BIORETENTION SYSTEM AS AN ALTERNATIVE METHOD FOR RESTORATION OF LAKE APOPKA, FLORIDA

By

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ABSTRACT OF THE DISSERTATION

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The eutrophication of the lake has become a worldwide environmental issue since mid-twentieth century. As the fourth largest lake in Florida, Lake Apopka was polluted leading to the hypereutrophic consequences mainly resulted from the drainage of its large floodplain marsh, which has a high concentration of nutrients, for agricultural development. The hypereutrophic water of Lake Apopka has resulted in the loss of recreational function and atheistic values to the public.

In response to this hypereutrophic issue, the St. John River Water Management District (SJRWMD) in charge of the Lake Apopka Basin has prepared a comprehensive management plan named Surface Water Improvement and Management (SWIM) Plan for Lake Apopka to restore and preserve the lake and its environment.

In this SWIM Plan, a marsh flow-way close to the outlet of the lake has been designed and operated as a major project to remove the high concentration of nutrients presented in the lake water, which could remove 30 percent total phosphorus (TP) and 80 to 90 percent total suspended solids (TSS) from the inflow of lake water.

To improve the pollutant removal efficiency in Lake Apopka, the bioretention system, one implementation of stormwater Best Management Practices (BMP), was researched and designed as an alternative method to treat lake water, subsequently, was compared with the marsh flow-way in three aspects: land area, removal efficiency, and cost.

With a flow rate of three hundred seventy two thousand cubic meters per day (37.2×10^4 m^3d^{-1}), the land area of bioretention system to treat lake water would be approximately 20 percent of the marsh flow-way. The established pollutant removal efficiencies of the bioretention system are remarkably higher than those of the marsh flow-way, with TP of 60 percent, TN of 30 percent, TSS of 90 percent, respectively. However, the preliminary analysis indicated that the cost of building bioretention system would be much higher than that for constructing marsh flow-way.

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1. Introduction

Since mid-twentieth century, with the rapid development of economies, industries and agricultures, the surrounding environment has been severely destroyed by the human activities due to lack of consciousness to protect the environment. As the discharges from industries agricultures and sewages increase, more and more nutrients within the discharges have flowed into the lake areas. According to the investigation took place in the early 1990s, the eutrophication has become one of the most urgent environmental issues of lakes in most countries, especially in Asia of 54%, Europe of 53%, North America of 48% and South America of 41% (ILEC/Lake Biwa Research Institute).

The eutrophication can be a natural process particularly in lakes, however, the anthropogenic activities, like increase in population and strengthening of land use, can dramatically increase the concentration of nutrients in water bodies, thus cause eutrophication. Eutrophication of the lakes is a process which receives excessive nutrients containing nitrogen and phosphorus in water body. The excessive nutrients, nitrogen and phosphorus result in the rapid growth of algae, that is, the algal bloom, subsequently causing the decrease of the water clarity and depletion of the available oxygen in the water. Moreover, dead algae sinks to the bottom of the water system with the nutrients, leading to the vast nutrients storage in the lower water system, and some of the sediments are suspended into the water body, making the nutrients available for algal growth again.

Lake Apopka is a statewide recognized ecosystem in Florida, located 15 miles northwest of the City, Orlando, stretching across the Orange County and Lake County, which supports a plenty of species whose survival depends on the natural cycles of water and nutrients under the lake water. Lake Apopka was also one famous attraction by its recreational value and game fish population.

In recent time, nutrients enrichment has happened in Lake Apopka with the excessive runoff water discharged from adjacent floodplain marsh. The water discharged from the muck farm lands, rich in nitrogen and phosphorus, provides the environment for the growth of algae, resulting in loss of the lake's recreational value and game fish populations (Hoge, et al., 2003).

Lake Apopka was identified by the Surface Water Improvement and Management (SWIM) Act of 1987 as a priority water body in need of restoration and preservation (Hoge, et al., 2003) and the SWIM Plan for Lake Apopka has been implemented subsequently. The Plan has called for a series of measures to recover the water system in Lake Apopka. Building the marsh wetlands is one of measures to restore the polluted water body inside the lake, which is a relatively complex process.

2. Summary Background on Lake Apopka

2.1. Geography of Lake Apopka

Lake Apopka is the fourth largest in Florida (Hoge, et al., 2003), as well as the headwater lake for the Harris Chain of Lakes, which contains nine lakes, including Lake Eustis, Lake Griffin, and the rest, covering more than 303 square kilometer [km^2] (75,000 acres [ac]). The lake is located at latitude 28°37′14″N and longitude 81°37′19″W and mostly within Orange County, though the western part is in Lake County. The nearest main city is Orlando, which is located to the southeast approximately 25 kilometers [km] (15 miles [mi]). The lake approximately occupies a water surface area of 124 km^2 (30,641 ac), and average depth at this surface elevation is 1.6 m (5.2 ft).

The largest spring, Apopka Spring, also known as Gourd Neck Spring, a narrow water body discharging into Gourd Neck, is located at the southern end of the lake. The only surface water outflow from Lake Apopka is the Apopka-Beauclair Canal, a single artificial outflow, which flows north into Lake Beauclair. Discharge from the canal is controlled at the Apopka-Beauclair Lock and Dam, which therefore influences lake stage.

2.2. The history of human activities at Lake Apopka

Historically, Lake Apopka once covered approximately 202 km^2 (50,000 ac) and had an average depth of 2.4–2.7 m (8–9 ft) (Hoge, et al., 2003). Lake Apopka was one of Central Florida’s main habitats for plentiful fish and wildlife populations, which was also one famous attraction by its recreational value and game fish population.

Since 1880s, frequent activities have expanded around Lake Apopka, resulting in the decline of the lake elevation. Although the lake has been altered anthropogenically in many ways (EPA, 1979), the significant human impact began with the construction of the Apopka-Beauclair Canal, which altered the hydrology of the lake in order for navigation and agricultural use. Subsequently, the most significant alteration is the drainage of its large floodplain marsh, which contents high concentration of nutrients, for agricultural development (Lowe, et al., 1992).

In 1880, with the purpose of creating a waterway for navigation and agricultural use, dredging of the Apopka-Beauclair Canal was originally begun by the Apopka Canal Company (Schiffer, 1994). Gradually, with the agricultural development, north shore area of the lake has been virtually cropped, but subsequently converted into a muck farm land, since a destructive hurricane hits in 1926 (Hoge, et al., 2003).

In 1941, farming returned due to improved technology. A levee was built along the north shore by the Zellwood Drainage and Water Control District (ZDWCD), in order to separate the large marshes (80 km^2(20,000 ac)) from the lake and allow the drainage of farm lands. Before the levee was built, these lands were swamped when the lake rose above the mean elevation and during lower lake stages, they had drained into the Apopka-Beauclair Canal or into the lake. The discharge of water into the Apopka-Beauclair Canal or into the lake, rich in nutrients from agricultural and other sources, improved a algal bloom and lead to loss of the lake’s recreational value and game fish populations (Hoge, et al., 2003).

In 1956, a permanent lock-and-dam structure was constructed in Apopka-Beauclair Canal. To restore the polluted water in the lake and control the further environmental problems, in 1985, Florida Legislature passed Chapter 85-148, Laws of Florida, which funds studies aimed at determining environmental sound and economically feasible restoration means for Lake Apopka. Subsequently, Lake Apopka was identified by the Surface Water Improvement and Management (SWIM) Act of 1987 as a priority water body in need of restoration and preservation (Hoge, et al., 2003) and the SWIM Plan for Lake Apopka is approved by Florida Department of Environmental Protection (FDEP).

By 1988, the Marsh Flow-Way Restoration Project has been initiated and its demonstration project was constructed in 1990 to test operation efficiency of wetland filtration. The full Marsh Flow-Way Restoration Project was fully designed in 1997, while Phase I of this project began to be constructed in the same year and completed in 2001.

2.3.Land cover/land use of Lake Apopka drainage basin

The whole area of Lake Apopka drainage basin (Figure 1) is 484.7 km^2 (119,773 ac), which is covered with 216.3 km^2 (53,437 ac) agricultural land and 137.9 km^2 (34,084 ac) surface water. The rest, 193.5 km^2 (22,252 ac) was composed of wetland, forest, rangeland, urban development, and barren land. The basin has plenty of animals and plants resources (Hoge, et al., 2003).

Due to multicropping, nearly 104.5 km^2 (25,800 ac) of total crops within the muck farm area of 59.1 km^2 (14,600 ac), located on the lake’s former floodplain, were harvested

(Hoge, et al., 2003). For the long-term agricultural use, the soil in the muck farm land experiences subsidence, oxidation, and compaction. The formal floodplain lies about 1 m (3 ft) below elevation of the lake surface. Since a levee built for the drainage from the farm land to the lake in 1940, the lake water has been used for irrigation or drainage, flood control and pest control (Hoge, et al., 2003).

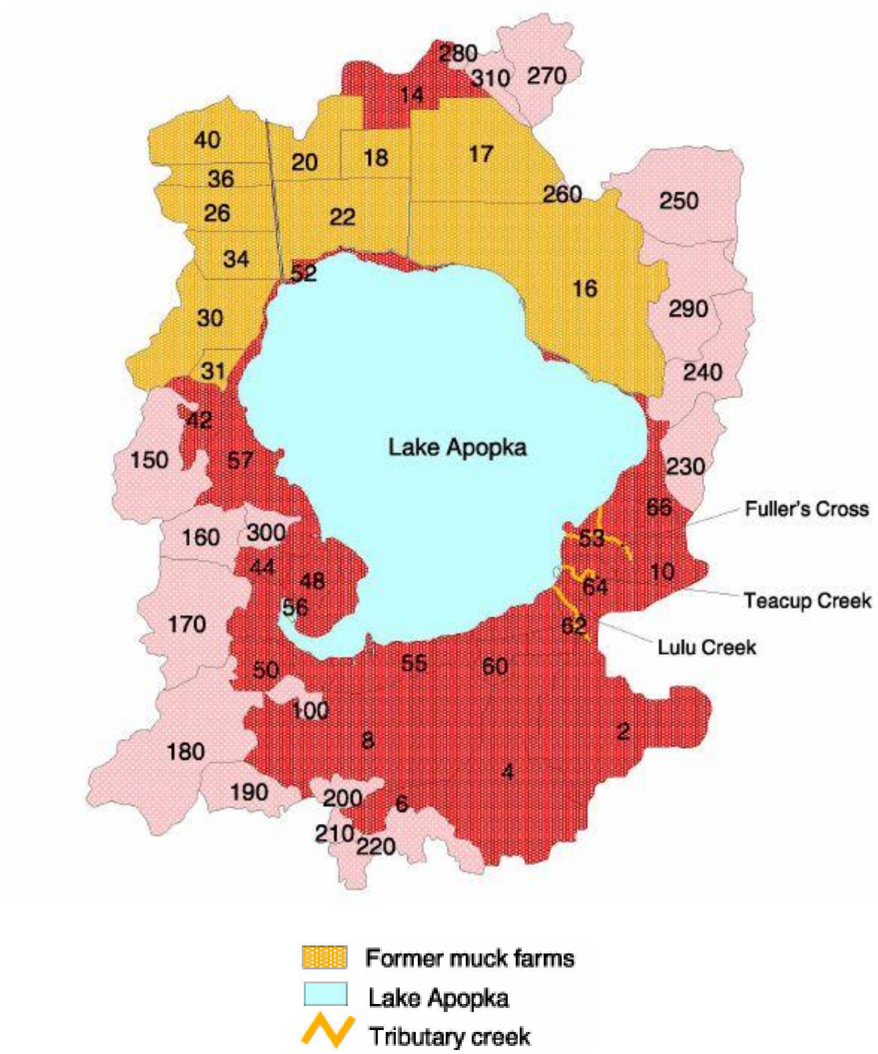

Figure 1 Lake Apopka Drainage Basin Area (Hoge, et al., 2003)

2.4.Hydrology of Lake Apopka

The lake occupies approximately a water surface area of 124 km^2 (30,641 ac), and average depth at this surface elevation is 1.6 m (5.2 ft). Lake Apopka characterizes subtropical climate, whose typical seasonal precipitation patterns contain a dry season, from November to May and a wet season, from June to September, and approximately 60% of the total annual rainfall occurs during the four-month summer season. The average annual potential ET[1] value for the Lake Apopka Basin is approximately 109 cm (43 in) (Fernald, et al., 1988).

The depth of the Apopka spring opening is about 11.2 m (37 ft). The average discharge rate of the spring was approximately 0.85 cubic meter [m^3]/second [s] from 1988-1998 (Hoge, et al., 2003). Although the lake has several small tributaries, the main source of water is direct rainfall (Coveney, et al., 2005), which has averages about 127 centimeters (cm) (50 inches [in]) annually (Hoge, et al., 2003). Several subbasins of the Lake Apopka drainage basin, about 484 km^2 (119,773 ac) including the surface of the lake, contribute either direct stormwater runoff or runoff through small tributaries during rainfall events.

Lake Apopka has a moderate hydraulic detention time of roughly 2.5 years in average. Water discharge from the lake occurrs via the Apopka-Beauclair Canal at a mean annual rate of 6.81 x 107 m^3/year (76.4 cubic feet [ft^3]/s) during the period from 1959-1999 (Hoge, et al., 2003). The water control structure in the canal dam has changed the natural fluctuation of the lake stage and discharge (Hoge, et al., 2003).

[1] Evapotranspiration (ET) is the combined water loss due to evaporation and transpiration. ET is a major component of the water budget in the basin, which is affected by wind, temperature, solar radiation, relative humidity, and plant transpiration.

2.5.Water quality of Lake Apopka

Lake Apopka is deemed as the most severely polluted large Florida lake (EPA, 1979). Lake Apopka has undergone cultural eutrophication since the late 1800s and accelerated to be a hypertrophic lake in the 1940s. The excess irrigation water and rainfall as the wastewater, which is of poor quality due to high concentrations of nutrients, discharged from 80 km^2 farm lands, which lead to the elevation of phosphorus loading seven-fold (Battoe, et al., 1999). In addition, as reported, in the period of 1989 through 1994, the farms contributed approximately 85% of the net phosphorus loading to Lake Apopka (Hoge, et al., 2003), which had become the primary source of eutrophication in the lake.

The lake water is highly turbid and pea green in color. The Secchi[2] transparency is about 30 cm (12 in) or less (Hoge, et al., 2003). Lake Apopka has received intense external loading of nutrients from muck farms located adjacent to the north of the lake. In addition, nutrients are recycled through decomposition in the sediments and subsequent mixed by wind effect, which is the source of internal loading form.

The Trophic State Index[3] (TSI) rating for Florida lakes set the range from 0 to 59 as good, from 60 to 69 as fair, and from 70 to 100 as poor (Huber, et al., 1982). Lake Apopka’s average TSI has the range from 82-91 by 1993, which is in the scale of poor/ hypereutrophic condition (Hoge, et al., 2003). Recently, with a serious of regulation and action adopted in Lake Apopka, the water quality of the lake has been along an

[2] Secchi disk is a circular disk used to measure water transparency in oceans and lakes
[3] The Trophic State Index is a water quality index for lakes based on nitrogen and phosphorus concentrations, transparency, and chlorophyll α values

improving trend (Hoge, et al., 2003). However, the nutrients data reported by 2002, Lake Apopka still has had high concentrations of nutrients, as well as considered as a hypereutrophic lake, the specific contents of nutrients as showed below (Table 1),

Table 1 Median values over the 29-month operational period for selected water chemistry variables in the inflow from Lake Apopka (Coveney, et al., 2002)

Variable	**TSS**	**Chl α**	**NH4+-N**	**NOx -N**	**DON**	**PON**	**TN**	**SRP**	**DOP**	**POP**	**TP**
Median ($mg\ l^{-1}$)	76	0.078	0.017	0.011	1.68	2.96	4.60	0.006	0.002	0.163	0.173

*TSS: total solids sediments; Chl α: chlorophyll α; DON: dissolved organic nitrogen; PON: particulate organic nitrogen; TN: total nitrogen; SRP: soluble reactive phosphorus; DOP: dissolved organic phosphorus; POP: particulate organic phosphorus; TP: total phosphorus

Concluded from the table above, lake water is characterized by high concentrations of suspended solids, and nitrogen and particulate phosphorus. Among of them, about 90% of the total phosphorus (TP) is particulate organic phosphorus. About 40% of the total nitrogen (TN) is dissolved organic nitrogen, only 1% is inorganic nitrogen, and the remainder is particulate organic nitrogen.

2.6. Sediments

The sediments in Lake Apopka have six different layers, including unconsolidated floc, consolidated floc, peat, sand, clay, and marl (Gale, et al., 1994). The unconsolidated floc, which contains up to 97% water, covers 96% of the lake under the bed and has an average depth of 32 cm (1.0 ft) (Reddy, et al., 1991). The high sedimentation rate is caused by plenty of nutrients being gathered by algae. After their death, algal cells are deposited on the sediment surface, thus resulting in the accumulation of sediment (Reddy, et al., 1988).

As reported in 1997, the phosphorus storage in the sediments has increased at least threefold in the last 50 years, compared by decade, and as much as fourfold if annual rates are compared (Schelske, 1997).

3. Eutrophication in Lake Apopka

3.1. Source, cause and external loading changes of eutrophication in Lake Apopka

Eutrophication, or more precisely hypereutrohphication, is a phenomenon that excessive amount of nutrients containing nitrogen and phosphorus occurring in the lake or costal aquatic systems. A variety of factors may increase the supply of organic substances to water aquatic systems, but the most common is clearly nutrient enrichment (Nixon, 1995). The main causes of nutrient enrichment in lake systems are associated directly or indirectly with meeting the requirements of human activities. The untreated sewage effluent and agricultural run-off carrying fertilizers as a consequence of anthropogenic factors are important causes of the eutrophication. Hypereutrophication is a high pollutant degree of eutrophication (Nixon, 1995). Lake Apopka is considered a large, hypereutrophic Florida lake (EPA, 1979).

Main three sources from human activities result in nutrient enrichment: urban discharges, agriculture discharges, atmospheric deposition of nitrogen from burning fossil fuels. For Lake Apopka, the main source of pollution has been the drainage of its large floodplain marsh for agriculture development (Lowe, et al., 1992).

The report on the Total Maximum Daily Loading (TMDL) of TP released in 2002 gave a comparison between existing TP loading and allowable loading TP, showed in table 2,

Table 2 Source loading allocations in Lake Apopka (Magley, 2003)

	Source	Existing P Loading (MT yr-1)	Allowable P Loading (MT yr-1)
Point source	**North Shore Restoration Area**	53.08	5.53
Non-point source	**Winter Garden WWTF**	1.38	1.21
	Atmospheric Deposition	5.03	5.03
	Apopka Springs	1.00	1.00
	Seepage	0.55	0.55
	Precipitation	0.60	0.60
	Tributaries	1.45	1.45
	Total	63.09	15.37

*MT: metric tons

Concluded from the table above, phosphorus loading from the farm lands was considerable when compared with the sum of the loading from Winter Garden WWTF, springs flow, seepage, and direct runoff and other sources.

There are another classification to the sources of nutrients and organic matter: point and non-point sources.

Point sources are directly contributed by one influence and the nutrient waste travels directly from source to the aquatic system, such as wastewater effluent (municipal and industrial), runoff and leachate from waste disposal systems, runoff and infiltration from animal feedlots and overflows of combined storm and sanitary sewers (Carpenter, et al., 1998). Point sources are comparatively easy to regulate. In Lake Apopka, the point sources have mainly come from three pathways: excess storm water and flood water, enriched with nitrogen and phosphorus, pumped from the adjacent floodplain marsh into the lake; effluent from the Winter Garden sewage treatment plant (WWTF); and a part of waste water from citrus processing plants.

Non-point sources are indirectly attributable to diffuse sources, such as runoff from agriculture/irrigation, runoff from pasture and range, urban runoff from unsewered areas and atmospheric deposition over a water surface (Carpenter, et al., 1998). Nonpoint sources are difficult to regulate and sometimes are happening temporally. In Lake Apopka, the nonpoint sources are mainly attributed by the loading from spring flow, seepage, and precipitation.

During the recent years, the Winter Garden sewage treatment plant has become the only NPDES permitted facility with discharge to Lake Apopka with the limiting discharge, which results in the TMDL of TP decreased to 1.38 MT P yr^{-1} by 2002 compared with 7 MT P yr^{-1} by 1977 (Lowe, et al., 1999) (table.2).

Since the Florida Legislature has passed Chapter 85-148 in 1985, Laws of Florida, which funds studies aimed at determining feasible means for restoring the lake, the two initial steps were taken to reduce phosphorus loading. Through reinforced regulation and purchase of farms for restoration, a 55% reduction on average of external phosphorus loading happened to start in 1993, which was still almost twice of the P loading target for the lake though (Coveney, et al., 2005).

Currently, the SJRWMD is developing improved estimates of external sources of N and P inputs to the lake, through extensive water quality monitoring.

3.2. Interior mechanism of eutrophication and aquatic changes in Lake Apopka

Typically, in micro aspect, nitrogen and phosphorus are considered to have vital roles in eutrophication. The eutrophic process gives a body of water a high concentration of nutrients, especially nitrogen and phosphorus, which promote the excessive growth of algae (Art, 1993). The full eutrophic process is showed below in Fig.2. With the algae die and decompose, the excessive amount of organic matters and the decay organisms deplete the water of available oxygen, thus resulting in the death of other organisms, such as fish (Art, 1993). Besides, excessive algae bloom, floating on the water surface, block the sunlight to the bottom of the aquatic system, which speed up the death rates of grasses, which grows in the bottom of the system, consequently significant reducing dissolved oxygen levels at lower depths of the water body.

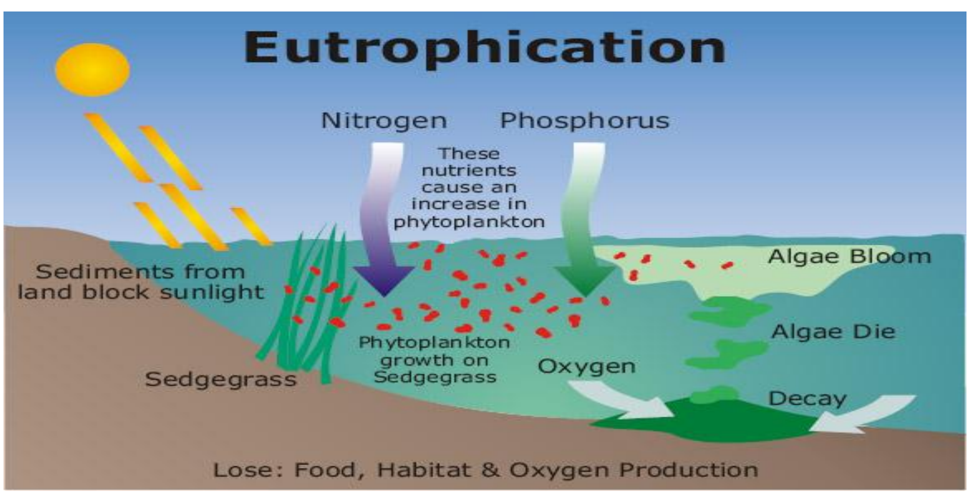

Figure 2 The eutrophication circle under the lake
(Source: http://05lovesgeography.blogspot.com/2011/02/eutrophication.html)

Inside Lake Apopka, the pollutants of most common concern are phosphorus, nitrogen, and carbon. Phosphorus and nitrogen are vital nutrients that often limit the rate of algal primary production and the source of flocculent sediments in the lake. Carbon, which is often regarded as a cycle in the lake, is constantly supplied by photosynthesis and removed by microbial respiration. Although carbon is a major component of the flocculent organic sediment, it is not as essential in eutrophication as phosphorus and nitrogen (Reddy, et al., 1991).

Comparing with the external nutrient loading, the internal nutrient mechanism is more complex and time-consuming. Until the 1940s, Lake Apopka had plentiful submerged macrophyte vegetation which colonized almost 90% of the lake bottom and has a depth of about 2.4 m (Clugston, 1963); (Lowe, et al., 1999). Subsequently, the densities of phytoplankton increased in the late 1940s as the amount of submerged macrophytes declined rapidly and disappeared in the 1950s. Since that time, the period of macrophyte dominance has switched to the one of phytoplankton macrophyte dominance. Only a few percent of surface area remained covered by submerged macrophytes, accordingly, resulting in the surface water been displaced by persistent and dense cyanobacteria and flocculent surficial sediments (Lowe, et al., 1999).

During the recent years, with the development on research of nutrient processing by aquatic biota and the biogeochemical processes in sediments of lakes, it has become apparent that these processes are major factor in determining a lake's trophic state. In Lake Apopka, the bottom sediments can be used as a source or sink for the nutrients in the water body environment. The trend of flux between the sediment and overlying water column is dominated by the external loads of the nutrients and biogeochemical processes in the sediments and water column (Reddy, et al., 1991). Most of the lake bottom is covered by organic sediments with low bulk density deposited since the 1940s (Coveney, et al., 2005). Due to the shallow water depth of the lake, these sediments can be easily suspended into the overlying water, resulting in producing the algae and furthermore affecting water quality.

3.3. Impacts of eutrophication and hypereutrophication in Lake Apopka

The impacts of eutrophication typically reflect at two main aspects as follow:

- The impacts to human beings:

The algae blooms cause the decrease in transparency of water body, bad water color, foul odors and other problems, resulting in the poor quality of water. Specific health risks arise when fresh water, taken from eutrophic areas, is used as source of drinking water for public's daily life. In addition, the excessive algae blooms on the surface water impede public entertainment activities and tourism development. As an important water body for public entertainment and recreation, the major consequence of eutrophication in Lake Apopka is lower recreational and aesthetic values, especially in the torrid summer time.

- The impacts to ecosystem:

The list below shows the specific impacts on the lake environment:

- Increased biomass of phytoplankton
- Toxic or inedible phytoplankton species
- Increases in blooms of gelatinous zooplankton
- Decreased biomass of benthic and epiphytic algae
- Changes in macrophyte species composition and biomass
- Decreases in water transparency (increased turbidity)
- Colour, smell, and water treatment problems
- Dissolved oxygen depletion
- Increased incidences of fish kills
- Loss of desirable fish species
- Reductions in harvestable fish and shellfish

Besides the impacts above, as the headwater lake for the Harris Chain of Lake, the quality of the water in Lake Apopka has a significant influence as the key water resource to the downstream water systems.

4. Surface Water Improvement and Management (SWIM) Plan for Lake Apopka

Due to the impacts causing by polluted water in Lake Apopka, to human and ecosystem, described in the last chapter, the St. Johns River Water Management District (SJRWMD), which is in charge of the water areas including Lake Apopka basin area, has decided to take actions to restore and preserve the lake water.

Since identified as a priority water body in need of restoration and preservation by Surface Water Improvement and Management (SWIM) Act of 1987, restoration of Lake Apopka has been supported by several watershed efforts to reverse the degradation of the system (Hoge, et al., 2003). The restoration goal of Lake Apopka is to achieve Florida Class III water quality standards (suitable for recreation and fish and wildlife). Based on this object, the SJRWMD has organized a comprehensive management plan to restore and preserve the lake and its environment.

Lake Apopka SWIM Plan has developed with the guidance based on staff knowledge, agency and governmental reviews, public comment, and general goals developed by the Lake Apopka Restoration Council (LARC) (Hoge, et al., 2003). These efforts have resulted in a considerate approach to develop economically feasible and environmentally friendly strategies for the Lake Apopka restoration. The SWIM Plan for Lake Apopka has been improving and has version of 1989, 1993 and 2003.

The goals of the SWIM plan has been summarized in 2003 version as follow,

> "The goals of the plan are to (1) restore the water in Lake Apopka to meet Class III water quality standards, (2) restore the functional capabilities of the lake's natural systems, (3) re-establish previous recreational and aesthetic values, and (4) implement a comprehensive basin management plan."

To achieve these goals effectively, SJRWMD has made various efforts (Hoge, et al., 2003) through years of scientific research since SWIM Act in order to explore a comprehensive and referenced management plan. The prior scientific study included diagnostic and feasibility programs. Subsequently, the implementation plan with six programs and sixteen projects was developed. The six programs include restoration, planning, land acquisition, regulatory, technical support, and public information. In this plan, the implementation consists of four important components:

- Reduction in nutrient loading mainly from the external source of the lake,
- Reduction in phosphorus and flocculent sediments from the lake by operation of a treatment wetland,
- Improve food-web structure by removal of gizzard shad to reduce phosphorus contents and reduce internal phosphorus cycling,
- Restore lake habitats through planting and increasing fluctuation of lake level to promote regrowth of littoral vegetation.

In the first place of restoration, reduction in external nutrient loading is the most necessary and emergency step to do, because the reduction is sufficiently large, the lake will improve in time even if no further steps are taken (Battoe, et al., 1999). To achieve this, a series of regulatory, land acquisition of the floodplain farms, and restoration activities have been initiated (Hoge, et al., 2003). Among of them, a major regulatory action in support of the Lake Apopka restoration was to restrict external nutrient loading from muck farms on the northern shore of the lake. Another action taken is to purchase the farm lands for restoration (Hoge, et al., 2003). By the end of 2000, a total of 13,846 ac east of the Apopka-Beauclair Canal was purchased with the funding from federal and state source. Earlier, all muck farm areas (5,833 ac) west of the Apopka-Beauclair Canal in use of the Marsh Flow-Way project to remove the nutrients and sediment solids from lake water were purchased as well.

A 21 km^2 constructed treatment wetland was implemented by the SJRWMD located in the west of the Apopka-Beauclair Canal, which is to reduce the particular phosphorus and flocculent sediments of the lake water by recirculating the lake water through marsh flow-way (Hoge, et al., 2003). The District primarily constructed a 2.1 km^2 (530 ac) pilot-scale treatment wetland as the Marsh Flow-Way demonstration project to examine nutrient-removal and hydraulic performance from Lake Apopka. The Marsh Flow-Way demonstration project provided essential data and experience for the design, construction, and operation of the 14 km^2 (3,400 ac) full-scale Flow-Way. The performance for 29 months of this pilot-scale treatment wetland has substantiated the ability to lower the nutrient by the larger wetland (Coveney, et al., 2002).

To increase the clarity of the lake water, and improve the conditions for game fishing accordingly, the Trophic Structure Manipulation and Rough-Fish Harvesting project was implemented as the economical means to remove nutrients from the lake. At the beginning of the implementation, a demonstration site in Lake Denham was used to test the removal efficiency of rough fish (gizzard shad). After getting success to improve the water quality and water transparency in Lake Denham, various harvesting techniques were tested in Lake Apopka to determine the most-effective method (Hoge, et al., 2003). From 1993 through 2002, the commercial Rough-Fish Harvest funded by SJRWMD in Lake Apopka removed 3,729,945 kg (8.2 million pounds) of fish (Hoge, et al., 2003). Furthermore, removal of gizzard shad will reduce interior phosphorus in the lake resulting from fish stirring up the bottom sediments, from reducing consumption of shad on zooplankton, and from reducing the phosphorus recycling caused by the shad's digestive processes (Catalano, et al., 2007).

The final component of the restoration plan calls for the Littoral Zone Restoration Project is to examine the potential for stabilization of near- shore sediments for improving the habitats around the lake by planting vegetation, which are inexpensive, movable and desirable. By 2001, 40 sites had been planted around the 40 mile perimeter of the lake (Hoge, et al., 2003).The county and local government and the Friends of Lake Apopka (FOLA) provide significant help to build public parks around the lake and gather volunteers to help planting annually.

As described in the last chapter, the external source pollution is relatively easy to regulate and control. For reducing the nutrient loading from external sources in the SWIM Plan, external phosphorus loading was reduced, through reinforced regulation and purchase of farms for restoration, by 55% on average starting from 1993 (Coveney, et al., 2005). The significant effects of improvement after implementing this measure also can be concluded from the control of inflow water flux as well as the water quality shown in following charts (Figure 3):

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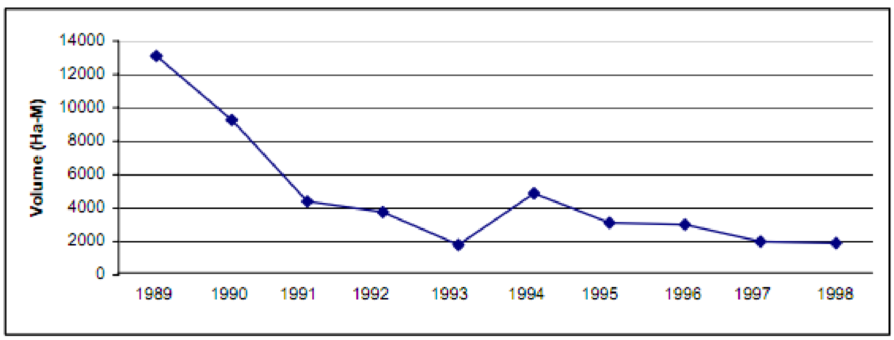
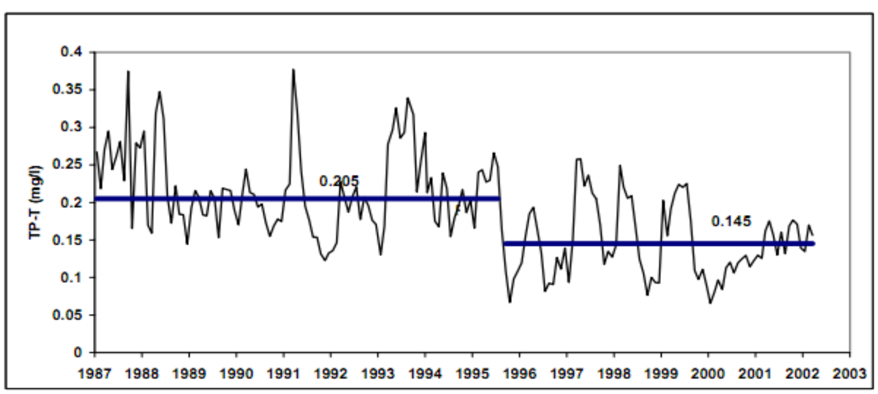
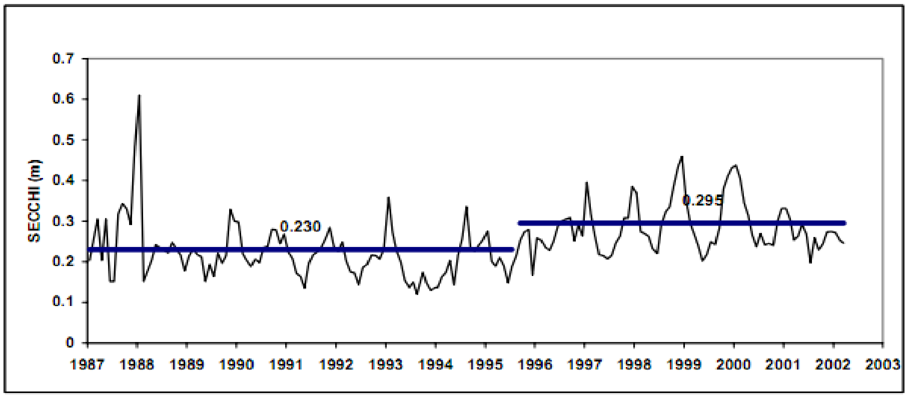


(1) Lake Apopka Basin muck farm volumetric discharge, 1989-1988



(2) Lake Apopka mean monthly total phosphorus, January 1987-March 2002



(3) Lake Apopka mean monthly Secchi depth, January 1987-March 2002

Figure 3 Changes of lake water quality as the changes of Lake Apopka Basin muck farm volumetric discharge (Hoge, et al., 2003)

However, while techniques to lower nutrient concentration can be effective in improving lake eutrophication, these approached ignore the biological interactions of the lake responsible for internal nutrient recycling, poor water clarity, and the slow response to nutrient diversion.

The interior lake environment is more complex and the pollutant existing in the water body is difficult to control and restore. For the pollution already existed in the lake, it is not that efficient to remove and restore. The Marsh Flow-Way project is expected to restore the polluted water environment, which is comparatively time-consuming and difficult to predict the effects.

5. Constructed Marsh Flow-Way (Wetlands) in Lake Apopka

For the purpose of restoring the polluted lake water and effectively preserving the water sources as the downstream lake water supply, the SWIM Plan includes a restoration measure, constructing a constructed marsh flow-way, before the lake water flows into downstream.

5.1. Overview of Marsh Flow-Way project

The Lake Apopka Marsh Flow-Way, a constructed wetland, is located at the west of the Apopka-Beauclair Canal. The major goal of the marsh flow-way project is to remove algae, resuspended sediments, and particle-bound phosphorus from Lake Apopka (Lowe, et al., 1992). To meet this, the whole project is designed to lead the lake water flow through 13 independent marsh cells (Figure 4) and return to the lake, as 10% of the water flow through the cells will go into downstream and the rest will re-circulate to the lake (Hoge, et al., 2003). Part of the water going downstream will be treated and turned to improved quality instead of poor quality, thus improve the downstream water environment. The objective of the 3400 ac full project is to remove 30 MT of phosphorus annually from Lake Apopka (Hoge, et al., 2003).

At the beginning of implementing this project, the District operate a 2.1 km^2 (530 ac) pilot-scale constructed wetland as the Marsh Flow-Way demonstration project to test and examine the capacity of wetland system to remove phosphorus and flocculent sediments from Lake Apopka. This demonstration project provides sufficient data and necessary experience on design and construction for Phase I of the full project. Through operation of 29 months between November 1990 to February 1994, from start-up to drawdown, the demonstration project accessed the removal of TP and suspended solids and satisfied the target efficiencies of 30% and 85%, respectively (Coveney, et al., 2002).

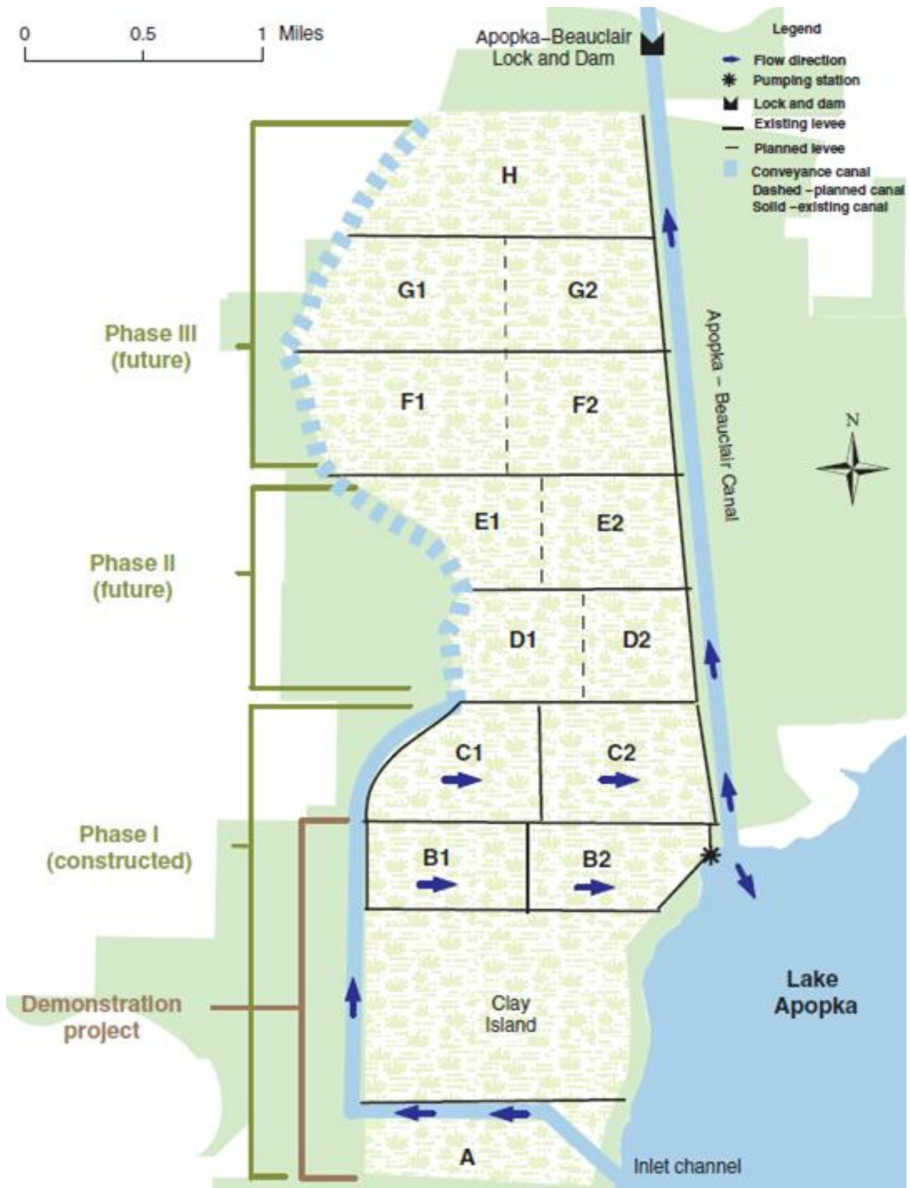


Figure 4 Lake Apopka Marsh Flow-Way conceptual design (Hoge, et al., 2003)

Table 3 Basic parameters of B and C cells in Marsh Flow-Way Project (Hoge, et al., 2003)

Cell	Area (ha)	Aspect (length/width) ratio	Width (m)	Length (m)
B1	73.1	2.2	576	1268
B2	49.2	1.5	573	859
C1	77.9	1.4	746	1044
C2	76.2	1.4	738	1033
Sum of cells	276		2633	4204
System*	308			

*Sum of B and C cells plus the area of canals in the marsh flow-way system

Construction of Phase I began in December 1997 and completed in 2001, spending approximately $4.32 million (Hoge, et al., 2003). The Phase I system covers approximately 760 ac and has been operating since November 2003. From operating through March 2007, when regular operation was interrupted for maintenance, the performance of removal of TP and suspended solids are examined to meet the target efficiencies (Dunne, et al., 2012).

Phases II and III as shown in Figure 4 will be constructed in the future as funding becomes available.

5.2. Site description

The Marsh Flow-Way demonstration project was at the southern end of the full-scale project site. Soil surface elevations of the demonstration site are below the mean lake water level ranged from 0.5 to 0.75 m in A cell and from 1.1 to 1.4 m in B areas (B1 and B2 cells) (Coveney, et al., 2002).The demonstration project consisted of two parts, A and

B areas. The water from Lake Apopka flowed by an inlet channel, or was pumped into the A cell during some period. A weir was built at the northwest corner of the A cell in order to outlet the water flow to a channel which flowed from south toward north for gravity effect. The water discharged from A cell flowed through this channel and terminated in 27 inlet culverts for the B wetland cells (Coveney, et al., 2002). The water flow within all cells is from west to east. After running over B cells, the treated water from both individual cells was collected and pumped from the northeast corner of B2 cell to the Apopka- Beauclair Canal and re-circulate to the lake.

Based on the construction of demonstration project site, Phase I of the full project was extended two more cells, C1 and C2, adjacent to B1 and B2 cells, respectively. Thus the treated water from all cells gets together and is pumped and discharged from the same outlet. Within each cell of B and C areas, there are lateral ditches (1.5 m wide ×1.5 m depth) every 80 m, which inflow water perpendicularly (Dunne, et al., 2012). The total inflow and outflow of the system can be regarded as the sum of flow into and out of the four individual cells (B1, B2, C1,C2)

6. Bioretention System as An Alternative Method to Treat Lake Water (need revise)

For the purpose of improving the removal efficiency of nutrients of the marsh flow-way, the Storm Water Best Management Practices (BMP) with the relatively high removal criteria has arisen as a considerable method to deal with the hypereutrophic conditions in Lake Apopka.

6.1. Stormwater Storm Water Best Management Practices (BMP)

Storm water best management practices are methods considered and designed to control storm water runoff including sediment control, and soil stabilization. The EPA defines storm water BMPs as

> "technique, measure or structural control that is used for a given set of conditions to manage the quantity and improve the quality of storm water runoff in the most cost-effective manner."

There are several implementations of Storm Water BMP such as: Bioretention System, Constructed Stormwater Wetland, Sand Filter, Vegetative Filter, Wet Pond and their removal criteria presented in New Jersey Stormwater BMP Manual as follow,

Table 4 TSS, TN, TP Removal Rates for BMPs (NJDEP, 2009)

Best Management Practice (BMP)	Adopted TSS Removal Rate (%)	Total Phosphorous Removal Rate (%)	Total Nitrogen Removal Rate (%)
Bioretention System	90	60	30
Constructed Stormwater Wetland	90	50	30
Sand Filter	80	50	35
Vegetative Filter	60-80	30	30
Wet Pond	50-90*	50	30

*Final rate based upon pool volume and detention time

With the comparison from above, the bioretention system has relatively high removal rate in TSS, TP, TN, which are main components of nutrient. Therefore, to achieve better removal effect, it was considered as a possible alternative method to treat lake water in Lake Apopka.

However, the inflow rate of bioretention system for treating runoff is not steady, varying during a storm event, whereas the lake water inflow is relatively steady. Therefore, the design of the bioretention system for treating lake water needs to be aware of this distinction.

7. Design of Bioretention System for Lake Water Treatment in Lake Apopka

As Figure 4 show, the Marsh Flow-Way project currently has 5 main cells, A cell, B cell (B1 and B2 cells), C cell (C1 and C2 cells). The lake water enters to A cell and subsequently transports to B and C cells through a channel connected with A cell. However, the water still contains a considerable amount of pollutants (Dunne, et al., 2012). To achieve the maximum nutrient-removal goals, the bioretention systems will be designed and its pollutant removal efficiency be compared with the current marsh wetlands.

In the bioretention system, the basic design parameters include its thickness, composition, and permeability rate of its planting soil bed, and the hydraulic capacity of its underdrain.

7.1. Bioretention component design

7.1.1. Pretreatment

Typically, the pretreatment process in the bioretention system for stormwater is to remove large solids and trash caused by the industries and residents. However, in Lake Apopka, the inflow source to the bioretention system is directly pumped from the lake, without much heavy solids, gravels and so on. Besides, the water from the lake enters through cell A firstly, when the most visibly large solids in lake water been removed. Therefore, in this bioretention system, there is no need to set a pretreatment process.

7.1.2. Inflow rate

The bioretention system is used to treat stormwater runoff. For bioretention system to treat lake water, which will be designed to locate at the same location as the marsh flow-way, the same inflow rate will be applied as the ones for the current Marsh Flow-Way Project. In the lake system, the lake water constantly exists and maintains at a relatively steady elevation. Hence, the inflow to the entire flow-way is regarded as continuous and the inflow of steady rate pumped from the lake to the flow way, differing from the unsteady inflow rate of the stormwater runoff. And also the overflow situation in stormwater will not happen in this lake-water bioretention system.

From the literature review, the representative inflow rate for various cells under which the current Phase I period of the Marsh Flow-Way project operates (Table 4) were found. They will be used as the major data in design of the bioretention system to treat lake water.

Table 5 Inflow rate of marsh flow-way at Lake Apopka, FL (Dunne, et al., 2012)

Cell	B1	B2	C1	C2	Sum of cells
Inflow rate ($\times 10^4$ m^3d^{-1})	9.3	7.2	10.3	10.4	37.2

* The monitoring period was from November 25, 2003 to March 27, 2007. Inflow rate is median values for the monitoring period.

7.1.3. Overflow

The overflow situation that occurs in the stormwater bioretention system during the stormwater events larger than the water quality design storm will not happen in the system to treat lake water due to the flow-control by pumps to relatively steady inflow rate. However, the rainfall can affect the elevation of the water in the bioretention system.

The average annual rainfall as recorded is 50 in in Lake Apopka areas, that is 50/365 (0.17) in/day in average. Compared with the daily inflow rate $37.2 \times 10^4 m^3 d^{-1}$ to the entire bioretention system, the inflow from rainfalls is too small and can be ignored in the calculation of the dimension of the treatment area.

7.1.4. Filter media

The filter media is the most significant layer in the entire bioretention system, which provides the pathway between water body and underdrain system (Figure 5). Therefore, the soil bed is the first filter when water infiltrate to the bioretention system. Additionally, the permeability rate of the planting soil bed should be the slowest to ensure proper system operation. The planting soil bed as the filter media also provides vegetation with the necessary water and nutrients.

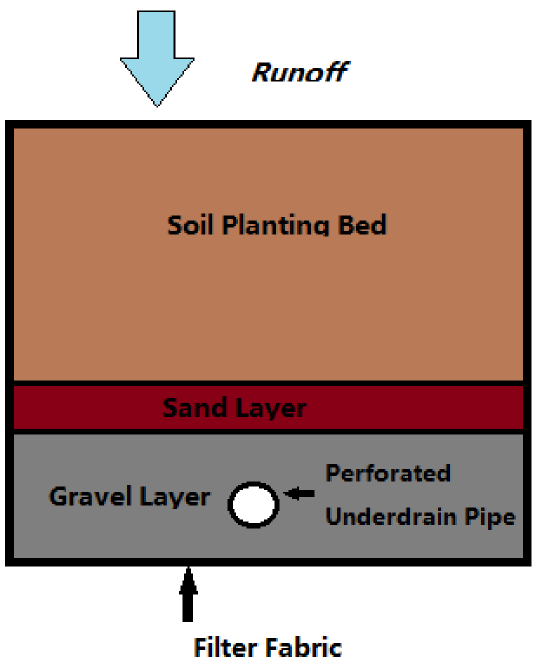


Figure 5 Underground bioretention system details (side view)

According to the rules in New Jersey (NJDEP, 2009), in Bioretention System, the planting soil bed material should consist of the following mixed separates, by weight:

Table 6 Soil separates of bioretention system in New Jersey Stormwater BMP Manual (NJDEP, 2009)

Separates	Sand (%)	Silt (%)	Clay (%)
Content percent	85-90 (≤25 fine or very fine sand)	15	2-5

There are additional requirements in the manual for the planting soil bed. The entire mix shall be added with 3% to 7% organics. And the material's pH should range from 5.5 to 6.5 (NJDEP, 2009).

In a bioretention system, the thickness of the soil planting bed and the type of vegetation grown in the bed will affect the removal rate. Various bed thicknesses, vegetation types will lead to different TSS removal rates as following,

Table 7 Bioretention system removal rate (NJDEP, 2009)

TSS Removal Rate (%)	**Thickness of Soil Planting Bed**	**Bioretention Vegetation**
80	1.5 Feet	Terrestrial Forested Community
80	2.0 Feet	Site-Tolerant Grasses
90	2.0 Feet	Terrestrial Forested Community

Hence, the thickness of soil planting bed will be designed at 2 ft, and the terrestrial forested community will be chosen as the majority vegetation cover, in order to achieve 90% TSS removal rate.

Permeability is facility with which water flows through soil. As Figure 5 show, the bioretention system divided into three layers from the top to bottom, soil planting bed, sand layer, and underdrain layer. The permeability rates of different layers vary, among of them, the permeability rate of planting soil bed is the significant parameter for the design of the dimension of the Bioretention System.

From the literature review, the permeability rate (hydraulic conductivity) of planting soil bed will be assumed as 2 in hr^{-1}. Since the actual permeability rate may differ from the test results in field or laboratory, and may also decrease sooner or later due to soil bed consolidation or the accumulation of sediments removed from the treated water, a safety factor shall be applied to the tested results to design the permeability rate. In this design, the permeability rate shall be adjusted to 1 in hr^{-1} for using a factor of safety of 2.

7.1.5. Land Area of Bioretention System

The design parameters of this bioretention system for treating lake water were shown as below:

- A 2.0 ft deep planting soil bed
- A planting soil bed with the permeability of 1 in hr^{-1}
- The inflow rate of the whole system from Lake Apopka can be obtained by adding the representative inflow rate to each independent cell, B1, B2, C1 and C2 (here ignore the water lost through cell A), then,

$$\text{Total inflow rate} = 37.2 \times 10^4 m^3 d^{-1}$$

The flow rate is governed by the following continuity equation,

$$Q = vA$$

where:

Q = rate of water flowing through an aquifer (m^3/day);

v = average velocity over the sectional area (m/day);

A = cross-sectional area (m^2).

In the design, the velocity through the sectional area should be regarded set equal to the permeability rate, k (hydraulic conductivity), and the cross-sectional area is the area of bioretention system, thus,

$$A = Q / k = \frac{37.2 \times 10^4 \mathrm{m}^3/\mathrm{d}ay}{1 in / hr} = \frac{372000 \mathrm{m}^3/\mathrm{d}ay}{0.61 m / day} = 0.61 km^2 (61 ha)$$

Since the inflow rates for future phases of the Marsh Flow-Way project in Lake Apopka were not found within the research period, the inflow rates of cell B and cell C only were summed and used as the entire system inflow rate. Therefore, the land area calculated in this design was only compared with the sum of the areas of cell B and cell C, 308 ha. Hence, the area of bioretention system to treat lake water, 61 ha, is approximate 20% of the marsh flow-way, 308 ha.

7.1.6. Filter Materials

7.1.6.1.Sand Layer

Based on the requirements of bioretention system in New Jersey, the sand layer must have a minimum thickness of 6 inches and contains clean medium aggregate concrete sand (AASHTO M-6[4]/ASTM C-33[5]) (NJDEP, 2009). In this design, the thickness of sand layer will be designed as 6 inches. Moreover, the sand layer must have a permeability rate at least twice as fast as the design permeability rate of the planting soil bed in order to prevent clogging situation or other operation problems from occurring.

7.1.6.2.Gravel Layer

Gravel layer provides the surrounding of the underdrain pipes for the purpose of protecting them from clogging potential. Placement of the gravel over the underdrain pipes must be done carefully. According to the design manual of bioretention system in New Jersey, the gravel layer must have 3 inches of gravel above and below the pipes to ensure the proper system operation. It must consist of 0.5 to 1.5 in clean broken stone or pea gravel (AASHTO M-43). In this design, the gravel layer will be designed as 3 inches thick above and 3 inches thick below the pipes, and composed of 0.5 to 1.5 inches clean broken stone or pea gravel.

7.1.6.3. Filter fabric

Filter fabric is a part of the soil planting bed to prevent the transport of soil particles from the adjacent soil. Thus the filter fabric should be placed along the sides of the soil bed (NJDEP, 2009).

7.1.7. Underdrain Specification

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[4] AASHTO: American Association of State Highway and Transportation Officials
[5] ASTM: American Society for Testing and Materials

Underdrain facilities are the pipes buried in the gravel layer. Underdrain piping beneath the soil planting bed and sand layer must be perforated to ensure the water flow into the pipes and go away through the pipe-way.

7.1.7.1. Underdrain Material Types

Underdrain systems can be composed of a variety of materials, among them, HDPE pipe material is one of the most commonly used as the underdrain facility. In this design, HDPE pipes (Figure 6) will be applied as the main underdrain material. Alternative pipe material can be flexible ADS pipe (Figure 7).

Figure 6 Perforated HDPE pipe
(Source: http://www.binaplast.com/catalog/hdpe-corrugated-subsoil-drainage-pipe)

Figure 7 ADS pipe
(Source: http://www.martignetti.us/adspipe.html)

7.1.7.2. Underdrain connections

Pipe joints and drain structure connections should be sufficiently sealed to avoid water leaking through the pipe or structure joints. Pipe sections shall be complied with suitable connection flanges and rings. Field connections to drain structures and pipes shall be sealed with polymer grout material which is capable of adhering to pipe surfaces (DER, 2007). Underdrains connected directly to drainage structure should not be perforated in case of leaking problems. In field construction, underdrain pipe should be capped until completion of site.

7.1.7.3. Underdrain perforations

The perforation locations commonly are closest to the invert of the pipe to achieve maximum potential for draining the facility. Perforated PVC pipe usually has one-quarter or one-half-inch perforations, 6 in center to center along the pipe (DER, 2007).

7.1.7.4.Dimension of underdrain piping

In this design, the entire bioretention area shall be uniformly divided to 650 (25 in length ×26 in width) cells (Figure 8). Subsequently the amount of pipes shall be 650 underground respectively. Therefore, the area and inflow rate of each cell can be calculated as below based on the bioretention system area of 0.61 km^2 (6.6×10^6 ft^2) and the total flow rate of 37.2×10^4 m^3d^{-1} (152.2cfs),

$$A_n = \frac{A}{N} = \frac{6.6 \times 10^6\ ft^2}{650} \approx 1 \times 10^4\ ft^2,$$

$$Q_n = \frac{Q}{N} = \frac{152.2cfs}{650} = 0.23cfs$$

where:

A = the area of entire bioretention system (ft^2);

Q = the total inflow rate of bioretention system (ft^3/s);

N = required amount of pipes;

A_n = the area of each pipe (ft^2);

Q_n = the cross-sectional average flow rate of each pipe (ft^3/s);

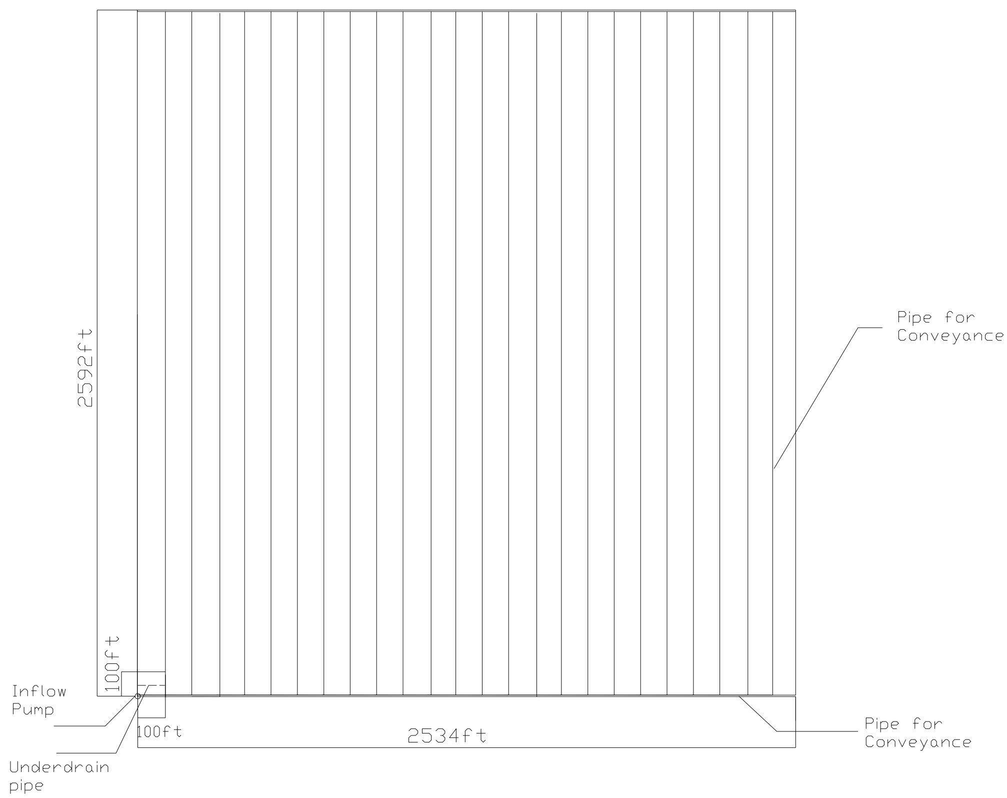

Figure 8 The ground pipe distribution of the proposal to treat lake water (plan view)

From literature review, the underdrain pipes are commonly used in the biortention system of 4 inches and/or 6 inches. In this design, the pipes of 4 inches shall be adopted in the entire system. Therefore the average velocity of the flow through each pipe can be calculated using continuity equation,

$$v = \frac{Q_n}{A} = \frac{4Q_n}{\pi D^2} = \frac{4 \times 0.23cfs}{\pi (0.33\,ft)^2} = 2.69\,ft/s$$

where:

v = average velocity of the fluid flow through pipe (ft/s);

A = the area of each pipe (ft^2);

D = diameter of the flow-way (pipe) (ft);

This velocity meet the range, 2ft/s to 10 ft/s, that is subjected to allow the water flow through the media.

The length of the each pipe is 100 ft. In order to ensure the acceptable elevation of the pipes comparing with the thick of gravel layer of 6 inches in total, hence the slope of the pipes shall be designed as 0.005, thus, the elevation of pipes shall be,

$$h = l \times s = 100\,ft \times 0.005 = 0.5\,ft(6in)$$

where:

h = the elevation of each pipe (ft);

l = the length of each pipe (ft).

7.2. Vegetation

The vegetation in a bioretention system can remove a few of the nutrients and other pollutants in the lake water inflow. The environment in the region of the plant root systems breaks some pollutants down and converts others to less harmful compounds. The use of terrestrial forested community is recommended for this bioretention system acquired from Table 6. As there will be diverse wetness zones within the constructed bioretention systems, plants must be selected and placed appropriately. Typically, trees should dominate the perimeter zone in order to less frequent flood. Shrubs and herbaceous species should be selected for the wetter zones. The number of stems per acre should be planted average 1,000 with tree spacing of 12 feet and shrub spacing of 8 feet (DER, 2007).

7.3. Cost of the bioretention system

The total cost of the entire bioretention system can be regarded as the sum of each bioretention cell. In each bioretention cell, the cost can be calculated by (Bioretention Cell Design and Construction, 2007)

$$C = 7300+51V$$

where:

C= the bid cost of bioretention system ($);

V = Volume of bioretention system (m^3).

The dimension of the bioretention system can be summarized from above:

- A 2.0 ft deep planting soil bed
- A 6 inches deep sand layer
- A 10 inches deep gravel layer (including 4 inches diameter pipe)
- A 1×10^4 ft^2 (100×100 ft^2) area of each bioretention cell

The estimated volume of each bioretention cell can be derived as below,

$$V_n = A_n D_b = 1\times10^4\ ft^2 \times 2.69\, ft = 2.69\times10^4\ ft^3 (762 m^3)$$

where:

V_n = the volume of each bioretention cell (ft^3);

A_n = the area of each bioretention cell (ft^2);

D_b = the depth of the bioretention system (ft).

Therefore, the cost of each cell can be derived as follow,

$$C_n = 7300 + 51V_n = 7300 + 51 \times 762 = 4.62 \times 10^4$$

where:

C_n= the bid cost of each bioretetnion cell ($).

Thus, the total cost of the entire bioretetnion system of 650 cells will be,

$$C = C_n \times 650 = 4.62 \times 10^4 \times 650 = 3.00 \times 10^7$$

where:

C= the bid cost of entire bioretetnion system ($).

Compared with the cost of marsh flow-way (Table 8), the cost of construction of a bioretention system of 30 million preliminary estimated is about 10 times of that the cost of marsh flow-way during 2004 to 2005.

Table 8 Estimated capital and operating funding required for Lake Apopka SWIM projects, FY 2002-2006 (Hoge, et al., 2003)

Year	**02-03**	**03-04**	**04-05**	**05-06**
Cost	483,930	540,857	3,298,474	380,132

When evaluating the costs of bioretention, there are some aspects should also be considered. The bioretention often replaces area that would likely be landscaped anyway (SMRC, 2006). The area in this design is much larger than those of typical bioretention system for treating stormwater. Therefore, the true cost of the bioretention system may be much lower than the cost reported based on the consideration of economics of scale. However, due to the continuity inflow, the maintenance cost of this bioretention system would be more expensive than the ones for treating uncertain storm water to ensure the removal efficiency. Besides, in terms of this bioretention design, it was designed to fit in the existing marsh flow-way area, thus, the cost of excavation should be less than the cost reported.

7.4. Maintenance and operation of the bioretention system

Bioretention needs seasonal landscaping maintenance. In most cases, bioretention areas need intense maintenance initially to establish the plants, but in the long term, less maintenance is required. Typically, maintenance tasks can be done by a landscaping contractor, who may already be hired in the site (SMRC, 2006).

Specific maintenance requirements for bioretention systems are presented below.

Table 9 Typical maintenance activities for bioretention areas (SMRC, 2006)

Activity	Schedule
• **Remulch void areas** • **Treat diseased trees and shrubs**	As required
• **Water plants daily for two weeks**	At project completion
• **Inspect soil and repair eroded areas** • **Remove litter and debris**	Monthly
• **Remove and replace dead and diseased vegetation**	Twice annually
• **Add additional mulch** • **Replace tree stakes and wire**	Once annually

8. Conclusions and further suggestions

A new design using a bioretention system to treat lake water in Lake Apopka was proposed. This proposal is mainly referred from current marsh flow-way included in SWIM Plan for Lake Apopka of the inflow rate and land use and from New Jersey Stormwater BMP Manual of the design process.

The proposed design will achieve a higher removal rate with TP of 60 percent, TN of 30 percent, TSS of 90 percent with considerably less of about 20% land area to improve highly polluted lake water. However, the cost of constructing a bioretention system would be approximately 10 times that of building the marsh flow-way based on a preliminary analysis such as ignoring the economics of scale.

For future consideration, the water conveyance system in order to allow the water inflow to each bioretention cell could be designed as spray system suspended over the entire bioretention area instead of pipes distributed on the ground, which may be more controlled of the inflow rate to each cell and as well as may reduce the construction cost.

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