WQ.1 Background Description of Southern Estuaries Water Quality Hypothesis

Water quality in South Florida estuaries is dependent upon the volume, distribution, and quality of freshwater flowing to the system. The biotic components (e.g., phytoplankton, benthic habitats) of estuaries are sensitive to salinity variability and nutrient loading which may be modified by CERP. Complex interactive mechanisms between water quality and hydrologic drivers as well as internal nutrient cycling will influence CERP effects.

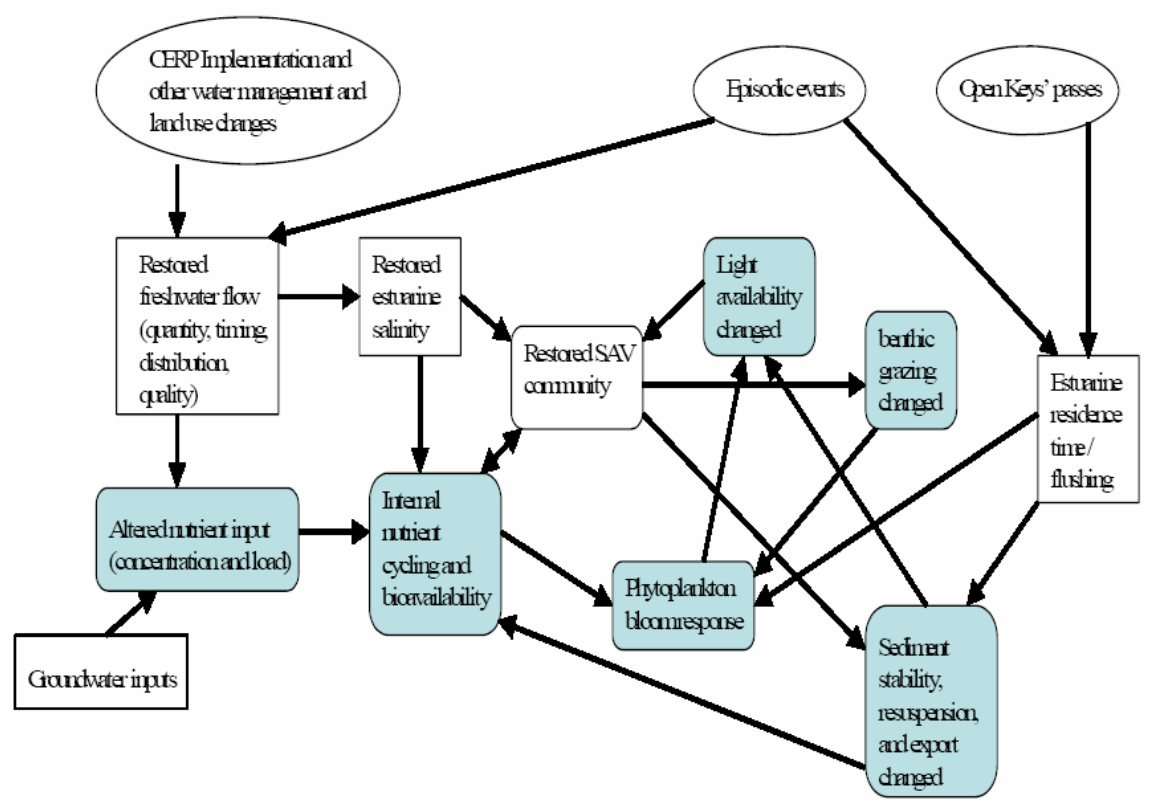

Figure WQ-1: Water Quality Conceptual Ecological Model

Major Relevant CERP Hypotheses

- Through modifications of quantity, quality, timing and distribution of freshwater, CERP implementation will affect dissolved and particulate nutrients delivered to the estuaries and alter estuarine water quality. These modifications will affect primary production and food webs in estuaries. These modifications include:
  1) *changes in the distribution and timing* of nutrient inputs through increased flow via Shark River Slough and diversion of canal flows from 'point source' to more 'diffuse' delivery through coastal wetlands and creeks;
  2) *changes in the quantity* of nutrient inputs to the estuaries through alteration of the mobilization and release of nutrients from developed and agricultural areas, through nutrient uptake in treatment areas, and through changes in nutrient processing and retention in the Everglades;

3) *changes in the* bioavailability of nutrients which depend on both the *quality* of nutrients (e.g., inorganic nutrients and DOM) from the watershed and internal estuary mechanisms (e.g., P limitation of DOM decomposition);

- Internal nutrient cycling rates (e.g., nitrogen fixation and denitrification) and biogeochemical processes, such as phosphate sorption, will change with CERP implementation because of salinity and benthic habitat changes.
- Nutrient accumulation and retention in estuaries is affected by episodic storm events, which can export nutrient rich sediments. CERP implementation will modify benthic habitats and nutrient loading which will affect this export.
- The spatial extent, duration, density, and composition of phytoplankton blooms are controlled by several factors that will be influenced by CERP. These include:
  1) external nutrient loading;
  2) internal nutrient cycling (seagrass productivity/die-off, sediment resuspension);
  3) light availability (e.g., modified by sediment resuspension and CDOM);
  4) water residence time;
  5) biomass of grazers (e.g., zooplankton, benthic filter-feeders).
- Nutrients inputs from groundwater discharges may affect water quality in coastal wetlands and estuaries. CERP implementation will modify these discharges in the coastal zone which will alter nutrient loads to the estuaries.

WQ.2 Data Status/Availability for Water Quality Hypothesis Cluster

Systematic monitoring of water quality at fixed stations in the southern estuaries has been ongoing since late 1989 as part of Florida International University's Southeast Environmental Research Center's (FIU/SERC) Water Quality Monitoring Network. This effort began in Florida Bay and by the mid-1990s had expanded to include the entire southern estuaries domain, including the mangrove transition zone (Table 1). Also, beginning in the mid-1990s NOAA/AOML began monitoring water quality and circulation throughout the southern estuaries via fixed station sampling and continuous synoptic sampling. All of the fixed stations (Figure 1) except those located on the southwest Florida shelf had been sampled monthly by both programs until recent funding shortcomings forced NOAA to cut sampling down to six times per year, hence the decreased sampling effort in 2006 (Table 1).

The continuous synoptic sampling measures sea surface temperature, salinity, chlorophyll *a* fluorescence that can be converted to biomass estimates, beam transmission (λ=660) that can be used to estimate Total Suspended Solids (TSS), and Chromophoric Dissolved Organic Matter (CDOM) fluorescence. These measures can then be used to estimate light attenuation along the underway track which is useful to determine if phytoplankton and/or seagrass growth is light-limited within specific regions of the southern estuaries. At each of the fixed stations samples are collected for chlorophyll *a* biomass and dissolved inorganic nutrients. Additionally, NOAA/AOML samples light attenuation, TSS, DOC, and pH at each station, and FIU/SERC samples TOC, TP, APA, and TN at each station. Recent analyses of water quality in the southern estuaries include: Boyer et al. (1997; 1999) for Florida Bay and mangrove transition zone water quality distributions and trends, Rudnick et al. (1999) for Florida Bay nutrient loading, Kelble et al. (2005) for Florida Bay light attenuation, Kelble et al.

(2007) for Florida Bay salinity variability, Caccia and Boyer (2005) for Biscayne Bay water quality distributions and Jurado et al. (2007) for bloom dynamics on the southwest Florida shelf. Much of this data is available to the public at www.aoml.noaa.gov/sfp/ and http://serc.fiu.edu/wqmnetwork/SFWMD-CD/index.htm.

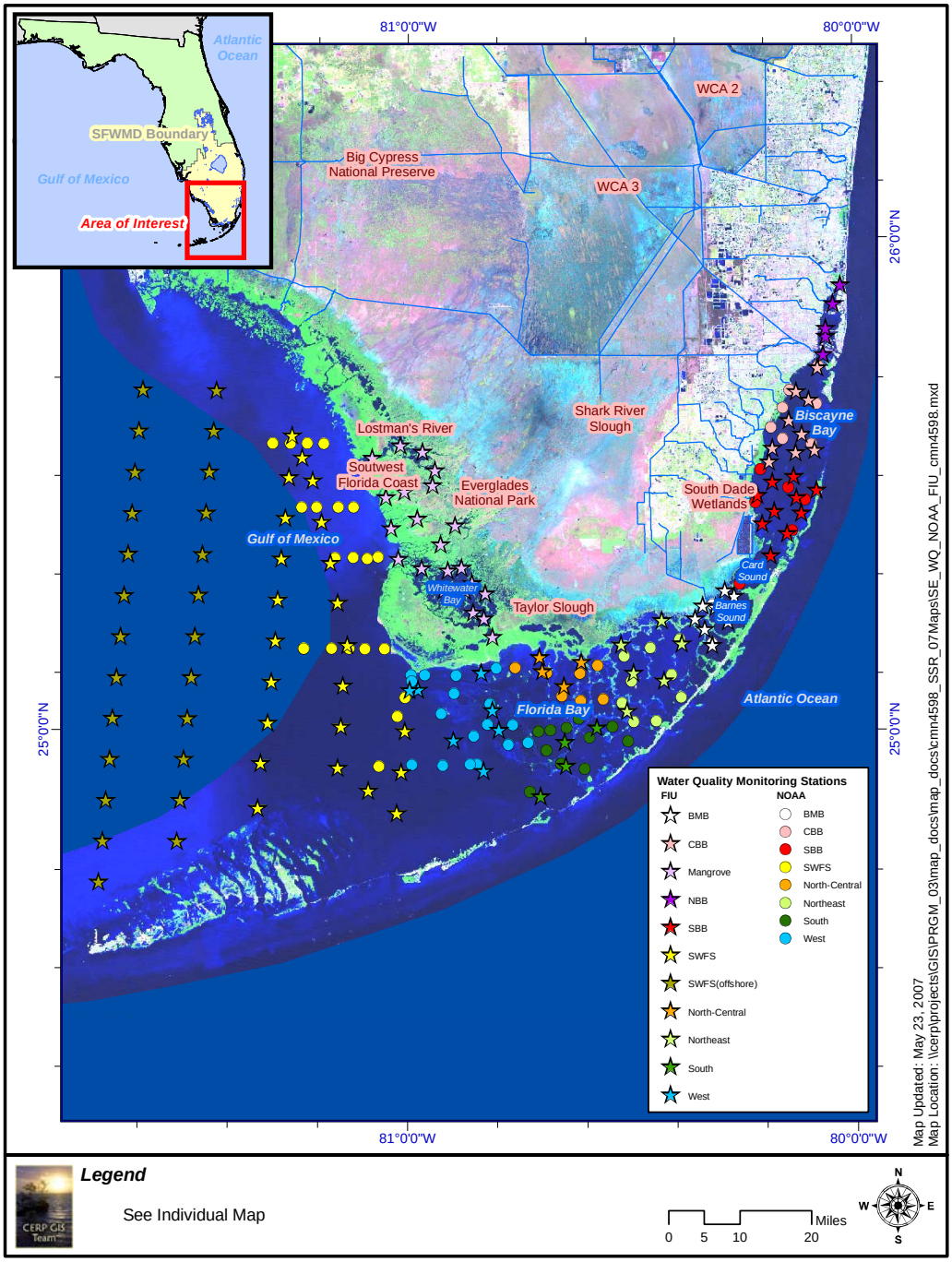

Figure WQ-2: Map depicting NOAA/AOML's and FIU/SERC's fixed water quality sampling stations in the southern estuaries.

Table WQ-1: Number of fixed station samples for water quality in each sub-region.

	SWFS	MTZ	WFB	SFB	NCFB	NEFB	BMB	SBB	CBB	NBB
1989	-	-	30	20	20	30	40	-	-	-
1990	-	-	90	60	60	90	120	-	-	-
1991	-	-	78	52	52	78	104	-	-	-
1992	-	88	72	48	48	72	96	-	-	-
1993	-	264	72	48	48	72	96	68	32	-
1994	-	264	78	52	52	78	104	204	96	-
1995	72	264	72	48	48	72	96	204	96	-
1996	72	242	86	63	62	89	96	162	103	35
1997	216	286	86	62	58	90	96	132	108	60
1998	216	242	152	106	104	132	96	121	99	55
1999	216	264	182	140	112	152	96	132	108	60
2000	216	264	209	161	120	169	96	132	108	60
2001	216	264	214	164	125	167	96	132	108	60
2002	216	264	215	169	124	171	114	173	139	60
2003	216	264	202	158	118	165	126	201	167	60
2004	186	264	232	180	132	180	132	216	180	60
2005	195	242	222	158	118	162	123	202	174	60
2006	182	264	166	114	89	126	114	174	150	60

WQ.3 Analysis framework to assess water quality in the southern estuaries

Based upon the major relevant CERP water quality hypotheses it was determined that salinity and chlorophyll *a* biomass should be utilized as the primary indicators to assess the status and trends in water quality for the southern estuaries. The hypotheses further state that CERP will affect the rates of external nutrient loading and internal nutrient cycling by several different mechanisms. These rates along with three other factors (light availability, water residence time, and biomass of grazers) which may also be influenced by CERP activities control the magnitude, duration, and spatial extent of phytoplankton blooms for which chlorophyll *a* is a proxy. Moreover, phytoplankton blooms are a major concern to the overall health of the southern estuaries (Rudnick et al. 2005). These blooms decrease light penetration through the water column that can lead to seagrass mortality. Seagrass mortality often results in the release of more nutrients via decomposition and increased sediment resuspension, which in turn stimulates more phytoplankton growth (Rudnick et al. 2005; Zieman et al. 1999). This potential to propagate a negative feedback loop throughout the ecosystem elevates the importance of monitoring water quality and chlorophyll *a*.

The role of nutrient inputs from the Everglades in initiating and perpetuating algal blooms in the southern estuaries is unclear and likely varies throughout the region. Several studies have hypothesized that this is an important factor and that increased freshwater flow with CERP may intensify algal blooms in the southern estuaries (CROGEE 2002; Brand 2002; Jurado et al. 2007). Given this possibility, it is necessary to quantify and understand the baseline conditions for salinity and chlorophyll *a* and be capable of identifying deviations from this baseline which may occur as CERP is implemented. The behavior of water quality variables, particularly salinity and

chlorophyll *a*, is distinct throughout individual sub-regions of the southern estuaries due to differences in freshwater runoff patterns (Kelble et al. 2007; Nuttle et al. 2000), circulation (Lee et al. 2006), sediment biogeochemistry (Zhang et al. 2004), nutrient inputs (Rudnick et al. 1999), grazer biomass (Peterson et al. 2006), and phytoplankton species composition (Phlips and Badylak 1996). Therefore, it was necessary to subdivide the southern estuaries module into ten sub-regions (Fig. WQ-2) based upon statistical methodologies (Boyer et al. 1999; Caccia and Boyer 2005) and analysis of circulation patterns (Lee et al. 2006; Lee et al. 2007).

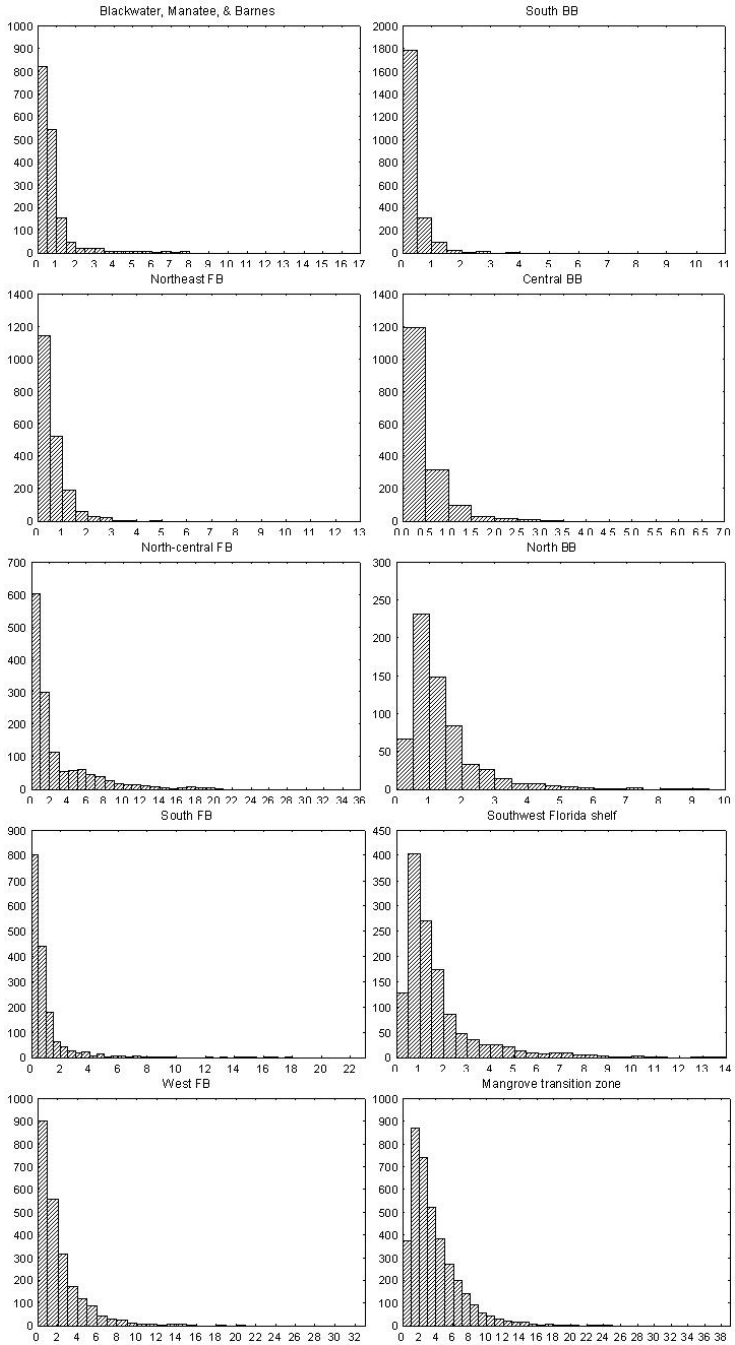

Figure WQ-3: Histograms of chlorophyll *a* (ppb) in each sub-region

The ten subregions are southwest Florida shelf (SWFS), mangrove transition zone (MTZ), west Florida Bay (WFB), north-central Florida Bay (NCFB), south Florida Bay (SFB), northeast Florida Bay (NEFB), Blackwater, Manatee, and Barnes Sounds (BMB), south Biscayne Bay (SBB), central Biscayne Bay (CBB), and north Biscayne Bay (NBB). The distribution of chlorophyll *a* concentrations was not normal in any of these sub-regions always being heavily weighted towards lower concentrations (Fig. WQ-3). As such, the midpoint of the data was best represented by the median and it was necessary to conduct non-parametric statistical tests to analyze the data. EPA guidelines were applied to establish the reference conditions for chlorophyll *a* concentrations and set criteria for determining what constitutes elevated levels of chlorophyll *a* (EPA 2001). This approach established that a median concentration greater than the reference conditions 75th percentile would be classified as elevated from baseline. Furthermore, Kruskal-Wallis tests were employed to statistically test for differences in chlorophyll *a* between 2006 and all data collected prior to 2006. If any differences were measured, more detailed analyses were undertaken to identify underlying changes in water quality parameters and determine the ultimate cause(s) of the observed change.

WQ.4 Present condition of water quality

The present condition of water quality in the southern estuaries has been the subject of numerous previously mentioned peer-reviewed papers. For consistency when undertaking the bi-annual assessment effort, the current condition of salinity and chlorophyll *a* were examined by a standard easily applied methodology. To examine the distribution of chlorophyll *a* throughout the southern estuaries, the data was divided between months that typically have high salinities (April-September) and those that have low salinities (October-March). This was determined based on analysis of salinity patterns in Florida Bay and Biscayne Bay (Fig. WQ-4). Then, the median for each station during high and low salinity months was calculated and the results were plotted with Surfer (Fig. WQ-5). The highest chlorophyll *a* concentrations are consistently measured along the southwest Florida coast, both in the mangrove transition zone and on the southwest Florida shelf. During low salinity, the elevated chlorophyll *a* water expands further west onto the shelf, further south towards the Keys, and further east along the northern edge of Florida Bay. The SFB, NEFB, BMB, SBB, CBB, and NBB sub-regions had consistently lower chlorophyll *a* concentration for both high and low salinity periods.

The median monthly chlorophyll *a* concentration was calculated in each sub-region and the typical annual cycles of chlorophyll *a* were examined for each sub-region (Fig. WQ-6). As depicted in the contour map there were significant differences in the magnitude of chlorophyll *a* between sub-regions. The three regions of Biscayne Bay displayed similar annual cycles in chlorophyll *a* with elevated concentrations from early summer through the end of the year. However, the NBB sub-region had over double the median chlorophyll *a* for each month compared to the other two sub-regions. There were significant differences in the annual cycles for the five sub-regions of Florida Bay, although they all had higher concentrations in the second half of the year. NCFB displayed the largest degree of variability with a peak in October that was over three

times the lower values observed from January through June. SFB had the second largest amount of variability with values in the second half of the year almost double those for the first half of the year. WFB had the highest median values for almost all months with all of the median monthly values greater than 1 ppb. BMB and NEFB had the lowest chlorophyll *a* concentrations without much variability. The southwest Florida coast region had significant differences between its two sub-regions. The MTZ had consistently high levels of chlorophyll *a* with a slight seasonal shift of decreased chlorophyll *a* during the second half of the year, which is the opposite of all other sub-regions in the southern estuaries. SWFS had a large degree of seasonal variability with a large peak in median chlorophyll *a* in November. However, this peak may be an artifact of the sampling effort in this sub-region which is undertaken on a quarterly basis. Thus each month has not been sampled each year and the results may be biased by sampling during November only in years with elevated chlorophyll *a* concentrations in this sub-region.

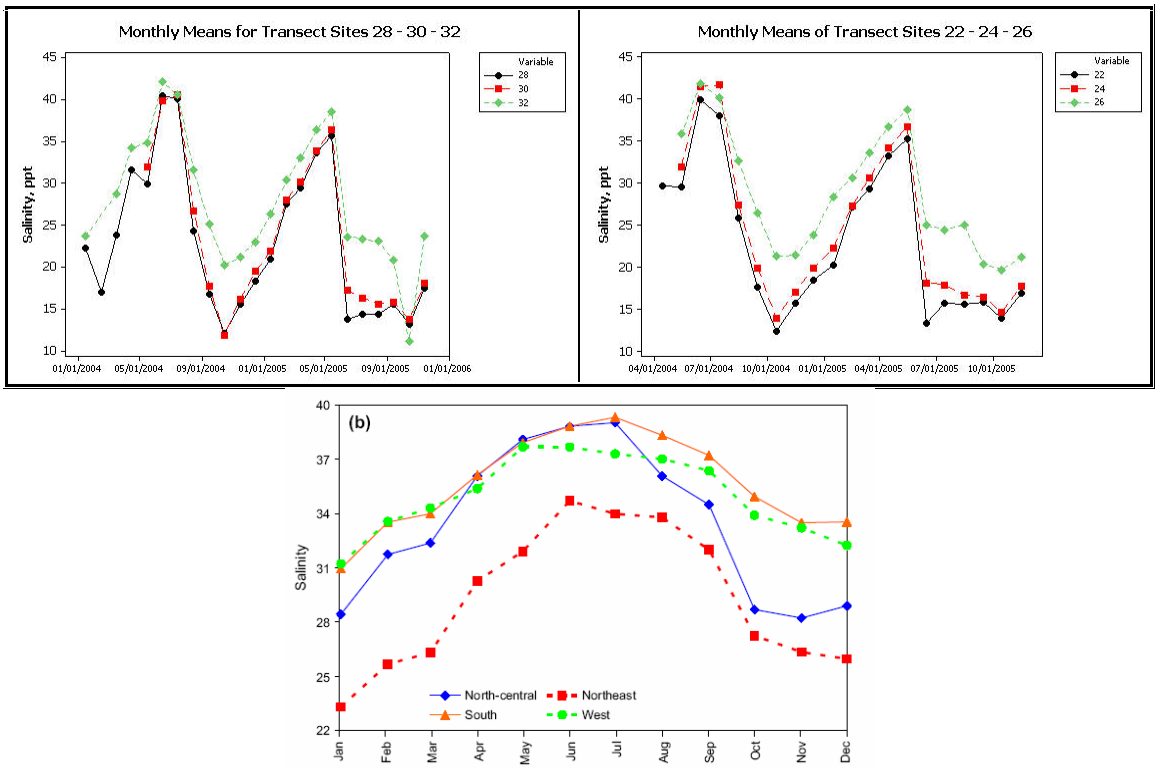

Figure WQ-4. Salinity cycles in Biscayne Bay (top two panels) and Florida Bay (bottom panel)

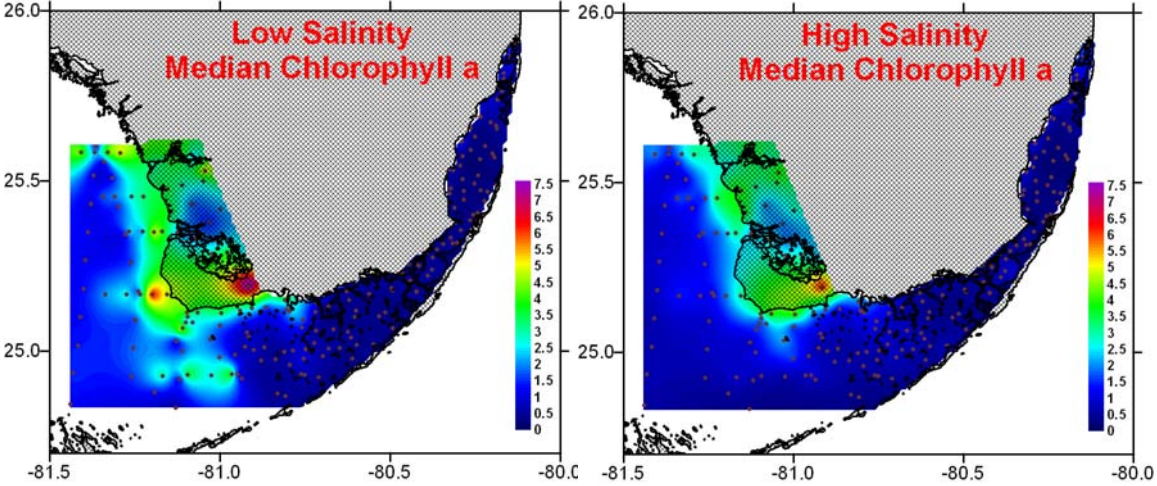

Figure WQ-5: Contour plots of the median chlorophyll *a* distribution in the southern estuaries during low salinity months (October-March) and high salinity months (April-September).

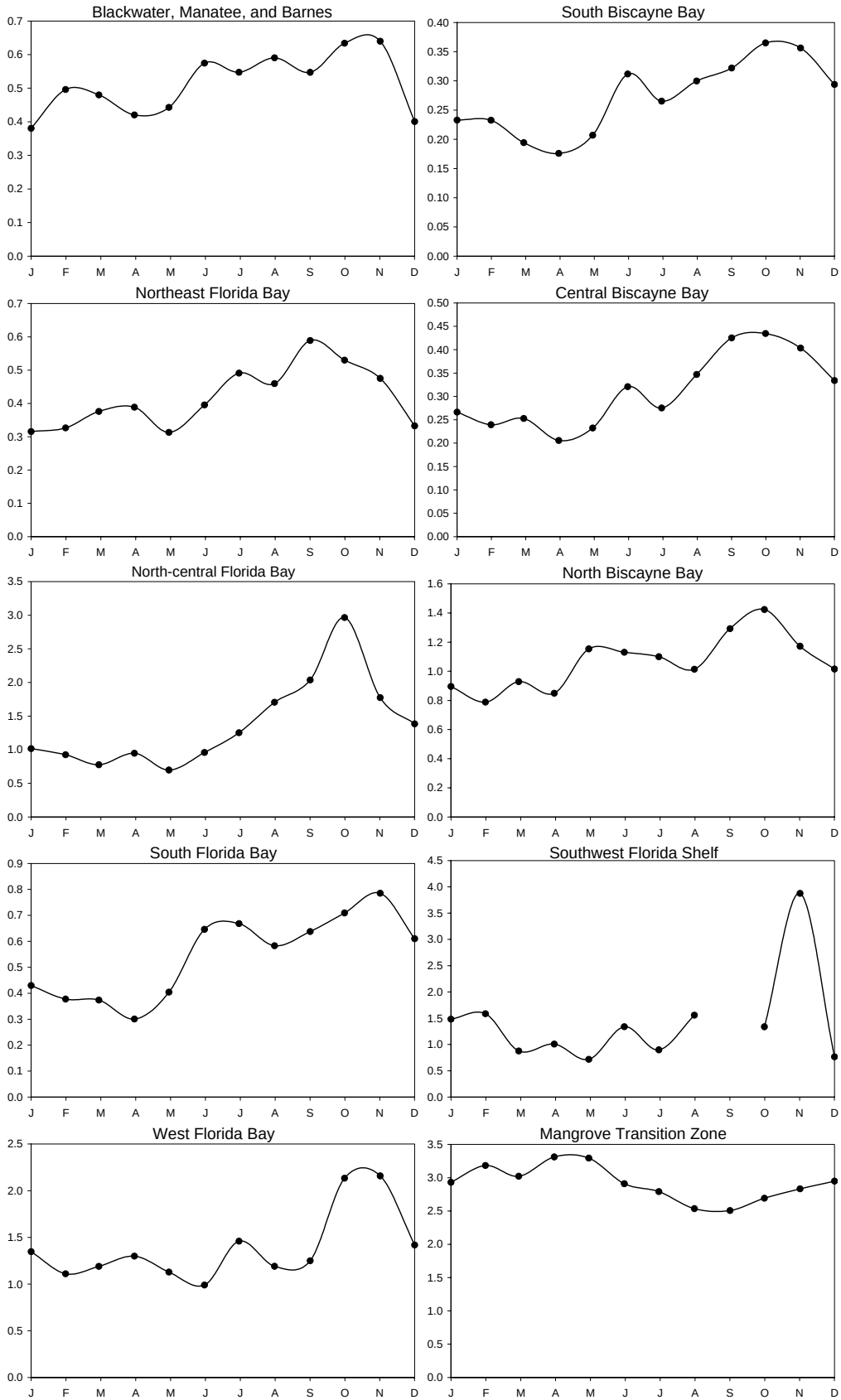

Figure WQ-6: Annual cycle of median chlorophyll *a* in each sub-region.

WQ.5 Detecting Change

To detect change the data were analyzed with respect to the EPA guidelines outlined above. The median and quartiles were calculated to quantify the reference conditions for the ten sub-regions of the southern estuaries (Table WQ-2). These reference conditions were then used to establish criteria from which the status of chlorophyll *a* and thus water quality in each of the sub-regions can be evaluated on an annual basis. If the annual median chlorophyll *a* concentration is greater than the reference median, but lower than the 75th percentile, the sub-region is marked yellow and if the annual median concentration is greater than the 75th percentile of the reference, the sub-region is marked red. This approach sets low thresholds (almost half of the sub-regions go red at greater than 1 ppb) and regions with higher thresholds like FBNC will still go yellow at slightly over 1 ppb. The only exception is the mangrove transition zone which has significantly higher thresholds. The data is plotted as a series of annual box and whisker plots to provide a visual representation of the analysis and account for the variability in the data. This also allows the criteria to be somewhat malleable, because a significant change in the variability will be observed even if there is not a coincident change in the median (Fig. WQ-7). The box and whisker plots have the median as their centerline, the 95% confidence intervals of the median as the notches in the box, the 25th and 75th percentiles demark the edges of the box and the whiskers extend to the 10th and 90th percentile. Thus, the notches and the boxes can be utilized as a pseudo-test for significant differences between medians.

Table WQ-2. Criteria for evaluating chlorophyll *a*.

Sub-region		Valid N	25th Percentile	Median	75th Percentile
Blackwater, Manatee, Barnes	BMB	1704	0.306	0.526	0.910
Central Biscayne Bay	CBB	1673	0.200	0.313	0.566
Mangrove Transition Zone	MTZ	3803	1.690	2.863	4.903
North Biscayne Bay	NBB	635	0.670	1.048	1.648
North-central Florida Bay	NCFB	1399	0.585	1.216	3.710
Northeast Florida Bay	NEFB	1979	0.254	0.417	0.790
South Biscayne Bay	SBB	2257	0.181	0.264	0.426
South Florida Bay	SFB	1695	0.327	0.533	1.059
Southwest Florida Shelf	SWFS	1297	0.739	1.180	1.976
West Florida Bay	WFB	2304	0.653	1.345	2.845

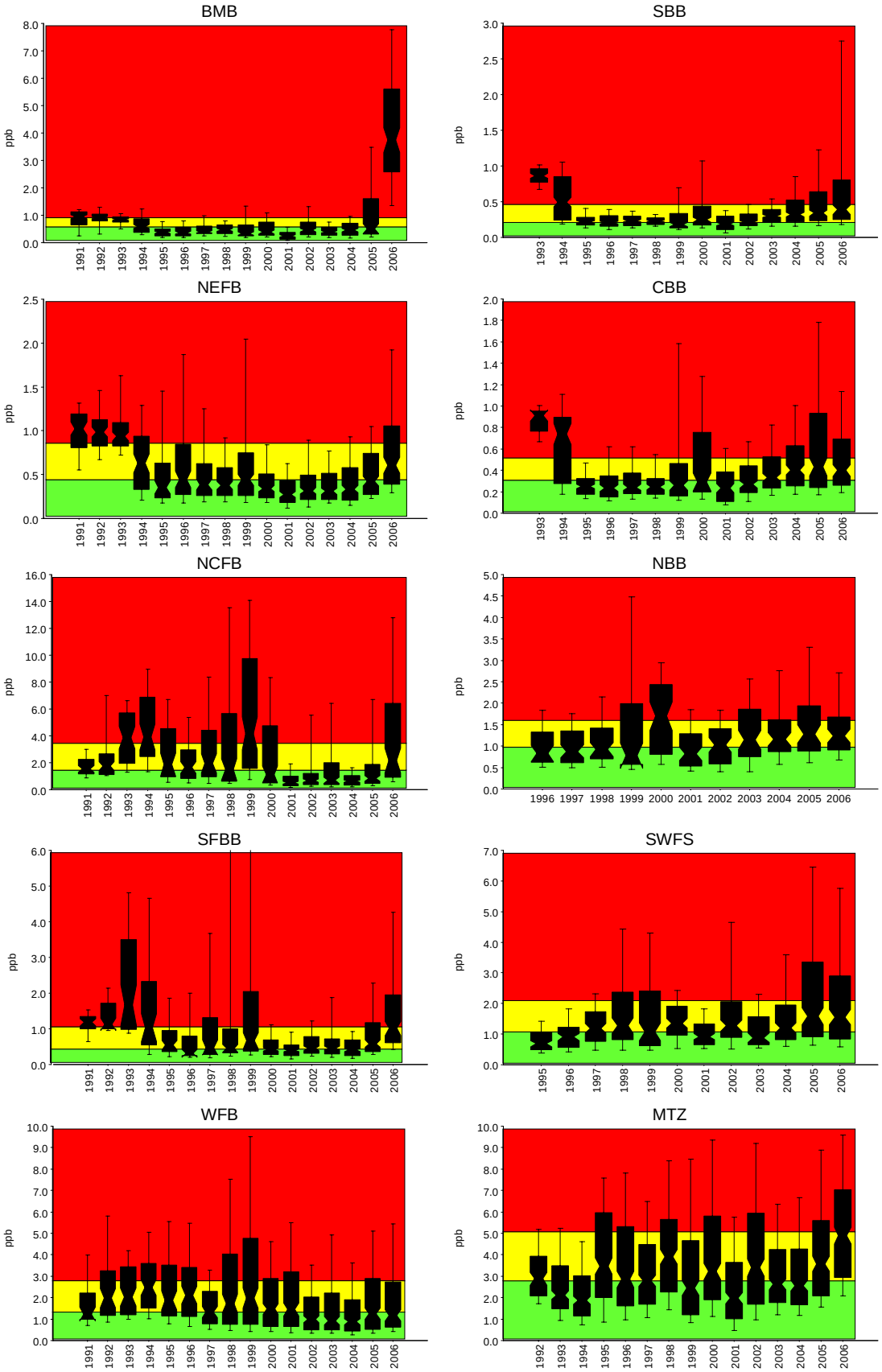

Figure WQ-7: Box and whisker plots of annual chlorophyll *a* in each sub-region.

From this box and whisker analysis a stoplight map is produced to display the status of chlorophyll *a*/water quality in each sub-region (Fig. WQ-8). The sub-regions which receive yellow ratings may undergo further analysis, if a Kruskal-Wallis test shows there has been a significant change in median chlorophyll *a* concentration. The additional statistical test is conducted, because a random sample will be higher then the median and thus yellow 50% of the time even if no significant change has occurred. The sub-regions which have received red ratings will be further evaluated to determine the cause of degradation in water quality and determine if it was the result of CERP, natural variability, or other anthropogenic activities. The physical environment of the southern estuaries, particularly salinity responds to meteorological events, such as tropical cyclones and El Niño (Fig. WQ-9). Thus, water quality likely responds to these natural events and a change must be shown to be definitively due to CERP.

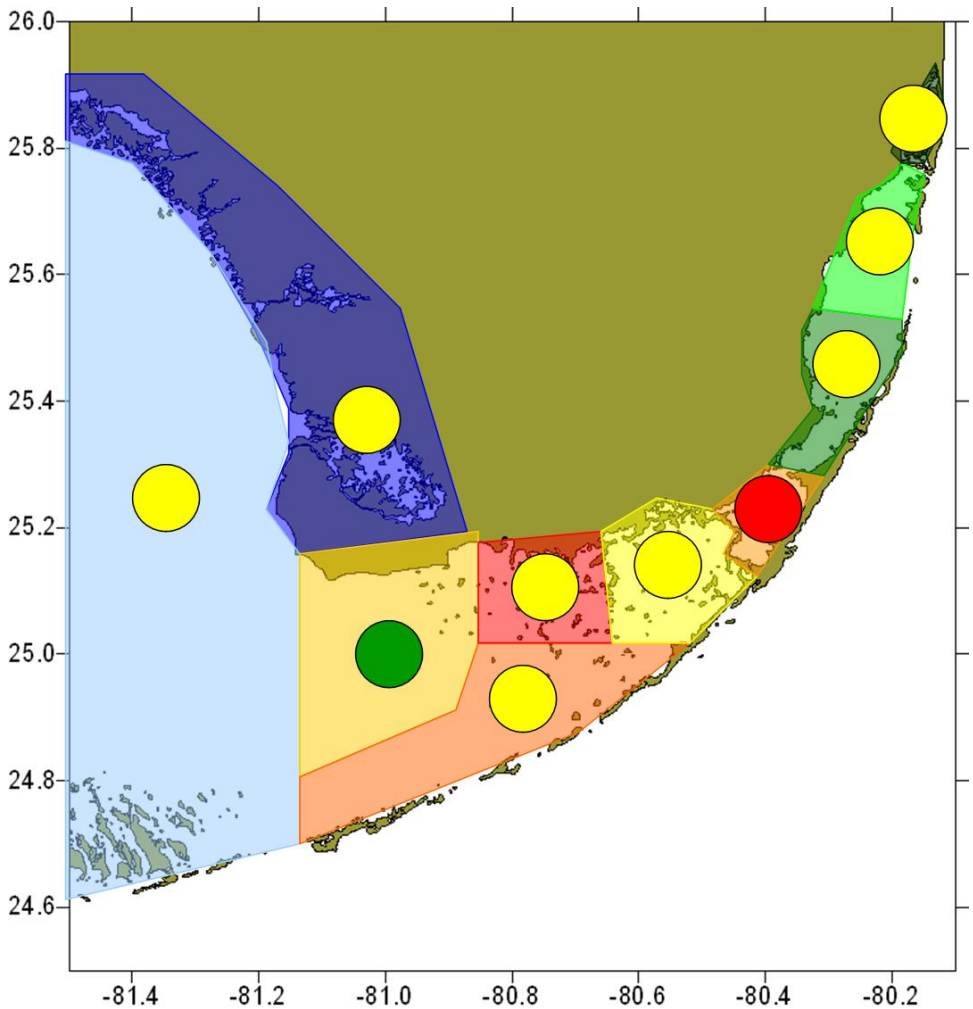

Figure WQ-8: The circle in each sub-region displays the current status of chlorophyll *a*.

The 2006 analysis showed that of the ten sub-regions 1 was green, 8 were yellow, and 1 was red (Fig. WQ-8). Two sub-regions, the MTZ and BMB, had the highest median chlorophyll *a* concentrations of any year on record. Thus, the 8 yellow sub-regions may warrant further investigation and the one red sub-region must undergo

further investigation. The red sub-region incorporates Blackwater, Manatee, and Barnes Sounds and the entire 95% confidence interval of the median is located in the red region of the graph, indicating there was a substantial increase in chlorophyll *a* in this sub-region in 2006. This is an area that has been subject to significant disturbances unrelated to CERP over the past two years. In April of 2005 a road construction project began to expand the US Highway 1 in this region. This involved a significant amount of cutting and mulching of mangroves and soil tilling. Also, from August to October 2005 this area was affected by the passing of three hurricanes over the region. In addition to causing a great deal of physical disturbance, there was a large managed release of water that contained elevated levels of phosphorous prior to the first hurricane.

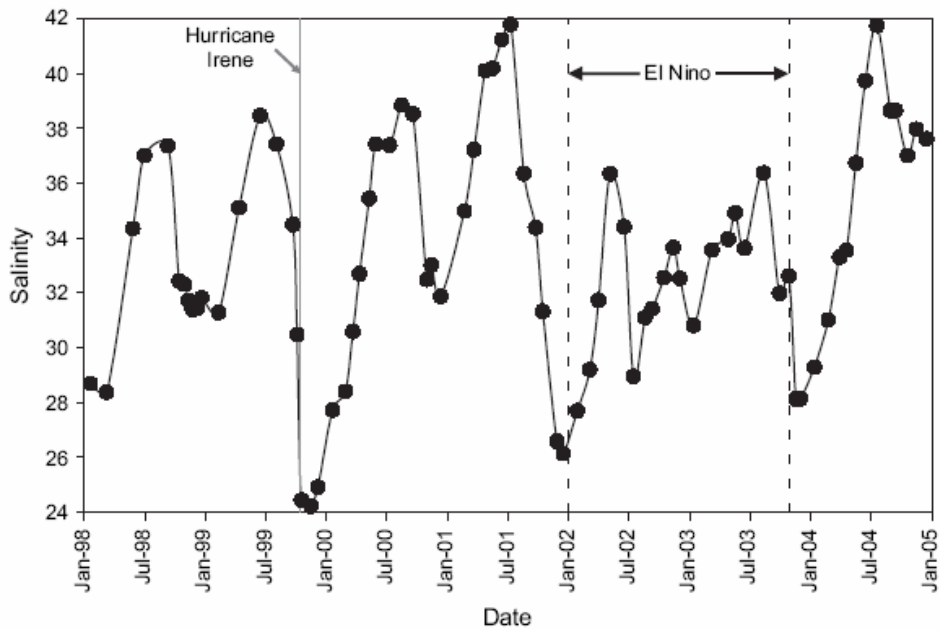

Figure WQ-9: The mean bay-wide salinity of Florida Bay depicts significant deviations due to climactic variation and tropical cyclones.

The result of these activities was the initiation of an atypical algal bloom in this sub-region shortly after October of 2005. Levels of chlorophyll *a* far exceeded previously measured values in this sub-region. Furthermore, the long residence times of this sub-region acted to maintain the bloom's location and helped the bloom to persist throughout 2006. The minimal flushing did not dilute the bloom and its persistence is likely due to the creation of a positive feedback loop, whereby the bloom shades the seagrasses which senesce and decay releasing nutrients and destabilizing the bottom which increases sediment and nutrient resuspension further fueling the bloom. Monitoring results indicate that the bloom was likely initiated by a large increase in total phosphorous prior to the bloom's initiation and total phosphorous has remained elevated throughout the bloom's persistence indicating its importance in fueling the bloom (Fig. WQ-10). The bloom is spatially associated with the road construction activities and temporally associated with the impacts of hurricanes. Thus, it is likely that the bloom was the result of these two events occurring coincidentally in the fall of 2005. For more

information on this phenomenon and its underlying causes please refer to Rudnick et al. (2007).

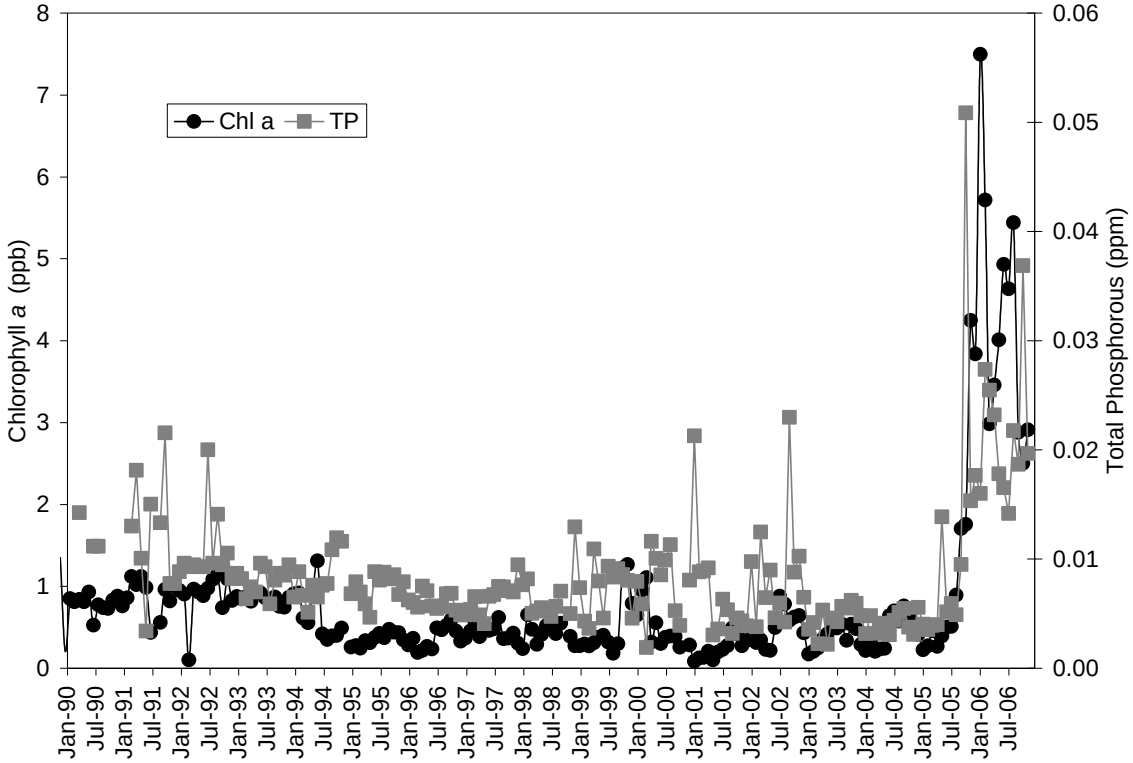

Figure WQ-10: Time series of median chlorophyll and total phosphorous in the BMB sub-region.

WQ.6 Interim Goals

The desired condition is sustained good water quality in Florida Bay, minimizing the magnitude, duration, and spatial extent of algal blooms in the bay such that light penetration is sufficient to sustain healthy and productive seagrass habitat. The interim goal for Florida Bay algal blooms is to prevent any increase in the intensity, duration, or spatial extent of such blooms in Florida Bay or adjacent waters. The proposed assessment along with current monitoring projects is capable of addressing this interim goal in all of the ten sub-regions with the possible exception of the southwest Florida shelf where sampling frequency may not be adequate. The current assessment shows that there has been an increase in algal blooms in one sub-region (Blackwater, Manatee, and Barnes Sounds); however, this increase was not due to CERP, and instead was the result of a combination of hurricanes, managed water releases, and road construction in this sub-region in fall 2005.

The ability to predict water quality and chlorophyll *a* response to CERP is dependent upon the further refinement of the Environmental Fluid Dynamics Code Model which is being developed as a task of CERP's Florida Bay and Florida Keys Feasibility Study. This model will be used to predict the intensity, duration, and spatial

distribution of algal blooms in Florida Bay and the nearshore southwest Florida shelf as CERP is implemented. A similar model may be required for Biscayne Bay. The current monitoring and assessment plans are adequate, except for on the southwest Florida shelf, to detect changes to the intensity, duration, and spatial distribution of algal blooms and assess the accuracy of the model.

WQ.7 Lessons Learned

This approach to assessing water quality has proven to be quite capable of detecting changes as it did in the Blackwater, Manatee, and Barnes Sounds sub-region for 2006. There is precedence for the criteria development and the graphical representations can be easily understood by all audiences. The one weakness is with respect to sampling frequency. It has been recommended by the Advisory Committee on Water Information and the National Water Quality Monitoring Council that water quality be measured monthly to assess the condition of specific estuaries (ACWI and NWQMC 2006). Currently the sampling frequency is not sufficient on the southwest Florida shelf, where sampling is conducted quarterly by both programs. Increasing the sampling frequency in this sub-region is of heightened importance, because CERP is likely to significantly increase freshwater discharge in this sub-region. Furthermore, it is recommended that NOAA/AOML increase its sampling frequency to conduct monthly surveys. This will enable the utilization of their flow-through chlorophyll *a* measurements in further analysis, which would substantially increase the spatial coverage of the assessment.

It is recommended that the salinity section be partitioned out into its own section with a distinct hypothesis cluster and relevant hypotheses. There are specific interim goals for salinity separate from water quality, indicating that it has on occasion been treated as a separate cluster and it should uniformly be treated as such in the future. The desired condition is to reduce the intensity, frequency, duration, and spatial extent of high salinity events, reestablish common mesohaline to oligohaline conditions in mainland nearshore zones, and reduce the frequency and rapidity of salinity fluctuations resulting from pulse releases of fresh water from canals. By altering freshwater flow, CERP will almost certainly affect salinity distributions in the southern estuaries which will in turn result in changes to water quality and all other performance measures. Thus, it is logical and necessary to have a separate salinity hypothesis cluster and performance measure which is assessed annually to ensure we are effectively monitoring this variable and capable of detecting changes which may occur as a result of CERP.

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