SARASOTA BAY
Numeric Nutrient Criteria:
Task 4 – Implementation Issues

Letter Memorandum

Prepared for:

Sarasota Bay Estuary Program

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FOREWORD

This letter memo was produced in partial fulfillment of SBEP Contract 2011SBEP04 - Development of Numeric Nutrient Criteria for Sarasota Bay, Task 4.

ACKNOWLEDGEMENTS

We wish to thank the partners of the Sarasota Bay Estuary Program (SBEP) for the numerous conversations providing direction and insight into concerns regarding numeric nutrient criteria establishment and appropriate methodology for developing the proposed criteria. We would particularly like to thank the following individuals who serve on the water quality subcommittee of the Technical Advisory Committee: Mark Alderson, Dr. Jay Leverone, Jack Merriam, Rob Brown, Lizanne Garcia, Kris Kaufmann, Veronica Craw, John Ryan, Gary Serviss, Amber Whittle, Pete Wenner, Charles Kovach, and Jon Perry.

EXECUTIVE SUMMARY

The objective of this task is to address two key issues identified by the U.S. Environmental Protection Agency regarding successful implementation of the proposed numeric nutrient criteria in Sarasota Bay, 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 year is relatively short. Median annual response times are three months or less in all segments, as are average annual response times. This indicates that the bay segments recover very quickly from normal loading events.
- The typical response times to unusual events, such as El Niño, are longer and, depending upon the timing of such events, can span over parts of two successive years.
- 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 Sarasota Bay Estuary Program (SBEP) has recommended numeric nutrient criteria to U.S. Environmental Protection Agency (EPA) for Sarasota Bay (Janicki Environmental, 2010a). EPA has identified several key issues that must be addressed if the proposed numeric nutrient criteria are to be successfully implemented in Sarasota Bay (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 effectiveness of these assessment periods is compared.
- EPA encouraged input on the treatment of tidal creeks and bayous in the implementation of the proposed nutrient criteria for Sarasota Bay.

This document addresses the first two of these issues while the recommendations regarding tidal creeks addressed in another document (Janicki Environmental, 2010b).

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 the Sarasota Bay system, 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 system following both unusual events and the annual maximum monthly chlorophyll *a* values under conditions that are more typically observed.

2.1 Unusual Events

The nutrient conditions and associated chlorophyll *a* responses in Palma Sola Bay, Sarasota Bay, Roberts Bay, Little Sarasota Bay, and Blackburn Bay can be affected by unusual loading events. These events may be non-anthropogenic, related to especially high rainfall conditions associated with hurricanes, El Niño events, or other unusually wet periods. Anthropogenic events, such as spills and accidental releases of wastewater, may also impact the estuary.

Consideration of these types of events must be included within the implementation plan of the proposed nutrient criteria for Sarasota Bay. To understand the impacts of these events in the bay, and the temporal extent of the effects, significant events occurring during the 1996-2008 period were identified, and the responses in the bay evaluated. Specifically, the duration of the responses as signified by elevated chlorophyll *a* concentrations were estimated for each event.

Figure 1. Bay segments within the Sarasota Bay Estuary Program system.

Water quality data collected by Sarasota County and Manatee County were used to develop monthly average concentrations of chlorophyll *a* and nutrients for the 1996-2008 period for each of the five bay segments (Figure 1) as available. These data were also used to develop median chlorophyll *a* values for each calendar month across years within the segments. The chlorophyll *a* response within each segment was evaluated for each event, with an unusually high chlorophyll *a* concentration identified as the beginning of the event response. Following this high concentration, we tallied the number of months until the concentration returned to a level at or below the median calendar month concentration. This provides a measure of the temporal extent of the response within the bay segment to an unusual loading event.

Figure 2 presents an example plot that displays how the response time was 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.

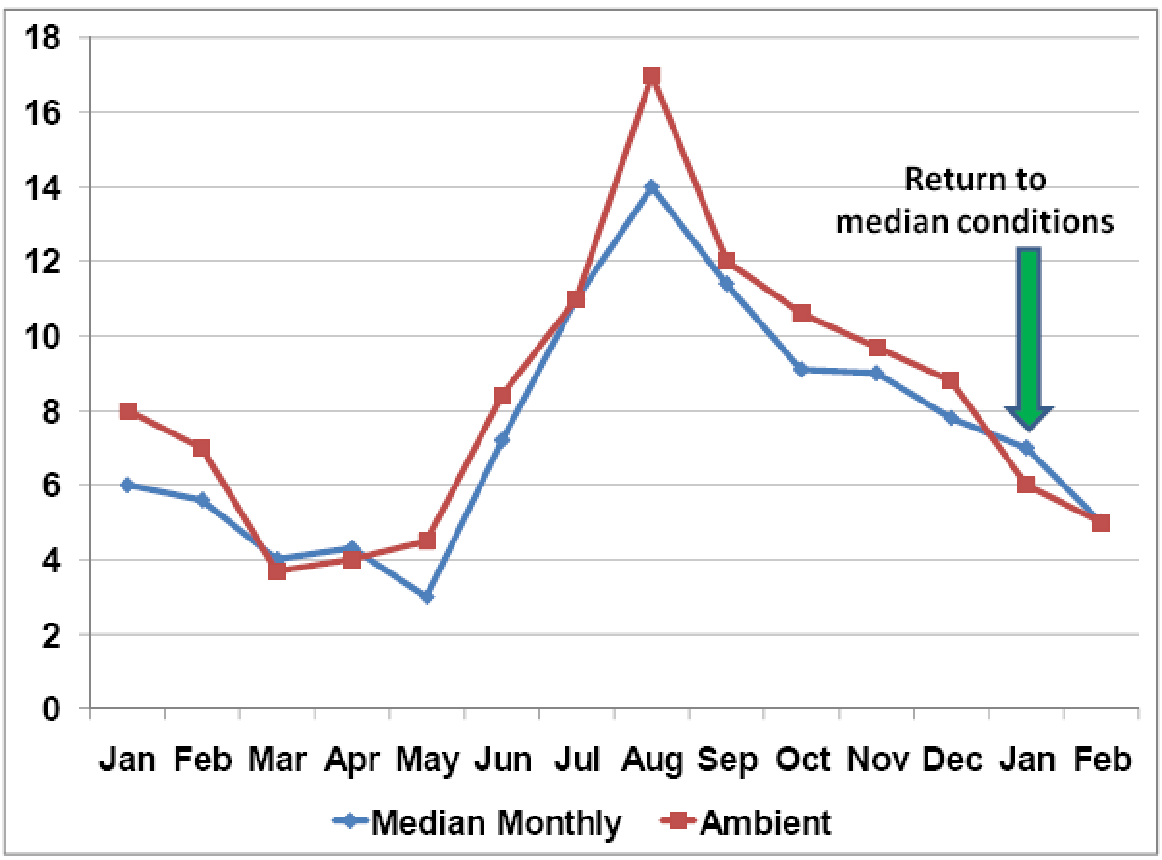

Figure 2. Example of the response time estimation method.

The events identified for response evaluation were as follows:

- Event 1: 1997 early months of El Niño,
- Event 2: 1998 late months of El Niño,
- Event 3: Unusually wet summer 2003, and
- Event 4: 2004 hurricane season.

The length of response (in months) was estimated as the temporal extent from the beginning of the chlorophyll *a* response (not necessarily the annual maximum), denoted by exceedance of the monthly median value, until values declined below the calendar month median. 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 the value to its long term monthly median, the seasonal correlation inherent in chlorophyll *a* responses due to seasonal changes in temperature and photoperiod is adjusted 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.

A discussion of each bay segment's response to these events is provided below.

2.1.1 Temporal Extent of Responses to Unusual Events – Palma Sola Bay

Event 1 - During the onset of El Niño in 1997, the chlorophyll *a* value in June was 16.9 µg/L, compared to the median value of 9.7 µg/L. Monthly values greater than the median calendar month values were maintained until September 1997, so the temporal extent of this response period was 3 months.

Event 2 - The El Niño event of 1997-1998 was well underway in 1998. The chlorophyll *a* value in January 1998 was 22.9 µg/L, almost four times the median value of 6.2 µg/L. Monthly values were potentially greater than the median values until July 1998 (no data were available for March 1998), giving a temporal extent of 6 months.

Event 3 - Unusually high rainfall occurred during the summer of 2003. The chlorophyll *a* value in September 2003 was 19.7 μg/L, compared to the median value of 14.5 μg/L. Data were lacking for the following month but the monthly value was below the median value in November, yielding a temporal extent of this response of 1 month.
Event 4 – The 2004 hurricane season was unusually active. The chlorophyll *a* value in September 2004 was 19.2 μg/L, compared to the median value of 14.5 μg/L. The monthly value was below the median value the following month, yielding a temporal extent of this response of 1 month.

2.1.2 Sarasota Bay

Event 1 - During the onset of El Niño in 1997, the chlorophyll *a* value in June 1997 was 7.5 μg/L, compared to the median value of 4.7 μg/L. Monthly values greater than the median calendar month values were potentially maintained until March 1998, (no data were available for September or November 1997), so the potential temporal extent of this response period was 9 months.

Event 2 - The El Niño event of 1997-1998 was well underway in 1998. The chlorophyll *a* value in January 1998 was 9.6 μg/L, over three times the median value of 3.0 μg/L. Monthly values were greater than the median values until March 1998, giving a temporal extent of 2 months.

Event 3 - Unusually high rainfall occurred during the summer of 2003. The chlorophyll *a* value in July 2003 was 9.2 μg/L, compared to the median value of 6.7 μg/L. The monthly value was above the median value until October 2003, yielding a temporal extent of this response of 3 months.

Event 4 – The 2004 hurricane season was unusually active. The chlorophyll *a* value in September 2004 was 12.2 μg/L, compared to the median value of 8.9 μg/L. The monthly value was below the median in October, for a temporal extent of this response of 1 month.

2.1.3 Roberts Bay

Event 1 – Chlorophyll *a* data for 1997 were not available for Roberts Bay.

Event 2 - The El Niño event of 1997-1998 was well underway in 1998. The chlorophyll *a* value in February 1998 was 9.2 μg/L, over three times the median value of 2.6 μg/L. Monthly values were greater than the median values until March 1998, giving a temporal extent of 1 month.

Event 3 - Unusually high rainfall occurred during the summer of 2003. The chlorophyll *a* value in July 2003 was 38.1 µg/L, over three times the median value of 9.2 µg/L. The monthly value was again below the median value in October, yielding a temporal extent of this response of 3 months.

Event 4 – The 2004 hurricane season was unusually active. The chlorophyll *a* value in August 2004 was 25.8 µg/L, compared to the median value of 9.3 µg/L. The monthly value was below the median value the following month, yielding a temporal extent of this response of 1 month.

2.1.4 Little Sarasota Bay

Event 1 – Chlorophyll *a* data for 1997 were not available for Little Sarasota Bay.

Event 2 - The El Niño event of 1997-1998 was well underway in 1998. The chlorophyll *a* value in July 1998 was 12.1 µg/L, compared to the median value of 7.3 µg/L. The monthly value was again below the median value the following month, giving a temporal extent of 1 month.

Event 3 - Unusually high rainfall occurred during the summer of 2003. The chlorophyll *a* value in July 2003 was 26.5 µg/L, compared to the median value of 7.3 µg/L. The monthly value was next below the median value in October, yielding a temporal extent of this response of 3 months.

Event 4 – The 2004 hurricane season was unusually active. The chlorophyll *a* value in August 2004 was 19.6 µg/L, compared to the median value of 8.6 µg/L. The monthly value was again below the median value the following month, yielding a temporal extent of this response of 1 month.

2.1.4 Blackburn Bay

Event 1 – Chlorophyll *a* data for 1997 were not available for Blackburn Bay.

Event 2 - The El Niño event of 1997-1998 was well underway in 1998. The chlorophyll *a* value in February 1998 was 6.0 µg/L, compared to the median value of 2.4 µg/L. Monthly values were greater than the median values until June 1998, giving a temporal extent of 4 months.

Event 3 - Unusually high rainfall occurred during the summer of 2003. The chlorophyll *a* value in July 2003 was 17.5 µg/L, compared to the median value of 6.3 µg/L. The monthly value was again below the median value in October, yielding a temporal extent of this response of 3 months.

Event 4 – The 2004 hurricane season was unusually active. The chlorophyll *a* value in August 2004 was 13.6 µg/L, compared to the median value of 7.1 µg/L. The monthly value was below the median value the following month, yielding a temporal extent of this response of 1 month.

2.1.6 Summary of Temporal Extent of Unusual Events

Table 1 provides a summary of the response times of each segment for each event. As provided in the table, the longest response times observed resulted from the El Niño event of 1997-1998. The next longest response times resulted from the wet 2003 summer. Response times to the 2004 hurricane season were one month in all segments.

The response to most unusual loading events to the bay is typically very rapid, with response times on the order of months, not years. Only the strong El Niño event resulted in a response time approaching a year in one segment. It is evident that the bay recovers relatively quickly from most unusual loading events.

Table 1. Chlorophyll *a* response time (months) to unusual loading events in Sarasota Bay.

Event	Palma Sola Bay	Sarasota Bay	Roberts Bay	Little Sarasota Bay	Blackburn Bay
Early El Niño 1997	3	9	No data	No data	No data
Late El Niño 1998	6	2	1	1	4
Wet Summer 2003	1	3	3	3	3
Hurricane Season 2004	1	1	1	1	1

2.2 Annual Maxima

Chlorophyll *a* concentrations reach annual maxima within each segment of the bay in response to loadings and light conditions that are conducive to increased productivity. The maxima often, but not always, occur in the wet season, as this is typically the time of year when conditions are most conducive to algal growth. The length of time for the maximum monthly segment chlorophyll *a* values within a given year to decline to levels below the median monthly values, as estimated from 1996-2008 observations as available, is denoted as the annual response time for this analysis.

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 analysis also includes those unusual loading events discussed above. The month in which the maximum chlorophyll *a* occurred in each segment was identified, then the number of months tallied until the monthly value declined below the median calendar month chlorophyll *a* concentration.

As shown in Figure 3, the maximum annual response time in Palma Sola bay was 8 months, with maximum annual response times in Sarasota Bay, Little Sarasota Bay, and Blackburn Bay of 7 months, while Roberts Bay maximum response time was 6 months. Mean response times (represented by blue dots in Figure 3) were 3 months for Palma Sola Bay and Blackburn Bay, 2.7 months for Little Sarasota Bay, 2.2 months for Sarasota Bay, and 1.7 months for Roberts Bay.

The maximum chlorophyll *a* during a given year is not always found in the wet season, however. Maximum chlorophyll *a* concentrations were sometimes found in the winter, as in Palma Sola Bay and Sarasota Bay, both in January. Figure 4 provides histograms for each bay segment of the number of occurrences of chlorophyll maxima within each month over the 1996-2008 period (for Sarasota Bay and Palma Sola Bay) or the 1998-2009 period (Blackburn Bay, Little Sarasota Bay, and Roberts Bay). Maximum chlorophyll *a* concentrations in all segments typically occur in September.

The annual response time to recover from the maximum monthly chlorophyll *a* concentration during a year is relatively short, except for unusual loading events. Median annual response times (Table 2) are three months in two segments (Palma Sola Bay and Little Sarasota Bay), two months in Blackburn Bay, and one month in Sarasota Bay and Roberts Bay. Average annual response times ranged from three months in Palma Sola Bay and Blackburn Bay to less than two months in Roberts Bay.

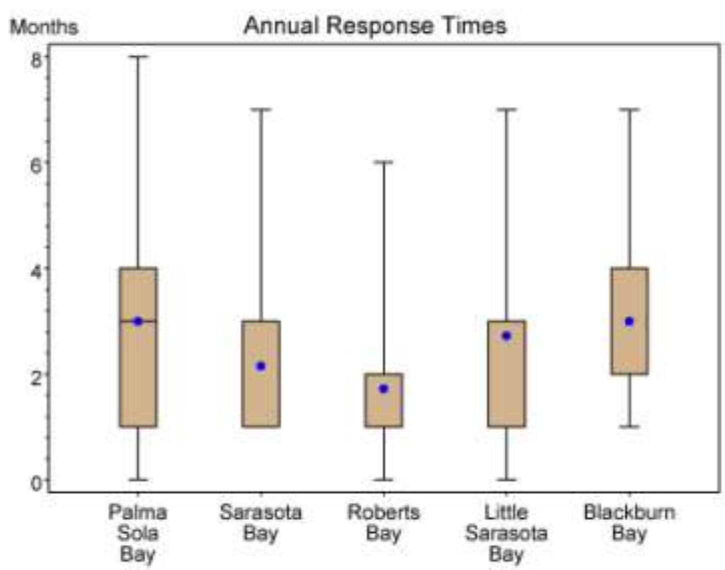

Figure 3. Annual chlorophyll *a* response times (months) for the period 1997-2008.

Table 2. Distribution of response times (months) following annual maximum chlorophyll *a*.					
Percentile	**Palma Sola Bay**	**Sarasota Bay**	**Roberts Bay**	**Little Sarasota Bay**	**Blackburn Bay**
100	8	7	6	7	7
95	8	7	6	7	7
90	6	4	3	4	5
75	4	3	2	3	4
50	3	1	1	3	2
25	1	1	1	1	2
10	1	1	0	1	1
5	0	1	0	0	1
0	0	1	0	0	1
Mean	3.0	2.2	1.7	2.7	3.0

Figure 5 shows histograms for each segment indicating the response time for chlorophyll *a* in the segment to recover from its annual maximum to below the monthly median. The annual patterns had similarities but were not identical. Palma Sola Bay had its longest response period – eight months – in 1999, which was preceded by a six month response period in 1998. In only four of the 12-year period of analysis did the segment respond in one month. Sarasota Bay, in contrast, had a response time of one month in seven years, with the longest response of seven months in 1998. Roberts Bay also had its longest response period in 1999 (six months), and four years with a one month response. Little Sarasota Bay had a seven month response period in 2002, with five years having three month responses and only two years having one month responses. Blackburn Bay had a seven month response in 2000 followed by four month periods in 2001 and 2002. Only in 2006 and 2008 were the response periods one month in this segment.

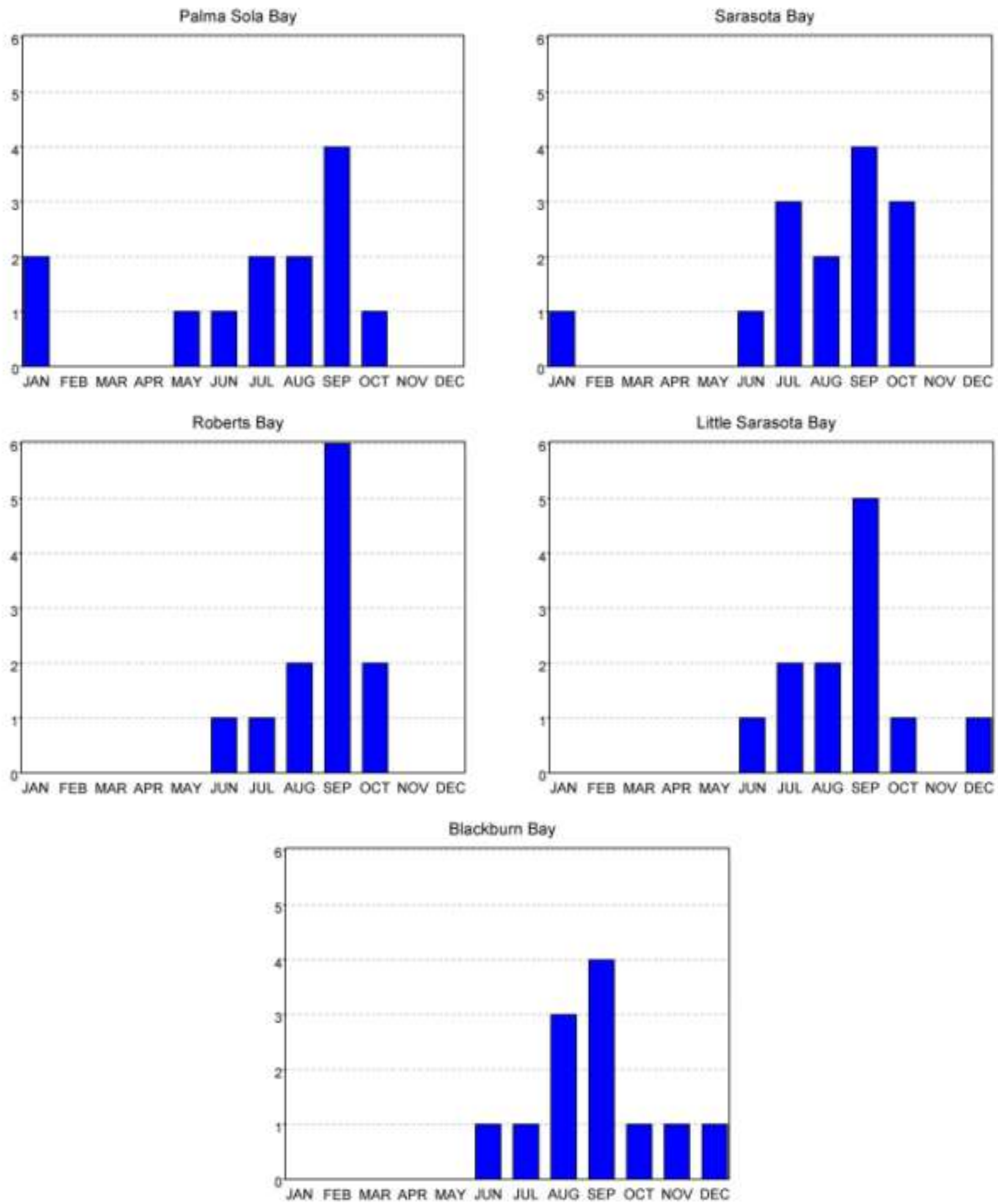

Figure 4. Number of occurrences within each month of maximum chlorophyll *a*.

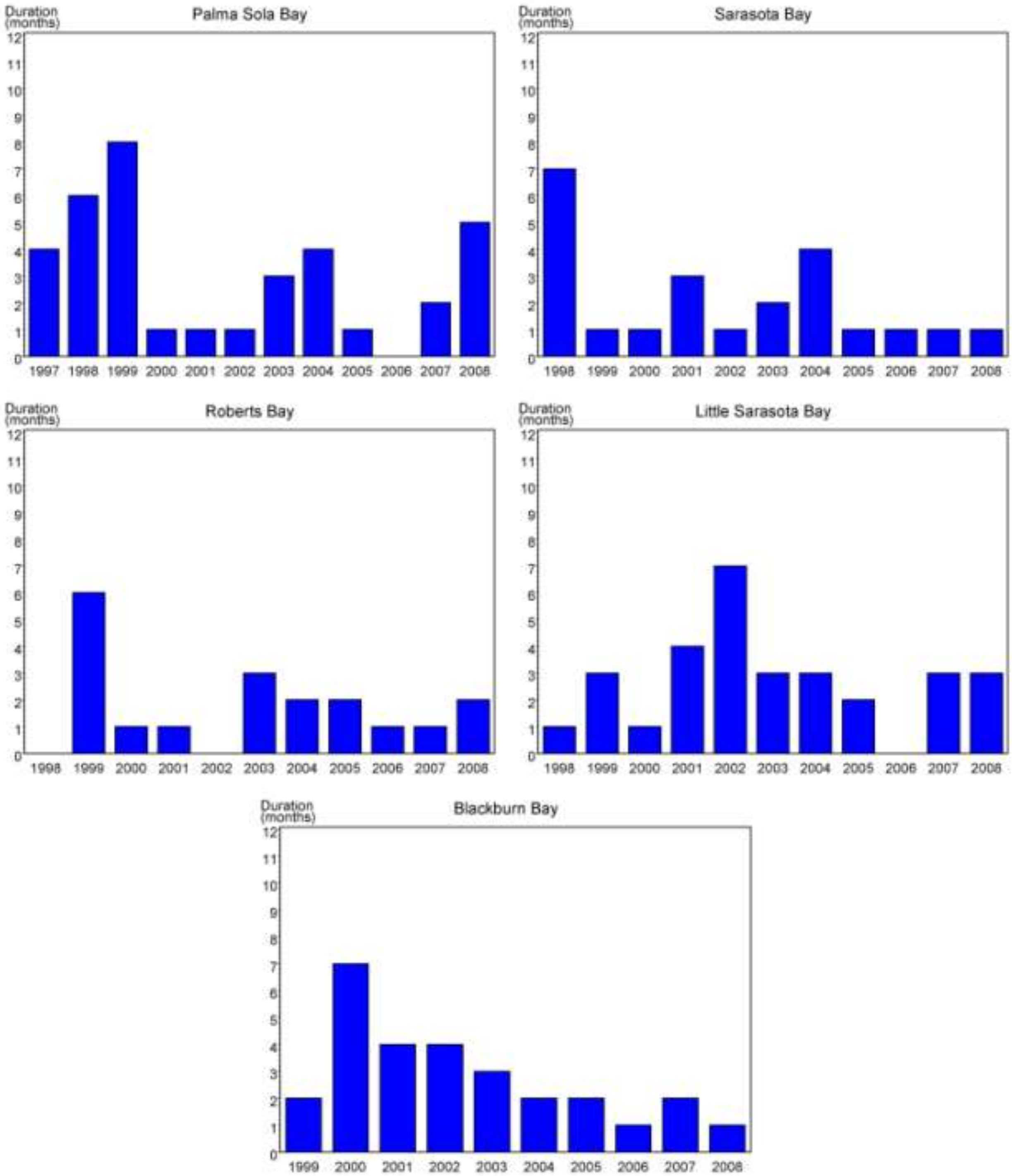

Figure 5. Recovery period (months) to return from annual maximum chlorophyll *a* to below monthly median value.

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 response conditions in Sarasota Bay, including the effects of hurricanes or other unusually high rainfall events, such as El Niño. Based on the analyses described above, the system recovers relatively quickly from most unusual loading events, with only the extreme events resulting in responses approaching a year.

It is recommended that any unusual loading events be considered when evaluating collected water quality data towards compliance assessment, in a manner similar to that currently accounted for in the Tampa Bay Estuary Program assessment process (Janicki Environmental, 2010c). The TBEP assessment process first identifies any water quality problems, then evaluates the severity of the problem, performs studies as necessary to aid in problem identification, and implements appropriate management actions. One example of this process has been the development and completion of several studies investigating the unexplained exceedance of chlorophyll *a* targets in Old Tampa Bay during the past decade, when the rest of the bay has been meeting targets. Similar responses should be included in the compliance assessment for Sarasota Bay numeric nutrient criteria.

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 a significant exceedance when one actually occurs) or too stringent (i.e., inappropriately identifying a significant exceedance when one has not occurred) 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 Florida Department of Environmental Protection (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. The El Niño Southern Oscillation (ENSO) and more locally, the Atlantic Multidecadal Oscillation are strong drivers of weather patterns and resulting stream flows in southwest Florida (Kelly and Gore, 2008). The temporal persistence of ENSO is highly variable 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 was 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 there is still much 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. It is the duration of these anomalies that will affect the outcomes of this assessment. Anomalies that carry over calendar years will likely result in a violation of the "1-in-3" rule. This same artifact in the data would not trigger an exceedance under the "2-in-5" rule unless another anomaly occurred within the 5 year window. Therefore this assessment is examining the correlation that exists from year to year. This is an assessment of autocorrelation in the annual statistics similar to that described in section 2 for the monthly time scale. In Tampa Bay, studies have 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 Sarasota Bay estuaries do not 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 due simply to 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 on 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.

Streamflow would have been preferable to rainfall as an index of natural variability in hydrology affecting the estuarine waters of the Sarasota Bay estuaries; however, no long term streamflow gages are available in any of the SBEP watersheds. The results of a similar analysis in Tampa Bay using streamflow suggested that the 2-in-5 assessment cycle was less likely to inappropriately classify a waterbody as impaired due to these types of anomalies. For the SBEP estuaries we use long term rainfall gages as well as the MEI data from 1950 to 2008 to evaluate these different assessment cycles.

3.2 Methods

Two datasets were chosen for this evaluation.

Long term rainfall records for the National Weather Service located at the Sarasota Bradenton Airport, Myakka River State Park and Venice Airport were used to assess long term variability in rainfall over the period of record (Figure 6). The period of record for rainfall estimates was:

- Bradenton Airport 1965 - 2009
- Myakka River 1948 - 2009
- Venice Airport 1948 – 2009

These long-term time series were used to calculate an index representing wet, dry, and normal years. To accomplish this, cumulative monthly rainfalls were calculated, 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.

$$\text{Standardized rainfall} = \frac{x - \mu_x}{\sigma_x}$$

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

For each of the gages there were short periods within the period of record where no data were available. In these cases 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 steps were taken to classify years: Each month was assigned a monthly score based on deviations from expected averages. A 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

- Dry years were classified when the cumulative monthly score was at least -4.

Figure 6. Location of long-term rain gages used in compliance assessment.

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 second dataset included sliding 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 Multivariate ENSO Index (MEI) 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 standardized exactly as described above for the 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 indicting anomalies that would potentially affect water quality in the SBEP study area though the exact correspondence of the MEI and localized variability in climate is not fully understood.

3.3 Results

Natural variability in rainfall over the period of record is evidenced for all three gauges within the study area as exemplified in Figure 7. Deviations above and below the horizontal lines indicate conditions classified as monthly anomalies. Rainfalls are highly variable month to month. While streamflow tends to be a better integrator of hydrology affecting the estuary in most systems, there is inadequate streamflow data to conduct this assessment.

The principal objective of this investigation was to assess the two regulatory assessment cycles in allowing for natural variability. Therefore, anomalies in the rainfall time series were classified as being a wet year, average year, or dry year to evaluate how the two regulatory assessment cycles differed with respect to characterizing natural variability as a violation.

The classification results for each of the three rainfall gauges are provided in Figures 8-10.

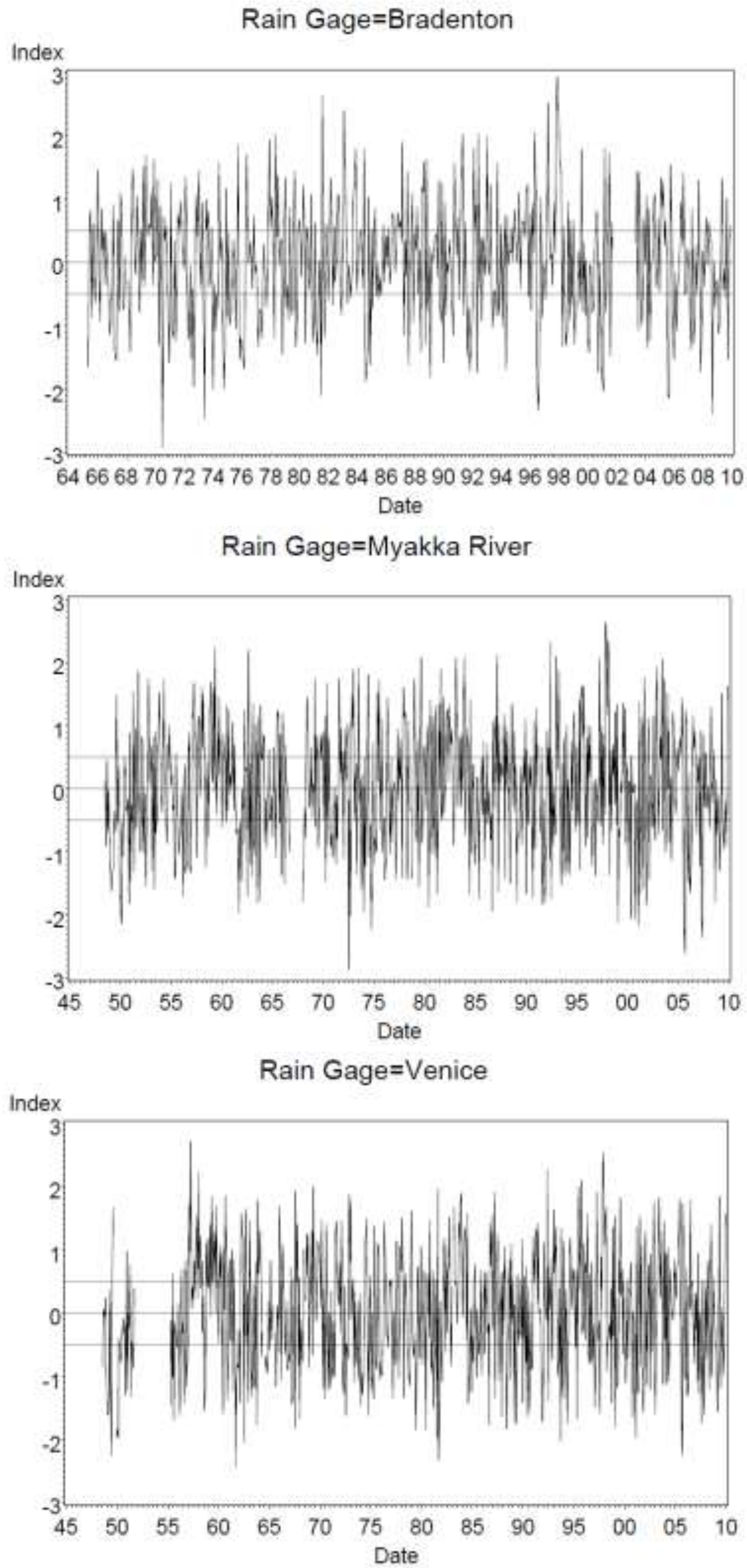

Figure 7. Time series of monthly rainfall values standardized to their long-term monthly average.

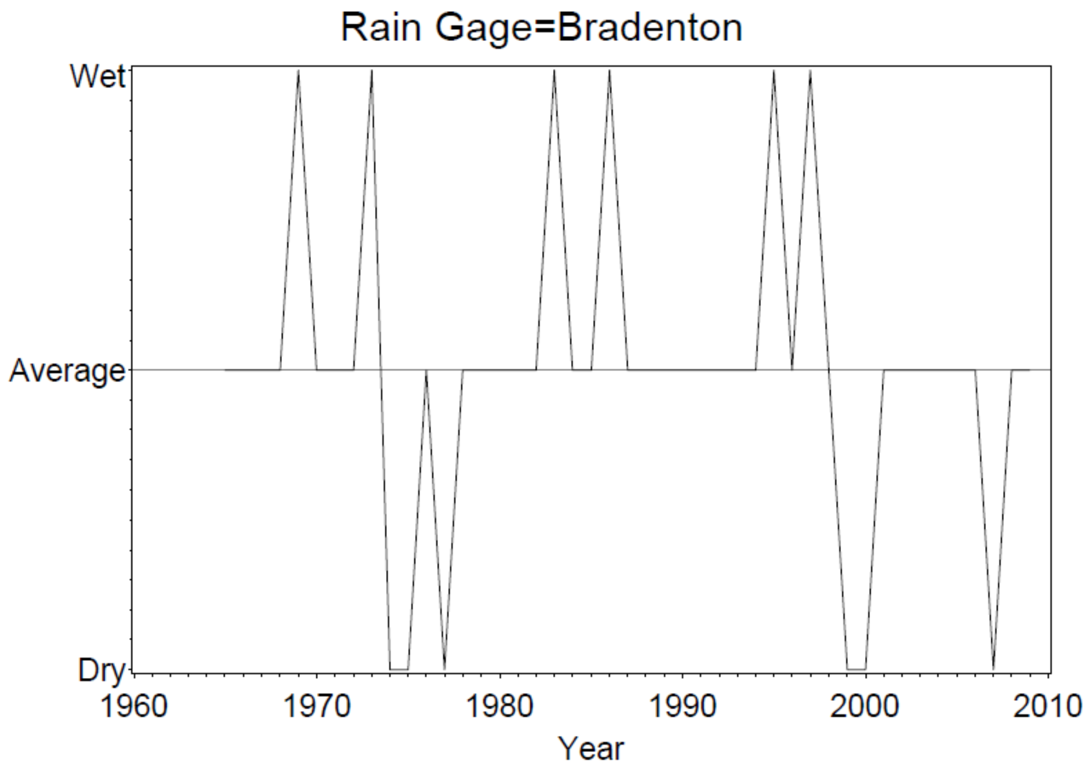

Figure 8. Results of annual classification of rainfall data anomalies for the Bradenton Rain gage.

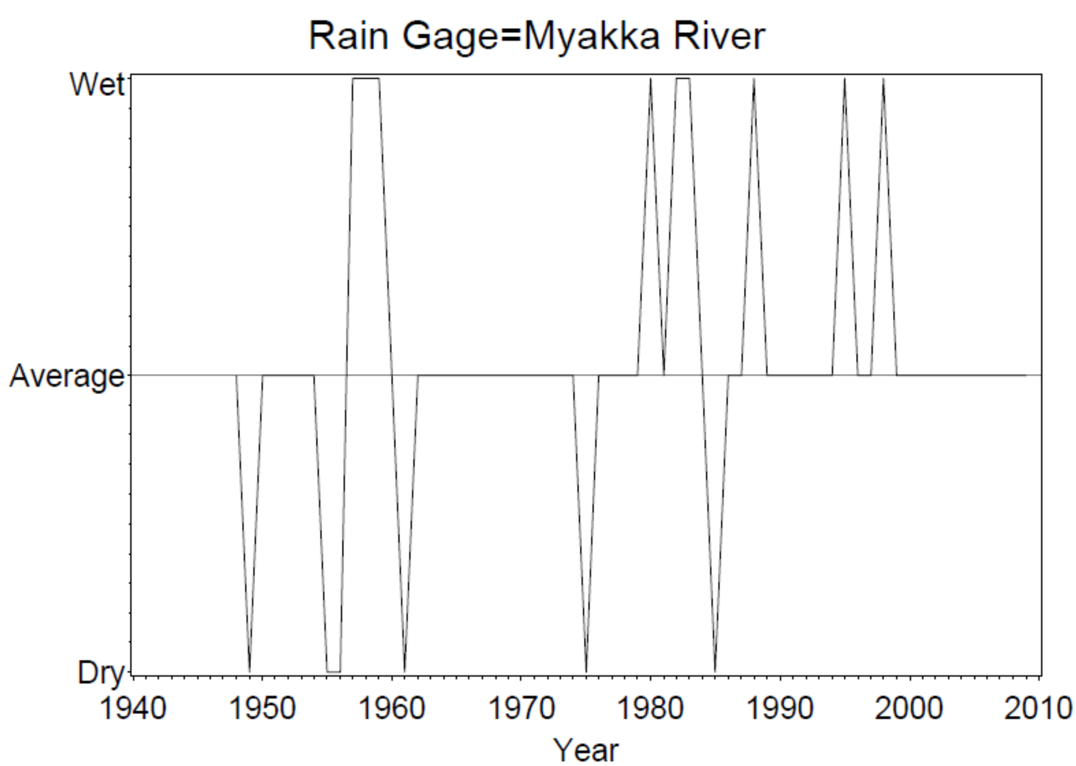

Figure 9. Results of annual classification of rainfall data anomalies for the Myakka River rain gage.

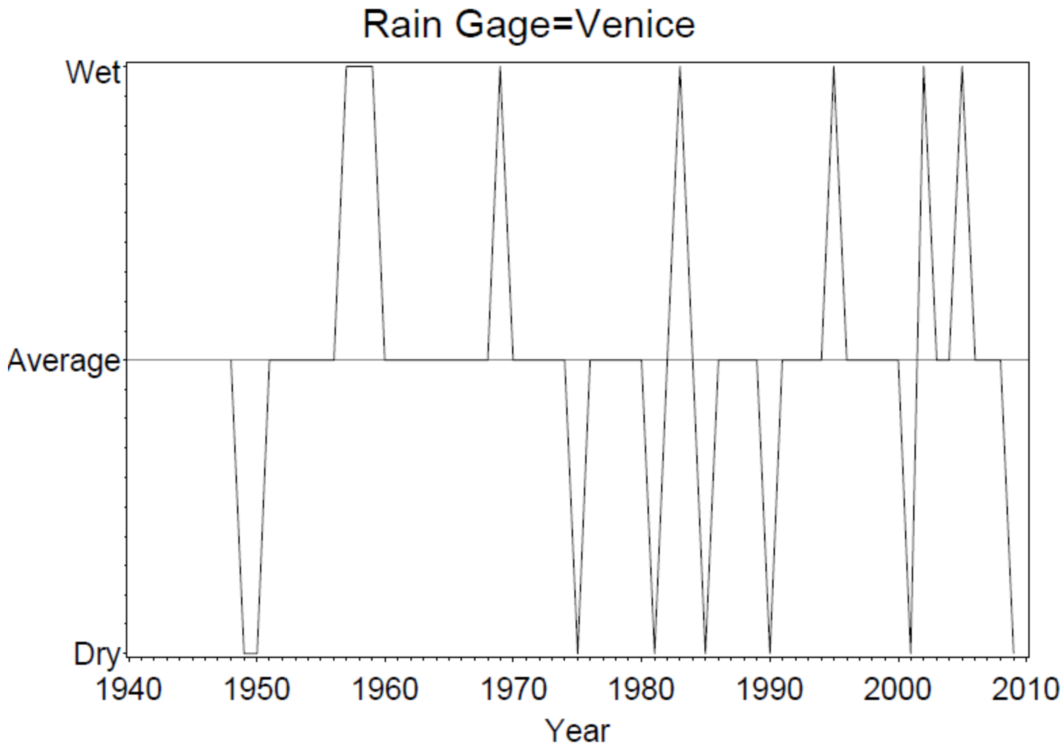

Figure 10. Results of annual classification of rainfall data anomalies for the Venice rain gage.

Generally there were few multi-year anomalies in the rainfall evaluation for either the wet or dry evaluation. Compliance assessment for the Bradenton rain gage suggested that either the 3 or 5 year assessment cycle would result in a similarly low number of exceedances due to natural variability in rainfall in wet years and slightly more (4) in dry years (Table 3). In both cases the 3 year assessment cycle resulted in more violations than the 5 year cycle. Compliance assessment for the Myakka rain gage (Table 3) also suggested that either the 3 or 5 year assessment cycle would result in a similarly low number of exceedances due to natural variability in rainfall in both wet and dry years; however, again in both cases the 3 year assessment cycle resulted in more violations than the 5 year cycle. Compliance assessment for the Venice rain gage (Table 3) 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 a violation using the 3 year assessment cycle with more than twice the number of violations during La Niña but only slightly more for El Niño years (Figure 11; Table 4).

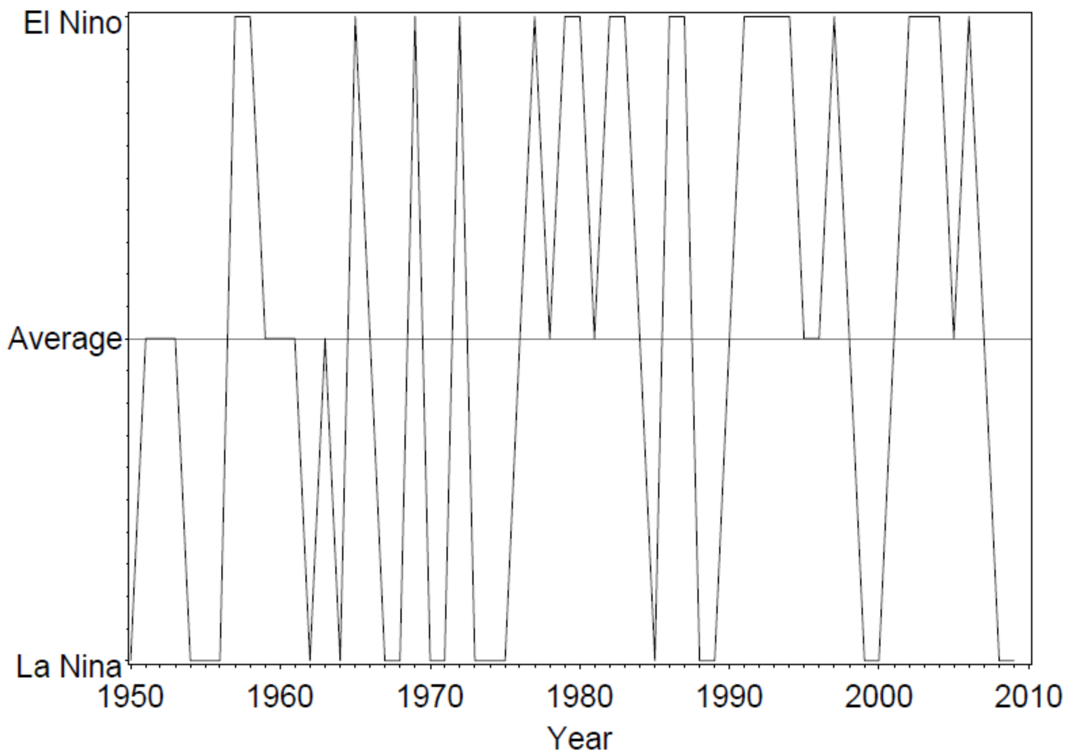

Figure 11. Results of annual classification of ENSO MEI data anomalies 1950-2008.

Table 3. Assessment of compliance length for rainfall data under the 3 year and 5 year rule.					
			5-Year Rule		
			Compliant	Exceedance	Total
Bradenton					
Wet	3-Year Rule	Compliant	40	0	40
		Exceedance	1	0	1
		Total	41	0	41
Dry	3-Year Rule	Compliant	36	1	37
		Exceedance	4	0	4
		Total	40	1	41
Myakka					
Wet	3-Year Rule	Compliant	53	0	53
		Exceedance	3	2	5
		Total	56	2	58
Dry	3 Year Rule	Compliant	57	0	57
		Exceedance	1	0	1
		Total	58	0	58
Venice					
Wet	3-Year Rule	Compliant	54	1	55
		Exceedance	1	2	3
		Total	55	3	58
Dry	3-Year Rule	Compliant	58	0	58
		Exceedance	0	0	0
		Total	58	0	58

Table 4. Assessment of compliance length for MEI data under the 3 year and 5 year rule.					
			5-Year Rule		
ENSO MEI			Compliant	Exceedance	Total
El Niño	3-Year Rule	Compliant	38	3	41
		Exceedance	6	9	15
		Total	44	12	56
La Niña	3-Year Rule	Compliant	44	2	46
		Exceedance	8	2	10
		Total	52	4	56

3.4 Recommendations

This investigation characterized natural variability in the hydrologic conditions in the Sarasota Bay Estuary Program watersheds using long-term rainfall records collected since the 1950s. This estimate of natural variability was 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 that a "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 Sarasota Bay Estuarine Numeric Nutrient Criteria: Assessment and Monitoring

It is recommended that the assessment of compliance with the proposed numeric nutrient criteria (Janicki Environmental, 2010a) 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 SBEP has determined that seagrasses are important indicators of desirable conditions in Sarasota Bay and has defined the water quality conditions (i.e., chlorophyll *a* concentrations) that allow for the maintenance and growth of seagrass beds in Sarastoa Bay. Therefore, the SBEP 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 Sarasota Bay Estuary Program region, monthly water quality monitoring at fixed monitoring sites has been underway since the mid to late 1990s for all five bay segments. These data were used in the development of water quality targets for the SBEP, and the TN and TP concentration-based criteria (Janicki Environmental, 2010a) 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 SBEP, 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, expressed as geometric means, 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 if such results obtain in the future the data compiled should be analyzed 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 year is relatively short. Median annual response times are three months or less in all segments, and average annual response times are three months or less in all segments. This indicates that the bay segments recover very quickly from normal loading events.
- The typical response times to unusual events, such as El Niño, are longer and, depending upon the timing of such events, can span over parts of two successive years.
- 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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