Appendix 5B-4: Potential Implications of Lake Okeechobee Water Quality on Releases to the STAs

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In Water Year 2014 (WY2014; May 1, 2013–April 30, 2014) and WY2015, the Everglades Stormwater Treatment Areas (STAs)—STA-1 East (STA-1E), STA-1 West (STA-1W), STA-2, and STA-3/4—received increased volumes of Lake Okeechobee regulatory releases for treatment and delivery into the water conservation areas (WCAs). In WY2014, approximately 175,000 acre-feet (ac-ft) of lake water was conveyed to the STAs. In WY2015, the District conveyed approximately 585,000 ac-ft of Lake Okeechobee water to the Everglades STAs and downstream WCAs. The WY2015 volume was unprecedented and occurred, in part, because of atypical rainfall patterns. The South Florida Water Management District (District or SFWMD) experienced above average rainfall north of Lake Okeechobee and below average rainfall in the WCAs and Everglades (see Chapter 2 of this volume for details). The 2008 Lake Okeechobee Regulation Schedule (LORS2008) called for maximum discharges to the WCAs for all but a few weeks in late May and early June 2014 (see Chapter 8 of this volume). Therefore, due to a lower amount of stormwater from the basin, the STAs were able to take the relatively large volume of lake releases. Analyses pertaining to the effects of lake releases on the STAs in WY2015 are included in the main chapter (Chapter 5B of this volume). In previous years, the amount of flows from the lake was limited, except in WY2003 when high volumes of lake releases were sent to the STAs. Prior to WY2014, the STAs received very little flows during the dry season, and received lake water during the dry season only for hydration purposes.

Isolating the effects of lake releases to the STAs is difficult because a multitude of other factors affect STA condition and performance. The purpose of this report is to summarize key water quality characteristics of Lake Okeechobee water that could have potential implications on STA conditions (e.g., vegetation or floc accretion) or performance over short- and long-term periods. Specifically, data were analyzed for total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), turbidity, and calcium (Ca) for the following structures: (1) S-352, which can discharge into STA-1E and STA-1W; and (2) S-351, which can discharge into STA-2 via the S-6 inflow structure and STA-3/4 via the G-370 inflow structure (**Figure 1**). Samples were collected upstream of the lake discharge structures as part of the District's routine Water Quality Monitoring Program. Two other lake structures convey water south to the STAs, i.e., CULV10A (to STA-1E and STA-1W) and S-354 (to STA-3/4 via G-372 and STA-2 via G-434).

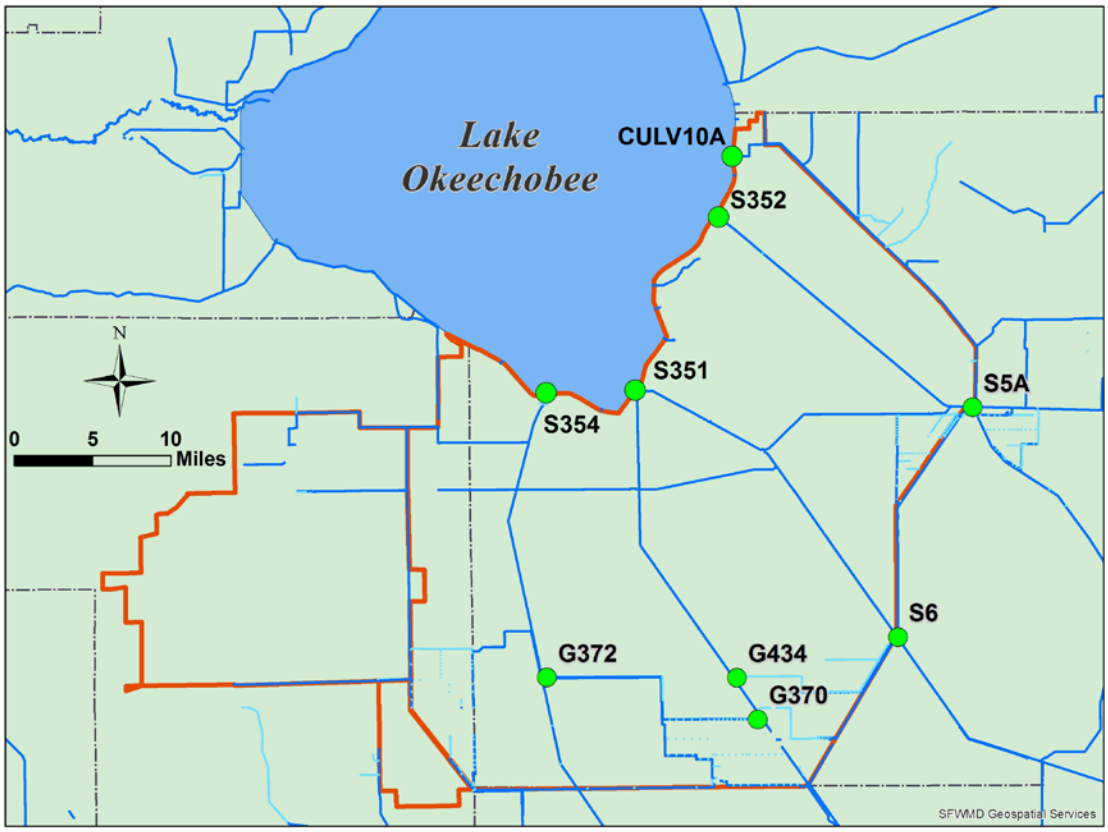

Figure 1. Relative location of main discharge structures at Lake Okeechobee used during regulatory releases to the Everglades STAs.

PHOSPHORUS

Inflow loading rate and, to a lesser extent, inflow concentrations have been reported as two key factors affecting STA performance (Chen et al. 2015, Kadlec 2006, Dunne et al. 2012). Since the hurricanes of 2004 and 2005, the annual average in-lake TP concentrations have declined from a high of 233 parts per billion [ppb; 0.2 parts per million (ppm)] in WY2005 to 92 ppb (0.09 ppm) in WY2012 (Zhang and Sharfstein 2013). However, the period of record (POR) data for S-352 indicates that water TP is generally higher and more variable in the dry months (November–April) (**Figure 2**). TP values greater than 0.4 ppm are more common in this period, and values greater than 0.7 ppm have been observed in November, December, January, and April. This is attributed primarily to strong wind events, typical in the dry months that stir up the sediment and cause particulates to be suspended, thereby elevating particulate phosphorus (PP) and TP concentrations (Maceina and Soballe 1990). In contrast, SRP was highest and most variable in the wet season (**Figure 2**). Based on the corresponding increases in turbidity and TSS at this location during the same time period, this suggests that the increased TP observed during the dry months is primarily due to increase in particulate-bound phosphorus (P). Reddy et al. (1995) reported that P-laden mud sediments in Lake Okeechobee cover approximately 45 percent of the lake bed, with the highest levels of P on the open water area on the eastern region, while the lowest levels are found on the western and southern regions where majority of the lake's littoral areas are located.

At the S-351 structure, where water arriving at the structure passes through a more sheltered region of the lake with dense vegetation, the POR monthly TP concentrations are lower and less variable than at S-352, which discharges directly from the open water region on the eastern side

of Lake Okeechobee (**Figure 3**). Concentrations and variability tend to be greatest during the rainy season, although the levels are mostly below 0.25 ppm, in contrast to the higher concentrations at S-352.

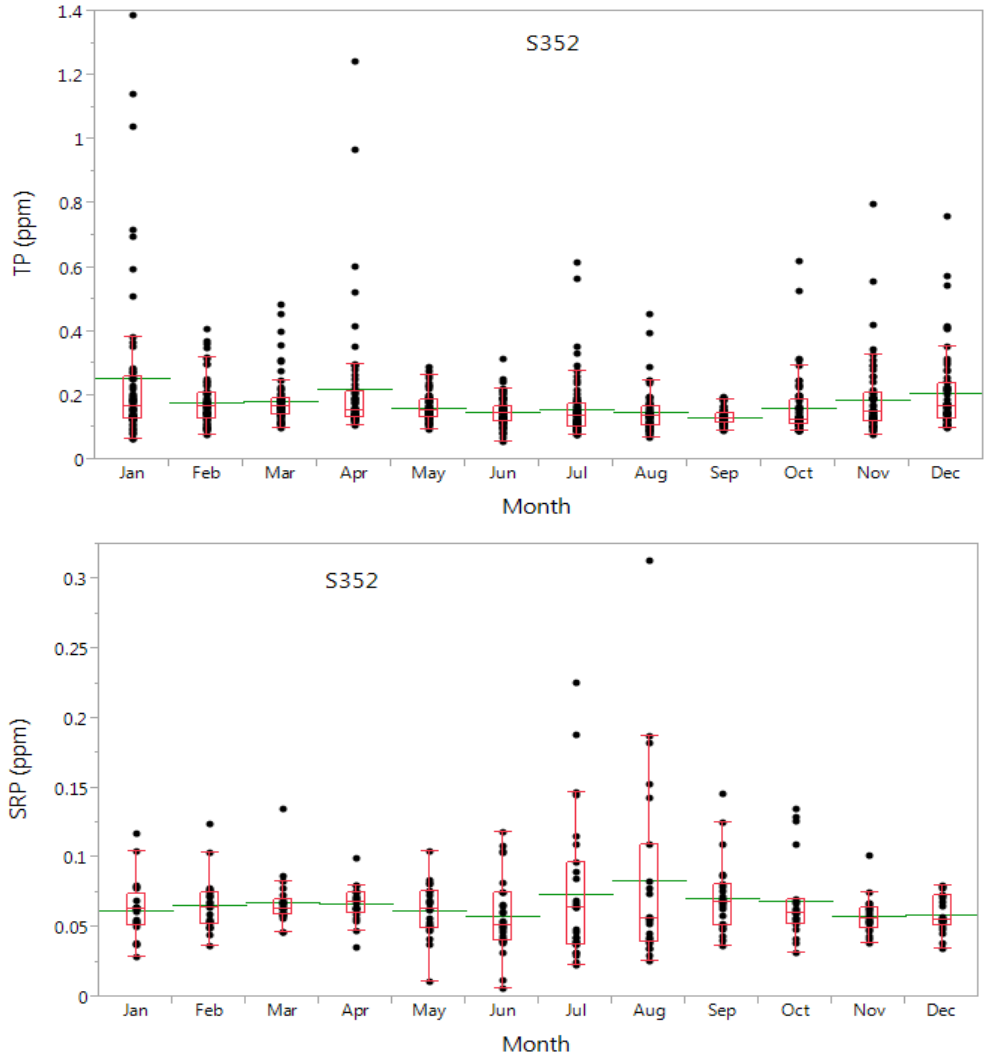

Figure 2. POR monthly TP (top panel) and SRP (bottom panel) concentrations at the S-352 Lake Okeechobee discharge structure. Each dot represents measured data, the box represents the upper and lower quartiles, red line across each bar represents the median value, green line represents mean, and red whiskers represents minimum and maximum values. Dots above the maximum line are outlier values.

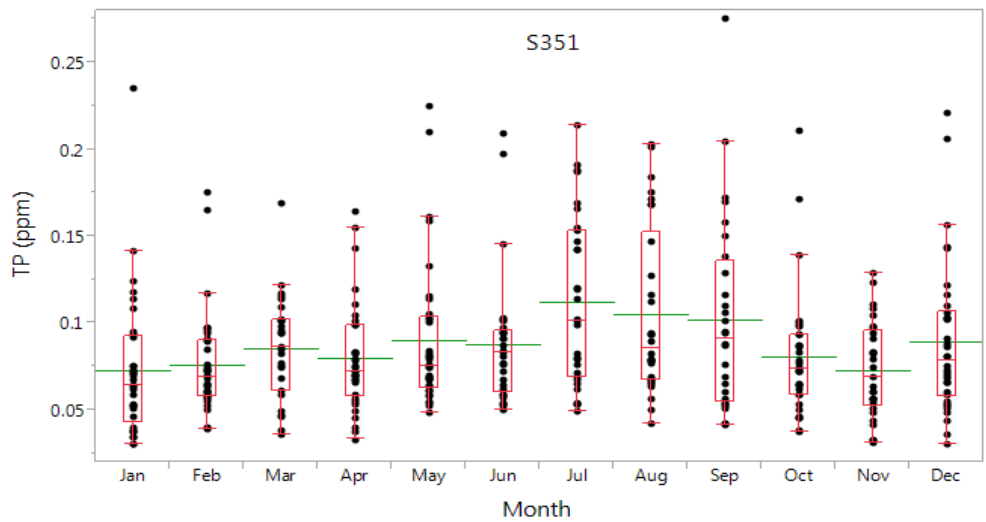

Figure 3. POR monthly TP concentrations at the S-351 Lake Okeechobee discharge structure.

The P loading rate (PLR) from lake releases can increase with increased volume of flows and increased P concentrations in the lake water, particularly in the dry months when sediment is stirred and high turbidity is persistent. In WY2015, the effects of increased loading rates were most notable in STA-2 Flow-way 1, where the 365-day PLR increased from < 0.8 grams per square meter per year ($g/m^2/year$) at the start of the water year to 2 $g/m^2/year$ by February 2015, and the outflow flow-weighted mean concentration (FWM) TP concentration increased from < 10 ppb to 25 ppb by March 2015. However, the overall PLR for STA-2 remained low but doubled from the beginning (0.4 $g/m^2/yr$) and end of the water year (0.8 $g/m^2/yr$), which is just slightly above the design PLR for the Restoration Strategies Program (see Chapter 5A of this volume). The PLR for Flow-ways 1, 2, and 3 were higher than the target PLR. During WY2015, the lack of extreme storm or high rainfall events allowed the District to send approximately 585,000 ac-ft of lake water, distributed among multiple flow-ways to regulate, as much as possible, the P loading into the STAs. In March 2015, as the treatment performance of this flow-way declined significantly, lake releases were terminated. Monitoring and management actions for future lake releases into the STAs should consider inflow concentrations and P loading to avoid impacts on the performance of individual flow-ways.

CALCIUM

Ca is evaluated in this report due to concerns about the potential effects of lower Ca levels in Lake Okeechobee water compared to runoff water that flows into the STAs. Ca is important for SRP reduction in wetlands as well as for periphyton growth, but the effects of Ca vary. Ca-related P reduction in an alkaline wetland environment may occur via two main pathways: sorption of P on calcareous soil particles, limestone surfaces, and marl-based detrital material, and co-precipitation with Ca in the water column or porewater (Gumbricht 1993). Under the right conditions (e.g., high pH, abundance of Ca, and presence of SRP), P will co-precipitate with Ca or magnesium in more alkaline systems (Reddy and DeLaune 2008). Linear relationships between P accumulation and Ca accumulation have been discussed in available literature (Reddy et al. 1993, Scinto and Reddy 2003). Documentation of the Dynamic Model for Stormwater Treatment Areas indicated that the first order P removal rate, *k*, is weakly correlated with inflow Ca concentrations based on data from some of the STA cells and WCAs (Walker and Kadlec 2005).

In wetland systems, when water column Ca and alkalinity levels are sufficiently high, pH elevations lead to calcium carbonate ($CaCO_3$) supersaturation and precipitation (Otsuki and Wetzel 1972). While high pH (e.g., pH > 8) required for insoluble Ca-P minerals to form is not frequently found in surface water, elevated pH during photosynthetic activity of dense aquatic vegetation and algae can elevate pH levels in the STAs (Kadlec and Wallace 2009, Dierberg et al. 2002). Dierberg et al. (2006) reported that higher Ca and alkalinity levels improve P removal in submerged aquatic vegetation (SAV) communities presumably by enhancing co-precipitation of P under high pH conditions.

However, an analysis of STA-5 performance indicated that Ca does not seem to be limiting the performance of that STA that receives stormwater containing lower Ca concentrations (67 ppm) than other Everglades STAs (77–91 ppm) (Gu et al. 2005, Ivanoff et al. 2012). In a mesocosm study where Ca was added as an amendment, Dierberg et al. (2006) found that Ca amendments does not enhance the minimum outflow P concentrations. However, the authors also stated that marl deposited through SAV turnover under high Ca condition was more stable in terms of P release. Knight et al. (2003) reported that Florida rivers and lakes with less than 50 ppm Ca has efficient TP removal, with an average settling rate constant (k) of 15 meters per year. It is important to note that not all water bodies or wetlands are calcitic; other minerals such as iron, aluminum, or magnesium can cause P removal under suitable environmental conditions. Previous analyses indicate that Ca is the controlling mineral for P sorption and co-precipitation in the STAs.

In STA-2 and STA-3/4, which each received over 200,000 ac-ft of lake water in WY2015, Ca concentrations at the inflow dropped by as much as 43 percent. The mean Ca concentration coming from the lake in WY2015 was 43 ppm, which is less than half of what is found in basin runoff. While there is no current guidance that can be provided with regard to optimal Ca levels for STA inflow water at this time, it is important to regularly monitor and evaluate the levels when sending large amount of lake water over an extended period. Further study and analysis of existing data are critical to determine what the optimal Ca levels are for the STAs. In the meantime, mixing lake water with any available runoff could help maintain Ca levels close to EAA runoff concentrations within these systems.

TURBIDITY AND TOTAL SUSPENDED SOLIDS

In WY2015, turbidity was used as a stop/go measure for sending lake releases into the STAs. Turbidity, which is a measure of water clarity or the degree in which light can penetrate through the water, is an important parameter for the STAs since it can negatively impact STA inflow TP concentration and loading, SAV, periphyton growth, and microbial activities. High turbidity was observed mostly in lake releases from S-352 and CULV10A, and lower turbidity and at lower frequency of high turbidity occurred in releases from S-351 and S-354. In addition, high turbidity can reduce the amount of light penetrating into the water column, which can negatively affect SAV, periphyton growth, and microbial activities. When the SAV is stressed, P reduction mechanism can be affected due to reduced P uptake by plants and periphyton and in a lack of photosynthetically driven pH increase necessary to drive P co-precipitation with Ca. Previous observations have demonstrated that water column P increases as a result of SAV die-off and decomposition. In STA-1W, high levels of turbidity persisted after a large volume of lake releases was sent to this STA in WY2003 in an effort to lower lake levels. The high turbidity resulted in vegetation loss and lack of regrowth until the affected cells were rehabilitated through drydown, then scraping of dried floc or disking of the dried floc. Also, a strong correlation ($r^2 = 0.89$) between TSS and TP in lake water was reported by James (2014) (**Figure 4**). This suggests that at times when turbidity of lake water is high, concentration of TP will also be higher than when turbidity is lower.

Within the lake, there is an estimated 252 million tons of mud, with the deepest accumulation in the eastern portion of the lake (Jin 2015). Wind speeds of 15 mph or greater can largely increase

TSS concentrations, particularly in the first eight to twelve hours after the start of a wind event (Jin and Wang 1998, 2015). Settling of these very fine particulates can take as long as 14 days. However, after major events, such as the hurricanes of 2004 and 2005, turbidity and suspended solids persisted years after the events.

Figure 5 shows the POR monthly data for turbidity and TSS. Data shows that the magnitude (median) and variability for these two parameters increased dramatically during the dry months (November to April). Turbidity exceeding 100 nephelometric turbidity units (NTUs) and TSS exceeding 100 ppm have been observed at S-352 during this period over the POR. At S-351, no TSS data was available; however, the limited turbidity data that was available did not show any extreme values during the POR. This suggests that releases via S-351 will have less effect on the STAs than releases via S-352, particularly during dry months. To protect the Eastern Flow-path (STA-1W and STA-1E) from receiving highly turbid waters, releases into these STAs should occur after April and before November. Turbidity, Secchi depth, and TSS monitoring should be conducted during periods when releases from the lake are delivered to any of the STAs. As a guide, discharging large volume of lake releases into the STAs should be avoided when water has turbidity is greater than 15 NTUs and/or Secchi depth is less than 1 foot, particularly in areas lacking dense cattail stands at the front end of the STA flow-ways. Previous observations in STA-1W indicates that turbidities greater than 15 NTUs can inhibit SAV growth and expansion. Further study is also recommended to determine optimal values for Secchi depth and TSS.

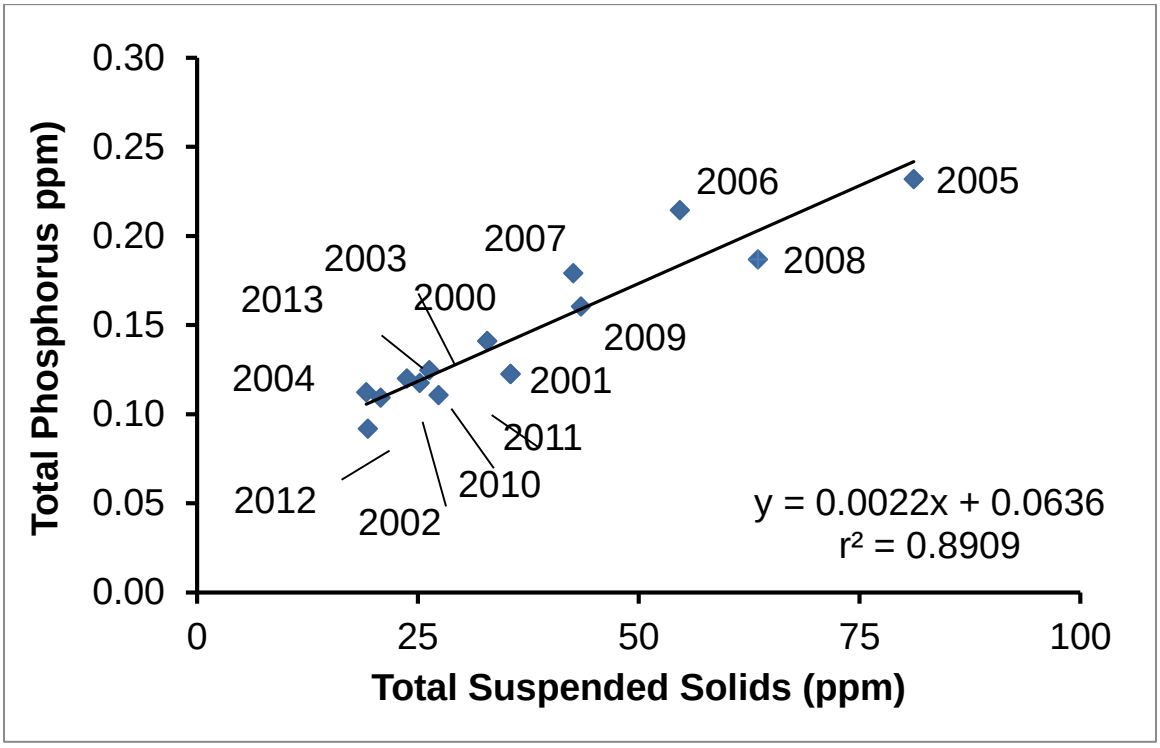

Figure 4. Regression of annual values from 2000–2013 for TSS and TP (James 2014).

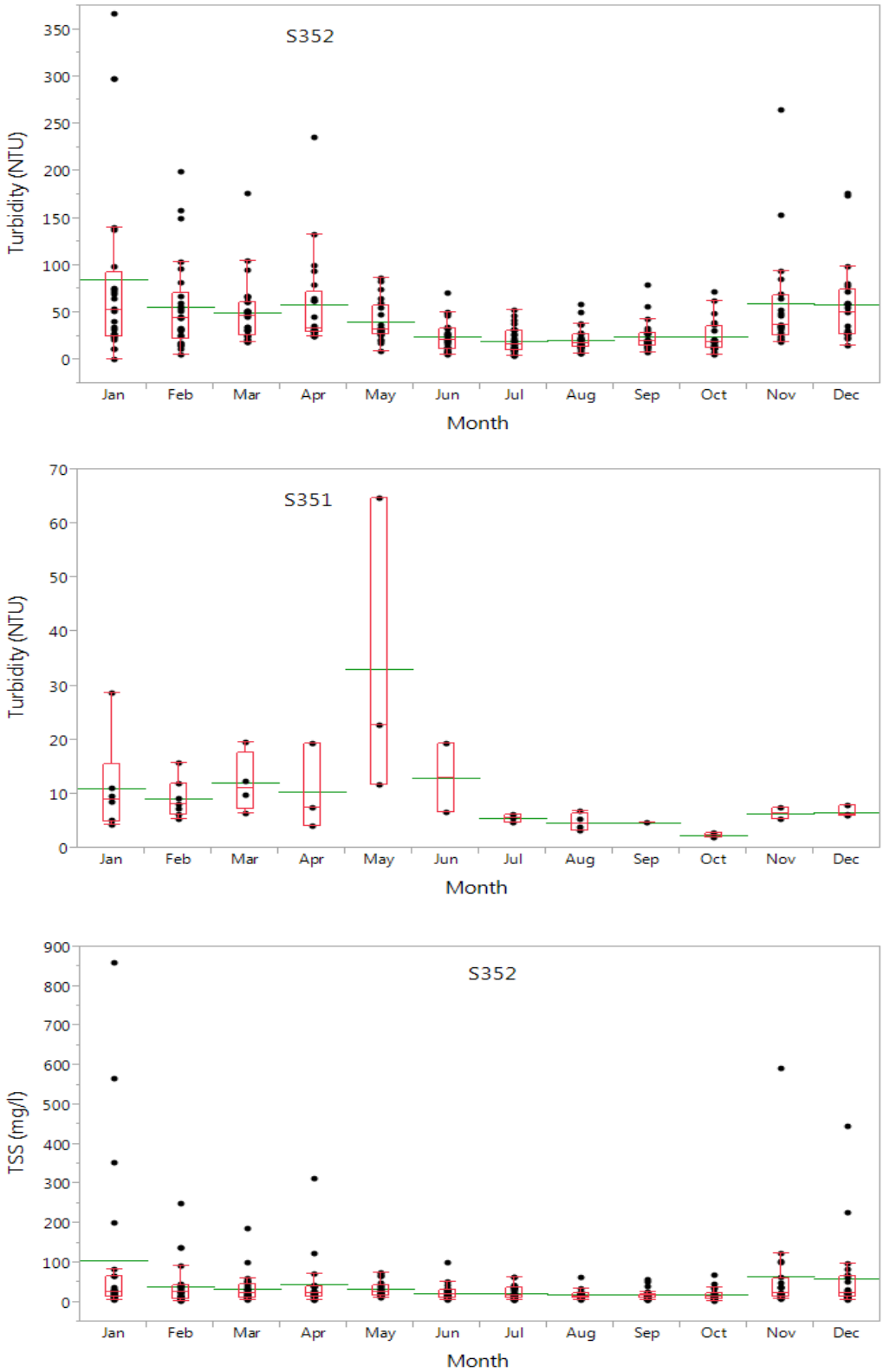

Figure 5. POR monthly turbidity plots for Lake Okeechobee discharge structures S-352 (top) and S-351 (mid), and monthly TSS plot for S-352 (bottom).

SUMMARY AND RECOMMENDATIONS

This report summarizes key characteristics of Lake Okeechobee water that could have potential implications for Everglades STA vegetation condition, floc accretion, or P performance over short- and long-term periods. The focus is on the quality of water released from the lake to the STAs.

The TP concentrations in the lake water have improved significantly since the hurricanes of 2004 and 2005. The lake discharge structure S-352, which discharges into the West Palm Beach Canal, and the source of lake releases for STA-1E and STA-1W, generally has higher TP than the values measured at the S-351 and S-354 structures (primary sources of lake releases into STA-2 and STA-3/4, respectively). CULV10A characteristics are very similar to S-352. Data for the S-354 and CULV10A structures are not included in this report. Based on POR data, significant increases in TP (up to 0.4–0.7 ppm) have been observed at S-352 in November, December, January, and April associated with strong winds and particulate-bound P. Observations of TP concentrations and variability during the POR were less during the wet season. At S-351, there was less variability and the concentrations are generally much lower (approximately half) than the values measured at S-352.

Concentrations of Ca in lake water are approximately 40 percent lower than in Everglades Agricultural Area runoff water. Given that Ca is important for wetland vegetation and Ca co-precipitation with P is an important P removal mechanism in the STAs, there have been concerns about the reduced Ca levels during the most recent WY2015 lake releases. Previous STA analyses indicate that Ca is the controlling mineral for P sorption and co-precipitation. However, other previous analyses also indicate that Ca levels as low as those found in Lake Okeechobee water may be sufficient for Ca-P reduction to occur in the STAs. Turbidity has been used as a basis to stop or continue lake releases into the STAs. The type of floc originating from the lake is generally easily resuspended and stays in suspension for several days or weeks, depending on the level of disturbance. In STA-1W and STA-1E, lake releases were halted when high turbidities (median of 45 NTU for WY2015 and values as high as 96–297 NTUs) were observed at S-352. In STA-2, turbidity was generally low, but lake releases into the SAV cells were suspended in January and February 2015 when turbidity at S-351 became slightly elevated. Aside from impacts on SAV, high turbidity from the lake generally equates to high TP loading into the STAs.

As a guide for future lake releases into the STAs, turbidity, TSS, TP, and Ca should be monitored frequently. Turbidity, TSS, and TP should be measured at the lake discharge structures on a weekly basis or before initiating releases to any particular STA. TP is already measured regularly at STA inflow and outflow structures, as part of routine STA monitoring. Close monitoring of P loading into each affected flow-way during extended periods of lake releases is critical. Ca should also be measured at the inflow and outflow structures at least biweekly during times of lake releases. Delivery of turbid water to the STAs for extended periods should be minimized when turbidity is greater than 15 NTUs and/or Secchi depth less than 1 foot, particularly in areas lacking dense cattail stands at the front end of the STA flow-ways. These values are provided as guidance and should be evaluated with other factors (such as the settleability of particulates in lake water and the condition of vegetation in the STAs). Delivery of lake releases into the STAs with much higher turbidity should be avoided, to the extent possible, as this can negatively affect the STAs in terms of increased P loading and SAV and periphyton growth. While there is no current guidance that can be provided with regard to optimal Ca levels for STA inflow water at this time, it is important to monitor these levels when sending large amount of lake water over an extended period. Mixing lake water with any available runoff could help maintain the Ca levels in the STAs as close to the levels found in runoff as much as possible. Future research should include determining the threshold for these parameters and quantifying the impacts of lake water characteristics in the STAs.

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