Methodology, Evaluation, & Feasibility Study of Total Phosphorus Removal Management Measures in Lake George & Nearby Lakes

Daniel L. Reisinger, Mary Brabham, Michael F. Schmidt, Patrick R. Victor, and Larry Schwartz

The St. Johns River is the largest river in Florida, extending from southeast of Orlando to Jacksonville and the Atlantic Ocean. The lower St. Johns River Basin has exhibited issues associated with eutrophication, which has led to the establishment of a Total Maximum Daily Load (TMDL) for Total Nitrogen (TN) and Total Phosphorus (TP). Independent of the TMDL process, the St. Johns River Water Management District (SJRWMD, district) has implemented the St. Johns River Algal Initiative, which will limit the growth and nitrogen fixation from cyanobacteria (blue-green algae) in the river.

Algal initiative planning has determined that the TP load needs to be reduced by at least 84 metric tons per year (MT/Yr) (93 tons per year) from current levels in the St. Johns River Basin (SJRWMD 2006) through multiple projects, including TP removal in Lake George, which is the largest lake in the river. To evaluate the feasibility of TP removal in Lake George, the district conducted a comprehensive review of potentially viable and cost-effective Best Management Practices (BMPs), also referred to as management measures, for reducing TP concentrations in the lake.

The comprehensive review was the first step in designing a potentially very large regional surface water quality facility treating 50 to 75 million gallons per day (MGD), or 78 to 116 cubic feet per second (cfs). This article focuses on the results of this review and the components that were key to its successful completion. Each section presents a key component in the review of TP removal in Lake George and nearby lakes.

Daniel L. Reisinger, E.I., is a water resources intern in the Denver, Colorado, office of the consulting, engineering, construction, and operations firm CDM. Mary Brabham, P.E., is the Middle St. Johns River Basin Program manager for the St. Johns River Water Management District in Altamonte Springs. Michael Schmidt, P.E., BCEE, is a vice president with CDM in the firm's Jacksonville office. Larry Schwartz, Ph.D., P.W.S., is a CDM vice president in the firm's Orlando office. Patrick R. Victor, P.E., is a CDM principal in the Jacksonville office. This article was presented as a technical paper at the 2008 Florida Water Resources Conference in May.

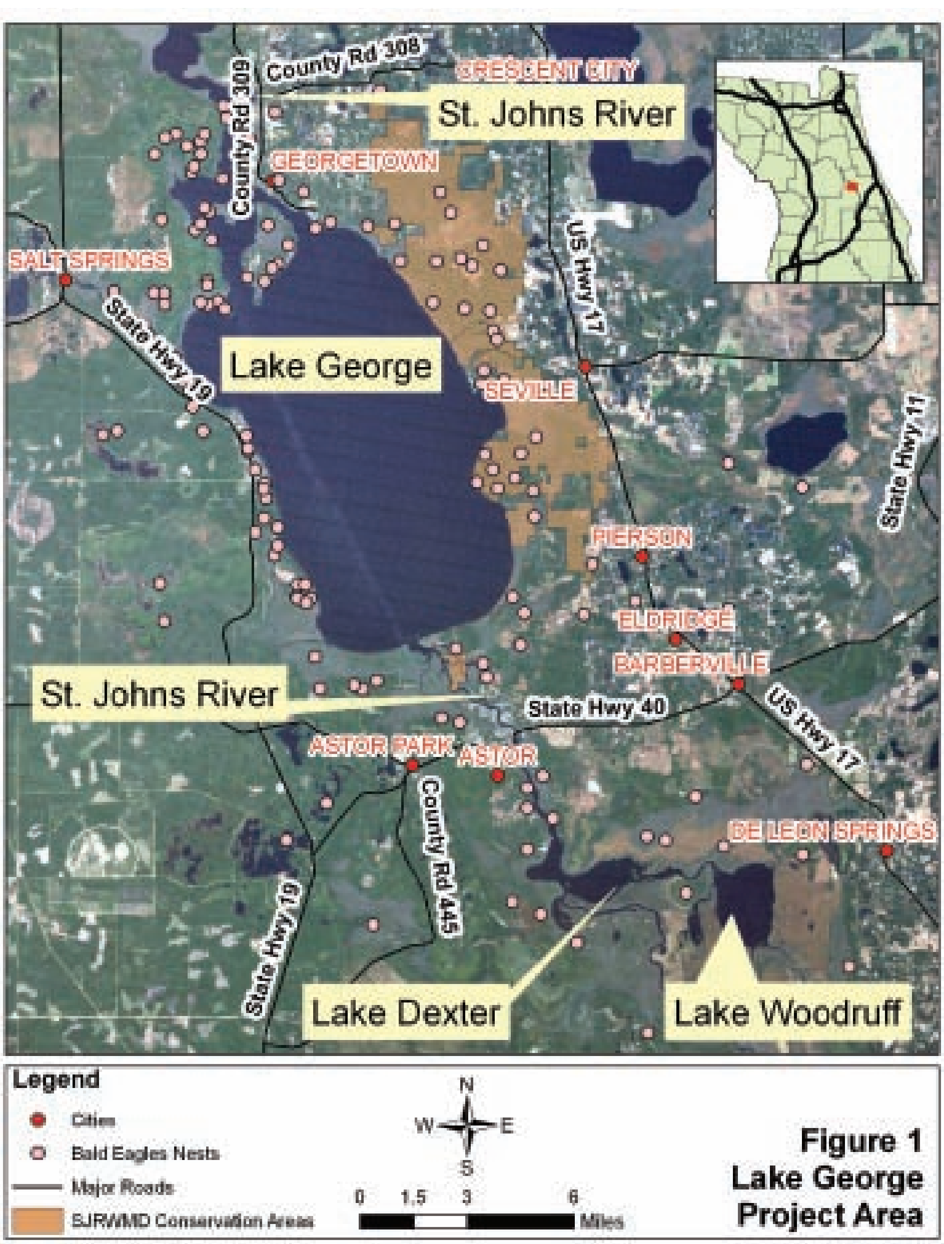

Figure 1
Lake George Project Area

Project Area & TP Removal Goals

Project Area

Lake George is Florida's second-largest lake, with an area of approximately 73 square miles. It is part of the main stem of the St. Johns River north of Astor, as shown in

Table 1 – Water Quantity and Quality in the St. Johns River at Astor, Florida

Statistic	Season 1 (Dec-Mar)	Season 2 (Apr-Jul)	Season 3 (Aug-Nov)	Annual Average
Average Absolute Flow (MGD) [1]	2,350	1,565	3,230	2,402
% of Absolute Flow [1]	32%	21%	47%	100%
Average TP Concentration (mg/L) [2]	0.068	0.073	0.093	0.078
Average TN Concentration (mg/L) [2]	1.36	1.29	1.43	1.36

Notes:
Water quality based seasons were determined by Hendrickson and Konwinski (1998)
[1] USGS Gage 02236125 at SR 40 in Astor, Florida
[2] SJRWMD stations SJR40 and 20020012 at State Road 40 in Astor, Florida

Figure 1. Two large lakes, Lake Dexter and Lake Woodruff, are located on a secondary channel of the river upstream of Lake George and were included in the evaluation of some management measures.

The area surrounding Lake George, Lake Dexter, and Lake Woodruff is largely in public ownership or divided into relatively small individual parcels. The district currently co-owns significant conservation lands on the east shore of Lake George, referred to as the Lake George Conservation Area and the Nine Mile Point area, which are shown as shaded areas in Figure 1. The land uses of the area are predominately classified as wetlands, silviculture (forested uplands), and agriculture (SJRWMD 2000).

Lake George is surrounded by sandy hills between 20 and 80 feet NGVD (National Geodetic Vertical Datum of 1929). Stages in Lake George normally range between 0 and 0.5 feet NGVD, but will increase to two feet NGVD in large flow events. The lake bottom is relatively uniform with a mean depth of eight feet and a maximum depth of 12 feet. The soils in the area are generally hydrologic group B/D or D (poor permeability), except on the western shore where they are almost entirely A soils (high permeable) (Lewis et al. 1987).

Eleven springs are located in the Lake George tributary area, with three large springs, Silver Glen, Juniper, and Salt Springs, discharging into Lake George on the western shore (Stewart et al. 2006). Lake George is not affected by marine salinity, but it is tidally affected and local sources of salinity have allowed the lake to support a large number of marine species. Also shown in Figure 1, the surrounding area has a large population of Bald Eagles—a threatened species in Florida that is currently proposed for delisting.

Summary of Water Quantity & Quality

Stewart et al. (2006) performed extensive hydraulic modeling of the Lake George area that provides excellent information for a period of 1996 through 2004. Measured flow data was available at the USGS flow gage located at the State Road 40 Bridge at Astor (USGS Gage 02236125) from 1994 through the time of this study, 2007.

Regular negative flows were recorded at the Astor gage. Since treatment will occur regardless of direction, negative flows were included in the possible treatment flow. Summary statistics for the gage as absolute flows are shown in Table 1.

The nutrient and solids concentrations are also measured at State Road 40 in Astor (SJRWMD Stations SJR40 and 20020012). The concentrations were found to be relatively low: less than 0.08 milligrams per liter (mg/L) of TP, less than 1.4 mg/L of TN, and less than 22 mg/L of Total Suspended Solids. Average seasonal and annual TP and TN concentrations at Astor are reported in Table 1. These low concentration levels and the variability by season have implications for the types of management measures that can be used cost-effectively and for potential efficiencies of treatment.

The variability of the water quantity and quality of Lake George provides significant challenges for the removal of TP. Because of the large flow and lower concentration, relatively high treatment volumes will probably be required to remove adequate TP mass. The relatively low nutrient and solids concentrations are expected to be near or below the practical limit of many standard technologies (e.g. wet detention, wetlands treatment), and infiltration systems on the permeable soils on the west side of the lake may cause nitrate impacts in the springs..

TP Removal Goal

Lake George has potential for very large TP removal facilities. The removal goal of 84 MT/Yr was set for the overall St. Johns River Algal Initiative, but the removal goal of individual projects will be decided based on a comparison of the potential projects in the initiative. The establishment of a nonbinding TP removal goal was considered important to be able to compare management measures using specific itemized costs.

The effect of phosphorus removal on Lake George concentration was estimated by performing a mass balance at Astor. Removing the total St. Johns River Algal Initiative goal of 84 MT/Yr, resulting in an average annual concentration of 0.053 mg/L in Lake George, would require at least 900 MGD (1,395 cfs) to be treated, as shown in Figure 2. A lesser removal goal of 21 MT/Yr, resulting in an average annual concentration of 0.072 mg/L in Lake George, would require treatment flow of at least 220 MGD (341 cfs).

Continued on page 44

Figure 2 – Lake George Total Phosphorus Concentration as a Function of TP Removal

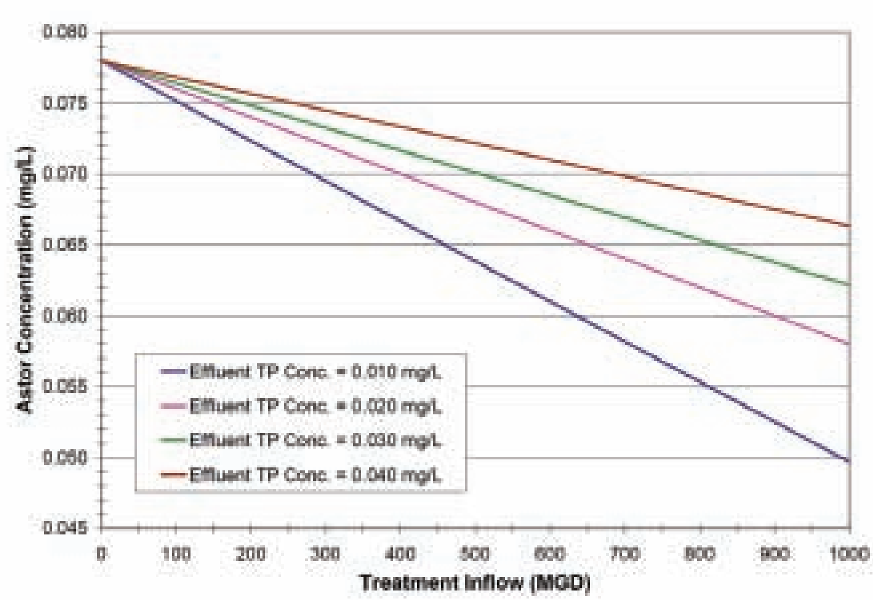

Figure 3 – Mechanical Harvester Removing Aquatic Plants (Texas Aquatic Harvesting Inc. 2007)

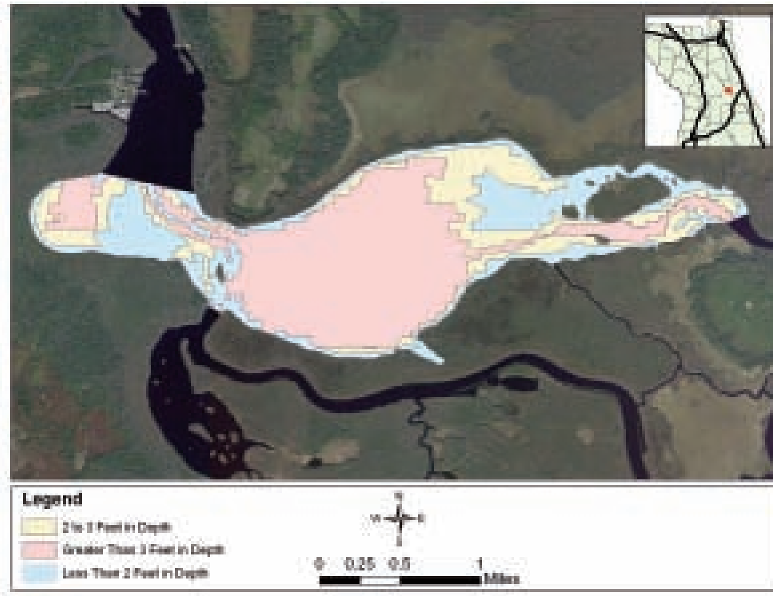

Figure 4 – Bathymetry of Lake Dexter where Depths Less than Three Feet Can Not Be Harvested

Continued from page 43

A goal of 5 MT/Yr was chosen by the district for the study, resulting in an average annual concentration of 0.076 mg/L in Lake George, which would require between 50 and 75 MGD (78 cfs to 116 cfs) of treatment flow. This removal rate was chosen because it would likely require several treatment units to be built, and if a higher goal was later chosen, the results could be scaled upward as necessary.

Evaluation of Potential Management Measures

Management Measure Review

A lake management approach was taken to determine possible management measures for phosphorus removal in Lake George. Using this approach, short-term and long-term measures with offline and in-lake treatment were considered.

Possible management measures were determined from lake management, stormwater control, and water quality improvement literature, relevant experts, and other implemented projects (both successful and unsuccessful). The U.S. Environmental Protection Agency (EPA) provides comprehensive review of lake and reservoir restoration and management techniques (EPA 1990), which was used as a starting point.

Because of the uncommon attributes of Lake George (e.g. large lake, variable flow rates, low inflow concentrations, in-stream, unregulated, and relatively shallow), many management measures were not considered, as discussed with the district, since they appeared not applicable or infeasible. The following nine lake management measures considered applicable to the configuration and constraints of the project area were evaluated:

1. Aquatic plant harvesting (e.g. hydrilla or water hyacinth)
2. Chemical addition (e.g. ballasted flocculation)
3. Constructed wetland treatment
4. Constructed water hyacinth treatment
5. Diversion of water for reuse
6. Dredging
7. Fish harvesting
8. Periphyton flowway treatment (e.g. HydroMentia Algal Turf Scrubber or Aquafiber)
9. Retention/infiltration

Each of the nine management measures was reviewed for its benefits, challenges, relative costs, relative time to implement, and references to publications used in order to verify the applicability of the management measure. Approaches that can be integrated for a synergistic benefit were also identified.

Management Measure Selection

District and CDM representatives met to discuss each evaluated management measure and to select three measures for further detailed evaluation. A feasibility study was to be conducted for each selected management measure, which included the conceptual design, TP and TN removal capability, benefits, operation, and maintenance requirements.

The feasibility of each management measure was discussed until a consensus was reached on whether or not the measure was appropriate for further study. The major decision criteria included its technical feasibility, cost, and the ability to permit the system. The three most promising management measures were determined to be:

1. Aquatic plant harvesting
2. Chemical addition
3. Periphyton flowway treatment

Feasibility Study of Management Measures

Detailed Planning of Potential Management Measure Processes

Detailed information on the configuration, sizing, nutrient removal, and byproduct disposal were determined in the feasibility study. All analyses were performed at a planning level of detail. The following paragraphs summarize each management measure and key components.

Aquatic Plant Harvesting—Aquatic plant harvesting was considered, using mechanical harvesters to remove TP and control the population of invasive aquatic plants. Harvesters use a conveyor belt system to remove aquatic plants from the water, as shown in Figure 3. The feasibility study of this management measure focused on water hyacinth, which is the main aquatic plant controlled in the Lake George area.

Harvesting was proposed to be the main method of control, with herbicidal spraying, which is the current population control method, as a secondary measure to assure very low water hyacinth populations are maintained. Windrow composting in a contained site was found to be the most feasible method to dispose of harvested water hyacinth. The resulting compost could be given away or sold, depending on demand.

This management measure is a departure from existing aquatic plant control in the lakes; therefore, study efforts focused on determining a feasible methods for har-

Continued on page 46

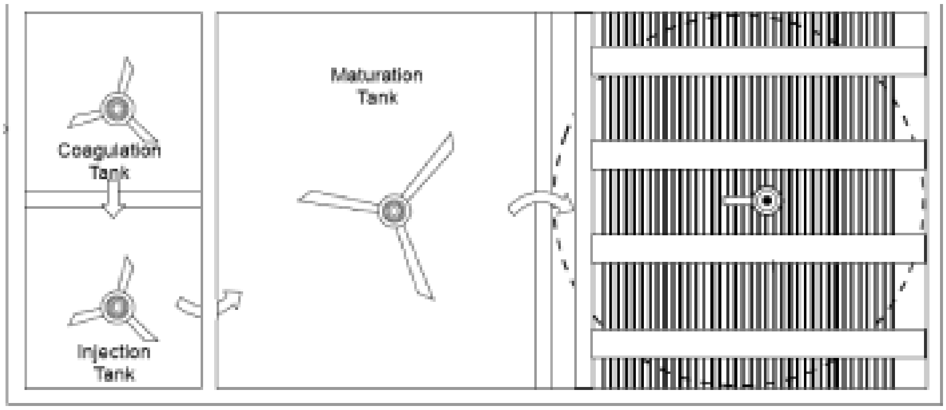

Figure 5 – ACTIFLO 35 MGD Modular Ballasted Flocculation System (Kruger 2007)

Continued from page 44

vesting.

Large harvesters are limited to operating in water depths greater than three feet. Bathymetric data for Lake George, Lake Dexter, and Lake Woodruff indicate that large areas of Lake Dexter and a significant portion of the near shore area of Lake George and Lake Woodruff are less than three feet in depth, as shown for Lake Dexter in Figure 4. Based on the average standing crop of water hyacinth, which was estimated from the acreage receiving herbicidal treatment (USACE 2007), no lake would have water hyacinths at a harvestable depth in an average year.

Several methods to remove water hyacinth from areas with less than two feet of water depth were evaluated. The most promising method proposed is to chop the hyacinth using chopping boats to move the chopped material in windrows to deeper water for harvesting. Chopping boats are typically shallow-draft vessels with large propellers affixed to the bow to chop the plant material. The working area will be contained by turbidity-capturing geotextiles to reduce effects of the chopping. The benefits of this method were provided by Weedbusters Inc. and include the following:

- Widely used with proven feasibility.
- Increases the efficiency of the harvesting process.
- May allow over five times more water hyacinth to be collected per harvester.
- Does not eliminate most submerged aquatic vegetation or suspend sediment.

The use of chopping boats and harvesters was considered feasible and was used to determine TP removal, TN removal, and costs.

Chemical Addition—Chemical addition of coagulants to a flow stream and subsequent settling of formed floc can improve water quality significantly. These processes are used widely in the water and wastewater treatment process in controlled facilities. Because of the possibility of treating a large volume of flow, patented or proprietary systems, which generally reduce the footprint of the chemical addition system, were primarily considered.

The ACTIFLO system that uses microsand ballast and settling plates to increase overflow rates (the effective treatment system flow) is shown in Figure 5. Implementation of the ACTIFLO process was evaluated in this study; however, other proprietary treatment systems may be equally effective.

The actual removal from chemical addition systems can be estimated only by bench and pilot scale tests; therefore, the collection and testing of a sample to provide an indication of possible removal was the key component of the chemical addition feasibility analysis.

A water sample was taken from the inlet of the St. Johns River to Lake George in April 2007 and sent to Kruger Inc. for bench scale ACTIFLO testing and chemical analysis. At the time of the testing, the St. Johns River watershed was in drought condition and the river exhibited low flow. The results from the water sample indicated TP concentrations of 0.064 mg/L, slightly below the seasonal average, and undetectable quantities of orthophosphate.

The bench scale testing conducted by Kruger Inc. evaluated TP removals associated with various dosages of cationic and anionic polymers, ferric sulfate, and ferric chloride coagulants. The results, presented in Table 2, show that ACTIFLO ballasted flocculation was able to remove at least 85 percent of particulate TP, defined as the difference between TP and dissolved TP, to limit of detection for the measurement method. There were undetectable quantities of ortho-phosphate in the water, so one-third removal of ortho-phosphate was used for this study.

Periphyton Flowway Treatment—Periphyton flowways are constructed, biologically based treatment systems that pass a shallow flow of water over a sloped mat of periphyton. Nutrients are removed from the water biologically by the periphyton, which are harvested to remove the nutrients from the system and encourage further growth of the periphyton.

These systems are differentiated from periphyton wetland systems by their flow characteristics. Flowways use shallow sheet-flow and higher velocity, although velocities would be considered low in most treatment applications. Periphyton flowways can be conceptualized as hydroponics-style horticulture of algae.

Two proprietary periphyton flowway systems were evaluated: Aquafiber and

Continued on page 48

Table 2 – Bench Scale ACTIFLO Results for Lake George

Coagulant	Coagulant Conc. (mg/L)	Polymer Conc. [1] (mg/L)	Microsand Conc. (mg/L)	Phosphorous as P	
				Raw (mg/L)	Settled (mg/L)
Raw Water Sample	NA	NA	NA	0.06	NA
$FeCl_3$	40.00	0.50	5.00	NA	0.02
$FeCl_3$	60.00	0.50	5.00	NA	<0.01
$Fe_2(SO_4)_3$	60.00	0.50	5.00	NA	0.02
$Fe_2(SO_4)_3$	80.00	0.50	5.00	NA	<0.01

Notes:
[1] Anionic Polymer LT 25 was used
Results based on a single sample taken in Lake George during April 2007
Bench-scale ACTIFLO tests were conducted by Krueger Inc.
NA = Not Applicable

Continued from page 46

HydroMentia. HydroMentia's Algal Turf Scrubber® (ATS) pulses a shallow flow of water over a bed of periphyton to remove nutrients, which is shown in Figure 5. Included in the process are patented phosphorus precipitation methods and biomass management techniques.

Aquafiber has developed patented and trade secret technologies, including a periphyton flowway system also using shallow sheet flow. The Aquafiber periphyton flowway system may include patented ozone treatment to release nutrients bound in organic matter, eliminate toxic compounds found in cyanobacteria, and destroy micro-invertebrates and their eggs.

HydroMentia and Aquafiber were engaged to provide information for this study. A detailed review of the ATS technology at Lake George was provided for the feasibility study by HydroMentia (Stewart E.A. 2007). The report included the facility size, anticipated removal rates, and an estimated cost per pound of phosphorus removed.

Aquafiber provided a short memorandum documenting the likely TP removal from a hybrid system of the periphyton flowway system and the company's patent-pending, trade secret technology (Fagan 2007). Aquafiber did not provide a cost estimate for this feasibility study.

The technical review of the document provided by HydroMentia found the facility sizing, TP removal methodology, and costs to be reasonable. HydroMentia used the best available data, results from the S-154 ATS facility, to determine the periphyton growth rate and subsequent TP removal rate; however, it was believed that this value may be different in Lake George because of much lower TP levels and environmental conditions, such as low bio-availability of nutrients, lower water temperatures, and solar radiation. Pilot testing was suggested to determine a more accurate estimate of nutrient removal.

The HydroMentia ATS information was considered to be acceptable and was used to represent the periphyton flowway management measure in the feasibility study.

Table 3 – Summary of Management Measure Sizing and Costs

Technologies	Units	Treatment System Area (acres)	Treatment Flow (MGD) or Area (acres)	Annual TP Removal (MT/yr)	Cost per lb of TP Removal ($/lb-TP)
Adapting Existing Aquatic Plant Management	3	30	590 acres	6.2[1]	$ 240
Periphyton Flowway Treatment (HydroMentia ATS)	3	50	75 MGD	5.1	$ 240
Chemical Addition (ACTIFLO)	2	6	70 MGD	4.3	$ 350

Notes:
[1] Based on harvesting in Lake Dexter

Feasibility Study Results & Costs

Results & Cost per Pound of TP Removed

The conceptual specifications and associated cost per pound of TP removed for each management measure is presented in Table 3. The sizing and TP removal for the feasibility management measures were based on detailed planning using the best available information. Each of the management measures were evaluated based on approximately 5 MT/Yr per year of TP removed from Lake George and the St. Johns River; however, the exact removal varied by process.

Costs in Table 3 are based itemized costs for each management measure, including conceptual probable capital and operational cost estimates of site preparation, pumps, and piping. Contingencies, engineering, survey, permitting, mobilization, and discount rates were also included. These costs supplemented the cost of the removal technology. The cost of land was not included, since the majority of land was in public ownership. All costs were based on a 20-year design life and include 20 years of operation and maintenance.

Figure 6 – HydroMentia ATS S-154 Basin Facility in Okeechobee County, FL (Stewart, E.A. 2007)

Discussion of Results

Each management measure was evaluated in terms of feasibility and cost to make a recommendation for further study and ultimately, design and implementation.

Aquatic Plant Harvesting was estimated to cost $240 per pound of TP removed. This process has a relatively higher level of uncertainty compared to the other alternatives because of a lack of data on the water hyacinth population and disposal site conditions; therefore, a study of the Lake Dexter and Woodruff water hyacinth populations was suggested. Harvesting water hyacinth in Lake George was not suggested, based on the long travel times and low density of water hyacinths in the lake.

Chemical Addition using ACTIFLO could provide high levels of TP removal on a small footprint at an estimated cost of $350 per pound of TP removed. It was recommended that the ACTIFLO technology be considered at sites other than Lake George, which would benefit from the ACTIFLO's small footprint. It was recommended that pilot testing of both the ACTIFLO system and potential dewatering equipment be performed to better determine phosphorus removal and operation and maintenance costs at a site near existing commercial or industrial land uses.

Periphyton Flowway Treatment using HydroMentia's ATS provides relatively high levels of phosphorus removal, and generates a marketable byproduct (compost) at an estimated cost of $240 per pound of TP removed. It was recommended that the Aquafiber technologies also be considered for pilot testing

Continued on page 50

Continued from page 48

Recommendations for Further Planning & Design

Three management measures listed in Table 3 are recommended for further study through pilot testing:

1. The harvest of water hyacinths should be pilot tested in Lake Dexter.
2. Periphyton flowway treatment should be pilot tested in the vicinity of Lake George.
3. ACTIFLO should be pilot tested in a predominantly industrial or commercial area.

Because of the water quality fluctuations in Lake George, pilot studies should be performed for a period of at least one year to evaluate a full range of water quality and flow conditions. The three management measures are modular and complementary; therefore, they can be used together if desired for additional removal.

References

- St. Johns River Water Management District (SJRWMD). 2006b. Lake George P Removal Project MSJRB St. Johns River Nutrient Discharge Reduction WBS 2.3.30.00.08 (part of the SJR Algal Initiative) Charter Document – 11/9/2006.
- St. Johns River Water Management District (SJRWMD). 2000. Elevation: SJRWMD 5 FT Contour (Line). Palatka, FL. St. John's River Water Management District. http://www.sjrwmd.com/programs/plan_monitor/gis/docs/metadata/elev_5ft.htm
- Lewis et al. 1987. Soil Survey of Okeechobee County, FL. Electronic Report. http://soildatamart.nrcs.usda.gov/Manuscripts/FL093/0/fl_okeechobee.pdf. Accessed February 2007.
- Stewart, Joseph B., Sucsey, Peter, and Hendrickson, John. "Meteorological factors affecting estuarine conditions within Lake George in the St. Johns River, Florida". Proceedings of the Seventh International Conference on Hydroscience and Engineering. Philadelphia, PA. September 2006. http://hdl.handle.net/1860/732
- Hendrickson, J.C. and J. Konwinski. 1998. Seasonal Nutrient Import-Export Budgets for the Lower St. Johns River, Florida. Final Report for Contract WM598, Florida Department of Environmental Protection. 109 pp.
- United States Environmental Protection Agency (EPA). 1990. "Lake and Reservoir Restoration Guidance Manual, Second Edition." Publication # 440490006, Electronic, NTIS # PB93-207926.
- United States Army Corps of Engineer (USACE). 2007. Unclassified Acreage, Herbicide Usage, and Man Hours for Herbicidal Spraying of Lake George, Lake Dexter, and Lake Woodruff, FL. Electronic Communication March 2007.
- Camp Dresser & McKee (CDM). 1999. "Renaissance Jar Testing." Submitted to Mr. Jeff Hiscock of Mock Roos & Associates.
- Stewart, E.A. 2007. "Preliminary Engineering Assessment for the Application of an Algal Turf Scrubber (ATS) for Reduction of Nitrogen and Phosphorus Loads into Lake George, Florida." Prepared by HydroMentia for SJRWMD: Ocala, FL.
- Fagan, William B. 2007. Aquafiber Application to Lake George. Letter to Mr. Daniel Reisinger of CDM. June 15, 2007.