MANAGED AQUATIC PLANT SYSTEMS (MAPS)

A TECHNICAL REVIEW

June 23, 2016

A COMMERCIALLY AVAILABLE ADAPTIVE MANAGEMENT MEASURE FOR IMPROVING EFFICIENCY AND SUSTAINABILITY OF WATER MANAGEMENT PROGRAMS IN SOUTH FLORIDA INCLUDING STORMWATER TREATMENT AREAS (STA) THE COMPREHENSIVE EVERGLADES RESTORATON PLAN (CERP) AND THE TOTAL MAXIMUM DAILY LOAD (TMDL) PROGRAM

Managed Aquatic Plant Systems (MAPS) represent a variant of typical agriculture, for the primary intent is not to maximize productivity of the targeted crop as with conventional agriculture, but rather to maximize reduction of pollutants from an impaired water source. In other words, MAPS operations do not involve adjustment of nutrient levels in the feed water to ensure high levels of crop production and quality, but rather involve adjustment of crop selection and operational strategies to ensure high rates of nutrient reduction from the raw feed water, such as a nutrient enriched, impaired surface water. With conventional agriculture the crop is the primary product, while with MAPS, enhanced water quality is the primary product. This approach represents a significant paradigm shift from the general acceptance of agriculture as a net pollutant contributor, to the reality that there are forms of agriculture that can offer substantial net pollutant removal and recovery.

SUMMARY

Managed Aquatic Plant Systems (MAPS) are a family of water treatment and nutrient recycling technologies oriented around the cultivation of select aquatic plants within an engineered platform, with cultivation meaning the purposeful production, frequent harvesting and processing of the aquatic plant crop for the removal and recovery of nutrients from the water column—the principal nutrients being nitrogen, phosphorus and carbon. MAPS are unique in that they are truly sustainable, and combine agriculture with water treatment. Carefully designed MAPS facilities have proven to be an effective tool in the development of meaningful nutrient management within impaired surface waters in South Florida, and have the same potential within other regions of the country. MAPS units presently are achieving substantial nutrient reduction and recovery within Indian River County, Florida, and are contributing significantly to the County’s goal of meeting their regulatory Total Maximum Daily Load (TMDL) allocation for nitrogen and phosphorus. Harvested plants from these MAPS units are being processed into compost, presently being marketed throughout Florida under the product name Lagoon Saver™.

A well planned series of MAPS units could be used to:

- Remove legacy phosphorus from Lake Okeechobee sediments
- Reduce nutrient loading to the Kissimmee-Okeechobee-Everglades Basin
- Remove nutrients associated with septic tank seepage and other non-point sources, while increasing dissolved oxygen

levels within stressed areas of the Indian River Lagoon and other Florida estuaries

- Reduce total phosphorus concentrations from flows south of Lake Okeechobee to levels acceptable for release into the Everglades
- Establish new agri-industries oriented around various products associated with MAPS aquatic plant crops, to include soil amendments and compost; livestock feeds; fiber products; biofuels; and other potential products.
- Extend the period of effectiveness of existing Stormwater Treatment Areas (STA).

MAPS facilities include attached algal systems such as the Algal Turf Scrubber® (ATS™); floating aquatic plant systems such as the Water Hyacinth Scrubber (WHS™); suspended algal (phytoplankton) systems; emergent plant systems such as managed STA's; combined systems such as the Low Energy Aquatic Plant System (LEAPS™) now being considered for application in Indian River County; and floating emergent wetland systems such as Beemats™ which are presently being used in lakes and water storage areas.

MAPS technology has been developed to be a reliable, cost competitive commercial option for nutrient control within impaired surface waters. As development continues, the effectiveness of MAPS designs, operations and product value and options can be expected to improve even further.

Cultivation of the floating aquatic plant, the water hyacinth, likely represents the initial effort to develop effective MAPS systems, with early investigations dating to the sixties. Noted in Picture ***(a)*** *is a pond in which water hyacinths were cultivated in 2003, just north of Lake Okeechobee. At this facility the water hyacinth crop demonstrated an ability to reduce both phosphorus and nitrogen from nutrient impaired surface waters at high areal removal rates. A significant percentage of these nutrients were removed through harvesting, which was conducted about two to four times a month, depending upon seasonal conditions. Harvesting was done using a specially designed light weight grapple* ***(b)*** *powered through a tractor PTO (Power Take-Off) to remove a portion of the plants at a rate greater than 10 wet tons per hour. The harvested plants were placed in a transport canal and picked up by a conveyor system, and deposited into a chopper system modified to accommodate the high moisture content of the plants* ***(c).*** *Chopping significantly increased the bulk density, while increasing surface area, making the crop easier to handle and amenable to direct windrow compositing without addition of a bulking agent* ***(d)****. At this facility much of the chopped hyacinth material—about 100 wet tons—was delivered to nearby MacArthur Farms, where it was fed to Dairy cattle as an additive to their green chop program* ***(e)****. In the past, chopped water hyacinths also proved effective in the generation of a usable biogas* ***(f)****.*

(a)

(b)

(c)

(d)

(e)

(f)

Attached algal systems, such as the Algal Turf Scrubber® or ATS™ developed at the Smithsonian Institute in the seventies, is a MAPS approach which involves cultivation of a community of attached algae and associated organisms, known as algal turf. This algal turf is grown on a flat mildly sloped floway down which water is delivered in a continuous shallow laminar flow. The facility known as Egret Marsh Stormwater Park in Indian River County, Florida as shown in Picture ***(g)*** *is typical of a full scale attached algal system. As the water flows down this system, nutrient pollutants within the water are taken up by the algal turf and incorporated into its growing biomass. Through photosynthesis, the algal turf releases oxygen, much of which is dissolved within the overlying water. The resulting effluent therefore is of high quality, being reduced in nutrients and other pollutants, while enhanced with increased levels of dissolved oxygen (DO).The biomass, or algal turf, is composed of periphytic and epiphytic algae and associated microbes and invertebrates. As the biomass increases, the system is harvested, and is recovered and converted to usable products such as compost. Noted in Picture* ***(h)*** *is one method of harvesting, in which the algae are scraped from the surface and then moved via a conveyance flume to a rake system* ***(j).*** *At this point the material is available for final processing into Lagoon Saver™ compost* ***(k).*** *As noted the effluent is of high quality, and is ideal for fish and wildlife production. The effluent at the Egret Marsh facility is released to a lake shown in Picture* ***(l).*** *Noted within the green circle on this picture is a large bass, typical of the type of fish population supported by the effluent. From the lake the effluent then is used to support a diverse wetland designed specifically for use by the Wood Stork, a threatened species* ***(m).***

(g)

(h)

(j)

(k)

(l)

(m)

INTRODUCTION

On April 26, 2016, a group from the **Miccosukee Tribe of Indians of Florida (TRIBE)**, many representing the **TRIBE'S** Department of Water Resources, and Bobby C. Billie one of the Clan leaders and spiritual leader, **Council of Original Miccosukee Simanolee Nation Aboriginal Peoples (COUNCIL)**, visited two unique stormwater treatment and nutrient recovery facilities located in Vero Beach, Florida. These two facilities are owned and operated by Indian River County, Florida. The tour was led by **Keith McCully P.E., Director of the Stormwater Division, Public Works Department, Indian River County, Florida** (kmccully@ircgov.com).

These facilities are unique in that they serve not only to remove nutrients from impaired surface waters, but also are designed to facilitate recovery and recycling of these nutrients through cultivation of aquatic plants within an engineered unit—which in the case of Indian River County, is an attached algal turf. This cultivation includes periodic harvesting and subsequent processing of this harvest into usable products. Such facilities are commonly known as **Managed Aquatic Plant Systems** or MAPS. The MAPS concept is presently an integral part of Indian River County's efforts to meet a **Total Maximum Daily Load** (TMDL) allocation for nitrogen and phosphorus set by the **Florida Department of Environmental Protection** (FDEP). Both MAPS units in Indian River County were developed around a technology known as an **Algal Turf Scrubber®** or ATS™. The older of the two MAPS, known as Egret Marsh Stormwater Park relies upon the ATS™ to treat water from a large drainage canal (Lateral D of the Main Canal of Indian River Farms Water Control District), with the treated water then being used to establish healthy viable habitat for fish, birds and other native plant and wildlife species, including a marsh designed specifically for use by the Wood Stork—a threatened species in Florida. The Egret Marsh facility has been in operation for over five years, and in 2015 provided removal of nearly two tons of phosphorus and ten tons of nitrogen. A substantial percentage of these removals were recovered through periodic harvesting of the algal turf and subsequent composting of the harvest. The resultant compost is managed and marketed through an agreement with **Van Ert-Nemoto and Associates, LLC** (www.venconsultingllc.com) under the name **Lagoon Saver™** (www.lagoonsaver.com).

The intent of this recent tour was to allow the representatives of the **TRIBE** and the **COUNCIL** to become more familiar with the MAPS technology, and to contemplate the possibility that application of a MAPS program might improve the effectiveness of long term efforts to directly or indirectly improve the quality of waters associated with **Conservation Area 3A** and **Intercept Canal System L-28** and the downgradient **Shark River Slough** and associated **Everglades** and the **Florida Bay Estuary**.

This written discussion was developed as a follow-up to this April meeting, with the intent of providing more detailed information related to MAPS technologies, and in addition, to present a series of plausible, more expansive MAPS applications as an adaptive management option for improving water quality within the **Kissimmee-Okeechobee-Everglades** (KOE) watershed and subsequent incorporation into the present **Comprehensive Everglades Restoration Plan** (CERP).

STORMWATER TREATMENT AREAS—PRESENT STATE OF THE TECHNOLOGY

Presently, water quality enhancement within the KOE watershed is being managed largely through expansive, created passive wetlands known as **Stormwater Treatment Areas** (STA), which are operated by the **South Florida Water Management District** (SFWMD). The strategy of STA development is part of CERP. At this time, within the Everglades Basin south of Lake Okeechobee there exist about 57,000 acres of STA located in the contiguous eastern and southern boundaries of the ≈ 650,000 acre **Everglades Agricultural Area** (EAA) located directly south of Lake Okeechobee. To date, these STA's have provided substantial reduction of nutrients within the water column, with phosphorus reduction approaching 80%. On the average, these reductions result in an effluent of 27 ppb total phosphorus. While this is impressive, and represents substantial progress towards the target total phosphorus concentration of 10 ppb for the Everglades, there does remain a need to improve upon system performance.

The STA approach presently has some inherent weaknesses however that go beyond the failure to meet the 10 ppb goal. These weaknesses, which will eventually require resolution, are recognized by the involved water managers. The most obvious of these are associated with the reality that STA's are basically storage units, rather than treatment systems. This is to say their capabilities are finite. Like any system which serves as storage, its limit of effectiveness is based upon its holding capacity. Once this capacity is reached, it can no longer provide the intended function unless of course its storage capacity is recovered through removal of the stored material. If the stored material is not removed, then there is a chance the system will become overloaded, and the material redistributed into the overlying water column—which of course defeats the original purpose. The present STA program therefore is not sustainable. To use a simile, STA systems as are presently designed and operated are like the man falling from a multi-story building. On his way down a group relaxing on a balcony asks him how things are going, to which he replies "So far, so good."

Of course it could be argued that the time required for an STA to become overloaded to the point of non-function might well be measured in decades. At that time in the future a replacement or augmenting technology may emerge. Alternatively, the STA may simply be abandoned and isolated, and another contiguous STA created. The expended STA then could become new agriculture or a quasi-terrestrial system, such as a tree Island or willow stand. And so the STA program would over time incrementally impose upon new areas—areas which might otherwise be functional Everglades.

As mentioned, another alternative would be to actually remove the accumulated material from the expended STA. This was done by the City of Orlando at their Easterly Wetland in eastern Orange County. Because this wetland was receiving much higher phosphorus loads than the Everglade's STA's, its storage capacity filled much quicker. The problem with such expansive long term removals is the costs of both removal and disposal, and the disruption to system performance.

STA TECHNOLOGY AND ADAPTIVE MANAGEMENT

There does not at this time appear to be a detailed plan for replacing or modifying the existing STA's once their capacity is reached, nor is it known exactly when this will happen. The term used when such uncertainty exists is "adaptive management". It is an approach designed to refine and implement necessary enhancements based upon operational experience and innovation developments. The concept of adaptive management should of course apply to the ongoing implementation of all aspects of CERP.

Whatever adaptive management is implemented in regards to STA's, it is important that it improves the efficacy of the STA in terms of water quality enhancement, while also extending the functional life of the STA. Ideally the adapted system would be fully sustainable, and for this to occur it should approximate a dynamic equilibrium, where energy and material inputs are equal, or at least nearly equal, to outputs. This means that captured materials must be recovered and recycled efficiently, rather than being allowed to accumulate internally.

MANAGED AQUATIC PLANTS SYSTEMS AS AN ADAPTIVE MANAGEMENT MEASURE

In recognition that the MAPS approach is sustainable, it makes sense to consider MAPS as a legitimate adaptive management candidate for existing and proposed STA systems, as well as for other potentially effective applications. Incorporation of a MAPS program into existing water management plans offers several clear benefits, including:

1. A MAPS unit applied as pretreatment for an STA will result in a reduction of nutrient loading to the STA, while also assuring continuous recovery and

recycling of a significant percentage of the captured nutrients. This MAPS pretreatment will increase the life of the downstream STA through reduced nutrient accretion within the STA. Because the MAPS will ensure lower total phosphorus and nitrogen concentrations and higher dissolved oxygen levels within the STA, the ecology within the STA can be expected to more closely resemble that associated with the historical Everglade's marsh.

2. A MAPS unit applied as post treatment to an STA will serve to further polish the effluent through additional nutrient reduction and high levels of dissolved oxygen. This ensures greater protection of the receiving waters or wetlands.
3. Because MAPS provides continuous sustainable nutrient removal and recovery over a reduced land area when compared to STA's, it is well suited to provide long term restoration of nutrient enriched water bodies, such as Lake Okeechobee. This would be done by delivering a high flow stream from the lake to a contiguous or nearby MAPS unit, then returning the treated, higher quality water to the lake. Such an arrangement would allow the MAPS to serve as a "kidney", continually removing deleterious pollutants, and thereby improving overall water quality within the lake. Also such an approach would contribute to compliance with TMDL requirements, and move the in-lake total phosphorus concentration towards the 40 ppb target set for Lake Okeechobee.
4. While it may appear that products developed through recovery and recycling of nutrients through a MAPS operation are not presently economically competitive with products produced from sequestered resources (e.g. phosphate rock), there are long term benefits associated with such recovery and recycling that extend well beyond short term financial considerations. With remaining phosphate rock stores in Florida's Bone Valley deposits estimated at only forty years, and recognizing Florida as the major phosphate producer in the United States, the U.S. may in the not too distant future find itself dependent upon other parts of the world—such as Morocco and China—for phosphate fertilizer. Recovery and recycling of phosphorus through MAPS type operations at this future time will become more economically and socially attractive.
5. The removal and recovery of phosphorus and nitrogen through MAPS means the rate of accumulation within the environment will be reduced. In fact legacy stores, such as those found in Lake Okeechobee sediments, could be reduced, and these stored nutrients recovered and recycled. Considering the devastating impact of eutrophication upon the Florida environment, including the recent large scale fish kills in the Indian River Lagoon; resolubilization of legacy nutrients from lake sediments; damaging changes in the ecology of Florida's Springs; and the replacement of sawgrass habitat with cattails in the Everglades, nutrient recycling through MAPS appears as a reasonable approach to avoiding such events and for promoting long term economic, environmental and social improvements.

6. MAPS facilities typically remove more nutrients per unit area over the same time period than STA systems—often at rates that can be as high as a factor of 10. This means less land requirement for the same level of treatment. For example, it would likely take less than 15,000 process acres of MAPS to remove the required 500 metric tons of phosphorus annually from Lake Okeechobee, while it is estimated it would take over 100,000 acres of STA to meet the same removal.
7. As the SFWMD establishes new large water storage areas there will be a need to ensure the water in these reservoirs is maintained at a high quality to avoid damaging algal blooms. Incorporating MAPS into the design, along with attendant littoral zone development and low nutrient STA's will ensure these reservoirs remain as high quality surface water resources which can provide meaningful fish and wildlife habitat, as well as recreational opportunities.
8. Because it is easy to clearly demonstrate nutrient reduction within a MAPS by simply monitoring the quantity and quality of harvested and processed material, the technology lends itself to the concept of nutrient trading or sale. Considering the present need for nutrient reduction associated with CERP and TMDL programs, there will at some point likely develop a market for the water quality enhancement associated with capturing and recycling nutrients. This market could be similar to the present market related to mitigation wetlands. This would provide groups such as the **TRIBE**, a means for being compensated for water quality enhancement while still retaining ownership of any products developed from the harvest.
9. Managed Aquatic Plant Systems (MAPS) represent a hybrid between water treatment and agriculture--the aquatic plants being the targeted crop, with their capture resulting in the generation of agricultural-based products. As noted, compost is presently targeted as a final product, and it has been shown by USDA and others as being of value. However, other products have also been investigated and deserve further evaluation, including fiber products, livestock feeds, fuels, insect repellents, protein supplements, pharmaceuticals, additives for the cosmetics industry, and various other value added products. With each of these possibilities comes the potential for improved return from product sales. The MAPS concept then represents a potential new and developing agri-industry, unique in that it can provide valuable agricultural products while also improving water quality and reducing dependence upon sequestered resources, such as phosphate rock and fossil fuels. Such an expansive industry would offer social benefits on many levels, including development of jobs; expanding knowledge of ecology and natural resource management in South Florida; enhancement of environmental quality; protection of drinking water resources; contributing to social sustainability; promotion of organic farming; and reducing dependence upon imported resources.

10. MAPS facilities can be used to support and augment traditional agriculture and aquaculture practices. In such cases, recycled nutrients processed either as a soil amendment such as compost, or a feed ingredient for aquaculture species or livestock, would be returned to the partnering farm. By removing and recycling nutrients from seepage and runoff waters associated with the partnering farm, the MAPS helps ensure compliance with permits and associated regulatory programs, such as TMDL, while protecting downstream surface waters.

HISTORY AND PERFORMANCE SUMMARY OF MANAGED AQUATIC PLANTS SYSTEMS

Cultivation of aquatic plants was practiced well before the emergence of the term MAPS. Populations indigenous to the Americas relied upon a number of aquatic plants for food and fiber, including cattail (*Typha sp*.) and duck potato (*Sagittaria sp*.), and likely cultivated these for such purposes on occasion. Water cress, water chestnut, and papyrus are examples of aquatic plants which have been, and still are, cultivated throughout the world for centuries, as well as rice, which can be cultivated in wetland environments. Recently interest has grown in the cultivation of certain high protein wetland crops such as duckweed (*Lemna minor)* for human consumption. The company Parabel located in Melbourne, Florida has made significant progress in developing viable duckweed cultivation for protein recovery. All of these examples however relate to cultivation for crop value, and not for the intentional enhancement of water quality.

The idea of using aquatic plants to treat nutrient enriched water while also recovering nutrient pollutants as a usable product is generally thought of as a recent concept. However, this is not totally true. The Mayan Culture about 1,500 years ago, as an agricultural practice, harvested and composted aquatic plants grown in canals contiguous to their fields in an effort to replenish soil nutrients on their farms while improving the quality of the water in the canals. It should be noted that this nutrient recycling was an important factor in allowing the Mayans to maintain long term agriculture at one site within a tropical setting, rather than relying upon short-term, slash and burn practices. This application of sustainable agriculture was a major factor in allowing them to establish city states and to expand their populations while developing a complex, dynamic culture.

The cultivation of aquatic plants for the primary purpose of improving water quality has been seriously contemplated in our modern society for only about 50 years. Over this period, as scientific and engineering principles were applied to this emerging technology, it was recognized by most serious researchers that if aquatic plants were to become effective in offering long term nutrient removal, they would have to be sustained through harvesting, and that ultimately in an optimal situation, this would yield high value products.

This realization led to the adoption of the term Managed Aquatic Plant Systems (MAPS), which was first used by the company **HydroMentia, Inc.** of Ocala, Florida in 2003 in classifying their **Algal Turf Scrubber®** (ATS™) and **Water Hyacinth Scrubber** (WHS™) water treatment technologies. The acronym MAPS is now commonly used in the water management community to identify a collection of water treatment technologies that rely upon direct plant uptake of nutrients and transformation of certain polluting factors through cultivation of aquatic plants, with cultivation meaning the purposeful production, frequent harvesting and processing of the aquatic plant crop. Because MAPS, as presently applied, includes both water quality enhancement and crop cultivation, it may be considered a hybrid of both water treatment and agriculture.

MAPS however is a variant of typical agriculture, for the primary intent is not to maximize productivity of the targeted crop as with conventional agriculture, but rather to maximize reduction of pollutants from an impaired water source. In other words, MAPS operations do not involve adjustment of nutrient levels in the feed water to ensure high levels of crop production and quality, but rather involve adjustment of crop selection and operational strategies to ensure high rates of nutrient reduction from the raw feed water, such as a nutrient enriched, impaired surface water. With conventional agriculture the crop is the primary product, while with MAPS, enhanced water quality is the primary product. This approach represents a significant paradigm shift from the general acceptance of agriculture as a net pollutant contributor, to the reality that there are forms of agriculture that can offer substantial net pollutant removal and recovery.

The floating aquatic vascular plant water hyacinth (*Eichhornia crassipes*) received much attention during the early years of MAPS development, largely because of its high rate of unit area net production and the fact that it shaded the underlying water which eliminated suspended algae (phytoplankton) development. Initially, water hyacinth was evaluated as a means of nutrient reduction from domestic wastewater in certain southern regions of the United States, and several large scale systems were developed during the seventies and eighties in Florida, Mississippi, California, and Texas. In addition, considerable work was done regarding the use of water hyacinth as a livestock feed; a substrate for the generation of biogas; compost and soil amendments; and fiber based products.

The appeal of water hyacinths for treating wastewater waned somewhat however with the development of wastewater reuse and deep well injection programs in the U.S.—neither of which required the extensive nutrient reduction offered by water hyacinth based MAPS. However, during the late eighties interest increased in water hyacinths as a means of reducing and recovering nutrients from stormwaters and impaired surface waters, particularly in South Florida where efforts were being targeted towards the restoration of Lake Okeechobee and the Everglades and towards compliance with new TMDL allocations for nutrients.

By the mid-nineties another MAPS technology was gaining interest, this being the **Algal Turf Scrubber®** or ATS™. This technology involved the cultivation of attached algal communities upon a sloped surface over which flow is delivered in a shallow laminar fashion. The ATS™ was developed by researchers with the Smithsonian Institute, with the patent rights eventually assigned to **HydroMentia, Inc.**

In 2003, the **South Florida Water Management District** (SFWMD) in cooperation with the **Florida Department of Environmental Protection** (FDEP) and the **Florida Department of Agriculture and Consumer Services** (FDACS) sponsored a 0.5 million gallon per day (0.5 MGD) MAPS demonstration project just north of Lake Okeechobee (S-154). This facility included a **Water Hyacinth Scrubber** (WHS™) followed by ATS™ units. The facility resulted in 84% reduction of total phosphorus with concentration reductions from an average influent of 479 ppb to an average effluent of 79 ppb. Much of the harvested water hyacinth were fed as green chop to local dairy cows, with the remainder mixed with the harvested algal to produce a compost. During the period of operation, experience was gained in the design and operation of ATS™ systems, and based upon the performance of this demonstration facility, SFWMD decided 1) to build a 4.5 acre, 10 MGD stand-alone ATS™ within the **Taylor Creek** watershed just north of Lake Okeechobee, and 2) to investigate the technology's potential in removing phosphorus from lower concentration waters characteristic of the Everglades region south of Lake Okeechobee by establishing a small 20 gallon per minute (gpm) pilot unit to receive effluent from the **STA-1W**, located east of **Belle Glade** along the edge of the EAA.

Shortly after initiation of the Taylor Creek MAPS Facility, it became evident that toxic influences were inhibiting development of the algal turf and were deleteriously impacting system performance. Bioassays verified the presence of a toxin, which was later substantiated by FDEP. Investigations into the nature and source of this toxin led to indications of a surfactant type compound(s) which could be associated with substances used as carriers or adjuvants intended to enhance effectiveness of herbicides or pesticides, although this was never confirmed, nor the compound specifically identified. It was noted with further testing that pretreatment with vascular plant systems, such as water hyacinths or emergent wetland systems removed the toxicity. However, recommendations to modify the Taylor Creek ATS™ with a pretreatment water hyacinth system were rejected by the SFWMD, and the facility was eventually closed. This experience clearly exposed the vulnerability of the ATS™ to certain toxic influences, and indicated that stand-alone ATS™ applications need to be thoroughly pilot tested on the targeted water before a full scale system is implemented, and as appropriate, the

ATS™ may need to be attended by a pretreatment vascular plant MAPS, such as a WHS™.

At the STA-1W pilot meanwhile, the ATS™ technology was showing promising performance in the reduction of phosphorus in waters of relatively low total phosphorus concentration. When the final effluent was filtered at 10 microns, total phosphorus was reduced from an average influent of 31 ppb to an average effluent of 15 ppb, with a removal rate of 4 gm/m^2-yr (36 lb/acre-yr), or about five times the average rate of total phosphorus removal as documented with the STA's in the Everglades at 0.80 gm/m^2-yr (7 lb/acre-yr), with an average effluent concentration of 27 ppb total phosphorus. In spite of this documented performance, because of concerns related to the toxicity issues noted at the Taylor Creek ATS™, and the management required by MAPS facilities when compared to the shorter term passive approach of the STA, the SFWMD chose not to pursue MAPS application at that time as part of the CERP program. It was apparent that SFWMD preferred dealing with the consumption of land through STA implementation, over confronting the challenges associated with the more involved MAPS operation, even though long term efficiency typically favors sustainable programs such as MAPS.

Indian River County (**Vero Beach**) however, unlike SFWMD, having reviewed various MAPS facilities, including those sponsored by SFWMD, did decide to aggressively pursue MAPS as one method of reducing nutrient discharges into the Indian River Lagoon. Following successful completion of a pilot study, Indian River County designed and constructed a 10 MGD MAPS facility, which included a 4.5 acre ATS™ unit followed by 14 acres of created lakes and wetland habitat. This facility commenced operation in August 2010, and was monitored extensively for the first year through provisions delineated within an EPA/FDEP 319(h) grant. The overall facility provided 49% removal of the total phosphorus, reducing the concentration from an influent of 101 ppb to an effluent of 53 ppb, with the rate of removal across the ATS™ unit averaging 17.46 g/m^2-yr (157 lb/acre-yr). Nearly all of the phosphorus removed through the ATS™ was recovered within the harvested material. This facility (**Egret Marsh Stormwater Park** as visited by the **TRIBE** and **COUNCIL** in April 2016)) remains operational, and is now providing nearly two tons of annual phosphorus reduction. The facility accounts for approximately 7-8 % of the total 26 annual tons of total phosphorus allocated for removal from the region per the TMDL program. This is suggestive that with less than 200 acres of active MAPS facilities, Indian River County could meet its TMDL requirements.

As a result of the success of the Egret Marsh MAPS facility, Indian River County built another 4.5 acre 10 MGD ATS™ facility to the southeast (known as Osprey Marsh), and it is presently performing at or above the level of Egret Marsh. Plans are to build a third MAPS facility in the northern reaches of the region, with the intent to have this facility remove 4,000 pounds of phosphorus annually. The design of this new facility will incorporate adjustments based upon the County's several years' experience with MAPS systems, and is expected to demonstrate higher levels of efficiency and system performance. The new design will incorporate various MAPS elements and systems, and will be referenced as a **Low Energy Aquatic Plant System** or LEAPS™.

During the period of MAPS expansion within Indian River County, the major phosphate mining company in the United States, chose to fund pilot work for a MAPS approach to nutrient reduction within their water management program. Their concern was also associated with regulatory nutrient reduction requirements related to the TMDL program. The pilot included a pretreatment hyacinth system followed by an ATS™ unit. In addition the pilot system was designed to facilitate effluent recycling from the ATS™ to the headworks of the hyacinth system. Recycling accommodates re- carbonation of the feed water to the ATS™, which ensures adequate carbon is available for algae production within the ATS™. The pilot unit operated in this recycle mode resulted in 77% removal of the influent nitrogen and 85% removal of influent phosphorus, with total nitrogen concentrations reduced from 4.87 mg/L to 1.12 mg/L and total phosphorus reduced from 2.07 mg/L (2,100 ppb) to 0.31 mg/L (310 ppb). Areal removal rates were 88 g/m^2-yr for total nitrogen and 41 g/m^2-yr for total phosphorus. The application of full scale MAPS facilities is presently under consideration.

As the result of the efforts listed in this section, as well as other applications not listed, MAPS has emerged as a viable technology for the removal and subsequent recovery of nutrients and for the overall enhancement of water quality when properly applied to many nutrient enriched surface waters, particularly those associated with peninsular Florida. During the course of these investigations, reliable models based upon first-order kinetics were developed by **HydroMentia Inc.** These models-- the ATS™ Design Model (ATSDEM) and the Hyacinth Design Model (HYADEM)--have proven effective in the projection of net community productivity, direct nutrient uptake rates, harvest quantities, and product quantities. These models are helpful tools for the water resource planner and the design engineer, and facilitate initial sizing and cost estimating for specific situations.

While MAPS have certainly developed to the point of being available for dependable full scale, long term application, it, like any technology, will continue to be refined both in terms of water treatment efficacy, and in crop processing and utilization. At this point of MAPS development harvesting and processing methods revolve around composting. The present value of compost is such that system operations must be funded largely through the value of the enhanced water quality and the compliance with applicable regulations. However, it is certainly plausible that with further research into various crop products that the value of these products would increase to a level that MAPS operations could be fully supported by product sales. As the number of MAPS projects increase, greater interest will develop in making the technology even more cost efficient through more effective harvesting and monitoring; a greater number of more valuable products; advanced processing methods; and improved, lower cost designs.

DESIGN CONSIDERATIONS ASSOCIATED WITH MAPS

Regardless of the MAPS technology under consideration, they all require sufficient levels and ratios of available nutrients and amenable environmental conditions to ensure adequate net community production and system performance. If there is no production, or very low production, then little if any nutrient reduction can be expected. As with any crop system, growth rates are seasonal, with the cooler months expected to have lower levels of production. Any MAPS design must accommodate these lower production periods.

Attached Algal Systems

MAPS which rely upon attached algal communities, such as the ATS™, can function in freshwater (salinity =0-2.0 ppt), estuarine (salinity = 2-32 ppt), or marine conditions (salinity =32-37 ppt). In freshwater systems, particularly those which might be classified as “soft” waters with low alkalinity (< 30 mg/L as $CaCO_3$), the availability of carbon can become problematic as the pH increases (>8.0). In such waters it may be necessary to use a recycle system in conjunction with a WHS™ or some other vascular plant system that relies upon atmospheric carbon dioxide as a carbon source. These systems tend to decrease the pH through the dominance of respiration within the water column, thereby increasing the solubility of carbon dioxide which then becomes available for the attached algal system.

Attached algal systems as noted previously may be vulnerable to organic toxins which might be present in the feed water. For example, algal communities have shown to be particularly susceptible to glyphosate—a commonly applied herbicide. This means that if an aquatic plant spraying program is associated with the feed water, measures should be taken to avoid exposing the system to water recently sprayed with glyphosate. To properly assess the toxicity of a feed water, long term pilot studies should always be conducted for each specific water source before an attached algal system is selected as a full scale option. Typically, if organic toxins are of concern, a pretreatment WHS™ or a similar vascular plant system should be considered and should be shown to nullify the impacts of potential toxins through pilot studies.

In addition to toxins, the performance of attached algal systems can be impacted by excess total suspended solids (TSS) and/or excessive Total Organic Carbon (TOC) or Biochemical Oxygen Demand (BOD) in the feed water.

Suspended solids tend to coat the developing algal turf, and can seriously reduce net productivity while reducing the value of the harvest. When TSS exceeds 25 mg/L over an extended period, consideration should be given to including a pre-settling unit as part of system design. The TSS may be as suspended algae (phytoplankton), inorganic silts and clay, organic floc, or a combination of these. Colloidal solids typically are not problematic unless they interfere with light penetration within a 2 to 4-inches water depth—which is generally not the case with Florida surface waters.

Organic carbon within the water at levels above 20 mg/L as BOD_5 will stimulate heterotrophic bacteria, which will develop upon the floway, and can retard the development of an algal turf. When such bacteria are dominant, the floway becomes a fixed film system, effective in organic carbon reduction, but typically not as valuable in nutrient reduction.

The effluent from attached algal systems tend to be higher in pH than the influent water, although this is less noticeable in high alkalinity freshwaters as well as estuarine and marine waters. In low alkalinity freshwaters pH levels in the effluent can exceed 9.5 during the daytime hours, dropping to near influent levels at night.

Water temperature in attached algal systems effluents tend to track existing air temperature, so an increase in temperature can be expected when the influent water temperature is lower than the air temperature, and a decrease can be expected when the influent water temperature is higher than the air temperature. Therefore, while there is typically very little diurnal fluctuation in influent water temperature, there can be a diurnal fluctuation of as much as 8-10° C in effluent water temperature.

During daylight hours, when photosynthesis is active, the oxygen generated from the algal productivity will saturate the overlying water, so the final effluent is typically super saturated in dissolved oxygen, often exceeding 10 mg/L. During the nighttime the dissolved oxygen gain is less dramatic, but still is higher than the influent because of the high reaeration coefficient associated with the shallow flow and high velocities. Consequently, nighttime dissolved oxygen levels consistently approach saturation and remain above the Class III water standard of 5 mg/L. This helps prevent the early morning oxygen sag which can occur in surface waters, and which is so often associated with large scale fish kills. It is suggested that had sufficiently sized attached algal units been incorporated into the water management plan for the North and Central Indian River Lagoon and Banana River Lagoon, the recent massive fish kill would have been avoided. The high dissolved oxygen levels for example associated with ATS™ effluents has shown to have beneficial impact upon fisheries, as has been observed in the lakes and wetlands receiving ATS™ effluent at Indian River County's Egret Marsh facility.

Any attached algal system must remain continually wet, and should the system be allowed to dry out, it takes at least a week to bring it back to reasonable performance. Consequently, any design must include provisions to ensure the unit stays wet, and preferably receives constant flow from an influent source or sources of similar quality. Ideally the feed water(s) would be associated with a large reservoir, lake, canal, stream or river from which water is available year round. If such is not the case, then an internal water storage unit should be included as part of the system design. In cases in which an attached algae system are preceded by a floating or emergent vascular plant MAPS, then that system can serve as the storage reservoir.

Delivery of flows to an attached algal system in Florida is typically through a dedicated pumping station. If the lift and friction losses are comparatively low, the pump needs may be accommodated by a high volume, low head pump such as an axial flow pump or an Archimedes pump. For higher heads centrifugal pumps may be required. The pumping system needs to be designed for continuous operation, meaning at least two alternating pumps would be necessary. In addition, back-up generators may be required. When a pump station is needed for water delivery, the energy costs associated with pumping often represent a major operating cost. Therefore, when possible, gravity flow is desirable. In Florida such situations would be rare, but could be available on the downside of a flow control structure, or behind a dike associated with an elevated reservoir or a major roadway.

Harvesting of attached algal systems is presently done through the use of small tractors equipped with a scraper blade or plow. The tractor moves the dislodged algae to an effluent flume, and it is eventually lifted from the water by a rake or other means as a fibrous mass, which can be readily drained and windrow composted. The carrier water which passes through the rake, is diverted to a dewatering pond so the associated solids can be recovered. These solids are also composted. The frequency of harvest depends upon the rate of production. At the Egret Marsh facility, half of the 4.5 acres is harvested weekly during the warmer months, somewhat less frequently during the cooler months. Harvesting takes two people about 2-4 hours. At Egret Marsh the harvest is composted by an outside contractor who markets the final product (Lagoon Saver™).

While attached algal systems are now commercially viable and available, there will undoubtedly arise opportunities to improve the cost effectiveness of attached algal systems with expansion in the number and size of facilities and as design and operational experience increases. Anticipated enhancements include automated and quasi-automated harvesting systems; development of value added products; more efficient pumping systems, including use of renewable energy sources; reduced earthwork requirements through reduced floway slope; and improvements in materials associated with floway surfaces.

Floating Vascular Plant Systems

Unlike algae, vascular plants are able to conduct water and minerals throughout the plant body through a series of specialized internal conduits—i.e. a vascular system. This allows floating aquatic plants such as the water hyacinth to capture and convey nutrients from the underlying water through its root complex, which is totally immersed in the water, and then deliver these to the remaining elements of the plant which are above water. This is to say that such plants are naturally hydroponic, and enjoy the obvious advantages of hydroponics—that being enhanced access to water and nutrients. This advantage facilitates high rates of production, and accordingly high rates of nutrient uptake. For example, at the previously mentioned S-154 demonstration project, north of Lake Okeechobee, the water hyacinth crop production was about 6 dry g/m^2-yr (19,520 dry-lb/acre-yr), which is about 3 times that expected for crops such as alfalfa.

There are of course other floating aquatic plants besides water hyacinths, and these are potential candidates for floating vascular plant systems. These include water lettuce (*Pistia stratiotes),* Salvinia (*Salvinia sp.),* Azolla (*Azolla sp.)*, and duckweeds (*Lemna sp.).* As noted, the majority of research and experience with floating aquatic plant systems for water treatment has been with water hyacinths.

Floating aquatic plant systems are typically engineered around ponds as the basic cultivation units. Pond design should allow access for periodic harvesting, and ensure crop movement is not severely impacted by wind and other factors, while maintaining ample hydraulic retention time and avoiding hydraulic short circuiting. With water hyacinths, it is typical to try to maintain a mean plant age of about 28 days—meaning that the average time for a plant to be sustained within the pond before being harvested is 28 days. Pond configuration is generally towards a high length to width ratio, with floating barriers established along the length every 100-200 feet, which helps avoid excessive packing of the crop during high wind events. Standing crop density is typically kept at 3-5 wet pounds per square foot, with pond coverage on calm days to be about 80% of the open pond area. This allows the crop the freedom to move, thereby avoiding stagnant or dead zones. When influent water is high in suspended solids (>20 mg/L) the ponds need to be deep enough to facilitate about six month’s storage of settled solids without imposing on the quality of the overlying water column.

While a portion of the hyacinth crop is harvested rather frequently, typically about once a week during the warmer months, there is still some sloughing, which along with any settled solids needs to be physically removed about every six months. This means pond design should facilitate drawdown and isolation, as well as provide sufficient redundancy to sustain performance during drawdown periods. To avoid excessive seepage ponds can be lined with clay or synthetic liners, or alternatively may be built with a rim canal with a pump station to allow return of seepage water.

Certain pests such as the hyacinth weevil and the hyacinth moth can be problematic. These insects were imported to help control wild growth of water hyacinth. They can be controlled through frequent harvesting to break the life cycle, or in the case of the weevil, certain nematodes available from the market have proven to be effective. Neem oil and BTI can be helpful in control of moths and red spider mites. Usually, when the mean plant age is maintained at or below 28 days, such pests do not threaten crop viability. The fungus *Cercospera rodamnii* can also attack the hyacinths as well, but typically are not problematic within a well-managed crop.

Floating aquatic plants are notably a freshwater, warm weather group. Water hyacinths can tolerate salinities at about 1.5 ppt, while duckweeds are a little more tolerant. Hyacinths can survive periodic frosts such as seen in Florida, but may not survive periods of continuous 24-hour period of below freezing temperatures.

Other types of MAPS

While extensive research and development has yet to be conducted on emergent and submergent plant based MAPS, there is a process known as Beemats™ which is commercially available which involves seeding of select emergent plants within a floating mat, thereby allowing the plants to grow hydroponically within the targeted water source. These mats can be removed periodically for harvesting.

It would also be feasible to design STA type wetlands such that they could be harvested and composted within the unit—and hence qualify as a MAPS operation. This would require a more elaborate multi-compartmental layout and sufficient redundancy to permit continued performance during the harvesting/processing stage.

The cultivation of suspended algae known as phytoplankton is largely done as aquaculture, i.e. the purpose is solely to produce usable algae, such as *Spirulina* without any operational effort to treat water. However, phytoplankton cultivation has been, and continues to be, investigated as a means of providing sustainable water treatment as a MAPS. Efficient, continuous harvesting of the suspended algae without excessive lysing of the cells however can be expensive and somewhat unreliable, and typically makes full scale implementation impractical.

ECONOMIC CONSIDERATIONS ASSOCIATED WITH MAPS

In August 1999, the South Florida Water Management District (SFWMD) established guidelines for comparing alternative treatment methods for application within the

Everglades relating to the 10 ppb total phosphorus standard. These guidelines, known as Supplemental Treatment Standards of Comparison (STSOC) included costing methods, standard unit costs for major construction and operational items, as well as methodologies for conducting a 50-year Present Worth Cost Analysis. In 2004, responding to proposals presented by HydroMentia regarding the application of the MAPS technology known as the Algal Turf Scrubber® or ATS™, the SFWMD requested development of a comparative STSOC economic analysis. The final analysis showed the application of ATS™ reduced the 50-year present worth costs to below $100/lb of phosphorus removed, and this included a $50/ton harvest disposal fee. Considering that the harvested algae would be a revenue producer through product sales, rather than a revenue consumer, these costs may be somewhat conservative. The present worth costs were typically below STA costs.

Of course the economic reality of MAPS application depends greatly upon the treatment required, the regional costs of construction and operations, and the net value of products. The STSOC analysis of 2004 however is helpful in demonstrating the relative range of expected costs when compared to systems such as STA's.

CLOSING COMMENTS

Managed Aquatic Plant System or MAPS is a proven, commercially available technology for nutrient removal and recovery, and overall water quality enhancement. When incorporated as the primary nutrient removal and recovery component of any comprehensive ecosystem restoration program designed for Peninsular Florida, MAPS can provide cost effective and sustainable service related to both water quality enhancement and as a new and expandable agri-industry. This includes application as an adaptive management measure for existing systems, such as passive wetland systems (STA), and for long term removal of sediment held nutrients, i.e. legacy nutrients, within impaired surface waters, e.g. Lake Okeechobee. Several MAPS designs are also applicable to estuarine and even marine systems, and could be used to remove nitrogen loads originating from wastewater systems such as septic tanks and from intensive farming operations, while providing high levels of dissolved oxygen, which is critical to avoiding extensive fish kills, such as those recently experienced in the Banana and Indian River Lagoons.

MAPS has been shown to be cost effective when compared to other nutrient removal technologies, and has promise to become even more economical as higher value products are generated from the harvested aquatic plants. As a form of agriculture, MAPS can also be used to complement existing farming operations, while reducing the demand for inorganic fertilizers through nutrient recovery via aquatic plant harvesting. MAPS then may legitimately be assessed as an agricultural solution to many of the agricultural problems related to excessive nutrient loading.