CHARLOTTE HARBOR
Numeric Nutrient Criteria:
Task 11 – Implementation Issues

Letter Memorandum

Prepared for:

Charlotte Harbor National Estuary Program

Prepared by:

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FOREWORD

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CHNEP Technical Advisory Committee
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FDEP Charlotte Harbor Aquatic Preserve (CHAP)
FDEP Estero Bay Aquatic Preserve (EBAP)
FDEP Southwest District
Florida Gulf Coast University
Johnson Engineering
Lee County
Lee County Environmental Laboratory
Lee County Hyacinth Control District
Lemon Bay League
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EXECUTIVE SUMMARY

The objective of this task is to address two key issues identified by the U.S. EPA regarding successful implementation of the proposed numeric nutrient criteria in Charlotte Harbor, namely the method to account for non-anthropogenic events, such as El Niño and hurricanes, and the allowable exceedance criteria (how often criteria may be exceeded before non-compliance is indicated). Analyses were performed to direct input on these subjects, with the following conclusions:

- The annual response time to recover from the maximum monthly chlorophyll *a* concentration during a given year is relatively short. Median annual response times are three months or less in all segments, and average annual response times are typically just over two months in most segments. This indicates that the bay segments recover quickly from normal loading events.
- In general, the duration of the response was independent of the magnitude of the chlorophyll *a* maximum. Several bay segments, however, responded to higher chlorophyll *a* maxima with longer response times.
- Response time to unusual events, such as hurricanes, may only be one month longer than the average response time, but is also spatially variable, with some parts of the estuary recovering within just a few months of the event and other areas requiring a year or longer.
- It is important to consider the effects of natural variability in establishing the compliance assessment scheme.
- Comparison of the two temporal assessment schemes, 1-in-3 years vs. 2-in-5 years, suggested that the 2-in-5 rule was less likely to result in a violation due solely to natural variability.

1.0 INTRODUCTION AND OBJECTIVES

The Charlotte Harbor National Estuary Program (CHNEP) has recommended numeric nutrient criteria to U.S. Environmental Protection Agency (EPA) for Charlotte Harbor (Janicki Environmental, 2011a). EPA has identified several key issues that must be addressed if the proposed numeric nutrient criteria are to be successfully implemented in Charlotte Harbor (Figure 1). These issues are as follows:

- Non-anthropogenic events (e.g., El Niño, hurricanes) can significantly affect the nutrient and response conditions in the bay. The effect of these events on the bay's response to nutrient inputs is evaluated, and potential methods to account for these events in the implementation of the proposed numeric nutrient criteria are provided.
- EPA is proposing an allowable exceedance of criteria as no more often that one in three years, while many of the important water quality assessments in the surrounding area (Tampa Bay) are based on a two in five years basis. The appropriateness of each of these assessment periods is evaluated.
- EPA encouraged input on the treatment of tidal creeks and bayous in the implementation of the proposed nutrient criteria for Charlotte Harbor.

This document addresses the first two of these issues, with the treatment of tidal creeks and bayous addressed in another document (Janicki Environmental, 2011b). In addition, the CHNEP has developed an annual assessment of ambient water quality conditions that would be an appropriate assessment reporting mechanism for estuarine numeric nutrient criteria for Charlotte Harbor.

2.0 Temporal Extent of Elevated Chlorophyll *a* Responses to Unusual Events

EPA encouraged input on potential methods to account for non-anthropogenic events that can significantly affect the nutrient and response conditions in Charlotte Harbor, including the effects of hurricanes or other unusually high rainfall events, such as El Niño. This section provides the results of analyses performed to evaluate the temporal extent of responses in the Charlotte Harbor system, following both unusual events and the annual maximum monthly chlorophyll *a* concentrations typically observed every wet season. A summary of chlorophyll statistics by segment is presented in Appendix 1.

2.1 Unusual Events

The nutrient conditions and associated chlorophyll *a* responses in the Charlotte Harbor system can be affected by unusual loading events. These events may be non-anthropogenic in nature, such as those related to especially high rainfall conditions associated with tropical storms, hurricanes, El Niño events, or other unusually wet periods. Anthropogenic events, such as nutrient-laden spills and accidental releases of wastewater, may also impact the bay.

Consideration of these types of events must be included within the implementation plan of the proposed numeric nutrient criteria. To understand the impacts of these events in the bay, and the temporal extent of these effects, events occurring during the 1996-2009 period were identified, and the responses in the bay were evaluated. Specifically, the duration of the responses as signified by elevated chlorophyll *a* concentrations were estimated for each event.

Water quality data collected by a number of organizations including Coastal Charlotte Harbor Monitoring Network (CCHMN), City of Cape Coral, Sarasota County, Florida International University (FIU), Lee County, Peace River/Manasota Regional Water Supply Authority (PRMRWSA), and South Florida Water Management District (SFWMD) were used to develop the monthly mean chlorophyll *a* and nutrient concentrations for each of the segments of the bay (Figure 1). These data were also used to develop median chlorophyll *a* concentrations for each calendar month within the segments. The chlorophyll *a* response time within each segment was evaluated for each event, with an unusually high chlorophyll *a* concentration (greater than the monthly median) identified as the beginning of the event. Following each event, the number of months until the chlorophyll *a* concentration returned to a level at or below the median calendar month concentration was tallied. This provides a measure of the response time within the bay to an unusual loading event. For this analysis, as in the numeric nutrient criteria development, the East Wall, West Wall, Cape Haze, and Bokeelia segments were combined into the Charlotte Harbor Proper segment.

Figure 2 presents an example plot that displays how the response time is estimated. In this example the peak chlorophyll *a* concentration occurred in August. The ambient chlorophyll *a* concentrations remain above the monthly median values until January, as indicated by the green arrow. Therefore, the response time for this example is 5 months.

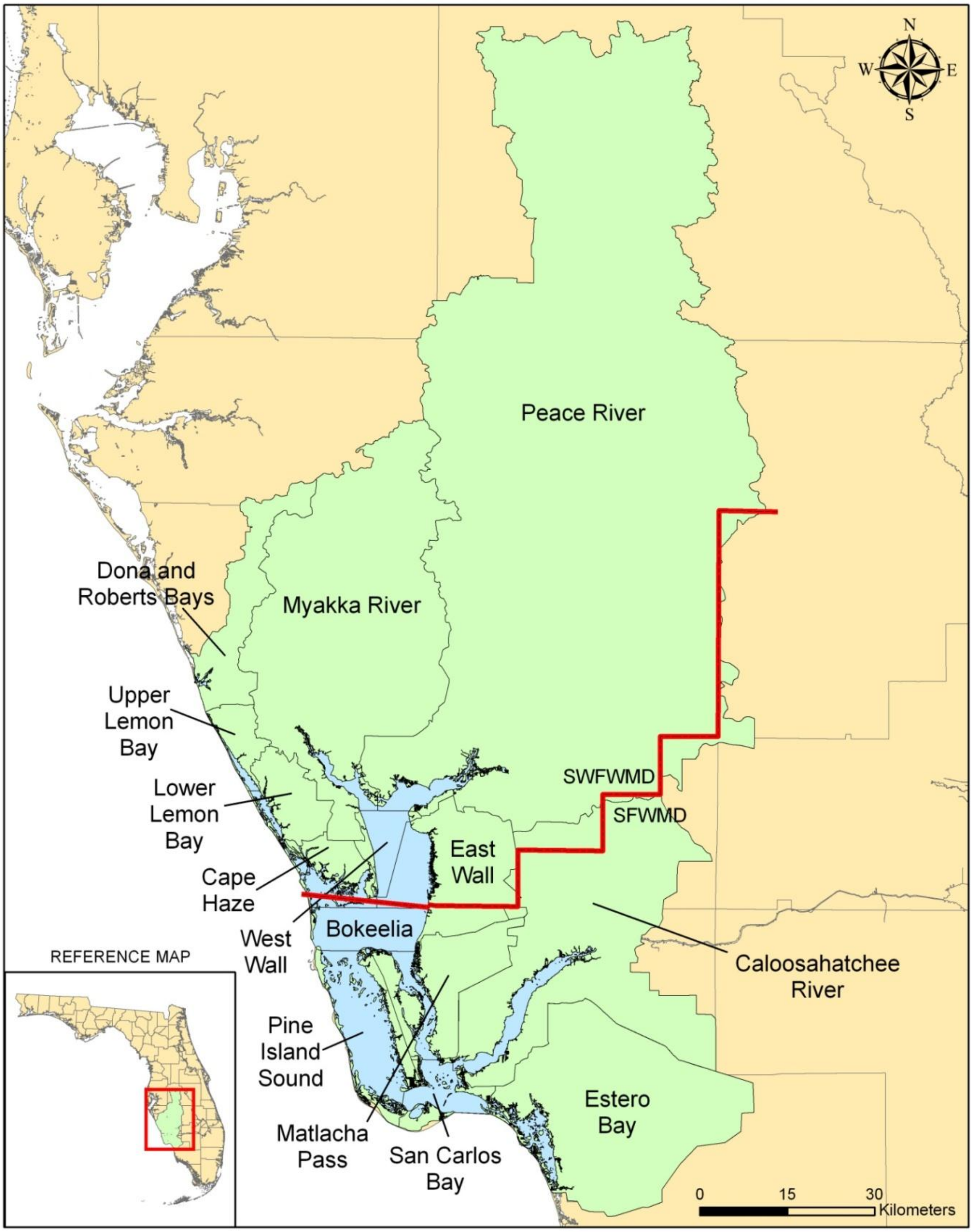

Figure 1. Charlotte Harbor and its major bay segments.

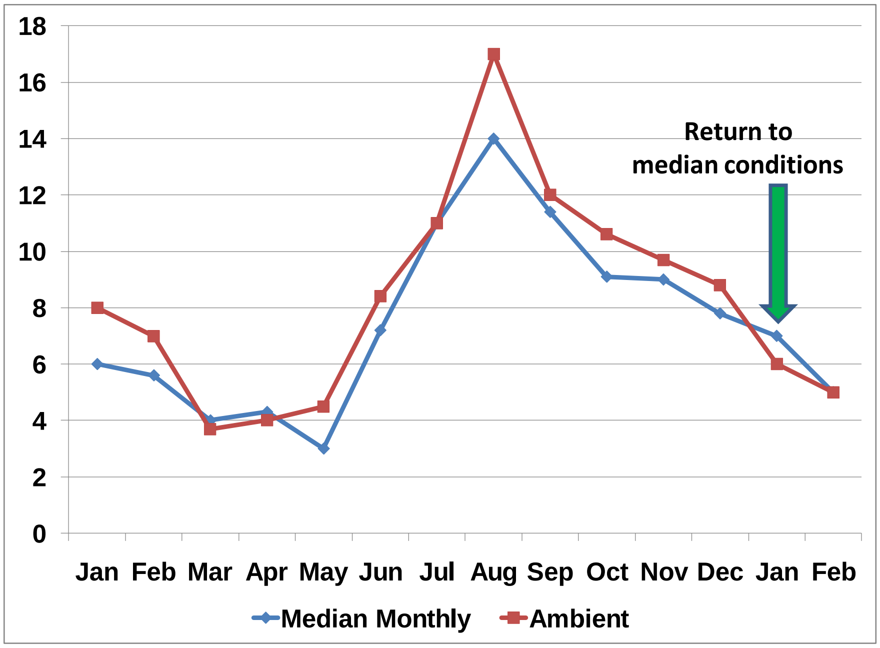

Figure 2. Example of the response time estimation method.

The duration of chlorophyll *a* responses during unusual events represents the serial correlation that exists for that particular event. Understanding how and why values are correlated over time is essential in evaluating the assimilative capacity of the estuary. Correlation across time is termed serial autocorrelation and is a violation of the assumptions associated with many standard statistical testing procedures including some tests used in assessments of the FDEP and EPA water quality standards. This analysis attempts to describe serial autocorrelation in terms of event duration. The assessment is conditional, based on the identification of an event and identified as a deviation from an expected monthly condition (the median value). By comparing observed monthly values to long term monthly medians, the seasonal correlation inherent in chlorophyll *a* responses due to seasonal changes in temperature and photoperiod are accounted for. The expectation is that a value in a given month will vary about its median value as a function of local influences and natural variability. For this assessment, a duration in months above the long term monthly median suggests the persistent effects of some influential event. Events examined for this analysis included the following unusual events associated with abnormal meteorological conditions:

- Event 1: Unusually high rainfall during the 1997-1998 El Niño,
- Event 2: Hurricane Charley, August 13, 2004.

A discussion of each bay segment's response to these events is provided below. Plots of each segments response to the events are presented in Appendix 2.

2.1.1 Temporal Extent of Responses to Unusual Events – Dona and Roberts Bays

Event 1 - The El Niño event of 1997-1998 began in the fall of 1997. However, the period of record for Dona and Roberts Bays was 2003 through 2009. Therefore, response to this unusual loading event could not be determined.

Event 2 – Chlorophyll *a* concentration in Dona and Roberts Bays peaked during August 2004, the same month as the passage of Hurricane Charley in mid-August and recovered 3 months later in November. During August, chlorophyll *a* concentration was 10.2 µg/L, compared to the median value of 6.8 µg/L. The response time following Hurricane Charley was 3 months.

2.1.2 Temporal Extent of Responses to Unusual Events – Upper Lemon Bay

Event 1 - The El Niño event of 1997-1998 began in the fall of 1997. The chlorophyll *a* concentration in February 1998 was 6.5 µg/L, compared to the median value of 4.4 µg/L. Monthly values remained greater than the median values during 16 of the next 17 months reaching the chlorophyll *a* maximum in August 1998 at 21.4 µg/L, compared to the median value of 10.2 µg/L. The response time was 15 months.

Event 2 – Chlorophyll *a* concentrations in Upper Lemon Bay peaked during August 2004, the same month as the passage of Hurricane Charley in mid-August and recovered 3 months later in November. During August, chlorophyll *a* concentration was 19.7 µg/L, compared to the median value of 10.2 µg/L. The response time following Hurricane Charley was 3 months.

2.1.3 Temporal Extent of Responses to Unusual Events - Lower Lemon Bay

Event 1 - The El Niño event of 1997-1998 began in the fall of 1997. However, data collection in Lower Lemon Bay did not begin until 2001. Therefore, response to this unusual loading event could not be determined.

Event 2 – Chlorophyll *a* concentrations in Lower Lemon Bay peaked during August 2004, the same month as the passage of Hurricane Charley in mid-August and recovered 1 month later in September. During August, chlorophyll *a* concentration was 7.7 µg/L, and did not exceed the median value of 8.4 µg/L. The response time following Hurricane Charley was 1 month.

2.1.4 Temporal Extent of Responses to Unusual Events – Charlotte Harbor Proper

Event 1 - The El Niño event of 1997-1998 began in the fall of 1997. However, data collection in all segments of Charlotte Harbor Proper did not begin until 2001. Therefore, response to this unusual loading event could not be determined.

Event 2 – Chlorophyll *a* concentrations in Charlotte Harbor Proper following the peak associated with Hurricane Charley recovered within 3 months and were below the median value in November 2004. However, chlorophyll concentrations again exceeded the median value in the 4 months following (December 2004-March 2005). It should be noted that although several months exceeded the monthly medians, all of these values were <0.5 µg/L above the median except in October and December when concentrations were more than 2.5 µg/L greater than the median value. The response time following Hurricane Charley was 3 months.

2.1.5 Temporal Extent of Responses to Unusual Events – Tidal Myakka River

Event 1 - The El Niño event of 1997-1998 began in the fall of 1997. The chlorophyll *a* maximum observed in July 1998 was 21.2 µg/L, compared to the median value of 11.0 µg/L. The response time was 1 month from the chlorophyll *a* maximum.

Event 2 – Chlorophyll a levels did not exceed the monthly median during August 2004, but were slightly (<0.1 µg/L) greater than the median in the two months following the passage of Hurricane Charley. Therefore, the response time following Hurricane Charley was 2 months.

2.1.6 Temporal Extent of Responses to Unusual Events – Tidal Peace River

Event 1 - The El Niño event of 1997-1998 began in the fall of 1997. From June 1997 to December 1998, there were only 8 values that exceeded the respective monthly median values and the maximum response time was only one month. Therefore, no extended negative impact was seen in chlorophyll concentrations in the Tidal Peace River as a result of the El Niño event of 1997-1998.

Event 2 – Chlorophyll *a* concentrations in the Tidal Peace River peaked during August 2004, the same month as the passage of Hurricane Charley in mid-August and recovered 1 month later in September. However, chlorophyll levels exceeded the monthly median during the next 7 months and were 2-3 times greater than the monthly median during 6 of those 7 months. Though the Tidal Peace recovered is September, the response time following Hurricane Charley was likely 9 months.

2.1.7 Temporal Extent of Responses to Unusual Events - Pine Island Sound

Event 1 - The El Niño event of 1997-1998 began in the fall of 1997. The chlorophyll *a* maximum in September 1997 was 7.1 µg/L and did not exceed the median value of 7.6 µg/L. Response time was 10 months, though quarterly sampling in Pine Island Sound resulted in numerous months without chlorophyll data during which levels may have recovered. The chlorophyll *a* maximum the following year was observed in July 1998 at 11.6 µg/L compared to the median value of 6.8 µg/L. The response time was 4 months from the chlorophyll *a* maximum and may have been shorter, but was not possible to determine due to seasonal sampling.

Event 2 – Chlorophyll *a* concentrations in Pine Island Sound peaked during September 2004, the month following the passage of Hurricane Charley in mid-August and recovered 3 months later in December. During August, chlorophyll *a* concentration was 14.6 µg/L, and compared to the median value of 7.6 µg/L. The response time following Hurricane Charley was 3 months.

2.1.8 Temporal Extent of Responses to Unusual Events – Matlacha Pass

Event 1 - The El Niño event of 1997-1998 began in the fall of 1997. The chlorophyll *a* maximum in September 1997 was 5.7 µg/L and did not exceed the median value of 6.4 µg/L. Response time was 6 months, though quarterly sampling in Matlacha Pass resulted in numerous months without chlorophyll data during which levels may have recovered. The chlorophyll *a* maximum the following year was observed in November 1998 at 7.6 µg/L compared to the median value of 3.3 µg/L. The response time was 2 months from the chlorophyll *a* maximum and may have been shorter, but was not possible to determine due to seasonal sampling.

Event 2 – Chlorophyll *a* concentrations in Matlacha Pass peaked during August 2004, the same month as the passage of Hurricane Charley in mid-August and recovered 4 months later in December. During August, chlorophyll *a* concentration was 52.3 µg/L, and compared to the median value of 6.0 µg/L. The response time following Hurricane Charley was 4 months.

2.1.9 Temporal Extent of Responses to Unusual Events – San Carlos Bay

Event 1 - The El Niño event of 1997-1998 began in the fall of 1997. The chlorophyll *a* maximum was in July 1997 at 5.3 µg/L compared to the median value of 2.2 µg/L. Response time was 8 months, though quarterly sampling in San Carlos Bay resulted in numerous months without chlorophyll data during which levels may have recovered. The chlorophyll *a* maximum the following year was observed in April 1998 at 8.3 µg/L compared to the median value of 3.6 µg/L. The response time was 12 months from the chlorophyll *a* maximum and may have been shorter, but was not possible to determine due to seasonal sampling.

Event 2 – Chlorophyll *a* concentrations in San Carlos Bay following the annual peak associated with Hurricane Charley did not recover for nearly 2 years (22 months) and may have been sustained by annual peak chlorophyll *a* concentrations in August 2005 and an early annual peak in March 2006. Chlorophyll *a* concentrations finally recovered to below-median levels in June 2006. The response time following Hurricane Charley was 22 months.

2.1.10 Temporal Extent of Responses to Unusual Events – Tidal Caloosahatchee River

Event 1 - The El Niño event of 1997-1998 began in the fall of 1997. However, data collection in the tidal Caloosahatchee River did not begin until 1999. Therefore, response to this unusual loading event could not be determined.

Event 2 – Chlorophyll *a* concentrations in the Tidal Caloosahatchee River peaked in August 2004 in response to Hurricane Charley but recovered the following month. The response time following Hurricane Charley was 1 month.

2.1.11 Temporal Extent of Responses to Unusual Events - Estero Bay

Event 1 - The El Niño event of 1997-1998 began in the fall of 1997. The chlorophyll *a* maximum was in August 1997 at 6.5 µg/L compared to the median value of 7.0 µg/L. Response time was 19 months, though lack of data in Estero Bay from September-December 1997 meant that chlorophyll levels may have recovered within 1-5 months. However, chlorophyll a levels remained above the monthly median from January 1998 until July 1999.

Event 2 – Chlorophyll *a* concentrations in Estero Bay were already in exceedance of the monthly median in July 2004 prior to the passage of Hurricane Charley in mid-August, peaked in September and recovered 3 months later in December. During the September maximum, the chlorophyll *a* concentration was 11.2 µg/L compared to the median value of 6.8 µg/L. The response time following Hurricane Charley was 4 months.

2.1.12 Summary of Temporal Extent of Unusual Events

Table 1 provides a summary of the response times in each segment for each event. As provided in the table, the most pronounced increase in response times resulted from the

El Niño event of 1997-1998. The response to most unusual loading events to the bay is typically very rapid, with response times on the order of months, not years. For example, the passage of Hurricane Charley resulted in response times that were typically no greater than 4 months. However, response times on the order of 1 year or more were observed for several bay segments during the El Niño years of 1997-1998 and following Hurricane Charley in 2004. The response of these bay segments to Hurricane Charley was less dramatic (probably a result of lower total rainfall amounts relative to the El Niño period), but still exceeded the annual average response time. Several bay segments exhibited prolonged response times to both the El Niño and hurricane events. Response times for Pine Island Sound, Matlacha Pass, San Carlos Bay and Estero Bay during the El Niño years were at least 6 months in duration and were substantially longer than the annual average response time.

Table 1. Chlorophyll *a* response times (months) to unusual loading events in Charlotte Harbor.

Segment	El Niño 1997-1998	Hurricane Charley 2004
Dona and Roberts Bays	-	3
Upper Lemon Bay	15	3
Lower Lemon Bay	-	1
Charlotte Harbor Proper	-	3,8
Tidal Myakka River	1	2
Tidal Peace River	1	7
Pine Island Sound	10,1*	3
Matlacha Pass	6,2*	4
San Carlos Bay	12,1*	22
Tidal Caloosahatchee River	-	1
Estero Bay	19,1*	4

*Indicates that the response time included months with no data.

Values separated by a comma represent response times for the 1997,1998 El Nino or the response time, number of months above monthly median immediately following recovery.

2.2 Annual Maxima

Chlorophyll *a* concentrations reach annual maxima within each segment of the bay in response to conditions that are conducive to increased productivity. The maxima normally occur in the summer months, as this is typically the time of year when conditions are most conducive to algal growth. The number of months for the monthly segment chlorophyll *a* concentrations to recede to levels below the median monthly concentrations, as estimated from 1996-2009 observations, is defined as the annual response time for this analysis. Therefore, the annual response time provides an indicator of the ability of each segment to recover from typical seasonal increases in loadings associated with the wet season.

The method used in this analysis to estimate the annual response time was the same as that used for examining the response times to unusual events. Following each annual maximum, the number of months until the chlorophyll *a* concentration returned to a level at or below the median calendar month concentration was tallied. This provides a measure of the response time within the bay to the annual chlorophyll *a* maximum. Because the period of record varied among bay segments, the percentage of months exceeding the monthly median was calculated as well.

The majority of bay segments in Charlotte Harbor had mean response times from 2.0-2.5 months with maximum annual response times of 6-8 months (Figure 3; Table 2). Estero Bay and Dona and Roberts Bays had the shortest mean annual response times which were both approximately 1.5 months. Response times for both of these segments never exceeded 3 months. In contrast, mean response time for Upper Lemon Bay was twice that observed in Estero Bay and Dona and Roberts Bay at 3 months. Upper Lemon Bay also had the longest annual response time at 11 months for chlorophyll *a* concentrations to return to levels below the monthly median (Figure 3). This event occurred during the wet season of 1998, which was a year of extremely high rainfall. During this time, chlorophyll *a* concentrations were above the monthly median in Upper Lemon Bay for 17 of 18 months from 1998 to 1999.

Most bay segments had chlorophyll *a* concentrations that exceeded the monthly median during approximately 50% of the months (52-57%). Dona and Roberts Bay has the lowest frequency of exceedances at 44%, while the highest frequency of exceedances was recorded for Lower Lemon Bay (65%) and Estero Bay (68%).

Maximum annual chlorophyll *a* concentrations typically occurred between July and September, with few winter annual maxima. The frequency of these chlorophyll maxima is depicted by month for each bay segment during the 1996-2009 period in Figure 4. It should be noted, however, that maximum chlorophyll *a* concentrations were sometimes found during the winter, as in the tidal Caloosahatchee River, Estero Bay and downstream segments – San Carlos Bay and Pine Island Sound during April-May 2000. Another mid-winter peak in chlorophyll *a* maxima was observed for San Carlos Bay, Estero Bay, Lower Lemon Bay and the tidal Peace River during February-March 2003. Annual peaks in February 1996 were recorded for Estero Bay and for San Carlos Bay in January 1997 and April 1998 and corresponded to years of extremely high rainfall amounts in 1995 and 1997-1998.

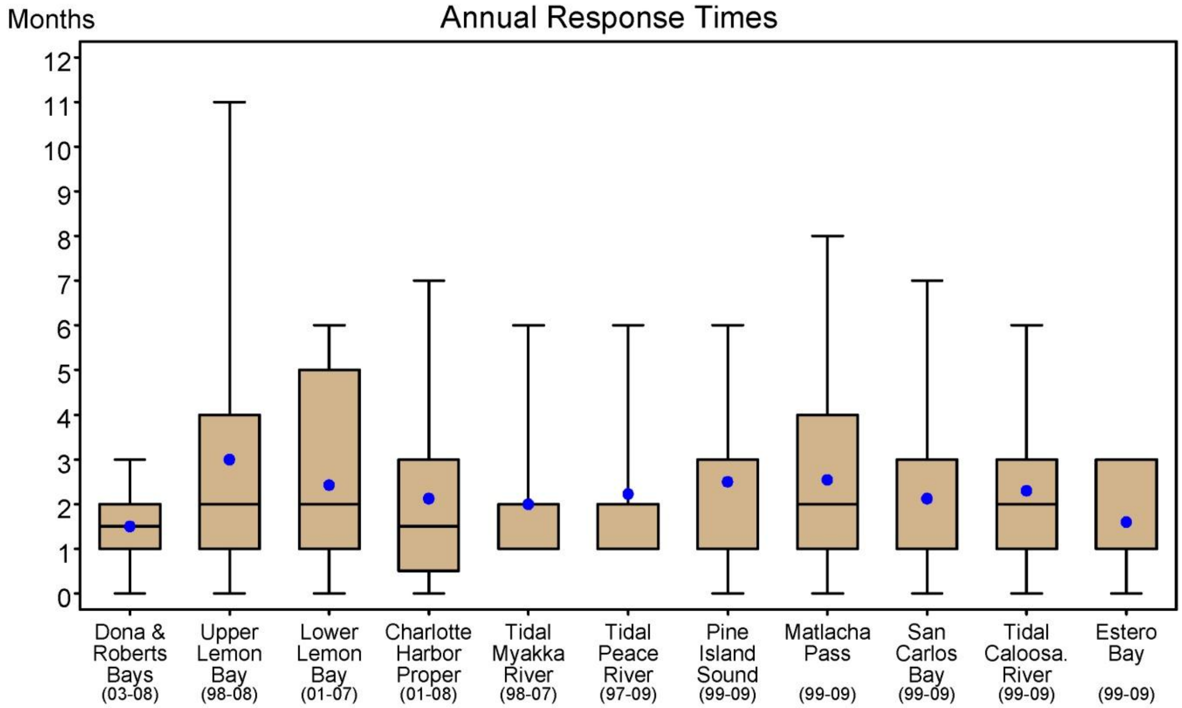

Figure 3. Annual chlorophyll *a* response times (months) for the period 1996-2009.

A long response time, as indicated by the 75th percentile of annual response times, was 4-5 months in Upper and Lower Lemon Bay and Matlacha Pass. Median annual response times were two months in these bay segments and in the Tidal Caloosahatchee River. As observed for Tampa Bay, these response times may be related to water residence time estimates for Charlotte Harbor (Burwell et al, 2000; Myers and Luther, 2008; Janicki Environmental, 2011c).

In general, the duration of the response was independent of the magnitude of the chlorophyll *a* maximum (Figure 5). Only Pine Island Sound, San Carlos Bay and, to some extent, Matlacha Pass and Upper Lemon Bay responded to higher chlorophyll *a* maxima with longer response times.

To summarize, response times were very similar for most bay segments, however, several segments differed from the typically observed response. Dona and Roberts Bays and Estero Bay had the shortest maximum and lowest average response times. Estero Bay, however, exceeded the monthly median chlorophyll *a* concentration more frequently than any other segment, while Dona and Roberts Bays had the lowest frequency of exceedances during the period of record. Estero Bay and San Carlos Bay were among the few bay segments to have mid-winter chlorophyll *a* maxima during several years. The response time for San Carlos Bay, Pine Island Sound, Matlacha Pass and Upper Lemon Bay appeared to be related to the magnitude of the chlorophyll *a* maximum with higher chlorophyll peaks inducing a longer response time. Upper Lemon Bay had the longest maximum and highest mean response time. While the mean and maximum response times for Lower Lemon Bay were very similar to the majority of the other bay segments, Lower Lemon Bay had a greater frequency of longer response times and one of the highest frequencies of exceeding the monthly median.

Table 2. Distribution of response times (months) following annual maximum chlorophyll *a*.

Percentile	Dona/ Roberts Bays	Upper Lemon Bay	Lower Lemon Bay	Charlotte Harbor Proper	Tidal Myakka River	Tidal Peace River	Pine Island Sound	Matlacha Pass	San Carlos Bay	Tidal Caloosa-hatchee	Estero Bay
100	3	11	6	7	6	6	6	8	7	6	3
99	3	11	6	7	6	6	6	8	7	6	3
95	3	11	6	7	6	6	6	8	7	6	3
90	3	11	6	7	6	6	6	8	7	6	3
75	2	4	5	3	2	2	3	4	3	3	3
50	1.5	2	2	1.5	1	2	3	2	1	2	1
25	1	1	1	0.5	1	1	1	1	1	1	1
10	0	0	0	0	1	1	0.5	1	0	0.5	0.5
5	0	0	0	0	1	1	0	0	0	0	0
1	0	0	0	0	1	1	0	0	0	0	0
0	0	0	0	0	1	1	0	0	0	0	0
Mean	1.5	3	2.4	2.1	2	2.2	2.5	2.5	2.1	2.3	1.6

2.3 Recommendations for Potential Methods to Account for Unusual Events

EPA encouraged input on potential methods to account for non-anthropogenic events that can significantly affect the nutrient and chlorophyll *a* concentrations in Charlotte Harbor, including the effects of hurricanes or other unusually high rainfall events, such as El Niño. It was not possible to assess how quickly some of the bay segments recovered following the 1997-1998 El Niño period. This is because some of the bay segments were not sampled during this period and most of those that were sampled then were only sampled quarterly rather than monthly. For those segments with adequate data during this time period, it was determined that response times were highly variable from 1 month to 2 years. The bay responded very clearly, however, to the passage of Hurricane Charley in August 2004, with 8 of the 11 bay segments reaching chlorophyll maxima during August and 2 of the remaining 3 reaching their peak the following month. Most of the bay segments recovered within 1-4 months of the event, which was less than or equal to the mean response time for some of the segments. The observed response was relatively rapid for most bay segments considering that the response time to this unusual loading event was only 1 month longer than the majority (75% percentile) of all recorded response times and in some cases was even shorter. Several bay segments, however, exhibited prolonged response times ranging from 10-22 months. A better understanding of the causes of the observed variation in response times (e.g., bay circulation, land-use patterns), as well as further assessment of the bay's response to future loading events are necessary to determine if the observed response times to Hurricane Charley are consistent within a bay segment.

It is recommended that the observed response times to unusual loading events in the future be considered when evaluating compliance with the proposed numeric nutrient criteria. This approach would be consistent with the identification of anomalous events in the assessment process utilized by the Tampa Bay Nitrogen Management Consortium for the Tampa Bay estuary to report compliance with the FDEP RA determination and the EPA TMDL. In Tampa Bay, the Tampa Bay Estuary Program process initially identifies any chlorophyll *a* concentration and/or water clarity exceedances, then evaluates the severity of these exceedances, and responds accordingly. One example of this process has been the development and completion of several studies investigating the unexplained exceedance of chlorophyll *a* thresholds in Old Tampa Bay in 2004 and 2005, when the rest of the bay was meeting thresholds. A series of studies examining the potential causes of these exceedances was completed and a nutrient management plan specific to Old Tampa Bay was planned for development from these assessments. Similar management responses could be applied to the Charlotte Harbor estuary and should be included in the compliance assessment for Charlotte Harbor numeric nutrient criteria.

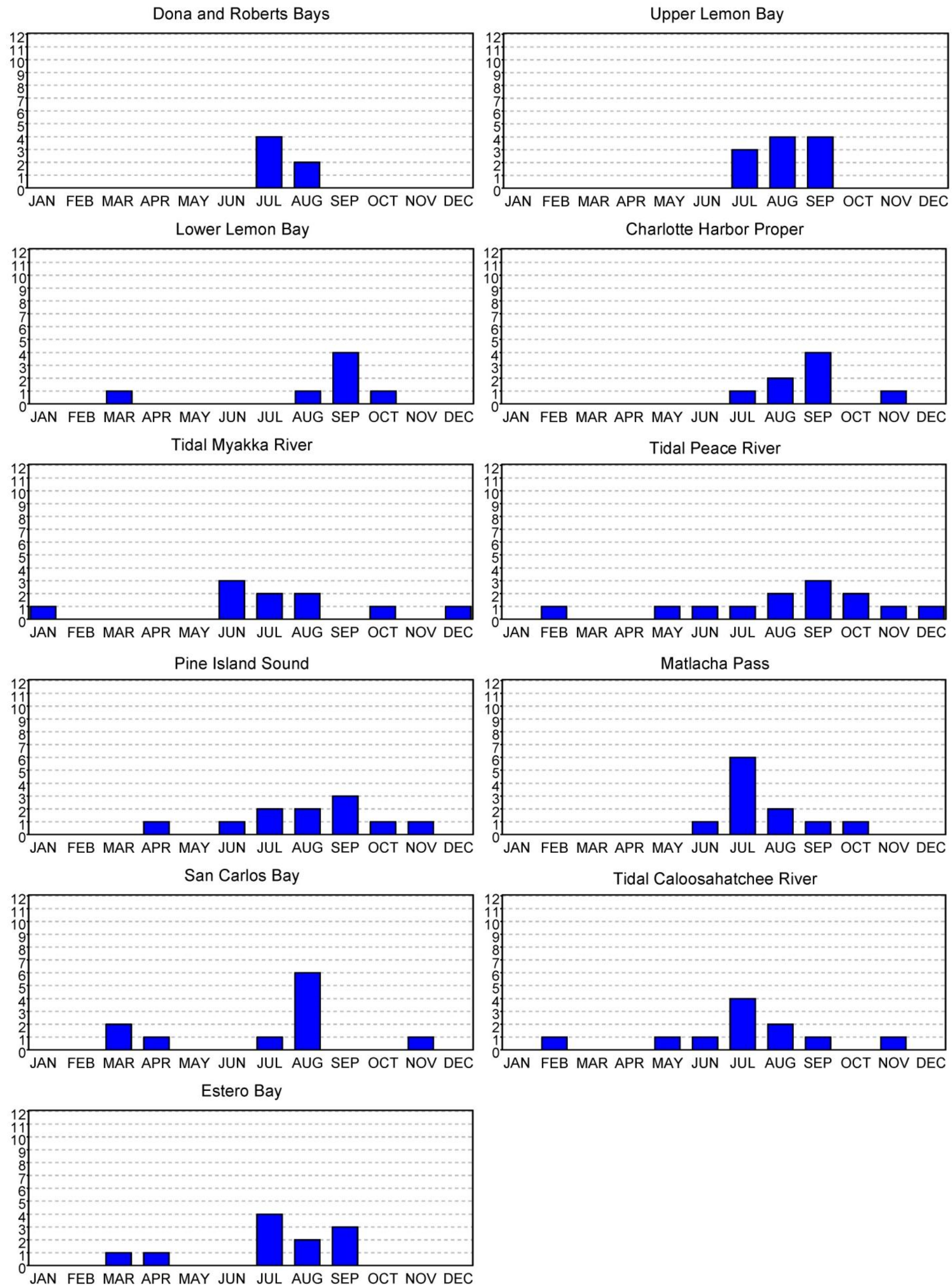

Figure 4. Number of occurrences within each month of maximum chlorophyll *a* for the year, 1996-2009.

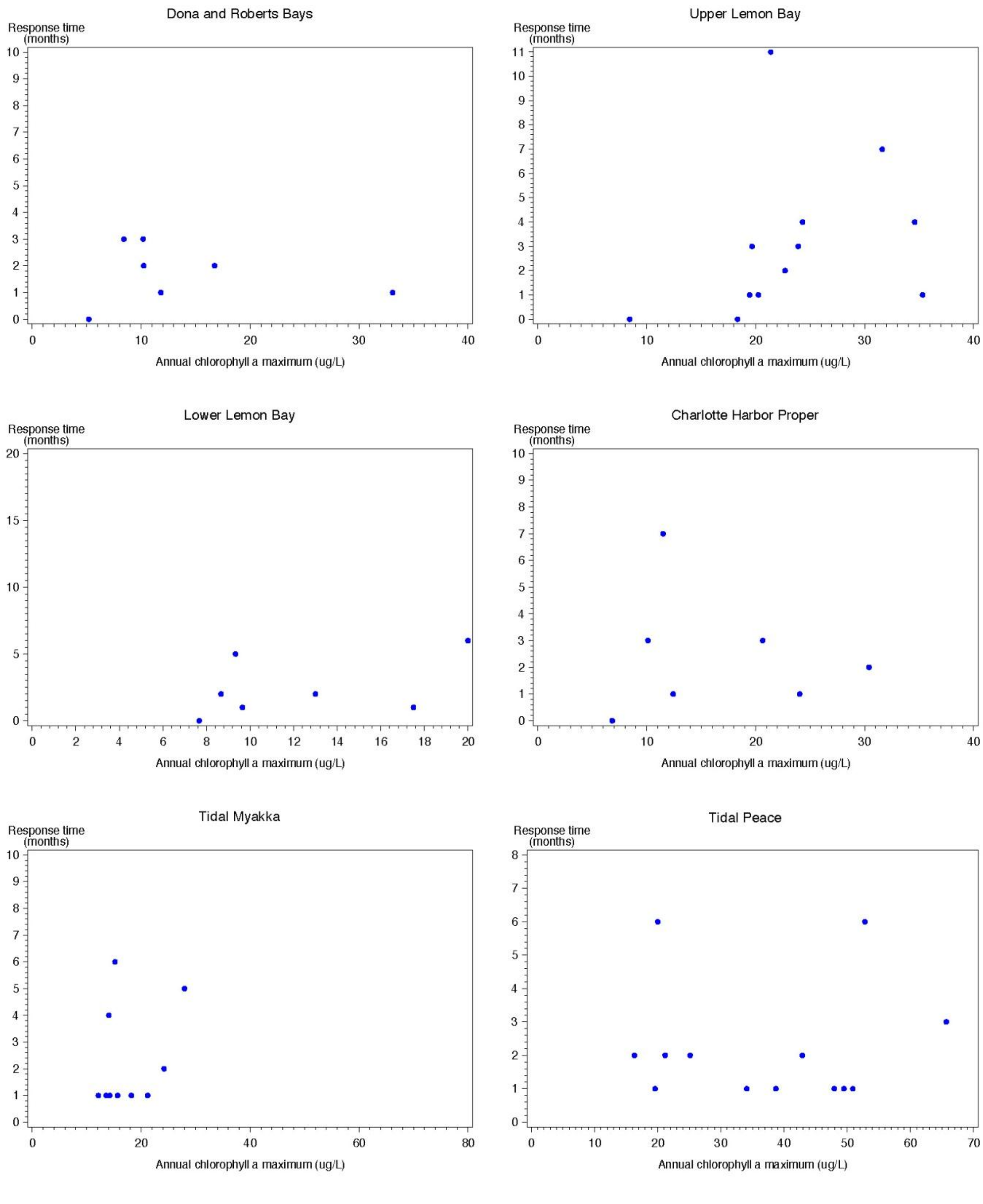

Figure 5. Relationship between annual chlorophyll *a* maxima and response time.

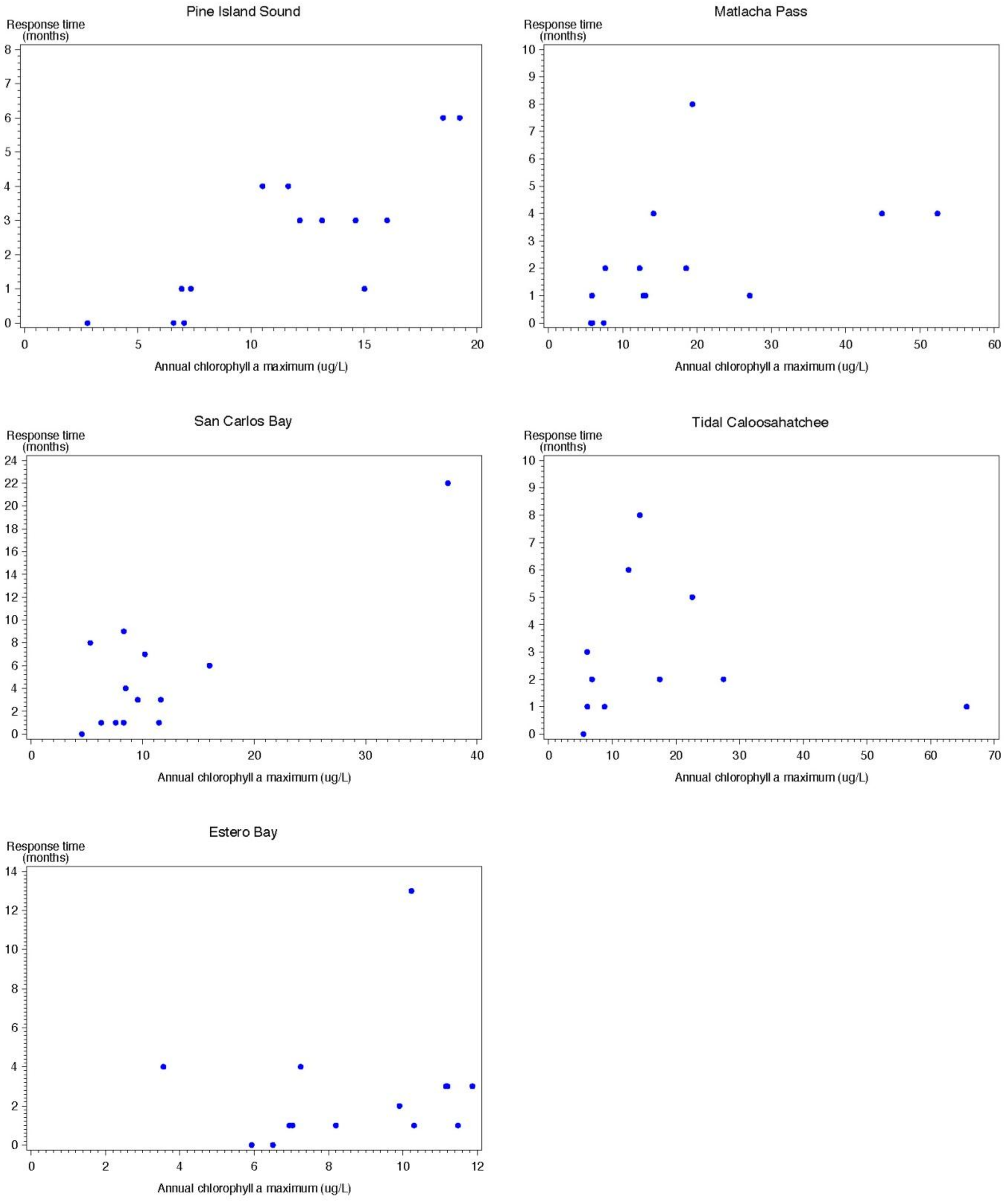

Figure 5 (cont). Relationship between annual chlorophyll *a* maxima and response time.

3.0 EVALUATION OF COMPLIANCE ASSESSMENT PERIOD LENGTH

The implementation of the Florida numeric nutrient criteria proposed by EPA will require the definition of an implementation and assessment cycle. Consideration of the potential ramifications of an assessment that is either too lenient (i.e., does not capture anthropogenic influences resulting in an exceedance) or too stringent (i.e., inappropriately identifies natural variability as an anthropogenic induced exceedance) is a critical element of the evaluation of alternative assessment cycles.

Both EPA and FDEP are considering allowances of criteria exceedance due to natural variability. The proposed methods for establishing an assessment cycle in Florida estuaries (EPA, 2010) identified a 3 year and 5 year assessment cycles as potential alternatives. EPA's proposal incorporates a "1 in 3" rule to allow one exceedance in a three-year assessment cycle to account for natural variability. The FDEP currently uses a 5-year assessment cycle for evaluation of impairment in waterbodies, as well as NPDES, MS4, and other regulatory permitting cycles. FDEP is considering a "2 in 5" rule to allow 2 exceedances in 5 years as an allowance for natural variability (FDEP, 2010). Therefore, if based on annual statistics, exceedances would occur when exceedances were at least 2/3 years (67%) or 3/5 years (60%), respectively.

Southwest Florida is periodically subjected to meteorological anomalies which result in deviations from expected rainfall and stream flow patterns. Non- anthropogenic catastrophic events have occurred in the Charlotte Harbor watershed, most recently in the exceptional year of 2004 when 4 hurricanes made landfall in the south Florida peninsula. The resulting changes in ecology and biogeochemistry following this event are reported in a special issue of Estuaries and Coasts (2006). Further, southwest Florida is subjected to periodic but persistent weather anomalies including droughts and floods. These patterns are influenced by broader variations in meteorological conditions including the El Niño Southern Oscillation (ENSO) and more locally, the Atlantic Multidecadal Oscillation. These are also strong drivers of weather patterns and resulting stream flows in southwest Florida (Kelly and Gore, 2008). The temporal persistence of ENSO is highly variable (i.e., between 2-7 years) and the magnitude and duration of the effects are dependent in large part on the gradient in atmospheric pressure differences between the eastern equatorial Pacific and Indo–Australian areas (Glantz et al., 1991). El Niño/Southern Oscillation (ENSO) is the most important coupled ocean-atmosphere phenomenon to cause global climate variability on interannual time scales (Wolter and Timlin, 1993). El Niño is indicated by a suppression of the upwelling of cold nutrient rich Pacific waters and tends to result in colder winter temperatures and wetter rainfall patterns in general. Ropelewski and Halpert (1986) studied North American precipitation and temperature patterns associated with ENSO conditions. In the southeastern United States and northern Mexico they reported above-normal precipitation recorded for 81% of the El Niño cases for the "season" that began in October of the ENSO year and concluded in March of the following year. For temperature anomalies during El Niño, the southeastern United States showed below-normal temperatures around 80% of the time. Clearly these conditions may persist across calendar years.

Hurricane activity is generally depressed during El Niño in the Atlantic Ocean while the La Niña is associated with an increased frequency of hurricanes and tropical systems. La Niña is typically triggered by a reversal of the southern oscillation and tends to result in warmer and drier conditions in southwest Florida. Recent evidence for the correlation of ENSO cycles and weather patterns include the strongest El Niño on record during late 1997 through early 1998 resulting in very wet winter conditions in southwest Florida, followed by severe drought conditions associated with the La Niña of 1999-2001 and a return of wet conditions associated with the El Niño in late 2002-2003. While much is still to learn about the direct correspondence between ENSO and weather patterns in southwest Florida on shorter temporal scales, the resulting natural variability in rainfall and stream flow associated with these events has profound effects on estuarine dynamics, influencing residence times, salinities, temperatures, nutrient delivery, and estuarine response.

The objective of this investigation was to examine the effects of these different temporal assessment schemes on the likelihood of concluding that a waterbody was in exceedance based solely on natural meteorological variability. That is, the analysis is designed to characterize natural variability in meteorological conditions, classify "anomalies" as meteorological conditions that deviate substantially in terms of magnitude and duration from long term average conditions, and test which rule is more likely to conclude that an excursion has occurred based solely on these anomalies. In Tampa Bay, analysis has demonstrated that water quality conditions are affected by rainfall and streamflow anomalies and that the estuary is resilient in response to these acute anomalies, returning to conditions fully supporting designated uses once meteorological conditions return to more typical conditions (e.g. Morrison et al., 2006, Sherwood, 2010). While the Charlotte Harbor estuaries monitored by the Charlotte Harbor Water Quality Monitoring Program (CCHMN) do not generally have the same duration of routine water quality collection, there is every reason to suspect that the same drivers affect these estuaries.

3.1 Conceptual Model

This investigation is based on a conceptual model expressed by the EPA that the regulatory compliance assessment cycle should allow for natural disturbance patterns resulting from episodic events in Florida. These events could include hurricanes and

ENSO-related droughts and floods that influence water quality independent of anthropogenic effects. Ideally, the natural variability would be absorbed within the assessment cycle while maintaining sensitivity to reporting exceedances due to anthropogenic impacts. Therefore, this investigation is intended to provide insights on the temporal assessment scale that best incorporates natural variability and is less likely to result in exceedance because of natural variability due to natural deviations from expected rainfall and stream flow conditions. There were two components of the analysis for this assessment:

- First, a method was derived to characterize individual calendar years based on deviations in rainfall from long term monthly averages and a test was conducted to determine which of the two assessment cycles described above was more likely to report violations due solely to deviations from expected rainfall patterns.

- Second, the same method was applied to the Multivariate ENSO Index (MEI) to assess the effects of the assessment cycle on a widely used index of broad scale climatological variability.

Many of the tidal tributaries in the Charlotte Harbor watershed with long term records (50 years) have had significant alterations to their natural flow patterns due to in-line water control structures (e.g. Myakka River and Caloosahatchee River). The Peace River does not have a significant control structure on its main stem and was therefore chosen for this analysis despite evidence of a long term declining trend in streamflow. To account for this long term trend, the timeseries was first detrended as described in the following methods section. Though additional local streamflow data would have been preferable, rainfall data and the MEI index data were used to make inferences of the potential ramifications of the assessment cycle on misclassifying natural variability as an anthropogenic event.

3.2 Methods

Three datasets were chosen for this evaluation.

- The Peace River gage at Arcadia (USGS 02296750) between 1931-2010 was used to assess natural variability in long term trends in streamflow.

- Long term rainfall records for the National Weather Service located at Venice Airport (1948 – 2009) were used to assess long term variability in rainfall.

- Bimonthly index values of the Multivariate ENSO Index calculated by Klaus Wolter of the National Oceanic and Atmospheric Administration (see Wolter and Timlin, 1993).

The first two datasets were used to calculate an index representing wet, dry, and normal years. To accomplish this, monthly average streamflow and cumulative monthly rainfalls were log transformed, and subtracted from the long-term monthly average over the entire period of record. This difference was then divided by the standard deviation of the long-term monthly average to derive an index representing deviations in monthly averages from the long-term monthly mean as described by the equation below.

$$\text{Standardized rain} = \frac{\mathrm{X} - \mu_{\mathrm{x}}}{\sigma_{\mathrm{x}}}$$

where:
X = Log transformed monthly rainfall value
μ_{x} = Long term monthly average of log-transformed values
σ_{x} = Standard deviation of long-term monthly average

To detrend the Peace River streamflow gage, a simple timeseries trend estimate was calculated using regression on the log scale monthly averages and the slope (i.e., 0.0057769) was added to the timeseries prior to calculating the deviations from expected conditions. For the Venice rainfall gage, there was a short time period within the period of record where no data were available. In this case the long term average value was substituted into the timeseries to maintain a continuous record. Cutoff values (events) and exceedance frequencies (durations) were then assigned to classify years as “Wet”, “Dry”, or “Average” based on these “standardized” flows. Common drought indices, such as the Palmer Drought Severity Index (Palmer, 1965), have been developed in a similar fashion to the approach used in this investigation.

The following ad hoc steps were taken to classify years: Each month was assigned a monthly score based on deviations from expected averages. A value of 1 indicates that the monthly value is greater than 0.5 std’s above the long term average. A value of -1 indicates that the monthly value is less than 0.5 std’s below the long term monthly average. Otherwise the monthly score is assigned a zero.

- Wet years were classified when the cumulative monthly score was at least 4 in a particular year.

- Dry years were classified when the cumulative monthly score was at least -4 in a particular year.

The annual rainfall classifications were then assigned an annual score and assessed separately for wet years and dry years. For example, each annual classification is either a 1 or 0 for the wet year based on the scoring above. The annual scores then are either 1 or 0 (i.e. wet or not wet). These scores are summed for each compliance period such that a score of 2 or more indicates an excursion for the 1 in 3 rule while an annual score of 3 or more indicates an excursion for the 2 in 5 rule. Only years when both rules had a full suite of years available were used to compare the rules.

The Multivariate ENSO Index calculated by Klaus Wolter of the National Oceanic and Atmospheric Administration (see Wolter and Timlin, 1993) is based on the six main observed variables over the tropical Pacific. These six variables are: sea-level pressure (P), zonal (U) and meridional (V) components of the surface wind, sea surface temperature (S), surface air temperature (A), and total cloudiness fraction of the sky (C). This dataset consists of MEI index values which are already standardized as described above for the streamflow and rainfall data. The index values represent deviation from expected conditions of the index when the ENSO cycle is neutral. Positive values indicate El Niño conditions while negative values indicate La Niña conditions. This dataset was used exactly as described above for rainfall to classify years as anomalous indicating anomalies that would potentially affect water quality in the CHNEP study area though the exact correspondence of the MEI and localized variability in climate is not fully understood.

3.3 Results

Natural variability in detrended streamflow measured at the Peace River gage is shown in Figure 6. Deviations above and below the horizontal lines indicate conditions classified as monthly anomalies based on our index. Noticeable is the recent severe drought of 2000-2001 and the above average streamflow of 2003-2004 concluding with the passage of 4 hurricanes in 2004. A graphic displaying the resulting scores of the wet year and dry year assessment for Peace River streamflow is provided in Figure 7. There were 9 cases over the time period where the 1 in 3 rule would be exceeded based on assessment of flood years; however, using the 2 in 5 rule only one exceedance would have been erroneously reported over the same time period. For drought years, 15 violations would have been reported using the 1 in 3 while 10 exceedances would have been recorded under the 2 in 5 rule.

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For the Venice Rain gage (Figure 8) a high degree of variability in monthly rainfall across years resulted in large standard deviations which in turn resulted in categorization of fewer anomalies. Generally there were few multi-year anomalies in the rainfall evaluation for either the wet or dry evaluation compared to the Peace River analysis. Compliance assessment for the Venice rain gage (Figure 9) suggested an equivalent number of exceedances due to natural variability in rainfall in both wet and dry years. The lack of differentiation between the assessment cycles is likely due in part to the highly variable nature of rainfall at individual rainfall gages within the watershed that resulted in a reduction in the cumulative frequency of anomalous conditions within a year to classify that year as an anomaly. Similar analysis in other estuaries indicates that stream flow seemingly integrates out the short term variability in rainfall to more accurately characterize anomalies on annual time scales used for the assessment. To this end, the ENSO data described above was used as a general test of the compliance assessment length.

Compliance assessment using the ENSO MEI data suggested that both El Niño and La Niña events were more likely to trigger an exceedance using the 3 year assessment cycle with more than twice the number of exceedances during La Niña but only slightly more for El Niño years (Figure 10; Table 3).

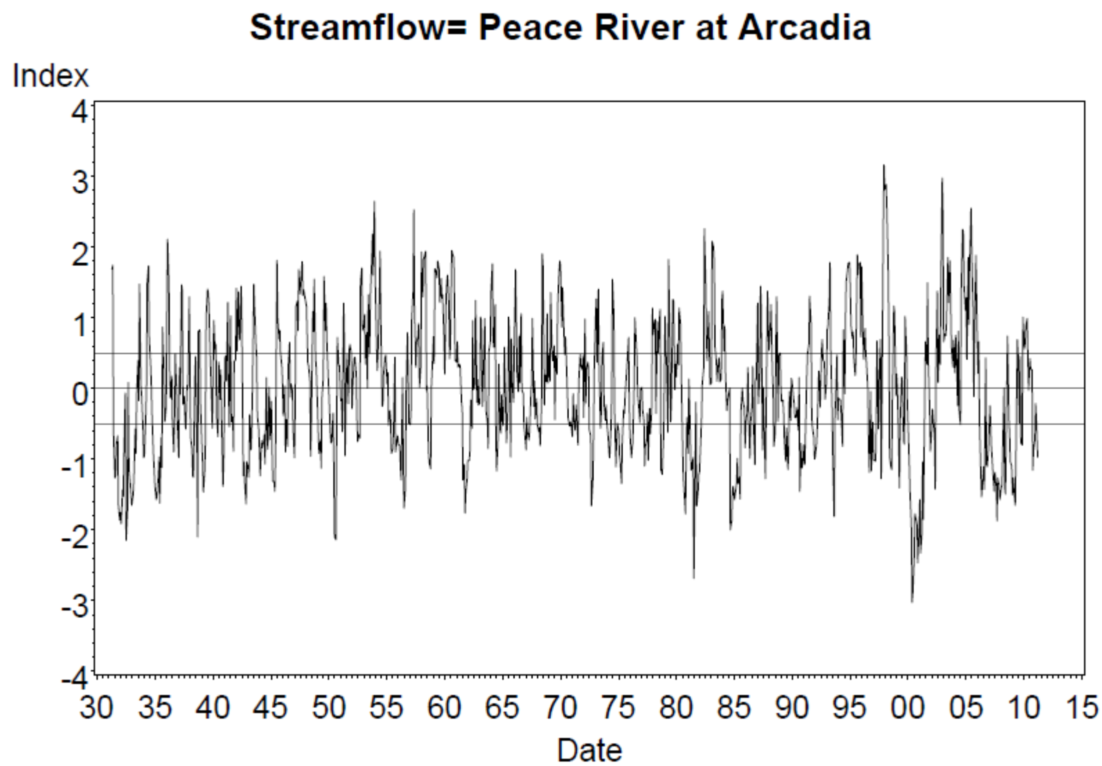

Figure 6. Peace River at Arcadia streamflow (USGS 02296750) index based on natural log transformed, detrended data and long term monthly values.

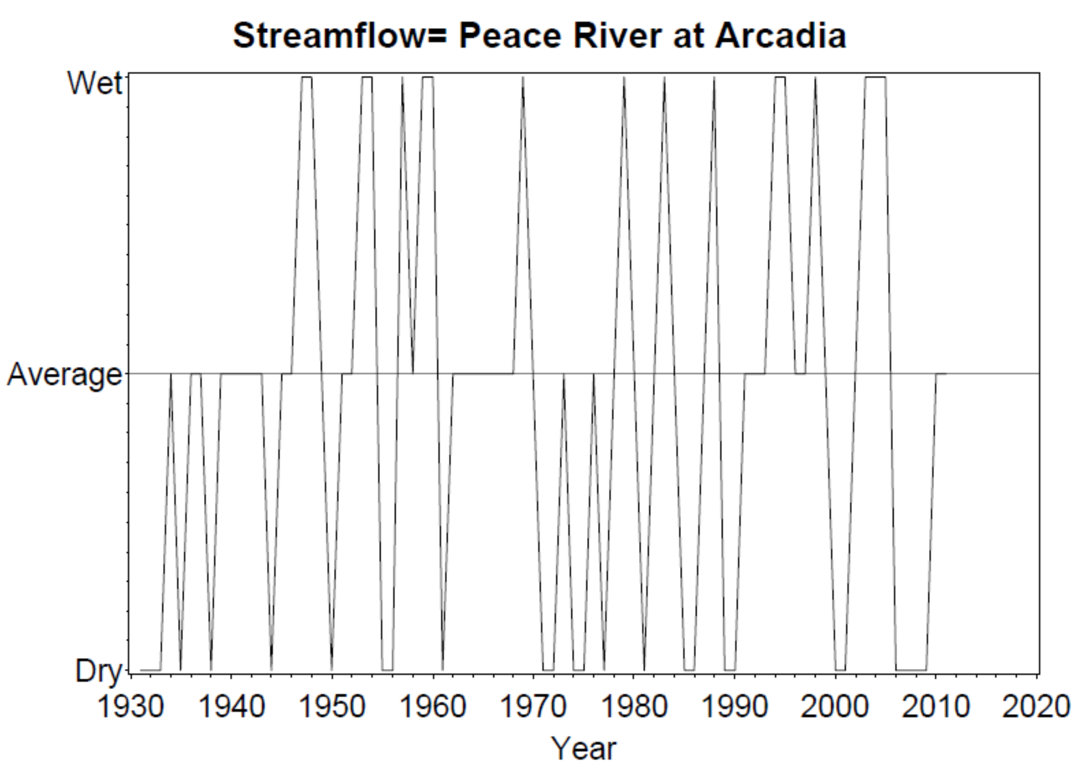

Figure 7. Classification of annual Peace River streamflow anomalies.

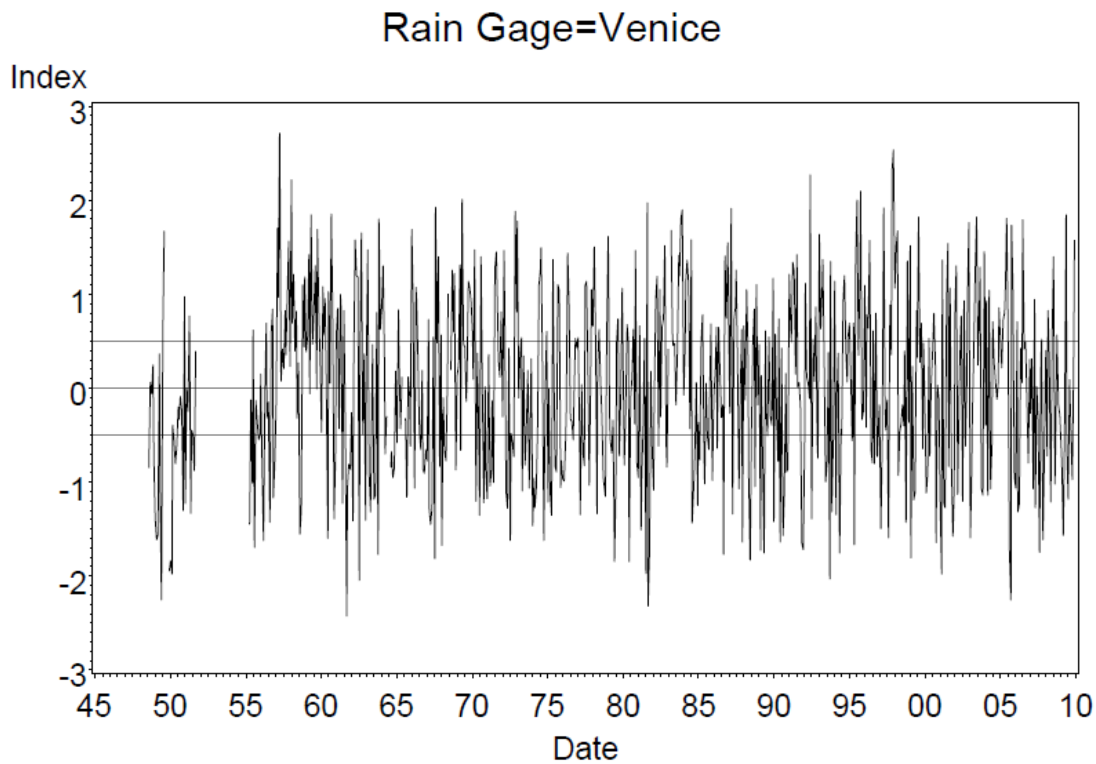

Figure 8. Timeseries of monthly rainfall values at Venice Airport standardized index based on natural log transformed data and long term monthly values.

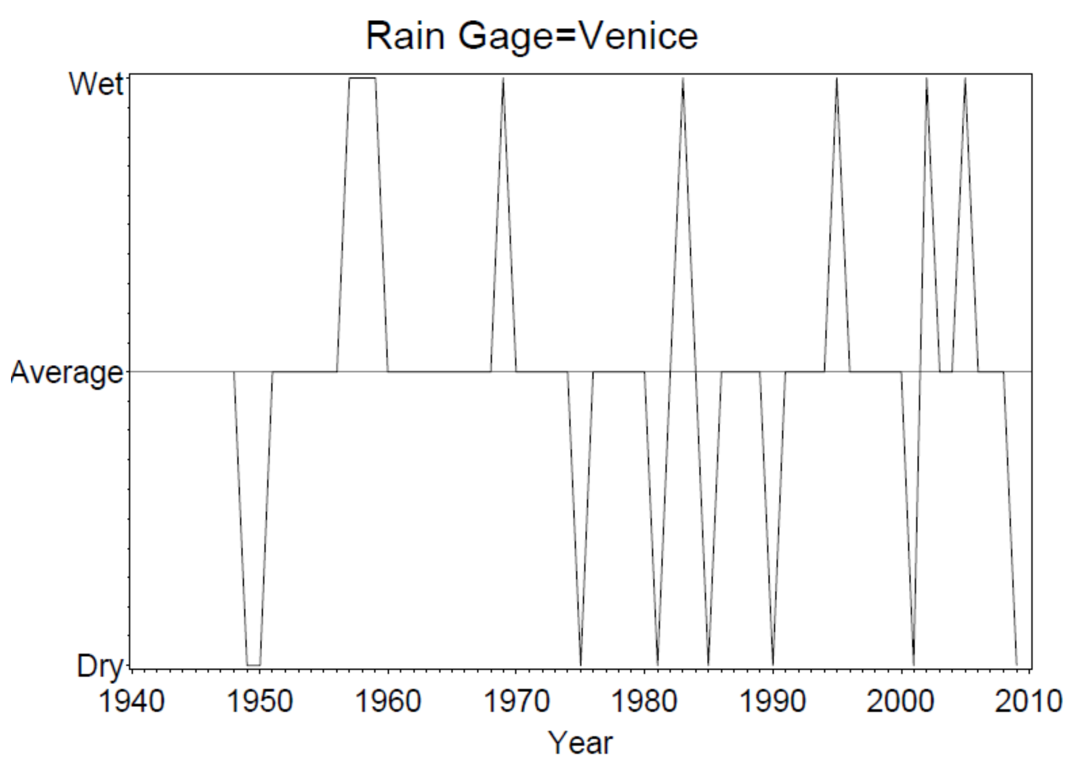

Figure 9. Results of annual classification of rainfall data anomalies for the Venice rain gage.

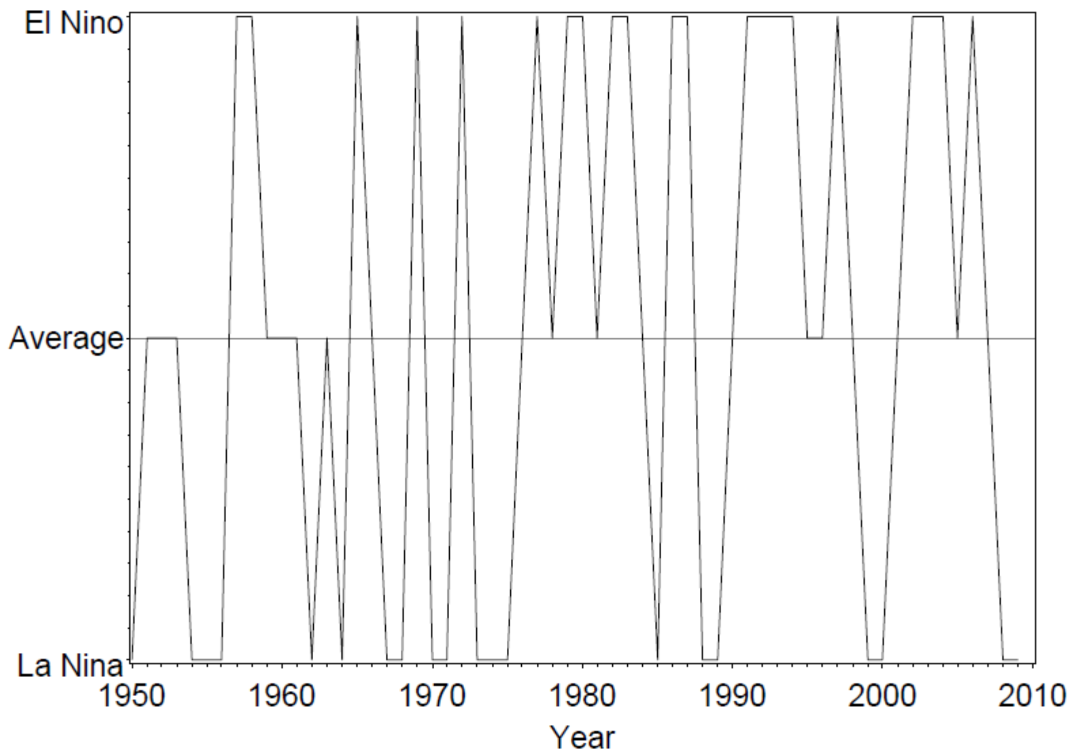

Figure 10. Results of annual classification of ENSO MEI data anomalies 1950-2008.

Table 3. Assessment of compliance length for MEI data under the 3 year and 5 year rule.

			5-Year Rule		
ENSO MEI			Compliant	Exceedance	Total
La Niña	3-Year Rule	Compliant	44	2	46
		Exceedance	8	2	10
		Total	52	4	56
El Niño	3-Year Rule	Compliant	38	3	41
		Exceedance	6	9	15
		Total	44	12	56

3.4 Recommendation

This investigation characterized natural variability in hydrologic conditions within the CHNEP estuary watersheds using long-term streamflow and rainfall records collected since the 1930s as well as a broad scale indicator of natural variability in meteorological conditions associated with the MEI. These estimates of natural variability were then used to test two potential temporal assessment schemes with respect to their ability to account for natural variability and identify exceedances related to anthropogenic activities.

Since the objective of the rule is to account for exceedances due to natural environmental variability, this analysis suggests natural variation in meteorological conditions can last more than a single year and therefore the "2 in 5" rule is more likely to absorb natural variability than the "1 in 3" rule. Based on these analyses, the "1 in 3" rule would result in more exceedances due to natural variability alone and, therefore, be overly sensitive to this variability compared to the "2 in 5" rule. Ideally, natural variability would be accounted for within the criterion development process. In cases where this variability is not accounted for in the criterion development process, this analysis suggested that the "2 in 5" rule may be more robust with respect to minimizing the chances of declaring exceedances due to natural variability.

4.0 IMPLEMENTATION OF CHARLOTTE HARBOR ESTUARINE NUMERIC NUTRIENT CRITERIA: ASSESSMENT AND MONITORING

It is recommended that the assessment of compliance with the proposed numeric nutrient criteria (Janicki Environmental, 2011a) be performed in a manner similar to that which has been proposed by the Tampa Bay Estuary Program for compliance with both the Tampa Bay Reasonable Assurance and TMDL (TBEP and Janicki Environmental, 2010). The goal of the estuarine numeric nutrient criteria is to provide full aquatic life support within the estuary. The CHNEP has determined that seagrasses are important indicators of desirable conditions in the Charlotte Harbor system and has defined the water quality conditions (i.e., chlorophyll *a* concentrations) that allow for the maintenance and growth of seagrass beds in the estuarine system. Therefore, the CHNEP bases its compliance assessment on the comparison of both observed chlorophyll *a* concentrations and seagrass extent to the goals that have been established, as does the TBEP.

In Tampa Bay, the TBEP has been utilizing an annual assessment strategy to track conditions in Tampa Bay with respect to chlorophyll *a* (Janicki et al., 2000). The strategy utilizes data collected at numerous stations within the bay on a monthly basis. Conditions are assessed with respect to the FDEP-approved chlorophyll *a* thresholds on an annual basis.

In the Charlotte Harbor National Estuary Program region, monthly water quality monitoring at fixed monitoring sites has been underway since the mid to late 1990s for all bay segments. These data were used in the development of water quality targets for the CHNEP, and the TN and TP loading and concentration based criteria (Janicki Environmental, 2011a) were developed using data collected from the same series of sampling stations. It is recommended that a similar procedure to that employed by the TBEP for compliance assessment of TN and TP concentration criteria be used in the CHNEP, using the same data sources and an annual assessment of compliance.

Chlorophyll *a* is the primary response variable that is most closely related to variations in nutrient conditions and is a major determinant of the growth and maintenance of seagrasses. Therefore, the recommended initial step in the compliance assessment is evaluation of the annual average chlorophyll *a* concentrations within each segment for a given year. Chlorophyll *a* threshold exceedances in two consecutive years do not in themselves indicate non-compliance of numeric nutrient criteria, as nutrient criteria compliance would still be determined by the “2-in-5 year” rule. Recognition of the fact that single anomalous events, such as the 1997-1998 El Niño, can result in two consecutive years of chlorophyll *a* exceedances is critical.

Concurrently, the annual TN and TP concentrations should be compared to the proposed criteria. While exceedances of either or both the TN and TP criteria may occur, an associated chlorophyll *a* response may be absent. These nutrient exceedances should not be ignored, and non-compliance need not be concluded. Rather, analyses should be revisited in the future to expand on the knowledge of how chlorophyll *a* concentrations respond to changes in nutrient conditions.

The ultimate assessment is the comparison of the seagrass extent to the established seagrass goals. Inconsistent results, for example exceedances in either or both of the chlorophyll *a* threshold or TN or TP criteria while seagrass extents continue to increase should also lead to further analyses of the interrelationships between nutrients, chlorophyll *a* concentrations, and seagrass growth.

5.0 CONCLUSIONS

The following conclusions can be drawn from the results discussed above:

- The annual response time to recover from the maximum monthly chlorophyll *a* concentration during a given year is relatively short. Median annual response times are three months or less in all segments, and average annual response times are typically just over two months in most segments. This indicates that the bay segments recover quickly from normal loading events.

- In general, the duration of the response was independent of the magnitude of the chlorophyll *a* maximum. Several bay segments, however, responded to higher chlorophyll *a* maxima with longer response times.
- Response time to unusual events, such as hurricanes, may only be one month longer than the average response time, but is also spatially variable, with some parts of the estuary recovering within just a few months of the event and other areas requiring a year or longer.
- It is important to consider the effects of natural variability in establishing the compliance assessment scheme.
- Comparison of the two temporal assessment schemes (1-in-3) vs. (2-in-5) suggested that the 2-in-5 rule was less likely to result in a violation due solely to natural variability.

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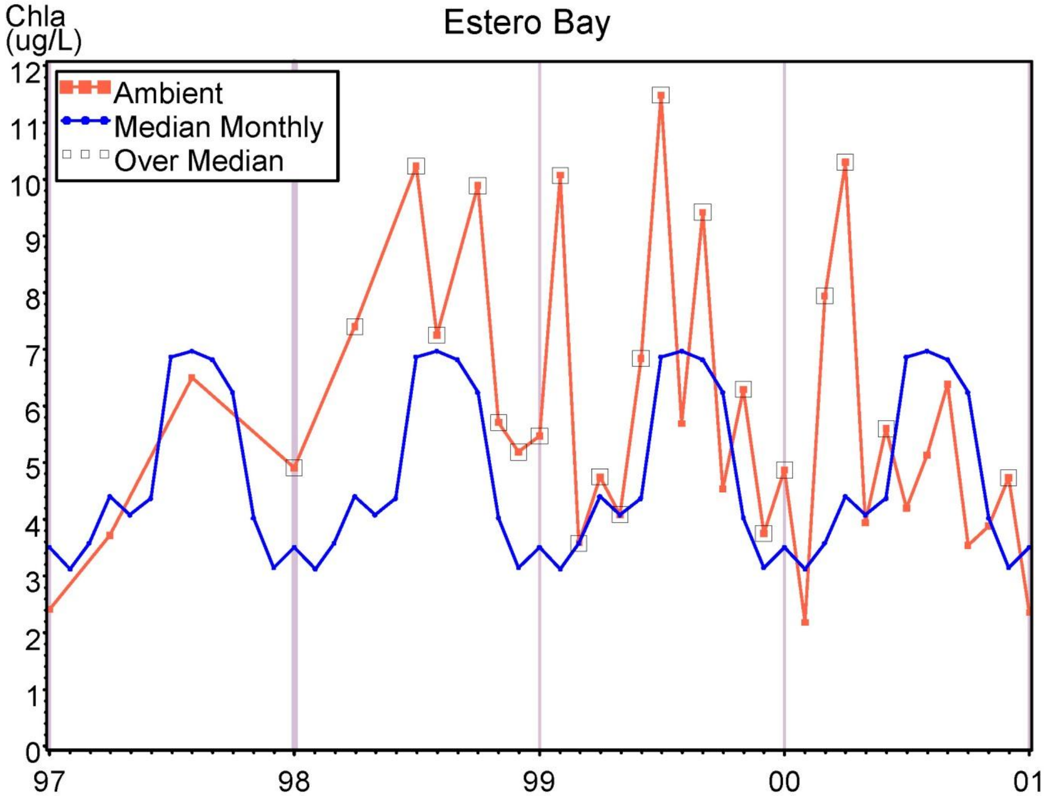
Appendix 1

Chlorophyll statistics

Chlorophyll *a* statistics by Segment.						
Segment	**Source(s)**	**Period of Record**	**Total # of obs**	**Summary of Monthly Means**		
				Mean	**Median**	**Maximum**
Dona and Roberts Bays	Sarasota County	2003 - 2009	367	4.5	3.4	33.1
Upper Lemon Bay	Sarasota County	1998 - 2009	683	8.5	6.4	35.3
Lower Lemon Bay	CCHMN	2001 - 2009	390	6.0	5.3	20.0
Charlotte Harbor Proper	CCHMN,Lee County, PRMRWSA	2001 - 2008	2,729	6.4	4.9	30.4
Tidal Myakka	CCHMN, Sarasota County	1998 - 2009	913	8.3	7.2	27.9
Tidal Peace	CCHMN, PRMRWSA	1997 - 2009	1,087	13.8	11.2	65.7
Pine Island Sound	CCHMN,FIU, Lee County	1996 - 2009	1,212	4.7	3.3	19.2
Matlacha Pass	Cape Coral, FIU, Lee County	1996 - 2009	790	6.0	3.7	52.3
San Carlos Bay	CCHMN,FIU, Lee County, SFWMD	1996 - 2009	1,707	4.7	3.4	37.4
Tidal Caloosahatchee	FIU, Lee County, SFWMD	1999 - 2009	454	5.4	3.4	65.7
Estero Bay	FIU, Lee County	1996 - 2009	1,518	5.1	4.5	11.9

Appendix 2

Event 1: Unusually high rainfall during the 1997-1998 El Niño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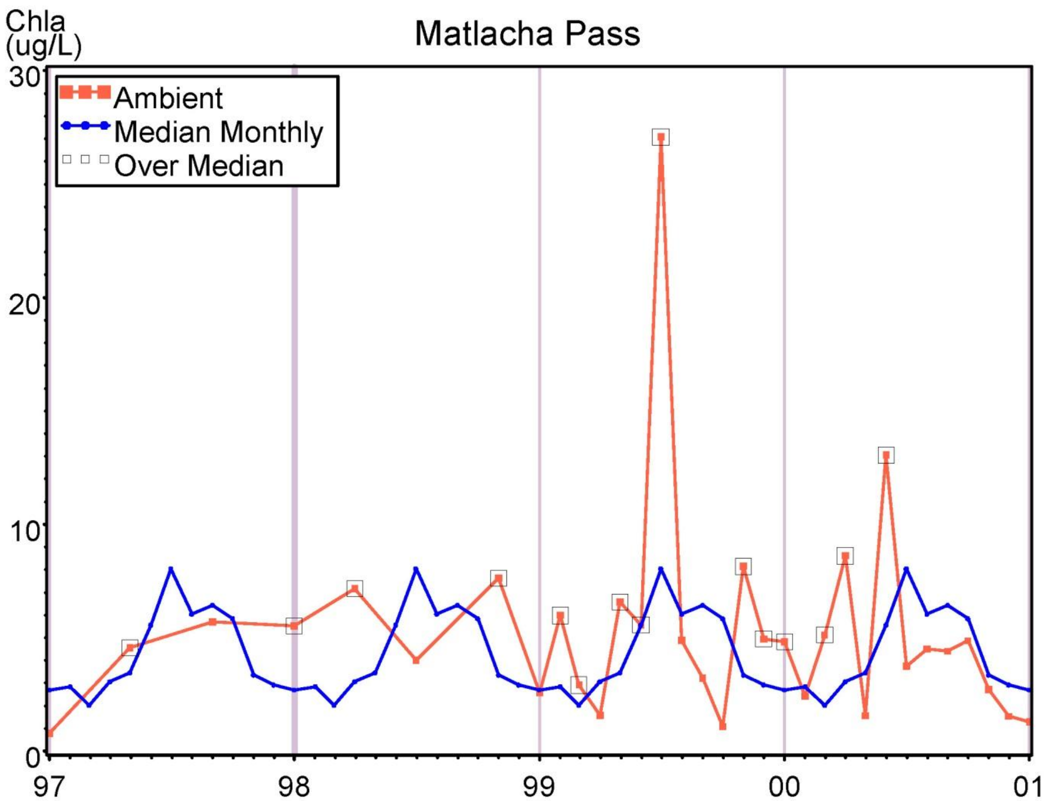
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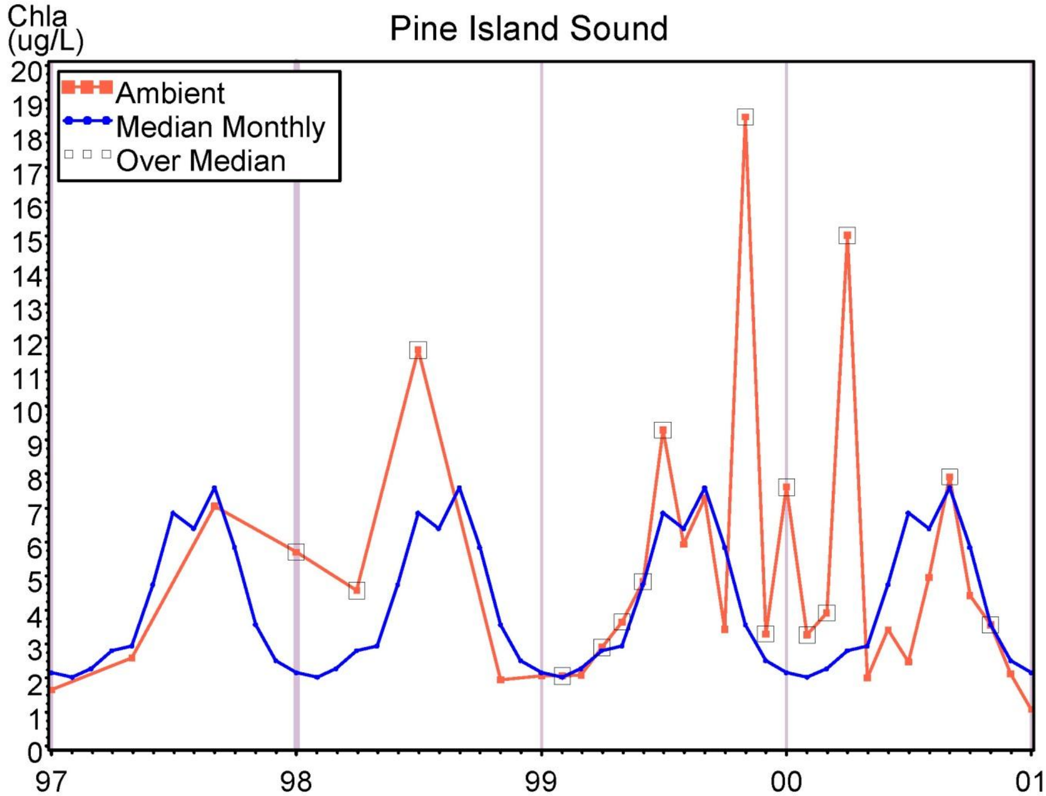
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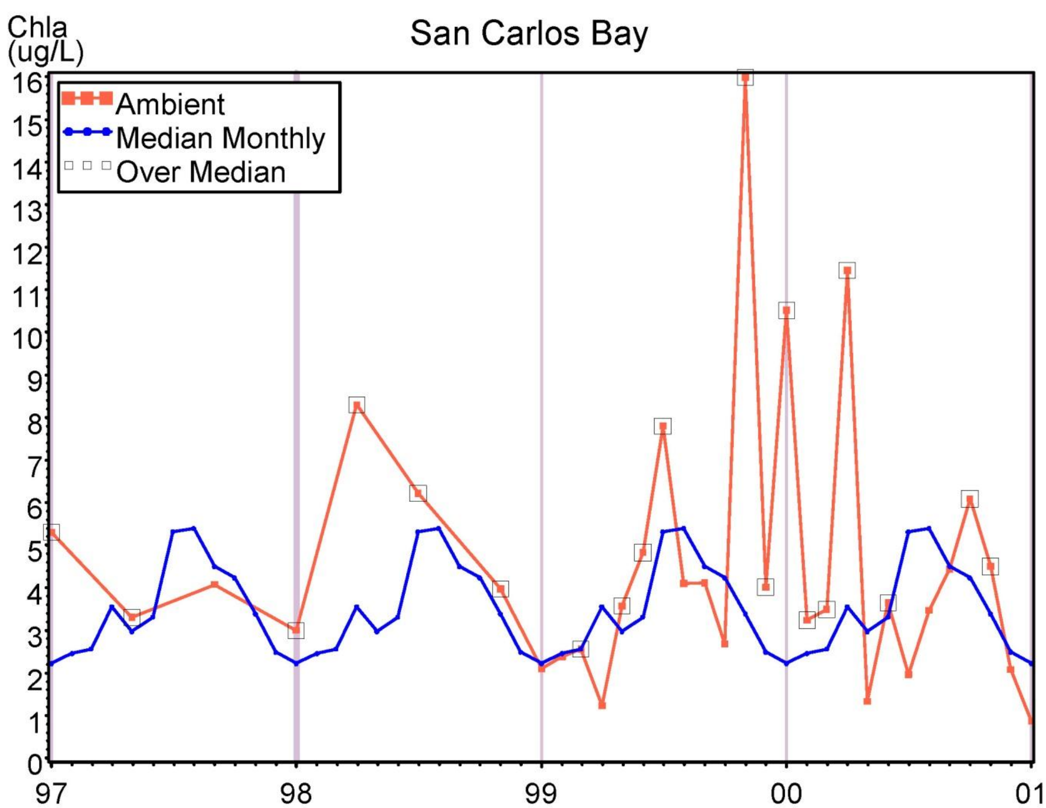
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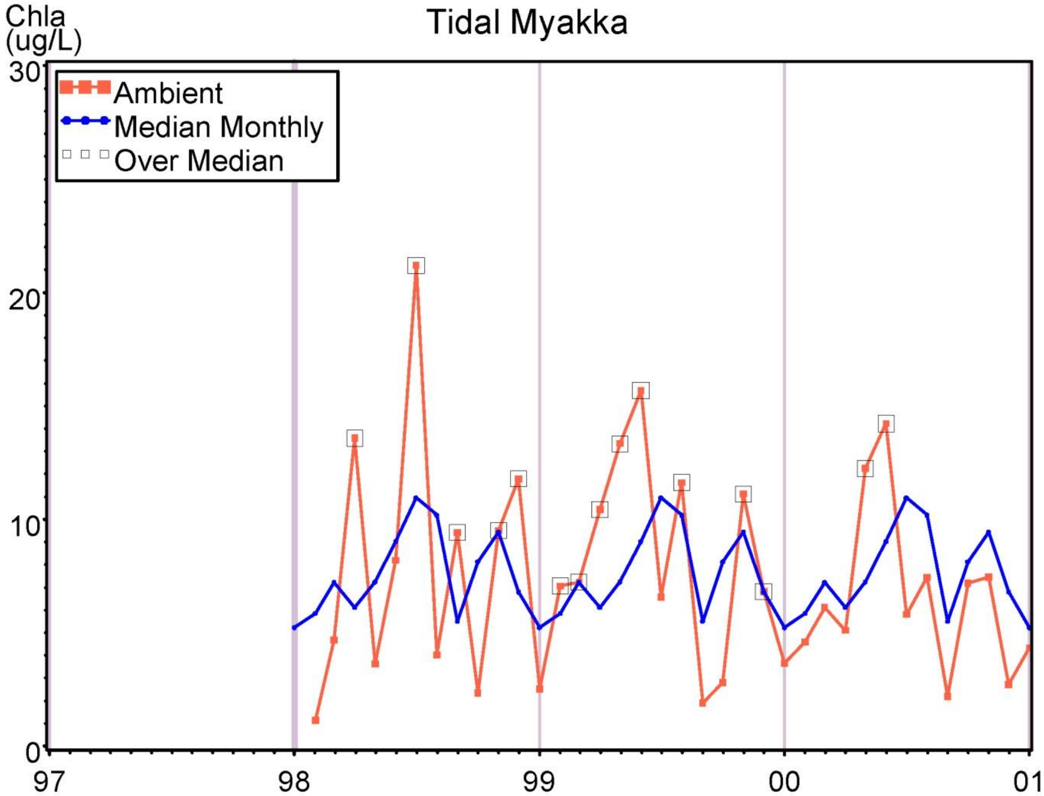
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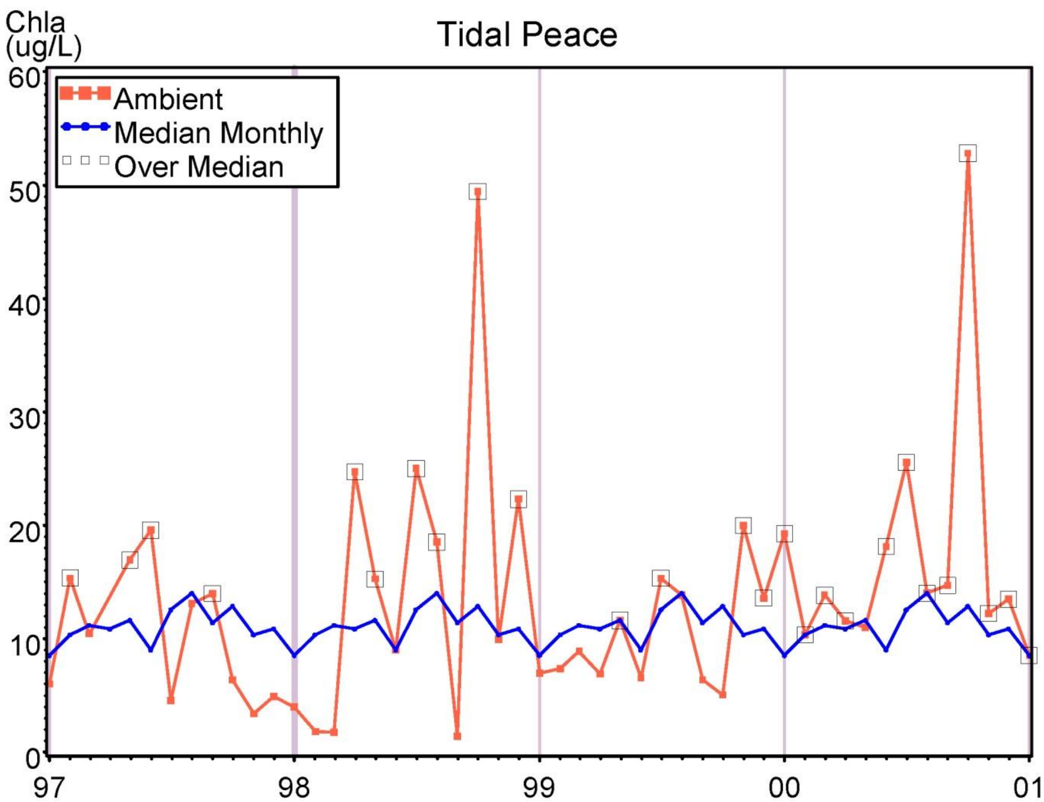
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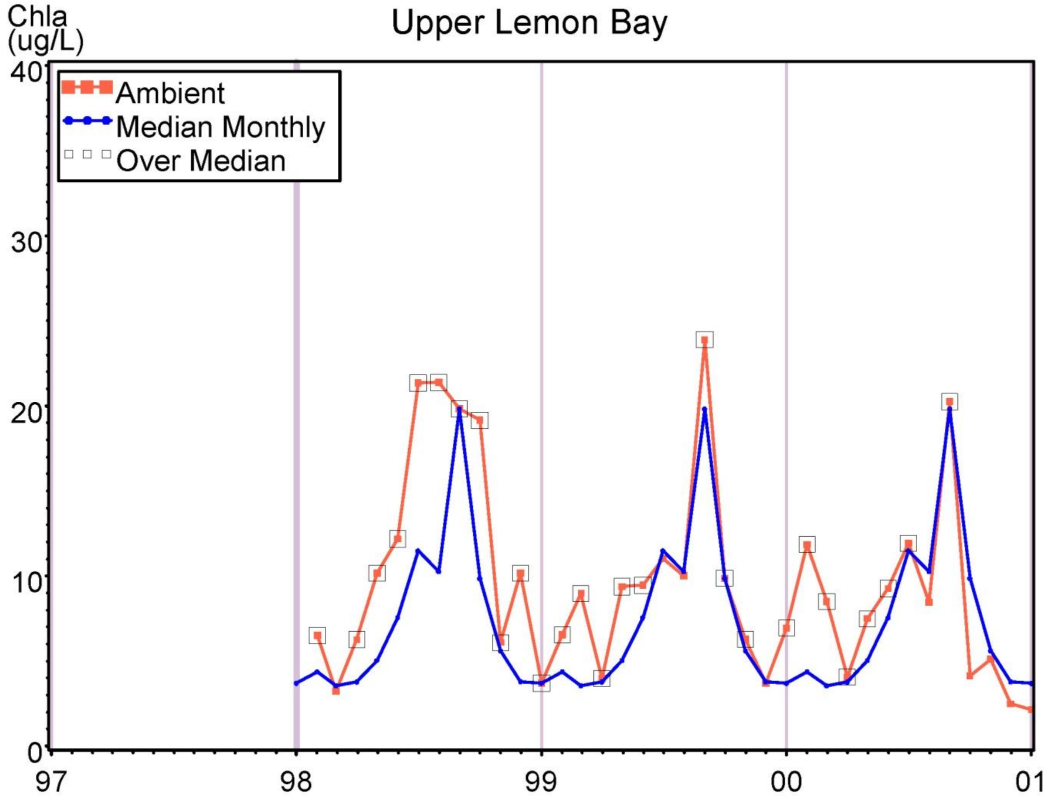
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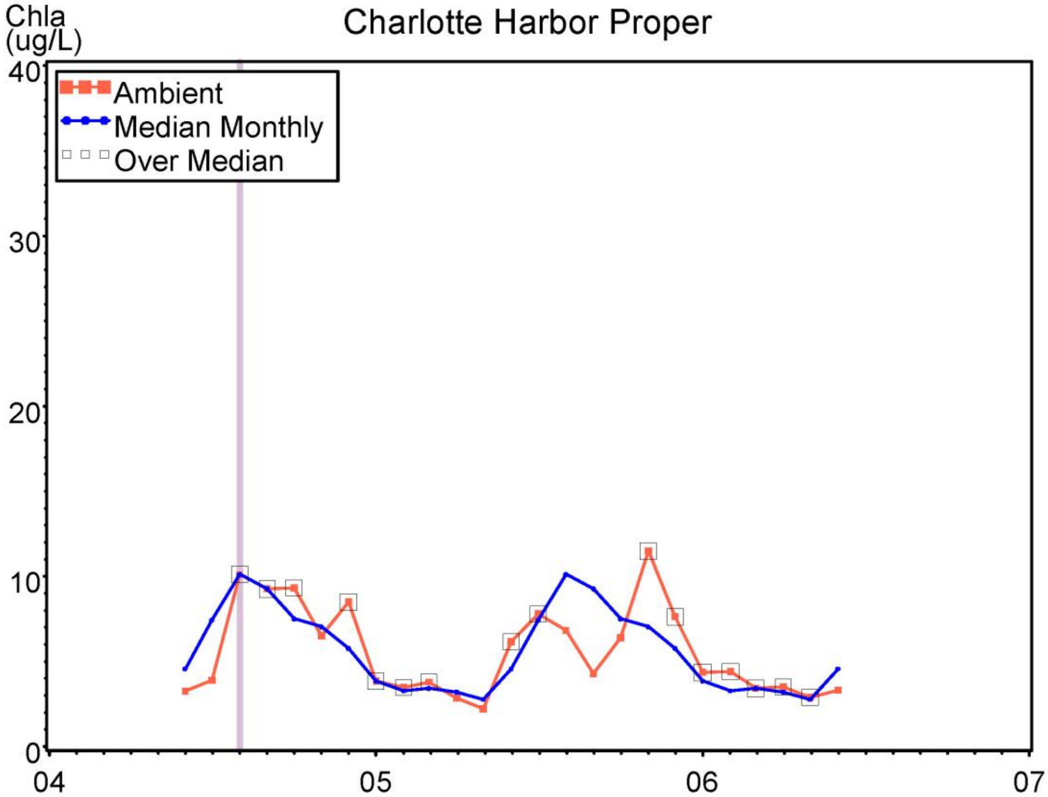
Event 2: Hurricane Charley, August 13, 2004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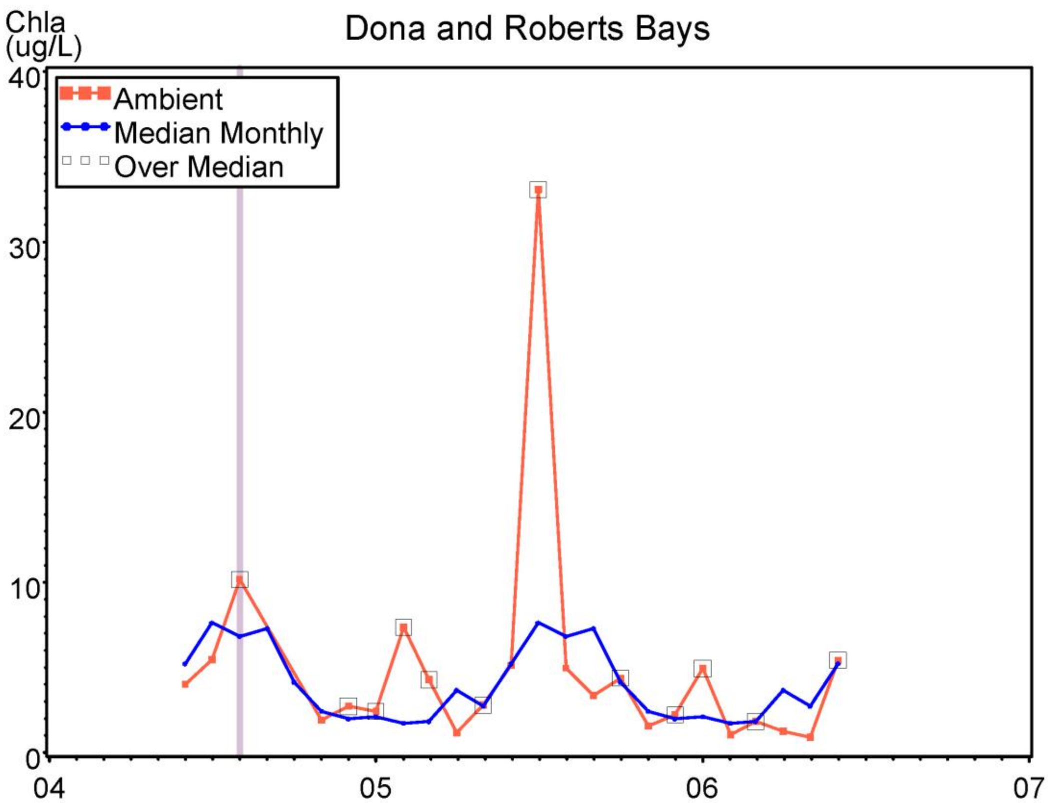
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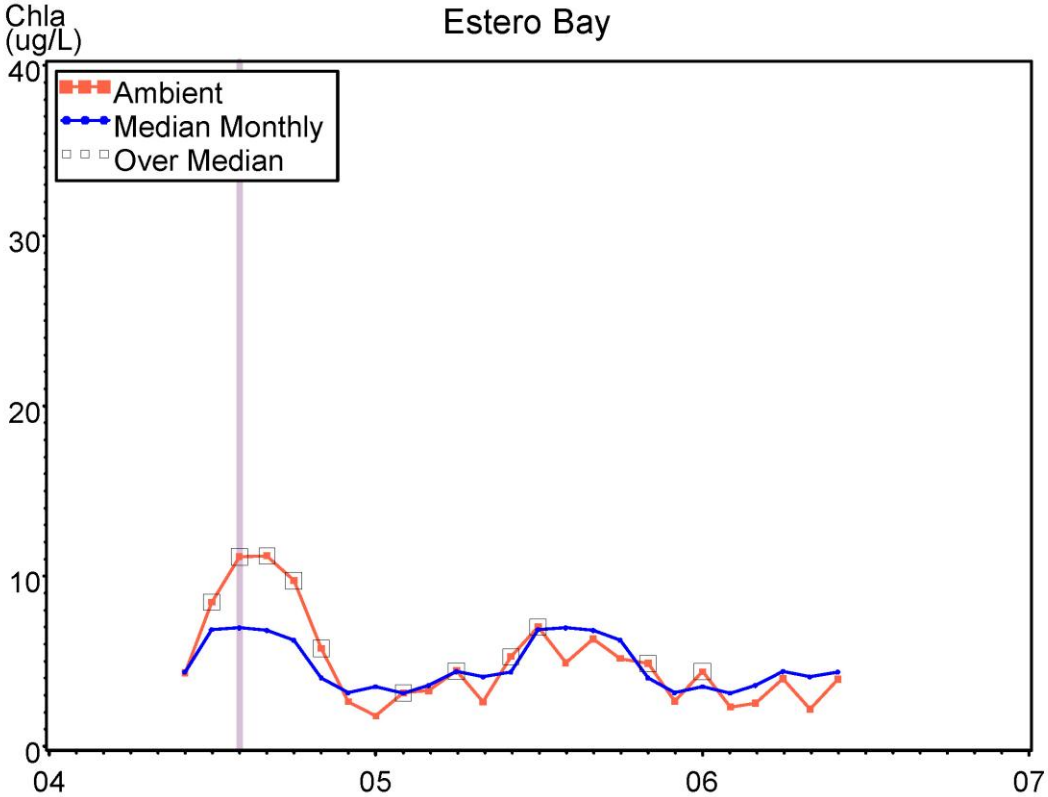
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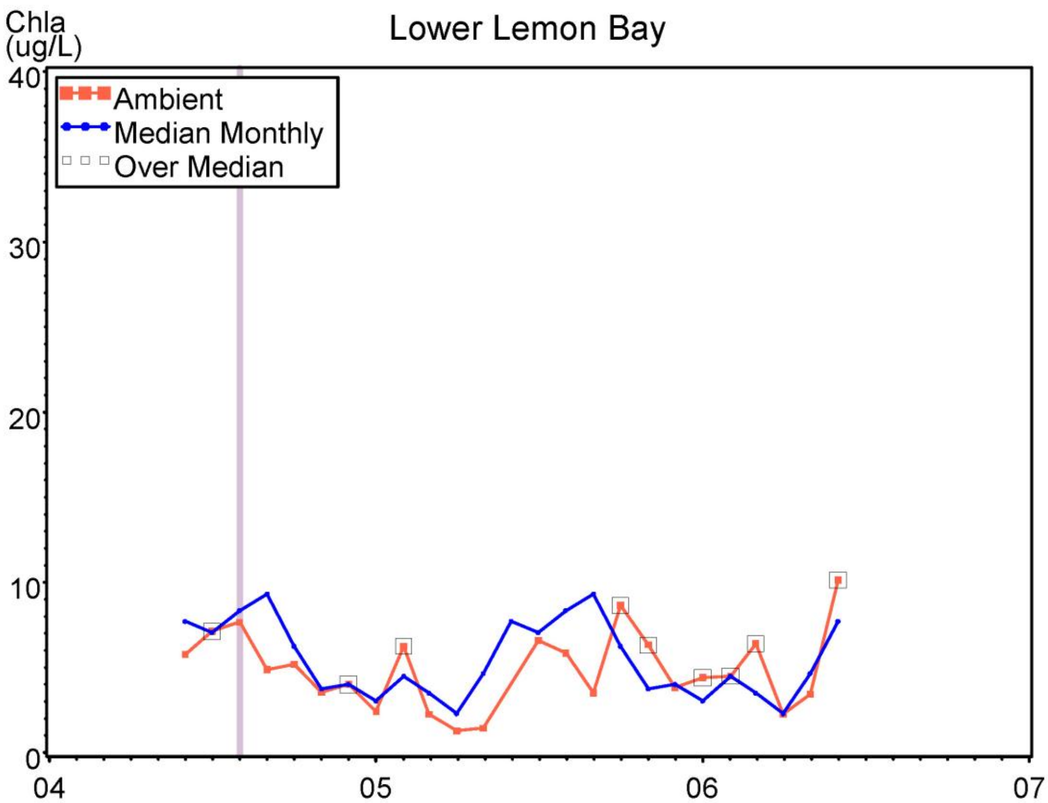
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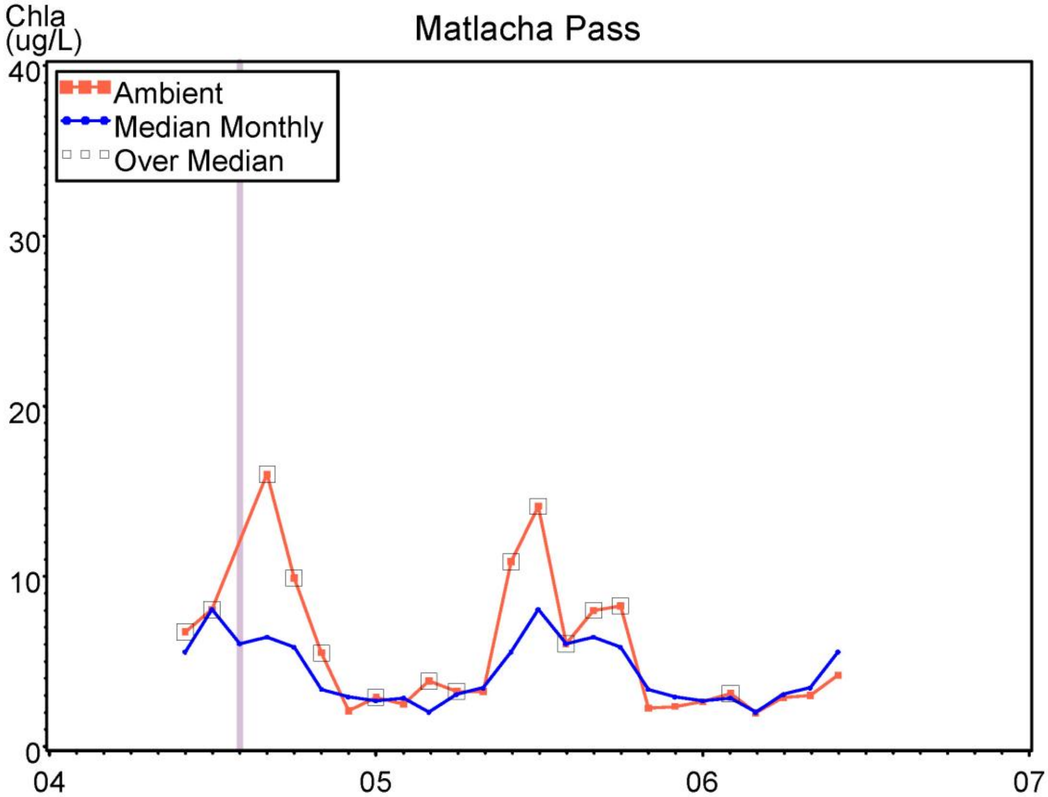
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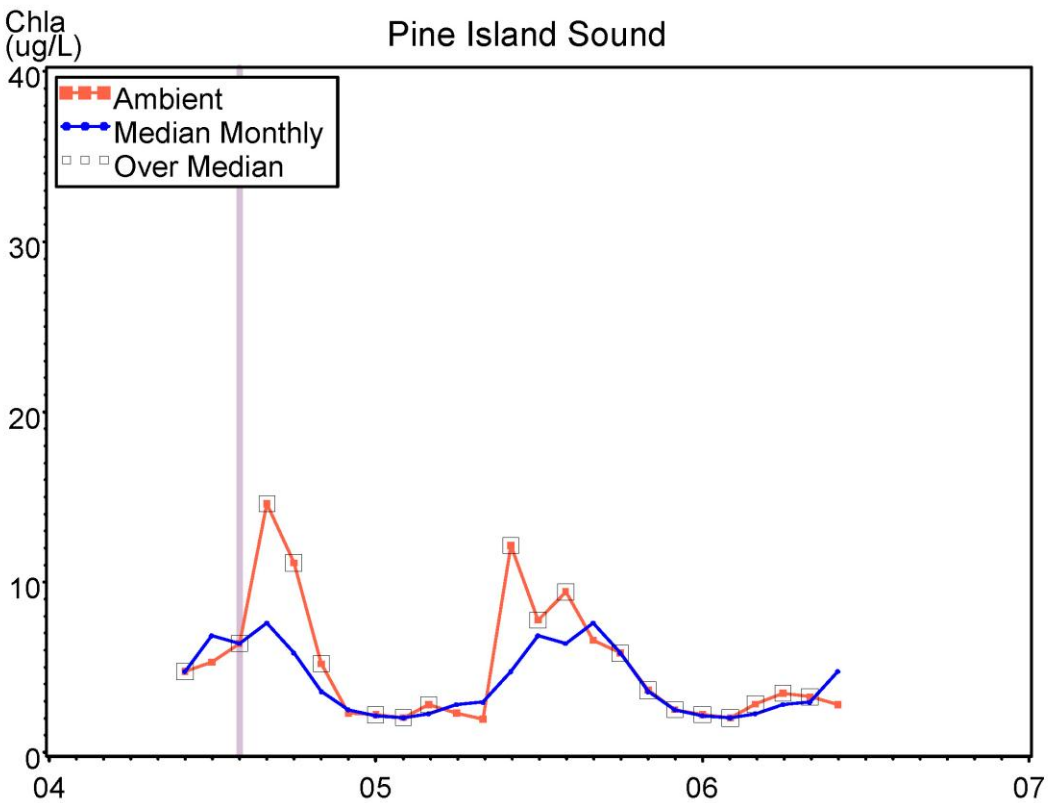
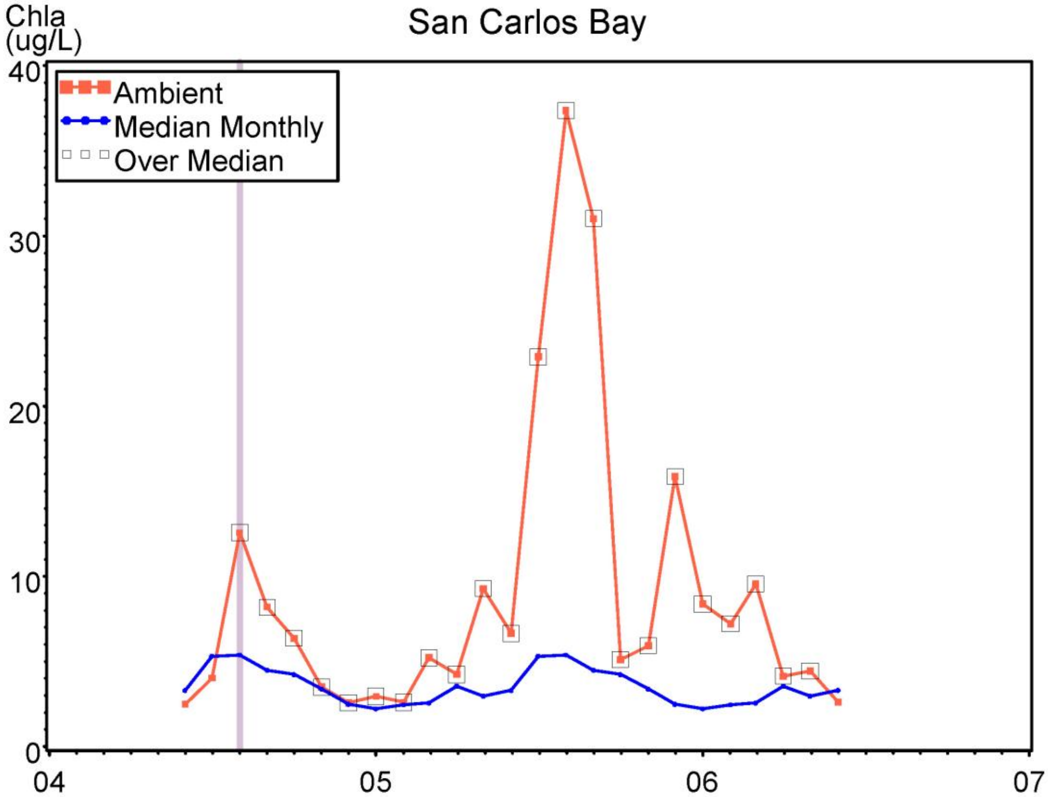
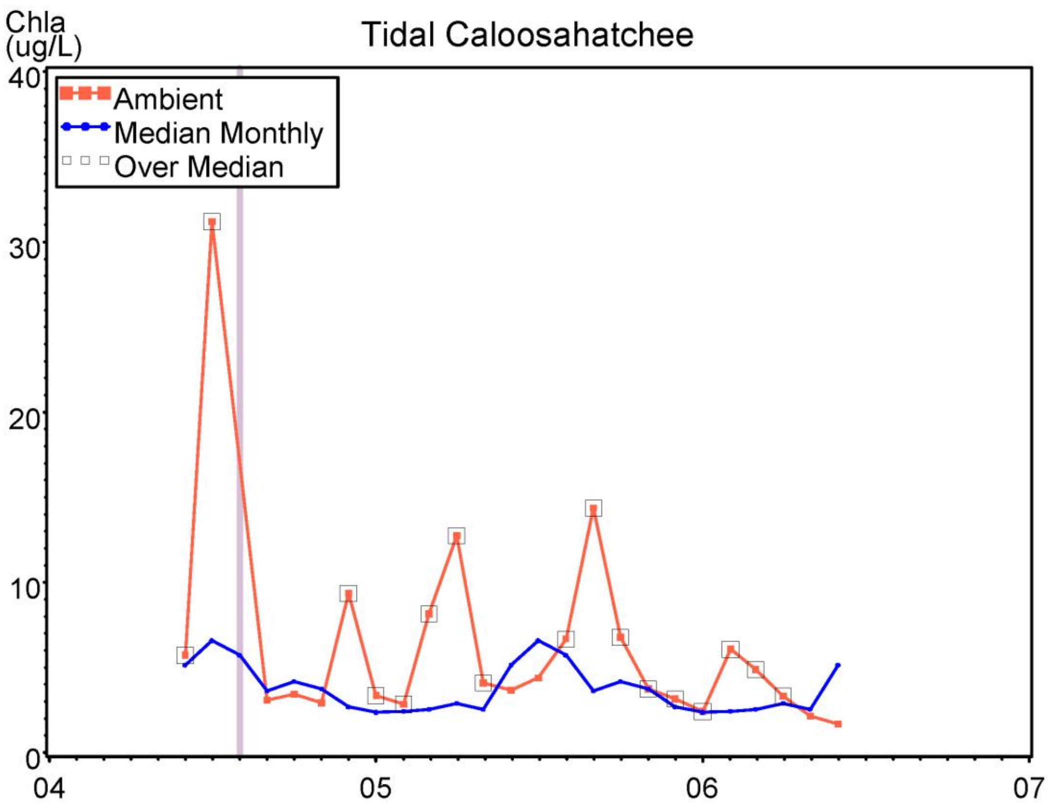
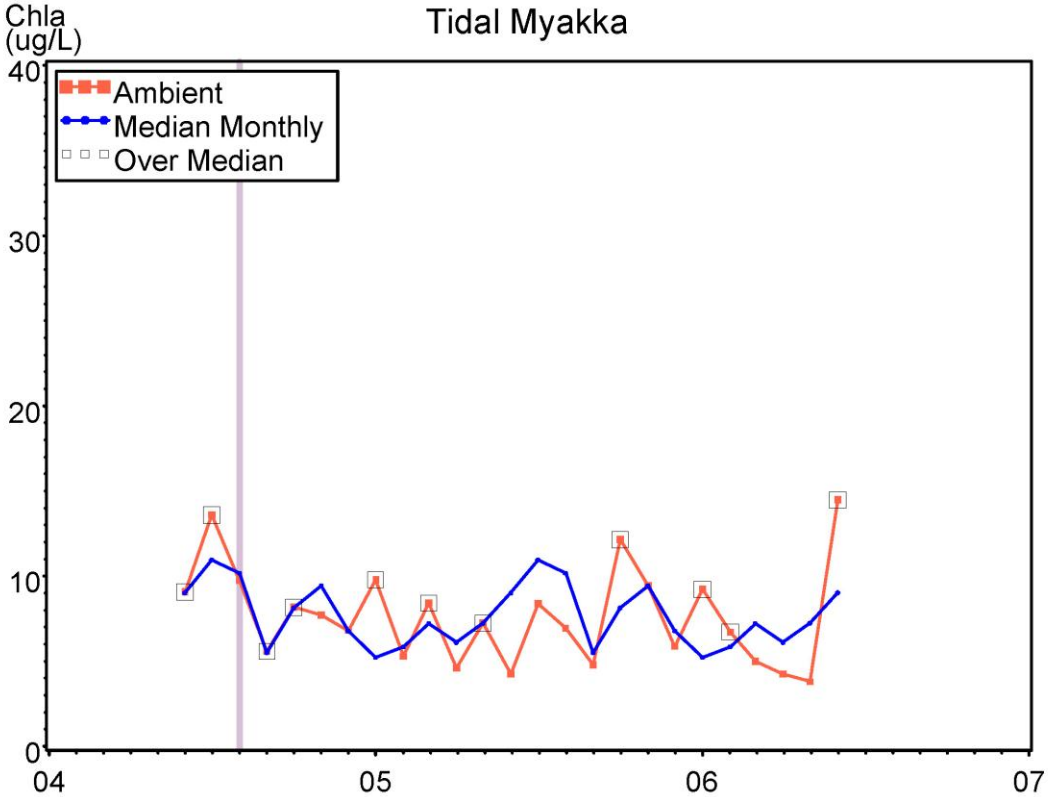
06
07

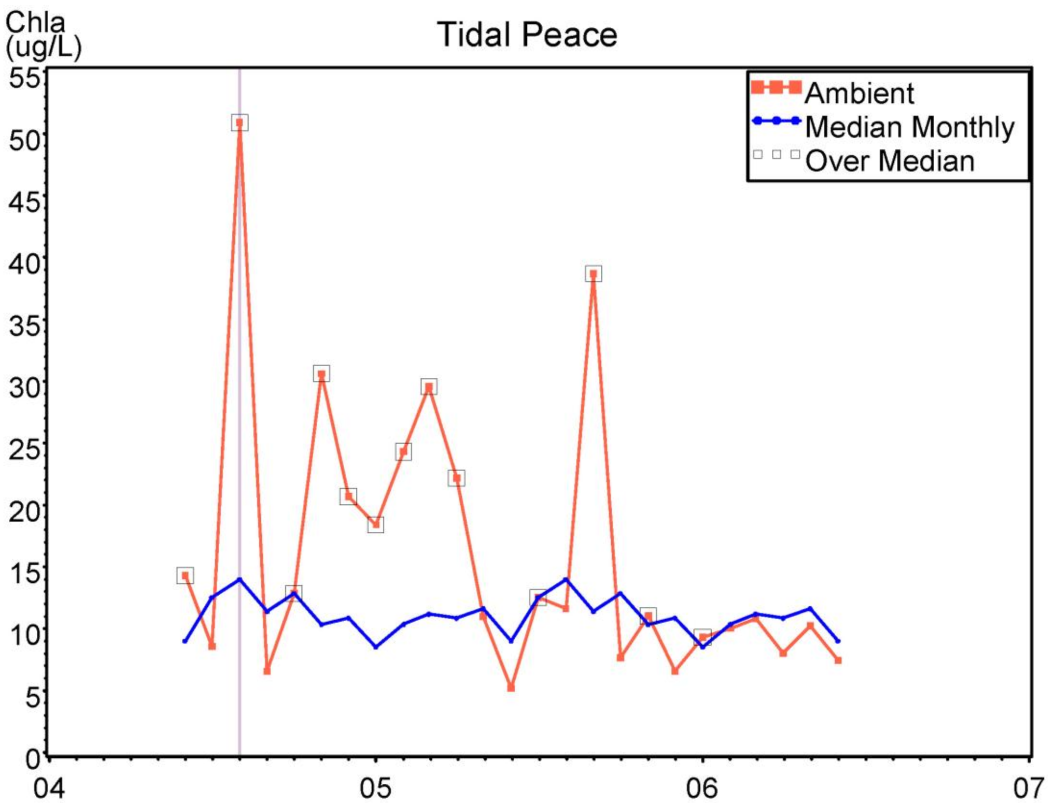

Chla
(ug/L)
Pine Island Sound
Ambient
Median Monthly
Over Median
0
10
20
30
40
04
05
06
07


Chla
(ug/L)
San Carlos Bay
Ambient
Median Monthly
Over Median
0
10
20
30
40
04
05
06
07

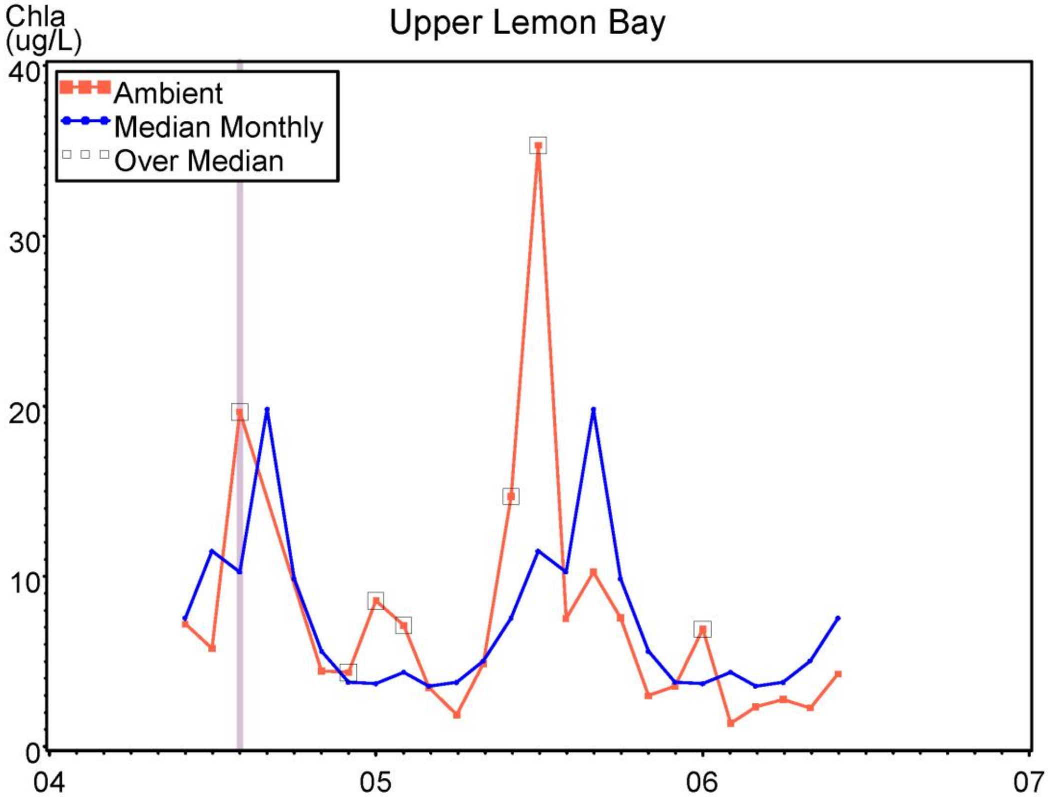

Chla
(ug/L)
Tidal Caloosahatchee
Ambient
Median Monthly
Over Median
0
10
20
30
40
04
05
06
07



Tidal Myakka
Chla
(ug/L)
40
30
20
10
0
04
05
06
07
Ambient
Median Monthly
Over Median



Tidal Peace
Chla
(ug/L)
55
50
45
40
35
30
25
20
15
10
5
0
04
05
06
07
Ambient
Median Monthly
Over Median


Chla
(ug/L)
Upper Lemon Bay
Ambient
Median Monthly
Over Median
40
30
20
10
0
04
05
06
07