Executive Summary

Background

The state of Florida requires the South Florida Water Management District (SFWMD) to develop Minimum Flows and Levels (MFLs) for priority water bodies within its jurisdiction. MFLs are developed pursuant to the requirements contained in Sections 373.042 and 373.0421 of Florida Statutes (F.S.). The minimum flow is defined as the “. . . limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area." The minimum level is defined as the ". . . limit at which further withdrawals would be significantly harmful to the water resources of the area." (Section 373.042(1), F.S.). Significant harm, as defined by the SFWMD in the Florida Administrative Code (F.A.C.) Section 40E-8.021(24), means the temporary loss of water resource functions, which result from a change in surface or ground water hydrology, that takes more than two years to recover, but which is considered less severe than serious harm. Technical supporting documentation, including scientific and technical data, methodologies, models and assumptions, is developed for each water body and subject to scientific peer review (Chapter 373.042(4) F.S.). The specific water resource functions addressed by a MFL and the duration of the recovery period associated with significant harm are established by rule (Chapter 40E-8 F.A.C.) for each priority water body.

To support the adoption of the existing MFL rule for the Caloosahatchee River, the District compiled results of previous and ongoing studies, initiated additional research, analyzed and interpreted data necessary to develop “technical criteria” for the Caloosahatchee River and Estuary (**Figure ES-1**) and determine low water flows that may cause significant harm to water resources. The resource at greatest risk for impact was identified as an existing 640-acre bed of aquatic vegetation, *Vallisneria americana*, commonly known as tapegrass or wild celery, located downstream of the S-79 water control structure. The final rule, which was adopted by the SFWMD in September 2001 and later incorporated into Chapter 40.E.8. F.A.C., included flow criteria for S-79 and salinity criteria in the vicinity of the vegetation bed, expressed as follows:

> “A MFL exceedance occurs during a 365-day period, when (a) a 30-day average salinity concentration exceeds 10 parts per thousand at the Ft. Myers salinity station (measured at 20% of the total river depth from the water surface at a location latitude 263907.260, longitude 815209.296) or (b) a single, daily average salinity exceeds a concentration of 20 parts per thousand at the Ft. Myers salinity station. Exceedance of either subsection (a) or subsection (b), for two consecutive years is a violation of the MFL.” (Chapter 40.E.8.221(2) F.A.C.)

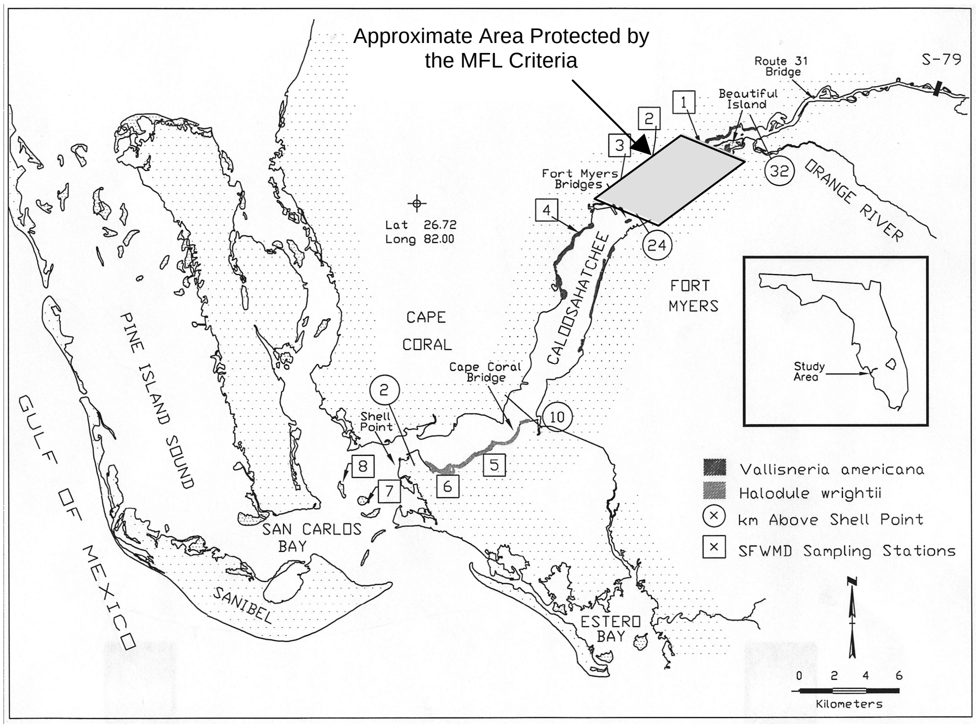

Figure ES-1. Location of the Caloosahatchee River, including major features, natural distribution of submerged aquatic vegetation and related sampling sites.

The MFL study indicated that the proposed criteria for the Caloosahatchee River and Estuary will be exceeded on a regular and continuing basis until additional storage is provided in the basin to supply the additional water needed. Therefore, the MFL document also included a recovery and prevention strategy, which was incorporated into the rule (Ch. 40E-8.421, FAC). Projects in the C-43 basin (reservoirs, aquifer storage and recovery wells) associated with the Comprehensive Everglades Restoration Plan (CERP) and Lower West Coast Regional Water Supply Plan (LWCRWSP), revised operational protocols for existing and new facilities, and modifications to SFWMD consumptive use permitting and water shortage rules and regulations, comprise the recovery and prevention strategy. These combined efforts are designed to supply the water necessary, over time, to achieve the minimum flow criteria.

Purpose and Scope

The MFL Rule, in Section 40E-8.011(3), F.A.C., also states that the minimum flow criteria for the Caloosahatchee River and Estuary shall be reviewed by the SFWMD, based on best available information, within one year of the effective date of the rule and amended as necessary. The purpose of this document is therefore to re-examine the technical and scientific basis of the Caloosahatchee minimum flows based on comments provided by an independent scientific peer review panel and results obtained from additional field observations, laboratory experiments, and numerical model development that have been obtained since adoption of the rule in 2001. The review specifically evaluates the ability of the 300 cfs discharge at Structure S-79 to protect the 640-acre bed of *Vallisneria americana.* This report documents the methods and results of these studies, management implications, and additional investigations that are needed to further refine the recovery and prevention strategy.

In September 2000, the scientific peer review panel reviewed and approved the general scientific approach used in establishing the MFL. However, specific scientific deficiencies in the technical documentation of the rule were identified. Major concerns with the initial effort were as follows:

1. Lack of a hydrodynamic/salinity model
2. Lack of a numerical population model for *Vallisneria americana*
3. No quantification of the habitat value of *Vallisneria* beds
4. Lack of documentation of the effects of MFL flows on downstream estuarine biota

A research program was initiated during 2001 to address these concerns, which included additional field observations, laboratory experiments and development of modeling tools. This program is still in progress. The scope of the review includes the following

1. Examine effects of low level freshwater flows on other organisms that are characteristic of the Caloosahatchee Estuary, especially those located downstream in more marine areas. This analysis tests a basic assumption of the Valued Ecosystem Component (VEC) approach: flows or salinities appropriate for VEC are not detrimental to other important estuarine organisms. This part of the review relied on analyses of data from long-term monitoring of plankton and fish larvae, as well as on recently conducted ecological studies of the American Oyster.
2. Evaluate the salinity tolerance of *Vallisneria americana* as it relates to the salinity criteria of the MFL Rule. Additional field observations and results of laboratory experiments conducted in the past year were analyzed for this purpose.
3. Review the relationship between freshwater inflow and salinity in the Caloosahatchee based on (1) a mass-balance, hydrodynamic model that is currently under development and (2) newly available estimates of freshwater inflows from the tidal basin downstream of S-79.
4. Review the MFL recovery strategy for the Caloosahatchee River and Estuary. The hydrodynamic model and modeled estimates of tidal basin were used to evaluate the ability of CERP projects to (1) provide total flows to the estuary, (2) distribute total flow between sources upstream of S-79 and the downstream tidal basin, and (3) affect the spatial distribution and temporal variability of salinity in the Caloosahatchee Estuary. A numerical

population model of *Vallisneria americana*, also under development, was used to determine whether these projects improve conditions for *Vallisneria*.

Due to time limitations, this review did not address the habitat value of *Vallisneria* beds. This issue is being investigated through a three-year contract with Mote Marine Laboratory, which began in January of 2002. The overall objective of the contract is to identify which organisms use *Vallisneria* habitat in the Caloosahatchee River and how season, salinity, flow, and plant /bed morphometry affect habitat use.

Conclusions

Valued Ecosystem Component Approach:

The Caloosahatchee MFL is intended to establish a salinity environment that indicates conditions that will result in significant harm to submerged *Vallisneria americana* grass beds in the upper estuary. A major assumption of this approach is that salinity and flow conditions that protect *V. americana* will also protect other key organisms in the estuary. Previous work on this subject (Chamberlain and Doering 1998) and results presented in this review support the validity of this assumption. MFL flows of about 300 cfs were not harmful to zooplankton and ichthyoplankton (fish larvae) or to oysters (Crassostrea virginica) living in the downstream higher salinity portions of the estuary. However, lower flows (less than 300 cfs) have been associated with phytoplankton blooms in the upper estuary that could result in water quality problems such as depressed oxygen levels. While evidence indicates that low flows in the 300 cfs range are not harmful, high flows above 2500 – 3000 cfs appear detrimental. This high flow limit agrees with previous estimates (Chamberlain and Doering 1998; Doering et al. 2002).

Salinity Criteria

The Caloosahatchee MFL Rule contains two salinity criteria at the Ft. Myers salinity monitoring site: a 30-day moving average salinity of 10 parts per thousand (ppt) and a daily average salinity of 20 ppt. The summary of published information and the results of investigations by District staff presented here agree that these are sound physiological and ecological thresholds for *V. americana*. The combination of results from field monitoring and laboratory experiments conducted by District and other investigators agree that 10 ppt is a critical threshold salinity for growth. Salinities above 15 ppt cause mortality. The 30-day moving average, as presented in the MFL rule, is consistent with laboratory experiments, which show that *Vallisneria* can survive exposure to 10 ppt for periods exceeding one month. The daily average maximum salinity limit of 20 ppt was included in the rule to avoid acute exposure to high salinity levels. Laboratory experiments conducted by District Staff indicate that a one day exposure to 20 ppt is a reasonable limit for acute exposure. Analysis of 11 years of salinity data demonstrates that in practice, the acute criterion is never exceeded before the 30-day moving average criterion.

Salinity and Freshwater Inflow

A thorough understanding of the relationship between freshwater inflow and the spatial distribution of salinity in the estuary is key to establishing an MFL. Over the past year, two new modeling tools have been developed to investigate this relationship. The Caloosahatchee Tidal Basin Model allows estimation of freshwater inflows down stream of S-79. The Caloosahatchee Hydrodynamic Model is a numerical, mass balanced, 3-dimensional model that estimates the distribution of salinity in the estuary under different freshwater inflow conditions. While both of these tools are still under development, they can be used to relate salinity in the estuary to total inflow (i.e. discharge at S-79 + downstream tidal basin inflows).

The greatest uncertainty in this analysis lies in the relationship between freshwater inflow and the distribution of salinity levels in the estuary. A mass balanced hydrodynamic model is the modeling tool of choice because all inflows need to be quantified and specified. In terms of development, the mass balance hydrodynamic model employed here is in its infancy. The current model uses existing (woefully inadequate) bathymetry. A new bathymetric survey for the Caloosahatchee Estuary will be available soon and incorporated into the model. The model was not calibrated with tidal basin inflows, which are themselves uncertain. The model was calibrated using a very a limited set of hydrologic conditions.

The major conclusions of the salinity and flow modeling effort are that the MFL is not currently being met and a recovery and prevention strategy is required. This conclusion is consistent with the initial technical documentation. Construction of reservoirs and other projects in the C-43 basin being completed under the CERP comprise the existing recovery strategy.

Downstream tidal basin inflows are an important supplement to flows at S-79. Under current conditions, for 300 cfs released at S-79 to produce 10 ppt at Ft. Myers, additional inflow from the downstream tidal basin is required. This additional inflow may be on the order of 200 cfs (total = 500 cfs) but this is uncertain. Whatever downstream contribution is needed, both the original regression analysis and the modeling approach presented here suggest that under current conditions a 300 cfs discharge at S-79 will, on average, produce a salinity of 10 ppt at Ft. Myers.

However, a 300 cfs discharge at S-79 is less likely to achieve 10 ppt under dry conditions when downstream inflows are below average. The effect of downstream, tidal basin inflows on the ability to achieve MFLs has two important ramifications. Under present conditions, releases of 300 cfs at S-79 from Lake Okeechobee may not produce the desired salinity in the estuary if these releases are made during dry periods when contributions from downstream tidal basin are below normal. The same constraint applies after CERP components are built. Releases of 300 cfs from reservoirs and ASR facilities may not satisfy MFL salinity criteria during dry periods when tidal basin inflows are low or absent. Overall, modeling results show that CERP components improve salinity conditions in the downstream estuary. The percentage of total flows that are less than 500 cfs decreases by half when these facilities are completed.

Resource Based Evaluation of the Recovery Strategy:

Modeling studies of *V. americana* shoot density were undertaken to estimate data for two monitoring sites. Site 1 (Bird Island) is located approximately 30 km upstream from Shell Point and Site 2 is located approximately 26 km upstream from Shell Point (**Figure ES-1**). Both sites are within the area designated for protection of *V. americana*. Results of this study indicate that the MFL is not presently being met and an inadequate level of resource protection exists. On the other hand, the results for *V. americana* shoot densities indicate that the CERP components may afford some level of resource protection at these two sites. Since Site two is located at 26 km upstream of Shell Point, the results suggest that CERP may provide resource protection over about two-thirds of the area set aside for protection of *V. americana* (24 – 30 km). Simulations using the hydrodynamic-salinity model indicate that exceedances of the 30-day average MFL salinity criterion occur at Site 1 and Site 2 even with CERP components in place. These exceedances are of less magnitude and duration than those that currently occur. Results from *the V. americana* model further indicate that the 10 ppt criterion provides appropriate protection of the resource from significant harm.

Recommendations

- Continue to apply the present MFL criteria while completing ongoing efforts to further refine and calibrate the models and collect additional monitoring data.
- Results of these studies suggest that changes may be needed to storage facilities in the watershed and/or regional water delivery protocols to provide more freshwater to protect the *V. americana* community from significant harm.
- However, before any decisions are made to modify CERP projects or the MFL criteria, the models need to be completed and fully calibrated and improved flow measurements need to be obtained, especially for downstream tidal basin inflows.
- CERP, the Southwest Florida Feasibility Study, and RECOVER need to consider the implications of these MFL studies which, when complete, may suggest that different management approaches and/or performance measures are needed to protect the resource from significant harm.
- Once restoration needs for this system have been defined as a result of the Southwest Florida Feasibility Study, and reservations have been defined to meet restoration needs, the existing MFL criteria may need to be modified, over time, to protect restored resources from significant harm.

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Section 1 -- Introduction

Importance of Fresh Water to Estuaries

The overwhelming influence of freshwater supply on (1) the composition, abundance and distribution of estuarine flora and fauna in space and time and (2) the physical, chemical, and biological processing of nutrients and other material in estuarine systems is well established (Schlacher and Wooldridge 1996; Nixon et al. 1996, Livingston et al. 1997, Brock, 2001). Modification of river discharge by diversion, withdrawal, channelization and damming has altered the timing and magnitude of the freshwater supply to estuaries (Whitfield and Wooldridge 1994; Hopkinson and Vallino 1995; Jassby et al 1995). In turn, these changes in delivery have had demonstrable impacts on estuarine receiving waters including decreased bio-diversity, loss of livable habitat, excessive stratification, hypoxia and eutrophication (Sklar and Browder, 1998; Estevez 2000a). As the human need for water increases, the amount of freshwater required by estuaries and other aquatic ecosystems has become an increasingly important issue for water managers (Postel et al. 1996). The challenge to management is how to allow human manipulation of freshwater while at the same time satisfying the needs of estuarine environments (Sklar and Browder 1998). A first step in meeting this challenge is to estimate estuarine requirements for freshwater.

Basis for Minimum Flows and Levels

The state of Florida requires the South Florida Water Management District (SFWMD) to develop Minimum Flows and Levels (MFLs) for priority water bodies within its jurisdiction. MFLs are developed pursuant to the requirements contained in Sections 373.042 and 373.0421 of Florida Statutes (F.S.). The minimum flow is defined as the ". . . limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area." The minimum level is defined as the ". . . limit at which further withdrawals would be significantly harmful to the water resources of the area." (Section 373.042(1), F.S.). Significant harm, as defined by the SFWMD in the Florida Administrative Code (F.A.C.) Section 40E-8.021(24), means the temporary loss of water resource functions, which result from a change in surface or ground water hydrology, that takes more than two years to recover, but which is considered less severe than serious harm. Technical supporting documentation, including scientific and technical data, methodologies, models and assumptions, is developed for each water body and subject to scientific peer review (Chapter 373.042(4), F.S.). The specific water resource functions addressed by a MFL and the duration of the recovery period associated with significant harm are established by rule (Chapter 40E-8 F.A.C.) for each priority water body.

MFLs are to be established based on the best available information. Protection of non-consumptive uses may be considered and provided for in the establishment of MFLs (Section 373.042, F.S.). A baseline condition for the protected resource functions must be identified through consideration of changes and structural alterations in the hydrologic system (Section 373.042(1), F.S.). If it is determined that water flows or levels will fall below an established MFL within the next 20 years or that water flows or levels are presently below the MFL, the water management district must develop and implement a recovery or prevention strategy (Section 373.0421(2), F.S.).

The District Water Management Plan (DWMP) for South Florida (SFWMD, 2000a) includes a schedule for establishing MFLs for priority water bodies within the South Florida Water Management District (SFWMD). Section 373.042(2), F.S. requires each water management district to develop a MFL Priority Water Body List that includes the name of the water body and the date (year) in which the MFL will be established. The SFWMD is further required to annually update this list and schedule, make any necessary revisions, and submit the revised list to FDEP for review and comment.

MFLs for the Caloosahatchee River and Estuary

Development of Initial MFL Criteria

The Caloosahatchee River and Estuary (**Figure 1-1**) were first placed on the MFL Priority List in 1999. The District compiled results of previous and ongoing studies, initiated additional research, analyzed and interpreted data necessary to develop "technical criteria" for the Caloosahatchee River and Estuary, to determine low water conditions (water levels and/or flows) that may cause significant harm to water resources. The resource that was at greatest risk for impact was identified as an existing 640-acre bed of aquatic vegetation, *Vallisneria americana*, located downstream of the S-79 water

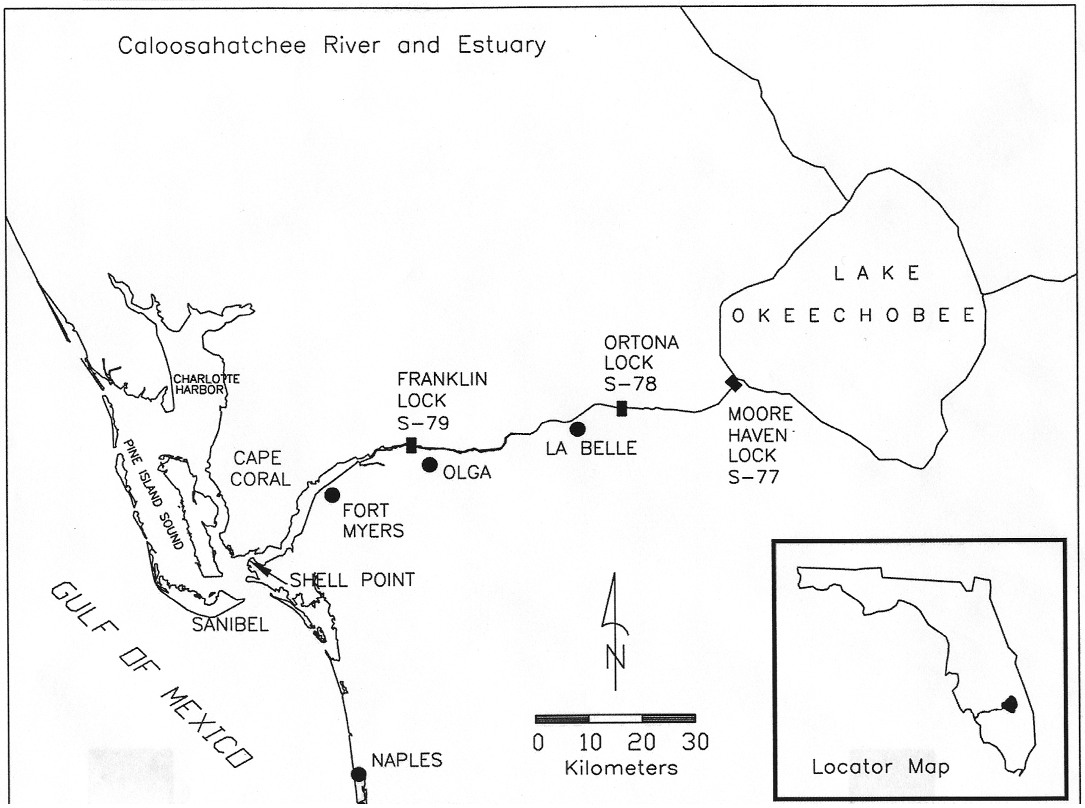

Figure 1-1. Map of the Caloosahatchee River and Estuary showing water control structures and major urban areas.

control structure. The MFL criteria consist of a minimum water flow rate, a duration of time that flows can fall below this rate before damage occurs, and a return frequency (how often such conditions can occur over a specified time period). Based on research conducted in the field and related laboratory studies, it was determined that the *Vallisneria americana* plant community would be adversely impacted if salinity exceeded 10 ppt for a period greater than 30 days. In order for full recovery to occur, such events should not occur during two consecutive years. Statistical analysis of historical flow and salinity data indicated that a flow of 300 cfs was needed through the S-79 structure to prevent salinity at the vegetation bed from exceeding 10 ppt. The proposed technical criteria were then subjected to scientific peer review. The original document was completed in July 2000 and received independent scientific peer review pursuant to Section 373.042, F.S.

Once the proposed technical criteria were approved by the Governing Board, rule development and rule making processes, including public workshops and opportunities for administrative challenge, were initiated. The rule defines the resources that are at risk and the water levels or flows necessary to protect these resources from significant harm. The MFL was not considered to be "established" until the final rule was approved and adopted. Rule development workshops were held in August and December 2000 and in January 2001 to discuss concepts proposed for the Caloosahatchee River and estuary. The final rule, which was adopted by the SFWMD in September 2001 and later incorporated into Chapter 40.E.8. F.A.C.

Other Resource Protection Tools

The proposed MFL's are not a "stand alone" resource protection tool; but must be considered in conjunction with all other resource protection responsibilities granted to the water management districts by law. These include regulatory components such as consumptive use permitting, water shortage management, and water reservations; construction and maintenance of structural components to improve water storage and conveyance capabilities; and the development and implementation of operational protocols to ensure that water is effectively distributed to meet regional needs.

Recovery and Prevention Strategy

The MFL study indicated that the proposed criteria will be exceeded on a regular and continuing basis until additional storage is provided in the basin to supply the additional water needed. Therefore the MFL document also included a recovery and prevention strategy. The structural and operational features of the recovery plan will be implemented through ongoing SFWMD water supply development efforts, including development of regional water supply plans and the Comprehensive Everglades Restoration Plan (CERP). The SFWMD has completed a Lower West Coast Regional Water Supply Plan (SFWMD, 2000a) and a Caloosahatchee Water Management Plan (SFWMD 2000b), pursuant to Chapter 373.0361, F.S., which include projects that are needed to implement the MFL recovery and prevention strategy. The CERP, which addresses water supply needs throughout South Florida as components of the effort to restore the Everglades, includes features that will increase storage in the Caloosahatchee Basin through the construction of a reservoir and Aquifer Storage and Recovery wells (SFWMD and USACE 1999). Modeling studies using discharge scenarios that included CERP and

LECRWSP projects indicate that the MFL will be met by 2020 when these facilities in the Caloosahatchee basin are completed and fully operational.

The MFL Rule, in Section 40E-8.011(3) F.A.C., also states that the minimum flow criteria for the Caloosahatchee River and Estuary shall be reviewed and amended as necessary within one year of the effective date of the rule. The purpose of this review is to re-examine the technical and scientific basis of the Caloosahatchee MFL in light of comments by a scientific peer review committee and results obtained from additional field observations, laboratory experiments, and numerical model development. The review specifically evaluates the ability of the 300 cfs discharge at Structure S-79 to protect the 640-acre bed of *Vallisneria americana*. This report documents the methods and results of these studies, management implications, and additional investigations that are needed to further refine the recovery and prevention strategy.

History and Major Features of the Caloosahatchee River and Estuary

The Caloosahatchee River and Estuary are located on the southwest coast of Florida (**Figure 1-1**). The Caloosahatchee River runs from Lake Okeechobee to the Franklin Lock and Dam (S-79) where it empties into the estuary, which is some 40 kilometers long and terminates at Shell Point. The Caloosahatchee River is the major source of freshwater to the estuary. Enough water enters the estuary at S-79 to fill its volume over 8 times per year (Doering and Chamberlain 1999).

The hydrology of the Caloosahatchee system has been altered over time. The river has been permanently connected to Lake Okeechobee and about 20% of the water entering the estuary now comes from the Lake mainly as regulatory releases to maintain the Lake at a prescribed water level. The river has also been straightened and deepened and three water control structures have been added. The last, Structure S-79, was completed in 1966 to act, in part, as a salinity barrier (Flaig and Capece, 1998).

These changes have increased the variability in freshwater input and salinity in the estuary. During the wet season, rainfall runoff that was historically retained and/or evaporated within the watershed now reaches the estuary in greater volume and shorter time (USACE 1957). During the dry season, agricultural and urban water supply demands result in reduced flows to the estuary. The construction of S-79 truncated the estuary by blocking the natural gradient of freshwater/saltwater that historically extended into the upper reaches of the estuary during the dry season from November to May.

Long-term records of salinity at the head (S-79) and mouth (Shell Point) illustrate this high variability and truncation of the salinity gradient (**Figure 1-2**). During periods of low freshwater discharge (50 cfs or less), salt water regularly intrudes all the way to the structure, often resulting in salinities that exceed 10 parts per thousand (ppt or $^{o}/_{oo}$). The loss of fresh-brackish water habitat, that can be critical to the successful recruitment of many estuarine dependant species, has resulted in the loss of an important water resource function of the estuary during the dry season. By contrast, high rates of freshwater discharge (up to several thousand cfs) can cause salinity to drop below 5 $^{o}/_{oo}$ at the mouth of the estuary near Shell Point. The transition between the two states can be rapid, sometimes requiring less than a week. The fluctuations observed at the head and mouth of the estuary exceed the salinity tolerances of oligohaline and marine species.

The South Florida Water Management District recognized the need to identify a range of discharges from S-79 that will protect the system and began a research program in 1985 (Chamberlain and Doering 1998). In addition, the Florida Legislature has required that water management districts establish minimum flows and levels for priority water bodies within their jurisdiction and the SFWMD subsequently identified the need to establish a MFL for the Caloosahatchee River and Estuary by 2001.

Approach Used to Establish the Caloosahatchee MFL

The SFWMD began work in the mid 80s to collect simultaneous biota and water quality data, which was later expanded to include continuous salinity sensor monitoring, preliminary modeling, and lab + field experiments. These data were used to attempt to understand the correlation in space and time between biota and their stressors (primarily flow and salinity). This early work provided a basis to formulate the MFL.

Investigations by other researchers have validated this resource-based approach. The methods used by the SFWMD to establish MFL criteria for the Caloosahatchee River and Estuary are thus similar to the Valued Ecosystem Component (VEC) approach (USEPA, 1987) and the habitat overlap concept of Browder and Moore (1981). The VEC approach is the general name given to a method developed by the U.S. Environmental Protection

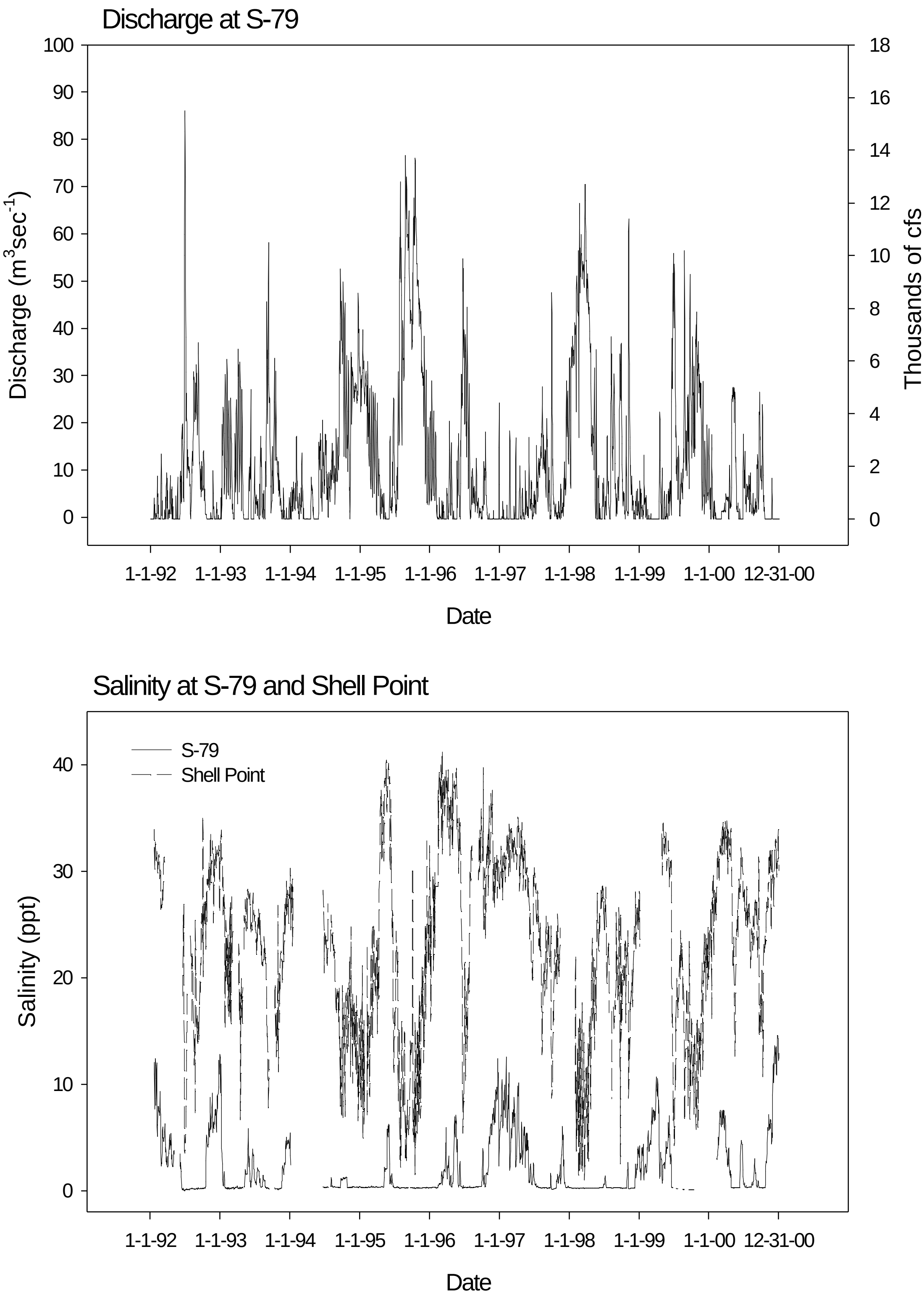

Figure 1-2. Daily freshwater discharge at Structure 79 (top panel) and corresponding daily average salinity at Structure 79 at the head of the estuary and at Shell Point near its mouth (bottom panel)

Agency (USEPA, 1987) to guide the monitoring programs within the National Estuary Program.

Definition of the Resource that Needs to be Protected

The approach has been modified to focus on providing critical estuarine habitat. In some cases that habitat might be physical, such as an open water oligohaline zone. In other cases the habitat is biological and typified by one or more prominent species (e.g. an oyster bar). For the Caloosahatchee, beds of submerged angiosperm grasses have been identified as a VEC. The salt tolerant freshwater species, *Vallisneria americana*, which occurs in the upper Caloosahatchee Estuary is the VEC for the minimum flow.

Vallisneria beds located in the upper Caloosahatchee Estuary represent an extremely important habitat found within the greater Charlotte Harbor estuarine system. When growing conditions are favorable, the most luxuriant beds are found in the 640 acre area between the Beautiful Island and the Ft. Myers bridge. This constitutes about 60% of the reported areal coverage of the species in the Caloosahatchee. *V. americana* grass beds have been documented as an important component of the upper and mid-estuary for more than 45 years (Phillips and Springer 1960; Gunter and Hall 1962).

Conditions Required for Resource Protection

As applied here the VEC approach assumes that (a) environmental conditions suitable for VEC will also be suitable for other species and (b) that enhancement of VEC will lead to enhancement of other species. Beds of submerged aquatic vegetation (SAV), like *Vallisneria americana*, are prominent species that are important to the ecology of shallow estuarine and marine environments. These beds provide habitat for many benthic and pelagic organisms, function as nurseries for juveniles and other early life stages, stabilize sediments, improve water quality and can form the basis of a detrital food web (Kemp et al. 1984; Thayer et al. 1984; Fonseca and Fisher 1986; Carter et al. 1988; Kilgore et al. 1989; Zieman and Zieman 1989; Lubbers et al. 1990; Virnstein and Morris 2000; Beck et al. 2001). Because of their importance, estuarine restoration initiatives often focus on SAV (Batiuk et al. 1992; Virnstein and Morris 2000; Johansson and Greening 2000). SAV are commonly monitored to gauge the health of estuarine systems (Tomasko et al.

1996) and their environmental requirements can form the basis for water quality goals (Dennison et al. 1993; Stevenson et al. 1993).

The concept of static and dynamic habitat overlap (Browder and Moore, 1981) is based on the ideas of Gunter (1961) that (a) estuaries serve a nursery function and (b) salinity determines the distribution of species within an estuary, and indeed different life stages of the same species. In addition, the concept recognizes the importance of the appropriate physical or static habitat to the nursery function and ability of the estuary to support diverse and abundant biotic populations. Freshwater inflow positions favorable salinities relative to important stationary habitat factors such as shoreline, water depth, and bottom type (Browder and Moore, 1981). In the present application, ecologically supportive freshwater inflows produce a temporal and spatial overlap between grass beds and physiologically tolerable salinity (**Figure 1-3).**

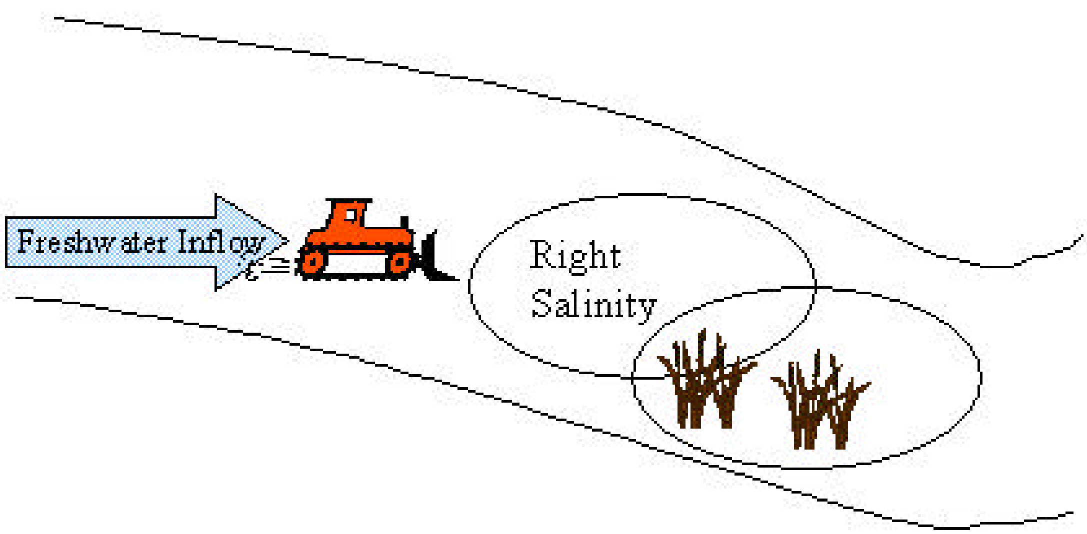

Figure 1-3. Habitat overlap concept. Freshwater inflow positions favorable salinity over grass beds in the upper Caloosahatchee Estuary

Since Browder and Moore (1981), more recent attempts to establish freshwater requirements are based on the concept of enhancing fisheries by providing appropriate spatial and temporal salinity structure. In the case of San Francisco Bay, the geographical position of the 2 ppt isohaline is correlated both with freshwater input and the abundance of striped bass (*Morone saxatilus*), starry flounder (*Platichthys stellatus*) and various components of their food web (Jassby et al. 1995). The relationships have been used in concert to indicate freshwater inflow requirements (Kimmerer and Schubel 1994; Jassby et al. 1995). In Texas, the overlap concept has been combined with a probabilistic approach (Sklar and Browder 1998). The salinity requirements of commercially important fish and shellfish are used to constrain possible inflow solutions that may, for example, maximize fisheries harvest (Longley 1994; Matsumodo et al. 1994; Powell and Matsumodo 1994). The requisite information for establishing a minimum flow is listed below.

1. Selection of an appropriate VEC
2. The distribution of VEC in the estuary
3. Physiological response of VEC over an environmentally representative range of salinities (magnitude and variability)
4. Relationship between freshwater inflow and the spatial distribution and temporal variability of salinity in the estuary
5. Salinity tolerance of the VEC
6. Definition of a degree of impact to VEC that constitutes "significant harm"
7. The spatial extent *or condition* of the VEC that requires protection by a minimum flow

An additional consideration that should be included in this analysis is the effect of flow on environmental factors other than salinity, such as sediment transport, overall water quality, light penetration and plankton dynamics. The first four requirements comprise the set of tools necessary to calculate the appropriate flow regime. The last three determine its actual magnitude. These tools allow us to answer the question: What magnitude of freshwater inflow will place the necessary salinity in a location in the estuary that will protect the resource from significant harm?

Review of the Caloosahatchee MFL Rule

MFL criteria were adopted and went into effect in September, 2001. The MFL was intended to maintain *Vallisneria* in a 640 acre area located between 24 and 30 kilometers upstream of Shell Point (**Figure 1-1**). The purpose of this review is to re-examine the technical and scientific basis of the Caloosahatchee MFL rule in light of comments by other agencies, the public and the scientific peer review panel and results obtained from additional field observations, laboratory experiments, and numerical model development.

As part of the development of the Caloosahatchee MFL, a scientific peer review of the technical criteria was conducted and a report produced (Edwards et al 2000). The review panel approved the general scientific approach used in establishing the MFL that has just been described. The panel also agreed that *V. americana* grass bed was an appropriate resource that needed to be protected and that the salinity criteria for protection of this resource were sufficient. The provision in the rule that exceedance of the salinity criteria for two consecutive years would cause significant harm was determined by the panel to be consistent with the SFWMD definition of significant harm, i.e. ". . . the temporary loss of water resource functions, which result from a change in surface or ground water hydrology, that takes more than two years to recover, but which is considered less severe than serious harm." (Section 40E-8.021(24), F.A.C.)

However, the peer review panel also identified specific scientific deficiencies in the technical documentation of the rule. Major criticisms of the initial effort were:

1. Lack of a hydrodynamic/salinity model
2. Lack of a numerical population model for *Vallisneria americana*
3. No quantification of the habitat value of *Vallisneria* beds
4. Effects of MFL flows on downstream estuarine biota

The SFWMD's existing research program (**Appendix A**) was expanded to address these concerns and included additional analysis of historical sampling efforts, field observations, laboratory experiments and development of modeling tools. This program is still in progress. The scope of this review is to:

1. Examine effects of low flows on other organisms in the Caloosahatchee, especially those located downstream in more marine areas. This analysis tests a basic assumption of the VEC approach: that flows or salinities appropriate for VEC are not detrimental to other important estuarine organisms. This part of the review relies on analyses of data from long-term monitoring of plankton and fish larvae and recently conducted ecological studies of American oysters.

2. Evaluate salinity and other criteria of the MFL Rule. The salinity tolerance of *Vallisneria americana* will be reviewed using additional field observations and results of new laboratory experiments conducted in the past year will be included. Other criteria will also be discussed.
3. Review the relationship between freshwater inflow and salinity in the Caloosahatchee Estuary based on (1) a mass balanced hydrodynamic model that is currently under development and (2) newly available estimates of freshwater inflows from the tidal basin downstream of S-79. This portion of the review will specifically look at the distribution of salinity in the estuary that results from a 300 cfs discharge at S-79.
4. Review the recovery strategy for the Caloosahatchee. The hydrodynamic model, currently under development, will be used to evaluate the effect of the CERP projects on the salinity distribution in the Caloosahatchee Estuary. In turn, a numerical population model of *Vallisneria americana*, also under development, will be used to determine whether these projects improve conditions for *V. americana*.

This review does not address the habitat value of *Vallisneria* beds. Habitat value is being determined through a 3-year contract (C-12836) with Mote Marine Lab that began in January 2002. The overall objective of the project is to identify which organisms use *Vallisneria* habitat in the Caloosahatchee River and how season, salinity and plant /bed morphometry affect habitat use.

Section 2. -- Effects of Minimum Flows on Other Organisms

As applied here, the VEC approach assumes that MFL flows based on *Vallisneria americana* will not harm, and may benefit, other estuarine organisms. The scientific peer review panel concluded that this assumption required additional documentation. The panel further recommended that the response of organisms in the lower estuary to the freshwater inflows and salinity associated with the MFL should be determined (Edwards et al 2000). In this section we summarize results of several studies that address this issue.

Oysters

The South Florida Water Management District (SFWMD) has conducted considerable research on SAV (Chamberlain and Doering 1997; Chamberlain and Doering 1998; Doering et al. 1999; Kraemer et al. 1999; Doering and Chamberlain 2000; Doering et al. 2002). However, studies of other valued ecosystem components, such as oyster reefs, that occur in the higher salinity waters of the lower Caloosahatchee Estuary are presently lacking. Such studies are clearly necessary. In response to this need, the District funded Drs. Aswani Volety and Gregory Tolley (Florida Gulf Coast University) to investigate oyster ecology in the Caloosahatchee Estuary. Results of their studies are summarized here and in **Appendix B**.

Investigations of oyster reef distribution indicate that these are prevalent in San Carlos Bay and Matlacha Pass, in areas that normally experience marine salinities. Oysters are not present as reefs above Shell Point on the south side of the estuary and Cattle Dock on the north side (**Figure 2-1**). Clumps of oysters may be found as far upstream (east) as the Cape Coral Bridge. As in other systems, oyster reefs form critical habitat for fish and a variety of invertebrates. To date, nine species of crabs and shrimp and 17 species of fish have been identified from lift net samples.

One of the major factors that can limit the distribution and life span of the oyster is infection with the protozoan parasite, *Perkinsus marinus*. *Perkinsus marinus* has devastated oyster populations in the Atlantic (Burreson and Ragone-Calvo 1996), where it is currently the primary pathogen of oysters, and in the Gulf of Mexico (Soniat 1996). Andrews (1988) estimated that *P. marinus* can kill up to 80% of the oysters in a bed. The

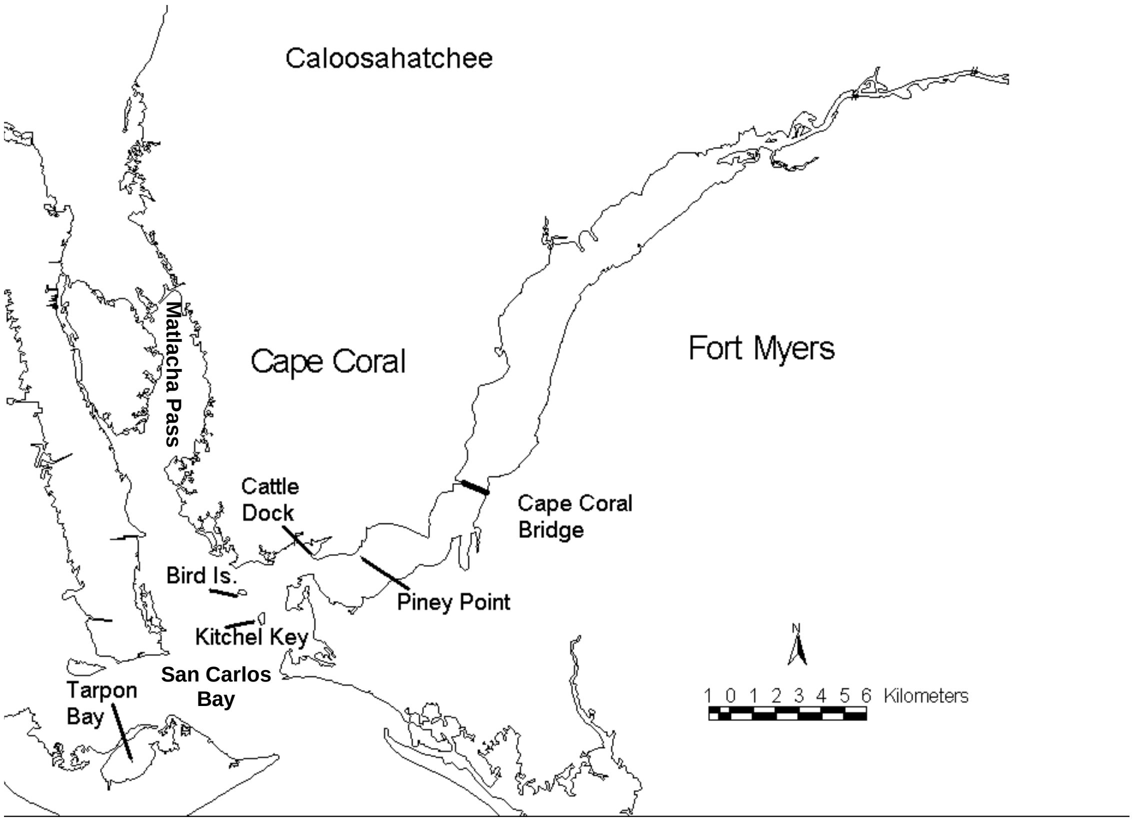

Figure 2-1. Location of oyster sampling sites in the Caloosahatchee River (Cattle Dock, Piney Point), San Carlos Bay (Bird Is., Kitchel Key) and Tarpon Bay

distribution and prevalence of *P. marinus* is influenced by temperature and salinity with higher values favoring the disease organism (Burreson and Ragone-Calvo 1996, Soniat 1996, Chu and Volety 1997). Field and laboratory studies indicate that *P. marinus* exerts severe pressure on growth, survival, and energy reserves of oysters, thereby limiting reproduction and recruitment.

Volety concluded that the antagonistic effects of temperature and salinity keep *P. marinus* infection in oysters at relatively low levels in the Caloosahatchee River. During the dry season, cool winter temperatures counteract the effects of higher, more favorable, salinity due to low freshwater inflow. During the wet season, lower salinity, due to rainfall and runoff, counteract the effect of higher more favorable temperatures.

Volety and Tolley (**Appendix B**) compared the response of oysters to infection by *P. marinus* during the dry season of 2001 (drought conditions) and during the dry season of 2002 when freshwater inflows were higher due to releases from Lake Okeechobee. Daily discharge at S-79 during the dry season of 2001 (Nov 1, 2000 – May 30, 2001) averaged

73 cfs. During the dry season of 2002, discharge averaged 460 cfs. While temperatures were similar at all sites during the two dry seasons, salinities were lower during all months of the dry season of 2002 at Piney Point, Cattle Dock, and Bird Island. Depending on site and month, differences ranged between 1 and 14 ppt. At Kitchell Key salinities were lower only during the months of January through April (Appendix B).

While infections were light during both years, the rate of infection was lower during the dry season of 2002 when low level releases of freshwater were made from Lake Okeechobee (**Figure 2-2** and **Figure 2-3**).

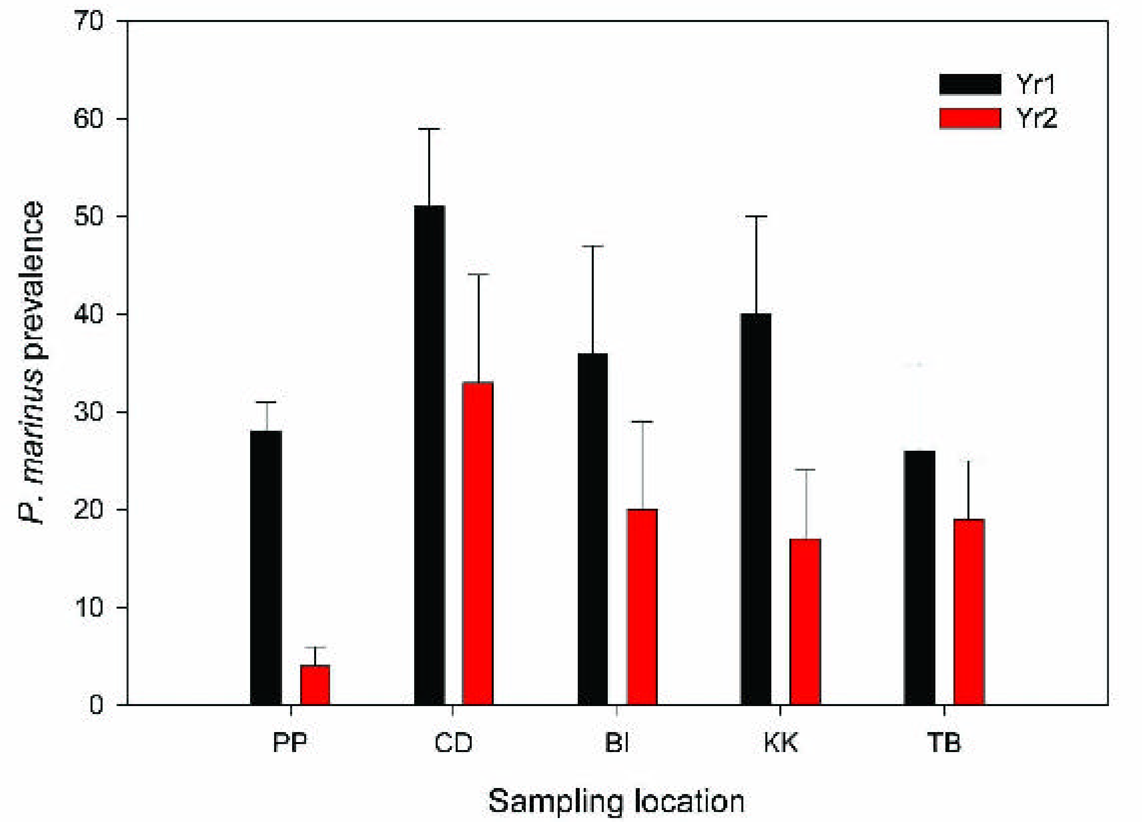

Figure 2-2. Mean *P. marinus* prevalence (± SE) during winter months in oysters from Piney Point (PP), Cattle Dock (CD), Bird Island (BI), Kitchel Key (KK), and Tarpon Bay (TB) in Caloosahatchee River (see **Figure 2-1** for locations) during years 1 and 2. November – May were considered as dry months due to paucity of rainfall. Years 1 and 2 are from September 2000–August 2001, and from September 2001–Present, respectively. Ten oysters were randomly sampled from each location per month and prevalence of *P. marinus* in oysters was analyzed according to Ray 1954. Increased freshwater releases from Lake Okeechobee and resulting decreased salinities were associated with lower infection intensities in oysters from all of these locations.

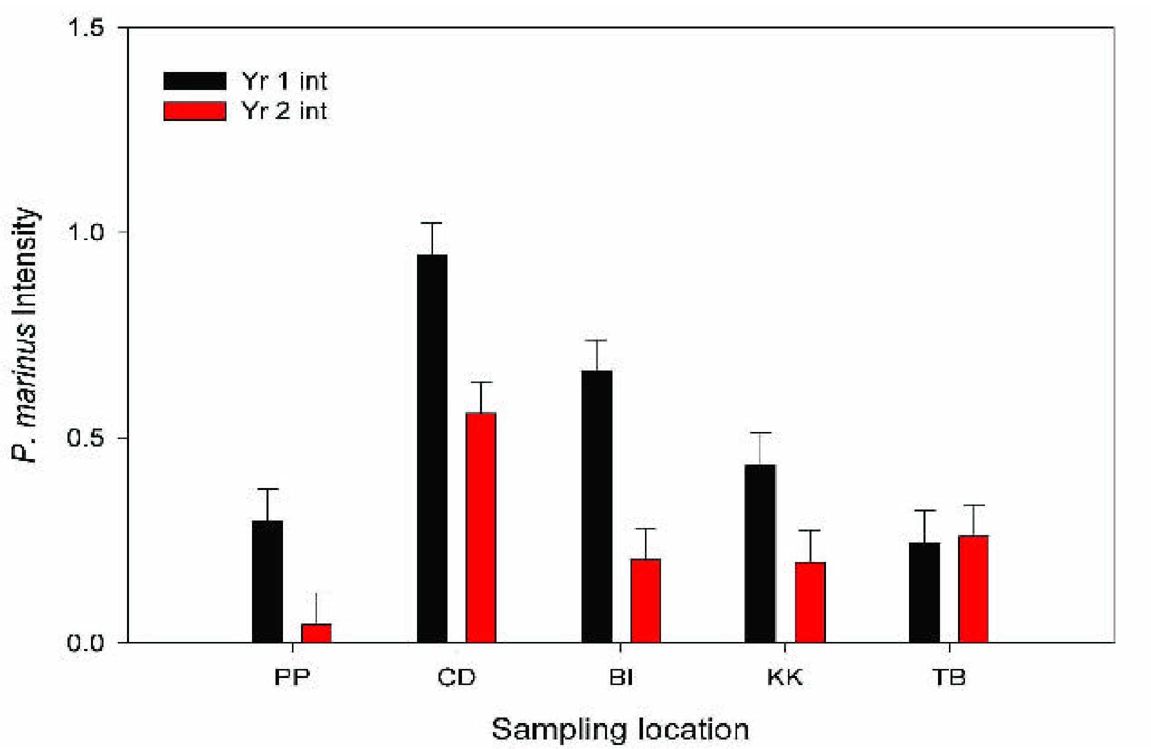

Figure 2-3. Mean *P. marinus* intensity (± SE) during winter months in oysters from Piney Point (PP), Cattle Dock (CD), Bird Island (BI), Kitchel Key (KK), and Tarpon Bay (TB) in Caloosahatchee River (see **Figure 2-1** for locations) during years 1 and 2. November – May were considered as dry months due to paucity of rainfall. Years 1 and 2 are from September 2000–August 2001, and from September 2001–Present, respectively. Ten oysters were randomly sampled from each location per month and intensity (Int) of *P. marinus* (weighted incidence) was analyzed according to Ray 1954. Increased freshwater releases from Lake Okeechobee and resulting decreased salinities were associated with lower infection intensities in oysters located upstream of Tarpon Bay.

These results suggest that low level releases may be beneficial. However, because infections were light and non-lethal, the results also suggest that flows less than 300 cfs during the dry season do not cause "significant harm" as measured by *P. marinus* infection. However, the current study did not examine mortality caused by marine predators that may be present during periods of high salinity.

Given that optimum salinity for oysters ranges from 10 to 28 ppt (Sellers and Stanley 1984), under the prevailing salinity regimes, high flows exceeding 3000 cfs, may cause severe mortality and low larval settlement. Based on a regression model (Volety and Tolley, **Appendix B**), flows between 500 cfs and 2000 cfs would result in salinities of 16–28 ppt in the region between Piney Point, in the Caloosahatchee River and Kitchell Key, in San Carlos Bay. According to the regression model (Volety and Tolley,

Appendix B), a flow of 300 cfs would keep salinity within the optimum range at Piney Point and Cattle Dock. Under current water management practices, oysters in the Caloosahatchee River are not stressed by low flows (less than 300 cfs), but are stressed when high flows exceed 3000 cfs for extended periods (2–4 weeks, **Appendix B**).

Phytoplankton

The District has monitored chlorophyll *a* as a measure of phytoplankton biomass in the Caloosahatchee Estuary, San Carlos Bay and Pine Island Sound under a range of freshwater discharge conditions at S-79 (Doering and Chamberlain 1998). Monitoring was not continuous but occurred on a monthly basis during periods from 1986 to 1989 and 1994 to 1995. Detailed results are presented in Doering and Chamberlain (1998).

Figure 2-4 shows a typical longitudinal distribution of chlorophyll *a*, with a distinct maximum in the upper part of the estuary just downstream of Beautiful Island. Highest concentrations of Chlorophyll *a* tended to occur most frequently in the upper Caloosahatchee Estuary and less often in San Carlos Bay and Pine Island Sound (see **Figure 2-5** for locations). In part, this pattern seems to be related to freshwater discharges at S-79. The statistically significant (P<.02) linear regressions shown in the bottom two panels of **Figure 2-4** demonstrate that both the magnitude of this maximum, and its location in the estuary are, in part, functions of discharge (Doering and Chamberlain 1998). Visual comparison of open circles (wet season, Jun 1– Oct 31) and closed circles (dry season, Nov 1– May 30) suggest that the relationships do not vary seasonally. While other factors such as light, temperature, nutrients and grazing influence the distribution and abundance of phytoplankton, the influence of freshwater discharge on the distribution of plankton in estuaries is a well documented phenomenon (Welch et al. 1972; Fisher et al. 1988; Doering et al. 1994).

These results suggest that large blooms, which may cause water quality problems such as reduced light penetration or low dissolved oxygen concentrations, can occur in the upper estuary over *Vallisneria* beds. In fact, relative to the rest of the southern Charlotte Harbor system, the upper Caloosahatchee Estuary exhibits the highest chlorophyll *a* concentrations and lowest dissolved oxygen concentrations in bottom waters (Doering and Chamberlain, 1998).

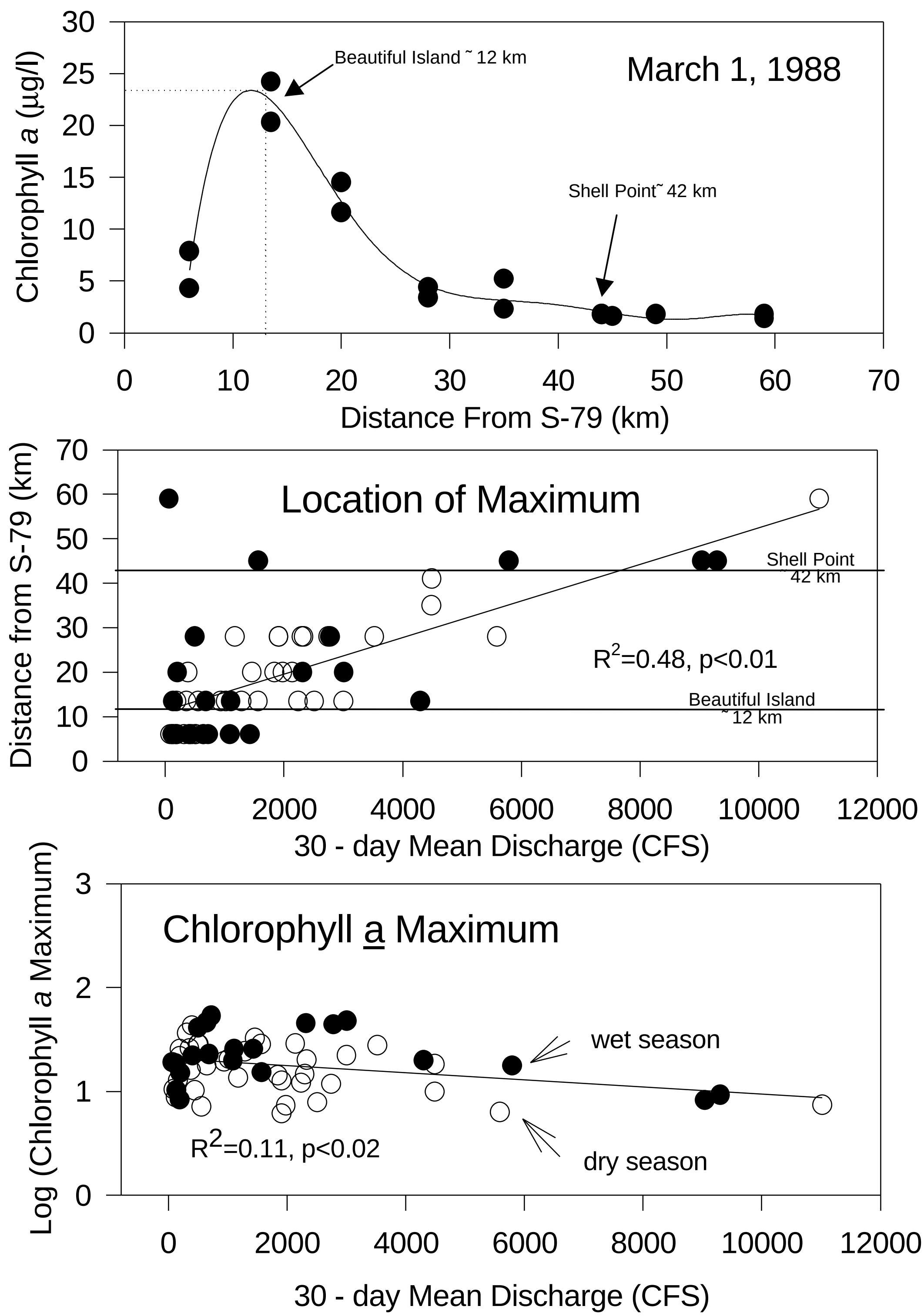

Figure 2-4. Chlorophyll a in the southern Charlotte Harbor system (0 km at S-79, 60 km in Pine Island Sound). Top: Typical distribution showing position and magnitude of bloom. Middle: Discharge and magnitude of bloom. Lower: Discharge and location of bloom.

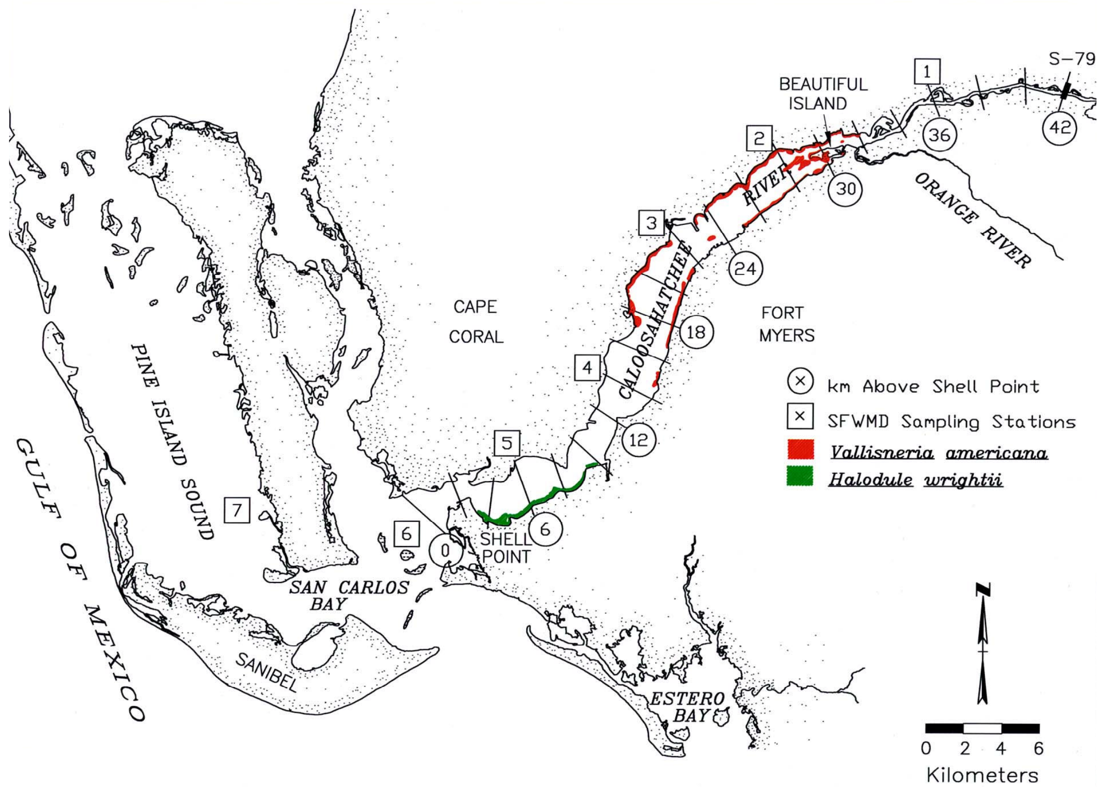

Figure 2-5. Location of sampling stations relative to locations of seagrasses within the Caloosahatchee Estuary.

Low flows can provide conditions that are favorable for phytoplankton blooms to occur in the upper estuary. These blooms, in turn can create water quality problems associated with decreased light penetration and night time oxygen levels as well as accumulation of metabolic wastes and plant toxins. The way in which low, MFL flows are delivered (pulse vs. constant) is important and deserves further attention.

Zooplankton and Ichthyoplankton

The District has monitored zooplankton and larval planktonic fish at 7 stations in the Caloosahatchee Estuary, San Carlos Bay and Pine Island Sound during various freshwater discharge conditions at S-79 (**Figure 2-5**). Monitoring was not continuous but occurred on a monthly basis during the following periods: 1986 to 1989, 1994 to 1995, and 1998 (**Appendix C**).

Mean zooplankton density increased along with salinity and distance from S-79. Zooplankton density was generally greatest during late spring to early summer and was lowest during August to November when rainfall tends to be highest. Low zooplankton abundance is associated with freshwater inflows and lower salinity regardless of the season. Zooplankton density was weakly related to salinity, but correlated well with freshwater inflow volume, possibly due to a "wash out" effect.

Although the mechanism is unknown, some freshwater inflow to the estuary appears to be necessary for zooplankton to achieve maximum density. Moderate rates of freshwater inflow may provide nutrients that stimulate production of phytoplankton, which in turn provide food for zooplankton. In the Caloosahatchee Estuary (Stations 1 to 5 on **Figure 2-5**), the greatest densities of zooplankton were measured when inflows were 150 to 600 cfs. At flows between 0 and 150 cfs, densities declined. Inflows that exceed 1,200 to 1,500 cfs were associated with reduced zooplankton density. Inflows that were greater than 2,500 to 3,000 cfs supported the lowest density (**Figure 2-6**). In San Carlos Bay (Station 6) and Pine Island Sound (Station 7) no relationship between discharge at S-79 and zooplankton density was detected (**Figure 2-6**).

Ninety percent of the shrimp and crab larvae were collected in the lower Caloosahatchee Estuary (Station 5 at Iona Cove) and in San Carlos Bay (Station 6). Peak abundance occurred in San Carlos Bay when salinity exceeded 20 to 25 ppt. Thus, inflows that do not exceed 2,500 to 3,000 cfs will protect the San Carlos Bay spawning and rearing area. Inflows below 1,200 to 1,500 cfs will also provide habitat upstream of Shell Point.

Freshwater inflows < 600 cfs were associated with the highest ichthyoplankton and egg density in the Caloosahatchee Estuary (Stations 2 to 5, **Appendix C**). The maximum ichthyoplankton use of the estuary and spawning occurred in most areas during low flows. Ichthyoplankton and eggs were greatest during the dry season, especially in spring (March-June). Dry season and spring minimum inflows necessary to protect upstream SAV will not adversely impact ichthyoplankton and egg abundance. Inflows < 600 to 800 cfs, associated with higher seagrass production near Station 5 (Doering et al. 2002), should also maximize ichthyoplankton and egg abundance in this region and downstream.

Marine Seagrasses

The marine seagrasses, *Halodule wrightii* and *Thalassia testudinum* occur in the lower Caloosahatchee Estuary (*H. wrightii*) and San Carlos Bay (*H. wrightii, T. testudinum*) (**Figure 2-5**). Laboratory experiments indicate that *H. wrightii* can survive salinities

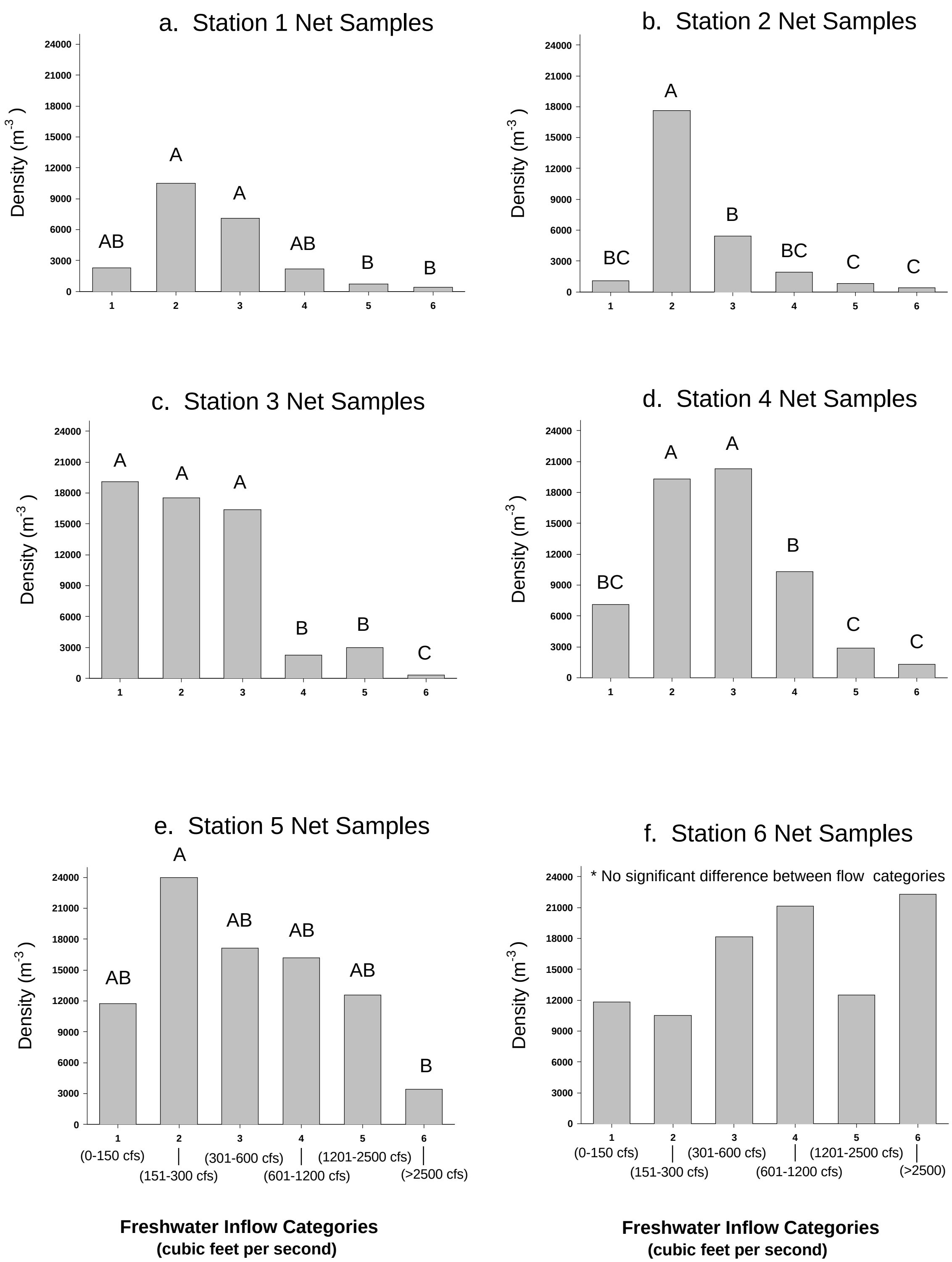

Figure 2-6. Effect of freshwater inflow at S-79 on net collected zooplankton density, sampled monthly at six downstream stations. Bars with different letters are significantly different ($p<0.05$).

greater than 6 ppt. Field data indicates that highest densities occur above 20 ppt (Doering et al. 2002). Likewise highest densities of *T. testudinum* occur in the field at salinities greater than 20 ppt. In the laboratory, *T. testudinum* has been shown to survive a six week exposure to 6 ppt (Doering and Chamberlain 2000). Discharges of over 2800 cfs at S-79 are required to lower salinity to 6 ppt in the lower estuary (Doering et al 2002). Flows of 300 cfs will not lower salinity sufficiently to impact marine seagrasses in the lower estuary or in San Carlos Bay (Chamberlain and Doering 1998).

In summary, low flows of about 300 cfs at S-79 do not appear to have detrimental effects on zooplankton, ichthyoplankton or oysters. This result suggests that the flows that benefit *V. americana* in the upper estuary are not detrimental to other organisms that utilize the estuary. In fact, low flows (<600 cfs at S-79) correlate with higher abundances of ichthyoplankton and zooplankton in the upper estuary. These flows may favor spatial overlap between ichthyoplankton and their zooplankton food source. Low flows at S-79 also correlate with the occurrence of phytoplankton blooms in the upper estuary. While blooms may serve as a food source for zooplankton, if unchecked by grazing, they can lead to water quality problems such as depressed oxygen levels. Oysters in the lower estuary do not appear harmed by low flows and may benefit through a reduction of the intensity of infection by *Perkinsus marinus*. **Table 2-1** summarizes relationships between various organisms and discharge at S-79. Low flows in the 300 cfs range are not harmful whereas flows greater than 2500–3000 cfs appear detrimental. This high flow limit agrees with previous estimates (Chamberlain and Doering 1998; Doering et al. 2002).

Table 2-1 . Summary of relationships between various groups of organisms and freshwater discharge at S-79.

Organism	**Area**	**Flows at S-79 (cfs)**		
		Not Harmful	**Optimal**	**Detrimental**
Oysters	Estuary –San Carlos Bay	300 - 500	500 – 2,000	> 3,000
Zooplankton	Estuary	----	150 - 600	>2,500 – 3,000
Shrimp & Crab Larvae	San Carlos Bay	----	< 2,500	> 2,500 – 3,000
Shrimp & Crab Larvae	Estuary (Iona Cove)	----	< 1,200	>1,500
Ichthyoplankton	Upper Estuary	----	< 600	----
	Estuary (Iona Cove)	----	600 – 800	----
Halodule	Estuary (Iona Cove)	----	<800	>2800
Halodule, Thalassia	San Carlos Bay	----	<800	>4500

Section 3 -- The Salinity Tolerance of *Vallisneria americana*

The physiological tolerance of the VEC to salinity is used to identify a particular salinity or range of salinities that will maintain the VEC in the estuary. Using a relationship between freshwater inflow and salinity in the estuary, a minimum flow can be identified that will protect the VEC from significant harm. Salinity tolerance was determined based on analyses of data from monitoring of field populations and from laboratory mesocosm experiments designed to measure the effects of salinity on growth and mortality. Description of laboratory and field methods may be found in **Appendix D.**

In brief, the laboratory data on salinity tolerance summarized in this report were collected during four experiments conducted between 1996 and 2001 (**Table D-1**, **Appendix D**). Plants were exposed to constant salinity treatments (n = two mesocosms per treatment) for periods of 3 to 10 weeks. Field observations were obtained from an ongoing program, started in 1998, to monitor *V. americana* on a monthly basis in the upper Caloosahatchee Estuary (**Figure 3-1**, Station 1-4).

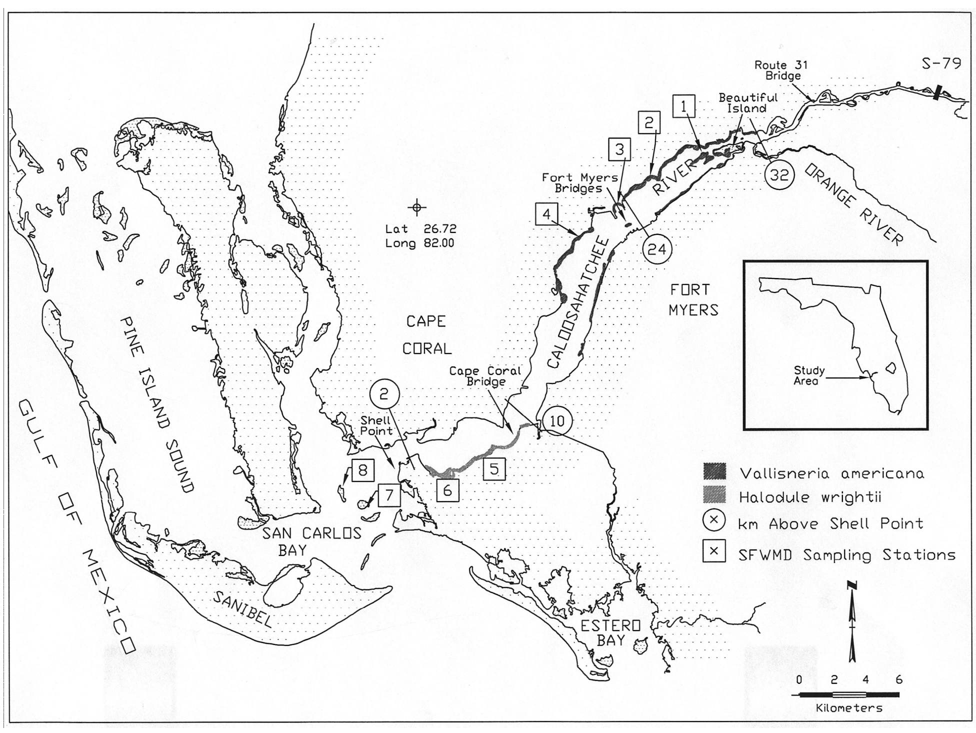

Figure 3-1 Distribution of *Vallisneria americana* and *Halodule wrightii* in the Caloosahatchee Estuary. Also shown are the locations of grass bed monitoring stations and the general locations of salinity recorders at S-79, Rt. 31 Bridge, Fort Myers Bridges, and Shell Point.

Both field and laboratory data were used to select salinity thresholds that could be used to calculate minimum and maximum flow conditions that are needed to maintain the VEC. Field salinity tolerances were identified from plots of plant density as a function of salinity on the day of sampling. Threshold salinities, which reflect the tolerance of *V americana* to salinity stress, were those associated with marked changes in plant density. Laboratory data were examined to identify salinity levels where growth was low, and close to zero. Using non-linearities to identify thresholds is common in methods used to determine flow requirements for streams and rivers (Estevez 2000b).

For *V. americana*, the net growth rates of shoots and blades in the laboratory decreased as salinity increased, with mortality occurring at salinities greater than 15 ppt (**Figure 3-2**). At 18 ppt a 50% loss of shoots would occur in 38 days. At 20 ppt a 50% loss would occur in 16 days. In the region between 10 ppt and 15 ppt, the change in growth in response to a change in salinity was very small. This lack of response was especially evident for the number of blades: growth rates at 10 ppt and 15 ppt were virtually identical. In this zone, plants survived but net growth rates of shoots and blades were very low.

Data from field monitoring agreed with results from the laboratory (**Figure 3-3**, upper panel). Higher densities in the field (> 400 shoots m^{-2}) occurred at salinities less than about 10 ppt. Lower densities (< 400 shoots m^{-2}) were more frequent at salinities above 10 ppt. Ten (10) ppt appears as a threshold because high densities of *V. americana* do not occur at higher salinities. At favorable salinities below 10 ppt where density may be high or low, other factors such as light and temperature may control plant density.

Our laboratory results suggest that for *V. americana* from the Caloosahatchee, growth is low or nil in the 10 ppt to 15 ppt range with mortality occurring at salinities greater than 15 ppt. This agrees well with transplant experiments conducted in the Caloosahatchee that indicated mortality at salinities greater than 15 ppt (Kraemer et al. 1999). Adair et al. (1994) found that the distribution of *V. americana* in Trinity Bay, Texas was limited to salinities less than 10 ppt. In outdoor mesocosm experiments, French (2001) observed minimal growth of *Vallisneria* from the Chesapeake Bay at 10 ppt and 15 ppt. French further concluded that “improving water clarity in Chesapeake Bay may increase distribution, but only into regions less than 10 psu [psu ~ ppt]” (French 2001).

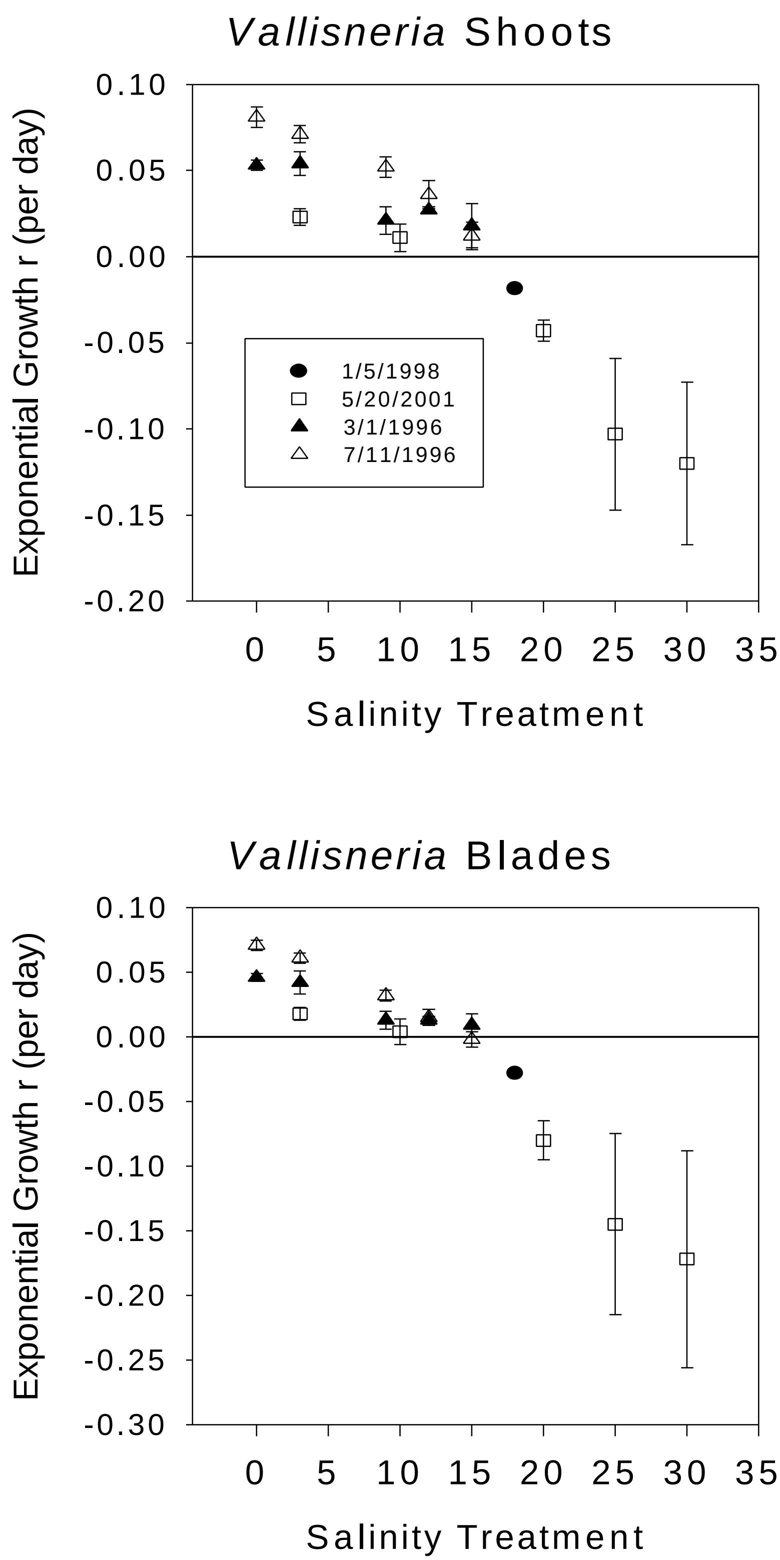

Figure 3-2 Net exponential growth rates (r ± 95% C.I.) of *Vallisneria americana* measured in laboratory mesocosms during constant exposure to different salinities. A negative value of r indicates mortality.

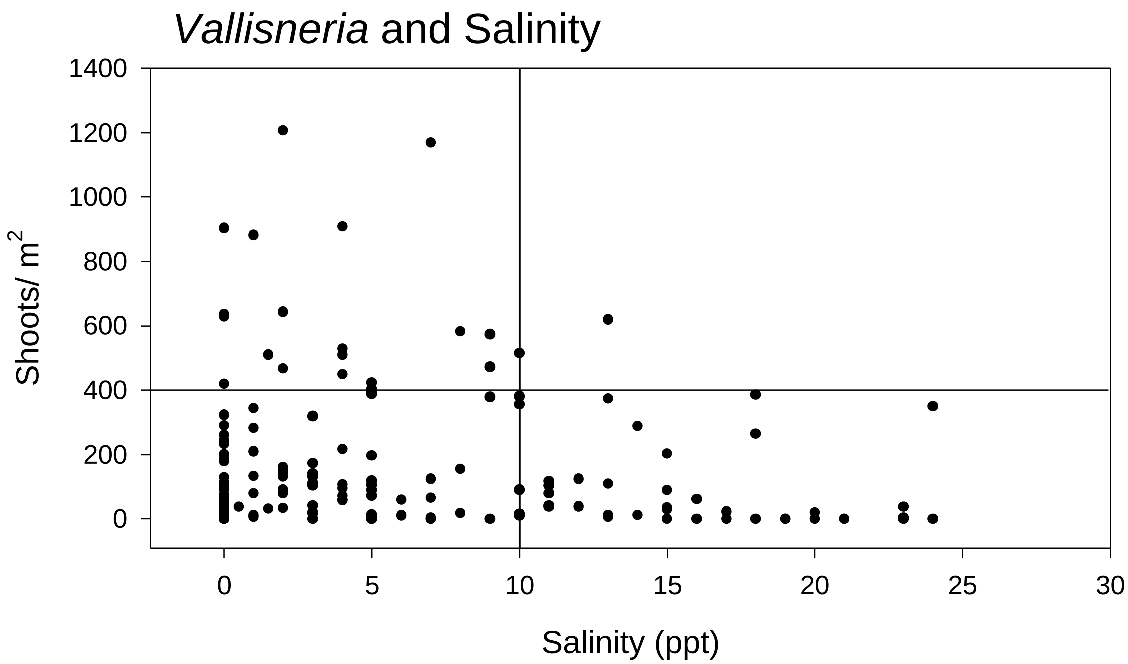

Figure 3-3. Shoot density of *Vallisneria americana* at monitoring stations 1, 2, 3 and 4 as a function of salinity on the day of collection. Data were collected from January 1998 to August 2000.

The combination of results from field monitoring and laboratory experiments conducted by the SFWMD and other investigators agree that 10 ppt is a critical threshold salinity for growth. Salinities above 15 ppt cause mortality. The 30-day averaging period in the MFL rule is consistent with laboratory experiments, which show that *V. americana* can survive exposure to 10 ppt for periods exceeding a month (Doering et al. 1999; French 2001).

The daily average salinity limit of 20 ppt was included in the rule to avoid acute exposure to high salinity. Experiments completed in 2001, suggested that mortality began after 3 days exposure to 20 ppt (**Appendix D, Figure D-4**). Therefore, a one day exposure to 20 ppt appears to be a reasonable limit for acute exposure.

Significant Harm Criteria

The general narrative definition of significant harm proposed by the District for the water resources of an area is as follows: “Significant Harm – means the temporary loss of water resource functions which result from a change in surface or ground water hydrology, that takes more than two years to recover but which is considered less severe than serious harm.” (Chapter 40E-8.021 (24), F.A.C.).

In the original technical documentation of the Caloosahatchee MFL, the habitat value of *Vallisneria* beds was identified as the water resource function of interest. Loss of the habitat function of *Vallisneria* beds was defined as occurring when densities fell below 20 shoots/m^2. This was based on best professional judgement and found to be inadequate by the peer review committee (Edwards et al. 2000). On-going investigation of the utilization of *V. americana* beds by estuarine fauna should provide a scientific basis for identifying a threshold density.

Significant harm was originally defined as occurring when loss of habitat function occurred for three consecutive years. The peer review committee concluded that this definition was not supported scientifically. The MFL Rule considers a violation to have occurred if the salinity criteria are exceeded in two consecutive years. Whether this frequency of violation protects against significant harm, defined as loss of habitat function that takes more than two years to recover, is not known with certainty.

Monitoring data provide some limited insight and indicate that violation of the MFL 30-day average salinity criteria can cause the loss of habitat function. **Figure 3-4** depicts the association between 30-day average salinities above 10 ppt and declining densities of *Vallisneria*. The data show that exceedance of the 10 ppt criterion in two consecutive years (1999, 2000) *can* (but may not always) be associated with a reduction in plant density to very low, non-detectable levels. The exact density of plants at which the habitat function is lost remains debatable. However, the absence of plants implies a loss of habitat function. Thus, exceedance of the 30-day average MFL salinity criterion can cause the loss of habitat function.

The period of record for the monitoring data is far too short to answer questions related to recovery with any confidence. If anything, the data depict the cumulative effects of multiple exceedances of the 30-day average MFL salinity criterion. A more sophisticated understanding of *Vallisneria*'s life cycle is required in order to address questions related to recovery.

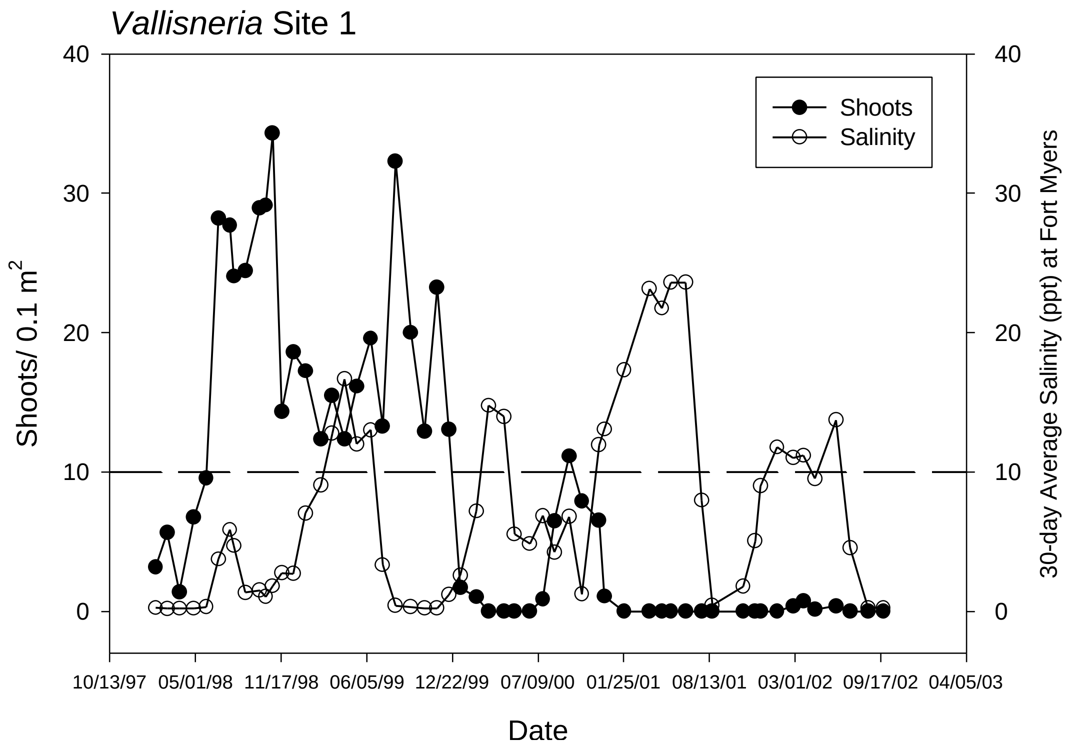

Figure 3-4. Number of shoots at monitoring Station 1 in the upper Caloosahatchee Estuary from January 1998 – September 2002. Also shown is the 30-day average salinity at Ft. Myers.

Section 4 -- Freshwater Inflow and Salinity in the Caloosahatchee Estuary

Introduction

Quantifying relationships between freshwater inflow and the spatial and temporal distributions of salinity in the estuary is a critical step in deriving a MFL. This relationship allows calculation of the freshwater inflow required to position the “right salinity in the right place”.

In the initial technical documentation, a statistical regression equation was used to quantify the relationship between discharge at S-79 and salinity in the downstream estuary. Freshwater sources to the Caloosahatchee Estuary include: the Caloosahatchee River at S-79, the Orange River and other tributaries in the tidal basin down stream of S-79, overland runoff, waste water treatment facilities, direct rainfall and ground water seepage. All these additional sources were implicitly included in the regression equation and this has two major consequences.

First, statistical regression models have low precision (**Figure 4-1**). For example, one equation predicted that a 30-day average discharge of 300 cfs would produce a mean salinity of 11.4 ppt at the Ft. Myers Yacht Basin. Accounting for error however the mean salinity could actually range from 5.4 to 17.4 ppt. Wild celery, *Vallisneria americana,* tolerates the mean and lower limit, but not the high limit of this range of variation.

The salinity at Ft. Myers results from a combination of discharge at S-79 and downstream sources in the tidal basin. The salinity produced by a discharge of 300 cfs at S-79 will depend on the magnitude of input from downstream tributaries and ground water. The magnitude of this downstream input will depend on whether antecedent conditions have been wet or dry. While on average a 300 cfs discharge at S-79 has been shown to produce a salinity of about 10 ppt at the Ft. Myers monitoring site, this will not always be the case. Sometimes the actual salinity will be lower and sometimes higher.

The second consequence of relating downstream salinity to discharge at S-79 is that downstream sources remain unquantified. When the discharge at S-79 is 300 cfs, the additional downstream inflow required to produce 10 ppt at Ft. Myers remains unknown.

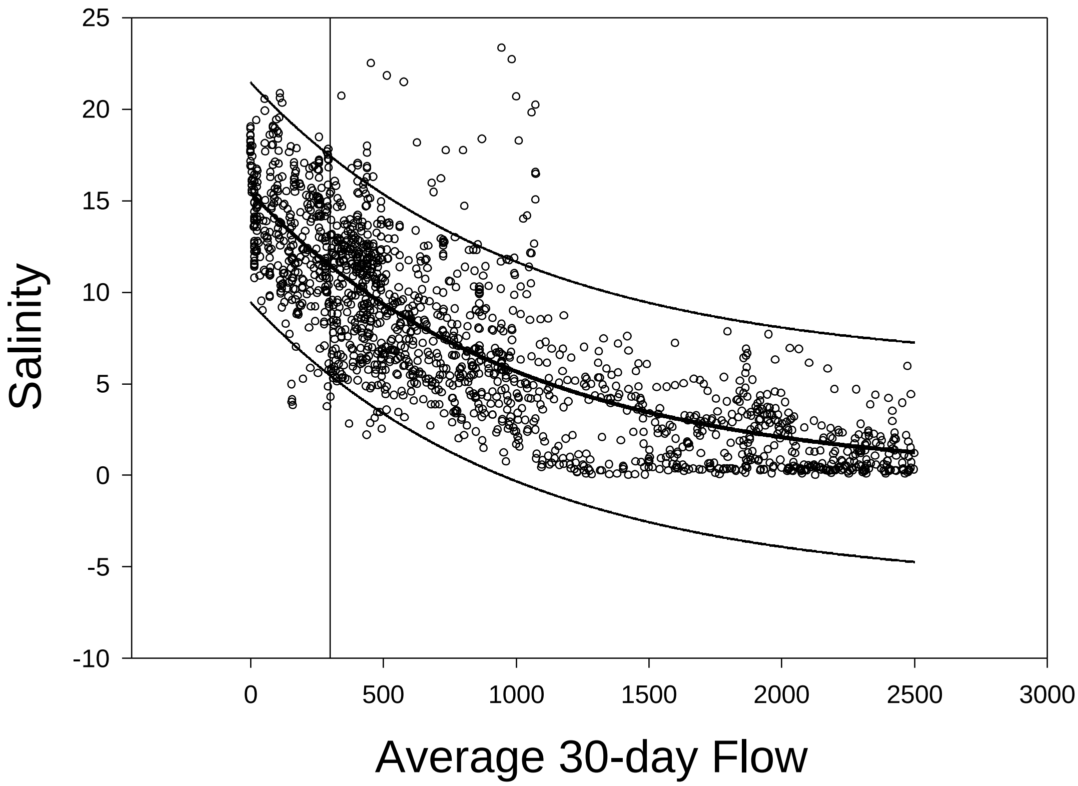

Figure 4-1. Daily average salinity st the Ft. Myers surface salinity sensor as a function of the 30-day average discharge at S-79. Vertical reference line is at 300 cfs. Upper and lower regression lines indicate 95% confidence intervals.

In other words, the total inflow required to produce 10 ppt at Ft. Myers is not known (Total inflow = Inflow at S-79 from basins east of S-79 + downstream sources in the tidal basin west of S-79, **Figure 4-2**).

An alternative and more acceptable approach to statistical regression, is to use a numerical, mass balanced model in which flows from different sources can be specified (Edwards et al. 2000). Thus, the total freshwater inflow required to produce a given salinity in the estuary can be estimated. The contribution of discharge at S-79 and the contribution from downstream tidal basin sources to total inflow can be quantified, compared and contrasted.

Relationship Between Inflows and Salinity

In this section the relationship between freshwater inflow and salinity in the Caloosahatchee Estuary is examined using recently developed modeling tools. The following relationships are evaluated:

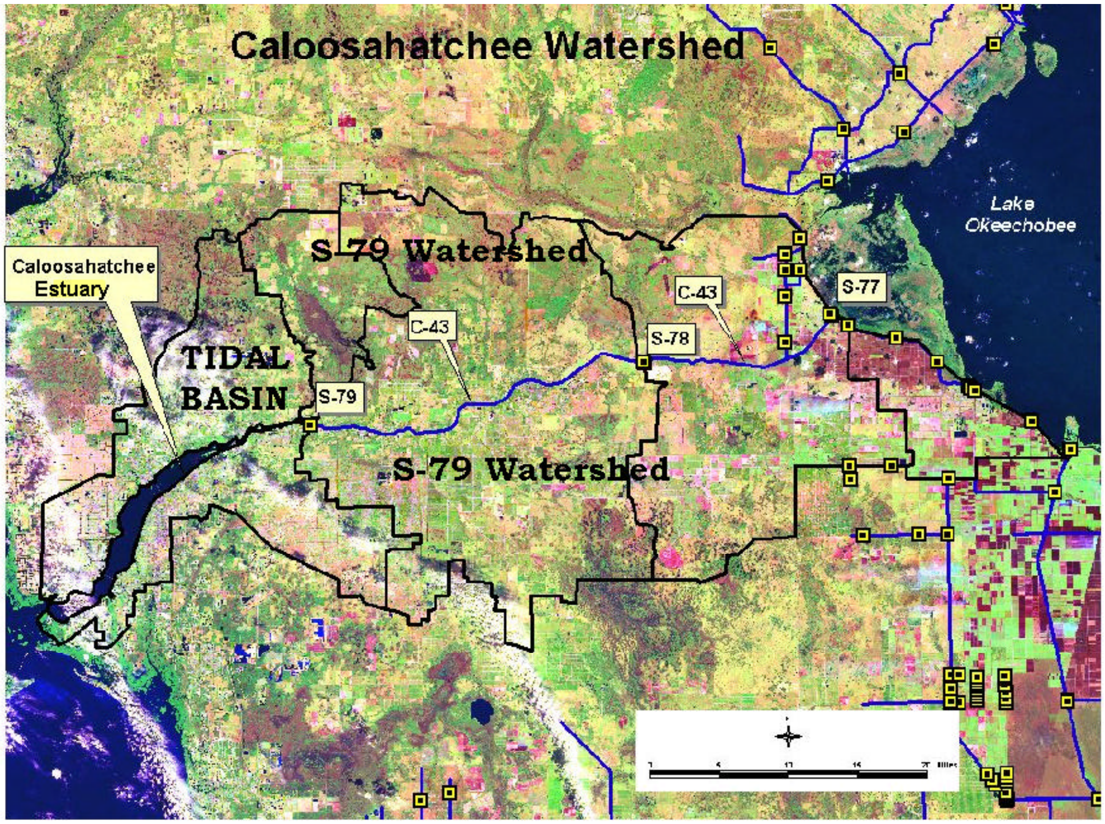

Figure 4-2. Caloosahatchee Watershed showing the Tidal Basin that drains into the estuary west of S-79 and the S-79 Watershed that drains to the estuary through S-79.

- Relationship between total freshwater discharge to the estuary and the distribution of salinity in the estuary. This relationship was derived from a newly developed hydrodynamic model.

- Relationship between tidal basin inflows and inflow at S-79. This relationship answers questions such as: If inflow at S-79 is 800 cfs, what is the inflow from the downstream tidal basin? Until recently, estimates of tidal basin inflow have not been available. However, completion of the Tidal Caloosahatchee Watershed Model (Petersen et al. in review) makes possible the first estimates of tidal basin inflow. Only a three year period of simulation was available to compare tidal basin inflows with inflows at S-79. This period of record was not long enough to make a meaningful comparison. Therefore, an application model was developed to simulate a long-term, rainfall driven period of record for the tidal basin.

- Relationship between present and future inflows and compliance with MFL criteria. The initial technical documentation concluded that the MFL was not now being met and construction of proposed CERP infrastructure facilities, in combination with operational changes and regulatory approaches, was identified in as a component of the recovery strategy. This analysis provides answers to questions such as: How often are MFL criteria now being met and how often will they be met in the future? A rigorous examination of this question requires long-term records of inflows and salinity that include a range of hydrological conditions.

Long-term (31 year) time series of freshwater discharge at S-79 were estimated in two ways: from actual measurements and from rainfall driven regional watershed models. Regional watershed models were used to derive time-series of discharge at S-79 for two scenarios: with and without CERP infrastructure components. Inflows from the tidal basin were estimated from a rainfall driven application model.

The hydrodynamic model was too computationally complex for a 31-year simulation of salinity. Therefore, a less complex regression model, based on short-term results from the hydrodynamic model, was used to estimate salinity. Using the discharge scenarios described above, two 31-year time series of salinity in the estuary were generated -- for present conditions and for future conditions with CERP components in place.

Present and Future Discharge at S-79

Time series of present and future discharge at S-79 were generated from existing measured data and from regional watershed models. Measured inflows at S-79, referred to as the “Historic Case”, cover the period from 1965 to 1995 and includes changes in discharge attributable to changes in land use. Present conditions were assessed by employing the so called CERP ‘1995 Base’ scenario. Using a regional watershed model, the time-series of rainfall for the 31-year period 1965-1995 was applied to generate a time-series of discharge at S-79. The model uses 1995 land use and thus controls for changes in runoff caused by temporal changes in land use during the 31-year period. This modeled time-series of discharge has served as an estimator of current hydrologic conditions through out the CERP process (USACE and SFWMD 1999).

A conclusion of the initial technical documentation supporting the Caloosahatchee MFL was that the MFL could not be met under current conditions. A recovery and prevention strategy was therefore required by Section 373.042(1) F.S. and was described for the Caloosahatchee River in Section 40E-8.421. The recovery plan includes operational, regulatory (Consumptive Use Permitting and Water Shortage Policy) and structural components. The structural components for recovery of the Caloosahatchee MFL depend on implementing key CERP water storage projects in the C-43 basin. These projects, which include reservoirs and aquifer storage and recovery wells (**Appendix E**), will help attenuate extreme flows to the estuary by reducing the surface water runoff 'peaks' during high flow events and providing supplemental flows during drier times.

To evaluate this recovery strategy, a long-term 31-year times-series of discharge at S-79 was generated using the same regional modeling approach as before, except that reservoirs and ASR facilities were included. This is termed the '2020 with Restudy Components' scenario and shows conditions in 2020 after the proposed water management facilities are constructed. The '2020 with Restudy Components' models these components as conceived in the initial CERP documents. These components are being refined as part of the process for development of the CERP C-43 Project Implementation Report. No refined hydrology is yet available.

Inflow from the Tidal Basin

The '1995 Base' and '2020 with Restudy' scenarios present estimates of discharge at S-79 (including regulatory releases from Lake Okeechobee). They do not estimate total inflow to the Caloosahatchee Estuary. Additional sources of inflow exist downstream (west) of S-79 in the Tidal Basin surrounding the Caloosahatchee Estuary. Until recently, there has been a lack of measured or modeled inflows from the downstream tidal basin. However, the completion of the Tidal Caloosahatchee Watershed Model (Petersen et al. in review) makes possible the first estimates of tidal basin inflow to the Caloosahatchee Estuary (**Appendix G**). The Tidal Caloosahatchee Basin Model (Petersen et al. in review) is an application of the MikeShe code. The model is a fully coupled, surface water and groundwater model intended to accurately simulate all significant hydrologic processes in the watershed including evaporation, runoff, stormwater detention, river hydraulics, stream water management, groundwater withdrawals and recharge, etc. Through contract (Petersen and Copp, 2002) a special three year (1998-2000) simulation examining the spatial distribution of inflows from the tidal basin to the estuary was obtained (**Appendix G**).

While instructive, the period of record (three years) from the Tidal Caloosahatchee Basin Model was not sufficient to assess the relationship between discharge at S-79 and total inflow to the estuary under a variety of hydrologic conditions. The record was also not sufficient to generate the 31-year period of record needed to examine compliance with MFL criteria. Therefore an application model was developed. A rainfall driven application model based on linear reservoir theory was developed to estimate inflow from the downstream tidal basin (**Appendix G**). This reservoir model was calibrated to the 3 years of output from the Tidal Caloosahatchee MikeShe model (**Figure 4-3**). Time-series of total inflow were created by combining estimates of downstream tidal basin inflows generated from the reservoir model with the two time-series (1995-Base, 2020 with Restudy Components) of discharge from the upstream watershed at S-79.

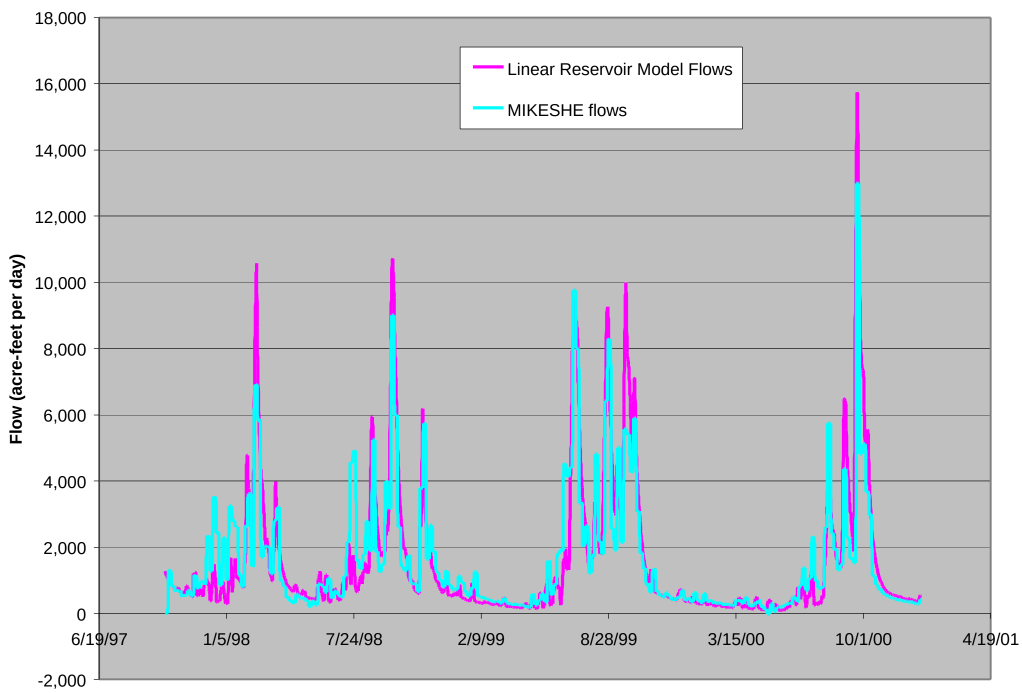

Figure 4-3. Comparison of 5-day flows: MikeShe Model for the Tidal Caloosahatchee

Estuarine Hydrodynamic Model

During the past year District Staff have been used the CH3D software to develop a numerical model (**Appendix F**). CH3D is a three-dimensional model with a curvilinear-grid that simulates time-dependent circulation in estuaries, lakes, and coastal waters. For the present application to an estuarine system, the model estimates the following hydrodynamic variables: surface elevation, 3-D velocities, salinity, and density.

The salinity model for the Caloosahatchee Estuary (**Appendix F**) was excerpted from a larger CH3D Charlotte Harbor model (Sheng, 2001). The larger Charlotte Harbor model was calibrated using data collected during the summer of 1986 at 6 stations located in Pine Island Sound and near the Peace River. The hydrodynamic model was calibrated with 2 months of data, while the salinity model was calibrated with 2 weeks of data. The Caloosahatchee and San Carlos Bay portions of the model were not calibrated by Sheng (2001). District staff calibrated the Caloosahatchee Estuary portion of the model using a 2.5 months period of data, collected every 15 minutes at five stations (**Figure 4-4**). During this period (October 15 to December 31, 2000), salinity rose from approximately 5 ppt to 20 ppt at Ft. Myers (**Figure 4-5**).

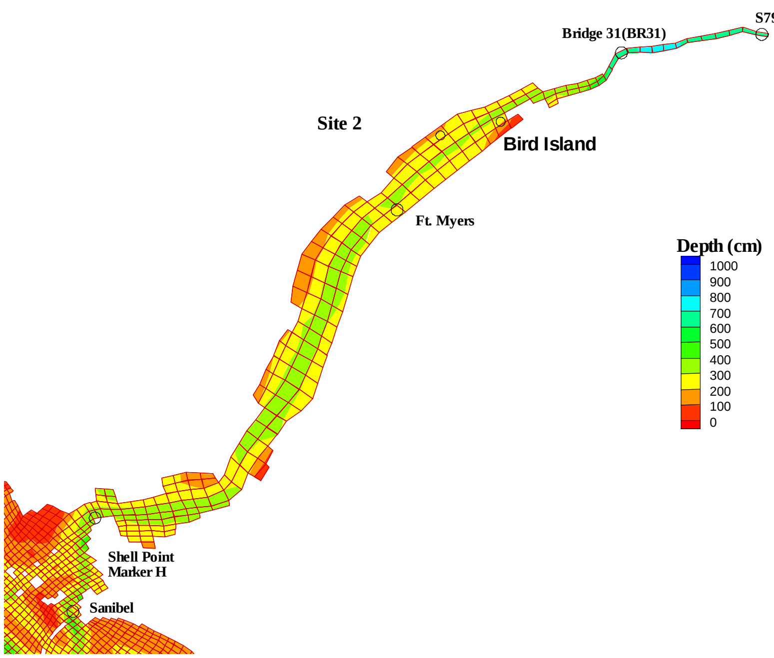

Figure 4-4. Bathymetry of the Caloosahatchee Estuary and location of monitoring stations. Salinity monitoring stations: S79, Bridge 31 (BR31), Ft. Myers, Shell Point (MarkerH) and Sanibel; Wild Celery, *Vallisneria americana*, monitoring stations: Bird Island and Site 2.

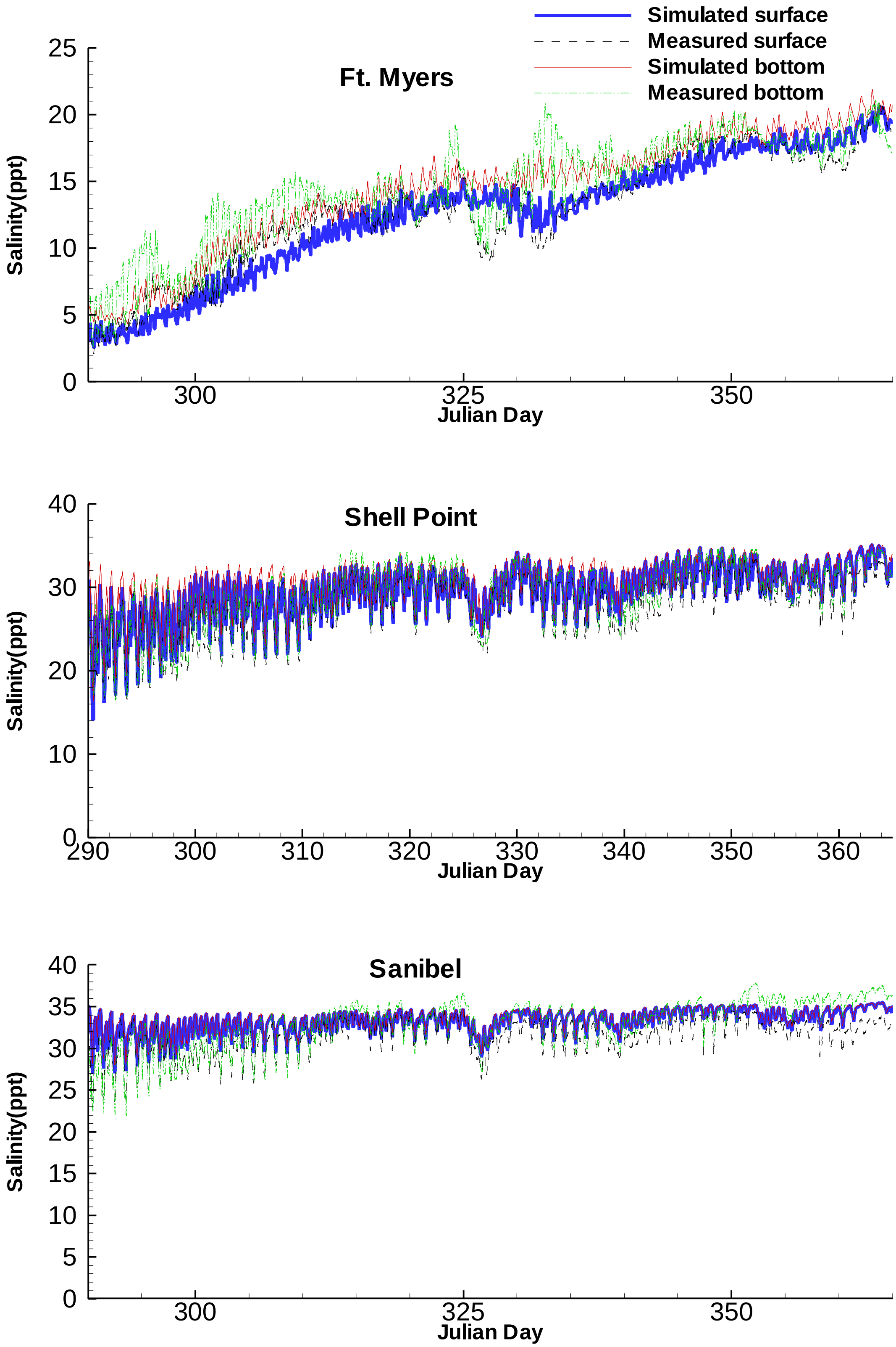

Figure 4-5 Salinity calibration at Ft. Myers, Shell Point and Sanibel.

The initial calibration of the model was driven by freshwater discharge at S-79, tide, wind, direct rainfall, and evaporation. For the initial model formulation and calibration, the total freshwater inflow to the estuary, including inflow from downstream tributaries, ground water, and other downstream sources were assumed to enter at S-79.

Freshwater Inflow and Salinity

Using the CH3D hydrodynamic model, a group of curves describing the relationship between **total inflow** and the spatial distribution of salinity in the estuary were generated. Eight (8) scenarios (discharges at 50 cfs, 100cfs, 200cfs, 300cfs, 500cfs, 1000cfs, 1500 cfs and 2000cfs) were simulated for 40 days. Forty-day simulations allowed the model to reach equilibrium conditions. The last 10 days of the 40 days simulation results were averaged to obtain the salinity at four locations: S-79 (42 km), BR31 (36 km) , Ft. Myers (23 km) and Shell Point (0 km)(**Figure 4-6**). A **total inflow** of 500 cfs produces a salinity of about 10 ppt at Ft. Myers (23 km) (**Figure 4-6**).

Partitioning Total Flow

Total inflow is a combination of discharge at S-79 from the upstream watershed east of S-79 and inflow from downstream sources in the tidal basin. Both sources need to be quantified in order to establish a minimum flow at S-79 that meets the downstream salinity criteria.

Time-series of total inflow were created by combining estimates of downstream tidal basin inflows with the three time-series (Historic Case, 1995-Base, 2020 with Restudy Components) of discharge from the watershed upstream of S-79. Downstream tidal basin flows were generated from the reservoir model.

The frequency distributions of total monthly flows for both the ‘Historic Case’ and the ‘1995 Base’ conditions are heavily skewed towards low flows < 325 cfs (**Table 4-1**, **Figure 4-7**). In both cases, there is a secondary peak of higher flows in the 1500 – 4500 cfs range. Under the ‘2020 with Restudy’ scenario the percentage of both low and high flows is diminished. This results in a frequency distribution of total monthly flows with a single maximum in the 500 to 800 cfs range (**Table 4-1**, **Figure 4-7**).

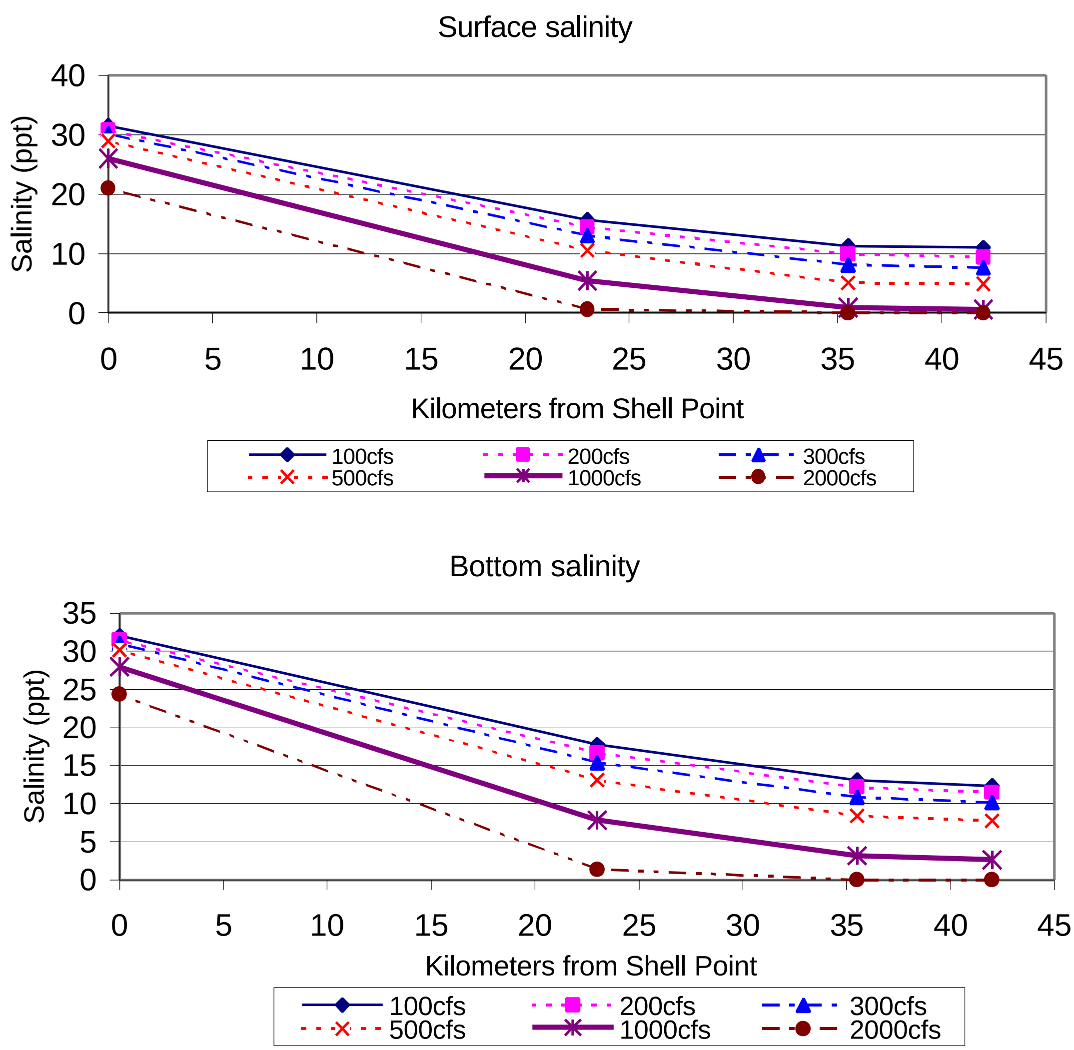

Figure 4-6. Results of Hydrodynamic Model. Salinity as a Function of Total Freshwater Inflow to the Caloosahatchee Estuary.

Table 4-1. Frequency Distribution of Total Estuary Inflows (see also **Figure 4-7**).

Flow Range	**Probability of Monthly Flows within Flow Range**		
	Historic	**1995 Base**	**2020 with Restudy Components**
<325 cfs	23%	32%	2%
325 to 500 cfs	9%	9%	16%
500 to 800 cfs	12%	6%	32%
800 to 1500 cfs	13%	12%	25%
1500 to 2800 cfs	17%	13%	10%
2800 to 4500 cfs	11%	14%	9%
4500 to 8000 cfs	11%	9%	4%
>8000 cfs	4%	4%	1%

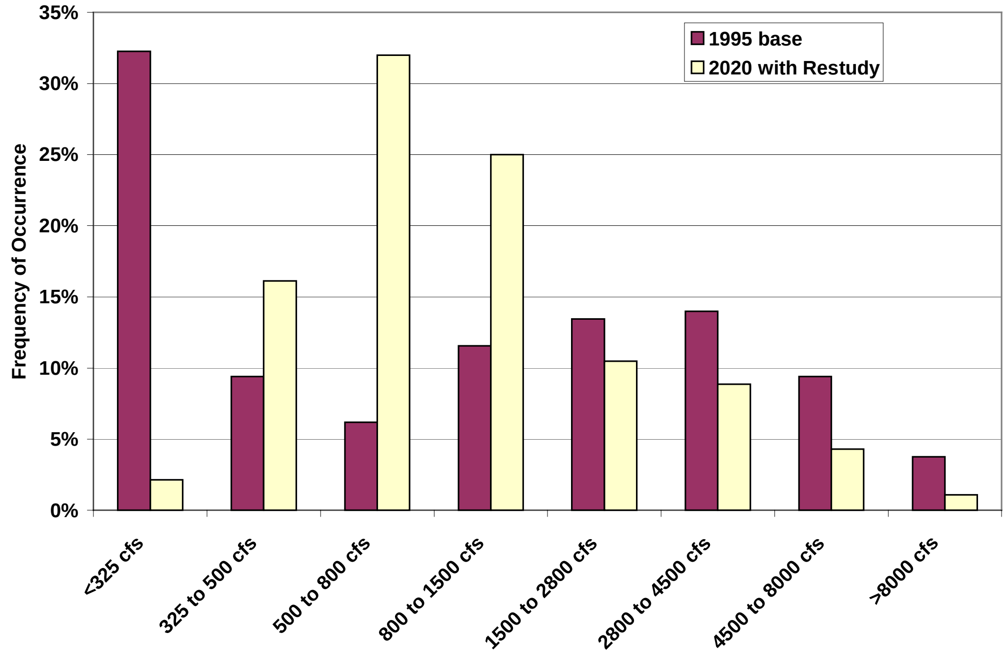

Figure 4-7. Distribution of Average Monthly Caloosahatchee Estuary Inflows – 1965 to 1995. Inflows include Upper Basins, Tidal Basin, and Lake Okeechobee regulatory releases

The new information on tidal basin inflows places the MFL flow criterion of 300 cfs at S-79 in the context of total inflow to the estuary. **Table 4-2** indicates that under present conditions ('1995 Base'), when discharge at S-79 is about 300 cfs, total inflow to the estuary is above 500 cfs about half the time (57%) and below 500 cfs about half the time (43 %). This proportionality also holds for the 'Historic Case' (**Table 4-2**).

Table 4-2. Evaluating watershed inflows when S-79 monthly flows are near 300 cfs (275 to 325 cfs)

	Probability total flow in range (cfs)		
Total Flow	**Historic**	**95base**	**2020 with Restudy Components**
<325 cfs	7%	0%	13%
325 to 500 cfs	53%	43%	68%
500 to 800 cfs	33%	43%	20%
800 to 1500 cfs	7%	14%	0%
1500 to 2800 cfs	0%	0%	0%
2800 to 4500 cfs	0%	0%	0%
4500 to 8000 cfs	0%	0%	0%
>8000 cfs	0%	0%	0%
months is in range	15	14	40

Under current conditions, a mean monthly discharge of 300 cfs at S-79 would be expected to produce an average salinity of about 10 ppt. About half the time salinity would be less than 10 ppt and about half the time greater. This partitioning of inflows, in part, explains the results of the original regression analysis: on average a discharge of 300 cfs at S-79 produces a salinity of about 10 $^{o}/_{oo}$ at Ft. Myers (**Figure 3-1**).

The relationship between S-79 flows of 300 cfs and total flows of 500 cfs changes under the '2020 with Restudy Components' scenario. Under this scenario, when S-79 flows are near 300 cfs, total flows are below 500 cfs most of the time (80%) and are in the range between 500 cfs and 800 cfs only 20% of the time (**Table 4-2**).

It is not surprising that the correlation of S-79 flows and total flows changes in the 2020 scenario; reservoirs and ASRs upstream of S-79 are designed to deliver base flows to the estuary. This shifting of sources is demonstrated in **Figure 4-8**, which shows the contribution of upper basin flow as a percentage of total estuary inflow for both '1995 Base' and '2020 with Restudy' scenarios. Under the '1995 Base' conditions, upper basins contribute 42% of flows in the 325 cfs - 500 cfs range and 62% of flows in the 500 cfs – 800 cfs range. Under '2020 with Restudy' conditions, upper basins contribute 78% of flows in the 325 cfs - 500 cfs range and 70% of flows in the 500 cfs – 800 cfs range.

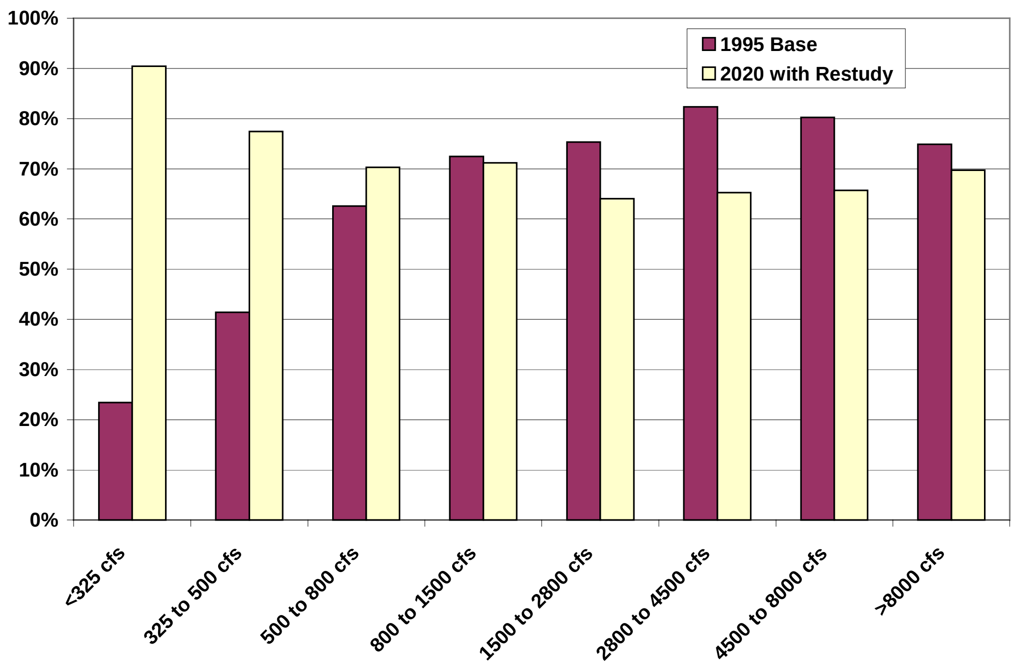

Figure 4-8. Percentage of Average Monthly Caloosahatchee Estuary Inflows contributed by Upper Basins.

Many of these 300 cfs flows are delivered at S-79 from CERP components during dry times when downstream tidal inflows are probably low and provide little augmentation. Under present conditions, we may also expect that releases of 300 cfs at S-79 from Lake Okeechobee will not correspond to a total inflow of 500 cfs to the estuary if these releases are made during drier periods.

Evaluation of MFL Salinity Criteria:

The Caloosahatchee MFL rule states that: "A MFL exceedance occurs during a 365 day period, when a) a 30-day average salinity concentration exceeds 10 parts per thousand at the Ft. Myers salinity station . . . or (b) a single daily average salinity exceeds a concentration of 20 parts per thousand at the Ft. Myers salinity station. Exceedance of either subsection (a) or subsection (b), for two consecutive years is a violation."

As indicated earlier, one purpose of this review is to ascertain the extent to which MFL salinity criteria are presently being met and the extent to which they will be satisfied in the future. Evaluation of the '1995 Base' and '2020 with Restudy' scenarios constitutes a viable method. Evaluation of the 'Historic Case' is another method, and both will be employed here.

Due to computer hardware constraints, the estuarine hydrodynamic model could not produce a 31-year simulation of salinity. To estimate long term salinity patterns in the estuary, a regression model was derived from the equilibrium relationships between fresh water inflow and salinity in the estuary shown earlier. The regression model was calibrated with a 10-year period of salinity records at Bridge 31 (BR31) and Ft. Myers, as well as a 6-month record at Bird Island (**Appendix F**). The time series of total inflow generated above (1995 base discharge or 2020 Restudy at S-79 + tidal basin inflow) was used to generated 31 years of salinity at various locations in the estuary. The SFWMD has been monitoring salinity at Ft. Myers since 1992. The period of record for daily average salinity and 30-day moving average salinity appears in **Figure 4-9**. During the eleven year period for Jan 1992 to March 2002, the 10 ppt moving average criterion was exceeded in 9 of 11 years (no exceedances in 1995 and 1998). At no time was the single daily average 20 ppt criterion exceeded before the 10 ppt criterion. It should be noted that during the period from January to March of 2001, salinity was greater than 20 ppt for a

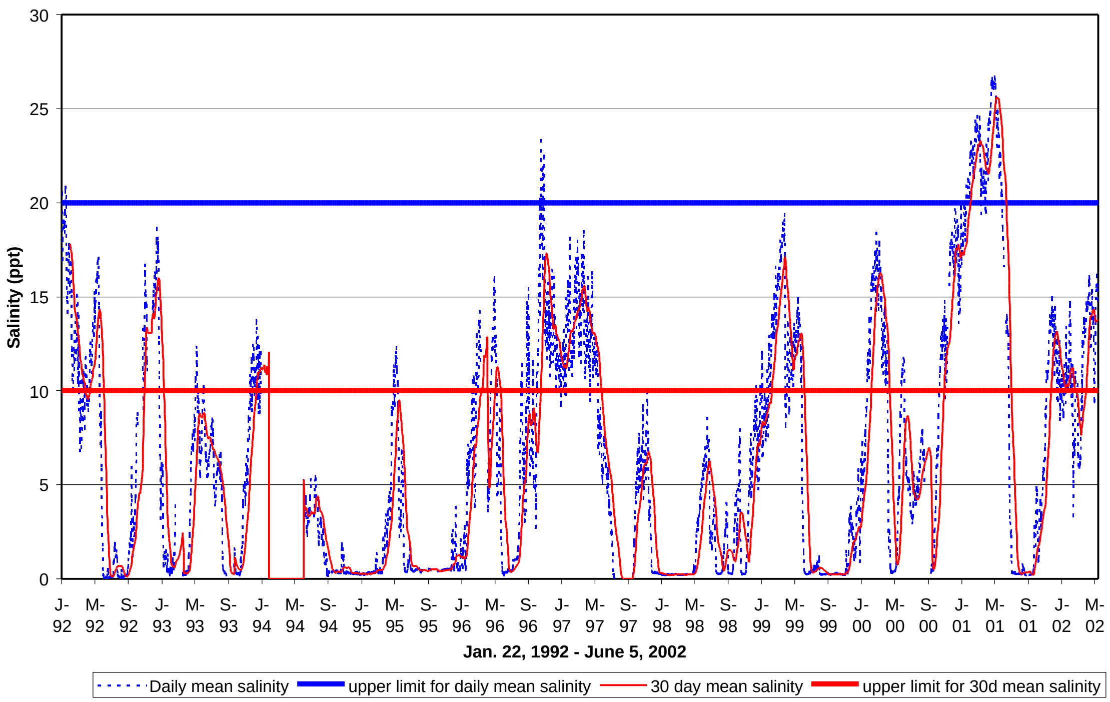

Figure 4-9. Salinity at Ft. Myers Yacht Basin and Exceedance limits for the Caloosahatchee Minimum Flow and Level. Period of record is January 1992 to March 2002.

duration that exceeded the 30-day moving average. These were the lowest flow conditions that occurred during the 10-year period of record, resulting in a major grass die-off. The *V. americana* community has not yet recovered from this event. Results of the 31-year '1995 Base' and '2020 with Restudy' simulations of estuarine salinity are shown in **Figure 4-10.** The 30-day moving average salinity at Ft. Myers exceeded 10 ppt in every year modeled for both simulations.

Nevertheless, **Figure 4-10** demonstrates a marked reduction in 30-day moving average salinity when CERP components are in place. However, this reduction is not quite enough to influence the predicted rate of exceedance (**Table 4-3**). While the percent of time that the 30-day moving average stays above 10 ppt is nearly the same for both scenarios (~50 %), the mean is closer to 10 ppt in the '2020 with Restudy' scenario -- within the 10–13 ppt range for 38 % of the time compared to 12 % for the '1995 Base.'

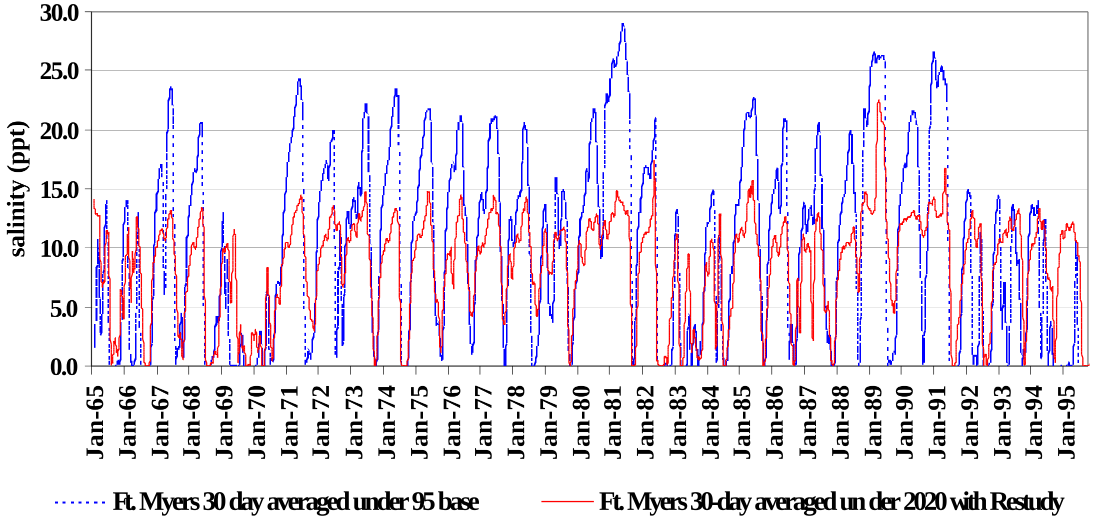

Figure 4-10. Results of the 31-year '1995 Base' and '2020 with Restudy' simulations of estuarine salinity.

Table 4-3. Predicted salinity at the Ft. Myers Yacht Basin (see Figure 4.2) for the '1995 Base' and '2020 Restudy' scenarios.

Ft. Myers salinity (ppt)	95 base		2020 with Restudy	
	daily (%)	30 day moving average (%)	daily (%)	30 day moving average (%)
0~5	37.9	36.7	25.3	24.5
5~10	8.6	12.0	25.1	27.2
10~13	12.5	11.7	39.1	37.6
13~15	12.5	10.9	8.3	9.2
15~20	11.6	13.9	1.3	0.8
20~25	13.4	11.2	0.9	0.7

Summary

A number of different modeling approaches were used, in conjunction with historical data, to estimate the effects of freshwater flow on salinity conditions in the Caloosahatchee Estuary. Some of these models are still under development and have not been fully verified or calibrated. Preliminary results from these analyses indicate that downstream tidal basin inflows may be an important supplement to flows at S-79. Under current conditions, for 300 cfs released at S-79 to produce 10 ppt at Ft. Myers an additional 200 cfs (total = 500 cfs) may be required from downstream tidal basin inflows. Under current conditions ('1995 Base'), the 300 cfs flow at S-79 is on average associated with a total estuary inflow of 500 cfs; correlating to total flows below 500 cfs 43% of the time and to total flows above 500 cfs 57% of the time. Under the '2020 with Restudy' scenario 300 cfs flows at S-79 correlate to total flows above 500 cfs only 20% of the time. Therefore, a delivery of 300 cfs at S-79, under '2020 with Restudy', is less likely to produce 10 ppt at Ft. Myers. Overall, salinity conditions in the downstream estuary do improve with the addition of CERP infrastructure because the frequency of total inflows <500 cfs decreases from 40% in '1995 Base' to 20% in '2020 with Restudy'.

These results suggest that whereas CERP projects provide significant benefits to the estuary in terms of providing freshwater flow during dry periods, even more freshwater flows may be necessary to protect the *V. americana* community from significant harm. Before decisions are made to modify CERP projects or the MFL criteria, however, the models need to be completed and fully calibrated and more sophisticated ways of measuring the flows, especially downstream tidal basin inflows, need to be considered.

Section 5 -- Resource Based Evaluation of the Recovery Strategy

The intent of the Caloosahatchee MFL is to protect wild celery, *Vallisneria americana*, in a 640 acre area located between 24 and 30 km upstream of Shell Point, from significant harm. This area encompasses about 60% of the total estuarine area that could potentially support *V. americana*. Additional water, supplied by CERP project components, should protect *V. americana* from significant harm. Significant harm was defined as loss of *V. americana* habitat function for two consecutive years. In this section, the recovery strategy is evaluated using a recently developed numerical model that estimates density of *V. americana*.

The density of *V. americana* was estimated on a daily time step based on responses to light, salinity and temperature at two sites (1 and 2, **Figure 4-2**) in the upper estuary (**Appendix H**). The model did not simulate sexual reproduction or seed germination. Water quality parameters and *V. americana* density have been monitored at these sites since 1998. The model was calibrated based on measured *V. americana* densities, water temperature, and transparency for the period 1998-2001. Daily salinity input was estimated from flows using the Caloosahatchee Hydrodynamic model (**Appendix F**). Daily incident PAR was obtained from a continuous recording station in Estero Bay.

The recovery strategy was evaluated by comparing the simulated performance of *V. americana*, monitoring Sites 1 and 2 (**Figure 4-2**) under the hydrologic conditions of the '1995 base' scenario (present conditions) and the '2020 with Restudy' (CERP components in place). Long–term (31-year) simulations were computed for *V. americana* using salinity regimes predicted by a regression equation derived from the 3-D hydrodynamic model (**Appendix F**) for both the '1995 base' scenario and the '2020 with Restudy' scenario. Input water temperature, transparency, and PAR were determined using averaged annual data sets (determined from the calibration period). Therefore, salinity was the only dynamic variable in these simulations and the remaining inputs were maintained as "average conditions" throughout each annual cycle.

The input salinity data for the two scenarios at the two monitoring sites are shown in **Figures 5-1 and 5-2** and summarized in **Table 5-1**. When compared to the '1995 Base' case peak salinities are much reduced in the '2020 with Restudy' scenario. The 30-day

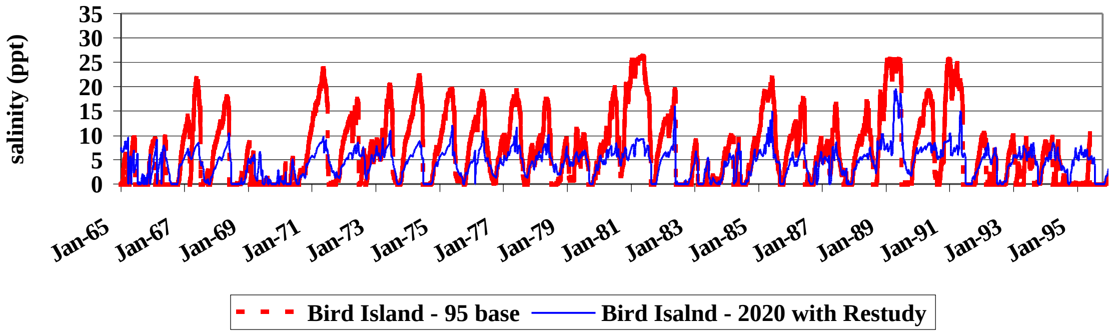

Figure 5-1. Predicted daily average salinity at *Vallisneria* Monitoring Site 1, Bird Island.

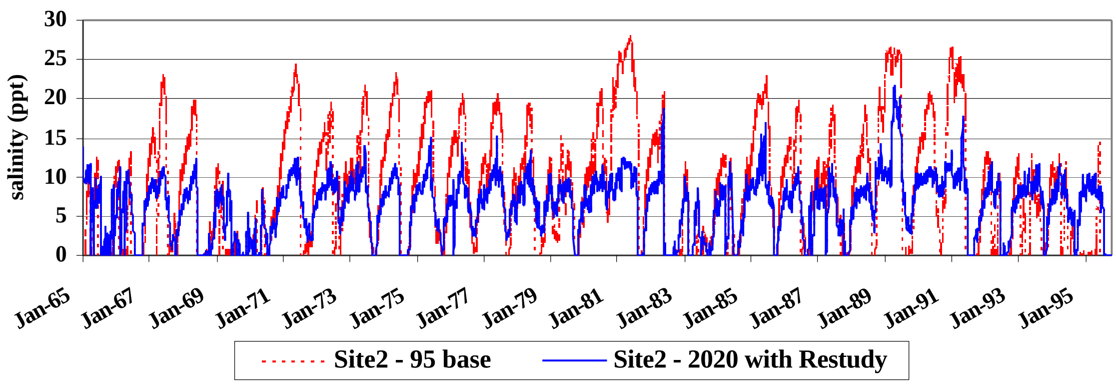

Figure 5.2. Predicted daily average salinity at *Vallisneria* Monitoring Site 2.

Table 5-1. Frequency analysis of predicted salinity at Site 1, Bird Island and Site 2. Percentages represent the fraction of days in the 31-year period of record when the daily average or moving average salinity was in a particular range.

	Site 1, Bird Island				Site 2			
	95 base		2020 with Restudy		95 base		2020 with Restudy	
salinity (ppt)	daily (%)	30-day moving average (%)	daily (%)	30-day moving average (%)	daily (%)	30-day moving average (%)	daily (%)	30-day moving average (%)
0~5	49	49	53	53	42	41	33	33
5~10	23	24	45	46	17	19	53	54
10~13	7	8	1	1	14	13	12	11
13~15	3	4	0	0	5	6	1	0
15~20	11	10	1	1	13	12	1	1
20~25	4	4	0	0	6	6	0	0
25~30	2	1	0	0	3	2	0	0

moving average salinity is below 10 $^{o}/_{oo}$ 98 % of the time at Site 1 and 87 % of the time at Site 2. At the most upstream Site 1, this criterion was exceeded in 23 of 31 years in the '1995 Base' and in only 5 of 31 years for the '2020 with Restudy' (**Figure 5-3**). Further downstream at Site 2, the 30-day moving average salinity exceeded 10 $^{o}/_{oo}$ in 30 of 31 years for the '1995 Base' and in 17 of 31 years for the '2020 with Restudy' (**Figure 5-4**).

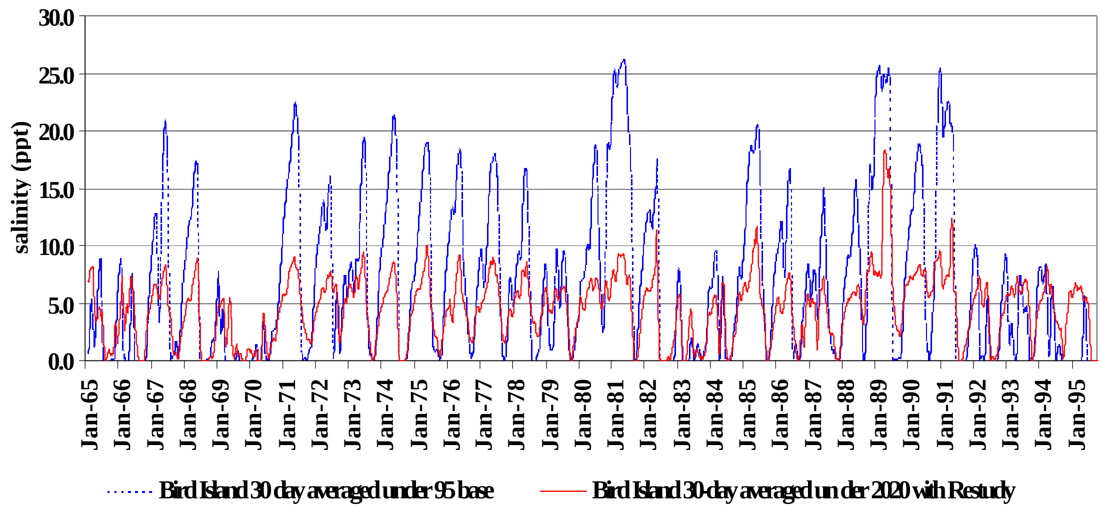

Figure 5-3. 30-day moving averaged salinity at Bird Island

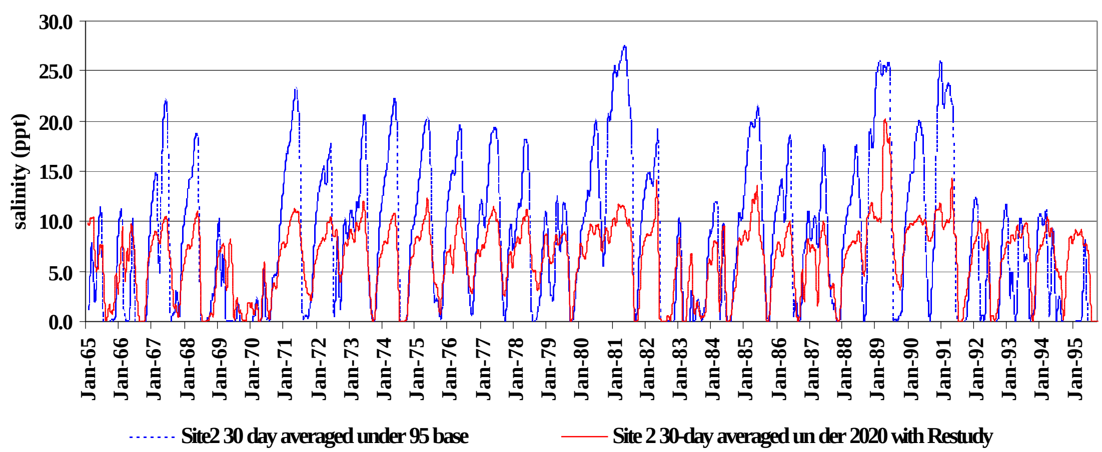

Figure 5-4. 30-day moving average salinity at Site 2.

The numerical simulations of *V. americana* shoot densities (Appendix 8) using the '2020 with Restudy' project flow conditions show more favorable densities than the 95 base case at both Station 1 and Station 2 (**Figures 5-5** and **5-6**). Specifically, there is a 68% increase in total number of shoots produced for the 31 year period modeled at Station 1 and 51 % increase at Station 2 in the '2020 with Restudy' scenario compared to the 95 base case. For blade density, there is a 74% increase at Station 1 and 23% at Station 2 in the '2020 with Restudy' scenario compared to the '95 base case.'

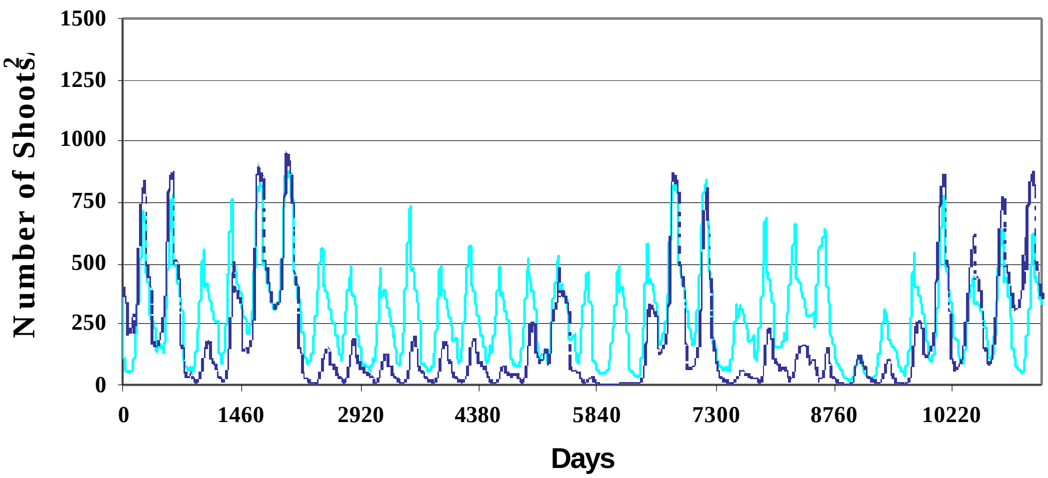

Figure 5-5. Simulated performance of *Vallisneria americana* at Site 1 under the '1995 Base' and '2020 with Restudy' scenarios.

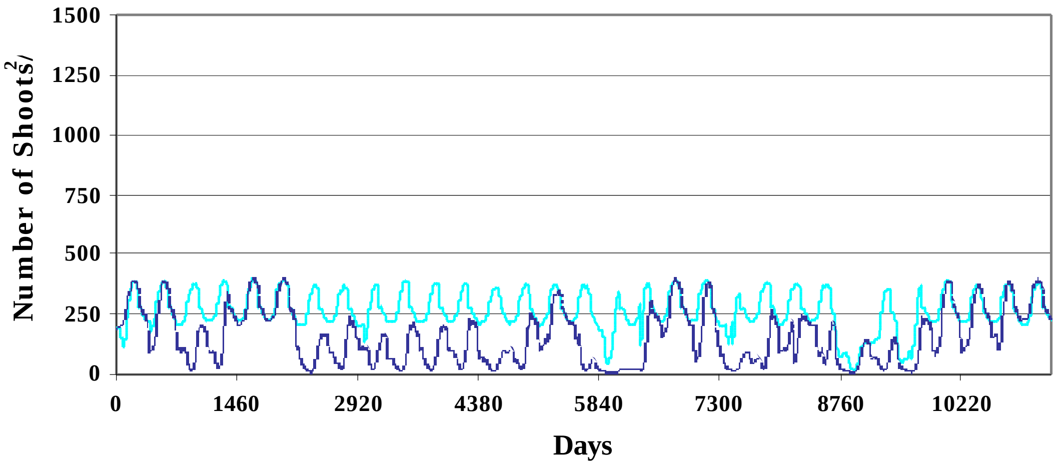

Figure 5-6. Simulated performance of *Vallisneria americana* at Site 2 under the '1995 Base' and '2020 with Restudy' scenarios.

Following the original technical documentation, loss of habitat function for a *V. americana* grass bed was assumed to occur at a density of 20 shoots/m^2 or less. Under the '1995 Base' loss of habitat function occurred in 9 of 31 years at Site 1, with significant harm (loss for two consecutive years) occurring 6 times. Further downstream, at Site 2 loss occurred 17 times in 31 years with significant harm occurring 12 times. By contrast, under the '2020 with Restudy' case, shoot densities fell below 20/m^2 only once at each site in 31 years.

Taken together, the simulated salinity and *V. americana* shoot density data for the two monitoring sites indicate that the MFL is not presently being met. Based on the analysis of salinity conditions downstream at Ft. Myers, this result is not surprising. On the other hand, the results for *V. americana* shoot densities indicate that the '2020 with Restudy' scenario may afford an acceptable level of resource protection at these two sites. Since Site two is located at 26 km upstream of Shell Point, the results suggest that the '2020 with Restudy' may provide resource protection over about two-thirds of the area set aside for protection of *V. americana* (24 km – 30 km). While exceedances of the 30-day average MFL salinity criterion appear to occur under the '2020 with Restudy' at both Site 1 and Site 2, these exceedances are of lower magnitude and shorter duration than those in the '1995 Base' (**Figure 5-3** and **5-4**). These results further indicate that 10 ppt is an effective criterion for protecting the *V. americana* community from significant harm.

Section 6 -- Conclusions and Recommendations

Conclusions

Valued Ecosystem Component Approach

The Caloosahatchee MFL is intended to provide a salinity environment that will protect the submerged aquatic plant, *Vallisneria americana*, in the upper Caloosahatchee Estuary from significant harm. One of the major assumptions of this approach is that salinity and flow conditions that maintain *V. americana* will not be detrimental to other organisms in the estuary. Previous work on this subject (Chamberlain and Doering 1998) and results presented in this review support the validity of this assumption. Low MFL flows of about 300 cfs were not harmful to zooplankton and ichthyoplankton (fish larvae) or to oysters (*Crassostrea virginica*) living in the downstream, higher salinity, portions of the estuary. However, low flows can be associated with phytoplankton blooms in the upper estuary and these may result in water quality problems such as depressed oxygen and decreased light penetration. While evidence indicates that low flows in the 300 cfs range are not harmful to most estuarine species, rather high flows greater than 2500–3000 cfs appear to be detrimental to zooplankton, oysters and seagrasses. This high flow limit agrees with previous estimates (Chamberlain and Doering 1998; Doering et al. 2002).

Salinity Criteria

The Caloosahatchee MFL Rule contains two salinity criteria at the Ft. Myers salinity monitoring site: a 30-day moving average salinity of 10 ppt and a daily average salinity of 20 ppt. The summary of published information and the results of investigations by District staff presented here agree that these are scientifically-defensible physiological and ecological thresholds. The combination of results from field monitoring and laboratory experiments conducted by District and other investigators agree that 10 ppt is a critical threshold salinity that limits growth and salinities above 15 ppt cause mortality of *V. americana* The 30-day averaging period in the MFL rule is consistent with laboratory experiments which show that *V. americana* can survive exposure to salinities of 10 ppt for periods exceeding a month. The daily average salinity limit of 20 ppt was included in the rule to avoid acute exposure to high salinity. Laboratory experiments conducted by District staff indicate that a one day exposure to 20 ppt is a reasonable limit for acute exposure. Analysis of 11 years of salinity data demonstrates that, in practice, the acute criterion is never violated before the 30-day moving average criterion.

Salinity and Freshwater Inflow

A thorough understanding of the relationship between freshwater inflow and the spatial distribution of salinity in the estuary is key to establishing an MFL. Over the past year, two new modeling tools have been developed to the point where they can be used to investigate this relationship. The Caloosahatchee Tidal Basin Model (Petersen et al. in review) allows estimation of freshwater inflows downstream of S-79. The SFWMD's Caloosahatchee Hydrodynamic model is a numerical, mass balanced, 3-dimensional model that estimates the distribution of salinity in the estuary under different freshwater inflow conditions. While both tools are still under development, they allow salinity in the estuary to be related to total inflow (i.e. discharge at S-79 + downstream tidal basin inflows).

The greatest uncertainty in the analysis presented here lies in the relationship between freshwater inflow and the distribution of salinity in the estuary. A mass balanced hydrodynamic model is the tool of choice because all inflows need to be quantified and specified. In terms of development, the mass balance hydrodynamic model employed here is in its infancy an has only been calibrated to a limited set of hydrologic conditions. The model uses woefully inadequate bathymetry, but new bathymetry data for the Caloosahatchee Estuary will be available soon. The model was not calibrated with tidal basin inflows, which are also uncertain. Major conclusions based on these preliminary salinity and flow modeling efforts are the following:

The MFL is not currently being met and a recovery and prevention strategy is required. This conclusion is consistent with the initial technical documentation. Construction of reservoirs and other projects in the C-43 basin being completed under the Comprehensive Everglades Restoration Plan (CERP) are major components of the recovery strategy.

Downstream tidal basin inflows are an important supplement to flows at S-79. Under current conditions, for 300 cfs released at S-79 to produce 10 ppt at Ft. Myers additional inflow from downstream tidal basin is required. This additional inflow may be on the order of 200 cfs (total = 500 cfs) but this is uncertain. Whatever the downstream contribution needs to be, both the original regression analysis and the modeling approach presented here suggest that under current conditions a 300 cfs discharge at S-79 will on average produce a salinity of 10 ppt at Ft. Myers.

However, the importance of downstream, tidal basin inflows has several important ramifications. Under present conditions, releases of 300 cfs at S-79 are less likely to achieve 10 ppt under dry conditions when downstream inflows are low. As CERP components are constructed, overall salinity conditions will improve in the estuary. However, reservoir releases of 300 cfs are anticipated to occur during drier times when additional contributions from downstream sources may be very low, so that the 300 cfs flow from S-79 may be less likely to achieve the 10 ppt criterion.

Resource Based Evaluation of the Recovery Strategy

Modeling of *V. americana* shoot density data for two monitoring sites in the area designated for protection of *V. americana* indicates that the MFL is not presently being met and an inadequate level of resource protection exists. On the other hand, the results for *V. americana* shoot densities indicate that the CERP components may afford some level of resource protection at these two sites. Since Site two is located at 26 km upstream of Shell Point, the results suggest that CERP may provide resource protection over about two-thirds of the total area (the 6 km long zone that extends from 24 km to 30 km) that is set aside for protection of *V. americana*. Simulations indicate that exceedances of the 30-day average MFL salinity criterion occur at both Site 1 and Site 2 even with CERP components in place. These exceedances are of lower magnitude and shorter duration than those that currently occur. These results further indicate that 10 ppt is an effective criterion for protecting the *V. americana* community from significant harm.

Recommendations

- Continue to apply the present MFL criteria while completing ongoing efforts to further refine and calibrate the models and collect additional monitoring data.
- Results of these studies suggest that changes may be needed to storage facilities in the watershed and/or regional water delivery protocols to provide more freshwater to protect the *V. americana* community from significant harm.

- However, before any decisions are made to modify CERP projects or the MFL criteria, the models need to be completed and fully calibrated and improved flow measurements need to be obtained, especially for downstream tidal basin inflows.
- CERP, the Southwest Florida Feasibility Study, and RECOVER need to consider the implications of these MFL studies which, when complete, may suggest that different management approaches and/or performance measures are needed to protect the resource from significant harm.
- Once restoration needs for this system have been defined as a result of the Southwest Florida Feasibility Study, and reservations have been defined restoration needs, the existing MFL criteria will need to be modified to protect the restored resources from significant harm.

Section 7 - Literature Cited

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