structure	Miami-Dade	Secondary	Low	Established	PTB – Unknown	Seasonal No Entry Zone
OUC – Indian Power Plant	Brevard	Potential	None	Discontinued	Power Plant	Seasonal Motorboats Prohibited/ No Entry Zone
Palmer Lake	Miami-Dade	Secondary	Medium	Unpredictable	PTB – Unknown	Idle Speed all year
Satellite Beach City Hall	Brevard	Potential	Medium	No Access	PTB – Aquifer	No Vessel Access
Sebastian River – C-54 Canal	Brevard	Secondary	Low	Established	PTB – Unknown	Motorboats Prohibited all year/ Idle Speed all year
Sebastian River, South Prong	Brevard/ Indian River	Secondary	Low	Unpredictable	PTB – Halocline	Slow Speed all year
Taylor Creek	St. Lucie	Secondary	Unknown	Unpredictable	PTB – Unknown	Idle Speed all year
Turkey Creek	Brevard	Secondary	Unknown	Unpredictable	PTB – Unknown	Idle Speed all year
Turkey Point Canal	Miami-Dade	Secondary	Unknown	Unpredictable	PTB – Unknown	None
Upper Keys Canals	Monroe	Secondary	Unknown	Established	PTB – Unknown	None
Willoughby Creek	Martin	Secondary	Low	Established	PTB – Unknown	Slow Speed all year

Warm-Water Site	County	Refuge Classification	Thermal Quality	Refuge Manatee Use	Refuge Type	Protection
Northwest Management Unit						
Chassahowitzka Springs Group	Citrus	Secondary	Medium	Unpredictable	Second Magnitude	25 MPH All Year
Crystal River Springs Complex*	Citrus	Primary	High	Established	First Magnitude	Seasonal No Entry Zone
Duke Energy – Crystal River Power Plant	Citrus	Secondary	Low	Unpredictable	Power Plant	Seasonal Slow Speed
Fanning Springs	Levy	Secondary	Medium	Established	Second Magnitude	None
Homosassa Springs	Citrus	Primary	High	Established	First Magnitude	Seasonal No Entry Zone
Ichetucknee/ Santa Fe River Springs Complex*	Columbia/ Gilchrist/ Suwanee	Secondary	Site Specific	Unpredictable	Spring Specific	None
Jenkins Creek Spring	Hernando	Secondary	Low	Unknown	PTB – Unknown	None
Manatee Springs	Levy	Secondary	High	Established	First Magnitude	Park Seasonal No Entry Zone
Mud River Spring	Hernando	Secondary	Unknown	Unknown	Unknown Magnitude	None
Rainbow Spring	Marion	Potential	High	No Access	First Magnitude	None
Suwanee River Springs Complex*	Dixie/ Gilchrist	Secondary	Unknown	Unpredictable	Spring Specific	None
Wakulla Springs	Wakulla	Primary	Medium	Established	First Magnitude	Park Access Only

Warm-Water Site	County	Refuge Classification	Thermal Quality	Refuge Manatee Use	Refuge Type	Protection
Weeki Wachee River Springs Complex*	Hernando	Primary	High	Established	First Magnitude	None

Warm-Water Site	County	Refuge Classification	Thermal Quality	Refuge Manatee Use	Refuge Type	Protection
Southwest Management Unit						
Big Cypress Preserve Canal	Collier	Secondary	Medium	Established	PTB – Aquifer	20 MPH all year
Burnt Store Marina	Lee	Secondary	Unknown	Unpredictable	PTB – Unknown	None
Cow Creek Spring	Pasco	Secondary	Medium	Unpredictable	Unknown Magnitude	None
Duke Energy – Anclote Power Plant	Pinellas	Secondary	Low	Unpredictable	Power Plant	None
Duke Energy – Bartow Power Plant	Pinellas	Secondary	Medium	Established	Power Plant	Federal Seasonal No Entry Zone
Everglades Complex**	Monroe	Secondary	Unknown	Established	PTB – Unknown	None
FPL – Ft. Myers Power Plant	Lee	Primary	High	Established	Power Plant	Seasonal No Entry Zone/Idle Speed all year
Franklin Locks	Lee	Secondary	Low	Unpredictable	PTB – Unknown	Slow Speed all year
Henderson Creek	Collier	Secondary	Unknown	Established	PTB – Unknown	No Entry Zone all year
Hudson Spring	Pasco	Secondary	Low	Unpredictable	Unknown Magnitude	None

Warm-Water Site	County	Refuge Classification	Thermal Quality	Refuge Manatee Use	Refuge Type	Protection
Marco Island Canals	Collier	Secondary	Unknown	Established	PTB – Unknown	Idle Speed/ Slow Speed all year
Matlacha Isles	Lee	Secondary	Low	Established	PTB – Unknown	Slow Speed all year
Mud Bay	Monroe	Secondary	Low	Established	PTB – Unknown	None
Southwest Management Unit						
North Cape Coral Canals (Ceitus Lake)	Lee	Secondary	Low	Established	PTB – Unknown	None
Port of the Islands – Mitigation Site	Collier	Primary	Medium	Unpredictable	PTB – Aquifer	No Entry Zone all year
Port of the Islands – Port Canals	Collier	Primary	Medium	Established	PTB – Halocline	Idle Speed all year
Spring Bayou (Tarpon Springs)	Pinellas	Secondary	Low	Unpredictable	Third Magnitude (or PTB)	Slow Speed all year
Sulphur Spring	Hillsborough	Secondary	Unknown	Unpredictable	Second Magnitude	None
TECO – Bayside Power Plant	Hillsborough	Secondary	Medium	Established	Power Plant	None
TECO – Big Bend Station	Hillsborough	Primary	High	Established	Power Plant	Seasonal No Entry Zone/Slow Speed all year
Ten Mile Canal – Borrow Pit	Lee	Secondary	Medium	Established	PTB – Unknown	Slow Speed all year
Ulele Spring	Hillsborough	Secondary	Low	Unpredictable	Third Magnitude	None
Warm Mineral Spring Creek/ Salt Creek	Sarasota	Primary	High	Established	Third Magnitude	Seasonal No Entry Zone

Warm-Water Site	County	Refuge Classification	Thermal Quality	Refuge Manatee Use	Refuge Type	Protection
Wooten's Pond	Collier	Secondary	Medium	Established	PTB – Unknown	None

*Spring Complexes
(and their individual springs)

- **Ocklawaha River Complex**
(Blue, Cannon, Strange, Hasty Greene [Garfish] and other springs)
- **Crystal River Complex**
(3 Sisters, Gator, Idiot's Delight, King, Magnolia, Hunters, Jurassic and other springs)
- **Weeki Wachee River Complex**
(Weeki Wachee, Hospital, Little Salt Spring and other springs)
- **Ichetucknee/Santa Fe River Complex**
(Ichetucknee, Blue, Cedar, Roaring and other springs)
- **Suwannee River Complex**
(Hart, Troy, Otter and other springs)

****Everglades Complex**
(Composed of multiple small sites in the coastal Everglades of Monroe County.)

Warm-Water Site Criteria and Definitions

Refuge Classification:

- **Primary:**
- Site is established with predictable and consistent manatee use. Site is regionally important.
- High or medium thermal quality with consistent thermal capacity.
- Manatees present in all winter conditions and site often has medium or high manatee use.

- **Secondary:**
  - Site is established with either predictable or unpredictable use by manatees. Site is regionally important.
  - Thermal quality is typically medium or low and may be unreliable in cold weather and is unreliable in severe weather
  - Typically, medium or low manatee use in mild or cold weather, but low or no manatee use in severe weather.

    Site is often a low flow spring, inconsistent power plant or passive thermal basin.
- **Potential:**
  - Little or no current manatee use.
  - There may be historical records of manatee use at the site. Physical and thermal attributes are unknown due to a lack of data.
  - The site may be inaccessible or have limited access for manatees. Location and other attributes suggest site has potential as warm-water habitat.

Refuge Manatee Use:

- **Established:** The site has consistent or predictable manatee use throughout the winter and is regionally important.
- **Unpredictable:** Manatee use is inconsistent. Thermal quality is generally unknown. The availability of freshwater may also be an attractant to the site.
- **Unknown:** Site has been reported to have some current or historic manatee use but there is little or no documentation on manatee use or thermal quality of the site.

Refuge Type:

- **Springs:**
  - ***First Magnitude Spring:*** ≥100 cubic feet/second or ≥64.6 million gallons/day
  - ***Second Magnitude Spring:*** ≥10 cfs up to 100 cfs or ≥6.46 mgd up to 64.6 mgd
  - ***Third Magnitude Spring:*** ≥1 cfs up to 10 cfs or 0.646 mgd up to 6.46 mgd
- **Thermal Quality:**
  - ***High:*** water temperatures ≥22°C during mild, cold or severe cold weather
  - ***Medium:*** water temperatures ≥22°C during mild, ≥20°C during cold, and ≥18°C during severe conditions
  - ***Low:*** water temperatures ≥20°C during mild, ≥16°C during cold and unreliable in severe cold conditions
  - ***Unknown:*** temperature data at the site has not been collected or is insufficient

Photo Credit: Andy Wraithmell

APPENDIX B: Glossary

Artificial warm-water discharges: see "industrial warm-water discharges"

Cold stress: a condition characterized by exposure to prolonged cold temperatures resulting in a complex, multi-factorial disease that involves metabolic, nutritional and immunological components

Exit strategy: identified actions are taken to prevent manatee deaths due to the loss of industrial warm-water sites

Flow rate: volume of water flowing out of a spring or along a spring run over a set period of time; generally expressed as cubic feet per second (cfs)

Industrial warm-water discharges: warm-water habitat characterized by water warmed by discharges from manufacturing plants (power plants, paper mills, water treatment facilities, etc.)

Natural warm-water habitat: includes warm-water habitat characterized by warm water derived from non-human-related sources

Passive warm-water habitat: warm-water habitats where thermoclines and other physical conditions slow localized water column cooling processes and temporarily retain pockets of relatively warm water

Regional warm-water network: a collection of warm-water refuge sites distributed within a region of the state supporting a distinct group of manatees during the cold season

Repowering: the conversion of older power generating units to newer ones, to enhance efficiency and electricity generation

Thermal basins: see "passive warm-water habitat" (Laist and Reynolds 2005a)

Thermal neutral zone: that range of temperatures where no additional metabolic energy is necessary and metabolic rates are independent of environmental temperature (Worthy et al. 2000). That is, the temperature range at which there is no metabolic cost to the manatee.

Warm-water carrying capacity: the maximum number of manatees supported by the volume of warm water at a site or all combined warm-water sites in Florida

Warm-water discharges: warm-water habitat feature characterized by the continuous flow of water at temperatures above ambient winter water temperatures

Warm-water habitat: manatee habitat characterized by site-specific water temperatures sufficient to attract manatees during the winter. Water temperatures are warmer than ambient waterway temperatures, and these elevated temperatures derive from either manmade or natural sources.

Warm-water refuge or warm-water refugia: synonymous with warm-water habitat, including habitat that derives heat from passive and discharge sources

Winter aggregation: a winter gathering of manatees at a warm-water site

APPENDIX C: History of the Warm-Water Task Force

On August 24-25, 1999, the U.S. Fish and Wildlife Service (Service) held a workshop in Jupiter, Florida, to review what was known about the Florida manatee's winter use of warm-water sites, what was known about the status and future of these sites, and to identify what was needed to ensure the future availability of warm water for this thermally sensitive species (USFWS 2000). Workshop members recommended the Service convene a "warm- water task force" charged with maintaining a safe and reliable network of warm-water refuges for manatees. In 2000, the Service convened the Warm-Water Task Force (WWTF) as a component of the Florida Manatee Recovery Team (USFWS 2001).

The WWTF included representatives from the Service, the Florida Fish and Wildlife Conservation Commission (FWC), the Florida Department of Environmental Protection (FDEP), the US Environmental Protection Agency (EPA), the US Marine Mammal Commission (MMC), the US Geological Survey (USGS), the Florida Power Corporation (FPC), the Florida Power and Light Company (FPL), Mote Marine Laboratory (Mote), Reliant Energy (Reliant), and the Tampa Electric Company (TECO). Members met regularly until the WWTF was disbanded in 2007, coinciding with the termination of the Service's Florida Manatee Recovery Team.

During the WWTF's tenure, task force members reviewed and implemented many of the recommendations made at the 1999 workshop. Significant accomplishments included addressing concerns related to warm-water losses associated with both section 316(b) of the Clean Water Act and deregulation of the power industry, providing support for significant, warm-water-related research projects, and the development of a draft document, "Recommendations for Future Manatee Warm-Water Habitat", which formed the basis for the WWAP. The WWTF document includes background information and identifies actions that the WWTF believes are needed to ensure the continued availability of warm water to manatees and, consequently, the long-term persistence of manatee populations throughout Florida.

After 2007, the manatee's warm-water habitat underwent many changes. Five power plants used by wintering manatees have been repowered (FPL's Cape Canaveral, Riviera Beach, and Port Everglades Energy Centers, Duke Energy's Bartow plant and Tampa Electric's Bayside plant) and planning for the repowering of the FPL Ft. Lauderdale plant is underway. Also, during this period, four facilities ceased operations (FPL Cutler and OUC Indian River power plants, and the City of Vero Beach and the City of Fort Pierce power plants). Manatee access to several springs has been improved, and minimum flows and levels (MFL) have been adopted for a few important springs used by manatees. Important warm-water sites have been acquired and rules have been adopted to further protect manatees using these sites. In addition to these changes in the manatee warm-water network, Florida experienced a prolonged and severe winter in 2010, when at least 252 (and up to 449) manatees died from cold stress (Barlas et al. 2011). These changes and the unexpectedly harsh winter brought new dynamics that must be considered in the development of long-term strategies for regional warm-water networks. While progress has been made in securing warm-water habitat for the future, it is clear additional steps must be taken to address the changing warm-water habitat landscape.

In view of these changes and through a new opportunity to move forward with long-term planning for manatee warm-water habitat, this plan has been updated. Florida Power and Light's repowering of its east coast power plants provided an opportunity for wildlife agencies and stakeholders to begin this process prior to the potential adverse effects resulting from cessation of power plant thermal effluents on the manatee population in the Atlantic region. The initial step in this process has been formalized in the site certifications for FPL's east coast plants during their repowering (Florida Power Plant Siting Act, Condition of Certification XX11.B, Section V.A.5.a(1)).

APPENDIX D: Manatee Winter Ecology

Throughout the summer months, the Florida manatee typically ranges north along the Atlantic coast to the Carolinas and west along the Gulf coast to Texas (Fertl et al. 2005; Rathbun et al. 1982). With the onset of autumn, most manatees head southward to wintering sites located along the coastal and riverine waterways of peninsular Florida where their physiological requirements are met (Irvine 1983; Worthy et al. 2000). The manatee's low metabolic rate, and poor insulation (Worthy et al. 2000), results in a lack of cold tolerance and susceptibility to cold-related mortality (Irvine 1983; Buergelt et al. 1984; Bossart et al. 2002). This lack of cold tolerance forces manatees to seek waters warmer than 20°C during the winter months. Failure to do so can result in cold-related death, which has been documented in every coastal Florida county by the FWC's Marine Mammal Pathobiology Lab (FWC 2017).

Behaviorally, manatees have adapted to Florida's winters by using natural springs, passive thermal basins, and industrial warm-water discharges. Due to the limited number of warm-water sites and the variability in their thermal quality, manatees aggregate in large numbers at the most significant and dependable of these warm-water refugia. Manatee warm-water aggregation behavior appears to be learned; calves learn when and where to seek out these refugia from their mothers during the winters that they are together (Bengtson 1981; Deutsch et al. 2003). Manatees show strong site fidelity, often returning to the same warm-water refuge(s) year after year (Rathbun et al. 1990, 1995; O'Shea and Hartley 1995; Deutsch et al. 2003). Most manatees are familiar with the location of multiple warm-water sites, traveling from one warm-water site to another during the winter (this is especially true on the Atlantic coast); some appear to be familiar with warm-water sites in just a given area (e.g., northern Indian River lagoon; Reid et al. 1991; Deutsch 2000; Beck 2000).

The age and size of manatees play a significant role in an animal's tolerate adjust to cold-water temperatures, resulting in disproportionately higher mortality among sub-adult manatees (O'Shea et al. 1985, Ackerman et al. 1995, Bossart 2001, Barlas et al. 2011). Adult manatees retain body heat better than sub-adults because of a more favorable surface-area-to-volume ratio. Furthermore, smaller manatees are apparently unable to raise their metabolic rate in response to water temperatures below their thermoneutral zone (Worthy et al. 2000). Adults also benefit from the cumulative experience of surviving many winters of varying severity. Small, dependent calves benefit from their mother's wintering experience and milk, which provides a high-fat food source. In conjunction with the physiological disadvantages noted above, sub-adults may be more vulnerable to the cold because of their inexperience in finding warm-water refugia on their own.

Manatee migrations to warm-water habitats occur each year when ambient water temperatures approach or drop below 20°C (68°F) (Hartman 1979, Bengtson 1981, O'Shea and Kochman 1990, Deutch et al. 2003). Powell (1981) observed that the first significant change in the number of animals present in Crystal River (in northwest Florida) occurred when Gulf of Mexico temperatures approached 21° to 22°C (70° to 72°F). Hartman (1979) and Bengtson (1981) noted that, when ambient water temperatures drop consistently below about 20°C (68°F), manatees move to sources of warm water. Kochman et al. (1983) observed that from November through February when manatee use of Kings Bay is highest, water temperatures in the Gulf of Mexico fall far below 20°C (68°F) and may remain below 16°C (61°F) during the coldest months. Deutsch et al. (2003) found that tagged manatees in Brevard County generally left their warm-season range when the ambient water temperature dropped to 19°C (66°F), but the "threshold" temperature that stimulated migration varied substantially among individuals, ranging from 16° to 22°C (61° to 72°F).

In addition to behavioral responses to cold temperatures, manatees physiologically react to cold by increasing their metabolic rate when water temperatures go below 20°C (68°F) (Irvine 1983, Worthy et al. 2000). Captive adult manatees at rest increased their metabolic rate by almost 100 percent when water temperatures dropped to 15°C (59°F); however, subadults (<300 kg body mass) appear incapable of raising their metabolic rate in response to cold temperatures (Worthy et al. 2000). Campbell and Irvine (1981) observed that captive manatees exposed to water temperatures below 16° to18°C (61° to 64°F) for several days experienced lethargy and anorexia. Hartman (1979) noted that manatees appeared to be thermally stressed at water temperatures below 18°C (64°F). Even though water temperatures below 20°C (68°F) increase the risk of cold stress, free-ranging manatees have been documented foraging in such conditions on a regular basis, as long as they have ready access to a thermal refuge (Deutsch et al. 2006; Laist and Reynolds 2005a, Barlas et al. 2011, Deutsch and Barlas 2016). An adult female ("Knicky") survived temperatures below 15°C (59°F) for nearly two weeks while migrating southward from Savannah, Georgia to Florida (Deutsch et al. 2000). Her young calf, however, perished during the journey.

While seeking refuge from the cold, manatees must also consume enough forage to sustain them during extreme cold periods to avoid a "shutdown" of the digestive tract (Bossart 2001). Water temperature is the obvious influence affecting manatee feeding activity during the winter. Rose and McCutcheon (1980) noted in their power plant research that, "It appears that manatees will forego feeding in times of severe cold to remain in association with the warmer waters of these effluents, or they may be limited to foraging in close proximity of a thermal refuge." This inference has been confirmed through radio-telemetry studies of manatee use of natural springs (Bengtson 1981) and industrial discharges (Deutsch 2000, Deutsch and Barlas 2016). Manatees visiting the Tampa Electric Company (TECO)-Big Bend refuge in Tampa Bay fasted for periods of up to one week during periods of extreme cold (Deutsch and Edwards 2005). During the extremely cold winter of 2010-11, one tagged manatee did not leave a manmade warm-water refuge for 32 consecutive days, further emphasizing the extremes some manatees will endure and still survive during the winter months (Deutsch and Barlas 2011, 2016).

Conversely, during warm winter periods, manatees may travel significant distances to preferred feeding areas and even to other warm-water refuge sites. Several primary aggregation sites are not near significant amounts of vegetation, and yet manatees survive winters in these locations, such as at FPL's Ft. Myers, Lauderdale, and Port Everglades power plants. Manatees using the Riviera Beach power plant often travel 20 to 35 km northward to feed in Hove and Jupiter Sounds (Lefebvre and Powell 1990). Manatees at these locations, as at others, take advantage of periods of warm winter weather to travel to foraging grounds and sometimes use secondary warm-water sites as temporary refuges during foraging trips. Some individuals along the Atlantic coast even make long-distance "mid-winter migrations" (i.e., roundtrips of >100 km), traveling from southeastern Florida to as far north as the Banana River in central Florida (Deutsch et al. 2003).

It may seem logical that the elimination of a warm-water refuge would result in manatees quickly choosing a new warm-water site. However, there have been a few opportunities to observe manatee response to the loss of a warm-water refuge and the results have not always been predictable. Reynolds (2000) noted that, "… manatee use of warm-water discharges seems to be a paradox. Over time, they show great ability to learn to use resources, such as artificial warm- water refugia that did not exist historically. On the other hand, they may react to the sudden elimination of such resources by simply waiting for the resources in question to reappear …" Manatees may also respond by seeking nearby, short-term alternatives, even if they are only marginally warmer than surrounding waters (Packard et al. 1989), or the manatees may wait at the site for the return of the warm- water source. In at least one event, this behavior proved fatal for several manatees in northeast Florida when a regionally important warm-water refuge was eliminated (Deutsch et al. 2000). As difficult as this behavior is to understand, from the manatees' perspective it does make some sense. Most, if not all the manatees using the current industrial warm-water sites have habituated to them because of their dependability and security. Many of these sites have been temporarily shut down and almost always return to their original operations. Manatee site fidelity has been and will continue to be a problematic issue for wildlife managers attempting to minimize the loss of manatees due the elimination of industrial warm-water habitat.

During the winter of 2009-10, Florida experienced extremely cold weather for protracted periods. During this winter, 252 manatee deaths were attributed to cold stress and an additional 197 were strongly suspected to be related to cold stress but were labeled as undetermined deaths because the manatees could not be physically recovered, or the carcasses were too badly decomposed to identify the cause of death (Barlas et al. 2011). Cold weather-related manatee deaths had not been documented in these numbers before 2010; the existing warm-water networks showed their current vulnerability as did manatee behavior associated with these networks. The usually dependable warm-water refugia created by power plant discharges were greatly stressed by increased human demands for power and the mechanical breakdowns at plants that occurred as a result. Also, ambient water temperatures reached lows that the power plant discharges could not overcome, resulting in refugia temperatures falling below 20°C (68°F) for extended periods even when plants were operating under full load.

When reviewing the locations of the 2010 cold stress deaths, most deaths occurred in areas where manatees are typically more susceptible, the central Atlantic and southwest coasts. These areas have warm-water networks supported primarily by power plant discharges or passive thermal basins. Manatees using warm-water habitat in northwest Florida and the St. Johns River rely on warm-water networks supported primarily by springs. In southeast Florida, water temperatures are moderated due to the proximity of the Gulf Stream and manatees using warm-water sites here fared much better (Barlas et al. 2011, Laist et. al. 2013). This extreme winter provided new and valuable information that will be used in shaping the long-term planning for regional warm-water networks that are supported by fewer power plant created warm-water refugia.

APPENDIX E: Manatee Warm-Water Overview

Although fossil evidence indicates that modern manatees (T. manatus) were present in Florida in the early Pleistocene up to 1.1-1.5 million years ago (Domning 1982, 1987; Morgan and Hulbert 1995), it is unclear whether they have been present in Florida continuously since that time (Laist and Reynolds 2005a). With about eight glacial cycles over the past 800,000 years, each lasting about 100,000 years, it is possible that manatees occurred in Florida only during relatively warm inter-glacial periods, such as the current inter-glacial period (i.e., the Holocene), which began about 11,500 years ago. The end of the last ice age and dawn of the Holocene coincided with the arrival of the first humans in Florida about 12,000 years ago, and there is evidence that Florida's first human residents hunted manatees. Three manatee ribs believed to be about 10,000 years old, with cut marks indicating they were from butchered animals, have been found along the Ocklawaha and Withlacoochee Rivers (Waller 1970 as cited in Cumbaa 1980). Manatee remains in more recent middens and other archeological sites up to the arrival of the first Europeans about 500 years ago are rare (Laist and Reynolds, 2005a), suggesting that manatees were taken opportunistically, perhaps as a supplemental food source (Hartman 1979, O'Shea 1988). Although archeological and paleoclimate records from the early Holocene are incomplete, Laist and Reynolds (2005a) speculate that natural warm-water springs in northern Florida may once have been important major over-wintering habitats for manatees – possibly more important than waters in southernmost Florida – and that opportunistic hunting at those sites in winter may have reduced their abundance and restricted their range to southernmost Florida.

By the mid-1900s, when Moore (1951a, 1951b) conducted the first directed studies of manatees in Florida, he reported that most manatees were concentrated in rivers and estuaries in the Everglades in southernmost Florida where "manatees have survived their persecution best" (Moore 1951b). He reported that the northern limit of the species' winter range at that time was Sebastian Inlet on the east coast and Charlotte Harbor on the west coast. By this time, five power plants had been constructed along Florida's east coast; one in Fort Lauderdale built in 1926, one in Riviera Beach built in 1946, one in Jacksonville (1912/1955), one in Miami (that was known to be discharging warm-water in 1949 as reported by Moore (1956)), and another constructed in Fort Pierce in 1912 (although the latter did not have a once-through cooling system discharging warm water until 1945).

By the mid-1960s, when Hartman (1979) initiated studies that would form the basis for a dedicated Florida manatee research program, the nuclei of current manatee aggregations in the Crystal and upper St. Johns Rivers were already in place. In the winters of 1967-68 and 1968-69, when the first manatee counts were made at Crystal River, Hartman identified 63 individuals, 35 of which were seen in both years. At that time, local guides and fishermen unanimously stated that manatees were far more numerous in the area than at any previous time. At Blue Spring in the winters of 1970-71 and 1971-72, 11 and 18 manatees, respectively, were identified, 7 of which were seen in both years (Hartman 1979). Compared to recent counts, it is apparent that manatee abundance at both sites increased exponentially over the past 40 years. Although manatee use of these sites has certainly increased over time, it also should be pointed out that substantial management actions have been taken at these important refuges that have secured this warm-water habitat for increasing manatee use.

All seven power plants now used, at least occasionally, by 50 or more manatees, were built before 1972 when the Clean Water Act (CWA) was passed. Since then, new power plants have been prohibited from discharging heated effluent into open waters. Older plants, however, have been granted waivers to those regulations, allowing them to continue their thermal discharges. The numbers of manatees using these discharges have increased significantly over the past 40 years, and many animals now exhibit a high degree of site fidelity to those discharges (Deutsch 2000). Based on a review of information on past and current manatee distribution, O'Shea (1988) concluded manatees are as widespread now as they ever were.

Although some people interpret Moore's findings regarding the winter range of manatees in the late 1940s (i.e., concentrated in southern Florida) as representing their historic winter distribution, this may not be the case. As noted above, the natural warm-water habitat best able to support large numbers of manatees in winter appears to be natural springs in central and northern Florida. While southern Florida is capable of supporting manatees through the winter, it is unclear whether natural warm-water habitats in that area can support more animals than current levels. Although very incomplete, Laist and Reynolds (2005a) suggest that available archeological and paleoclimatic data indicate that natural springs may have been principal winter habitats for manatees in the distant past and that hunting by natives and Europeans, particularly in the 1800s, may have artificially restricted their winter range to extreme southern Florida by the time of Moore's studies in the mid-1900s.

Photo courtesy of USGS

Manatees enjoying the warmth at the restored Fanning Springs. Photo by FWC.

APPENDIX F: Literature Cited

Ackerman, B. B., S. D. Wright, R. K. Bonde, D. K. Odell, and D. J. Banowetz. 1995. Trends and patterns in mortality of manatees in Florida, 1974-1991. Pp. 223-258 in T. J. O'Shea, B. B. Ackerman, and H. F. Percival, eds., Population Biology of the Florida Manatee (*Trichechus manatus latirostris*). National Biological Service, Information and Technology Report 1. 289 pp.

Barlas, M.E., C.J. Deutsch, M. de Wit, and L.I. Ward-Geiger (editors). 2011. Florida manatee cold-related unusual mortality event, January – April 2010. Final report to USFWS (grant 40181AG037). Florida Fish and Wildlife Conservation Commission, St. Petersburg, FL. 138pp.

Barbour, T. 1944. That Vanishing Eden: a naturalist's Florida. Little, Brown & Company, Boston. 250pp.

Bartram, W. 1791. Travels through North & South Carolina, Georgia, east & west Florida. James and Johnson. Philadelphia. Reprinted 1928, as Travel of William Bartram. Mark Van Doren, ed. Dover Publications. New York, NY.

Baugh, T. M., Valade, J. A. and Zoodsma, B. J. 1988. Manatee use of Spartina alterniflora in Cumberland Sound. Mammal Science 5: 88-90.

Beck, C. A. 2000. Winter Use of Warm Water Sites by Photographically Identified Manatees. Pages 65-66 in U.S. Fish and Wildlife Service. Florida manatees and warm water: Proceedings of the warm- water workshop, Jupiter, Florida, August 24–25, 1999

Bengtson, J. L. 1981. Ecology of manatees (*Trichechus manatus*) in the St. Johns River, Florida. PhD. Dissertation, University of Minnesota, Minneapolis.

Bossart, G. 2001. Manatees. In: L. Dierauf & F. Gulland (eds.) Marine Mammal Medicine, pp. 939–960. CRC Press, Boca Raton, FL.

Brinton, D. G. 1869. A guide-book of Florida and the south, for tourists, invalids, and emigrants. Geo. Maclean. Philadelphia, Pa. 136p.

Buergelt, C.D., R.K. Bonde, C.A. Beck, T.J. O'Shea. 1984. Pathologic findings in manatees in Florida. Journal of the American Veterinary Medical Association, 185: 1331-1334.

Campbell, H.W., and A. B. Irvine. 1981. Manatee mortality during the unusually cold winter of 1976-1977. Pages 86-91 in R. L. Brownell, Jr. and K. Ralls, eds. The West Indian manatee in Florida. Proceedings of a workshop held in Orlando, Florida, 27-29 March 1978. Florida Department of Natural Resources, Tallahassee, Florida, USA.

Canova, A. P. 1885. Life and adventures in South Florida. Southern Sun Publ. Palatka, Fl. 136p.

Cumbaa, S.A. 1980. Aboriginal use of marine mammals in the southeastern United States. Southeastern Archeological Conference Bulletin 17: 6-10.

Deutsch, C.J. 2000. Winter movements and use of warm-water refugia by radio-tagged West Indian manatees along the Atlantic coast of the United States. Final Report prepared for the Florida Power and Light Company and U.S. Geological Survey. 133 pp.

Deutsch, C. J., J. P. Reid, L. W. Lefebvre, D. E. Easton, and B. J. Zoodsma. 2000. Manatee response to elimination of a thermal refuge in northeastern Florida: A preliminary report of results. Pages 71-73 in U. S. Fish and Wildlife Service. Florida manatees and warm water: Proceedings of the warm-water workshop, Jupiter Florida, August 24-25, 1999.

Deutsch, C. J., J. P. Reid, R. K. Bonde, D. E. Easton H. I. Kochman and T. J. O'Shea. 2003. Seasonal movements, migratory behavior, and site fidelity of West Indian manatees along the Atlantic coast of the United States. Wildlife Monographs, 151: 1-77.

Deutsch, C. J. and H. H. Edwards. 2005. Recording fine-scale movements of manatees using marine GPS tags. Final report to the U. S. Fish and Wildlife Service. FWC/FWRI file F2337-02-04-F. 34 pp.

Deutsch, C. J., H. H. Edwards, and M. E. Barlas. 2006. Florida manatee foraging behavior around a winter warm-water refuge. Final Report to the Wildlife Foundation of Florida. Grant No. CWT0405-12. FWC/FWRI file FCWT0405-12-F. 42 pp.

Deutsch, C.J. and M.E. Barlas. 2011. Manatee response to the conversion of the FPL Cape Canaveral power plant: Movements, warm-water habitat use, and thermal regime of satellite-tagged manatees during winter 2010-11. Annual Report to Florida Power & Light Company. FWC/FWRI file F2864-10-A1. 61 pp.

Deutsch, C.J. and M. E. Barlas. 2016. Manatee response to the conversion of the FPL Cape Canaveral power plant: Movements, warm-water habitat use, and thermal regime of satellite-tagged manatees during winters 2010-11 through 2014-15. Final Report to Florida Power & Light Company. FWC/FWRI file F2864-10-15-F. 113 pp. + appendices. http://f50006a.eos-intl.net/ELIBSQL12_F50006A_Documents/16Deutsch.pdf

Domning, D. P. 1982. Evolution of manatees: a speculative history. Journal of Paleontology 56(3): 599-619.

Domning, D.P. 1987. Sea cow family reunion. Natural History (April 1987) 96(4): 64-71.

Edwards, H. H. 2013. Potential impacts of climate change on warm water megafauna: the Florida manatee example (*Trichechus manatus latirostris*). Climatic Change, 121(4): 727-738.

Edwards, H. H., J. Martin, C. J. Deutsch, R. G. Muller, S. M. Koslovsky, A. J. Smith, and M. E. Barlas. 2016. Influence of manatees' diving on their risk of collision with watercraft. PLOS ONE 11(4): e0151450. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0151450

Fertl, D. A., A. J. Schiro, G. T. Regan, C. A. Beck, N. Adimey, L. Price-May, A. Amos, G. A. J. Worthy, and R. Crossland. 2005. Manatee Occurrence in the Northern Gulf of Mexico, west of Florida. Gulf and Caribbean Research 17: 69-74.

FWC. 2007. Florida Manatee Management Plan. Florida Fish and Wildlife Conservation Commission, Tallahassee, Florida. 178 pp. + addendum.

FWC. 2017. Manatee Mortality Database. Accessed June 5, 2017. See: https://myfwc.com/research/manatee/rescue-mortality-response/statistics/mortality/

Florida Fish and Wildlife Conservation Commission, Imperiled Species Management Section, 2007.

Florida Springs Task Force. 2000. Florida's Springs: Strategies for Protection and Restoration, Tallahassee, FL. pp. 1-63.

Glaser, K. and J.E. Reynolds, III. 2003. Mysterious Manatees. University Press of Florida, Gainesville, FL. 208 pp.

Hallock, C. 1876. Camp life in Florida. Smith and McDugal, New York, NY. 348p.

Hardy, S. K., C. J. Deutsch, T. A. Cross, M. de Wit, and J. A. Hostetler. In press. Cold-related Florida manatee mortality in relation to air and water temperatures. PLOS ONE.

Hartman, D. S. 1979. Ecology and behavior of the manatee (*Trichechus manatus*) in Florida. American Society of Mammalogists Special Publication No. 5.

Irvine, A. B. 1983. Manatee Metabolism and Its Influence on Distribution in Florida. Biological Conservation, 25 (4): 315-334

Kochman, H.I., G. B. Rathbun, and J.A. Powell. 1983. Use of Kings Bay, Crystal River, Florida, by the West Indian manatee (Trichechus manatus). Pp. 69-124 in Packard, J.M. (ed). Proposed Research/Management Plan for Crystal River Manatees. Vol. III. Compendium. Technical Report No. 7. Florida Cooperative Fish and Wildlife Research Unit. University of Florida, Gainesville, FL. 346 pp.

Laist, D. W., and J. E. Reynolds, III. 2005(a). Influence of Power Plants and Other Warm-Water Refuges on Florida Manatees. Marine Mammal Science 21(4):739-764.

Laist, D. W. and J. E. Reynolds, III. 2005(b). Florida Manatees, Warm-Water Refuges, and an Uncertain Future. Coastal Management, 33: 279-295

Laist, D. W., C. Taylor, and J. E. Reynolds III. 2013. Winter Habitat Preferences for Florida Manatees and Vulnerability to Cold. PLoS ONE 8(3): e58978. doi:10.1371/journal.pone.

Lefebvre, L. W. and Powell, J. A. 1990. Manatee Grazing Impacts on Seagrasses in Hobe Sound and Jupiter Sound in Southeast Florida during the Winter of 1988-1989. Final Report prepared for the Marine Mammal Commission in Fulfillment of Contract T62239152.

Moore, J. C. 1951a. The Status of the Manatee in the Everglades National Park, with Notes on its Natural History. Journal of Mammalogy, 32: pp.22-36.

Moore, J. C. 1951b. The Range of the Florida Manatee. The Quarterly Journal of the Florida Academy of Sciences. Volume 14, No. 1. pp.1-18.

Moore, J. C. 1956. Observations of manatees in aggregations. American Museum Novitates No. 1811: 1-24.

Morgan, G. S., and R. C. Hulbert, Jr. 1995. Overview of the geological and vertebrate biochronology of the Leisey Shell Pit local fauna, Hillsborough County, Florida. Bulletin of the Florida Museum of Natural History 31, Part I: 1-92.

NewFields Companies, LLC. 2007. Analysis of Blue Spring Discharge Data to Determine a Minimum Flow Regime. St. Johns River Water Management District Special Publication SJ2007-SP17.

O'Shea, T.J., C.A. Beck, R.K. Bonde, H.I. Kochman and D.K. Odell. 1985. An Analysis of Manatee Mortality Patterns in Florida, 1976-81. Journal of Wildlife Management, 49(1), pp. 1-11.

O'Shea, T. J. 1988. The Past, Present, and Future of Manatees in the Southeastern United States: Realities, Misunderstandings, and Enigmas. In R.R. Odom, K.A. Riddleberger, and J.C. Ozier, eds. Proceedings of the Third Southeastern Nongame and Endangered Wildlife Symposium. pp.184-204. Georgia Department of Natural Resources, Game and Fish Division, Social Circle, GA. 253 pp.

O'Shea, T.J. and H.I. Kochman 1990. Florida Manatees: Distribution, Geographically Referenced Data Sets, and Ecological and Behavioral Aspects of Habitat Use. Pp. 11-22 in J.E. Reynolds, III, and K.D. Haddad, editors. Report of the Workshop on Geographic Information Systems as an Aid to Managing Habitat for West Indian Manatees in Florida and Georgia. Florida Marine Research Publications 49: 1- 57.

O'Shea, T. J., and W. C. Hartley. 1995. Reproduction and early-age survival of manatees at Blue Spring, Upper St. Johns River, Florida. Pp. 157-176 in T. J. O'Shea, B. B. Ackerman, and H. F. Percival, eds., Population Biology of the Florida Manatee (*Trichechus manatus latirostris*). National Biological Service, Information and Technology Report 1. 289 pp.

Packard J. M., R. K. Frohlich, J. E. Reynolds, III, and J. R. Wilcox. 1989. Manatee Response to Interruption of a Thermal Effluent. Journal of Wildlife Management, 53(3): 692-700.

Powell, J. A. 1981. The manatee population in Crystal River, Citrus County, Florida. Pages 33- 40 in R. L. Brownell, Jr. and K. Ralls, eds. The West Indian manatee in Florida. Proceedings of a workshop held in Orlando, Florida, 27-29 March 1978. Florida Department of Natural Resources, Tallahassee, Florida, USA.

Powell, J. A. and G. B. Rathbun. 1984. Distribution and abundance of manatees along the northern coast of the Gulf of Mexico. Northeast Gulf Science 7(1): 1-28.

Rathbun, G.B., R.K. Bonde and D. Clay, 1982. The Status of the West Indian Manatee on the Atlantic Coast North of Florida. In Proceedings of the Symposium on Nongame and Endangered Wildlife (R.R. Odom and J.W. Guthrie, eds.). Georgia Department of Natural Resources, Game and Fish Division, Tech. Bull. WL5. 179 pp.

Rathbun, G. B., J. P. Reid, and G. Carowan. 1990, Distribution and movement patterns of manatees (*Trichechus manatus*) in northwestern peninsular Florida. Florida Marine Research Institute Publication Number 48: 1-33.

Rathbun, G. B., J. P. Reid, R. K. Bonde, and J. A. Powell. 1995. Reproduction in free-ranging Florida manatees. Pp. 135-156 in T. J. O'Shea, B. B. Ackerman, and H. F. Percival, eds. Population biology of the Florida manatee (Trichechus manatus latirostris). National Biological Service, Information and Technology Report 1.

Reid, J. P., G. B. Rathbun, and J. R. Wilcox. 1991. Distribution Patterns of Individually Identifiable West Indian Manatees (Trichechus manatus) in Florida. Marine Mammal Science, 7(2): 180-190.

Reynolds, J. E., III. 2000. Distribution and Abundance of the West Indian Manatee (*Trichechus manatus*) Around Selected Florida Power Plants Following Winter Cold Fronts. 1999-2000. Final Report Prepared For FP&L Company, Juno Beach, FL. Contract Number B93135-00139: 47 pp.

Rose, P. M., S. P. McCutcheon. 1980. Manatees (*Trichechus manatus*): Abundance and Distribution In and Around Several Florida Power Plant Effluents. Final Report Prepared for The Florida Power & Light Company, Contract No. 31534 86626. pp.1-128.

Runge, M. C., C. A. Sanders-Reed, C. A. Langtimm, J. A. Hostetler, J. Martin, C. J. Deutsch, L. I. Ward-Geiger, and G. L. Mahon. 2017. Status and threats analysis for the Florida manatee (*Trichechus manatus latirostris*), 2016. U.S. Geological Survey Scientific Investigations Report 2017–5030. 40 p. https://doi.org/10.3133/sir20175030

Scott, T. M., G. H. Means, R. C. Means, and R. P. Meegan. 2002. First magnitude springs of Florida. Open file report No. 85. Florida Geological Survey. Tallahassee, FL. 138 pp.

Sucsy, P., R. Hupalo and B. Freeman. 1998. Minimum Flow Determination for Blue Spring, Volusia County: The Relationship Between Ground Water Discharge and Winter Refuge for Manatees. Draft 7. Dept. of Water Resources, St. Johns River Water Management District. pp. 1-73.

True, F. W. 1884. The sirenians or sea-cows. The Fisheries and Fishery Industries of the U.S. Sect. 1. Natural history of useful aquatic animals. Part 1. Art. C. pp. 114-136.

U. S. Fish and Wildlife Service. 2000. Florida manatees and warm water: Proceedings of the warm-water workshop, Jupiter, Florida, August 24–25, 1999.

U.S. Fish and Wildlife Service. 2001. Florida manatee recovery plan, (*Trichechus manatus latirostris*), Third revision. U.S. Fish and Wildlife Service. Atlanta, GA. 144pp + appendices.

Vergera, B. 1994. Water supply needs and sources assessment. Technical Publication SJ94-7. St. Johns River Water Management District, Palatka, FL.

Waller, B.I. 1970. Some occurrences of Paleo-Indian projectile points in Florida waters. Florida Anthropologist 23:129-134.

Worthy, G. A. J., T. A. Miculka, and S. D. Wright. 2000. Manatee Response to Cold: How Cold is too Cold? Pages 16-22 in U. S. Fish and Wildlife Service. Florida manatees and warm water: Proceedings of the warm-water workshop, Jupiter, Florida, August 24–25, 1999. 0006-3207/83/0025-0315/503-00.

Migrating manatees at Crystal River. Photo credit Karen Parker, FWC

Florida Fish and Wildlife Conservation Commission
MyFWC.com