SCIENTIFIC REVIEW OF THE CHASSAHOWITZKA RIVER SYSTEM RECOMMENDED MINIMUM FLOWS AND LEVELS

Scientific Peer Review Report

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Scientific Peer Review of Proposed Minimum Flows and Levels for the Chassahowitzka River System, Florida

EXECUTIVE SUMMARY

These studies were conducted by the Southwest Florida Water Management District (the District) because Florida Statutes (§373.042) mandate the District's evaluation of minimum flows and levels (MFLs) for the purpose of protecting the water resources and the ecology of the Chassahowitzka River, Bay and Estuary System from "significant harm" that might result from continued reductions of freshwater inflows from the contributing watersheds in the future. With appropriate water management, including science-based MFL rules for environmentally safe operation of water supply projects from ground and surface water resources, the District can ensure that the Chassahowitzka ecosystem and its associated tidal (estuarine) marshes, brackish wetlands and artesian springs will continue to provide essential food and cover for the myriad of marine and estuarine-dependent fish and wildlife, as well as freshwater species in the headwaters, that need them for successful survival, growth and reproduction in these beautiful waters of interest.

The District is to be commended for voluntarily committing to independent scientific peer review of its MFLs determinations. The Scientific Review Panel (the Panel) finds that the District's goals, data, methods and conclusions, as developed and explained in the MFL report, are reasonable and appropriate. The District's multi-species approach is to be applauded because it does not ignore species with variable life history requirements. The District approached this analysis in an appropriately holistic manner; that is, with attention paid to both the ecological requirements of the river system and to the various watershed and springshed segments of the contributing landscape already modified by humans.

The Panel supports the District's finding that changes in the shallow-water distribution of estuarine-dependent fishes and shellfish is related to freshwater inflow and salinity regimes. Freshwater discharges attract these organisms, particularly the young-of-the-year, into areas that provide habitat (i.e., food and cover) in which they can survive and grow. In particular, the Panel notes that the entire Chassahowitzka River System appears to be tidal (read: estuarine) and the ecosystem contains many important nursery habitats for fish and wildlife, including intertidal marshes and spring run wetlands that deserve special consideration and protection. The Panel recognizes the Chassahowitzka springs, river, bay and estuary as parts of one ecosystem, which serves as a prime example of the classic artesian systems found on the Florida Springs Coast, where the mineral content in the spring water resembles minerals found in sea water, allowing an interesting mix of freshwater, estuarine and marine species.

Overall, it appears to the Panel that the MFL determination is adequate and based on the best available data, but the lack of detailed knowledge about the hydrogeology of the contributing springs, which seem to behave differently from each other and vary in water quality, would suggest that any MFL expressed in cfs alone may be somewhat inadequate or at least requires careful monitoring during implementation. Especially if groundwater withdrawals on the inland side of the aquifer, seawater intrusion into the artesian formation on the Gulf side, or other potential impacts (e.g., increased nitrogen and other pollutants) can affect the water quality of the Chassahowitzka ecosystem in the future, weakening the value and accuracy of the MFL as the District goes forward with water management in this area. Until then, the Panel recommends that the District follow the Precautionary Principle and establish the initially recommended MFL as based on best available data and analyses until more and better scientific information is available in the future to better understand how changes in the springshed and the spring flows, both in quantity and quality, will affect the Chassahowitzka River System.

As the District moves forward to plan and supply water in the future to the people of the region, their economy and their environment, the Panel strongly recommends that the District continue to monitor the system for the purpose of verifying that the MFL is having its intended effect of maintaining the ecological health and productivity of this outstanding waterway. The verification monitoring might include spring flows, stream flows, tidal flows, basic water quality (e.g., temperature, salinity, pH, DO, chlorophyll, minerals and nutrients) and changes in vegetation, benthos, fish and shellfish, particularly during the spring season, which coincides with the beginning of peak utilization of nursery habitats by many estuarine-dependent fish and shellfish species in this part of Florida.

INTRODUCTION

The Southwest Florida Water Management District (the District) is mandated by Florida statutes to establish minimum flows and levels (MFLs) for state surface waters and aquifers within its boundaries for the purpose of protecting water resources and the ecology of the area from “significant harm” (Florida Statutes, 1972 as amended, Chapter 373, §373.042). The District implements the statute directives by periodically updating a list of priority water bodies for which MFLs are to be established and identifying which of these will undergo a voluntarily independent scientific review. Under the statutes, MFLs are defined as follows:

1. A minimum flow is the flow of a watercourse below which further water withdrawals will cause significant harm to the water resources or ecology of the area; and
2. A minimum level is the level of water in an aquifer or surface water body at which further water withdrawals will cause significant harm to the water resources of the area.

Revised in 1997, the Statutes also provide for the MFLs to be established using the “best available information,” for the MFLs “to reflect seasonal variations,” and for the District’s Board, at its discretion, to provide for “the protection of nonconsumptive uses.”

In addition, §373.0421 of the Florida Statutes states that the District's Board "shall consider changes and structural alterations to watersheds, surface waters and aquifers, and the effects such changes or alterations have had, and the constraints such changes or alterations have placed on the hydrology of the affected watershed, surface water, or aquifer…." As a result, the District generally identifies a baseline condition that realistically considers the changes and structural alterations in the hydrologic system when determining MFLs. While flow-related alterations were consider minimal in this MFL Report, it is still important to understand because the Chassahowitzka River System has source waters that are dominated by artesian spring flows from the Floridan aquifer, and these are directly affected by groundwater pumping and pollution.

Current state water policy, as expressed by the State Water Resources Implementation Rule (Chapter 62-40.473, Florida Administrative Code) contains additional guidance for the establishment of MFLs, providing that "…consideration shall be given to the protection of water resources, natural seasonal fluctuations, in water flows or levels, and environmental values associated with coastal, estuarine, aquatic and wetlands ecology, including:

1. Recreation in and on the water;
2. Fish and wildlife habitats and the passage of fish;
3. Estuarine resources;
4. Transfer of detrital material;
5. Maintenance of freshwater storage and supply;
6. Aesthetic and scenic attributes;
7. Filtration and absorption of nutrients and other pollutants;
8. Sediment loads;
9. Water quality; and
10. Navigation."

The Panel notes that Chapter 373.042(2) of the Florida Statutes directs the state water management districts to adopt MFLs for "all first magnitude springs, and all second magnitude springs within state or federally owned lands purchased for conservation purposes." Presumably, this would include the Chassahowitzka River Swamp Sanctuary, the Chassahowitzka National Wildlife Refuge, and other parts of the 60,348 acres of land and water habitats that have been preserved. Therefore, in addition to establishing an MFL for the Chassahowitzka River System, the District may be required to specifically identify or otherwise estimate MFLs for Chassahowitzka Springs and the other major springs that contribute flow to the river system, depending on land ownership. At some future time, the District may consider revising this flow recommendation in such a way that MFLs are specified for each contributing major spring, as well as for the overall river, bay and estuary system.

After a site visit on March 16, 2010 to perform a reconnaissance survey of the Chassahowitzka River System, the Panel held an initial meeting, discussed the scope of work and subsequently prepared their independent scientific reviews of the District's April 2010 draft report and associated study documents (e.g., appendices). The peer reviews were compiled by the Panel Chair and edited by all Panel Members into the consensus report presented herein.

BACKGROUND

The quantity, quality and timing of freshwater input are characteristics that define an estuary. Freshwater inflows affect estuarine (tidal) areas at all levels; that is, with physical, chemical and biological effects that create a vast and complicated network of ecological relationships (Longley 1994). The effects of changes in inflows to estuaries are also described in Sklar and Browder (1998) and reviewed in Alber (2002). This scientific literature describes and illustrates how changing freshwater inflows can have a profound impact on estuarine conditions: circulation and salinity patterns, stratification and mixing, transit and residence times, the size and shape of the estuary. In the end, the distribution of dissolved and particulate materials, including nutrients and sediments, may all be altered in ways that negatively affect the ecological health and productivity of coastal bays and estuaries.

Consequently, inflow-related changes in estuarine conditions will affect living estuarine resources, both directly and indirectly. Many estuarine organisms are directly linked to salinity, which determines the distribution of plants, benthic organisms and fishery species (Drinkwater and Frank 1994, Ardisson and Bourget 1997). If the distributions become uncoupled from their food source or preferred habitat, estuarine biota may be restricted to areas that are no longer suitable habitat for their survival, growth and reproduction. Potential effects of human activities, particularly reductions in fresh ground and surface water resources, on the adult and larval stages of fish and invertebrates include impacts on migration patterns, spawning and nursery habitats, species diversity and distribution, and production of lower trophic level (food) organisms (Drinkwater and Frank 1994, Longley 1994). Changes in inflow will also affect the delivery of nutrients, organic matter and sediments, which in turn can indirectly affect estuarine productivity rates and trophic structure (Longley 1994).

There are a number of approaches for setting freshwater inflow requirements of an estuary. The District prefers to use a "percent-withdrawal" method that sets upstream limits on water diversions or losses as a proportion of river flow. This links daily withdrawals to daily inflows, thereby preserving natural streamflow variations to a large extent. In some cases, a low-flow threshold or limit is employed as well. This type of inflow-based policy is very much in keeping with the approach that is often advocated for river management, where flow is considered a master variable because it is correlated with so many other factors in the ecosystem (Poff et al. 1997; Richter et al. 1997). In most cases, the emphasis is on maintaining the natural flow regime while skimming off surplus flows along the way to meet water supply needs. Normally, regulations are designed to prevent impacts to freshwater and estuarine resources during sensitive low-inflow periods, and to allow water supplies to become gradually more available as inflow increases. The rationale for the District's MFL setting, along with some of the underlying biological studies that support the percent-of-flow approach, is detailed in Flannery et al. (2002).

REVIEW

Developing minimum flow rules requires several steps: (1) setting appropriate management goals; (2) identifying indicators to measure characteristics that can be mechanistically linked to the management goals; (3) reviewing existing data and collecting new data on the indicators; and (4) assembling conceptual, qualitative, and quantitative models to predict behavior of the indicators under varying flow regimes. The first two steps above represent the overall approach to setting the minimum flow rule.

The District's management goal for the Chassahowitzka River System is to maintain ecosystem integrity and, thereby, protect ecological health and productivity. As a result, the District's MFL was developed to limit potential changes in aquatic and wetland habitat availability associated with reductions in freshwater inflows that are dominated by spring flows (SWFWMD 2010). When biologically meaningful thresholds or breakpoints were not found in the more or less continuous physical, chemical and biological responses, as is often the case in field studies, a criterion of no more than a 15% loss of habitat or other resources, as compared to the estuary's baseline condition, was used as the limit for "significant harm." While the use of 15% as a constraint in the MFL analysis is a more or less arbitrary management decision, the Panel agrees that it is a reasonable approach for avoiding the most serious negative impacts, particularly where the ecosystem has not been as well studied and has little historical data available on its essential parts. The remainder of this report is focused on review of data, methods and analyses used as a basis for the District's recommended MFL.

Specifically, the District's proposed MFL was determined based on the following information and procedures:

1. The Chassahowitzka River, located north of Tampa Bay on the Florida Springs Coast, has been designated as an "Outstanding Florida Water." River flows are dominated by artesian spring discharges from the upper Floridan Aquifer. The

headwater springs alone are estimated to contribute 50% of the total river flows. The river system drains a surficial watershed of approximately 89 square miles (~56,960 acres); however, most of its stream flow comes from near coastal springs that have a 180 mi² (~115,200 acre) contributing area in their groundwater springshed. Although streamgaging did not occur before February 1997, the District estimated the overall median flow of the river at 63 cfs from 1967-2007 using a regression relationship with water levels in a nearby Floridan aquifer well at Weeki Wachee. All 5.6 miles (9 km) of the river are tidally influenced from the headwaters to Chassahowitzka Bay on the Gulf of Mexico (Figure 1).

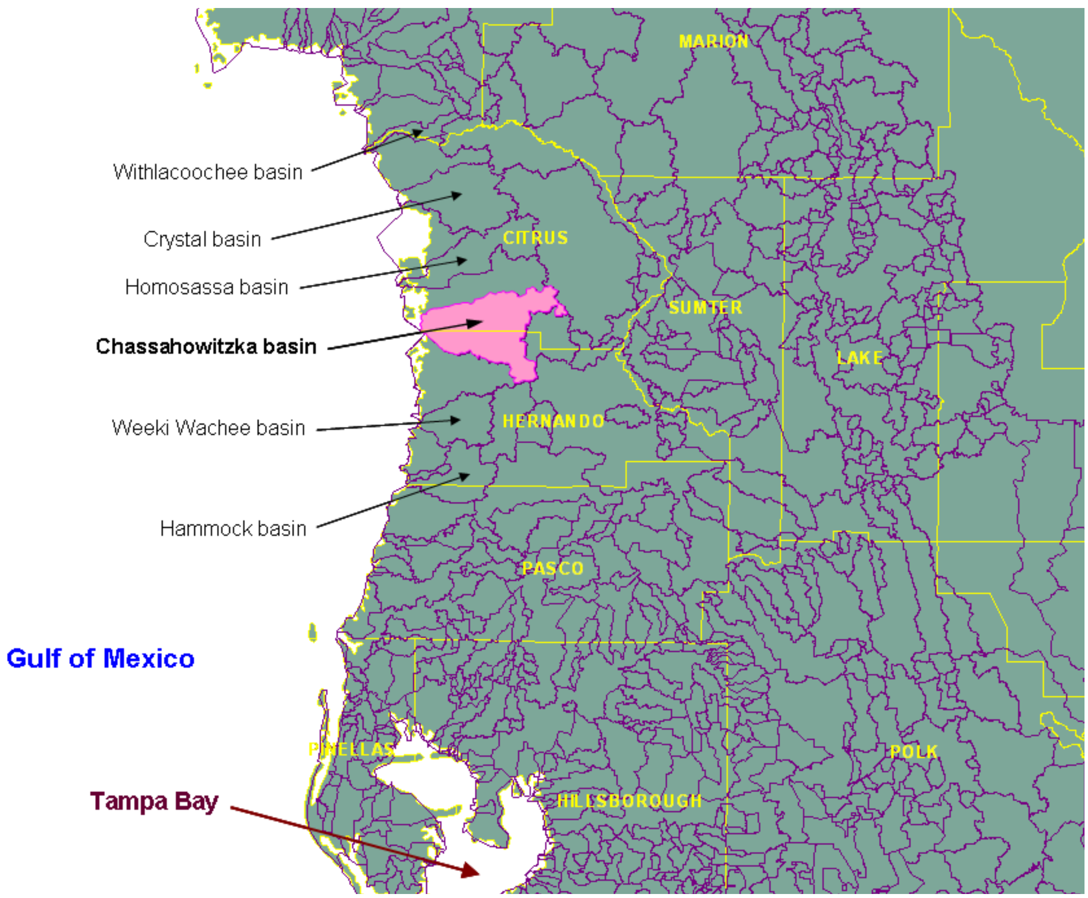

Figure 1. Location of the Chassahowitzka River Basin, Florida.

2. Ecological resources of concern identified by the District included submerged aquatic vegetation, benthic macroinvertebrates, mollusks, planktonic and nektonic fish and invertebrates, salinity-based habitat, and thermal refuge habitat for

Manatees during critical cold periods. Numeric models and empirical regressions were used to assess their responses to reduced inflows (SWFWMD 2010).

3. The District evaluated 29 ecologically relevant responses. Since no inflection points or reasonable thresholds in the ecological responses were observed, the District used the previously mentioned 15% loss of habitat or resources as a default for the point of "significant harm." The abundance of mollusks and the diversity of benthic macroinvertebrates were both positively related to salinity, which is inversely related to freshwater inflows and, thus, they were not used in the District's minimum flow analysis. Also, a lack of confidence in the unusual responses from the SAV model (a 4^{th} order polynomial salinity/SAV density equation) resulted in its omission from the MFL analysis as well. Similarly, the estimated hypersensitive responses (i.e., abundances predicted near zero with only 1-2 % flow reduction) of some planktonic fish and invertebrate taxa were considered suspect and were not used because the actual river flows had little variability (~11%) over the two-year sampling period (Greenwood et al. 2008). A couple of taxa in the seine and trawl sample analysis also had estimated hypersensitive seasonal responses that seemed unreasonable and were not used. The Panel believes that these were probably the result of the rather limited duration of the sampling program over a period with minimal changes in flow, which leaves little in the field of variation to be explained by the statistical routine.

   As a result, the District decided to compute the median allowable flow reduction over all 10 of the fish and invertebrate taxa included in the response analysis and use that value (11%) in the MFL. Support for this MFL value comes from the Manatee thermal refuge analysis that indicates a 15% loss of thermal refuge area in the stream occurs at an 11% reduction in flows.

   Long-term compliance standards in the form of five- and ten-year mean and median flows were then developed to accommodate variations in climate. The

District's intent is that these minimum long-term flow statistics should be maintained in the presence of future withdrawals in order to maintain 89% of the system's baseline flow.

Hydrologic and Hydrodynamic Simulations

This part of the scientific review focuses on the District's MFL report and the supporting numerical modeling discussed in the appendices (SWFWMD 2010). Appendix 10.2 discusses the application of the well known three-dimensional (3-D) groundwater model, MODFLOW (McDonald and Harbaugh 1988), supported by the U.S. Geological Survey and used here to assess the impact of groundwater withdrawals on spring flows in the river. Groundwater withdrawals within a 10-mile radius of the Chassahowitzka Springs were estimated at 14.4 mgd in 2005, mostly for non-consumptive uses associated with limestone mining (SWFWMD 2010, Appendix 10.2). Modeling 2005 groundwater withdrawals resulted in the conclusion that it caused only a 0.7 cfs reduction in the discharge of the main Chassahowitzka spring. This was considered insignificant; therefore, the impact of existing groundwater withdrawals was not used to correct or otherwise adjust the estimated baseline flows from 1967-2007, nor was it considered in determining the MFL.

The Panel believes that the MODFLOW application is appropriate and the modeling effort seems well founded. Nevertheless, the detailed hydrogeology of the springs is not well known, unusual differences in flow quantity and quality are commonly exhibited by the contributing springs, and nitrate levels are increasing from pollution in both the watershed and the springshed.

The review of the 3-D hydrodynamic / salinity / temperature modeling effort discussed in Appendix 10.13 focused on addressing the following questions:

1. Was an appropriate numerical model employed?
2. Were the data employed adequate?

3. Was the development of the numerical grid employing available bathymetry data adequate?
4. Were boundary conditions appropriate?
5. Were the calibration / validation of the numerical model adequate?
6. Were the scenarios simulated by the model appropriate for determining an MFL?

Was an Appropriate Model Employed?

As stated in the main report and Appendix 10, the purpose for conducting the 3-D numerical hydrodynamic / salinity / temperature model study was to:

- Predict available thermal refuge habitat for Manatees during critically cold conditions.
- Predict the impact of various spring flow reductions on salinity zones in the estuary.

To address these issues, the District's consultant selected the Environmental Fluid Dynamics Computations (Hamrick 1992). EFDC is a well known general-purpose modeling package for simulating 3-D flow, transport, and some biogeochemical processes in surface water systems including coastal rivers, bays and estuaries. The model is supported by the EPA and used by several federal and state agencies. A discussion of the basic model's properties is provided in Appendix 10.2 and will not be repeated here. It should be noted that the version of EFDC applied here is one that interfaces with various pre- and post-processing routines developed by the District's consultant (Dynamic Solutions, LLC) that make the application of the model easier and allows for an improved processing of model output. The Panel finds that EFDC is an adequate hydrodynamic model code to apply to the Chassahowitzka River to address the issues of interest here.

Were the Data Employed Adequate?

In most numerical modeling studies, one always would like to have more data. Starting at the beginning, there must be sufficient data, especially bathymetry data on the water body's physical dimensions, to at least generate a computational grid, set numerical boundary conditions, and compare model results to data collected in the interior of the numerical grid. An intensive bathymetry survey of the entire Chassahowitzka River System was supported by the District and conducted by the University of South Florida in 2007. These data along with bathymetry data for Chassahowitzka Bay obtained from NOAA resulted in the development of a good physical representation of the modeled length, area and volume of the system.

Water surface elevations, salinity, and temperature data were available at four USGS Stations (Nos. 02310674, 02310673, 02310663, and 02310650) beginning at the mouth of the Chassahowitzka River and extending up to the headwaters and the main springs at the upper end of the numerical grid. Data for the first station were collected from September 2006 – September 2007. Data for the next two stations were collected from October 2005 – September 2007. Water stage, salinity and temperature data were collected from May 2003 – September 2007 at the last station near the headwaters of the river. In addition, daily averaged flow data from the main spring were available for February 1997 – November 2007. Flow data and salinity data at five other springs that contribute to the Chassahowitzka River were very limited and based on just a few observations.

The Panel believes that there were sufficient data available to calibrate the model, although the calibration period involved a relatively low flow period. It is technically preferred that the calibration period cover a wider range of physical events in the system (e.g., a more complete range of flows, set ups and set downs of the ocean water surface, etc.). The more or less constant flow regime, dominated by the springs, led the modelers to be more comfortable with the shortened period.

Normally after calibrating a numerical model, it is applied to a separate set of data in what is called a "validation" phase of the model application. This was not done in the modeling study under review here. If the calibration period is long (e.g., a year or more), many modelers believe that both calibration and validation have been satisfied. Unfortunately, the calibration period in this study was only four months. The Panel questions whether calibration and validation have been accomplished with this rather short simulation period.

Water surface elevations, spring flow and temperature data were needed for the entire baseline period of 1967 – 2007 to determine worst case critical conditions for manatee habitat. A regression equation was developed using long term water surface levels from a USGS station located at Cedar Key, about 124 miles (200 km) from Chassahowitzka Bay. Historical data from 1997 - 2007 exist for spring flow only from the main spring. A regression equation relating the spring flow to water levels in a groundwater monitoring well nearby at Weeki Wachee was developed to generate flow estimates for the baseline period.

To generate a time series for temperature data at USGS Station No. 02310663, a regression equation was developed relating the water temperature to the air temperature at the St. Petersburg Airport. Each of these regressions had R^2 values above 0.75. As a result, the Panel agrees that the modeling study utilized all the data available, generated appropriate regressions to fill in missing data, and the data were adequate for conducting the modeling study, including the synthesized time series data used for determining critical three-day cold events for Manatee during the 1967-2007 baseline period.

Was the Numerical Grid Adequate?

The numerical grid over most of the river contained four cells across the river and four sigma layers in the water column profile. A sensitivity simulation using eight sigma layers was conducted. Doubling the number of vertical layers had more impact on the predicted salinity than the predicted temperature. Based on the beneficial salinity impact, perhaps eight layers should have been used. However, the report states that the time-step for stable computations was only 5 seconds. This means that computing time (i.e., CPU hours) might have become excessive with eight layers.

Since EFDC is a semi-implicit model, a basic question arises as to why the time-step had to be so small. The Panel understands that the controlling criterion on the time-step in this model is the water velocity through the computational grid cells. With horizontal grid cells being typically 164 feet by 282 feet, the Panel wonders why a much larger time-step could not have been used. In view of the reported effect of increasing the vertical layers in the aforementioned sensitivity analysis, the Panel would like to have seen the impact of doubling the number of horizontal cells across the river as well in order to evaluate any impacts on the simulation of shoreline salinity regimes under various flow reductions.

There is a lot of estuarine marsh area from the river mouth up to about river mile 3.1 (km 5) and the District's MFL report states that much of this marsh area is flooded during normal high tide levels, not just with storm tides. Because of this important inundation effect, the Panel believes that there should have been some discussion as to why the computational grid used in the modeling study did not incorporate the wetland marsh areas. This is especially puzzling since the EFDC model allows for wetting and drying of grid cells for just such a purpose.

Although the Panel believes that the questions above should be addressed, it also finds that the numerical grid is adequate to allow basic comparison of one model simulation of flows, salinities and temperatures with another in a precise, if not always the most accurate, manner.

Were the Boundary Conditions Adequate?

There were three separate modeling efforts. The **first** centered on calibrating the basic hydrodynamic, salinity, and temperature model. A four month period, November 2006 –

February 2007, had overlapping periods where the data coverage was good for water levels (stage), salinity and temperature variations. In addition, data were available for the main spring discharge, salinity and temperature. The groundwater discharge and salinity for five other significant springs were based on very limited data and assumed to be constant. This seems to be a more or less reasonable assumption at first glance since conditions at the springs appear not to change much, at least over short periods of time (i.e., days to months). However, based on salinity measurements taken in the various springs during the Panel's March 16, 2010 field trip to the site, the Panel questions the salinity boundary conditions at the springs, which may not be always accurately represented in the model. Overall, the Panel finds that the boundary conditions were based on observed data and are, thereby, considered best available over this four month period.

Water surface elevations, salinity and temperature on the open bay portion of the grid were represented by USGS Station No. 02310674, which is located near the mouth of Chassahowitzka River. However, the salinity was "adjusted" by 4 ppt to better match observed salinities at the mouth of the river.

The **second** modeling effort centered on predicting manatee habitat for both chronic and acute criteria. These are given as follows:

- Chronic--Minimum depth of 3.8 ft with temperatures remaining above 68º F for the duration of critically cold three-day periods.
- Acute--Minimum depth of 3.8 ft with temperatures not be less then 59º F for four or more hours.

Using the long-term time series data developed for water level, flow and temperature discussed above, a joint probability analysis was conducted to determine critical condition periods with a return interval of 50 years. This analysis resulted in selecting the January 4-6, 2002 period for simulation. Water depths and temperatures on the open portion of the grid were obtained from the regression equations previously discussed.

The salinity was taken from the four month calibration period. Measured discharge, salinity and temperature at the main spring were employed at the head of the numerical grid. Discharge, salinity and temperature were the same as from the calibration period for the other springs. Metrological data needed to compute surface heat exchange and equilibrium temperatures were taken from observations at the St. Petersburg Airport. The Panel finds that the assumptions made in setting the boundary conditions and the data employed are appropriate for this simulation effort.

The **third** modeling effort centered on assessing the impact of spring flow reductions on salinity. A three-year period (2004 – 2006) was selected for simulation. An analysis of the flow record for the 1967 – 2007 baseline period revealed that the cumulative distribution function (CDF) for flow during the three-year period was fairly typical of that for the longer baseline period. This would suggest that the simulation period was more or less representative of the baseline period. Again, measured data were employed where available and other data for setting boundary conditions were obtained from the regression equations. The Panel finds that the data utilized for setting boundary conditions and assessing the impact of flow reductions are appropriate and best available.

Were Calibration / Validation of the Model Adequate?

A four-month period (November 2006 – February 2007) was used for calibration of the hydrodynamic model. The calibration centered on comparing model results for water levels (stage), salinity and temperature at USGS Stations Nos. 02310674, 02310673 and 02310663. The calibration involved the visual inspection of graphical time series comparisons of observed and simulated measures, as well as statistical analyses. One statistic was the Nash-Sutcliffe efficiency coefficient. This statistic was developed to assess the goodness-of-fit of hydrology models, but it can be used for many other variables. The Panel believes that it is appropriate to employ this statistic, but recognizes that it has not been used often in other estuarine modeling efforts. The second statistic used was the Root Mean Square Error (RMSE). The Panel finds this statistic to be routinely employed in estuarine modeling and easy to understand.

Water Level Calibration

The calibration on water surface elevations (stage level) is very good, but in a relatively small system only 5.6 miles (9 km) long this is to be expected if the open boundary water tidal elevations are accurate. There is little dampening between USGS Stations 02310673 and 02310663, where the tidal ranges are about 3-4 feet at both locations. There is a Gulf tidal influence all the way to the main spring at Station No. 02310650, but the range of water level fluctuations there is only about 1 foot between normal ebb and flood tides. Unfortunately, results aren't presented for this station (Figure 2), which means that the Panel can not evaluate the model's ability to simulate the important observed tidal dampening between Station 02310663 and upstream Station 02310650.

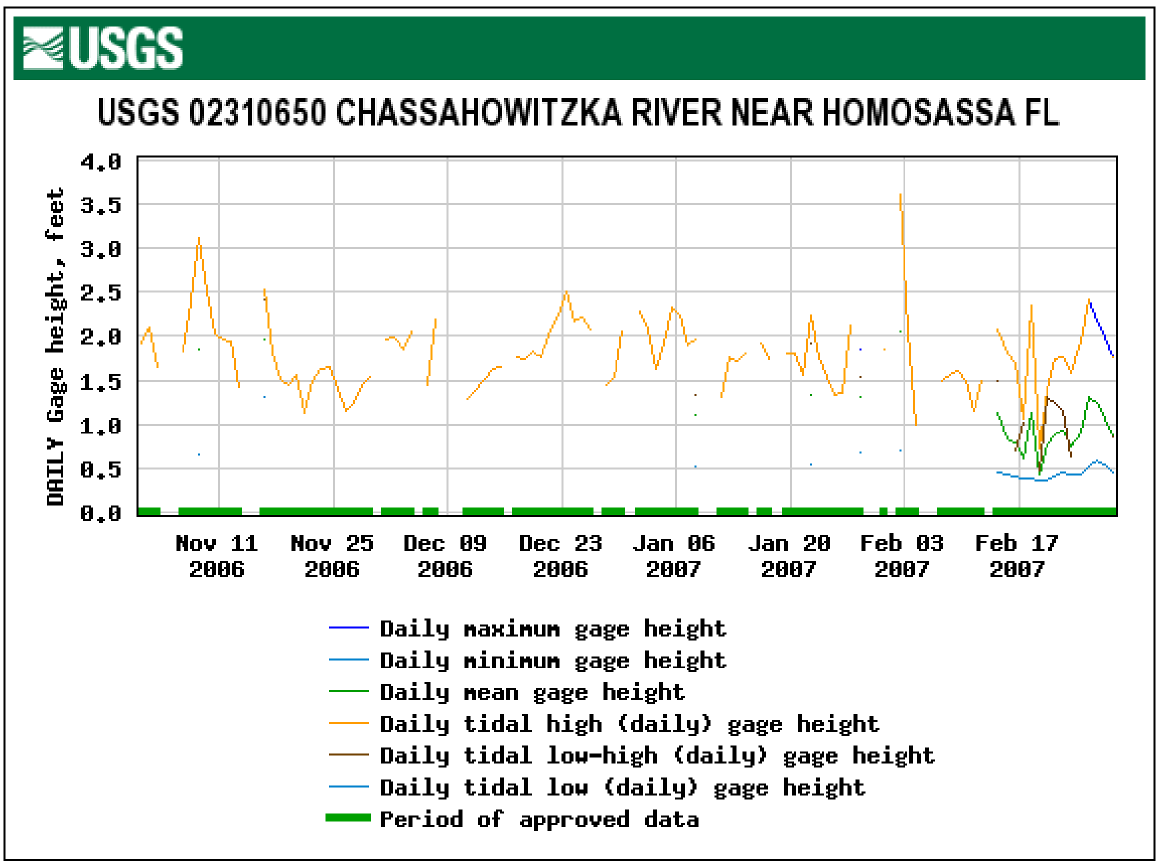

Figure 2. Daily Water Surface Elevations at USGS Station No. 02310650 during the November 2006 – February 2007 model calibration period.

Salinity Calibration

A time series comparison of salinity at Station 02310674 at the river mouth isn't given, although some statistics are presented. The statistics don't appear to be very good, which is somewhat surprising after the modelers made a special effort to "adjust" the open boundary salinity by 4 ppt in order to force a better match at the mouth of the river. The calibration at Stations 02310673 and 02310663 are better. An inspection of the time series plots shows that observed and computed salinities can differ by as much as 5 ppt, with the RMSE errors generally being around 2.0 – 2.5 ppt. The U.S. Environmental Protection Agency (EPA 1990) recommends the Relative Mean Absolute Error (RMAE), a statistic defined as:

$$RMAE = SUM (ABS (O_i - C_i)) / SUM (O_i),$$

where O_i are observed values and C_i are computed values.

The EPA guideline for a calibrated salinity model is that the RMAE should be less than 20%. Since the model results are only being compared to other flow reduction simulation of the same model in the District's MFL analysis, rather than being used to make absolute predictions of the actual salinity levels, the Panel concludes that the salinity calibration is adequate for estimating relative differences due to reduced freshwater inflows. However, it should be noted that determining the level of uncertainty in a model, or a cascade of models, is a normal procedure in some scientific disciplines, but it is only just beginning to be applied to water resources projects. Therefore, the District should consider conducting quantitative uncertainty analyses on the models it uses for flow recommendations.

Temperature Calibration

A visual comparison of the temperature calibration shows that during flood stage there can be differences of 5 – 10 ºF. However, the Nash-Sutcliffe statistic here is better (i.e., the values are closer to 1.0) than it was in the salinity calibration. The Panel understands that in large coastal bays, the water temperature is primarily driven by surface heart exchange; however, in smaller bodies of water such as the Chassahowitzka River estuary, the temperature of the artesian spring flow is also a major factor in determining water temperature in the river near the sources. The metrological data used to compute the surface heat exchange came from the St Petersburg Airport. If metrological data closer to the river had been available, the calibration might have been better. The Panel finds that the model does reproduce the cooling and warming trends very well and, thus, the temperature calibration is considered to be adequate.

Were the Simulated Scenarios Adequate for Determining a MFL?

The basic scenarios were simulated to predict available thermal Manatee habitat during critically cold spells, as well as the impact of various spring flow reductions on the length, area and volume of salinity habitats in the river. As previously discussed, time series data for water level (stage), temperature and spring discharge for the baseline period were generated from regression equations and were used in a joint probability analysis to determine critical condition periods for manatee habitat. The simulation of a critical period over January 4-6, 2002 revealed that there was no habitat satisfying the chronic criteria of at least 3.8 ft water depth at low tide with a water temperature greater than 68 ºF. The major factor leading to the troubling finding was the controlling criterion for water depth. This result led the modelers to suggest, and the Panel agrees, that more refined bathymetry data should be collected to better define narrow channels in the upper river. Increasing the grid resolution with better bathymetry might yield some available habitat after all. If the District supports additional modeling at some future time, the Panel recommends that this be done.

Salinity regimes in the river were simulated over the 2004-2006 three-year interval with spring flow reductions of 10%, 20% and 40%. Model results were then used to assess the impact of flow reductions on the length, area and volume of aquatic habitats in salinity zones of 0-2 ppt, 0-5 ppt, 0-10 ppt and 15 ppt. Cumulative Distribution functions were developed and areas under each of the curves for the different flow reductions were determined and compared to the no-flow reduction case. The analysis of salinity-based habitats (i.e., shoreline length, surficial area and water volume at 2, 5, 10 and 15 ppt) produced 12 estimates of habitat loss. The most sensitive were the length of shoreline habitat less than 5 ppt (15% loss at 13 % flow reduction), the volume of aquatic habitats less than 5 ppt (15% loss at 13% flow reduction), and the amount of habitat area less than 5 ppt (15% loss at 15% flow reduction).

This analysis led to the result that a 13% reduction in flow would result in a 15% loss of habitat for the low-salinity (0-5 ppt) zone. As a result, the Panel concludes that the application of the calibrated model to evaluate thermal and salinity habitats is appropriate and can be used to help determine a MFL for the Chassahowitzka River System.

Biota and Ecology of the Chassahowitzka River System

The District's effort to follow the legislative study mandate is focused on limiting flow reductions that could be significantly harmful to the natural resources of the area. The basic approach is to use a quantifiable reduction in habitat as the metric of choice, which is normally a good one. Since estuarine plants and animals live in a fluctuating salinity environment, they commonly have broad tolerances to changes in flows and mechanisms for dealing with physiological stress. Nevertheless, it is especially important at the fresh/brackish interface, where modest flow reductions can move the isohalines upstream, significantly reducing suitable freshwater habitat. As a result, the Panel agrees with the District that this would normally be the most relevant part of the spring-fed system to evaluate here. On the other hand, freshwater plants and animals are usually very intolerant of even low salinity conditions and are, thus, more likely to be impacted by lower freshwater inflows and increasing intrusion of brackish waters into previously fresh water habitat. In most riverine estuaries, seasonal low flow conditions are all that is required to eliminate intolerant freshwater species from the area of tidal influence.

The Panel understands and observed that the water of the Chassahowitzka River is mostly clear, slightly alkaline pH, extremely low in phosphorus concentrations, but high in nitrogen (SWFWMD 2010, Figure 4-4). The lack of phosphorus produces a general oligotrophic condition in the estuary where primary production, phytoplankton in particular, is also low. Although the nitrogen concentrations do not appear significantly related to the amount of spring flow, there is one troubling aspect to this nutrient, it exhibits a strong significant increase ($p = 0.0005$) with time (SWFWMD 2010, Figure 4-6).

Since it is primarily spring-fed, the Chassahowitzka River System has little seasonal variation. The Panel agrees that measuring the extent of and changes to the sensitive freshwater zone from reductions in flow is a logical approach to the MFL determination, although it would be more comforting if the contributing springs could all be considered "fresh." There were several important data sets in the study that suggest the analytical results utilized by the District for setting the MFL for the Chassahowitzka River System are still problematic at low flows because of the potential for saline discharges from the springs.

The District's approach to the MFL can be interpreted as assuming that the major contributing springs and the headwaters of the river feeding the estuary are essentially fresh; however, Figure 4.1 (SWFWMD 2010) reveals that the entire system from headwaters to mouth has substantial salinity levels and qualifies as estuarine, not fresh waters. The biological significance here is related to the fact that even marine animals intolerant of freshwater can survive under near fresh (< 5 ppt) conditions if the important marine dissolved solids are sufficiently abundant to allow osmoregulatory substitution of critical ions. This expands their metabolic scope for activity and, thereby, their potential range of distribution in the ecosystem.

The floral and faunal communities present at the time of the Panel's site visit and reconnaissance survey suggested that dissolved ions must be abundant in all of the springs, and this was confirmed by the District's MFL Report and Appendices (SWFWMD 2010). For example, the Panel observed marine fishes, including the Mangrove snapper (*Lutjanus griseus*), all the way up to the headwaters and even in the main spring area, because salinity was still a couple parts per thousand salt above freshwater. Marine mammals, including Manatee (*Trichechus manatus latirostris*) and Bottle-nose dolphin (*Tursiops truncates*), were also present in the immediate area that day. At Crab Spring, the water at the surface was notably saline. Here and in at least one other spring, the Panel observed a brown floc that has been described variously as brown diatom clusters or as iron-based precipitates, with visible deposits on the bottom. The latter would again suggest that the spring water contained high concentrations of dissolved solids. Data from the District showed iron (Fe) concentrations as high as 80 µg/L in Crab Spring.

The District's MFL Report also provides faunal evidence that the headwaters were not populated by insect larvae and peracarid crustaceans considered typical of fully freshwater regions of other Florida estuaries. For example, the burrowing anthurid isopod, *Cyathura polita,* is considered a mesohaline species (Burbanck 1967), but in the Chassahowitzka River System it was a constituent of the plankton and benthic community virtually everywhere, including the headwaters. Again, this suggests that the fauna did not recognize the upper reaches of the Chassahowitzka River as a freshwater ecosystem. The District's report notes that there is currently no freshwater/saltwater boundary in the river system. Perhaps this is why several of the biotic analyses produced ambiguous results or, like the benthos, respond to salinity in a positive way such that flow reductions increase salinity and their biotic diversity in this estuary.

It is not clear to the Panel that there is enough data on the discharge rates and water quality from the contributing springs prior to 1997 to be able to fully understand the pre-pumping state of the Chassahowitzka groundwater system. It is clear that the District can evaluate prior hydraulic pressure that drives the springs, but without more detailed hydrogeology of the artesian system, it is questionable if historical spring conditions can be adequately evaluated beyond some estimate of flow volume.

The various artesian springs that constitute the primary flow of the river have a wide range of discharges and salinities suggesting that they intersect different portions, or perhaps different depths, of the aquifer formation. For example, an analysis of solutes in water samples collected from Crab Spring suggests that the solutes are derived from ocean water. The oceanic ratio of Na to Mg is 8.213 (Sverdrup et al. 1942), while the ratio in the spring was reported at 7.680 (October 11, 1993), 8.322 (July 21, 1994) and 8.260 (October 25, 1994). The Panel's calculation of other ion ratios produces similar results, providing another piece of evidence that the dissolved solids in these springs were from oceanic sources (e.g., Gulf saline intrusion) rather than dissolved from the internal geology (read: rock strata) of the groundwater aquifer formation.

Scott et al. (2004) provide an additional analysis of the Chassahowitzka springs that argues that the saline water in these springs is derived from a past sea level high, which inundated the karst landscape and flooded the underlying aquifer with sea water. If this is correct, then the ocean-derived salts discharging from these springs today are fossil water contributions. There is a boundary layer in the aquifer above which freshwater sits and below which more saline water can be found. This means that future withdrawals of freshwater from the top can increase the amount of saline water in the aquifer, resulting in more saline discharges at the springs.

The Panel notes that reported chloride levels in the springs vary by an order of magnitude (SWFWMD 2010, Table 2.5) suggesting that the ultimate origin of their water could be from very different parts of the Floridan Aquifer. This concerns the Panel if modest changes in future aquifer pumping rates can potentially alter the amount and proportion of salts discharged from these springs. Unfortunately, the District's simple regression equation of river flow and water levels may be too inaccurate during low flow periods to adequately address the potential contribution of saline waters in spring discharges to the river. This means that the springflow MFL may have to be adjusted in the future as the District goes forward with its regional water management duties and responsibilities.

The Panel additionally finds that Chassahowitzka Springs data from the past half century strongly suggest that there has been a substantial change in the concentration of salt ions (e.g., Na and Cl), although the Cl/Na ratio appears to be ocean derived and varies little from the 1.8 ocean ratio (Sverdrup et al. 1942). Specifically, the concentration of chloride was 53 mg/L in 1941, 320 mg/L in 1971 and 680 mg/L in 2001 (Scott et al. 2004). Changes in levels of ocean-derived salts can be attributed to ground water withdrawals affecting the pathway of water discharged from the aquifer, or to severe and prolonged drought.

In the end, the Panel believes that a better understanding of the hydrogeology of these springs and an investigation of how groundwater withdrawals can affect the concentration of salts in these springs, as well as a better accounting of their individual contributions to the overall flow, will be required to fully address the MFL issues here.

Saltwater intrusion is a problem that has crept up on coastal water managers in many parts of the nation, and Florida is no exception, even if it's not the main problem at Chassahowitzka Springs right now. Continued development in the springshed can increase demand for freshwater water and the resulting strain on groundwater supplies can open the gates for more saltwater intrusion. According to the District, deposits of remnant sea water were left over from a time when much of the Florida Peninsula was submerged thousands of years ago. When the oceans receded, not all the sea water was flushed out of the surficial aquifer systems. The Panel observes that this source of contamination, also known as "connate sea water," is the least common and least studied form of saltwater intrusion. While that may explain the past situation, it may not adequately predict the future of the Chassahowitzka River System.

Other Panel Comments

The District is to be commended for the thorough response to the questions and data requests from the Panel Members after their initial reading of the District's draft report.

Overall, it appears to the Panel that the MFL determination is adequate and based on the best available data, but the lack of detailed knowledge about the hydrogeology of the contributing springs, which seem to behave differently from each other and vary in water quality, would suggest that any MFL expressed in cfs alone may be somewhat inadequate or at least requires careful monitoring during implementation. Especially if groundwater withdrawals on the inland side of the aquifer, seawater intrusion into the artesian formation on the Gulf side, or other potential impacts of nutrients and pollutants can affect the water quality of the Chassahowitzka ecosystem in the future, weakening the value and accuracy of this initial MFL recommendation.

Therefore, the Panel recommends that the District follow the Precautionary Principle and establish the initially recommended MFL, which is based on the best available data and analyses, until more and better scientific information is available in the future to better understand how changes in the springshed and spring flows, both quantity and quality, will affect the Chassahowitzka River System.

As the District moves forward to plan and supply water in the future to the people, their economy and their environment, the Panel strongly recommends that the District continue to monitor the system for the purpose of verifying that the MFL is having its intended effect of maintaining the ecological health and productivity of the Chassahowitzka River System, including the associated bay and estuary. The verification monitoring might include spring flows, stream flows, tidal flows, basic water quality (e.g., temperature, salinity, pH, DO, chlorophyll, minerals and nutrients), and changes in wetland vegetation, benthos, fish and shellfish, particularly during the dry season, which coincides with the beginning of peak utilization of nursery habitats by estuarine-dependent fish and shellfish species in Florida.

ERRATA and EDITORIAL COMMENTS

Page	Paragraph	Line	Comment
9	3	3	Insert comma after Chapter 3.
9	4	3	Insert comma after Chapter 6.
10	Footnote		Elevate footnote 2 into superscript font [2].
11	Footnote		Elevate footnote 3 into superscript font [3].
12	Last	2	Put parentheses around "See Figure 2-5 in section 2.3.1"
13	1	1	Change "sewer. [4]" to "sewer[4]."
13	Footnote		Elevate footnote 4 into superscript font [4].
14	1	3	Insert comma after "(1892-2006)."
20	1	4	Insert space after "Figure 2.6"
20	Last	1	Remove space between "(" and "Figure 2.6)."
20	Last	3	Insert comma after "mid-1960's"
31	1	8	Insert "Inc." after "Janicki Environmental"
37	3	17	Insert comma after "However" and put period at end of "Williams et al."
40	3	4	Insert comma after "Thus"
46	3		Put period at end of last sentence.
54	7	4	The Goldspotted killifish is *Floridichthys carpio*, not *Cyprinodon variegatus*, which is the Sheepshead minnow, a common species of pupfish. It is noted that the endemic Eustis Pupfish (*Cyprinodon variegatus hubbsi*) is present in the nearby Oklawaha River, Florida (Jordan 1993). Also, *C. variegatus* is <u>not</u> very sensitive to low D.O. and tolerates hypoxic (< 2 mg/L) waters rather well, while *F. carpio* exhibits extreme osmotic stress at moderate 4-5 mg/L D.O. concentrations (Kraill 1967).
55	Last	2	Insert comma after "transformation"
59	2	7	Insert comma after "determination"
63	Last	2	Insert comma after "composition"
64	Last		Change last word from "sytem" to "system"
66	Footnote		Elevate footnote 7 into superscript font [7].
67	Footnote		Elevate footnote 8 into superscript font [8].

REFERENCES

Alber, M. 2002. A Conceptual Model of Estuarine Inflow Management. *Estuaries* 25: 1246-1261.

Ardisson, P.-L., and E. Bourget. 1997. A study of the relationship between freshwater runoff and benthos abundance: a scale-oriented approach. *Estuarine, Coastal and Shelf Science* 45: 535-545.

Burbanck, W.D. 1967. Evolutionary and ecological implications of the zoogeography, physiology, and morphology of *Cyathura* (Isopoda). Pages 564-573 in book *Estuaries*, G.H. Lauff, ed. Amer. Assoc. Advmt. Sci., Washington, D.C. 757 pp.

Drinkwater, K. F., and K. T. Frank. 1994. Effects of river regulation and diversion on marine fish and invertebrates. *Aquatic Conservation: Freshwater and Marine Ecosystems* 4: 135-151.

Environmental Protection Agency. 1990. "Technical Guidance Manuel for Performing Waste Load Allocation, Book III, Estuaries--Part 2, Application of Estuarine Waste Load Allocation Models." EPA 823-R-92-003. 173 pp.

Flannery, M. S., E. B. Peebles and R. T. Montgomery. 2002. A Percentage-of-Streamflow Approach for Managing Reductions of Freshwater Inflows from Unimpounded Rivers to Southwest Florida Estuaries. *Estuaries* 25: 1318-1332.

Greenwood, M.F.D., E.B. Peebles, S.E. Burghart, T.C. MacDonald, R.E. Matheson, Jr., and R.H. McMichael, Jr. 2008. Freshwater Inflow Effects on Fishes and Invertebrates in the Chassahowitzka River and Estuary. Prepared for the Southwest Florida Water Management District by the University of South Florida and the Florida Fish and Wildlife Conservation Commission and the University of South Florida at St. Petersburg, FL. 87 pp. + 155 pp. appendices.

Hamrick, J.M., 1992. A Three-Dimensional Environmental Fluid Dynamics Computer Code: Theoretical and Computational Aspects. Special Report No. 317 in Applied Marine Science and Ocean Engineering, Virginia Institute of Marine Science, Gloucester Point, VA. 64pp.

Jordan, F., D.C. Haney and F.G. Nordie. 1993. Plasma Osmotic Regulation and Routine Metabolism in the Eustis Pupfish, *Cyprinodon variegatus hubbsi* (Teleostei Cyprinodontidae). *Copeia* 1993 (3): 784-789.

Kaill, WM. 1967. Ecology and behavior of the cyprinodontid fishes *Jordanella floridae* (Goode & Bean), *Floridichthys carpio* (Günther) and *Cyprinodon variegatus* (Lacépède). Ph.D. Dissertation, Cornell University, Ithaca, NY. 172 pp.

Longley, William L., (ed.) et al. 1994. Freshwater Inflows to Texas Bays and Estuaries: Ecological Relationships and Methods for Determination of Needs. Texas Water Development Board and Texas Parks and Wildlife Department, Austin, TX. 386 pp.

McDonald, M.G. and A.W. Harbaugh. 1988. A modular three-dimensional finite-difference groundwater flow model. U.S. Geological Survey Techniques of Water-Resources Investigations Book 6, Chapter A1.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks and J. C. Stromberg. 1997. The Natural Flow Regime: A Paradigm for River Conservation and Restoration. *BioScience* 47: 769-784.

Richter, B. D., J. V. Baumgartner, R. Wigington and D. P. Braun. 1997. How Much Water Does a River Need? *Freshwater Biology* 37: 231-249.

Scott, T.M., G.H. Moore, R.P. Meegan, R.C. Means, S.B. Upchurch, R.E. Copeland, J. Jones, T. Roberts, and A. Willet. 2004. Bulletin #66, Springs of Florida, Florida Geological Society. 377 pp.

Sklar, F. H., and J. A. Browder. 1998. Coastal Environmental Impacts Brought About by Alterations to Freshwater Flow in the Gulf of Mexico. *Environmental Management* 22: 547-562.

Southwest Florida Water Management District. 2010. Chassahowitzka River Recommended Minimum Flow and Levels (Peer Review Draft). Brooksville, FL. 104 pp. + 1958 pp. appendices.

Sverdrup, Johnson & Fleming. 1942. The Oceans. Prentice-Hall, Englewood Cliffs, NJ. 1087 pp.