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TWENTY YEARS OF PERFORMANCE AT THE LAKE APOPKA MARSH FLOW-WAY

by

Jennifer Mitchell, Ph.D.
Lori McCloud

St. Johns River Water Management District
Palatka, Florida

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Scientific Reference Center
St. Johns River Water Management District
4049 Reid Street/P.O. Box 1429
Palatka, FL 32178-1429 (32177 for street deliveries)
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EXECUTIVE SUMMARY

The Lake Apopka Marsh Flow-Way (MFW), a constructed recirculating treatment wetland, has been in operation since 2003. At the time of its construction, in the early 2000s, it was considered an innovative approach to water quality improvement for hypereutrophic Lake Apopka. The property that the MFW was constructed on was acquired by the St. Johns River Water Management District (District) in the late 1980s. At the time of acquisition, these parcels were muck farms that pumped water off the farm fields to maintain dry conditions conducive to agriculture. This was the primary source of excess nitrogen and phosphorus (P) responsible for converting Lake Apopka from a clear shallow lake to a hypereutrophic system with chronic algal blooms. After decades of agricultural use, the organic soil subsided several feet, which provided an opportunity to construct this wetland system without additional excavation. Water gravity flows from Lake Apopka through a network of canals and shallow marsh cells, before collecting in a single pump basin where it is pumped back into the lake. The MFW treats 30% of the lake volume per year during normal operation. The treatment effectiveness results from particulates and associated nutrients falling out of suspension as water flows through one of the shallow marsh cells. This results in increased clarity and decreased bioavailable nutrients in the lake. During periods of reduced lake nutrients, the system remains effective for suspended sediment removal.

After 20 years of operation, the MFW continues to be a cost-effective method for nutrient removal. Over its entire period of operation, it has removed over 39.5 tons of Total Phosphorus (TP), 1,500 tons of Total Nitrogen (TN) and 75,000 tons of Total Suspended Solids (TSS) from Lake Apopka at a total cost of $13.5 million. This cost includes capital costs (design, construction, and infrastructure) as well as operation and maintenance costs (cell and levee maintenance, staff time, cost of electrical pumps, water quality analyses, pump maintenance, etc.). These water quality improvements are directly observable in both Lake Apopka and the Apopka-Beauclair Canal (AB Canal). However, as water quality improves within Lake Apopka, the MFW's TP removal efficiency also declines. Anticipated future maintenance needs include systematic replacement of main inflow and outflow structures, cell maintenance (mowing and clearing spreader ditches to encourage sheet flow through each cell), and pump basin maintenance for the continued operation of the MFW.

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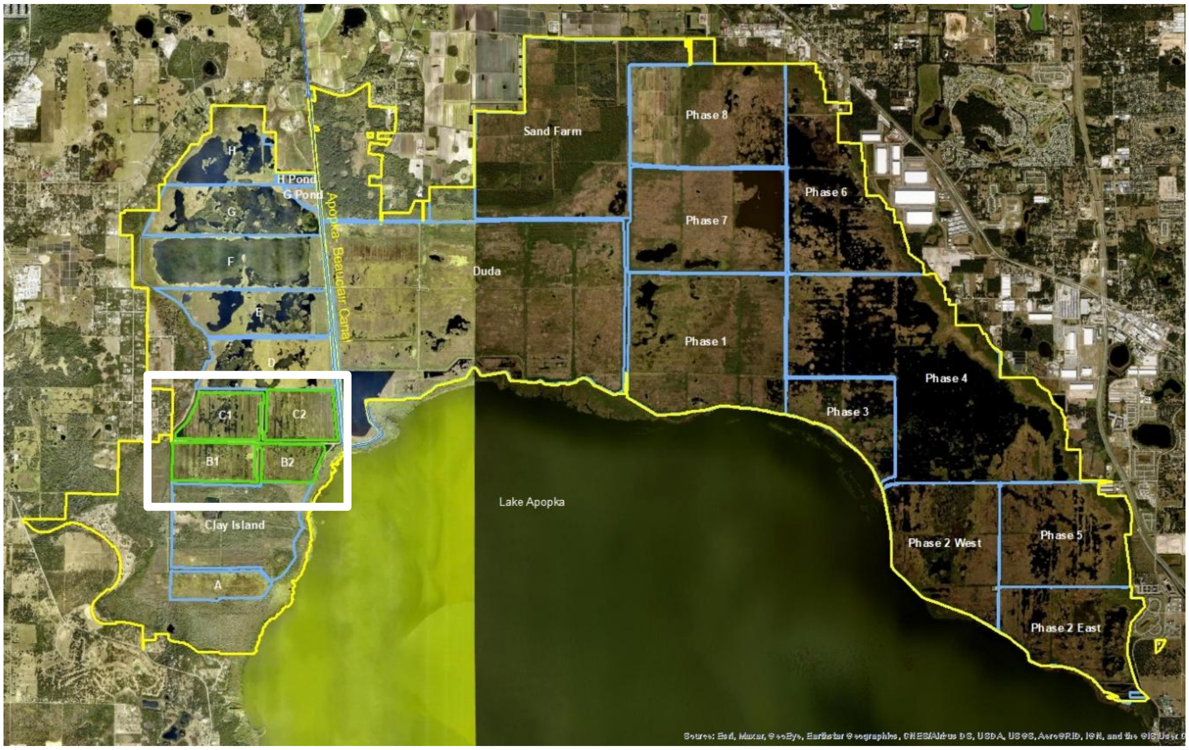
BACKGROUND

The construction and operation of the MFW in the northwest corner of Lake Apopka is one of the District's management techniques to improve the water quality in the lake and restore a healthy ecosystem (Figure 1). Lake Apopka is the fourth-largest lake in Florida and is the headwaters for the Ocklawaha Chain of Lakes. Historically, this lake was a shallow, clear lake with abundant submerged aquatic vegetation (SAV) and a world-renowned bass fishery. After the floodplain marshes were separated from the lake by the construction of a perimeter levee along the northern border of the lake, as well as the creation of the AB Canal, the marshes were ditched and drained for agricultural purposes. Over the roughly 60 years of operation of the muck farms along the North Shore of Lake Apopka, they contributed excessive nutrient loading to the lake (Coveney et al. 2005) and caused soil subsidence of approximately 1 foot per decade while in agriculture. The excessive nutrient loading created conditions favorable for algal blooms, which began to dominate the lake, causing a collapse of SAV habitat due to shading by algal blooms.



Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User

Figure 1. Map of the Lake Apopka North Shore historic muck farms restored to wetland condition, Lake and Orange Counties, Florida. MFW located white box.

Since 1985, the District has been working to restore the lake to Class III water quality standards as directed by the State Legislature. Early feasibility studies identified the potential benefit of utilizing constructed wetlands to improve water quality in Lake Apopka, and a pilot project was undertaken to verify the concept and develop full-scale construction specifications (Coveney et al. 2002). One aspect of the District's plan was to purchase the muck farms on the west side of the AB Canal for the construction of the MFW. The original demonstration project was constructed on the A and B cells shown in Figure 1 (Coveney et al. 2002). This project operated from 1990 to 1994, and information gathered from its construction and operation guided the design and operation of the current MFW (Coveney et al. 2001 and Coveney et at. 2002). The original plan was to construct subsequent phases of the MFW on the D-E and F-G cells (Lowe et al. 1992). In 1996, the District was directed to purchase all the Lake Apopka North Shore's muck farms through a special legislative appropriation of $20 million, with a $26 million match from the Wetlands Reserve Program in the Natural Resources Conservation Service (NRCS). Following the purchase of the remainder of the muck farm properties and the resulting decline in external P loading, a decision to build the subsequent phases of the MFW was delayed and ultimately deemed unnecessary to construct.

SITE DESCRIPTION

Construction of the MFW began in 2000, and operation began at the end of 2003, but nutrient removal did not occur until January 2004. A more extensive site description is detailed in Dunne et al. (2012). As an overview, the MFW is composed of four independently operating cells (B1-180 acres, B2-121 acres, C1-192 acres, C2-188 acres) and associated conveyance canals (Figure 2). Inflow structures are culverts with screw gates, and outflow structures are culverts with boarded risers. Boards can be added or removed to adjust the depth of water within each cell, thereby influencing the hydraulic gradient within each cell. Water from Lake Apopka flows through a feeder canal into one of the wetland cells (Figure 2), where it sheet flows by gravity to a collection canal that empties into a single pump basin. Elevation of the cells is lower than the lake because of years of soil subsidence from agriculture, so hydraulic forces allow water to gravity flow through the system to the pump basin. Each cell is maintained for similar target vegetation communities, including shallow marsh, shrub swamp, and areas of open water. As water collects in the pump basin, it is lifted back into the lake via a pump station. The location of the pump station at the confluence of Lake Apopka and the AB Canal was intentional, as it allowed for treated water from the MFW to preferentially flow through the Apopka dam and towards Lake Beauclair, as a means to reduce its P loading. The balance of the water not flowing downstream through the AB Canal is returned to Lake Apopka.

The MFW was constructed to remove suspended sediments and associated nutrients, primarily P, from the lake water to improve water quality and increase clarity of the water column in Lake Apopka (Coveney et al. 2002). In contrast to other treatment wetlands, performance goals of the MFW are quantified based on removal efficiency rather than target concentrations. Flow rates through the cells must be balanced so that sediments fall out of suspension, the release of soluble P from the organic soils and accumulated sediments into the water column is minimized, and short-circuiting within each cell is avoided. Established target removal efficiencies for the MFW are TSS 80%, TP, and TN 30% each (Hoge et al. 2003).

Figure 2. Schematic of the MFW and water quality station names with relative location indicated by stars; inflow is collected from a single structure, while outflow samples are collected at each structure and homogenized.

METHODS

WATER LEVEL MONITORING

Water levels and hydraulic flows through the MFW are monitored through a network of 14 water level telemetry sites, located at the inflow and outflow of the system, as well as the inflow and outflow of each cell. Daily average water levels are utilized for estimating inflow and outflow for each cell, including direction and rate of flow to calculate water depths, hydraulic loading rate (HLR), and nominal hydraulic residence time (HRT), as well as inform management decisions. Calculations for HLR include precipitation and evapotranspiration (ET) for the area. On occasions when power is lost to the pump station or when pumps do not work, backflow conditions can occur in the cells.

OPERATION AND MAINTENANCE

Cell discharge is controlled by maintaining appropriate hydraulic gradients within each cell. Inflows can be closed during periods of anticipated heavy rain, like hurricanes, or when repairs and/or maintenance are needed to stop operation of the system or a cell; no nutrient removal efficiencies are calculated during times of closure. Conveyance and spreader ditches are typically cleared, and cells are mowed approximately every 5 years, with an associated water level drawdown, to consolidate sediments and improve nutrient removal efficiency. A large-scale regrading of each cell was conducted from 2019–2021 to eliminate short-circuiting that had formed over the initial 15 years of operation.

WATER SAMPLING AND LABORATORY ANALYSIS

Composite water samples are collected weekly during operation at 10 locations to quantify both system and individual cell nutrient removal (Figure 2). Sites classified as inflow are sampled from a single inflow structure, while sites classified as outflow are sampled from each structure and homogenized in a churn splitter. Samples are collected following District Standard Operating Procedures using a Van Dorn sampler placed mid-water depth; water samples are field filtered (0.45 µm filter) and preserved (acidification), as needed. Samples are then transported on ice to the laboratory for analysis.

Water samples are analyzed for Total Kjeldahl Nitrogen (TKN), Nitrate and Nitrite (NO_x), TSS, TP, Total Dissolved Phosphorus (TDP), and Soluble Reactive Phosphorus (SRP) using standard methods detailed in Table 1. Water quality constituents derived from measured values include particulate phosphorus (PP) (TP minus TDP), and TN (TKN +NO_x). This report will present data from 2004–2024.

Table 1. Standard methods utilized for water sample analyses.

Analyte	Abbreviation	Preservation	Instrumentation	Method
Total phosphorus	TP	Cool, 4°C, H_2SO_4 to pH<2	Perstorp autoanalyzer	EPA 365.4
Total dissolved phosphorus	TDP	Filtered immediately, cool, 4°C	Perstorp autoanalyzer	EPA 365.4
Soluble reactive phosphorus	SRP	Filter immediately, cool, 4°C	LabChat Quickchem AE	EPA 365.1
Total suspended solids	TSS	Cool, 4°C		EPA 160.2
Total Kjeldahl nitrogen	TKN	Cool, 4°C, H_2SO_4 to pH<2	Perstorp autoanalyzer	EPA 315.2
Nitrite and Nitrate	NO_x	Cool, 4°C	Seal QuAAtro segmented flow autoanalyzer	EPA 353.2

CALCULATIONS

Linear interpolation between weekly measured water quality concentration values was utilized to calculate daily concentrations at each monitoring site, which were multiplied by daily flow (m^3 d^{-1}) to estimate mass into and out of each cell (kg d^{-1}) and the system as a whole. Mass removal rates were calculated by subtracting outflow mass loads (kg d^{-1}) from inflow mass loads (kg d^{-1}), and percent mass removal was also calculated using the following equation: mass removed (kg d^{-1})/ (inflow mass load (kg d^{-1})x 100). All calculations were conducted on an annual areal basis (g m^{-2} yr^{-1}) for total mass into and out of the system and total mass removed. HLR was calculated by dividing the flow volume (m^3) by the system treatment area (m^2) for a given period, while nominal hydraulic residence time (days) was determined by dividing the cell volume (m^3) by the inflow rate (m^3 d^{-1}). Cell volume for HLR was calculated using average soil elevation (collected during construction) for each cell, average daily water level, and cell area (Dunne et al. 2012).

COST ANALYSIS

Costs are expressed in dollars at the time of expenditure. Capital costs include design, construction, and infrastructure. For structures that have been replaced, both at the initial construction cost and the cost of replacement were included. Operations and maintenance include nine categories: cell and levee maintenance, staff time, cost of electrical pumps, water quality analysis, pump maintenance, alum, grass carp, flights for aerial imagery, and miscellaneous expenditures. Alum was used intermittently, typically after maintenance to reduce the first flush of TP as soils become rehydrated.

The cost of land acquisition is not included in this cost analysis. Total land acquisition cost for the footprint of the 847 acres encompassing the MFW was just under $2.5 million, which was acquired in two purchases: the C cells in 1988 and the B cells in 1990.

RESULTS AND DISCUSSION

HYDROLOGY

Results discussed in this report are system-wide and not specific to individual cell performance. Annual average hydraulic loading rates varied between 15 and 44 m yr^{-1} (Table 2). Long-term average HLR was 27 ± 12 m yr^{-1}. Over the period of record for MFW operation, an annual average of 30% of the lake's volume flows through the MFW. Cell maintenance typically decreases HLR for the system, and periods of maintenance often have lower HLR than years with full system operation. Over the lifetime of the MFW, HLR from the lake greatly exceeded either rainfall or ET; rainfall averaged 1.2 ± 0.1 m $yr^{-1,}$ and ET averaged 1.1± 0.03 m yr^{-1}. Annual mean hydraulic residence time for the MFW ranged from 2 to 9 days (Table 2).

The MFW is operated at higher HLRs than other constructed wetlands to achieve a maximum load reduction, not a target outflow concentration. The MFW is a recirculating system with a consistent supply of water (the lake) where HLR is relatively stable, and there are multiple opportunities for lake water to be treated depending on flow conditions through the AB Canal. Contrast the MFW treatment with stormwater systems that have highly variable HLR, rainfall-dependent, with only one opportunity to treat water and meet the outflow nutrient target. The Stormwater Treatment Areas (STAs), which are a part of the Everglades restoration, have a maximum annual HLR of 27 m yr^{-1} (Pietro 2012) and a maximum short-term operational range of 18.25- 54.75 m yr^{-1} (Welch et al. 2025, Juston and Kadlec 2019). The HLR for the MFW is maintained at a constant rate, whereas those of the STAs are stormwater-driven and therefore flashier (Juston and Kadlec 2019).

Annual average water depth ranged from a low of 0.40 m in 2015 to a high of 0.63 m in 2019 (Table 2); operational target water depth is 0.5 m to encourage broad leaf emergent vegetation (*Typha spp*., *Pontederia cordata*, and *Sagittaria spp*.) and wetland shrubs (*Salix spp.* and *Ludwigia spp.*) to dominate the system (Kadlec and Knight 1996).

Table 2. Hydrologic budget components of the MFW constructed wetland at Lake Apopka, FL. HLR = Hydrologic loading rate, HRT = Hydrologic retention time. Annual averages calculated from daily values. Values in brackets are one standard deviation of the annual average. When the system inflow was closed, cells were not classified as operational and were not included in this analysis.

Year	Number of months in operation	HLR (m yr^{-1})	HRT (d)	Water depth (m)
2004	12	37 (11)	4 (1.3)	0.51 (0.1)
2005	12	33 (8)	5 (1.5)	0.55 (0)
2006	12	44 (9)	3 (0.6)	0.57(0)
2007	9	32 (13)	3 (1.8)	0.48 (0.1)
2008	12	27 (8)	4 (1.1)	0.41 (0.1)
2009	12	19 (7)	9 (4.3)	0.44 (0.1)
2010	12	33 (5)	4 (0.4)	0.54 (0)
2011	12	25 (10)	4 (0.9)	0.51 (0.1)
2012	12	20 (7)	5 (1.6)	0.52 (0.1)
2013	12	23 (6)	4 (1.1)	0.54 (0)
2014	10	25 (8)	3 (0.8)	0.51 (0)
2015	12	15 (6)	4 (0.9)	0.40 (0)
2016	11	18 (11)	6 (4.1)	0.47 (0.1)
2017	10	32 (16)	4 (3.3)	0.58 (0.1)
2018	11	21 (10)	5 (2.3)	0.60 (0.1)
2019	4	34 (6)	4 (1.6)	0.63 (0)
2021	3	16 (10)	8 (3.8)	0.53 (0.1)
2022	10	26 (13)	4 (1.7)	0.52 (0.1)
2023	12	31 (8)	3 (1.9)	0.55 (0.1)
2024	10	35 (10)	2 (0.5)	0.53 (0.1)

PHOSPHORUS REMOVAL

Phosphorus Concentration

Over the duration of the MFW operation, annual mean TP concentrations of Lake Apopka have had a decreasing trend because of multiple water quality improvement projects completed by the District (Figure 3). Periods of low lake water levels are inversely related to TP concentrations in the water column (Figure 3). In 2007, 2008, and 2012–2014, there were extreme drought conditions, and lake levels were well below the desired regulation level, producing elevated TP concentrations and high nutrient inflows to the MFW (Figures 3 and 4).

Inflow and outflow TP concentrations showed similar patterns for 2004–2015 and again in 2023–2024, with lower concentrations occurring for outflow data, indicating that nutrient removal occurred (Figure 5). Between 2016–2022, TP was exported from the system, either resulting from soil oxidation during cell maintenance and P flux following reflooding or damage to structures following Hurricane Irma, which compromised system functionality. However, in these years of TP release, the concentration of PP declined between the inflow and outflow concentrations (Figure 5), indicating that removal of particulate P still occurred when the system was not working optimally.

During the first 9 years of operation 2004–2012, Dunne et al. (2015) reported a positive linear relationship between TP concentration of inflow and outflow (R^2=0.6193). This relationship became weaker but remained significant for the entire period of operation (Figure 6; R^2=0.3648). Since the majority of P removal by the MFW is by the removal of particulates, the relationship between PP concentration in and out was also significant with an R^2 similar between the entire period of operation and the period discussed in Dunne et al. (2015) (R^2= 0. 6458 and R^2=0. 6856, respectively, Figure 6).

Inflow annual mean TP concentration fluctuated between 0.06 and 0.20 mg/L (Figure 4), and consisted of between 78–90% PP (Figure 5). With the exception of 2015 and 2016, the MFW maintained an efficiency above the target of 30% for PP removal over its operation. Cell maintenance corresponded with the years where PP removal efficiency declined and may be responsible for decreased performance. Similarly, years following cell drawdown and rehydration (2016, 2018, and 2021) were associated with elevated DP leaving the MFW (Figure 5). These indicators of performance may be utilized to increase future performance and decrease the cost per kg of TP removed.

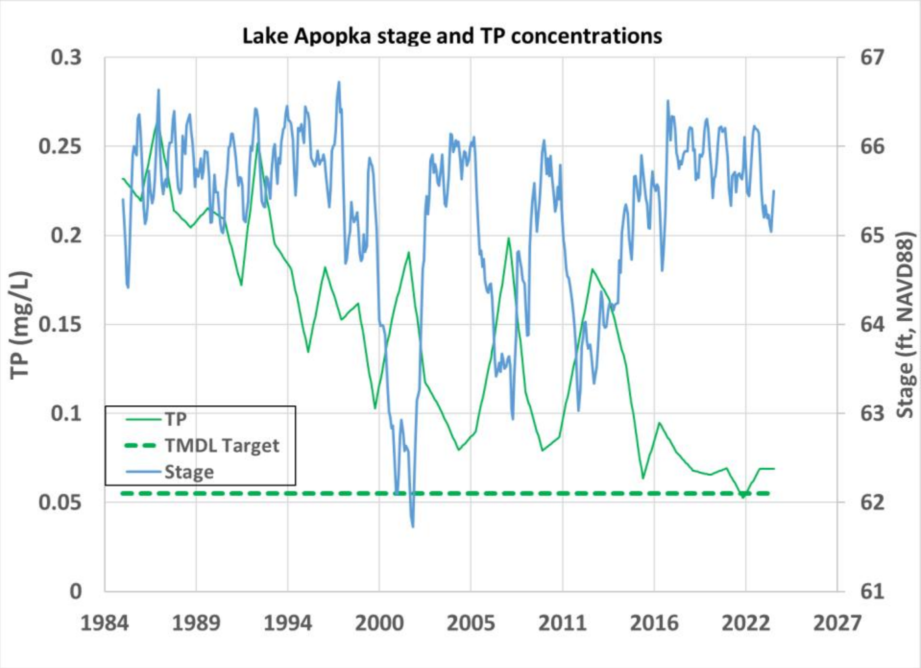


Figure 3. Annual average TP concentration (mg/L) of water quality stations in Lake Apopka (solid green line), Total Maximum Daily Load (TMDL) target concentration of 0.055 mg/L for Lake Apopka (green dotted line), and monthly stage of Lake Apopka (blue line).

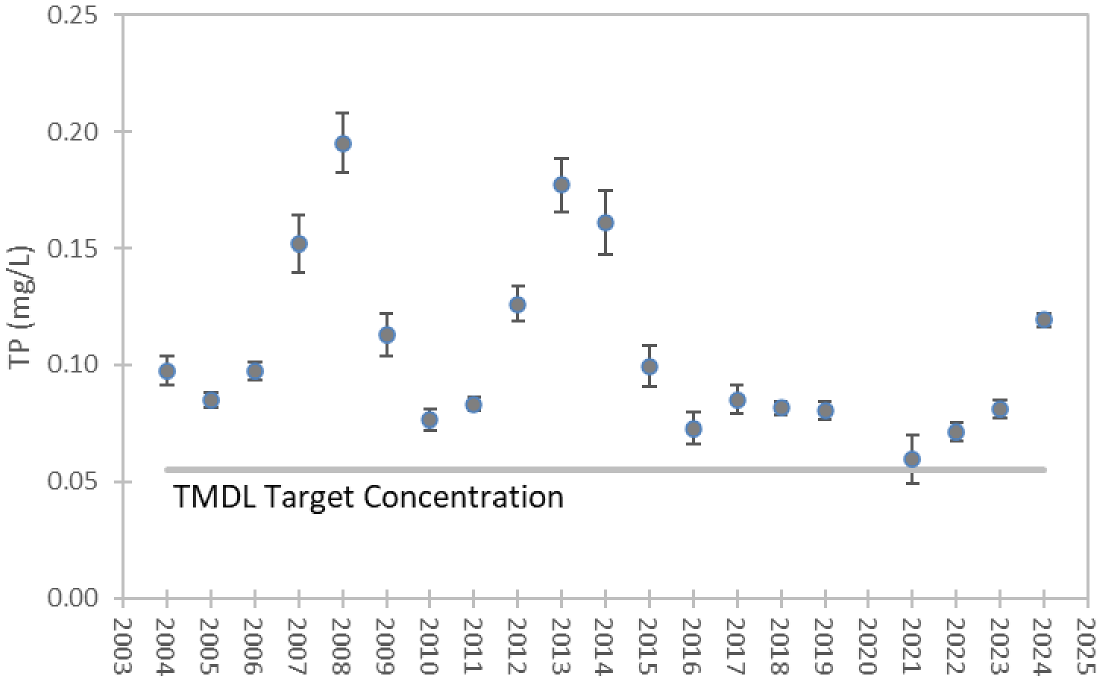


Figure 4. Annual mean TP concentration (mg/L) into the MFW with error bars representing standard error. Lake Apopka TMDL target concentration 0.05 mg/L (grey line).

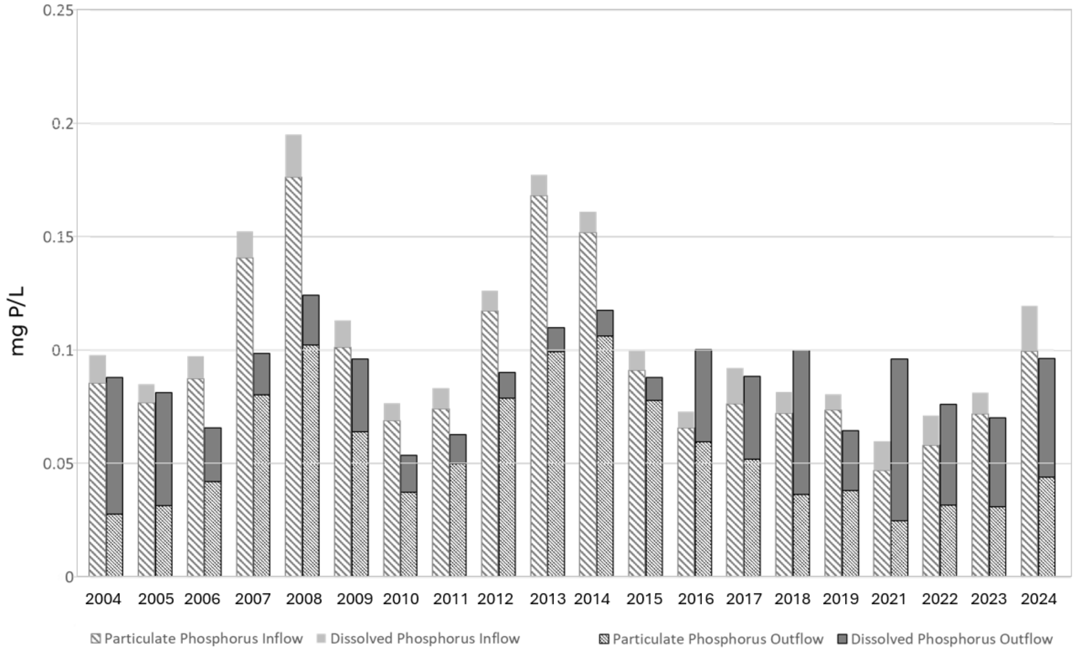


Figure 5. Annual PP and DP concentration (mg/L) into the MFW (left) and out of the MFW (right). Solid bars represent PP and hashed bars represent DP.

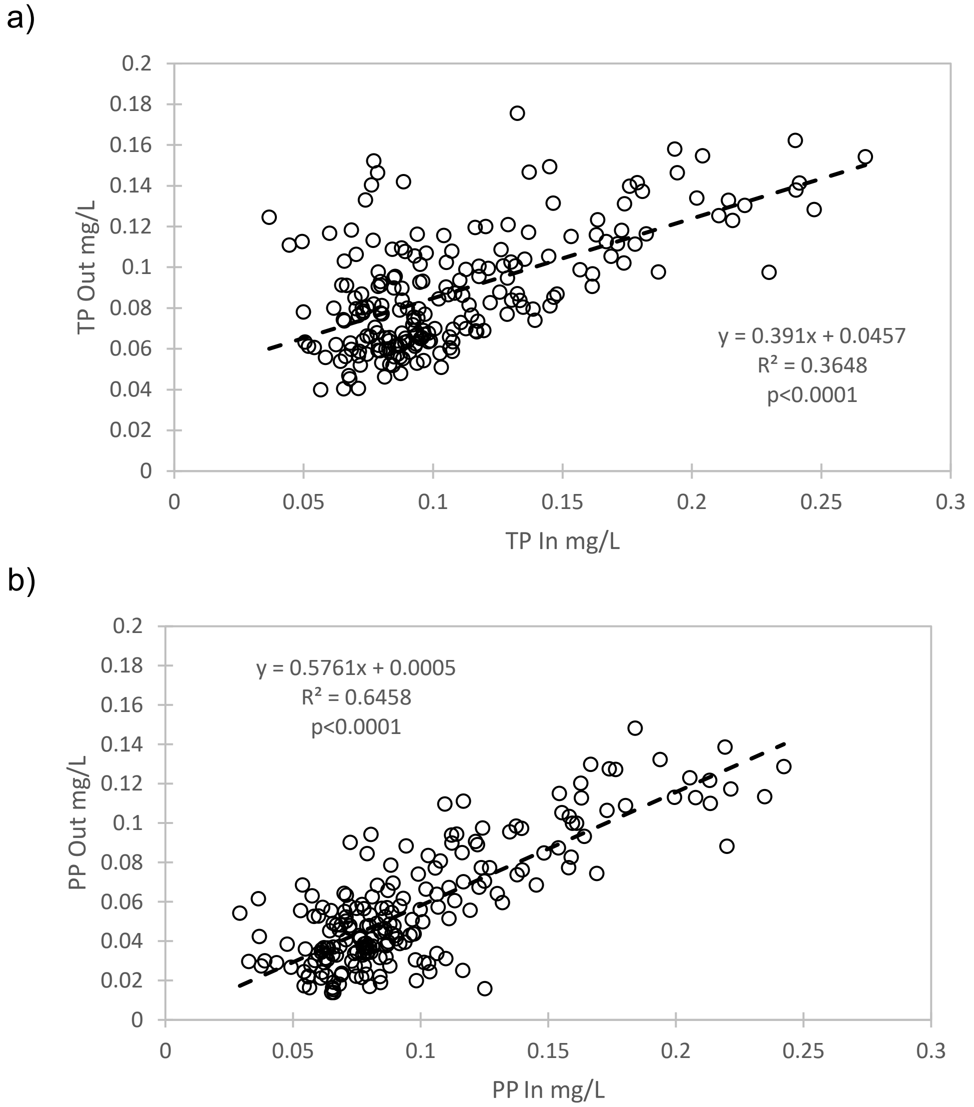


Figure 6. Regression of monthly average TP (a) and PP (b) concentration (mg/L) into and out of the MFW during operation Jan 2004 to Dec 2024.

Phosphorus Removal Performance

Annual total removal of TP from the water column varied greatly between years of operation, ranging from exporting 1,391 kg TP to removing 5,979 kg TP (Figure 7). Years of export typically followed prolonged periods of drawdown of cell(s) for maintenance. Cumulative TP removal from 2004-–2024 is 34.5 MT of TP. Target removal of P is 30%, when examining PP removal the MFW meets this target most years with the exception of 2011, 2012, 2015, and 2016 (Figure 8).

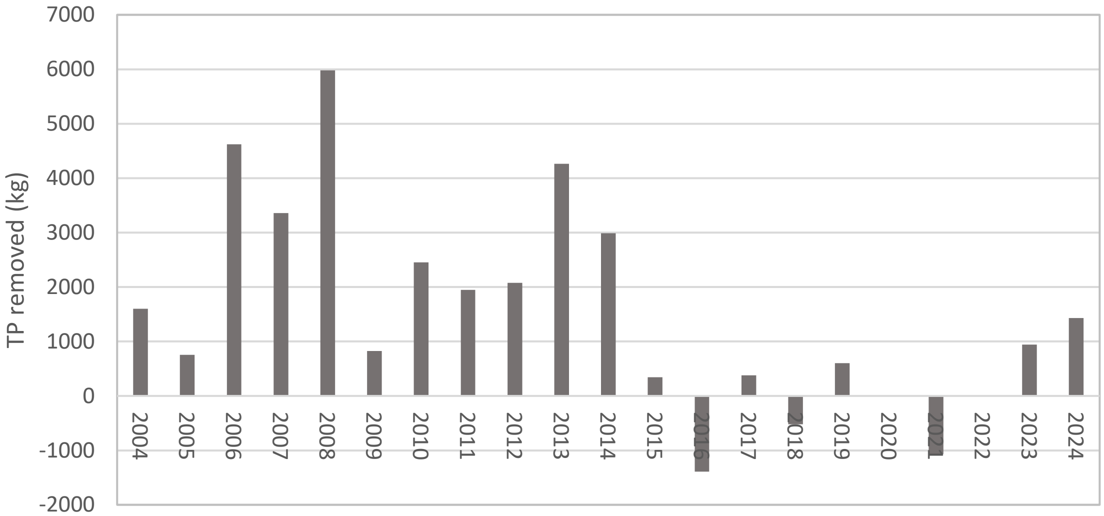


Figure 7. Total annual TP mass removed by the MFW.

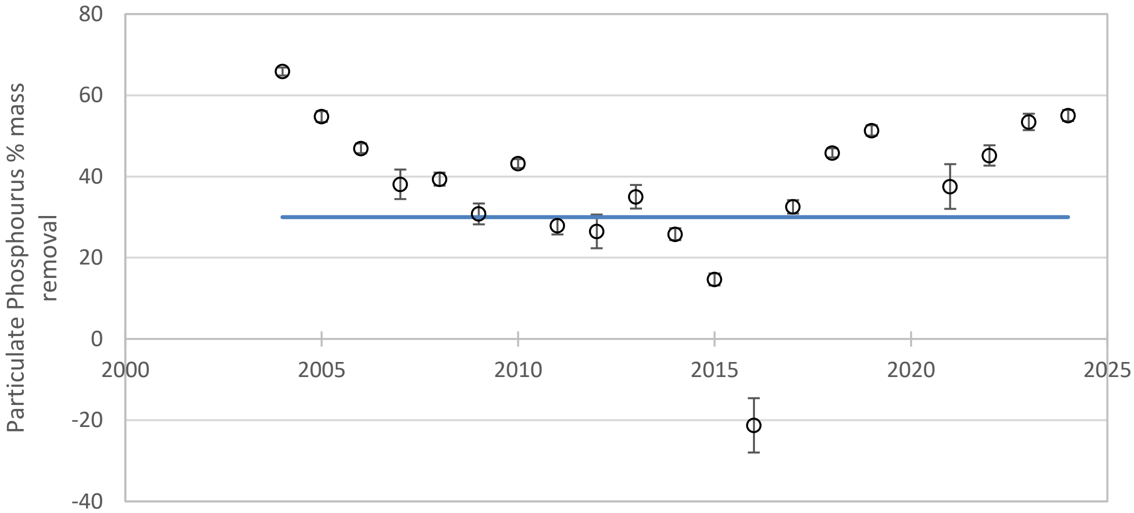


Figure 8. Annual mean percent mass removal of PP for the period of operation. Target removal rate of 30% (blue line).

NITROGEN REMOVAL

Nitrogen Concentration

TN entering the MFW ranges between 2.35 and 5.98 mg/L (Figure 9). Fluctuations of inflow concentration followed the same pattern as TP, with increasing concentrations occurring with decreased water level in the Lake (Figure 9). Outflow concentrations followed a similar pattern to inflow (Figure 9), but were lower, indicating the balance was retained in the wetland. Contrary to TP concentrations and removal, TN removal remained more consistent over the years of operation (Figures 5 and 9).

Inflow nitrogen concentrations had a strong linear relationship with outflow concentration (Figure 10). This relationship is most likely explained by nitrogen removal being driven by the settling of particulates rather than chemical transformation, as observed in Dunne et al. 2013.

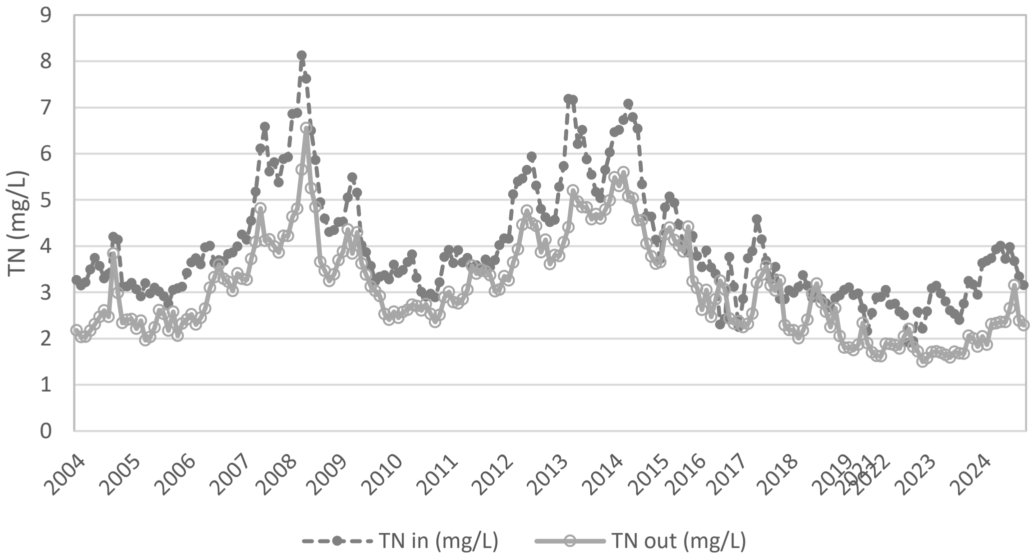


Figure 9. Mean monthly inflow, Total Nitrogen (TN) (dashed line) and outflow TN concentration (solid line).

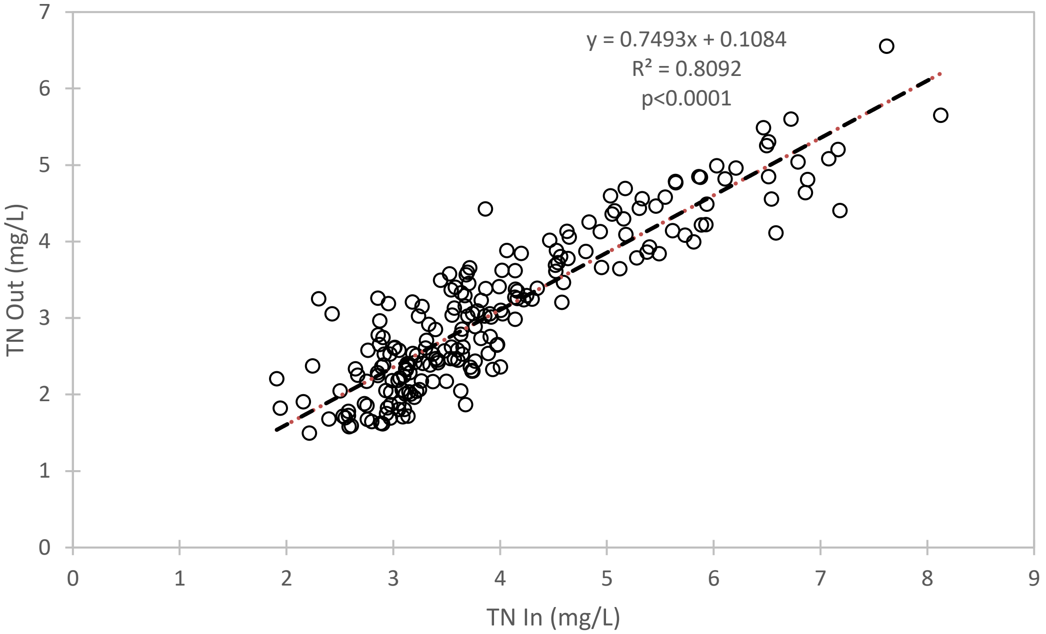


Figure 10. Monthly TN concentration (mg/L) into the MFW plotted against mean monthly TN concentration (mg/L) out of the MFW from Jan 2004 to Dec 2024.

Nitrogen Load Reduction

Annual total TN removal ranged from 7 MT in 2021 to 130 MT in 2008 (Figure 11). Removal rates were influenced by both the concentration of incoming water and the hydraulic loading. Although 2008 was a year of extreme drought, and hydraulic loading targets were not achieved because of physical limitations of structures, it was the year of greatest TN mass removal (Figure 11). Annual mean percent mass removal for TN removal often did not achieve its target of 30% (Figure 12).

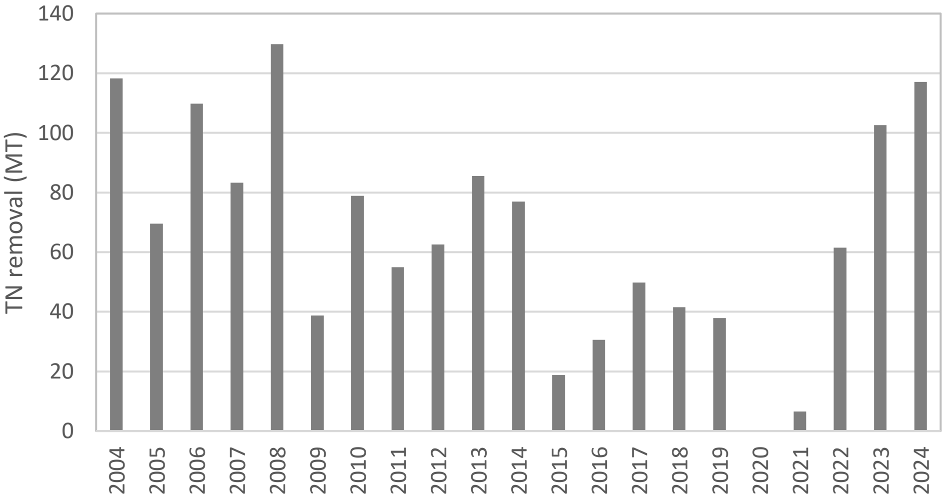


Figure 11. Total annual TN mass removed by the MFW.

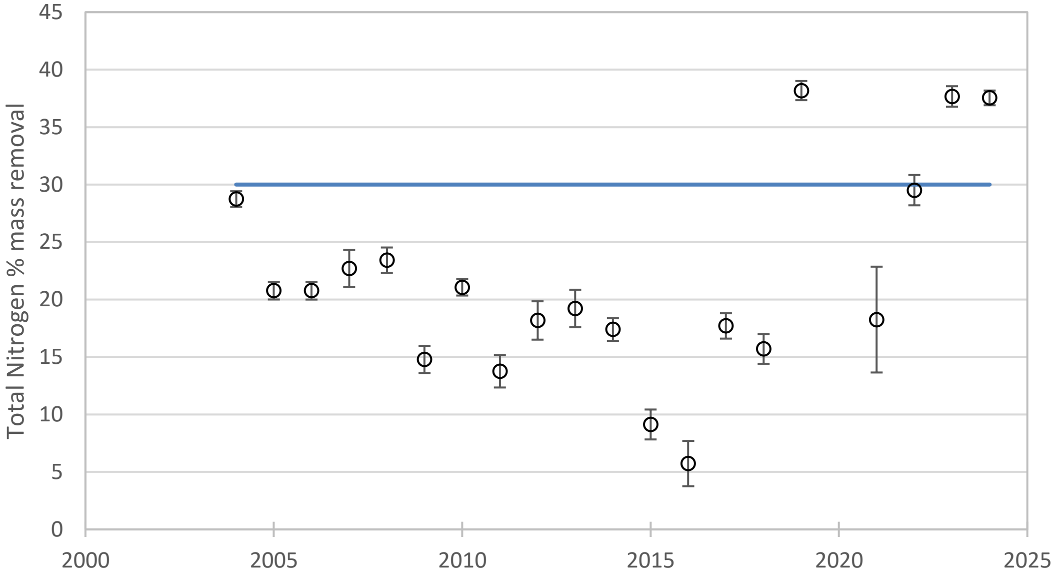


Figure 12. Annual mean percent mass removal of TN for the period of operation. Target removal rate 30% (blue line).

TOTAL SUSPENDED SOLIDS REMOVAL

TSS Concentration

TSS concentration in the lake also increased during periods of low water levels (Figures 3 and 13). Between 2007–2010 and 2013–2015, which were extreme drought years, had elevated concentrations of TSS coming into the MFW in comparison to other years (Figure 13). The lowest annual average TSS concentration was 22.4 mg/L (2021) and the highest was 120.2 mg/L (2008; Figure 14). Over the past 20 years, outflow TSS concentrations mimicked inflow TSS concentrations (Figure 13), but were consistently lower, indicating that the balance was retained in the MFW.

The MFW operates with the goal of maximizing nutrient removal efficiency instead of targeting a specific outflow concentration. Inflow TSS concentrations displayed a positive relationship with outflow concentrations (Figure 15). With the exception of 5 years, the MFW achieved its target percent mass removal for TSS (Figure 16). Over the life of the MFW, it has been extremely effective in removing sediments from the water column.

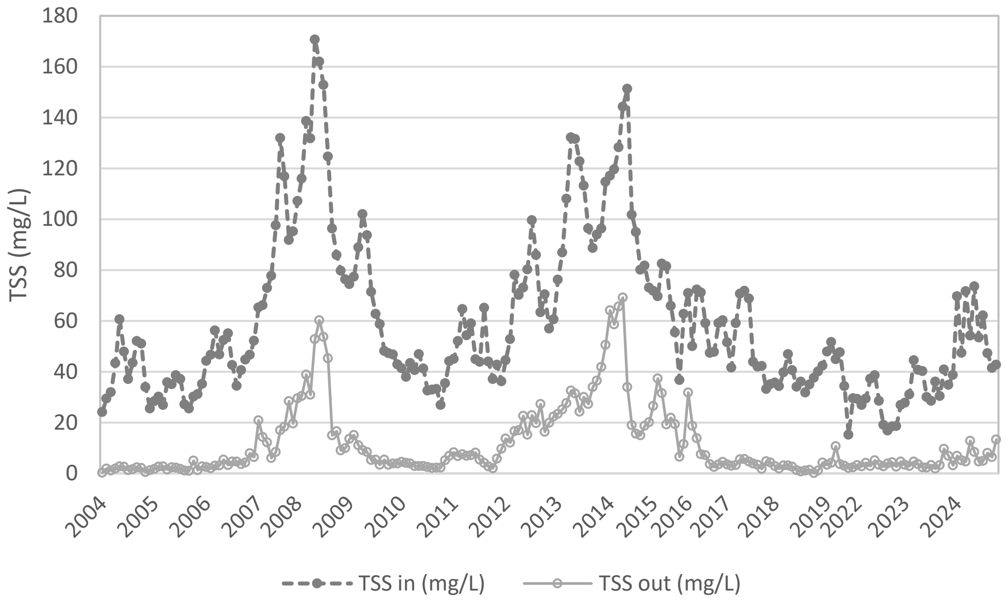


Figure 13. Mean monthly concentration TSS inflow (dashed line) and outflow (solid line).

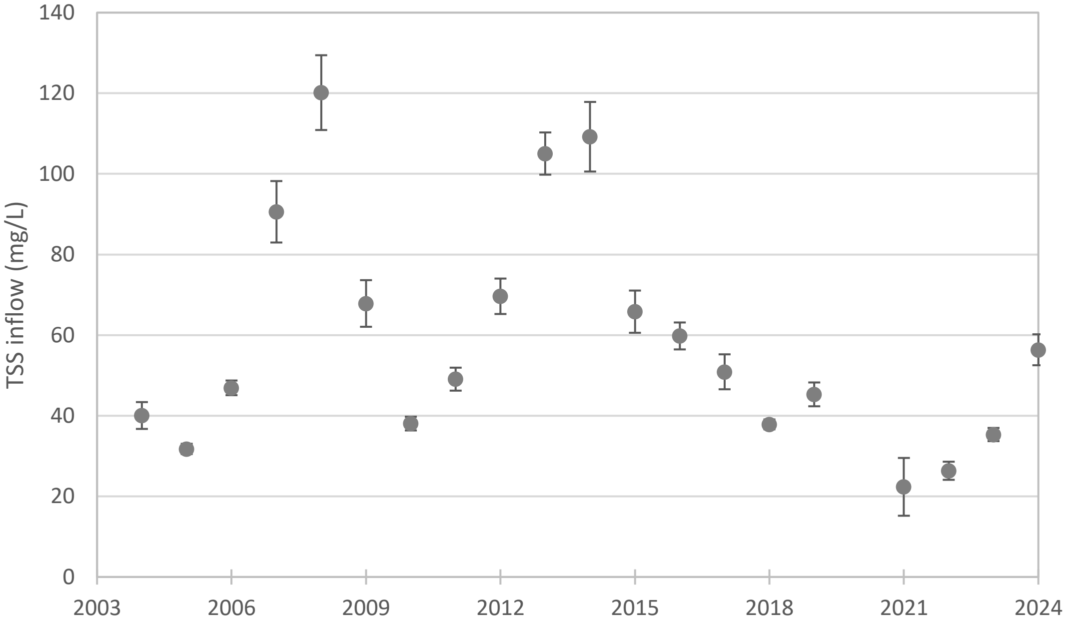


Figure 14. Mean annual inflow TSS concentration with error bars indicating standard error.

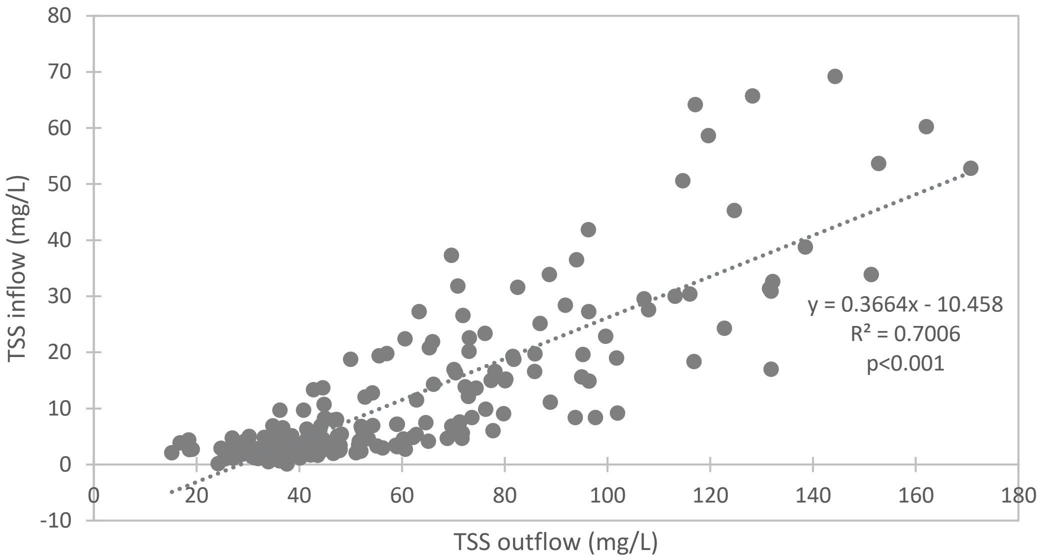


Figure 15. Mean monthly TSS concentration (mg/L) into the MFW plotted against mean monthly TSS concentration (mg/L) out of the MFW from Jan 2004 to Dec 2024.

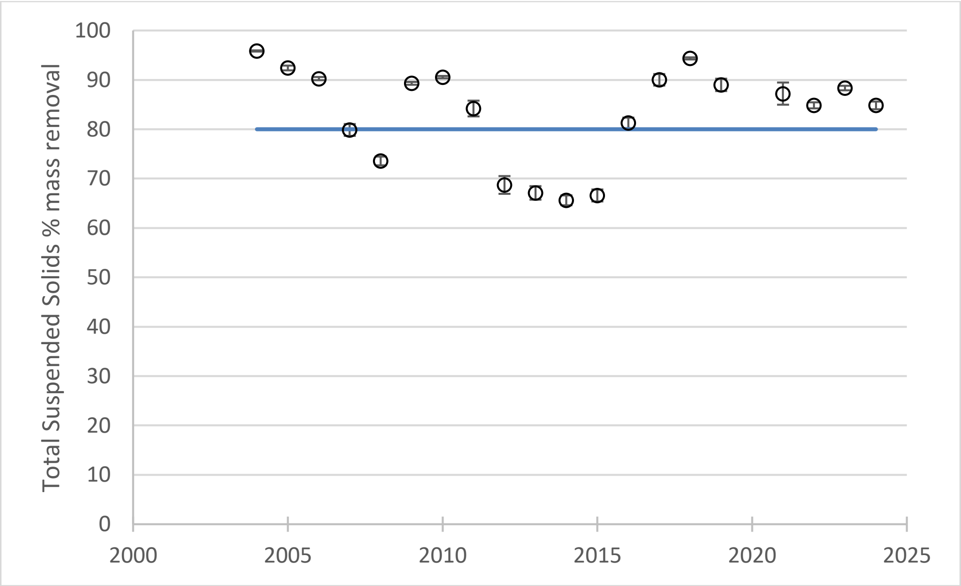


Figure 16. Annual mean percent mass removal of TSS for the period of operation. Target removal rate 80% (blue line).

TSS Load Reduction

Total annual TSS removal fluctuated annually, with a mean annual removal of 3,290 MT (Figure 17). The MFW removed 69,209 MT of TSS from Lake Apopka between 2004–2024. Sediments fall out of the water column and settle throughout each cell, which necessitates occasional clearing of internal spreader ditches.

The 69,209 MT of TSS removed by the MFW would be equivalent to dredging 40 cm of unconsolidated and consolidated floc from Lake Apopka with a bulk density range of 0. 055 to 0.075 g/cm3 (Lumbard et al. 2025) from a 2307—3145-hectare area, respectively.

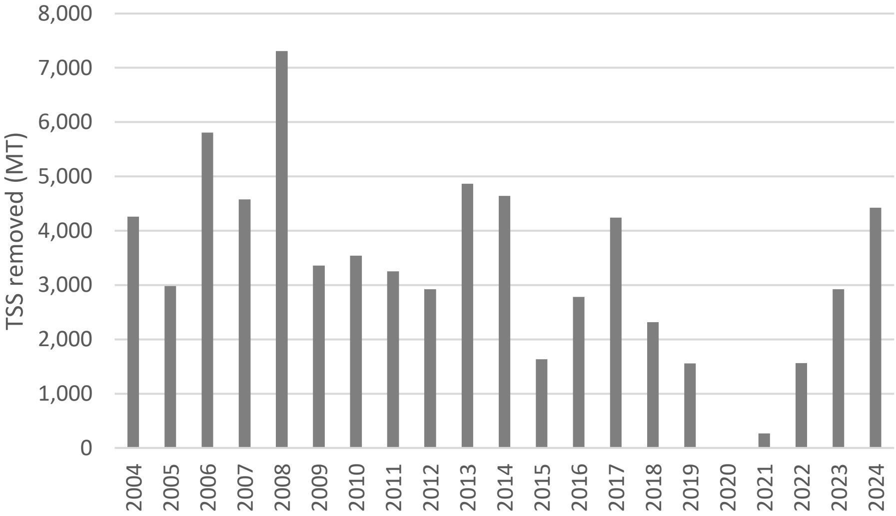


Figure 17. Total annual TSS mass removed by the MFW.

COST OF OPERATING MFW

Operational costs for the MFW are tracked closely and classified as either Capital or Operation and Maintenance costs. From its initial design in 1998–2024, the total expenditure has been $13.5 million.

Capital Costs

Capital costs were $4.8 million and included initial design services, initial earth work, pump installation, pumps, finger dike construction, and structures. Because the MFW was constructed on subsided fields, the costs typically associated with excavating the cells to remove the roughly 1,300 acre-feet of soil that was lost over the two decades of farming were avoided. Capital costs are expenditures that typically have an extended lifespan (Table 3).

Table 3. All costs for the MFW. Values represent the cost at the time of expenditure.

Category	Description	Cost
Capital	Design and construction	$3,148,207
	Structures	$1,643,169
	Total	**$4,791,376**
Operation and Maintenance	Cell maintenance	$3,658,962
	Pump electrical	$1,992,957
	Personnel	$1,750,406
	Pump Maintenance	$256,408
	Levee Maintenance	$ 679,913
	Water quality analysis	$ 371,768
	Grass carp	$15,325
	Aerial photography	$2,891
	Total	**$8,737,012**
	Grand total	**$13,528,389**

Operation and Maintenance Costs

Costs associated with Operation and Maintenance from 2004–2024 totaled $8.7 million (Table 3). These costs were associated with a variety of expenditures, including personnel costs, pump maintenance and electrical costs, water quality analysis, cell and levee maintenance, grass carp, performance evaluation, and aerial imagery. Cell maintenance, pump electrical cost, and personnel are the three largest categories in Operation and Maintenance.

Cell maintenance is conducted when water quality data indicate that cells are not removing TSS and TP at the desired efficiency and/or when aerial imagery indicates that short-circuiting has altered sheet flow. There are two types of maintenance that have occurred over the past 20 years. Typical maintenance involved drawing down water within cells to consolidate sediments and mowing and clearing the spreader ditches to remove accumulated sediments and restore sheet flow through the cells. In 2019–2021, a more extensive maintenance event regraded each cell, and every third ditch was widened and deepened to encourage sheet flow and potentially increase time periods between maintenance. Cell maintenance has occurred six separate times over the past 20 years. Additionally, native vegetation was planted to fill in short circuits as needed and included in cell maintenance costs.

Pump electrical costs totaled $2 million from 2004–2024 (Table 3). Water must be pumped out of the basin for the HLR to be maintained through the cells. Annual cost of pumping ranged from

$28,338 in 2020, when the cells were dewatered for major regrading and only rainfall was pumped back to the lake, to a high of $160,960 in 2006 when cells were operated at extremely high hydraulic loading rates (Table 2 and Figure 18). Fluctuations in cost per kWh have been minimal, with the greatest increases and volatility occurring in the past 5 years (Figure 19).

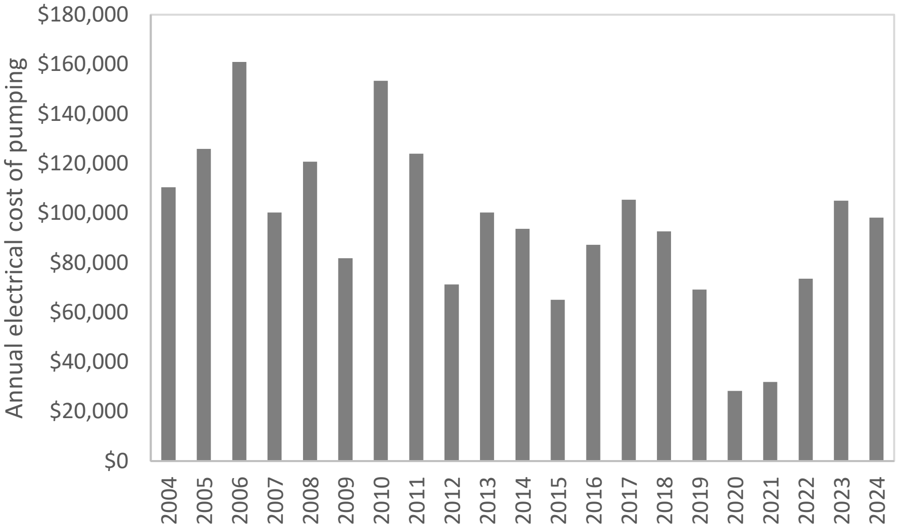


Figure 18. Annual total cost of power for operating the MFW's pump station.

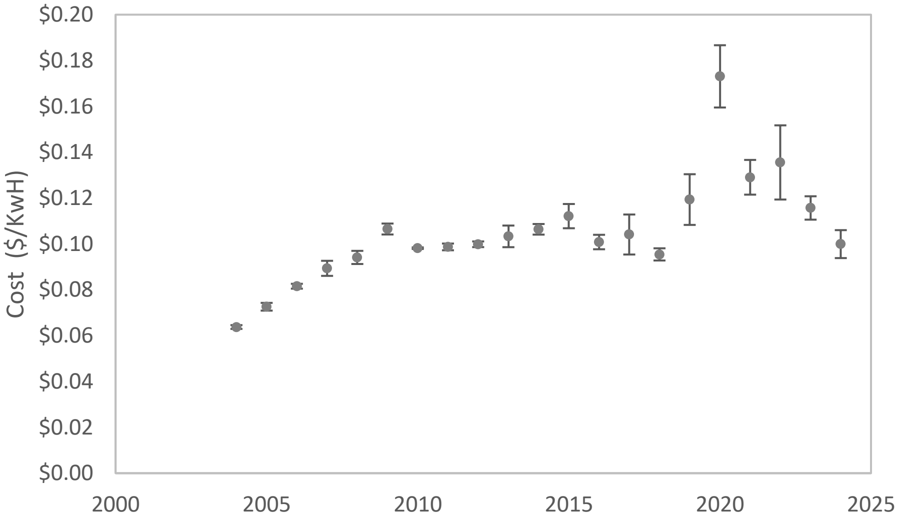


Figure 19. Mean annual cost per KwH of power for operating the pump station at the MFW, with error bars indicating standard error.

Personnel costs included both staff salary and benefits and total $1.8 million (Table 3). Staff were surveyed to determine the approximate number of days they worked on MFW activities and included staff who collected water quality samples, provided QA/QC for the water quality data, and managed the operation of the MFW. After the first several years of operation, the staff costs at the MFW decreased, and there were fewer intensive studies conducted on MFW processes. Since 2011, the hours staff spend on MFW operation and sampling have stabilized. The largest use of staff time has been weekly water sample collection for performance analyses and periods when results indicated a need for operational changes.

The other categories of expenses for Operation and Maintenance do not fluctuate much annually and account for less than 10% of expenses.

Nutrient Removal Costs

Total costs of nutrient removal were determined by totaling costs and dividing by the mass of analyte removed. The MFW was constructed to target TP removal from Lake Apopka, and the cost of removal over its operation was $177/ lb. (Table 4). Similar wetland treatment system projects conducted by the South Florida Water Management District have costs that range from $217–$639/ lb. TP removed (Welch et al. 2025).

As TP concentration in Lake Apopka approaches the target concentration of 0.055 mg/L TP, improving clarity in the lake becomes the dominant goal for improvement. The MFW typically removes TSS at a rate exceeding 80% efficiency, which improves clarity of water and allows light to penetrate deeper into the water column, benefiting the recovery of SAV (Figure 16). TSS is removed by the MFW at a nominal rate of $0.09/ lbs. of TSS (Table 4). Often, dredging is proposed as a solution to remove unconsolidated floc and improve water clarity in Lake Apopka. This paper shows that the operation of the MFW has accomplished the removal of sediments in the water column and has prevented these sediments from becoming part of the unconsolidated floc at the bottom of the lake. A simple cost comparison of mass removed by the MFW and mass of unconsolidated floc removed when dredging 40cm of Lake Apoka from an area of 2,307 – 21345 hectares. Associated costs can be approximated using a 2019 project for Lake Apopka with an estimated cost of $10 million to dredge to a depth of 40 cm over an area of 190 hectares. Extrapolating that cost to the 2,307–3,145 hectares of projected material dredging cost would be between $120–$160 million to remove the same quantity of sediment that the MFW has removed. This further highlights the cost-effectiveness of operating the MFW.

TN removal occurred between 2004–2024 at a cost of $4.47/ lb. TN (Table 4). Other wetland systems built by the South Florida Water Management District (SFWMD) range from $15–$48/ lb. removed (Welch et al. 2025).

Table 4. Total cost of MFW removal of TP, TN, and TSS from 2004–2024. All costs are presented as value at the time of expenditure.

Analyte	Mass removed (MT)	Cost per kg analyte removed	Cost per lb. analyte removed
TP	34.5	$391	$177
TN	1,374	$9.84	$4.47
TSS	69,208	$0.20	$0.09

The cost of operating the MFW has provided a high return on investment when examining the mass of nutrients and suspended solids that have been removed from Lake Apopka.

Anticipated Improvements

During 2025, there were numerous challenges that prevented consistent pump operation. These challenges resulted in missing the targeted HLR and an increased residence time in the cells. When this happens, PP concentration decreases and DP increases, often leading to the MFW operating as a source of P to the lake. 2025 provided an opportunity to identify the importance of consistently functioning pumps in order to maintain the target HLR and the consequences of failure. Future projects to help resolve pump failure issues have been identified and planned, and include installing pump remote programming to control pump cycling and send alerts of power outages, as well as re-contouring the pump basin to eliminate an existing ridge contributing sediment to the discharge water (total $300,000). Three of the existing five pumps need to be refurbished, and all five pump sheaves need replacement ($140,000). Additionally, several inflow structures need to be replaced ($300,000 each). Mowing and ditch maintenance is scheduled for fiscal year 2026–2027 and is budgeted for $225,000.

CONCLUSIONS AND RECOMMENDATIONS

This report provides long-term monitoring data on the effectiveness of nutrient and suspended sediment removal from Lake Apopka by the MFW, a constructed treatment wetland. Sedimentation was the dominant process for nutrient removal, highlighting the need for scheduled maintenance of internal canals. Future efforts should focus on the timing of maintenance work that requires dewatering to minimize P flux from the soil into the water column during reflooding, specifically by maintaining a short drawdown and refilling period. Pump operation of the MFW should continue to be adaptive, examining cell performance, seasonal trends, and utilizing only the cells that are best performing for summer operation. Poorly functioning cells can undergo light maintenance to plant vegetation to fill in minor short-circuits, but not be dewatered. Every effort should be made to ensure the reliability of the pumps since they are required to maintain HLR through the cells; when pumps do not work effectively, DP is released from cell sediments, decreasing the efficiency of system performance.

Over the operational period of the MFW, water quality within the lake has varied greatly, and periods of low water levels have been linked with elevated concentrations of TSS, TP, and TN (Figures 3, 4, 9, and 14). On a time scale greater than the past 30 years, there have been significantly improved conditions with regard to nutrient concentrations within the lake (Figure 3). TP concentrations are approaching the TMDL target concentration of 0.055 mg/L, and in 2022, the annual average TP was below the Lake Apopka TMDL target concentration (Figure 3). With decreasing TP load into the MFW, there is a lower quantity of mass that can be removed by the system in comparison to periods of high nutrient loading, but nutrient removal is still possible and cost-effective. With these improving phosphorus conditions in the lake, the focus of treatment now shifts to TSS removal and the associated improvements in water clarity for continued expansion of SAV.

Examining the costs of construction, maintenance, and operation of the MFW provides fiscal results to support continued operation of the MFW. Since water quality and lake health goals have not yet been achieved for Lake Apopka, treatment of lake water by the MFW remains a cost-effective method for improving water clarity, removing legacy nutrients, and reducing internal nutrient recycling.

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