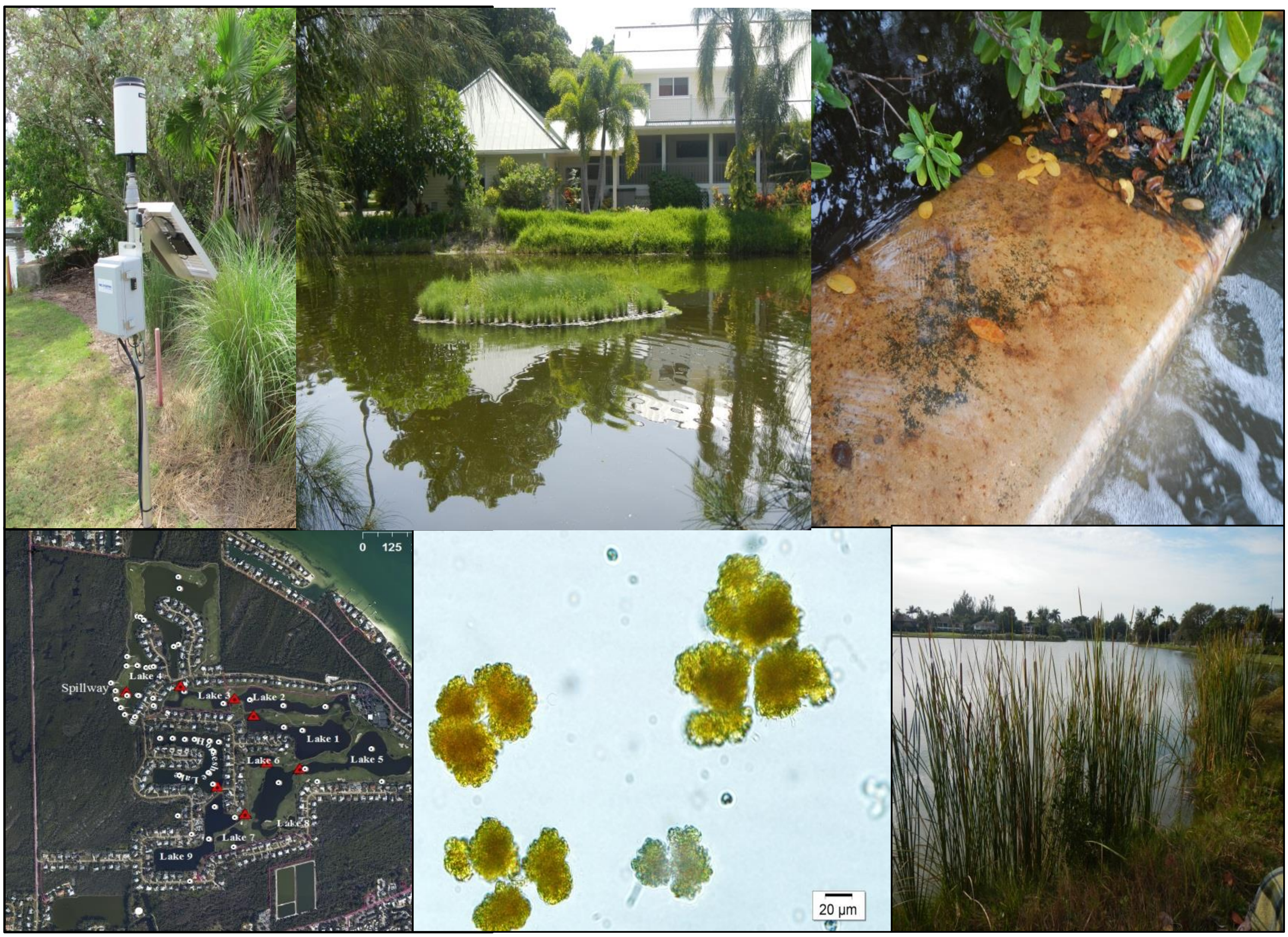
Water Quality in The Dunes Stormwater System: 2018 Update 1

For Dunes Golf and Tennis Club, Sanibel FL

October 2018

Mark Thompson, SCCF Marine Lab



Executive Summary

The SCCF Marine Lab began monitoring water quality for The Dunes stormwater system in 2012 at the request of The Dunes Golf and Tennis Club. SCCF currently monitors 4 of the 11 lakes within The Dunes development on a quarterly basis. The nutrients, nitrogen (N) and phosphorus (P) and chlorophyll *a* are the main focus of the monitoring. Dissolved oxygen, turbidity, salinity, pH and colored dissolved organic matter (CDOM) are also monitored due to their effects on aquatic organisms.

Past reports (July 2012, October 2012, December 2012, February 2013, December 2013, July 2014, December 2014, May 2015, February 2016, June 2016, September 2017) give in-depth discussion and background on The Dunes stormwater system monitoring results and conclusions. Please refer to those reports for more complete background. This update includes only new information obtained since the September 2017 report.

Overall, the stormwater system would still be classified as impaired due to average trophic state index (TSI) scores over 60 (TSI-used for evaluating the overall condition of a lake), and nitrogen and phosphorus concentrations consistently above state criteria (1.27 mg/l and 0.5 mg/l respectively) during a majority of sampling events. Since monitoring began in 2012, the system exhibited both positive changes and negative swings. The period between 2012 and 2016 showed significant improvement throughout the stormwater system and trend analyses showed that total nitrogen, inorganic nitrogen, and chlorophyll *a* (algae) are declining significantly, as was the TSI score. Since 2016 the positive trends have reversed and in the main body of The Dunes stormwater system nitrogen, phosphorus and chlorophyll *a* have all increased, producing a higher TSI score which indicates decreasing water quality. However, during the same period Horseshoe Lake, which is located within The Dunes development but physically separated from the other Dunes stormwater system lakes, showed only a slight decrease in water quality and currently has positive water quality trends. Comparison of The Dunes stormwater data to data collected for 70 other lakes on Sanibel between 2016 and present showed similar negative trends in water quality island-wide. Although The Dunes stormwater system is currently exhibiting negative water quality trends, weather, precipitation and their effects on groundwater flow are potential major factors in these trends. The continued improvement in the water quality of Horseshoe Lake, also suggests that management activities at the Dunes Golf Course are likely also a factor in the poorer water quality report.

After Hurricane Irma in September of 2017, large vegetative mats of *Bacopa* and *Ruppia* (aquatic vegetation) were ripped away from their positions floating at the surface of the water along the shoreline of Lake 4. The mats were acting as “floating treatment islands” and were potentially capable of removing large amounts of nutrients from Lake 4. After the hurricane, the mats were removed from the lake and have not been re-established. In the same time period, a tide gate was installed at the Lake 4 overflow weir to help prevent estuary water from filling the lake during high tides. This change has prevented large swings in salinity within the lake and resulted in a more stable freshwater aquatic environment. Although the tide gate prevents unwanted filling (reducing capacity) of the stormwater system, it also provided a more stable environment allowing a greater amount of freshwater algae to develop in that lake than previously seen. The loss of the natural floating mats of vegetation along with the more stable salinity regime has produced higher micro-algae concentrations (chlorophyll a) in that lake.

BMPs such as (re) establishment of aquatic vegetation (planting *Bacopa* and *Ruppia* or allowing it to re-establish in areas where it was lost during Irma), increasing the width of the vegetated buffer zone around waterbodies, manual harvesting of macro-algae and some aquatic vegetation, reduced fertilizer application, native vegetation plantings, installation of floating islands and exotic fish removal are all recommended to help reduce nitrogen (and total phosphorus) concentrations in the stormwater system again.

The persistent excess phosphorus in The Dunes stormwater system can be partly attributed to the use of reclaimed water for irrigation. Other studies have shown reclaimed water is potentially the main source of inorganic phosphorus to the Dunes landscape (Thompson and Milbrandt 2013, Thompson and Milbrandt 2014, Thompson and Milbrandt 2017). Although phosphorus can be adsorbed onto soil and used by terrestrial plants, any reclaimed irrigation water applied to impervious surfaces such as driveways or directly to waterbodies adds phosphorus to the stormwater system. Calculations show if just 4% of the reclaimed irrigation water used is accidently applied to impervious surfaces or waterbodies, the loading is enough to keep the stormwater system in non-compliance with state phosphorus criteria. In other words, if 4% or more of the reclaimed water used for irrigation enters the stormwater system directly through improperly placed nozzles, spills or leaks, the stormwater system will fail to meet state water quality criteria. Preventing direct runoff of reclaimed water may be a relatively straightforward way to achieve significant reduction in phosphorus concentrations and effectively control algae biomass and gain compliance with state water quality criteria.

Due to continual loading from irrigation, soils can become saturated with phosphorus and release phosphorus into stormwater runoff or groundwater. The City of Sanibel is currently planning to modify the Donax wastewater treatment plant in an effort to reduce phosphorus and nitrogen levels in the reclaimed water. When complete, the modification should provide large reductions in total amounts of N and P applied to lands through irrigation.

Introduction

This document summarizes data collected during 6 years (2012-2017) of stormwater system water quality monitoring by SCCF Marine Lab for The Dunes Golf and Tennis Club (the Dunes). Included is all data available through October 2018 which was collected during dry season and wet season monitoring each year. The Marine Lab monitors stormwater lakes within The Dunes on a quarterly basis per an agreement with The Dunes. The primary goal of this monitoring program is to provide science-based information needed to understand the causes of poor water quality and offer potential solutions by encouraging development of a lakes management plan. Results from this program can be integrated into a lakes management plan and help measure the success of best management practices (BMPs) and other activities aimed at improving water quality. Implementation of a successful management plan can result in lakes suitable for recreational use, and provide aesthetically pleasing conditions, beneficial habitat and good water quality which will not degrade surrounding estuarine habitats.

Methods

Under the adaptive monitoring strategy, the number of sites monitored was reduced from 8 to 4 in the second year of the study. The four lakes now monitored are a representative subsample of the larger stormwater system. Lake 4 is the most downstream lake and until recently when a tide gate was installed on its weir, periodically received water from the estuary. Because this lake discharges to the estuary and historically received flow from all upstream lakes as well as the estuary, it has unique characteristics. Its chlorophyll *a* and nutrient concentrations were typically lower due to dilution by estuarine waters while its salinity was highest amongst the lakes (3-20 PSU). Lake 5 is typical of the interior lakes of the stormwater system with high chlorophyll and nutrient concentrations and salinity between 2 and 4 PSU. The Lake 5 watershed includes golf course and residential land uses. Lake 9 is also surrounded by residential and golf course land classes and is very productive with a high biomass of fish and periodic phytoplankton blooms. Horseshoe Lake is completely surrounded by residential land use and its maintenance is the responsibility of the Dunes HOA. This lake is not directly connected to the other lakes in the stormwater system, and has had unique algae blooms in the past although its nutrient concentrations are relatively lower than other lakes in the system. Lake 4 and Horseshoe Lake have aeration systems while Lake 9 and Lake 5 do not. The aeration system in Horseshoe Lake is managed by the HOA and is set on a timer so that aeration runs during the time of lowest dissolved oxygen (late night and early morning). The aeration system in Lake 4 runs continuously except during mechanical breakdowns.

Sampling stations (Figure 1) are located near the discharge points of lakes which have existing discharge structures. For those lakes without discharge structures, monitoring sites were located based upon best professional judgment. Sampling was conducted per Florida DEP FS1000.

In 2016, The City of Sanibel began its Communities for Clean Water Program and it now monitors over 70 lakes on Sanibel for the same parameters as sampled in The Dunes. We compare The Dunes lakes water quality to the water quality of lakes monitored by that program in this report.

Sampling: Lakes (stormwater ponds) in the Dunes development are monitored seasonally. Sampling usually occurs twice during dry season and twice during wet season.

Event-driven Sampling: One sampling event per season is undertaken after a rain event of at least 0.5 inches (1.27 cm) in the previous 24 hours and one event per season occurs after a “dry” period of at least 7 days with no rain. Wet season is defined as those months which have greater than 5 inches (12.7 cm) of total rainfall (historically mid-June through mid-October, but often mid-May through late October).

All analyses were conducted using EPA-approved methods. Some analyses are contracted a State NELAC certified laboratory. Analyses results were entered into an Access relational database located at SCCF Marine Lab which is regularly backed up. Field and analyses logsheets are stored and archived at SCCF Marine Lab.

Data evaluation and analyses: For comparison purposes, raw data is presented in table form along with pertinent water quality criteria and 90th percentile values for all Florida lakes data. The 90th percentile values represent the value of a parameter for which 90 percent of all Florida lakes have a lesser (better) value (if measured values are greater than these values, the lake is in the worst 10 % of all monitored lakes in state for that parameter).

A trophic state index (TSI) was calculated for each lake using the methodologies described by Florida Department of Environmental Protection for assessing lakes (FDEP 1998). Since a lake's trophic state is associated with nutrient loading and phytoplankton concentrations, the TSI is calculated using phosphorus, nitrogen and chlorophyll *a* values. The greater these values, the higher the TSI and the more eutrophic (nutrient enriched) a system is thought to be. The TSI is used by the state for assessing impairment status of lakes. Values below 60 are considered "good" while above 70 is considered "poor" water quality. A lake may be classified as "impaired" with an annual average above 60 (at least one sample each quarter).

Results and Discussion

From 2012 through 2016 Kendal seasonal trend analyses found significant downward trends in chlorophyll a, TN and TSI for The Dunes stormwater system as a whole (results from all lakes 4, 5 and 9 combined). Those positive trends have reversed for the stormwater system since 2016 (Tables 1-4 and Figures 2-4). The current upward trend and high value of the TSI (which takes into account nitrogen, phosphorus and chlorophyll a) is an indicator water quality conditions need to be addressed. However, a downward trend in phosphorus over the past year is promising (Figure 5). The downward trend in phosphorus may be due to decreased use of reclaimed water during the last year, or dilution during rainy season. Currently, both N and P are in excess in the lake system and both must be reduced to result in decreased algae bloom potential (reduced chlorophyll a). A perceived loss of shoreline and aquatic vegetation in the overall Dunes stormwater system partially due to Hurricane Irma should be countered with new efforts to re-vegetate affected shorelines such as those that lost *Bacopa* on Lake 4.

In this report, Horseshoe Lake (HSL) data is analyzed separately from the other Dunes lakes data due to its isolation from the system. Overall, Horseshoe Lake has shown continuous improvement in water quality since 2012 (Figures 6-9). Isolation from watershed areas with reclaimed water use and lack of direct golf course runoff give this lake an advantage over the other Dunes lakes. The improvement in lake vegetation (submerged and shoreline) with discontinued use of herbicides was a major BMP change in 2012 and has likely contributed to the lakes continued improvement along with time dependent aeration.

Since 2016 nitrogen, phosphorus and chlorophyll *a* have all increased in the main body of The Dunes stormwater system, producing a higher TSI score which indicates decreasing water quality. However, during the same period Horseshoe Lake, which is located within The Dunes development but physically separated from the other Dunes stormwater system lakes, showed only a slight decrease in water quality and currently has positive water quality trends. Comparison of The Dunes stormwater system water quality data to results collected for 70 other lakes on Sanibel between 2016 and present showed similar negative trends in water quality island-wide (Figures 10-12). The current negative water quality trends at The Dunes are likely partly due to regional short term differences in weather, precipitation and their effect on groundwater flow. The improvements originally realized due to BMPs implemented since 2012, are still applicable to the long term water quality conditions of the stormwater system as long as management practices have not been disregarded since first implemented. The current degraded water conditions may be a short term fluctuation caused by weather. However, the continued improvement in the water quality of Horseshoe Lake during the same period, suggests that management activities at the Dunes Golf Course are likely also a factor in the poorer water quality. Managers should evaluate changes in BMP implementation and determine if their practices have changed.

Devitt Pond on SCCF's Bailey Homestead has been used as a reference lake for the vicinity. Its values should be the best lake water quality possible in this area of Sanibel. Analysis of Devitt Pond data showed TN, TP and chlorophyll levels remained low and in compliance with state water quality standards for 2 years after initial pond installation. During the 2016 dry season which had record precipitation, TN, TP and chlorophyll *a* all began trending upward. Since then, the poor water quality levels have continued. The TN and TP levels in the lake have jumped up to the average values of groundwater in the area as determined from a 2015-16 study by SCCF. One hypothesis for the sudden deterioration of water quality in Devitt Pond is its interaction with groundwater.

Groundwater monitoring wells were installed around Devitt pond and between Devitt Pond and The City of Sanibel's reclaimed water holding ponds located less than 400 meters east. A significant and continuous increasing gradient of phosphorus and nitrogen were found closer to the reclaimed water ponds. Groundwater flow estimates derived from deferential water table elevation readings at the monitoring wells showed a flow gradient from the reclaimed water ponds to Devitt Pond. A explanation has been developed suggesting abnormally high groundwater levels and flow rates in 2015-2016 caused by record precipitation, caused greater groundwater flow to Devitt Pond. High TN and TP levels in the groundwater due to the nearby reclaimed water holding ponds were pushed by the flow into the pond. The vegetation around and within the pond has not yet been able to process the loads of nutrient delivered to the pond by groundwater. At the same time, non-native, invasive Mayan cichlid fish found their way into the pond. These fish can eliminate the algae eating zooplankton and stir up phosphorus in pond sediments, both contributing to potential algae blooms (high chlorophyll *a*).

Similarly, the long term use of reclaimed water on The Dunes golf course has produced very high TN and TP concentrations in the groundwater surrounding The Dunes (reference City of Sanibel Comprehensive Nutrient Management Plan, 2017). When weather conditions result in increased groundwater flow into the Dunes stormwater system, concentrations of nutrients will increase, resulting in greater chlorophyll *a* concentrations. Reducing the impact of reclaimed water use on the Dunes stormwater system will require reduced flow of reclaimed water into the surrounding surface and ground water and/or reduced concentrations of nutrients in the reclaimed water.

The City of Sanibel is currently upgrading their wastewater treatment facility to remove a larger proportion of phosphorus from the wastewater. The reclaimed water derived from this advanced wastewater treatment process will be 50-70% lower in phosphorus with reduced nitrogen levels also. This process improvement will have a beneficial effect on reducing TP and TN introduced into the environment through use of reclaimed water for irrigation.

Evidence to date suggest reclaimed water used for irrigation is the main source of phosphorus loads from Sanibel, and that most of Sanibel’s waterbodies have excess phosphorus so that little improvement in water quality will be seen until we reduce phosphorus inputs. Renewed efforts should be made to be sure phosphorus-rich reclaimed water does not flow directly into the stormwater system or other waterbodies. **All sprinkler heads should be adjusted to be sure they cannot spray directly into waterbodies or onto impervious surfaces such as roadways and golf cart paths. The reclaimed water system should also be rigorously and periodically checked for leaks and potential intermittent releases such as spills.**

Since reclaimed water has high concentrations of P and N, users of reclaimed water should consider its fertilization qualities when irrigating. The application of 10000 gallons of reclaimed water to any landscape delivers 0.5 pounds of nitrogen and 0.2 pounds of phosphorus (Thompson 2013). These P and N loads should be accounted for when estimating fertilizer needs and when reporting fertilizer usage.

Currently, addition of either nitrogen or phosphorus to the stormwater system could cause significant increases in unwanted algae; however the increasing presence of aquatic plants due to cessation of herbicide usage will help tie up excess nutrients. Periodic **manual thinning and removal** of these plants will effectively remove nutrients from the system. The harvesting of significant numbers of the planktivorus fish present in the lakes (tilapia and cichlids) would also help reduce system nutrients and benefit the water quality in various other ways.

Research has shown that an excessive abundance of planktivorus fish (tilapia and cichlids) in stormwater ponds allow phytoplankton blooms to go unchecked by natural processes. Blooms of edible phytoplankton (micro-algae) in these lakes can be naturally controlled by zooplankton such as cladocerans. These zooplankton are a primary food source for tilapia and cichlids. Healthy aquatic plant populations in the lakes can provide refugia for zooplankton, allowing them to avoid predation by fish resulting in algae reduction in the water column. Previous aquatic plant eradication efforts around lake edges and within the lakes significantly reduced zooplankton populations, resulting in increased algae in the water column. The large population of plankton-eating tilapia and cichlids can make re-establishment of healthy zooplankton populations difficult unless fish numbers are reduced.

Trophic state indices (TSI) for the four lakes monitored throughout this study were above 60 for all sampling events (Tables 1-5). Values above 60 are defined as "poor" water quality by Florida DEP. The TSI score is calculated from nutrient and chlorophyll *a* levels. As described in the methods section, the TSI score is an average of three indices which use nitrogen, phosphorus and chlorophyll values as their basis. The TSI for The Dunes stormwater system is currently increasing and BMP efforts should concentrate on reducing not only the amount of runoff but also the nutrient concentrations in groundwater. Increased vegetative cover and decreased fertilization is a key.

Level, Flow and Rain Monitoring at Discharge Weir

We estimated that 13,688,000 ft^3 (102.4 million gallons) of water were discharged from The Dunes stormwater system in 2016 (Table 5). As a result of these discharges an estimated 2,215 pounds of nitrogen and 140 pounds of phosphorus were released to Tarpon Bay in 2016 (Table 5). By design, discharges from the stormwater system were intended to be rare. In October 2016, the City of Sanibel is installed a one way tide gate on the weir to prevent future weir overtopping by extreme high tides. This should increase the seasonal holding capacity of the stormwater system and decrease the amount of nutrients discharged to the estuary. With the installation of the tide gate, flow monitoring at the weir with the existing monitoring became inaccurate. The system can still be used to monitor levels but flow predictions cannot be made.

Summary

The lakes in the Dunes stormwater system and Horseshoe Lake are still eutrophic due to nutrient levels and subsequent phytoplankton (algae) blooms. The TSI scores of the lakes in the stormwater system are above the threshold value of 60 set by Florida DEP to classify a waterbody as "impaired". The TSI for Horseshoe Lake in the 2018 wet season was just above the 60 threshold and emphasizes that lake's significantly better water quality compared to the stormwater system. The influence of reclaimed water and fertilizer use on the golf course adjacent the stormwater system drive poor water quality there. The legacy nutrients in groundwater and soils in the stormwater system basin will affect water quality even after BMP improvements are made, however improvements will be realized if a continuing effort at implementing BMPS is made.

Nitrogen concentrations in all lakes are above the numeric water quality criteria established for Florida by USEPA, while a majority of the phosphorus monitoring results exceed state water quality criteria. Modeling shows that the lakes have excess concentrations of phosphorus in the water column at most times of the year, suggesting efforts should focus on controlling phosphorus through more efficient use of reclaimed water

Although the stormwater system has had a recent downturn in water quality, improvements made since the initiation of BMP practices in 2012 show that BMPs will gradually help. The discontinuance of herbicide treatment of aquatic vegetation within the stormwater system has probably had the greatest benefit to improved water quality conditions. Aquatic vegetation takes up nutrients which would otherwise be available to phytoplankton (micro-algae) and macro-algae (algal mats). Aquatic vegetation also provides habitat for zooplankton which consumes microalgae. More plants result in less algae and clearer water. Shoreline vegetation which grows suspending over the water extending out from shoreline provides a natural “floating island”. These floating mats with roots extending into the water column have been shown to remove nitrogen directly from the water and return it to the atmosphere. Floating mats of *Bacopa* and *Ruppia* (native vegetation) such as found along the shorelines of Lake 4 before hurricane Irma should be nurtured and expanded to other lakes.

Other beneficial activities in the past have included manual harvesting of a portion of aquatic plants and macro-algae in the lakes, development of a vegetated buffer around lake edges, installation of two floating islands, and removal of exotic bottom-foraging fish.

The four lakes currently monitored have excess amounts of inorganic phosphorus in the water column. In these lakes it was estimated that the phosphorus concentration must be reduced by 30-50% to effect a noticeable reduction in phytoplankton (chlorophyll). Before additional reduction in algae will be realized, phosphorus concentrations must be significantly reduced.

Reclaimed water used for irrigation on the golf course is likely the main source of phosphorus entering the stormwater system. Although the reclaimed water contains very significant concentrations of N, it is relatively high in P compared to most fertilizers used in the area. Any reclaimed irrigation water which runs off directly into a waterbody will add potential for more algae biomass. However, this may be one of the easiest sources of P to control by preventing direct application of irrigation water to water body surfaces, or other impervious surfaces such as driveways and roads. An irrigation system survey and sprinkler head adjustment/modification program may be able to have immediate beneficial impacts to water quality in the stormwater system.

Using plants (i.e. Cattails, rushes, floating islands) and animals (i.e. tilapia fish) to uptake nutrients then periodically harvesting 30-50% of the mass is an effective method to remove nutrients from the water column. Fertilizers used on lawn and golf courses should continue to be reduced. The inflow of fertilizer-based nutrients will continue to raise concentrations within the system until something can be done to effectively control transport during rain events, either by preventing water runoff or preventing fertilizer contact with rainwater (i.e. by reducing amount of fertilizer on grounds). The reduction in volume of direct reclaimed irrigation water runoff is the most efficient way to further reduce phosphorus concentrations. Prevention of direct irrigation spraying onto impervious surfaces and lakes should be top priority along with preventing and containing leaks or spills of reclaimed water.

A probable scenario for lake restoration would be a comprehensive management plan which involves the following priority actions:

1. Elimination of herbicide and algaecide application to all lakes.
2. Increasing vegetative canopy (trees and shrubs) in watershed which will both decrease surface water runoff and nutrient concentrations.
3. Allow re-establishment of native submerged aquatic vegetation (SAV) within in each lake. Nurture and plant vegetation along the shoreline which will grow out over the water surface such as *Bacopa*.
4. Eliminate direct runoff of reclaimed irrigation water through adjustment and transfer of spray nozzles and prevention of leaks and spills.
5. Periodic harvesting (and off-site composting) of up to 30% of submerged and immersed vegetation to remove nutrients. Should concentrate on the invasives such as torpedo grass and cattails for harvests.
6. Implementing BMPs for watershed which reduce stormwater runoff and fertilizer application.
7. Significant reduction of non-native planktivorus fish populations through active removal.
8. Re-establish zooplankton populations in lakes by re-establishment of SAV and fish removal and through possible introduction of native zooplankton.
9. Use of stormwater system water to irrigate golf course or at least salinity tolerant plantings around golf course. This would allow more nitrogen and phosphorus removal by plants in the uplands and reduce water column concentrations.

This document is intended as a data transfer and annual evaluation of results. Contact Mark or Eric at SCCF Marine Lab with any questions related to the data presented here. We would like to meet with your group to discuss questions and possible management actions which will impact the water quality of the Dunes stormwater system.

References

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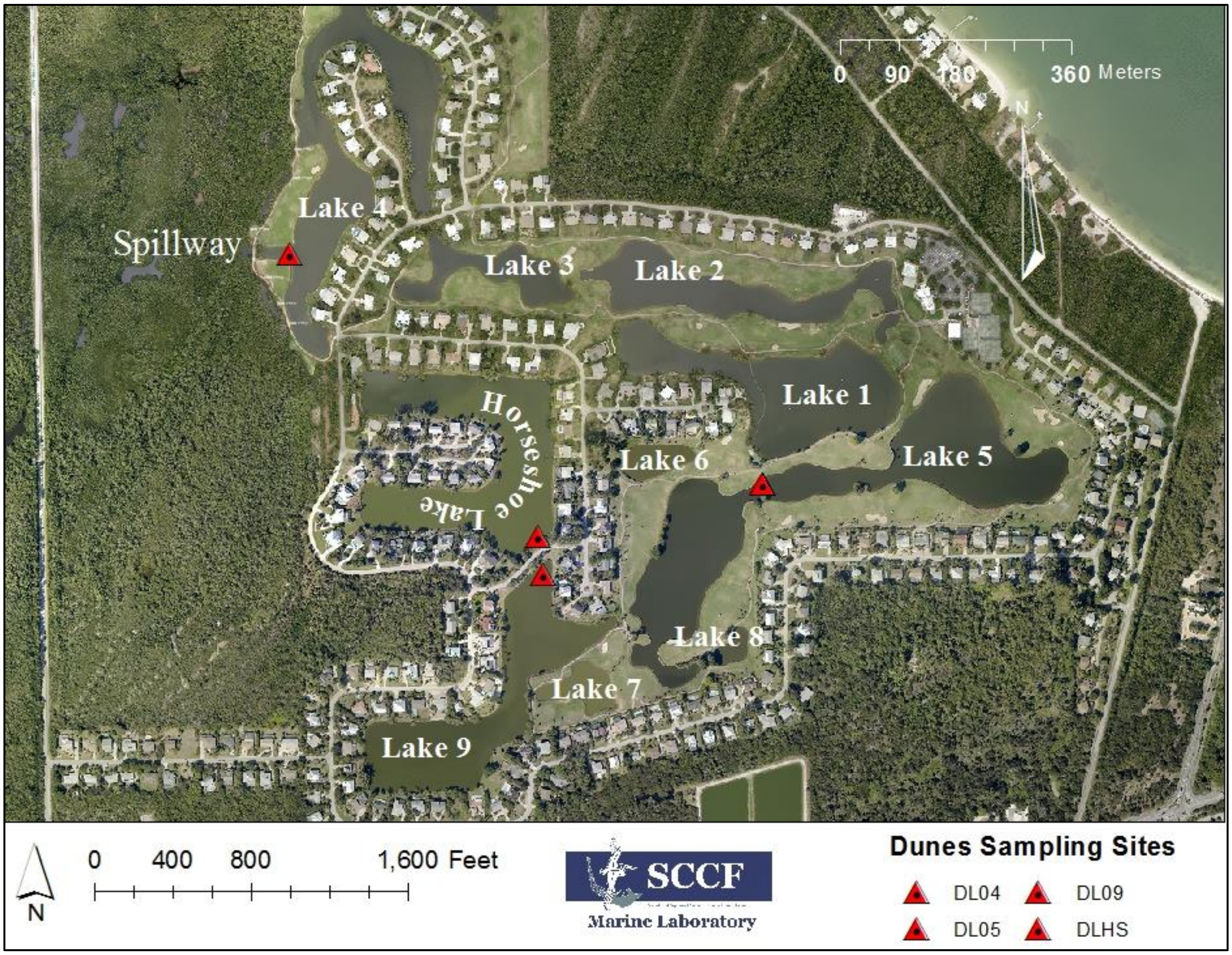

Figure 1. The four locations currently sampled 4 times each year at on the Dunes stormwater system. Samples are taken after a rain event of more than 0.5 inches in wet and dry season and after a dry period of at least 7 days in the two seasons.

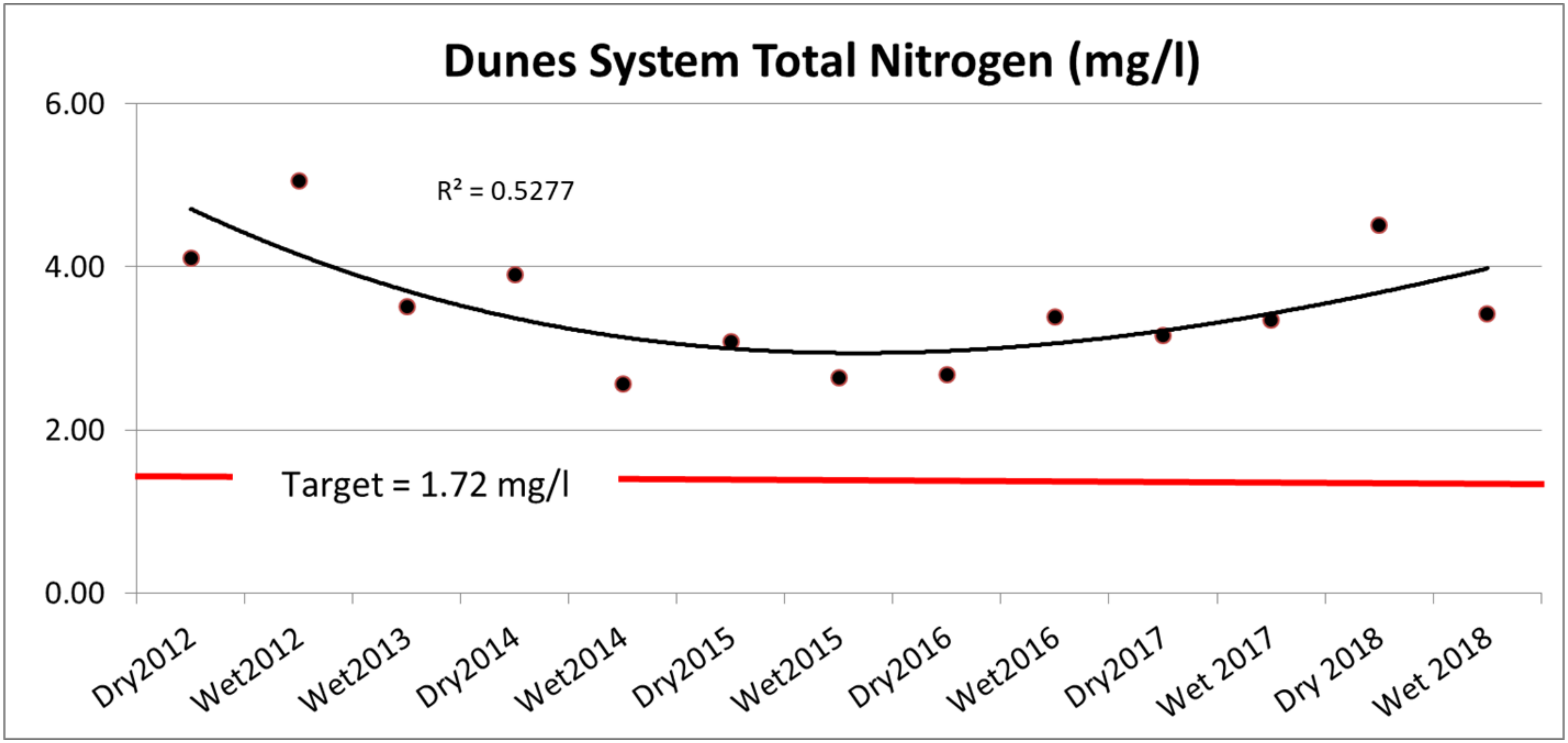

Figure 2. TN concentrations in the Dunes stormwater system since monitoring began in 2012. A clear downward trend is apparent from 2012 through 2016 followed by an upward swing.

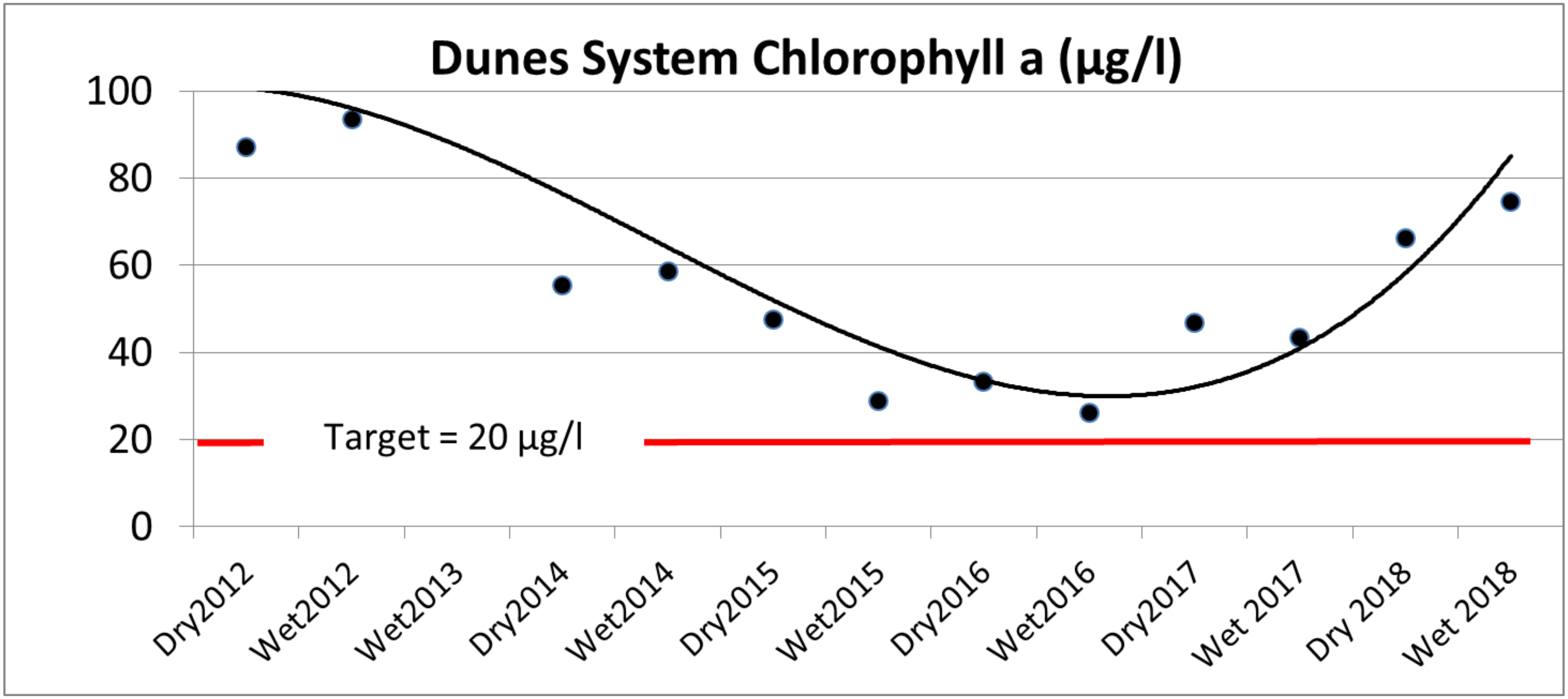

Figure 3. Chlorophyll a concentrations in the Dunes stormwater system since monitoring began in 2012. A clear downward trend is apparent from 2012 through 2016 followed by an upward swing.

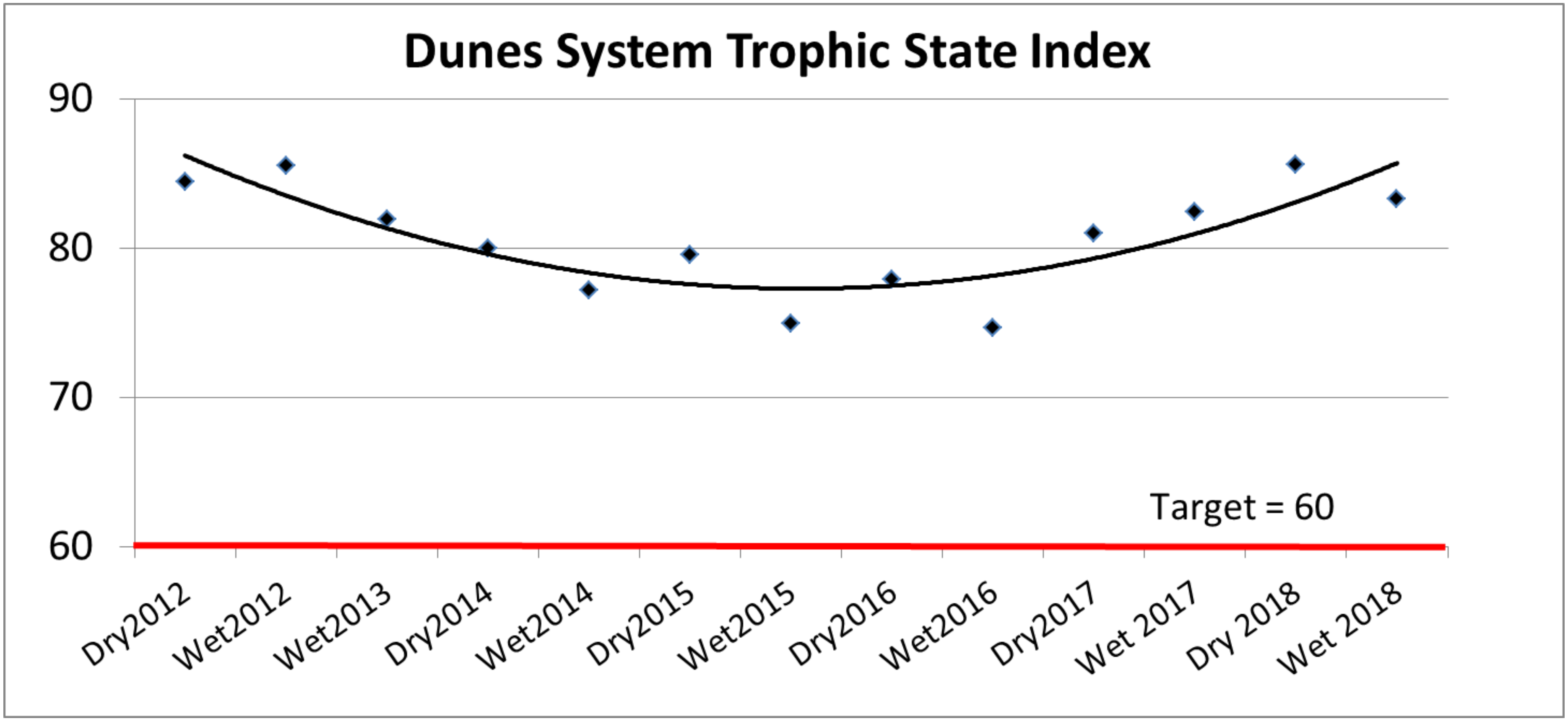

Figure 4. The TSI score for the Dunes stormwater system since monitoring began in 2012. A clear downward trend is apparent from 2012 through 2016 followed by an upward swing similar to trends in TN and Chlorophyll *a*.

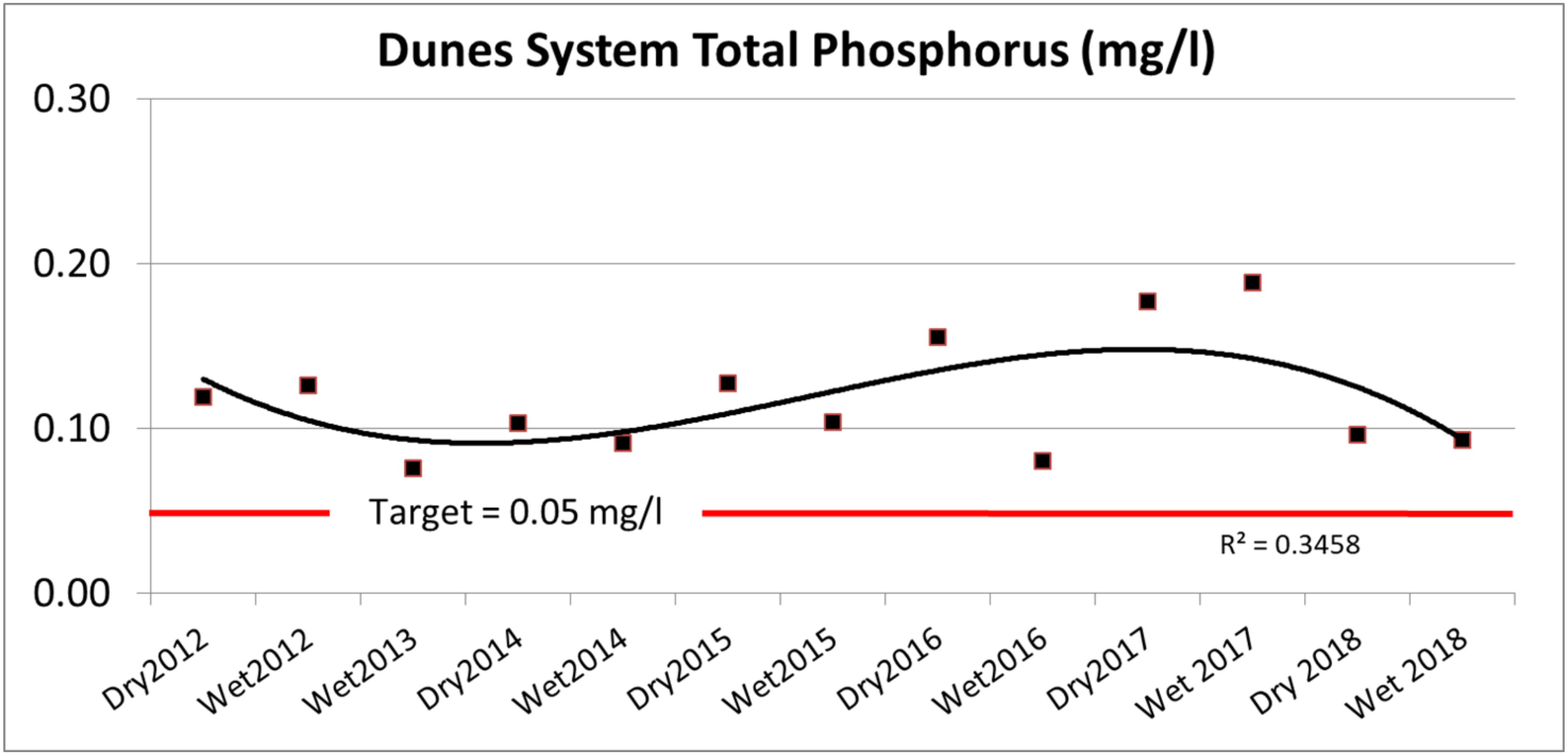

Figure 5. Trend in TP found for the Dunes stormwater system since monitoring began in 2012. In 2018 phosphorus concentrations were lower than previous years.

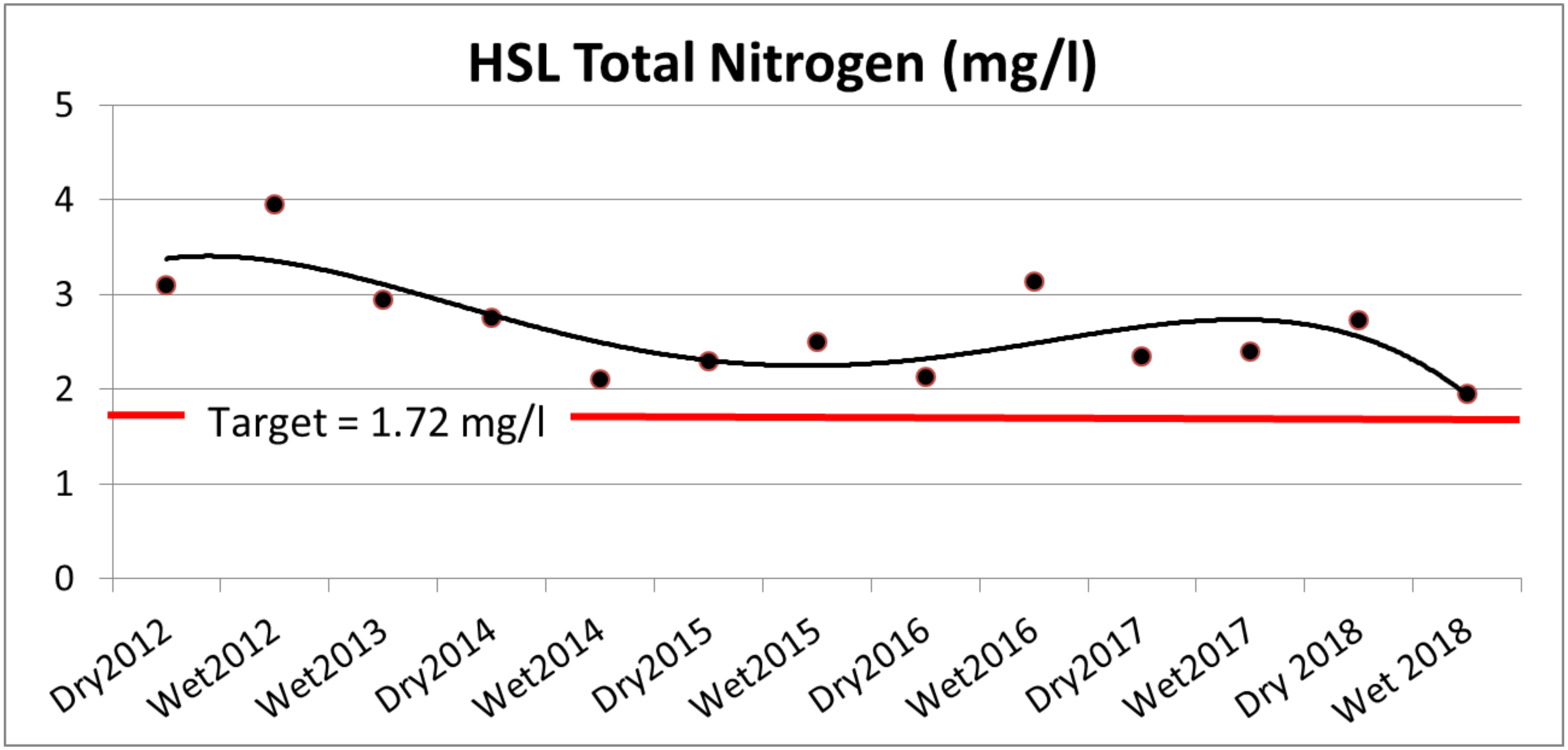

Figure 6. TN concentration in Horseshoe Lake since monitoring began in 2012. A long term downward trend is apparent with shorter term increases and decreases in concentration.

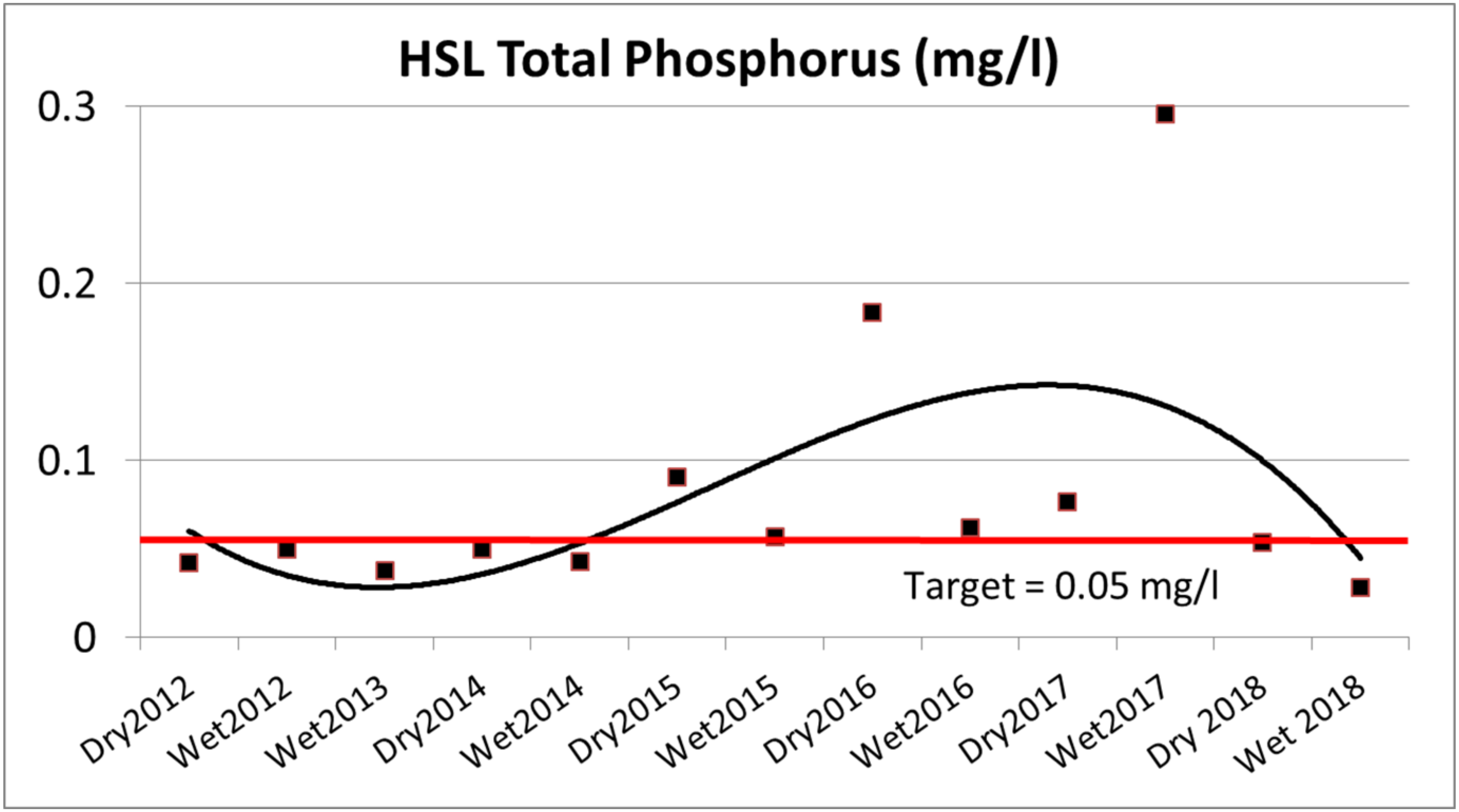

Figure 7. Total phosphorus (TP) concentrations in Horseshoe Lake since monitoring began in 2012. A recent downward trend followed rapid increase in TP from 2016 through 2017.

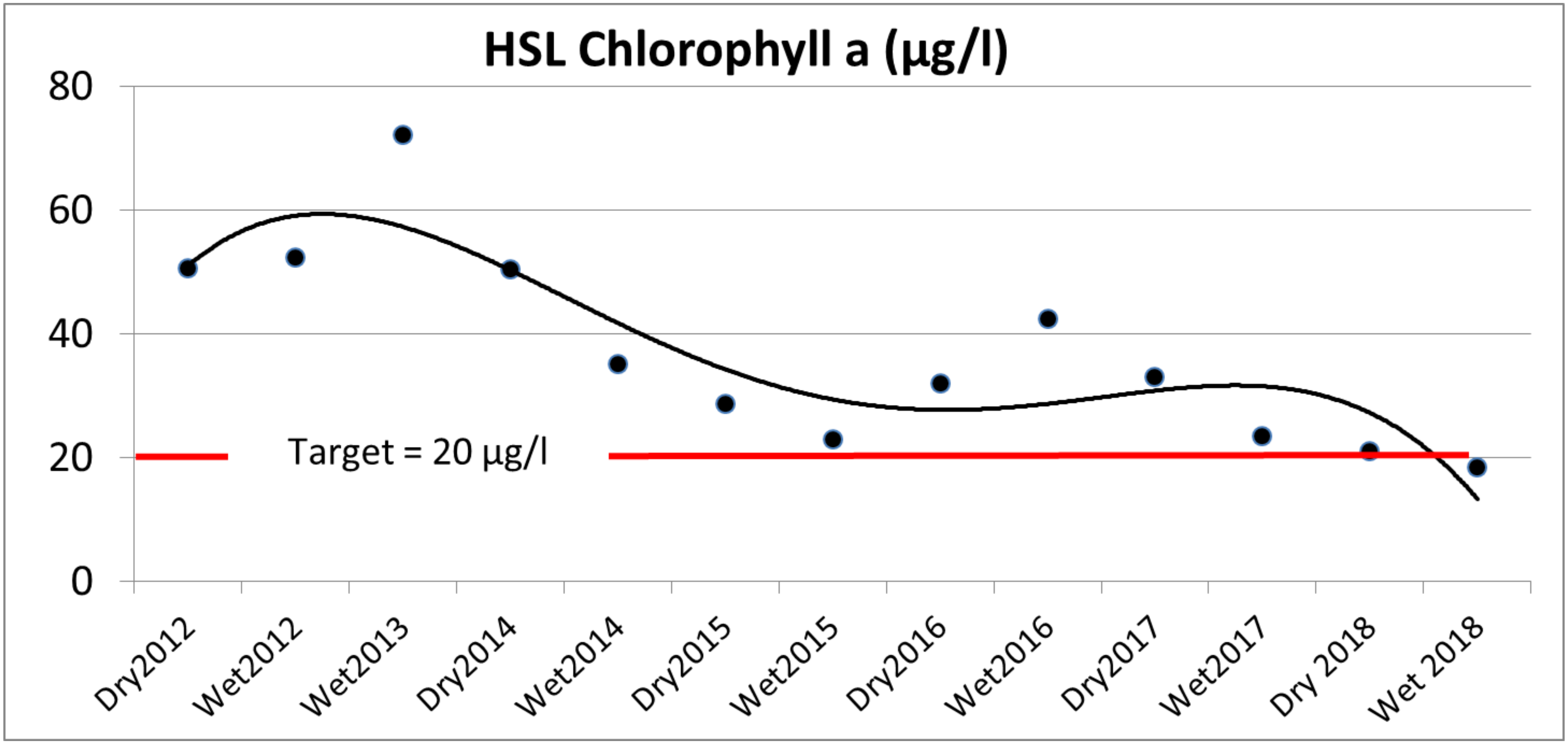

Figure 8. Chlorophyll a concentration in Horseshoe Lake since monitoring began in 2012. An overall downward trend is apparent within short term increases and decreases.

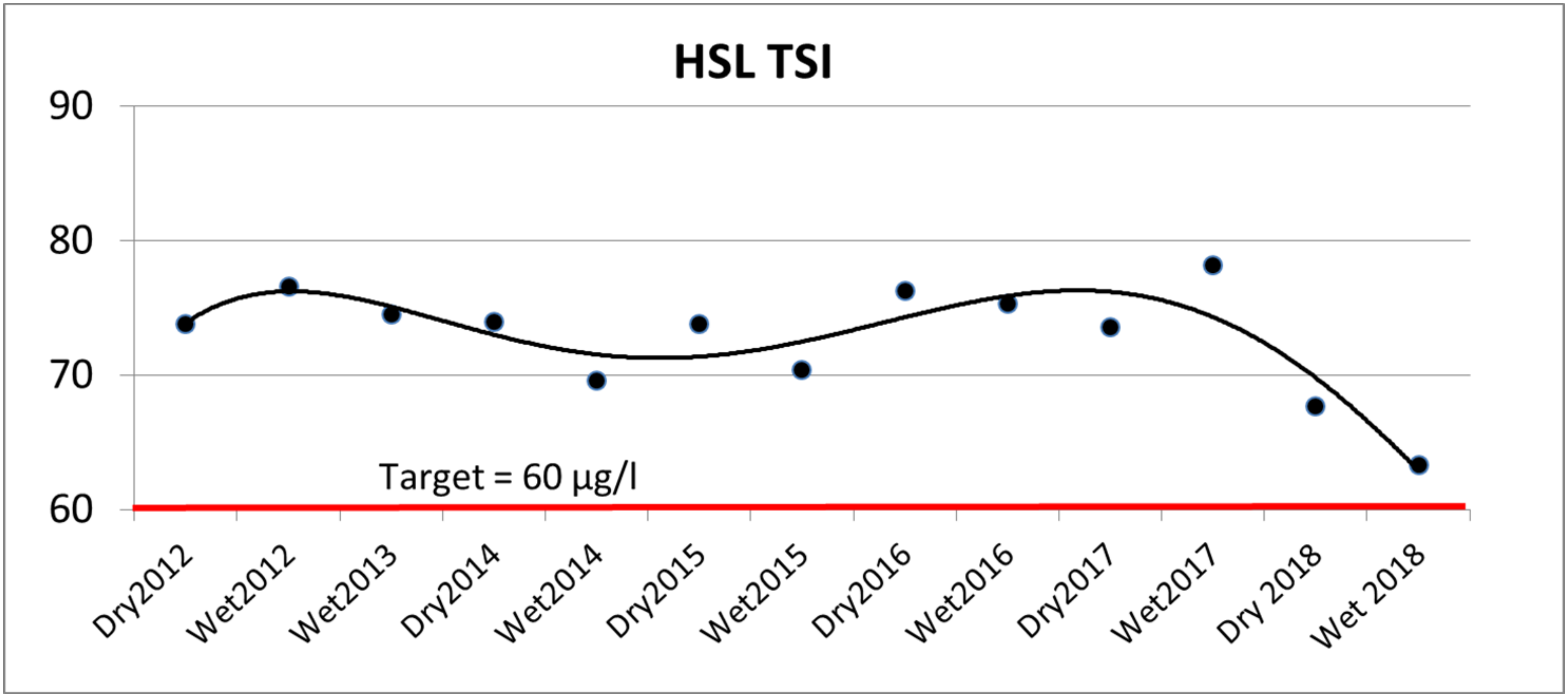

Figure 9. The TSI score for Horseshoe Lake since monitoring began in 2012. An overall downward trend is apparent with short term swings in score trends.

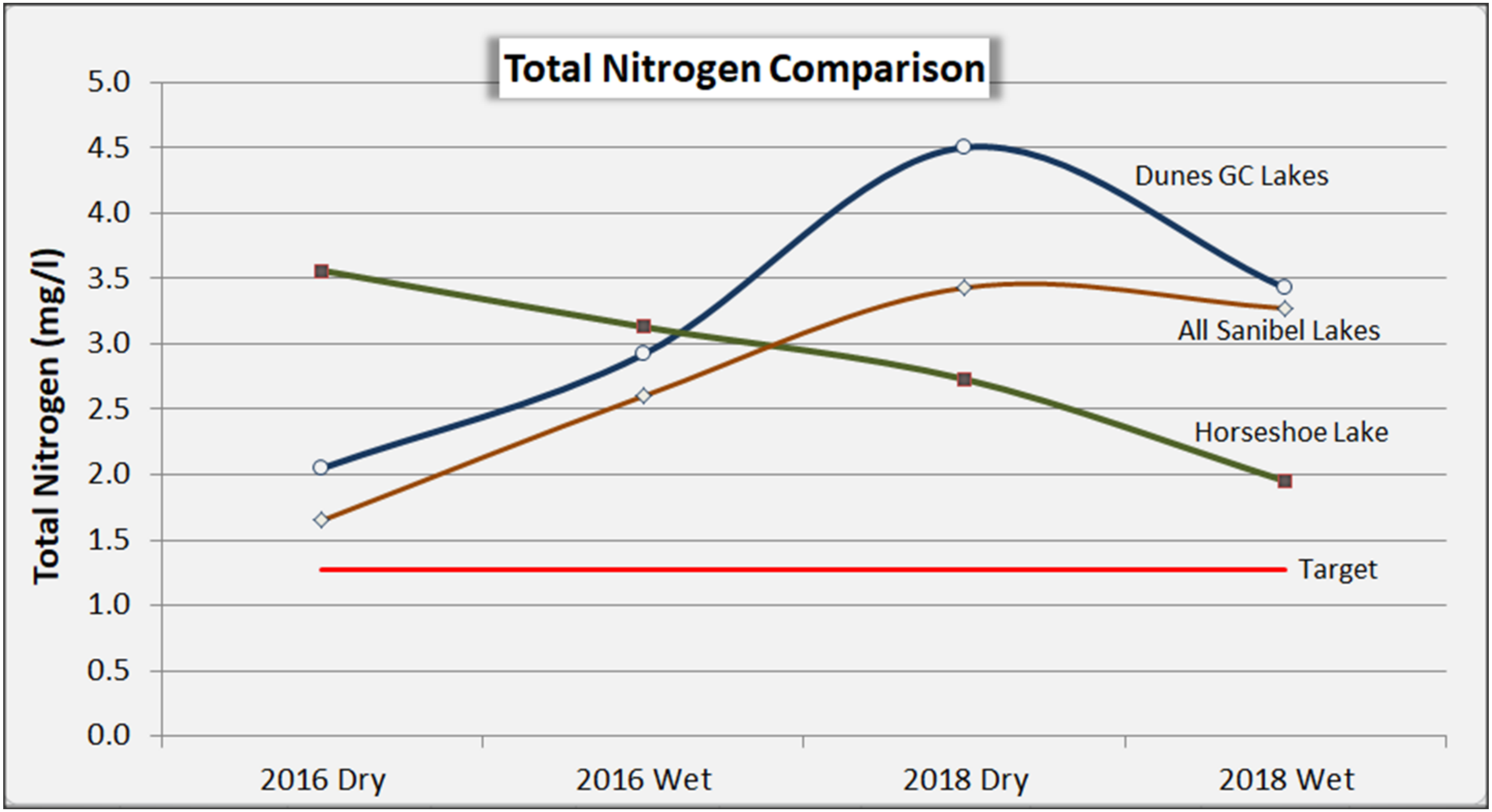

Figure 10. Comparison of TN concentrations between the Dunes stormwater system, Horseshoe Lake and the average TN concentrations of 72 lakes sampled on Sanibel between 2016 and 2018.

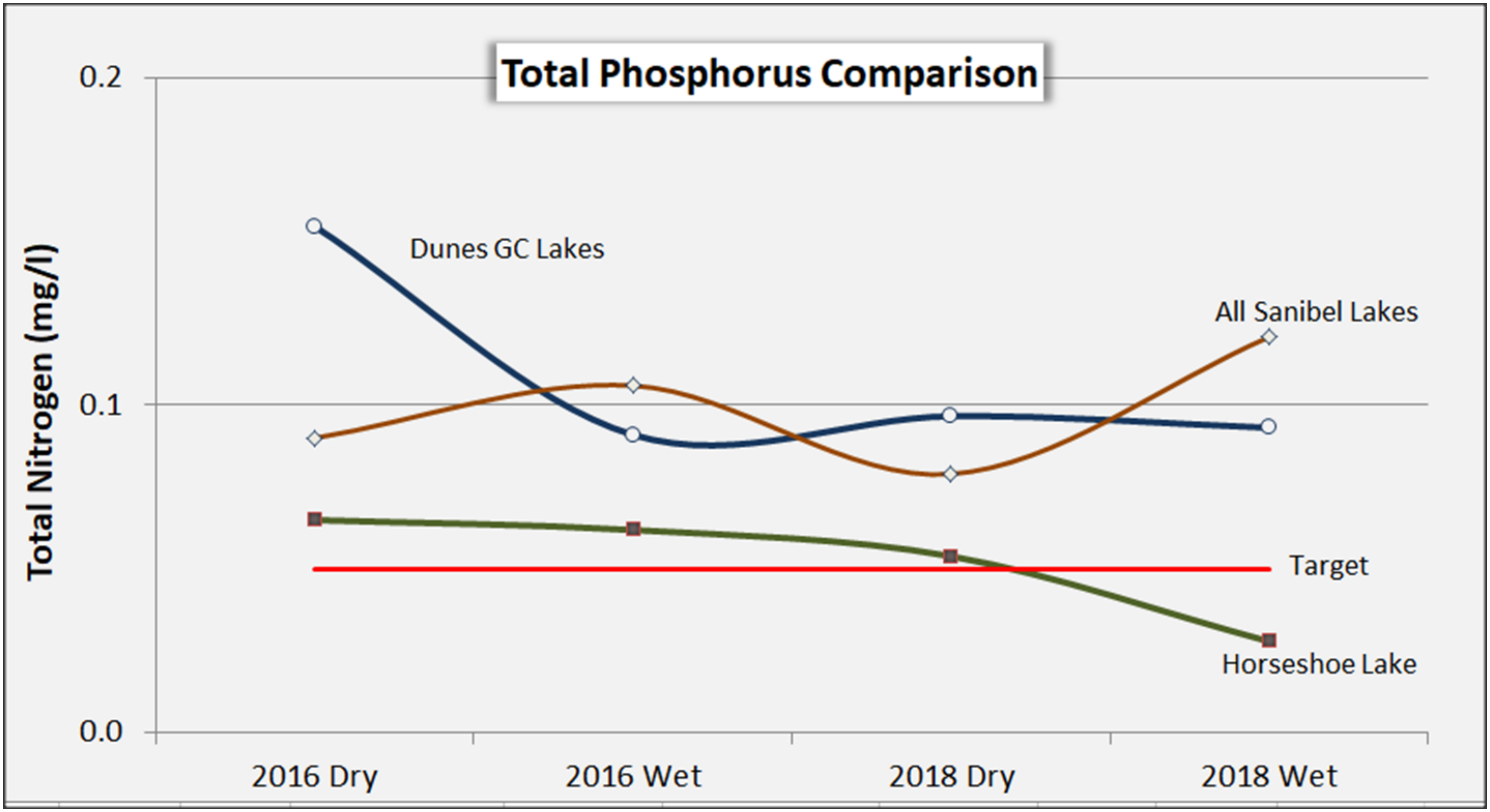

Figure 11. Comparison of TP concentrations between the Dunes stormwater system, Horseshoe Lake and the average TN concentrations of 72 lakes sampled on Sanibel between 2016 and 2018.

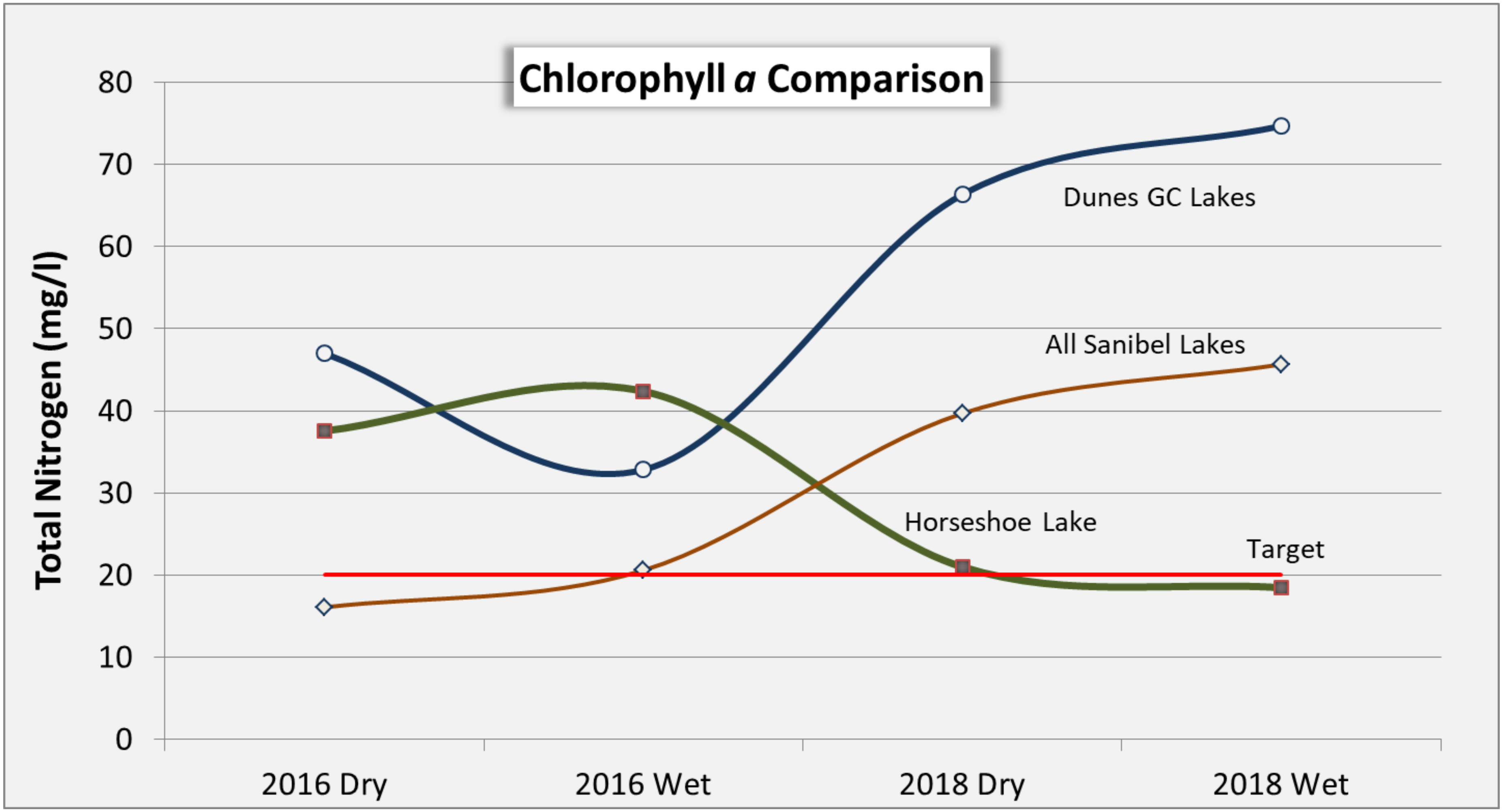

Figure 12. Comparison of chlorophyll *a* concentrations between the Dunes stormwater system, Horseshoe Lake and the average TN concentrations of 72 lakes sampled on Sanibel between 2016 and 2018.

Table 1. Lake 4 water quality data summary. Values exceeding state water quality criteria are shown in bold.

Lake 4	**2012**		**2013**		**2014**		**2015**		**2016**		2017		2018		**FL WQ Criteria**
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	
Chlorophyll a (µg/l)	38.8	**36.2**	**32.5**	**39.4**	**24.2**	**25.3**	20.3	15.8	15.1	17.4	12.3	**42.2**	**68.0**	**85.6**	20
Total N (mg/l)	**3.55**	**3.7**	**9**	**3.45**	**3.85**	**2.4**	**2.96**	**2.7**	**2.35**	**4.17**	**2.35**	**3.54**	**4.53**	**4.08**	1.27
Inorganic N (mg/l)	0.124	0.152	0.241	0.1457	0.1865	0.258	0.1143	0.022	0.041	0.153	0.119	0.196	0.077	0.082	
Nitrate/Nitrite (mg/l)	0.011	0.010	0.010	0.010	0.017	0.020	0.032	0.010	0.005	0.092	0.017	0.184	0.069	0.029	
Ammonia (mg/l)	0.114	**0.293**	**0.231**	**0.209**	0.170	0.238	0.083	0.034	0.037	0.061	0.102	0.012	0.012	0.054	0.2
TKN (mg/l)	3.55	3.7	4.8	3.45	3.85	2.4	2.937	2.7	2.35	4.08	2.34	3.35	4.46	4.05	
Total P (mg/l)	**0.093**	**0.074**	**0.110**	**0.079**	**0.150**	**0.093**	**0.153**	**0.140**	**0.149**	**0.094**	**0.177**	**0.185**	**0.207**	**0.118**	0.05
Orthophosphate (mg/l)	0.022	0.019	0.034	0.034	0.056	0.018	0.057	0.056	0.137	0.054	0.081	0.103	0.049	0.021	
N:P	38.2	50.0	81.8	43.7	25.7	25.8	19.3	19.3	15.8	44.4	13.3	19.3	23.3	36.8	
ChlA:TP	0.4	0.5	0.3	0.5	0.2	0.3	0.1	0.1	0.1	0.2	0.1	0.2	0.3	0.7	
Limiting Nutrient	None	None	None	None	None	None	None	None	None	None	None	None	None	None	
Trophic State Index	**80.5**	**76.8**	**84.6**	**77.1**	**79.5**	**73.7**	**77.1**	**74.7**	**73.8**	**75.6**	**74**	**83**	**87.5**	**84.5**	< 60
Surface DO (mg/l)	**4.5**	**4.0**	**3.5**	5.9	5.4	**2.9**	6.9	4.7	**2**	**2.1**	5.2	**2.9**	8.0	5.15	> 5
Surface Salinity (PSU)	9.1	17.3	11.9	7.1	4.4	6.0	7.5	6.3	5.2	6.3	5.5	3.8	3.2	4.2	
Surface Temp (°C)	25.4	26.8	28.4	29.1	21.6	30.6	23.5	30.6	29	32.7	22.1	32.0	23.4	33.3	
Turbidity (NTU)	4.5	6.6	*	4.5	4.5	7.1	3.4	2.2	10.7	4.4	3.4	6.5	9.0	18.0	
CDOM (QSE)	192	167	185	201	206	203	181	198	163	156	218	204	193	198	
Center Depth (m)	3.4														

Table 2. Lake 5 water quality data summary. Values exceeding state water quality criteria are shown in bold.

Lake 5	2012		2013		2014		2015		2016		2017		2018		FL WQ Criteria
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	
Chlorophyll a (µg/l)	**133.8**	**146.5**	-	**168**	**46.3**	**67.8**	**67.8**	**43.4**	**30.6**	**32.9**	**73.8**	**57.6**	**86.3**	**103.6**	20
Total N (mg/l)	**4.15**	**6.3**	-	**3.5**	**3.2**	**2.65**	**3.14**	**2.6**	**2.62**	**3.13**	**3.55**	**3.607**	**3.83**	**3.88**	1.27
Inorganic N (mg/l)	0.026	0.857	-	0.244	0.196	0.3195	0.1597	0.028	0.019	0.101	0.281	0.2	0.087	0.02	
Nitrate/Nitrite (mg/l)	0.01	0.01	-	0.01	0.01	0.01	0.0207	0.01	0.007	0.068	0.074	0.188	0.079	0.012	
Ammonia (mg/l)	0.068	**1.276**	-	**0.234**	0.186	**0.3095**	0.139	0.018	0.012	0.033	0.207	0.012	0.012	0.008	0.2
TKN (mg/l)	4.15	6.3	-	3.5	3.2	2.65	3.127	2.6	2.62	3.06	3.48	3.42	3.75	3.87	
Total P (mg/l)	**0.0855**	**0.16**	-	**0.065**	**0.1065**	**0.125**	**0.1417**	**0.1**	**0.16**	**0.099**	**0.2135**	**0.153**	**0.163**	**0.124**	0.05
Orthophosphate (mg/l)	0.02	0.0225	-	0.043	0.024	0.0185	0.0327	0.023	0.107	0.038	0.064	0.08	0.046	0.0285	
N:P	48.5	39.4	-	53.8	30.0	21.2	22.2	26.0	17.0	31.6	16.6	23.9	28.3	33.7	
ChlA:TP	1.6	0.9	-	2.6	0.4	0.5	0.5	0.4	0.2	0.3	0.3	0.4	0.5	0.8	
Limiting Nutrient	None	None	-	P	None	None	None	None	None	None	None	None	None	None	
Trophic State Index	**84.7**	**91.8**	-	**83**	**79.3**	**80.9**	**82.8**	**77.2**	**78.3**	**77.1**	**86.5**	**83.29**	**86.1**	**85.4**	< 60
Surface DO (mg/l)	8.7	**4.0**	-	**2.9**	5.9	**2.5**	7.6	**4.1**	5.8	5.9	5.35	**3.7**	5.7	7.2	> 5
Surface Salinity (PSU)	3.5	3.6	-	3.5	3.6	3.7	3.2	3.6	2.3	2.3	2.5	2.3	2.1	2.1	
Surface Temp (°C)	27.5	24.7	-	28.5	21.5	30.0	23.0	31.1	29	31.7	21.5	31.2	26.2	30.3	
Turbidity (NTU)	14.9	22.2	-	15.6	5.3	15.3	6.3	7.1	5.7	5.1	8.1	10.6	11.2	28	
CDOM (QSE)	183	194	-	202	218	200	196	192	155	159	297	194	212	189	
Center Depth (m)	4.1														

Table 3. Lake 9 water quality data summary. Values exceeding state water quality criteria are shown in bold.

Lake 9	2012		2013		2014		2015		2016		2017		2018		FL WQ Criteria
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	
Chlorophyll a (µg/l)	**89**	**97.6**	-	**202**	**96**	**83.1**	**54.2**	**27.1**	**54.2**	**28.3**	**54.4**	**30.15**	**68.2**	**34.9**	20
Total N (mg/l)	**4.6**	**5.15**	-	**3.6**	**4.65**	**2.65**	**3.127**	**2.6**	**3.06**	**2.85**	**3.55**	**2.897**	**4.33**	**2.32**	1.27
Inorganic N (mg/l)	0.0477	0.507	-	0.0575	0.291	0.1595	0.1653	0.065	0.021	0.135	0.1895	0.193	0.229	0.025	
Nitrate/Nitrite (mg/l)	0.0115	0.01	-	0.01	0.01	0.01	0.01533	0.01	0.005	0.098	0.0265	0.181	0.086	0.013	
Ammonia (mg/l)	0.06	**0.497**	-	0.0475	**0.281**	0.1495	0.15	0.055	0.016	0.037	0.163	0.012	**0.287**	0.012	0.2
TKN (mg/l)	4.6	5.15	-	3.6	4.65	2.65	3.117	2.6	3.055	2.75	3.53	2.715	4.24	2.31	
Total P (mg/l)	**0.18**	**0.1455**	-	**0.085**	**0.0545**	**0.0565**	**0.08733**	**0.073**	**0.159**	0.048	**0.141**	**0.229**	**0.066**	0.038	0.05
Orthophosphate (mg/l)	0.0225	0.0215	-	0.043	0.0075	0.021	0.025	0.014	0.111	0.045	0.0845	0.146	0.019	0.030	
N:P	25.6	35.4	-	42.4	85.3	46.9	35.8	35.6	22.0	59.4	25.2	13.0	104.9	61.1	
ChlA:TP	0.5	0.7	-	2.4	1.8	1.5	0.6	0.4	0.4	0.6	0.4	0.1	1.0	0.9	
Limiting Nutrient	None	None	-	P	None	None	None	None	None	None	None	None	None	None	
Trophic State Index	**88.1**	**87.9**	-	**85.7**	**81.1**	**76.9**	**78.7**	**73**	**81.5**	**71.2**	**82.5**	**81.2**	**82.5**	**80.1**	< 60
Surface DO (mg/l)	8.0	**4.3**	-	5.0	**4.8**	**3.7**	7.6	**3.8**	**4.2**	6.1	5.4	5.3	5.3	7.1	> 5
Surface Salinity (PSU)	4.9	4.8	-	4.5	5.0	4.8	4.4	4.9	3.2		3.6	3.25	3.3	3.3	
Surface Temp (°C)	25.4	25.4	-	29.0	22.1	30.7	23.3	31.2	28.7	32.4	21.5	31.85	31.85	26.2	
Turbidity (NTU)	5.5	9.2	-	11.0	9.3	7.5	5.9	3.6	16.0	4.1	5.3	4.2	4.2	10.4	
CDOM (QSE)	153	149	-	154	175	144	172	150	120	112	201	143	129	161	
Center Depth (m)	3.9														

Table 4. Horseshoe Lake water quality data summary. Values exceeding state water quality criteria are shown in bold.

Horseshoe Lake	2012		2013		2014		2015		2016		2017		2018		FL WQ Criteria
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	
Chlorophyll a (µg/l)	**50.7**	**52.3**	**-**	**72.2**	**50.5**	**35.1**	**28.7**	**23**	**32.0**	**42.4**	**33.05**	**23.45**	**37.2**	18.5	20
Total N (mg/l)	**3.1**	**3.95**	**-**	**2.95**	**2.75**	**2.1**	**2.3**	**2.5**	**2.13**	**3.13**	**2.3465**	**2.4**	**2.63**	**1.95**	1.27
Inorganic N (mg/l)	0.04	0.092	-	0.044	0.115	0.133	0.082	0.012	0.033	0.125	0.0795	0.219	0.079	0.035	
Nitrate/Nitrite (mg/l)	0.01	0.01	-	0.01	0.01	0.01	0.023	0.01	0.021	0.089	0.0085	0.207	0.055	0.027	
Ammonia (mg/l)	0.066	0.128	-	0.128	0.105	0.123	0.059	0.014	0.012	0.036	0.071	0.012	0.024	0.008	0.2
TKN (mg/l)	3.07	3.95	-	2.95	2.75	2.05	2.3	2.5	2.11	3.04	2.34	2.195	2.575	1.92	
Total P (mg/l)	0.042	0.05	-	0.038	0.05	0.043	**0.091**	**0.057**	**0.184**	**0.062**	**0.077**	**0.296**	**0.12**	0.028	0.05
Orthophosphate (mg/l)	0.0145	0.012	-	0.023	0.005	0.016	0.007	0.015	0.147	0.046	0.0555	0.160	0.096	0.019	
N:P	73.8	79.0	-	77.6	55.0	48.8	25.3	43.9	22.3	50.5	30.5	17.8	36.4	69.6	
ChlA:TP	1.2	1.0	-	1.9	1.0	0.8	0.3	0.4	0.2	0.7	0.4	0.1	0.3	0.7	
Limiting Nutrient	None	None	-	P	None	None	None	None	None	None	None	None	None	None	
Trophic State Index	**73.8**	**76.6**	**-**	**74.5**	**74**	**69.6**	**73.8**	**70.4**	**76.3**	**75.3**	**73.6**	**78.18**	**77.8**	63.3	< 60
Surface DO (mg/l)	8.3	6.1	-	4.7	7.9	5.3	6.5	4.8	6.2	6.8	7.1	5.3	7.3	7.3	> 5
Surface Salinity (PSU)	4.7	4.6	-	4.5	4.6	4.8	4.2	4.6	3	3	3.1	3	2.55	2.9	
Surface Temp (°C)	24.4	25.6	-	29.3	21.7	31.1	23.3	30.7	29.1	32.5	22.4	32.05	22.05	30	
Turbidity (NTU)	9.5	7.8	-	8.7	7.2	5.5	4.8	5	5.5	4.3	3.8	4.9	3.4	5.5	
CDOM (QSE)	89	101	-	118	110	104	112	100	94	85	126	109	115.4	97	
Hardness	1000														
Copper (ug/l)	30														
Center Depth (m)	3.4														