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memorandum

date March 7, 2018

to Tim Hall, Turrell, Hall and Associates, Inc.

from David Tomasko, Ph.D.
Emily Keenan, M.S.

subject Annual Report on Clam Bay Numeric Nutrient Concentration (NNC) Criteria

Executive Summary

Water quality data collected from Clam Bay between November 2016 and October 2017 were analyzed to determine the degree to which the waters of Upper, Inner and Outer Clam Bay are in compliance with relevant criteria. For nutrients, it was found that levels of phosphorous were out of compliance with existing site-specific criteria for Clam Bay. Levels of nitrogen were not out of compliance. Based on data from throughout the Clam Bay system, there is a positive correlation between phosphorous concentrations and the amount of algae in the water column, and an inverse correlation between phosphorous and levels of dissolved oxygen (DO). These results suggest that phosphorous concentrations are at potentially problematic levels in Clam Bay, and they should be carefully monitored, to ensure that conditions do not deteriorate. Should phosphorous continue to exceed established criteria; the County would benefit from the development of a detailed and data-rich phosphorus loading model, to develop appropriate management responses. Although this is supposition at this time, the temporal pattern of phosphorus exceedances suggests that nesting behavior of wading bird might better explain the temporal pattern of phosphorus enrichment than stormwater runoff. This potential link needs to be investigated in greater detail.

Levels of DO are problematic when compared to newly adopted criteria developed by the Florida Department of Environmental Protection (FDEP). For DO, 13 of the 98 samples had levels lower than existing guidance criteria from FDEP, a value in excess of the 10 percentile exceedance rate allowed by FDEP. For copper, 16 of 98 samples collected in Upper, Inner and Outer Clam Bay exceeded FDEP criteria for Class II marine waters. Based on this exceedance rate, the waters of Clam Bay would be determined to be “impaired” for copper. The majority of the copper impairments occurred within Upper and Inner Clam Bay, at stations 1, 2 and 3, and special attention should be placed on determining the potential cause(s) of elevated copper at those locations. The determination of copper exceedances in freshwater sampling sites in the watershed requires the simultaneous collection of data on “hardness”. Unfortunately, not all of the copper values from freshwater locations were accompanied by hardness values, so the degree of impairment cannot be fully investigated.

Future sampling should include measurements of water clarity for all Clam Bay sites, and measurements of hardness for all freshwater sampling sites.

Background

Over the past several decades, it has become well-established that an over-abundance of the plant nutrients nitrogen and/or phosphorous can have adverse impacts on the water quality and ecology of lakes, rivers and estuaries. Excessive nutrient supply can stimulate the growth of nuisance plants, creating nuisance algal blooms. In a system like Clam Bay, algal blooms can reduce water clarity, which is essential for the continued persistence of seagrass meadows, which provide food and shelter for the majority of recreationally and commercially important species of fish and invertebrates (such as crabs and shrimp). Once algal blooms die-off, their decomposition can reduce levels of DO, which is essential to most forms of aquatic life. Successful management of coastal waterbodies thus requires the collection, analysis and interpretation of results from water quality monitoring programs, particularly data related to nutrient amounts and sources.

Determination of Impairment Status

In 2012, the United States Environmental Protection Agency formally adopted nutrient concentration criteria for Clam Bay, as produced for Collier County, which had also been reviewed and approved by FDEP. The Numeric Nutrient Concentration (NNC) criteria produced for Clam Bay are termed Site Specific Alternative Criteria (SSAC) and they are listed in Florida Administrative Code (FAC) 62-302.531. The SSAC for Clam Bay was derived based upon a relationship between salinity and nutrients that was initially established at one of FDEP's "reference sites" in Estero Bay. The need to take into account salinity was based upon the finding that nutrient concentrations in estuaries and tidal rivers vary as a function of rainfall and runoff, as well as the amount of tidal influence. For example, even in FDEP's reference sites, which were chosen to represent waterbodies with little to no human impacts, nutrient concentrations are lowest on high tides, in areas close to passes, and during dry periods with little rainfall-generated stormwater runoff. Even in these reference sites, nutrient concentrations increase as one moves farther away from passes, as the tide falls, and during wet seasons and wet years. Therefore, a single nutrient concentration criterion does not make much sense, if water quality data from even pristine locations could potentially pass or fail proposed criteria simply as a function of location, tidal stage or antecedent rainfall.

The SSAC for Clam Bay therefore considers the concentration of nutrients, while also taking into account the salinity, such that a finding of elevated nutrients in combination with higher salinities is considered more problematic than elevated nutrients in combination with lower salinities. As such, the relationship between nutrients and salinity is determined as part of the process to determine if the waters of Clam Bay are "impaired" or not. Also, the frequency with which values exceed NNC criteria is taken into account when determining the appropriate management response, as is the amount of time over which an exceedance has occurred. For example, if nutrient concentrations were to exceed NNC criteria by a relatively small percentage, and if such an exceedance was to only last a short period of time, the appropriate management response would be different than if water quality was to exceed criteria to a larger extent, and if the condition of exceedance was to have lasted for a greater period of time. Therefore, the management response associated with any impairment determination is proportional, and based upon both the magnitude and duration of any exceedances.

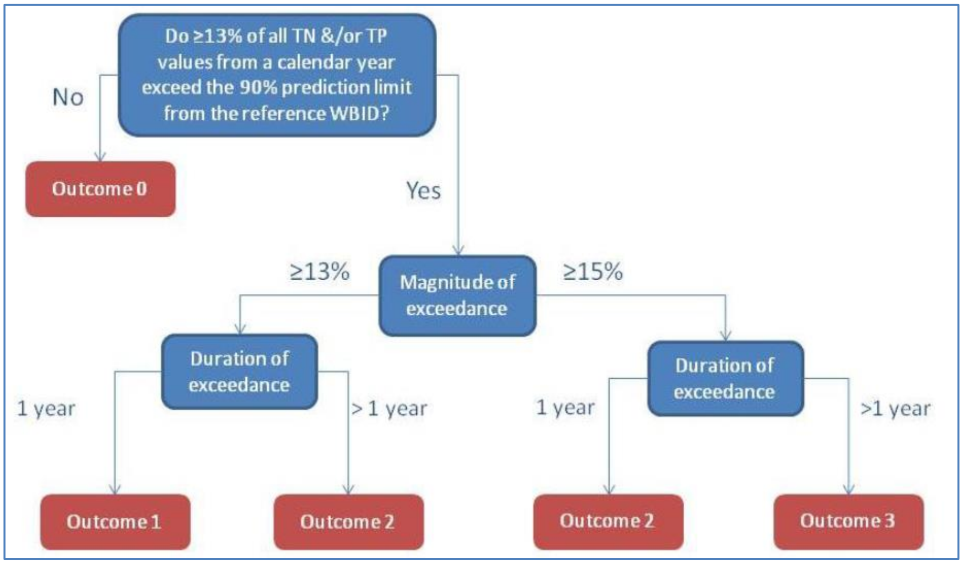
Based on prior work conducted in Clam Bay, it was found that the amount of floating microscopic algae (i.e., phytoplankton) in the bay was likely stimulated by both Total Nitrogen (TN) and Total Phosphorous (TP). Consequently, the amount of both TN and TP in Clam Bay is used to determine the degree of nutrient enrichment of Clam Bay's waters.

As outlined in FAC 62-302.531, the water quality status of waterbodies is to be determined on an annual basis, preferably within a calendar year. For this report, the data collection effort comprised 12 months of effort, but the 12 months did not fall within a single calendar year. Nonetheless, the compilation of results and the interpretation of results presented in this report should be fully consistent with that which would have occurred if the full 12 months of data had been collected in a single calendar year.

As outlined in FAC 62-302.532, for each year, each individual TN and TP value collected within Clam Bay is compared to an "upper boundary" of the expected relationship between those two variables and salinity, which was originally informed by the water quality data from an FDEP-designated reference water body. The formal name of the upper boundary condition is the "90th percentile prediction limit" which was originally derived for the relationship between nutrient concentrations and salinity in Clam Bay, and which is based on the determination by FDEP that Clam Bay's water (in 2012) was sufficient to protect its biological integrity. In other words, a TN or TP concentration higher than the 90th percentile prediction limit is a nutrient concentration higher than at least 90 percent of the values that would be expected, after taking into account the salinity value at the time that the water quality sample was collected.

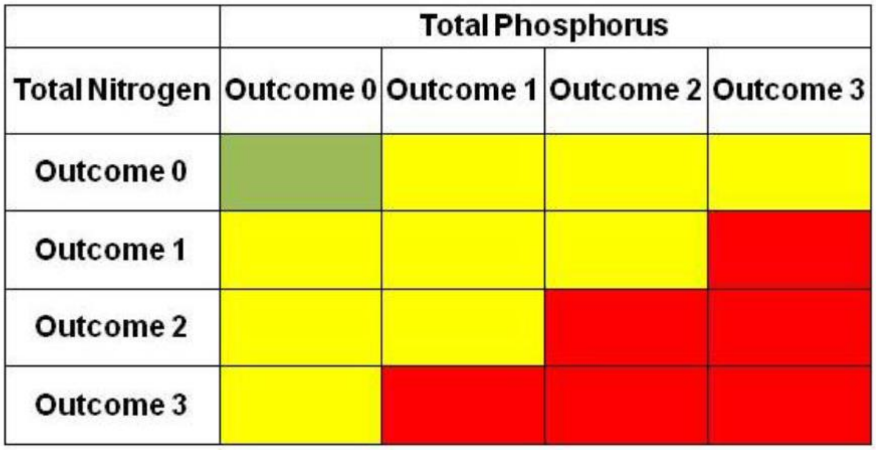
The number of occasions when a nutrient concentration is higher than the 90th percentile prediction limit is quantified for each year, and an annual percent exceedance is then calculated. To be consistent with methods currently used by FDEP, if more than 13 percent of TN or TP concentrations exceed the 90th percentile prediction limit (for a given year) then the year as a whole is classified as one where water quality is out of compliance with the existing criteria. If fewer than 13 percent of the values exceed the 90th percentile prediction limit, then water quality is not considered to be out of compliance. If more than 15 percent of TN or TP values exceed the 90th percentile prediction limit, then the degree of impairment is determined (as per FDEP guidance) to be more problematic than if only 13 percent of values exceeded the established criteria. The screening of water quality data against the adopted NNC criteria is performed as outlined in Figure 1, where different outcomes are given different scores, depending on the frequency of impairment, as well as the duration that the impairment has lasted.

Figure 1. Flow chart for determining water quality compliance in Clam.



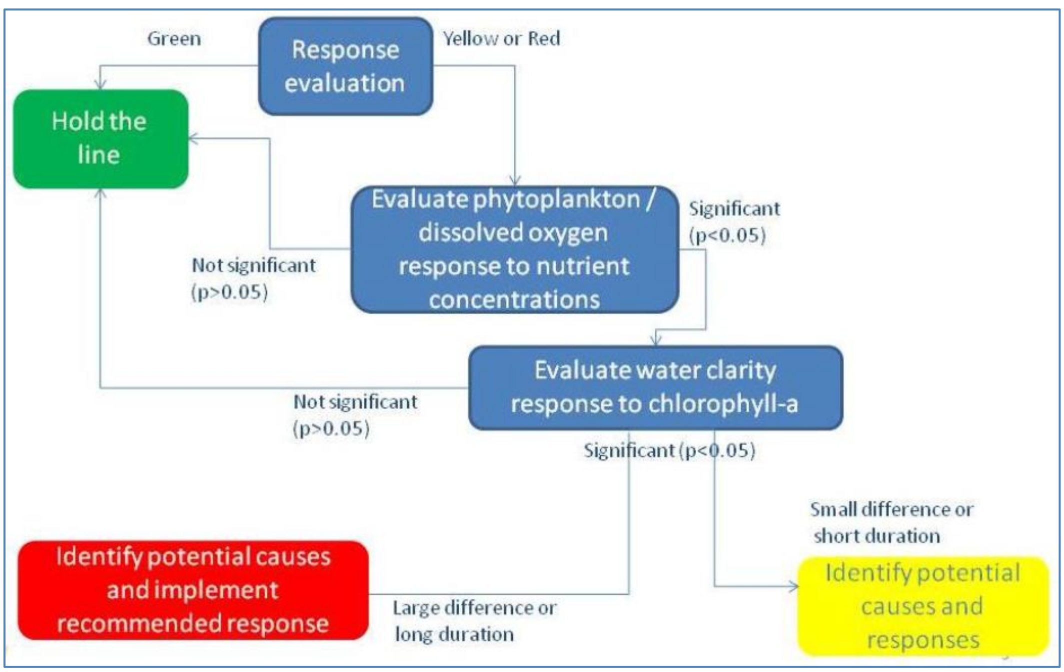
The possible outcomes displayed in Figure 1 are then compared for both TN and TP, and the combined outcomes are converted into designations of "green", "yellow" and "red" which correspond to an increasing need for concern (Figure 2).

Figure 2. Management response matrix using outcomes for TN and TP.



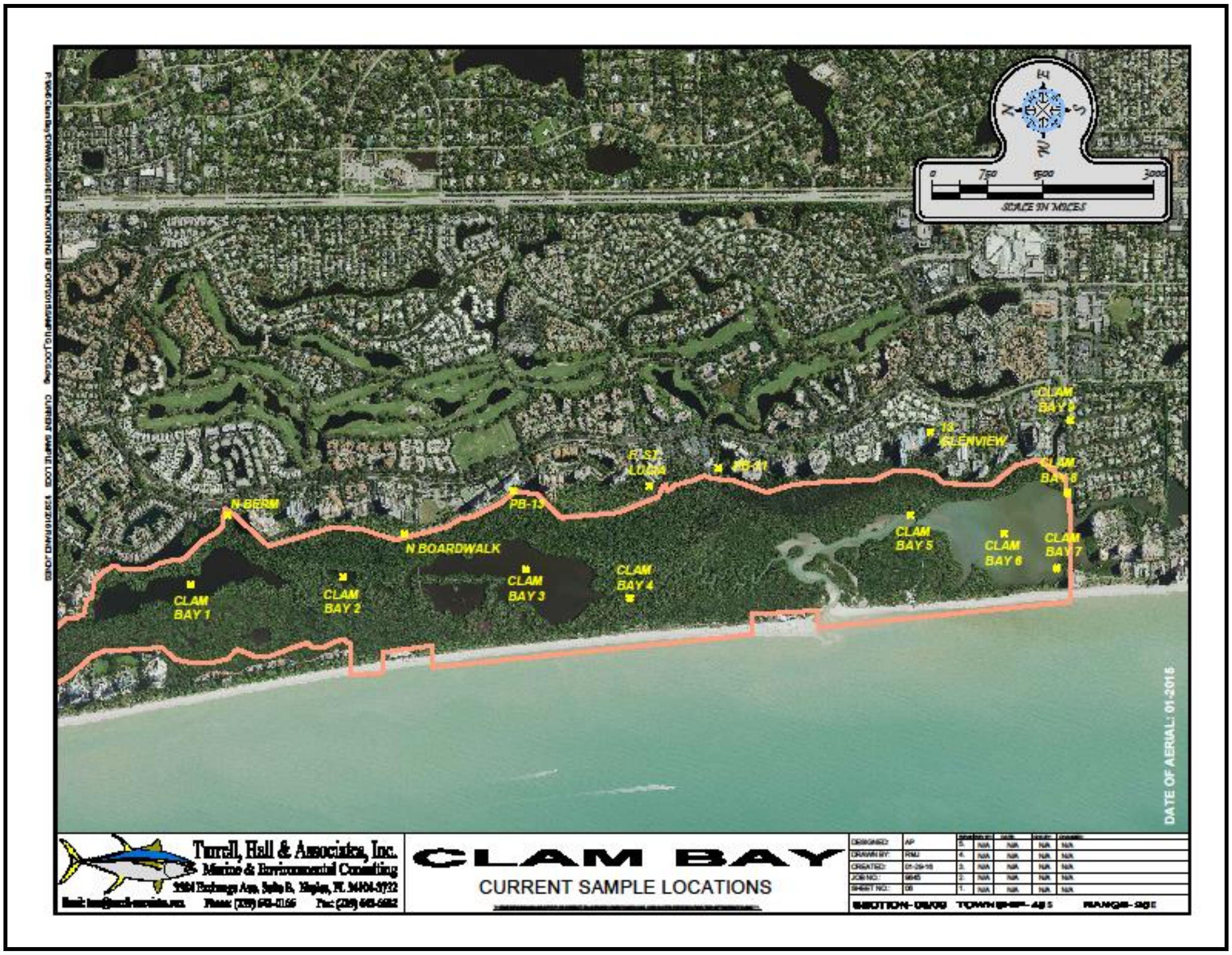
As a final step, the appropriate management response to water quality within a given year is then identified based on the results from Figure 2. For example, if water quality data suggest that TN and TP concentrations are elevated, then it is important to determine if the ecological health of Clam Bay appears to be adversely impacted by those nutrient concentrations. As a test of the impact of potential nutrient enrichment, water quality data would then be tested to determine if phytoplankton levels are perhaps higher, or dissolved oxygen levels lower, based on nutrient concentrations (Figure 3).

Figure 3. Management response actions in response to various outcomes



In this manner, management responses are proportional to the frequency and duration of exceedance conditions, as well as the determination of whether or not nutrient supply appears to be causing adverse water quality conditions. With this information as background, the rest of this report will focus on the analysis of water quality data collected during the period of November 2016 to October 2017, at nine open water locations shown in Figure 4. In addition to the open water sample sites, a number of sampling locations were located in the stormwater treatment ponds east of the mangrove fringe on the east side of Outer, Inner and Upper Clam Bays (Figure 4).

Figure 4. Locations of monthly monitoring stations sampled for Clam Bay and its directly adjacent watershed.



Data Analysis – Nutrient Status

The analysis conducted below was used to assess the water quality status of Clam Bay during the months of November 2016 to October 2017. While the period of analysis was not from a single calendar year, it does encompass twelve consecutive months of data collection. A monitoring event was not performed in September 2017 due to the landfall of Hurricane Irma in Immokalee, Florida. In addition, a sample was not collected at station Clam Bay 1 in October 2017 due to debris blocking access to the monitoring site. Therefore, a total of 98 water quality samples were reported within Clam Bay for the analysis period. Water quality data from Clam Bay and its watershed were provided by Turrell, Hall and Associates, Inc.

For comparison with the FDEP adopted SSAC for Clam Bay, as listed within FAC. 62-302-532, the water quality data set provided by Turrell, Hall and Associates was analyzed based on the following:

"No more than 10 percent of the individual Total Phosphorus (TP) or Total Nitrogen (TN) measurements shall exceed the respective TP Upper Limit or TN Upper Limit."

The Upper Limits for TP and TN concentrations noted above are derived based on Equations 1 and 2, respectively:

Equation 1: TP Upper Limit (mg/L)= $e^{(-1.06256-0.0000328465*\text{Conductivity}(\mu s))}$

Equation 2: TN Upper Limit (mg/L)= 2.3601 – 0.0000268325*Conductivity(µS)

The nutrient dataset examined was supplemented with *in situ* water quality data (e.g., temperature, dissolved oxygen, pH, conductivity, and salinity) retrieved from the chain of custody forms for each sampling event. TN and TP concentrations were compared to the derived upper limit thresholds to quantify the presence or absence of elevated concentrations of TP and/or TN, with results listed in (Appendix A).

Over the period analyzed (November 2016 to October 2017), a total of three (3) ambient water quality values for TN exceeded the respective TN Upper Limit, for an exceedance frequency of approximately 3 percent. In comparison, 33 of the 98 TP measurements (approximately 34 percent) exceeded their respective TP Upper Limit. Based on these results, the frequency of exceedance would not be high enough for the waters of Clam Bay to be determined to be impaired for TN, but those same waters would be determined to be impaired for TP.

Table 1 displays the results in a manner intended to allow for a quick visualization or results by month and by station. Sampling locations and months are color coded as to the results, with green representing "passing" values, boxes with an "x" representing data that numerically exceed established criteria. In addition, boxes in yellow represent values within the error rate (i.e., ± 5 percent) of threshold criteria, whether in exceedance, or slightly below exceedance.

Table 1. Representation of frequency of impairment for TN and TP for different site and date combinations. Green represents sample clearly not out of compliance with criteria. Boxes with "x" represent values out of compliance with criteria. Boxes in yellow with "x" represent data out of compliance, but within the range of resolution of laboratory values (i.e., ± 5 percent) and/or rounding errors. Boxes in yellow but without "x" represent values in compliance, but also within range of resolution of laboratory values (i.e., ± 5 percent) and/or rounding errors. Clear cells represent a lack of data.

Month	1		2		3		4		5		6		7		8		9	
	TN	TP	TN	TP	TN	TP	TN	TP	TN	TP	TN	TP	TN	TP	TN	TP	TN	TP
Nov-16				x														
Dec-16												x						
Jan-17																		
Feb-17		x		x				x		x								
Mar-17		x		x		x				x								x
Apr-17	x	x		x								x		x				
May-17		x		x		x		x		x		x		x		x		x
Jun-17						x										x		x
Jul-17																		
Aug-17																		
Sep-17																		
Oct-17								x	x	x		x		x		x	x	x

The overall pattern shown in Table 1 is that of reduced frequencies of exceedance of criteria for TN, compared to TP. As well, the months of November 2016 to January 2017 and then July to August 2017 had relatively low rates of exceedance. The months of February to May had, on average, the highest rates of exceedance of nutrient criteria, usually for phosphorus. These results suggest that nutrient impairment may not be driven by stormwater runoff alone, as the months of February to May are typically some of the drier months in Southwest Florida. In contrast, the months of July and August of 2017 exhibited lower rates of exceedance, even though they typically represent times of maximal runoff of stormwater from the Clam Bay watershed.

A possibility, worthy of further investigation, is whether or not the trend of elevated phosphorus concentrations might reflect seasonal changes in the abundance of wading birds, and in particular the nesting habits of wading birds. In a study titled "South Florida Wading Bird Report" it was noted that wood storks (*Mycteria americana*) typically initiate nesting in South Florida in the months of February to March (Cook 2016). Other species, such as White Ibis (*Eudocimus albus*) and herons within the genus *Egretta* nest somewhat later, up to April, but they extend their nesting behavior until May or June, if the wet season starts later in the year (Cook 2016). Thus, the abundance of wading birds, particularly nesting pairs and their offspring, may have an influence on water quality not only in Clam Bay, but in the nearby ponds that drain into Clam Bay. Bird guano has an exceptionally high phosphorus content, which could explain the apparent concurrence between those months with the greatest frequency of impairment for phosphorus (February to June) and those months where wading bird nesting in South Florida is at a seasonal high (February to May).

Since the TP exceedances have occurred in two consecutive reporting periods, the outcome from the flowchart shown in Figure 1 would that of a score of "3" for TP, compared to a score of "0" for TN (Figure 2). With two years' worth of data, the combination of outcome "3" for TP and outcome "0" for TN would result in a "yellow" management response, as illustrated in Figure 3. Since the TP exceedance rate was greater than 15 percent, then the "yellow" management response would be the outcome for this first year's data collection effort. Consequently, the following additional data investigations were conducted:

- Determining the relationship, if any, between TP and chlorophyll-a
- Determining the relationship, if any, between TP and dissolved oxygen
- Determining the relationship, if any, between chlorophyll-a and water clarity

Depending upon the findings of the analyses listed above, management implications would be developed, which could include the need to determine the basis for a potential adverse impact on water quality.

A review of the last 12 months of data indicated a direct relationship between TP and chlorophyll-concentrations (Figure 5) as well as an inverse relationship between TP and DO (Figure 6). As measurements of water clarity were not available for review, water clarity data was not included in the reviewed data sheets. Unfortunately, this did not allow for the determination of whether or not there was a correlation between chlorophyll-a concentrations and water clarity. As such, we were unable to evaluate the influence of chlorophyll-a on water clarity in Clam Bay.

Figure 5. Relationship between total phosphorus and chlorophyll-a over the period of November 2016 to October 2017 in Clam Bay (p<0.0001).

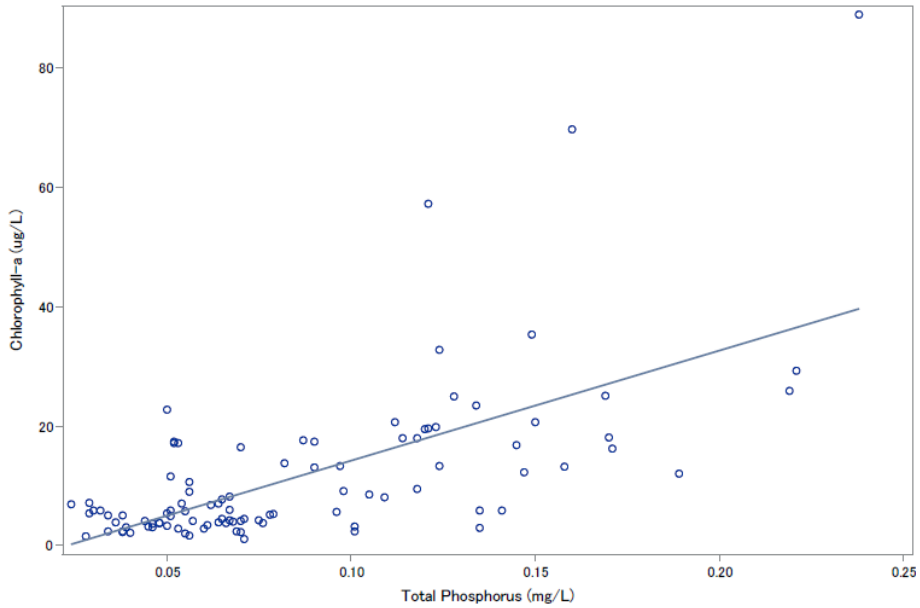
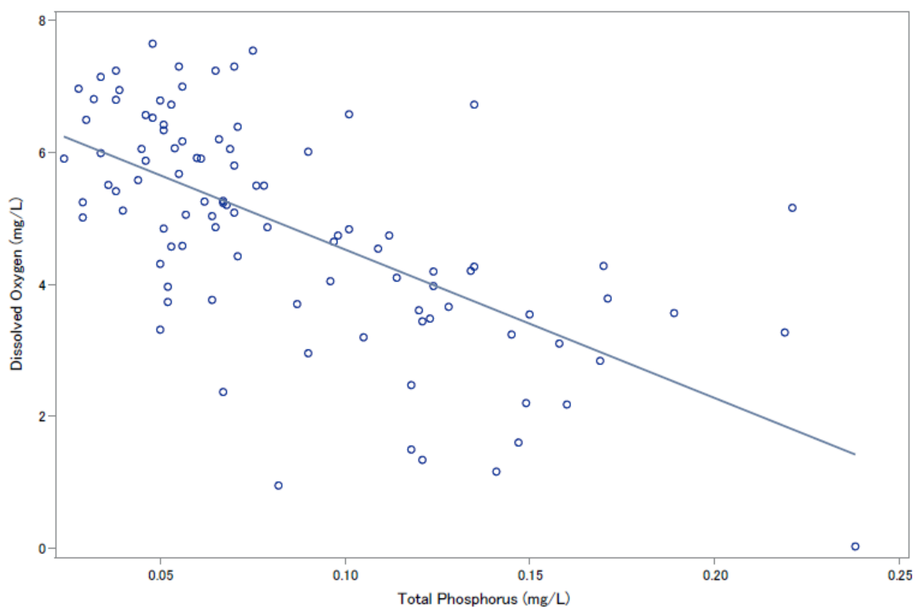


Figure 6. Relationship between total phosphorus and dissolved oxygen over the period of November 2015 to October 2016 in Clam Bay (p<0.001).



In addition to the data assessments described above, data from Clam Bay outfall monitoring stations were compared to the proposed Downstream Protective Values (DPV) derived for Clam Bay (PBS&J 2011). Outfall TN and TP concentrations were compared to the median and 90th percentile DPV values to determine if elevated concentrations were found at those locations (Appendix B). The median DPV quantity represents a value that would be expected to be exceeded approximately 50 percent of the time, while the 90th percentile value represents a concentration sufficiently high that only 10 percent of values would be expected to be higher. Using this approach, the amount of TN or TP in the water column at stations sampled in the Clam Bay watershed can be compared to criteria that are meant to be protective of the open waters of Clam Bay. The TN and TP concentrations in DPV estimates are expected to be higher than concentrations in the open waters of Clam Bay, as the influence of the more saline and lower nutrient content waters of the Gulf of Mexico would not yet have diluted the higher nutrient concentrations found in freshwater inflows from the watershed. The median and 90th percentile DPVs for TN are 1.31 and 1.8 mg/L, respectively. The median and 90th percentile DPVs for TP are 0.10 and .25 mg/L, respectively.

For data collected at the outfall monitoring sites, 53 and 17 percent of the TN concentrations exceeded the median and 90th percentile DPV values for TN, respectively (Table 2). For those same outfall monitoring sties, 83 and 32 percent of the TP concentrations exceeded the median and 90th percentile DPV values, respectively (Table 1).

Table 2. Percentage of TN or TP concentrations from outfall stations which exceeded the median or 90th percentile DPV values.

DPV	***Total Nitrogen***		***Total Phosphorus***	
	Median	**90th Percentile**	**Median**	**90th Percentile**
Below	47	83	17	68
Exceed	53	17	83	32

Results – Nutrient Status

Based on the data collected from this year's monitoring efforts, the waters of Clam Bay do not appear to be problematic in terms of nitrogen, but they do exceed regulatory criteria for phosphorous. The abundance of phosphorous positively correlates with chlorophyll-a concentrations in Clam Bay, which suggests that the availability of phosphorous influences the amount of phytoplankton in Clam Bay. Also, increased phosphorous concentrations are inversely correlated with levels of dissolved oxygen in Clam Bay.

Data collected from the outfall monitoring stations suggest that nitrogen concentrations are somewhat elevated, but that most of the elevated concentrations of nitrogen are from the highest values recorded, rather than there being a "typical" condition of elevated nitrogen enrichment. For phosphorous, elevated concentrations are found both in typical conditions and also amongst the highest concentrations, compared to guidance criteria.

These results strongly support the recommendation that the watershed and open waters of Clam Bay should continue to be monitored on a regular basis, as there is the possibility that phosphorous loads, in particular, could become problematic to the water quality and ecosystem health of Clam Bay, particularly if phosphorous concentrations were to increase over time.

Additionally, as nutrient concentrations vary as a function of the balance between stormwater runoff and mixing with the waters of the Gulf of Mexico, the tidal prism for the Clam Bay system should be maintained such that it continues to allow for sufficient tidal exchange of the waters of Upper, Inner and Outer Clam Bay.

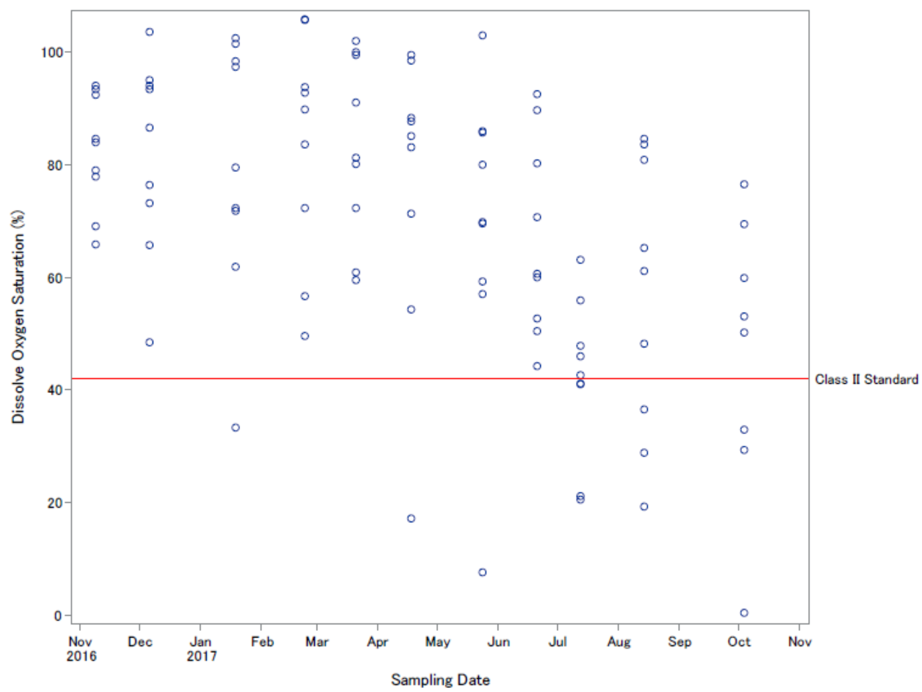
Results – Dissolved Oxygen

For levels of DO the applicable regulatory criterion, as outlined in FAC 62-302.533, is that minimum DO levels (for Class II waters like Clam Bay) shall not be lower than 42 percent saturation more than 10 percent of the time (for average daily values) or that 7-day average values shall not be below 51 percent saturation more than once in any 12-week period, or that the 30-day average DO percent saturation shall not be below 56 percent more than once per year.

The less-restrictive 7-day and 30-day criteria require DO measurements to be made over a 24 hour period, which is not applicable for comparison with water quality data collected at a single time of day, once a month. As such, the more restrictive criterion was used for Clam Bay, and DO values (in units of percent saturation) were compared against the 42 percent saturation value.

Results are shown in Figure 7.

Figure 7. Dissolved oxygen values (percent of 100 percent saturation) for nine stations in Clam Bay, over the period of November 2016 to October 2017.



Since DO values were collected at nine stations for eleven months (n = 98) it would take 10 values below 42 percent saturation for Clam Bay to be considered to be out of compliance with the DO criteria listed in FAC 62-302.533. Thirteen values show DO at lower than 42 percent saturation, the majority of which occurred during the months of July to October. Based on these results, the waters of Clam Bay would be considered to be out of compliance with existing DO criteria. Of the thirteen depressed values, five were reported at the Clam Bay 2 monitoring location, which is located in a narrow channel between Upper Clam Bay and Inner Clam Bay (Table 3).

Table 3. Dissolved Oxygen Saturation values at sites Clam Bay 1 to 9, in units of %. Values highlighted in yellow are below the criteria for Class II waters (42%).

Station	1	2	3	4	5	6	7	8	9
11/9/2016	65.9	69.1	92.5	84.0	94.1	93.5	79.0	84.7	77.9
12/6/2016	65.8	48.5	73.2	86.6	103.6	95.1	93.5	94.1	76.5
1/19/2017	61.9	33.3	72.4	102.5	98.4	97.4	101.6	79.5	71.9
2/23/2017	49.6	56.7	72.4	93.8	105.8	89.9	105.9	92.8	83.7
3/21/2017	59.6	60.9	102.1	91.1	100.1	99.6	80.2	81.3	72.4
4/18/2017	54.3	17.2	98.6	88.4	99.5	87.7	85.1	83.2	71.3
5/24/2017	69.9	57.1	80.1	85.8	103.0	86.0	69.6	7.6	59.3
6/21/2017	44.2	50.5	60.6	80.3	92.6	89.8	70.7	60.0	52.7
7/13/2017	47.9	20.5	42.7	41.0	56.0	46.0	63.1	21.1	41.1
8/14/2017	28.9	19.3	36.5	48.2	84.7	80.9	83.6	61.2	65.2
10/4/2017	-	0.4	29.3	33.0	76.6	69.5	59.9	53.1	50.2

Results - Copper

For levels of copper, there are different criteria used for marine waters vs. freshwater systems such as stormwater ponds. For marine waters, the standard, as listed in FAC 62-302.530, is that concentrations are not to exceed 3.7 µg / liter. However, the State of Florida's Impaired Waters Rule (FAC 62-303) allows for a certain amount of "exceedances" to occur, before water quality is considered to be out of compliance. Table 4 summarizes the data collected from all stations, from November of 2016 to October of 2017, for Stations Clam Bay 1 to Clam Bay 9, all of which are located in the open waters of Upper, Inner or Outer Clam Bay.

Table 4. Copper values at sites Clam Bay 1 to 9, in units of μg / liter. Values highlighted in yellow exceed copper criteria for Class II waters (3.7 μg Cu / liter).

Station	1	2	3	4	5	6	7	8	9
11/9/2016	**2.34**	**3.39**	**2.30**	**2.25**	**1.63**	**1.50**	**1.18**	**2.03**	**1.30**
12/6/2016	**2.33**	**2.93**	**5.10**	**2.45**	**2.39**	**1.78**	**1.27**	**1.88**	**1.72**
1/19/2017	**2.57**	**3.56**	**2.11**	**1.99**	**0.82**	**0.80**	**0.96**	**1.11**	**2.02**
2/23/2017	**2.51**	**3.35**	**1.60**	**1.12**	**0.85**	**0.85**	**1.50**	**2.57**	**2.60**
3/21/2017	**7.97**	**4.08**	**1.71**	**1.12**	**0.89**	**0.85**	**1.08**	**1.09**	**0.96**
4/18/2017	**6.48**	**8.16**	**1.62**	**1.24**	**0.80**	**0.96**	**1.28**	**1.01**	**1.10**
5/24/2017	**2.84**	**4.06**	**4.99**	**0.80**	**0.80**	**0.96**	**0.80**	**0.92**	**0.95**
6/21/2017	**3.84**	**4.24**	**3.85**	**0.91**	**1.20**	**1.14**	**1.26**	**1.11**	**0.76**
7/13/2017	**4.70**	**2.95**	**3.80**	**4.08**	**2.50**	**2.44**	**2.37**	**2.38**	**2.21**
8/14/2017	**4.29**	**3.81**	**3.22**	**2.65**	**1.40**	**1.22**	**1.47**	**1.02**	**0.70**
10/4/2017	**.**	**2.68**	**1.27**	**0.60**	**0.80**	**12.60**	**1.61**	**0.60**	**0.60**
mean	3.99	3.93	2.87	1.75	1.28	2.28	1.34	1.43	1.36
median	3.34	3.56	2.3	1.24	0.894	1.14	1.27	1.11	1.1
N	10	11	11	11	11	11	11	11	11
#> 3.7	5	5	4	1	0	1	0	0	0
% > 3.7	50%	45%	36%	9%	0%	9%	0%	0%	0%

Of the 98 samples collected for copper, 16 of them exceeded the established criteria of 3.7 μg / liter. Based on guidance in Table 3 of FAC 62-303, if a water body has between 97 and 104 samples collected, it would be determined to be out of compliance if 15 values exceeded established criteria. For Clam Bay, 16 of 98 samples collected in Upper, Inner and Outer Clam Bay exceeded FDEP's criterion for copper, which is sufficient for Clam Bay to be determined to be out of compliance for copper.

Elevated copper concentrations were observed more frequently stations 1, 2 and 3, which are located in Upper Clam Bay down to Inner Clam Bay, and where the immediate shoreline is that of a natural mangrove fringe. It would be helpful to determine the reason(s) for elevated copper at these stations, as they are responsible for more than 90 percent of the exceedances of copper criteria in the entire Clam Bay system.

The determination of copper exceedances in freshwater sampling sites in the watershed requires the simultaneous collection of data on "hardness". Unfortunately, most of the copper values from freshwater locations do not appear to have been accompanied by hardness values, so the degree of impairment cannot be fully investigated. However, 35 of the 61 samples from freshwater locations included results on hardness, and those data are analyzed below.

The water quality standard for copper differs between predominately marine waters and freshwater. As classified by FDEP, open waters of Clam Bay have a water quality standard for copper of < 3.7 μg /

liter. In contrast, the copper standard for freshwater is more complicated, as it requires the concurrent recording of a value for “hardness” in units of mg $CaCO_3$ / liter. The toxicity of copper is mostly restricted to the abundance of the copper ion, and the greater the abundance of other dissolved compounds, the lower the probability that free copper ions will be available to bind with cell membranes, etc. and cause direct and indirect biological impacts. Briefly stated, the higher the hardness level of a water sample, the lower the probability that a given level of copper will be toxic.

Once the level of hardness is determined, the copper criterion for a sample collected from freshwater is derived as:

$$\text{Copper standard (mg / liter)} = e^{(0.8545[\ln H]-1.702)}$$

Where:

e = the base of the natural logarithm (ca. 2.718281), and
lnH = natural log of hardness (in units of mg CaCO3 / liter)

Thus, the determination of whether a sample meets or exceeds the water quality standards for copper only requires determination of the concentration of copper for marine samples; a concurrent value for hardness is required to determine compliance with freshwater criteria

In the data set examined it appears that there were only 35 date and location combinations for freshwater stations where both hardness and copper levels were analyzed. Those stations and date combinations include the following:

- The site “Glenview” on the dates of 2/28/2017, 5/22/2017, 6/22/2017, 7/12/2017, 8/15/2017 and 10/3/2017
- The site “PB-11” on the dates of 2/28/2017, 5/22/2017, 6/22/2017, 7/12/2017, 8/15/2017 and 10/3/2017
- The site “PB-13” on the dates of 6/22/2017, 7/12/2017, 8/15/2017 and 10/3/2017
- The site “N-Boardwalk” on the dates of 2/28/2017, 5/22/2017, 6/22/2017, 7/12/2017, 8/15/2017 and 10/3/2017
- The site “N-Berm” on the dates of 2/28/2017, 5/22/2017, 6/22/2017, 7/12/2017, 8/15/2017 and 10/3/2017
- The site “St. Lucie” on the dates of 5/22/2017, 6/22/2017, 7/12/2017, 8/15/2017 and 10/3/2017
- The site “N-41 PIPE” on the dates of 6/22/2017 and 7/12/2017

Copper concentrations at the sites Glenview, N-Berm, N-Boardwalk and St. Lucia exceeded the hardness-normalized copper criteria for Class III freshwater systems during at least one monitoring period. Typically, levels of copper were many times higher than impairment thresholds. These stations are located within the series of open water features on the west side of the Pelican Bay development, just east of the mangrove fringe that separates Clam Bay from its developed watershed. In contrast, none of the copper values from sites N-41, PIPI, PB-11, or PB-13 exceeded criteria for Class III freshwaters.

Recommendations

For the waters of Upper, Inner and Outer Clam Bay, water quality monitoring should continue at the same nine stations locations sampled in the reviewed data set. For determining compliance with nutrient criteria, chlorophyll-a should continue to be collected (and be corrected for phaeophytin) along with both Total Nitrogen and Total Phosphorous. To ensure results can be compared to NNC criteria established specifically for Clam Bay, values of specific conductance also need to be collected, as they were here.

Future sampling should include measurements of water clarity for Clam Bay sites 1 through 9, through the use of a Secchi disk or through the direct measurement of light attenuation coefficients.

If phosphorous concentrations continue to be elevated, a more detailed pollutant loading model should be developed, so that loading sources could be identified and appropriate management responses developed. This loading model should include the potential for wading bird populations to be a significant factor, since the overall temporal pattern appears to be that phosphorus concentrations correlate better with presumed populations of wading birds than with stormwater runoff.

For copper, the sampling sites in Upper and Inner Clam Bay should be investigated in greater detail, as that these three stations (of 9 total stations) are responsible for more than 90 percent of copper impairments in the Clam Bay system. As well, measurements of copper in freshwater ponds need to have concurrent measurements of hardness, as impairment determination in freshwater samples requires the “normalization” of copper values to the level of hardness in the water. Based on the locations where copper and hardness values were both recorded, it appears that levels of copper are elevated (often to a considerable degree) in the open water features to the east of the mangrove fringe that separates the developed watershed of Clam Bay from the marine waters of Clam Bay. The source(s) of the copper in these ponds should be determined, as those sources could also be impacting the waters of Clam Bay itself, particularly in the wet season.