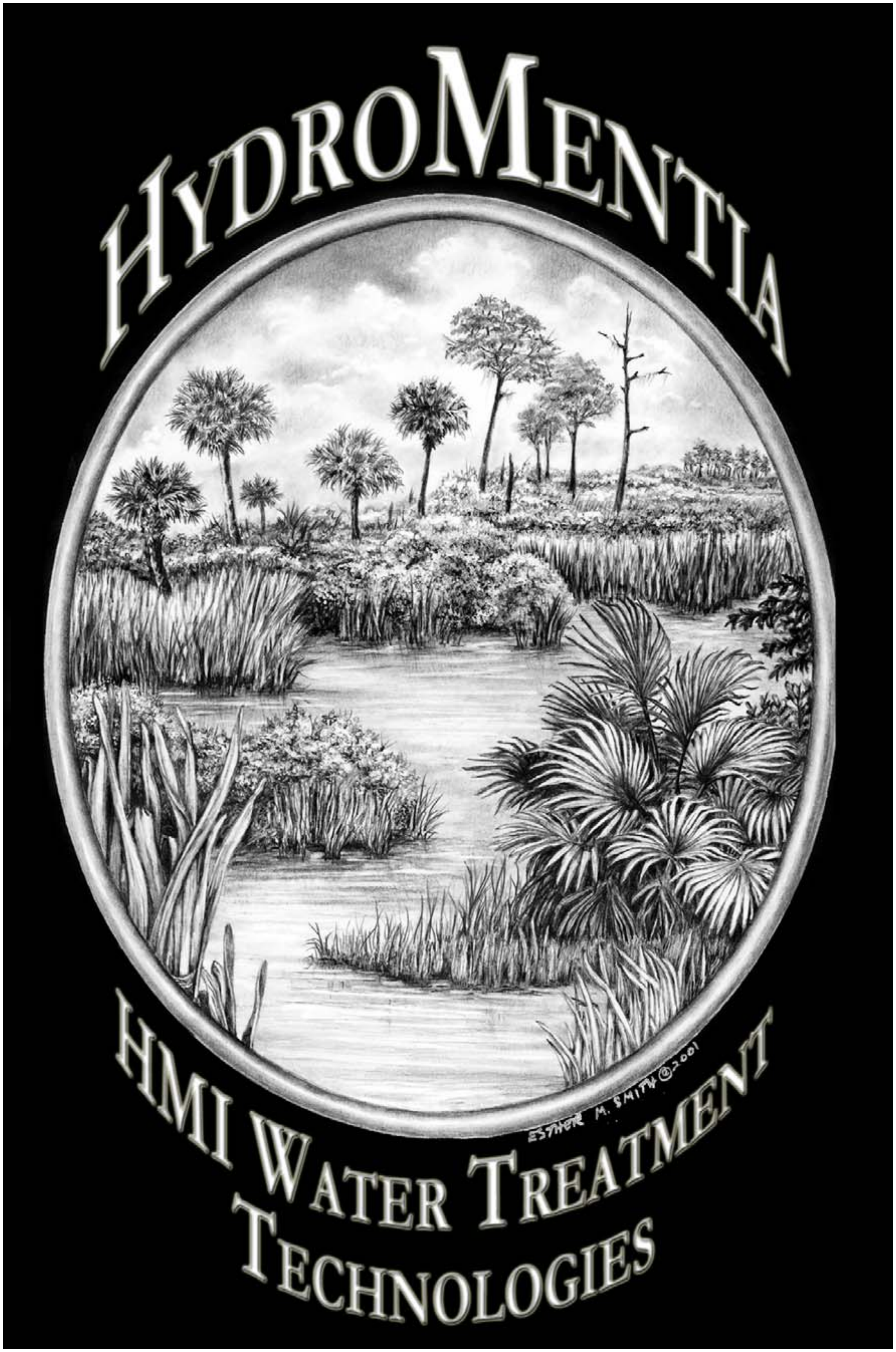
HydroMentia
HMI Water Treatment
Technologies
Esther M. Smith © 2001

Algal Turf Scrubber Technology

This technology is presented here as an example of technology currently available to improve water quality using natural phyto-remediation. Plants can be used to naturally cleanse degraded water. We do not endorse the use of Water Hyacinths but they have been demonstrated to work remarkably well at cleansing surface waters. Water Hyacinths are invasive exotics and do not perform as well in North Florida as they do in South Florida. Our harsher winters cause them to be inactive for three months of the year. We need to explore these techniques with native plants more suited to our climate. The water hyacinth is a preliminary treatment step. The algal turf scrubbers are the water polisher. They can reduce the level of nutrients to pristine levels. The algae used are typically harvested from local water bodies and are native. This water treatment process produces good water quality and a commercially viable product, mulch or animal feed (after the plants have removed the nutrients from the water). Dr McGlynn visited these plants in South Florida where they were used in the Everglades Cleanup and was quite impressed.

1.0 BACKGROUND

1.1 WATER POLLUTION CONTROL

Prior to about 1972 it was a generally accepted strategy in Florida to manage stormwater within developed and developing watersheds by accommodating the need for flood control through the accelerated collection and conveyance of runoff into the closest downstream surface waterbody—typically a lake, river or estuary. Alternatively, it was not uncommon for groundwater to be the receiving resource through sinks or drainage wells. While agriculture was the early beneficiary of such wholesale drainage efforts, by the second quarter of the 20th century urban expansion demanded further refinement of stormwater infrastructure, with the demand that runoff be removed even more expeditiously to the receiving water. In addition, it was not unusual during these times to manipulate the morphometry of the receiving surface waterbody through perimeter berming, control structures, dredging and filling, and drainage wells in an expanded effort to manage flooding; lower shallow groundwaters; retain water for potable and agricultural uses; and to control mosquito breeding.

This strategy was challenged with the implementation of the Federal Clean Water Act (CWA)—PL92-500—in 1972, which may be seen as the first unanimous institutional recognition that the disruption of pre-development water quality was attributable not only to discharged wastewaters (point sources), but also to the extent and nature of pollutant loading, and scheduling and timing of flows, attendant with stormwater flows associated with a disrupted watershed (non-point sources). During the early years of this implementation, while only point source management received any sizable funding for construction projects, there were a number of parallel efforts to quantify the extent of stormwater impacts. The collection of programs targeted at non-point source pollution were called “208 plans”, from Section 208 of the CWA. Typically these plans resulted in the delineation of watersheds and the extent of land uses and land-use loading rates, and a general assessment of pollutant and hydraulic loads associated with stormwaters. From the “208” efforts; the EPA National Pollution Discharge Elimination System (NPDES) program; Florida’s Surface Water Improvement and Management (SWIM) plans; and regional and local programs, a series of best management practices (BMP), and passive structural technologies have been developed and incorporated into regional stormwater programs, regulations and development codes. Stormwater utilities have also been developed in many counties, which provide a funding mechanism for more aggressive stormwater treatment programs.

While the increased awareness of the deleterious impacts of non-point source pollution upon regional water resources has resulted in a general reduction in pollutant loading and adjustments of flow scheduling to be more emulative of pre-development patterns, in many cases these efforts have not been sufficient to allow these resources to recover to acceptable water quality conditions. These “impaired” water resources accordingly became an issue as the courts attempted to determine the intent of the CWA and the nature and extent of the remaining responsibilities related to reclamation and sustained management of these resources. From these discussions has emerged a mandate to not only identify these “impaired” resources and the critical pollutants responsible for these impairments, but also to establish load allowances, known as Total Maximum Daily Load or TMDL, for these pollutants.

It is the responsibility of the Florida Department of Environmental Protection (FDEP) to establish TMDL’s, and to inform the impacted public of the TMDL program. However, outside of a few exceptions, such as with the joint Federal/State funded Comprehensive Everglades Restoration Program (CERP), the fiscal responsibility for satisfying the TMDL requirements remains largely with local governments. The TMDL program then may be seen as an un-funded mandate.

It is not only the TMDL program however that is soliciting action from local entities to seriously confront the challenges of comprehensive treatment and management of stormwaters. Loss of recreational opportunities, imposition upon property values, and major ecological impacts associated with excessive pollutant and hydraulic loading attendant with stormwater runoff are all serious quality of life factors that erode the general economic and social welfare of a community. While in the recent past such issues may have not been viewed by many as serious impediments to economic development, it is now recognized that poor surface water quality can result in loss of aesthetic and recreational appeal; continuous fish kills; overgrowth by exotic and nuisance aquatic plant species; red tide blooms and sea grass loss in coastal areas; increased mosquito populations; human health issues; toxic blue-green algae blooms; serious degradation of springs and groundwater; and loss of fisheries and wading bird populations, and that each of these can directly and profoundly impact the socio-economic health of a region.

Recognizing the need for serious, effective treatment and management of stormwaters however is only one requirement for resolving the present problem. The next phase—implementation-- is presently hindered by a paucity of administrative and technical tools to develop and initiate successful programs, and consequently the social demands to protect the resources typically outpace the ability of the state-of-the-art to meet these demands. This is particularly true in urbanized areas that are under heavy development pressure. Ironically, these regions are typically those with an abundance of critical water resources. For example the lake region of Florida's central ridge is under extraordinary development pressure (Orange, Seminole, Polk, Lake and Osceola counties), as are the counties contiguous to the coastal estuaries on both the east and west coast of the peninsula as well as the gulf coast of the panhandle, and northern inland regions, such as Alachua, Marion and Leon counties associated with large lake systems, surrounded by major springs and spring runs.

From a technical perspective, the primary challenges in treating and managing stormwater are 1) management of flows and allocating those flows to the receiving waters in a manner emulative of pre-development conditions, and 2) treating the collected and retained stormwaters prior to release to the receiving waters, with treatment, as a minimum, usually involving the reduction of floatable solids, oils, suspended solids, biodegradable organics, and nutrients. In addition, if full restoration of the receiving water is desired, the program should include a mechanism for restoring, to the extent practical, the original morphometry of the resource, as well as removal of accumulated solids and nutrients. Such efforts often need to include restoration of littoral zones; reclaiming buffer areas; establishing native submerged aquatic vegetation; removal or stabilization of organic sediments; elimination or reduction of septic tanks; and removal of exotic and nuisance species.

Stormwater flow and sediment management can be effectively accomplished through the use of detention areas and reservoirs, assisted with proper infrastructure sizing and upstream BMP's such as baffles, screens, grassed swales, road paving, etc. New developments are typically required to provide these levels of treatment, with older systems usually in need of upgrading. For large watersheds, major downstream impoundments may be needed, such as the large reservoir systems planned for the Lake Okeechobee Watershed (LOW) and the Everglades Protection Area, both part of CERP, or alternatively, Aquifer Storage and Recovery (ASR). In many urban and sub-urban areas, land area may not be available to provide the required storage, and therefore it may not be practical or possible to prevent heavy loads from being discharged directly to the receiving water resource. In such cases, mechanical methods can be used to reduce sediment loads (e.g. tangential separators), chemical addition can help to immobilize and settle solids and labile phosphorus, and continuous "kidney" type facilities can serve to remove nutrients prior to or even after they have been discharged into the receiving water resource.

1.2 MAPS WATER TREATMENT TECHNOLOGIES

Technologies for nutrient removal from stormwaters have been slow in development, and those which have been developed, such as large regional stormwater wetland treatment areas (STA) and marsh floways require extensive land areas, and are not often practical in urban and sub-urban watersheds, or regions in which land costs are escalating rapidly. In addition, these "passive" type wetland approaches rely not upon actual removal of nutrients, but rather upon finite storage within the treatment units themselves. Therefore long term management of these stored nutrients is an issue of concern—the cost of which can be quite extensive.[1] Chemical treatment units have been noted to be

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[1] The City of Orlando just recently had to remove over 500,000 cubic yard of organic sediment after 15 years of operation of

effective for reduction of phosphorus, and capable of removals to concentrations at 10 ppb total phosphorus.[2] However, chemical costs and sludge disposal can be problematic. Nonetheless, engineered chemical treatment units do result in actual removals of phosphorus, rather than in-process storage. Managed Aquatic Plant System (MAPS) [3] have been developed, and are now commercially available, which rely upon direct nutrient uptake by cultivated aquatic plants and the subsequent frequent removal and recovery through harvesting and processing of the targeted crop. This approach offers reduced land area requirements when compared to “passive” wetland treatment, while providing quantifiable removal, recovery and reuse of captured nutrients. HydroMentia, Inc. has developed two MAPS technologies—the water hyacinth scrubber or WHS™ and the Algal Turf Scrubber® or ATS™.

The WHS™ involves the cultivation of the floating aquatic plant, water hyacinths, within an engineered treatment cells, including specialized harvesting and processing equipment. Water hyacinths have been used for successfully treating nutrient laden waters for over three decades. The WHS™ technology offers the advantage of establishing the management of these plants for purposes of water pollution control as sustainable and cost effective. Harvested hyacinths can be processed into compost, livestock feed and other marketable products, which can either be sold outside the watershed, or recycled within the watershed, thereby reducing the net import of nutrients. The WHS™ provides high rates of nutrient removal with the additional advantage of providing relatively long hydraulic retention times, which permits both settling and flow attenuation. The WHS™ relies upon atmospheric CO_2 as a carbon source, and hence does not depend upon bicarbonate and carbonate levels in the water, thereby avoiding increased daytime pH levels in the effluent. Because of the shading provided by the hyacinth crop, phytoplankton blooms are typically repressed, and effluent suspended solids concentrations are usually quite low. Effluents from WHS™ units however are normally low in dissolved oxygen, and may require aeration before being released into the receiving waters. WHS™ facilities require permitting through FDEP Aquatic Plant Management, as the water hyacinth is an exotic plant of concern. Provision must be included in the design and operation of WHS™ to ensure there is no release of water hyacinth tissue that could propagate in native waters.

WHS™ units quite often serve as an appropriate pre-treatment unit prior to a final treatment by an Algal Turf Scrubber® or ATS™. The WHS™ technology does not provided the high areal nutrient removal rates associated with ATS™ when nutrient concentrations are comparatively low. As a general rule, WHS™ is applicable when influent nutrient concentrations are greater than 300 ppb total phosphorus and 2.00 mg/l total nitrogen. WHS™ is ideally suited for treatment of runoff associated with heavy agricultural activity, or conditions influenced by point source discharges. Quite often suburban watersheds are characterized by somewhat lower concentrations, and accordingly WHS™ application may be less practical.

The Algal Turf Scrubber® or ATS™ relies upon the sustained cultivation of a community of attached algae within an engineered system. This cultivation requires that the rate of flow and nutrient allocation be such that high levels of productivity are maintained. Nutrient removal accordingly results primarily from the frequent removal of excess productivity. As with the WHS™, harvested material can be processed into viable products, such as compost or livestock feed. The ATS™ offers the advantage of very high areal removal rates for both nitrogen and phosphorus, and hence reduced land area requirements.[4] In addition, the ATS™ effluent is highly oxygenated, often exceeding

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the Orlando Easterly Wetland.

[2] The South Florida Water Management District (SFWMD) conducted a pilot project and a Supplemental Technology Standard of Comparison (STSOC) on chemical (alum) treatment in the Everglades, and found the technology to be cost effective when compared to STA technology.

[3] MAPS is an acronym first used by HydroMentia to define the family of processes involving the actual cultivation of aquatic plants within an engineered unit for the purposes of providing general water quality improvements and removing and recovering nutrients from polluted waters.

[4] For example, STA systems may achieve phosphorus removal rates of 1-4 g-P/m^2-yr or less than 0.10 lb-P/acre-day; WHS™ units at high nutrient concentrations may achieve as high as 25 g-P/m^2-yr removal or about 0.62 lb-P/acre-day; ATS™ systems at comparatively low nutrient concentrations have been documented as achieving well over 50 g-P/m^2-yr or 1.24 lb-P/acre-day. The implication is that an ATS™ unit may provide treatment in 1 acre equivalent to 50 acres of STA or treatment wetlands.

saturation during the daytime, and well above 5 mg/l dissolved oxygen (DO) during the nighttime. ATS™ units provide no substantial hydraulic detention, and little storage for heavy sediment loads. As the producing algae relies heavily upon dissolved bicarbonate, carbon dioxide and carbonate as a carbon source, pH levels within the effluent can increase during the daytime as alkalinity shifts towards hydroxyl alkalinity. ATS™, like WHS™, can be effective at removing metals and select organic compounds. Typically ATS™ applications are associated with comparatively low influent nutrient concentrations, following reduction of suspended solids and biodegradable organics (e.g. BOD). The ATS™ technology was specifically developed for lower nutrient conditions, and is well suited for many stormwater management applications. Provided within the next section is a more detailed review of ATS™.

2.0 ATS™ TECHNICAL REVIEW

Periphytic and epiphytic (attached) algal communities[5] are seen throughout nature, being particularly prevalent in highly energetic situations such as tidal areas, coral reefs, and freshwater rivers and streams. These algae serve not only as part of the primary producing community, dominated typically by photosynthetic organisms, but they also sequester and allocate nutrients in a manner that protects the function and diversity of the larger ecosystem. For example, it has been documented that within coral reefs[6], whose sustenance relies upon very low levels of nutrients, periphytic algae can achieve relatively high levels of production at very low nutrient levels, thereby gaining a selective advantage over suspended algae (phytoplankton). Odum[7] in his classic study on Silver Springs found epiphytic algae had a similar role in stabilizing the nutrient dynamics within the spring run. Both of these examples involve high levels of water movement, and it has been noted that such movement assists in nutrient accessibility in low nutrient environments.[8,9] However, within the Everglades, a much less energized environment, periphyton has also been identified as important in retaining oligotrophic conditions.[10]

Considering this evolved function of nutrient management it is logical that an engineered emulation of these attached algae communities would serve as a means of managing nutrients within nutrient laden stormwaters, just as the emulation of heterotrophic communities through activated sludge technology serves to manage biodegradable organics and reduced nitrogen within wastewaters. The first engineered attached algae systems involved the use of a sloped bed over which recycled seawater was delivered in surges at a rate that ensured shallow laminar flows at comparatively high velocities.[11] These systems, labeled Algal Turf Scrubber® or ATS™ [12] were ancillary to aquaria used in the cultivation of reef corals. The surging was used to simulate the effects of oscillatory waves, which stimulated the productivity of the attached algae community. Larger scale systems followed in California and Florida in an effort to apply the system as a large-scale pollution control technology[13,14,15]. In 2001, the possible application of ATS™ as a means of providing cost effective phosphorus management within the LOW resulted in the issuance of a Grant [16] to HydroMentia for a 0.50-1.0 MGD Prototype Facility within the S-154 Basin - one of the more problematic watersheds in terms of phosphorus loading. This project was a jointly funded public-private endeavor by the South Florida Water Management District (SFWMD), the Florida Department of Environmental Protection (FDEP), the Florida Department of Agriculture and Consumer Services (FDACS) with private contributions from HydroMentia, Inc. During the first year the MAPS system was operated as a two-

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[5] Periphytic refers to algae attached to inanimate substrates, such as rocks and soil particles. Epiphytic refers to algae attached to other organisms, such as other algae, vascular plants, and animals (e.g. turtle shells).

[6] Work conducted by Dr. Walter Adey and others associated with the Smithsonian Institutes in establishing methods for cultivating corals reef communities.

[7] Odum, H.T. (1955) "Trophic Structure and Productivity of Silver Springs, Florida" *Ecol. Monographs,* **27,** 55-112

[8] Carpenter, R.C., J.H. Hackney and W.H. Adey (1991) "Measurement of primary producer and nitrogenase activity of coral reef algae in a chamber incorporating oscillatory flow" *Limnol. Oceanogr.* **36**(1): 40-49

[9] Brezonik, P.L. (1994) Chemical Kinetics and Process Dynamics in Aquatic Systems,505-525, Lewis Publishers, Boca Raton, Fl, USA ISBN 0-87371-431-8

[10] Thomas, S, E.E. Gaiser, M. Gantar, A. Pinowska, L.J. Scinto and R.D. Jones (2002) "Growth of calcareous epilithic mats in the margin of natural and polluted hydrosystems: phosphorus removal implications in the C-111 basin Florida Everglades, USA" *Lake and Reservoir Management* **18(4):**324-330

[11] Adey, W.H. and J. Hackney (1989) "Harvest production of coral reef algal turfs." In *The Biology, Ecology and Mariculture of Mithrax spinosissmus Utilizing Cultured Algal Turfs.* W.H. Adey (Ed.) Mariculture Institute, Washington, DC

[12] Adey,W.H. and T. Goertmiller (1987) "Coral reef algal turfs:master producers in nutrient poor seas" *Phycologia* **26**: 374-386.

[13] Craggs, R.J., W.H. Adey, K.R. Jensen, M. St. John, F. B. Green, and W. J. Oswald (1994) Evaluation of the ATS™/UV System for Tertiary Wastewater Treatment at Patterson, California. EEHSL Report No. 94-1. University of California, Berkeley, CA

[14] Adey, W.H., C. Luckett and K. Jensen (1993) "Phosphorus removal from natural waters using controlled algal production." *Restor. Ecol.* **1**: 29-39

[15] HydroMentia, Inc. (2004) S-154 Pilot ATS™-WHS™ Aquatic Plant Treatment System Q3 Report. Submitted to South Florida Water Management District

[16] Stewart, E.A. (2000) *Estimates of Phosphorus and Nitrogen treatment Efficiency Aquatic Plant Based Wastewater Treatment System Phase 1A HydroMentia's Recirculating Aquaculture System, Okeechobee, Fl.* Prepared for HydroMentia, Inc. Ocala, Fl, USA

process unit, with the WHS™ providing initial treatment and the ATS™ providing polishing. In an extended investigation, the ATS™ was used as the sole treatment unit, and hydraulic and pollutant loadings were increased to optimize areal removal rates.

Typically, an ATS™ engineered for handling sizable hydraulic loads are composed of the following:

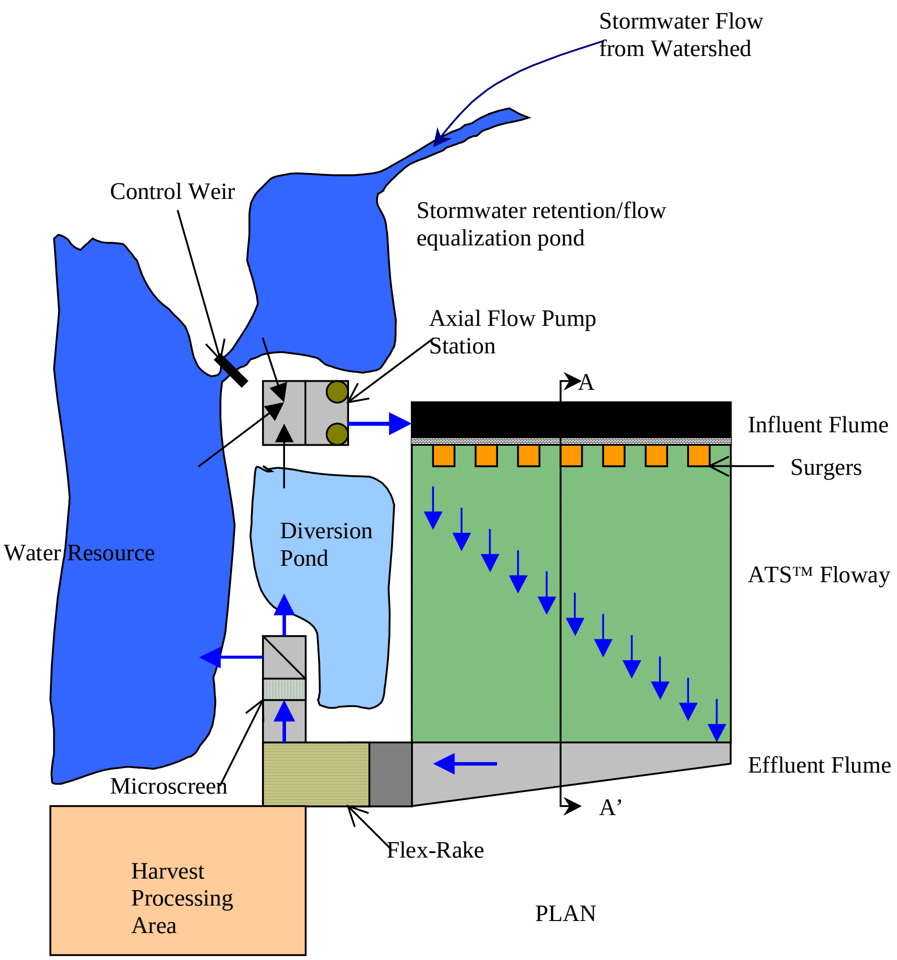
1. Influent flow delivery system, which may be a low head, high flow pumping system (e.g. axial flow pumps), or a gravity conveyance system in association with a natural or structural drop in water level, (e.g. control structure, locks)
2. An influent flume designed to distribute water equitably along the width of the ATS™ floway, and from which intermittent release control devices are placed to deliver flow to receiving surger boxes.
3. Flow delivery surgers, designed to pulse flows in a manner emulative of oscillatory waves. These devices are automatic siphon mechanisms placed on a surger box. The intermittent surging of water helps disrupt the boundary layer, which develops around the algal cell wall, which can impair the rate of diffusion of nutrients, particularly at low concentrations.
4. A sloped ATS™ floway that includes a compacted soil sub-base upon which is laid an HDPE geomembrane, and over which is installed a geotextile mesh, which serves as an attachment matrix for the algae. Floway length is typically no less than 250 feet, with the actual length being determined by treatment requirements and influent characteristics.
5. An effluent and harvest flume that runs the full width of the ATS™ floway. Typically this flume is triangular in cross section, with a variable cross sectional area, increasing as flows accumulate. The slope is designed to ensure at least 1.5 fps velocity throughout the flume, which ensures conveyance of the harvested material. The flume serves both as a means to move effluent, and, during harvest, to transport harvested algae to a pick-up rake.
6. An automatic Flex-Rake, typically as manufactured by Duperon Corporation of Saginaw Michigan. The Flex-Rake not only facilitates capture and removal of harvested algae filaments, but also the continuous removal of sloughed algae and any incidental rogue solids.
7. Harvesting vehicles and attachments for dislodging and moving excess production into the effluent flume

A general plan and section schematic of a typical ATS™ system is noted in Figure A. As noted, optional ancillary components are also shown. These include a microscreen unit to remove residual fine solids (<10 ppb) and a diversion mechanism and diversion pond to avoid discharge of flows which may be high in algae solids, such as during harvesting or during heavy rainfall. Both of these options would be included if very high levels of treatment and low nutrient concentrations are required, such as in the Everglades where there is a 10 ppb total phosphorus limit.

Also noted in Figure A is the option to pull influent upstream of, or directly from the receiving water. This ensures the system functions on a continuous basis, even during the dry season when stormwater runoff is negligible, and detention ponds and tributaries may be dry.

While there are a number of processing options available for the harvested algae, the easiest to implement and operate is windrow composting. This would require construction of a compost pad, and would require loading and mixing equipment.

Operational demands are oriented around 1) the O&M of the mechanical equipment (pumps, rakes, screens) and vehicles 2) harvesting and processing of the algae crop and 3) performance and process monitoring and operations. While overall performance and process oversight should be by a trained process engineer or biologist, the dynamics of the ATS™ are similar to other biological processes, and could be managed on a daily basis by a certified wastewater operator. As with wastewater facilities, the larger and more complex the facility, the high the level of certification needed, and the greater the frequency of necessary visitation.



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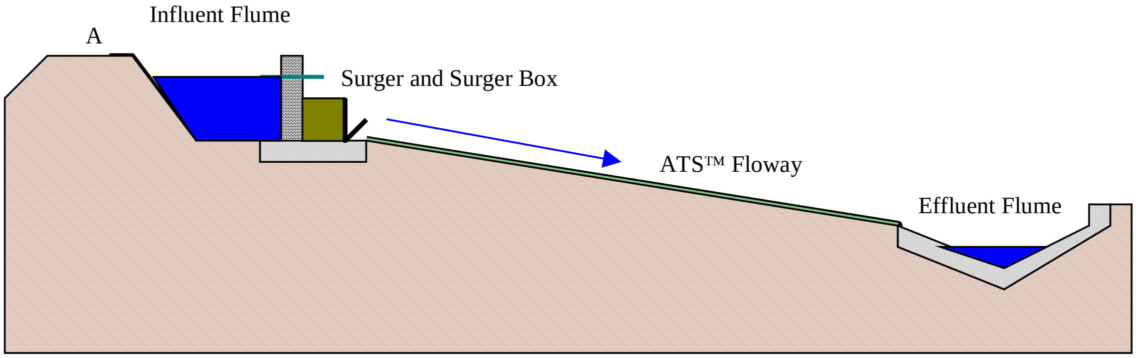

SECTION

Figure A: Typical ATS™ Layout Schematic (NTS)

3.0 ATS™ PROCESS DYNAMICS AND MODEL

As with many biological water treatment processes, the dynamics associated with the ATS™ can be described through a first-order reaction—that being that the rate of reduction is a function of the concentration of the targeted substrate (nutrient). This can be expressed through Equations 1 through 3.

$dS/dt = -kS$ Equation 1

or

$dS/S = -kdt$ Equation 2

Integrated between t = 0 to t = i as

$\ln(S_i/S_0) = -kt$ or $S_i = S_0e^{-kt}$ Equation 3

Where S is the nutrient concentration, t is time, and k is the rate constant

This general expression was initially applied to enzymatic reactions as described by Michaelis-Menten[17]. While the value "k" within the laboratory was initially applied to a specific substrate and a specific enzyme, the "k" value has come to be identified within more complex biological treatment processes with the cumulative effect of a broad and fluctuating collection of reactions and organisms. For example, within treatment wetlands, the value of "k" is identified as the rate coefficient associated with the accretion of phosphorus into the sediments and standing crop of biomass, without any attempt to identify and segregate the specific processes involved, such as chemical precipitation, adsorption, immigration and direct plant uptake.[18] While repetitive experimentation in such cases can strengthen confidence in establishing values for "k" on a short-term basis, it cannot determine the rate of change in "k" as environmental conditions change within the wetland itself—i.e. as accretion begins to change to chemical and physical complexion of the process.

Within sustainable biological processes, in which biomass removal allows long-term stabilization of the chemical and physical environment, it is possible to orient the first-order reaction around the principle mechanism involved in nutrient removal—that being actual biomass productivity. In some cases, modeling of this productivity can target a dominant species, such as with the WHS™ technology. However, in most cases, the application of growth models is applied to a set community of involved organisms, such as with activated sludge, fixed film technology, and ATS™.

The MAPS technologies differ from activated sludge and fixed film processes such as trickling filters and Rotating Biological Contactors (RBC), in that the targeted biological community is a photoautotrophic, carbon fixing community, instead of a heterotrophic, carbon respiring community. In ecological terms, the MAPS would represent the primary production trophic level, while the heterotroph based processes would represent the detritivoral trophic level.

When a biological unit process is oriented around sustainable community production, the first order kinetics are generally applied through the Monod[19] relationship.

$Z_t = Z_0e^{mt}$ Equation 4

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[17] Michaelis, L. and M/L/ Menten,(1913) *Biochem.Z.,***49**, 333

[18] Walker, W.W. (1995) "Design basis for Everglades stormwater treatment areas" Water Resource Bulletin American Water Resources Association Vol 31 No. 4

[19] Monod, J. (1942) *Recherches sur la Croissance ds Cultures Bacteriennes,* Herman et Cie, Paris

Where Z is the biomass weight and m is the specific growth rate (1/time) when:

$m = m_{max}S/(K_s+S)$ Equation 5

Where m_{max} is the maximum potential growth rate and K_s is the half-saturation constant for growth limited by nutrient S, or the concentration of S when $m = ½\, m_{max.}$

Considering the flow dynamic of the ATS™ as noted in Figure A, the system may be viewed as a plug flow system. Recognizing that the average biomass at any one time on the ATS™ is assumed stable (Z_{ave}), and relatively constant when harvesting is done frequently, and the reduction rate at steady state of S is also a function of the concentration of S within the tissue or S_t, then S_{y1} at a sufficiently small increment "*y*" down the ATS™ may be expressed as:

$$S_{y1} = S_{y0} - \{Z_{ave}e^{[m_{max}S_{y0}/(Ks+S_{y0})][(y_1-y_0)/v]} - Z_{ave}\}/[q(y_1-y_0)/v] \qquad \text{Equation 6}$$

Where "v" is the flow velocity down the ATS™ at unit flow rate "q".

The conditions required for Equation 6 are that the temperature is optimal for growth, that solar intensity is relatively constant, that the process is irreversible, and that there is no inhibitory effects related to S within the ranges contemplated, and that the difference between S_{y1} and S_{y0} is sufficiently small as to not influence m. If temperature impacts are considered, then the classical V'ant Hoff-Arrhenius[20] equation (Equation 7) may be incorporated as noted in Equations 8.

$$m_{opt}/m_1 = Q^{(T_{opt}-T_1)} \text{ or } m_1 = m_{opt}/Q^{(T_{opt}-T_1)} \qquad \text{Equation 7}$$

Where m_{opt} is the growth rate for given S at the optimal growing temperature ^{o}C, T_{opt}, and m_1 is the growth rate for the same given S at some temperature ^{o}C, T_1, when $T_1 < T_{opt}$, and Q is an empirical constant ranging from 1.03 to 1.10.

$$S_{y1} = S_{y0} - \{Z_{ave}e^{[m_{max}S_{y0}/(Ks+S_{y0})][(y_1-y_0)/v][1/Q^{(T_{opt}-T_1)}]} - Z_{ave}\}/[q(y_1-y_0)/v] \qquad \text{Equation 8}$$

In more northern applications, adjustments might need to be made for light intensity as well. While there are seasonal fluctuations in Florida for both solar intensity and photoperiod, the impacts are assumed to be minimal when compared to temperature influences, and can be incorporated into the empirical determination of Q.

Estimation of m_{max} and K_s can be done by applying field data as described by Lineweaver-Burke [21]. A Lineweaver-Burke review of S-154 data is noted within Figure B. As is often done with individual wastewaters in which activated sludge is to be applied, it is quite often helpful to conduct a bench level analysis with an ATS™ unit to establish these values in the field, and to identify the limiting nutrient. A bench study is suggested for the applications discussed within this proposal. The nature and costs for these studies are included in a later section of the text.

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[20] As described by Brezonik, P.L.(1994) *Chemical kinetics and process dynamics in aquatic systems,* CRC Press, Boca Roaton, Fl pp 114-117

[21] Lineweaver, H and D. Burke (1934) "The determination of enzyme dissociation constants" *J.Am.Chem.Soc.* **56,** 568

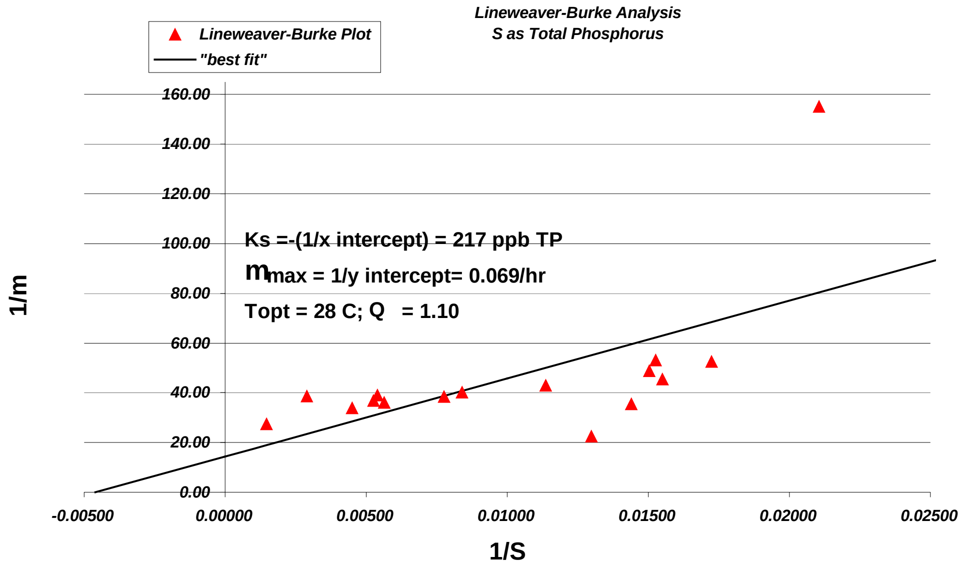

Figure B: Lineweaver-Burke Plot for S-154 single stage ATS™ floway; S as total phosphorus

The plot noted as Figure B is for a floway hydraulically loaded at a rate of about 21 gallons/minute for each foot of floway width, a parameter called linear hydraulic loading rate or LHLR. From the LHLR and the slope of the floway it is possible to use the Manning's equation to estimate average velocity, "v". This requires assignment of Manning's coefficient –"n"—which can be estimated based upon field velocity measurements.

The model that is developed for estimating performance is based upon a composite average condition for the entire floway. For example an average standing biomass, Z_{ave} represents the standing crop at anytime as dry-g/m^2 averaged over the whole ATS™ area. It is a function of the frequency of harvesting, and can be estimated through Equation 9.

$$Z_{ave} = \left(\sum_{m=1}^{n} Z_0 e^{24\mu m} \right) / \; n$$

Equation 9

It is recognized that any one section of the ATS™ may be providing better or less treatment than the model projection, but as an average, the model effluent estimate and actual composite effluent can be expected to be similar. This applies to any time period during the operation. While photosynthesis occurs only during the daytime, productivity projections are based upon a 24-hour period. While there may be some concern that nocturnal performance is below diurnal performance, experience on Florida stormwater indicates that nutrient uptake does continue with the loss of sunlight, even if carbon fixation is discontinued.

While the model is based upon the assumption that direct nutrient uptake within the plant biomass is the sole removal mechanism, under certain conditions other phenomenon may also contribute—including chemical precipitation, both within the water column directly, and upon the surface of the algal cell wall, luxury uptake, adsorption and emigration through invertebrate pupae emergence and predation. Some evidence of these factors is noted with the change in tissue phosphorus concentration with change in water column total phosphorus concentration, as noted within Figure C. By incorporating the change in phosphorus concentration within the tissue, the Monod based model can be considered to incorporate the influence of these other phosphorus removal mechanisms.

APPENDIX A

Algal Turf Scrubber® (ATS™)

Patent No. 4,333,263 – Algal Turf Scrubber®

Patent No. 4,966,096 - Water Purification System and Apparatus

Patent No. 5,097,795 - Water Purification System and Apparatus

Patent No. 5,527,456 - Apparatus for Water Purification by Culturing and Harvesting Attached Algal Communities (License Rights Granted to ABES)

Patent No. 5,573,669 - Method and System for Water Purification by Culturing and Harvesting Attached Algal Communities (License Rights Granted to ABES)

Patent No. 5,715,774 - Animal feedstocks comprising harvested algal turf and a method of preparing and using the same

Patent No. 5,778,823 - Method of raising fish by use of algal turf

Patent No. 5,851,398 – Algal turf water purification method

Patent No. 6,572,770 – Apparatus and Method for Harvesting and Collecting Attached Algal Communities

Water Hyacinth Scrubber (WHS™)

Patent No. 5,811,007 - Vascular Plant Aquaculture and Bioremediation System and Method

Patent No. 5,820,759 – Integrated aquaculture and bioremediation system and method

Patent No. 6,393,812 – Method and apparatus for gathering, transporting and processing aquatic plants.

Patent No. 6,732,499 – Method and apparatus for gathering, transporting and processing aquatic plants.