CONCEPTUAL PLAN

Twenty-year Hydrilla Management on West Lake Tohopekaliga

Hydrilla Cultivation and Mechanical Harvesting Strategy (HCMHS)

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PREFACE

Photo from Orlando Sentinel

It would be difficult to look at this picture of a Central Florida lake where Hydrilla has totally blocked access to open water and think of this invasive non-native aquatic plant as anything but a menace. Consequently, for most people in Florida the suggestion that Hydrilla, if properly managed, could become a valuable resource may seem preposterous.

But the fact is Hydrilla, when managed effectively, can provide valuable environmental services, including generation of dissolved oxygen and sustenance of a healthy aquatic habitat and fishery. However, the most notable of these services is the ability to remove nutrients such as phosphorus from impaired surface waters, thereby facilitating water quality improvement and impeding the development of harmful algae blooms, or HAB's. These HAB's have become so threatening in Florida, particularly those associated with Blue-Green Algae or Cyanobacteria, that the Governor has established a Blue-Green Algae Task Force to expedite effective measures to avoid future blooms and to identify actions to attenuate the impact of any blooms which might develop. It is understandable then that the Task Force has focused much of its attention to the reduction of available phosphorus within impaired surface waters, as they recognize that Cyanobacteria production can be stimulated by high levels of biologically available phosphorus.

The Task Force's efforts regarding phosphorus management are congruent with the Federal Total Maximum Daily Load program or TMDL, per section 303(d) of the Clean Water Act (PL92-500). The intent of TMDL is to provide water resource managers a guideline for developing responsive Basin Management Action Plans (BMAP) to facilitate restoration of water quality within impaired surface waters.

TMDL's set for Florida's impaired freshwaters often mandate reduction of phosphorus loading. For example, the TMDL for Lake Okeechobee is 149 metric tons of phosphorus per year—which is considerably lower than the present phosphorus loading of about 500 metric tons per year. This means phosphorus loading to Lake Okeechobee needs to be reduced by over 70% to comply with the TMDL. And as if this challenge were not difficult enough, if these impaired waters are to be brought into TMDL compliance it is not sufficient to just reduce present day loading from imports, for stored within the lake sediments and the soils of the watershed are extensive quantities of available phosphorus—also known as legacy phosphorus. In the Northern Everglades Basin, for example, which includes the Lake Okeechobee watershed, the University of Florida Water Institute noted in a 2015 report to the Florida Senate that there is 110,000 metric tons (one metric ton is 2,205 pounds or 1.10 tons) of available legacy phosphorus which, without removal or long term sequestration, will continue loading Lake Okeechobee at the present rate of 500 metric tons per year for the next two hundred years, even if all loadings from imported phosphorus were eliminated!

Similarly, the Blue-Green Algae Task Force in their Consensus report of October, 2019 gave recognition to the importance of legacy phosphorus stating that *legacy nutrients-----are a concern in the South Florida landscape and the task (force) recommends that their contribution to loading figure prominently in the Lake Okeechobee, Caloosahatchee and St. Lucie River and Estuary BMAPs. The task force further recommends that projects with the demonstrated potential to expedite legacy nutrient removal merit special attention and be designated as priority projects.*

Managing legacy phosphorus presents a serious challenge, for the magnitude of available phosphorus stores associated with legacy phosphorus are typically much larger than the annual net imported loads. For example, annual phosphorus imports to Lake Okeechobee are about 500 metric tons, while the legacy stores as noted are about 110,000 metric tons of available phosphorus. Based upon simple calculations, reductions of about 2,000 metric tons of legacy phosphorus would need to be removed each year for the next fifty years before compliance with TMDL would be realized. In comparison, present efforts by the South Florida Water Management District (SFWMD) to remove phosphorus from the water through their 57,000 acres of Stormwater Treatment Areas (STA's) amount to about 150 metric tons per year, with a phosphorus removal rate of (+/-)1.0 g m^{-2} y^{-1}. It also needs to be recognized that STA's simply transfer phosphorus from the water column to the underlying sediments, where it adds to the legacy stores within the basin.

So, what options do the managers have to remove or effectively immobilize legacy phosphorus at the pace of 2,000 tons per year? In their 2015 report the UF Water Institute refers to immobilization of this phosphorus--- *in-situ immobilization of legacy P by chemical amendments, will be needed to meet TMDL targets.* The strategy suggested would be to mix chemicals such as calcium, iron or aluminum salts within the soils or sediments to firmly sequester phosphorus, rendering it biologically unavailable. Considering the magnitude of the Okeechobee Watershed—circa 4,000 square miles—there is question as to the practicality and costs of such a widespread *in-situ* immobilization. In addition, phosphorus behavior in soils and saturated sediments is dynamic and not that well understood, and it would be quite possible that in response to fluctuations in environmental factors such as pH and Redox potential, that the phosphorus thought to be immobilized could again become mobile and available.

It is noteworthy that in their Consensus Report the Blue-Green Algae Task Force did not refer to immobilization of legacy phosphorus, but rather to its removal-- *projects with the demonstrated potential to expedite legacy nutrient* ***removal*** *merit special attention and be designated as priority projects.*

So, what would be required for actual removal of legacy phosphorus? The three most obvious methodologies are:

1. Wholesale removal of phosphorus laden soils to be moved out of basin, an example being dredging.
2. External treatment facilities which rely upon chemicals to precipitate (e.g. calcium, iron or aluminum salts) or adsorb (e.g. certain polymers and clays) phosphorus, perhaps combined with filtration, with the phosphorus containing solids to be recovered and moved out of basin.
3. Biological uptake, and the periodic harvesting of the involved organisms. Typically, photoautotrophs (primary producers) such as aquatic plants would be the biological agent, but in some cases, particularly within wastewater treatment systems, heterotrophic organisms (bacterial sludge) can be used. The harvested biomass would be recovered and moved out of the basin.

It is possible that a combination of these approaches may prove optimal, including perhaps the application of *in-situ* immobilization. At this point of strategic development none of these options can reasonably be eliminated.

But returning to the issue of managing Hydrilla, perhaps the problem associated with Hydrilla "over-growth" or what is known as "topping out", can be managed not solely through herbicide application, which does nothing to remove phosphorus from the waterbody, but through a mechanical harvesting strategy by which the Hydrilla standing crop is managed much in the way turf is managed—through frequent cutting to sustain a desired standing crop. Hydrilla harvesting protocols could be established such that the standing crop would be kept at levels which not only create open water for free movement of boats, but also provide habitat and inhibition of Cyanobacteria, while also providing sustained removal of phosphorus laden biomass from the basin. Such a strategy not only meets the needs of those charged with the responsibility of controlling Hydrilla growth such that it does not impede boat access or negatively impact water quality, but also provides substantial removal of phosphorus through biological uptake and harvesting for those assigned the responsibility of meeting TMDL allocations. Such a strategy then would provide two benefits—Hydrilla management and TMDL compliance through removal of phosphorus from the basin.

For such a strategy to become a reality two actions are necessary. The first is for those involved with Hydrilla management such as the Florida Fish and Wildlife Conservation Commission or FWC and the University of Florida Institute of Food and Agricultural Services Center for Aquatic and Invasive Plants (UF/IFAS/CAIP) to establish and maintain a coalition with those directing efforts to meet the TMDL allocations, such as the Water Management Districts, the Florida Department of Environmental Protection (FDEP), and the Florida Department of Agriculture and Consumer Services (FDACS) among others. Through this coalition the two groups would negotiate a cooperative implementation scheme for Hydrilla management which is mutually beneficial.

The second required action is for those directing efforts to meet the TMDL allocations to establish a value for environmental services as a cost per pound of phosphorus removed, and to provide long-term written commitments to issue compensation to those who demonstrate and verify the removal of phosphorus from the basin—a strategy known as **Pay-for-Performance**.

With a **Pay-for-Performance** program in place, the private sector would be incentivized to develop large-scale programs which provide substantial returns in exchange for assuming the risks of capitalization, permit compliance and operation. It is a public-private concept similar to those which have been effectively employed in the past, such as with the Space Race of the mid-twentieth century, or the expedited industrial adjustments during World War II.

Presented within the main text of this report is a conceptual plan for a Hydrilla Cultivation and Mechanical Harvesting Strategy or **HCMHS** which will provide effective control of Hydrilla and substantial removal of available legacy phosphorus. The plan is evaluated at a maximum build-out of 12,000 acres on West Lake Tohopekaliga, which is within the Lake Okeechobee Basin. The 12,000 acres would be configured as 40-300-acre modules, with each module divided into tracks—each at 50 acres. During the growing season (April through October) harvesting of a module would be done every six days, with the harvest frequency reduced to every 12-15 days during the cooler season (November through March). The annual harvest at build-out is projected at nearly 5 million wet tons, resulting in the removal of over 1 million pounds of phosphorus. For purposes of this initial conceptual plan it is assumed the harvest would be windrow composted at land-based processing facilities. It is estimated that about 550,000 cubic yards of compost at 40% moisture would be generated annually with a value of $30 per cubic yard.

If the environmental service fee is set at $100 per pound of phosphorus removed—a rate commensurate with present costs using existing technologies based upon a fifty-year present value—then the return would exceed $100 million per year. Capital Cost are estimated at about $139 million, with annual operating, maintenance and monitoring costs at about $77 million. Annual return from sales, of which fees associated with phosphorus removal are by far the largest, is estimated at about $120 million. For a twenty-year period, the Internal Rate of Return (IRR) is projected at 30.7% with a profit margin of 35.7%.

While these are preliminary numbers, there is indication that an efficiently designed and operated program could well result in substantial profits, and that an IRR in the 30% range would typically have appeal to investors, even for new and innovative concepts. The conceptual plan evaluated within this text is an initial effort, and design and operational parameters would need to be identified through a long-term full-scale demonstration—for example 50 acres over two years. Also, there is some technical development work that would be required, particularly as related to harvesting and processing equipment and logistics, and in product development. Over time, as products from the harvest are developed and their value increased, the business appeal could well improve as return from product sales increase.

Twelve-thousand acres at build-out is perhaps ambitious, but it is not outside the realm of feasibility. Also, while West Lake Tohopekaliga is used in this evaluation, certainly other lakes, and smaller acreages could be considered. Conversely, larger facilities, such as might be developed on Lake Okeechobee itself, may eventually become viable. It is intended that this analysis be used as a vanguard effort which hopefully will elicit further refinement and serious consideration.

EXECUTIVE SUMMARY

Extensive expansion of Hydrilla has created a serious management problem for the people of Florida, and for the Florida Fish and Wildlife Conservation Commission (FWC) and other agencies, governments, private sector participants and academic institutions charged with the responsibility of controlling Hydrilla growth in Florida's surface waters. When Hydrilla expands laterally, and extends vertically to the water surface—what is called "topped-out"—it not only poses a serious impediment to traditional boat traffic, it also can impair water quality by restricting oxygenation of the underlying water column and by sloughing large amounts of organic debris as necrotic tissue to the sediments. So while some would suggest a "no action" alternative—that is just let the Hydrilla grow and accept the consequences—this is not really a helpful approach as such growth would impose seriously on the fishery, on aquatic ecology in general, on recreational opportunities, on property value, and on water quality and attendant health concerns.

With the rejection of a "no action" approach, the FWC and others are left with three options—biological control, herbicides, and mechanical harvesting, or a combination of these. Biological controls such as the use of triploid grass carp to graze the Hydrilla biomass, has had some success. To a lesser degree so have the use of imported insects. But both have limitations, and typically do not provide the management required.

Herbicides have been the preferred method of control for decades, as they were shown to be "cost-effective"[1]. As a result, an entire industry arose from the development, testing, production and application of herbicides. But there are negatives associated with herbicides. The most obvious is that these compounds are designed toxins. They are synthetic organic compounds for the most part--compounds not entwined within the ecological or genetic history of the aquatic organisms which must confront them—both targeted and non-targeted organisms. Therefore, the long-term impact of herbicide use is difficult to assess. In addition, as might be expected, plants such as Hydrilla are now developing effective resistance to many of these herbicides—such as Fluridone. This means new compounds will need to be developed, with the attendant uncertainty of ecological impact. While there may be disagreements as to the actual and potential deleterious impact of herbicides, all persons who want to protect and reclaim Florida's waters and the associated biological diversity and economic contributions, can agree that if synthetic toxins are going to be used, this use should be minimized, and preferentially eliminated once other equally cost-effective, but less impactful alternatives become available.

Another harmful impact of herbicide use is the fact that it does not remove nutrients (nitrogen and phosphorus) from the water column, but rather results in their release

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[1] One needs to be careful using the term cost-effective, for often long term, less tangible issues arise which may initially be difficult to assess in terms of costs and benefits lost. Residual impacts of toxicity from herbicides would be one such issue. Providing opportunities for Cyanobacteria (Blue-Green Algae) blooms would be another.

from the necrotic plant tissue. These nutrients have the potential of stimulating Cyanobacterial (Blue-Green) phytoplankton within the open waters created by the elimination through herbicide spraying of areas previously shaded by aquatic plants. Cyanobacteria have become associated with serious ecological and human health issues, with some species generating BMAA and other toxins which have been implicated in serious diseases such as ALS and Parkinson's[2]. After the heavy Cyanobacteria blooms of 2016, this issue became a serious concern with the people of Florida, which resulted in the creation by the Governor of a Blue-Green Algae Task Force. One of the first things the Task Force recognized was that nutrients, particularly accumulated nutrients known as legacy nutrients, were directly related to the density and duration of Cyanobacterial blooms. In a statement included in their first consensus report:

"Legacy nutrients, as indicated previously, are a concern in the South Florida landscape and the task force recommends that their contribution to loading figure prominently in the Lake Okeechobee, Caloosahatchee and St. Lucie River and Estuary BMAPs. The task force further recommends that projects with the demonstrated potential to expedite legacy nutrient removal merit special attention and be designated as priority projects."

The creation of the Task Force and the implementation of Basin Management Action Plans (BMAP) designed to reduce nutrients to levels specified within the Total Maximum Daily Load (TMDL)[3] investigations have brought nutrient management to the forefront of water quality management in Florida. Within Florida's lakes phosphorus is often the targeted nutrient.

This concentrated effort to reduce nutrients within impaired surface waters therefore adds another dimension to aquatic plant management—as actual removal of the plants is recognized as a method of nutrient reduction and can accordingly contribute to the timing and efficacy of a BMAP. Herbicide application does not remove nutrients, but mechanical harvesting programs can.

Without consideration of any credit for nutrient removal, mechanical harvesting of aquatic plants has been assessed as a less "cost-effective" aquatic plant management alternative when compared to herbicide application. Consider the following from a 2005 report from the University of Florida Institute of Food and Agricultural Services (IFAS)[4].

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[2] Cox, P.A., R.M. Kostrzema and G.J. Guillemin (2018) BMAA and Nuerodegenerative Illness Neurotox Res. 2018 Jan;33(1):178-183. doi: 10.1007/s12640-017-9753-6. Epub 2017 May 24.

[3] TMDL refers to requirements with Section 303(d) of the Clean Water Act (PL92-500) in which surface waters which are impaired, do not exceed an established limit of pollution which ensures compliance with applicable water quality standards. Basin Management Action plans or BMAP's are the implementing strategy for TMDL compliance.

[4] Hoyer, M.V., M. D. Netherland, M. S. Allen, and D. E. Canfield, Jr. (2005) Hydrilla Management in Florida: A Summary and Discussion of Issues Identified by Professionals with Future Management Recommendations Final Document. Institute of Food and Agricultural Sciences University of Florida Funded by Florida LAKEWATCH, Department of Fisheries and Aquatic Sciences, University of Florida/IFAS

“The lack of discussion on mechanical harvesting likely reflects the fact that there have been limited advances in technology over the past several decades. While mechanical harvesting can provide immediate relief from hydrilla, the typical cost of control ($500 to $1,200 per acre), limited capacity to address large-scale infestations, and rapid re-growth of hydrilla have greatly limited the use of harvesting as a primary tool for hydrilla control. It should be noted that as the potential for integration of mechanical harvesting is discussed, in-lake disposal methods could significantly increase efficiency and reduce costs by up to 50% compared to standard trucking and disposal methods. While recent evaluation of a machine called the Kelpin harvester provided hydrilla control at approximately $200 per acre, these large machines can be difficult to move from site to site, and the upfront costs for building the number of machines necessary to integrate this technology into a statewide program would be substantial. Lastly, a significant increase in the use of harvesting suggests the issue of non-target organism mortality would need to be revisited. While mechanical harvesting represents a tool that could be immediately integrated into the larger state hydrilla control program, issues such as cost-effectiveness, use patterns and efficiency, non-target impacts, and disposal methods would require further discussion prior to embarking on a large-scale mechanical control effort.”

If the benefit of nutrient removal is not considered, this IFAS assessment is understandable and defendable. The paradigm applied to Hydrilla management at the time of this IFAS report (2005), was built upon a long-standing presumption that Hydrilla was a menace which need to be eliminated as effectively as possible, and that its elimination would improve habitat and water quality. In other words, Hydrilla is bad. What is bad of course is not Hydrilla, but the overgrowth of Hydrilla, for in reality Hydrilla sustained at management levels—i.e. not “topped-out”-- provides excellent aquatic habitat, for not only does the growth provide cover and food, but it also generates oxygen, and competes with Cyanobacteria, and hence can reduce the likelihood of dangerous blooms. Hydrilla also removes nutrients, including legacy nutrients within the sediments, and this has value and appeal to those charged with achieving the TMDL allocations.

Considering this, what if the efforts of aquatic plant managers, water quality managers, and farmers were combined to establish a new paradigm. Hydrilla could now be considered good because we can cultivate it to optimize nutrient uptake (water quality); we can manage its growth through a sustained large-scale mechanical harvesting program (aquatic plant management); and we can develop the biomass as a crop with value (farming). Hydrilla then would move from the status of menace to resource.

When Hydrilla production is managed as a resource and phosphorus removal is given a reasonable and competitive value through institutional instruments initiated through long term **Pay-for-Performance** programs[5], it is possible that a viable business plan can be built around a Hydrilla Cultivation Mechanical Harvesting Strategy or **HCMHS**.

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[5] As described in https://www.pasop.org/a-plan-for-the-kissimmee-okeechobee

Considered within this review is a 20-year program for West Lake Tohopekaliga within the Kissimmee-Okeechobee-Everglades Basin, of up to 12,000 acres as forty 300-acre modules, each divided into six 50-acre tracks. If the total 12,000 acres is managed, about 100 large harvesters capable of harvesting 1.5 acres per hour, operating two 8-hour shifts per day would be required. Hydrilla would be sustained at a dry density of 120 to 300 g m^{-2} and be at least 2 feet below water surface. Total annual harvest would be nearly 5 million wet tons per year. This would be chopped and composted on land based receiving and processing facilities. Compost production would be anticipated at 555,000 cubic yards annually, with a value of perhaps $30-35 per cubic yard. The phosphorus removed annually would be over 1 million pounds per year, with a value of over $100 million at $100 per pound of phosphorus removed.

Shown in Table ES-1 is the preliminary cost estimate for this conceptual plan. As noted, with an attractive long-term (at least 20 year) **Pay-for-Performance** rate of $100 per pound of phosphorus removed, the Internal Rate of Return would be about 30.7% with a profit margin of 35.7%.

Key to a successful **HCMHS** is the **Pay-for-Performance** unit return rate—i.e. environmental service fee. Without credit being provided for phosphorus removal, the **HCMHS** is not viable, unless much more valuable products can be generated from the Hydrilla harvest. And without the **Pay-for-Performance** fee, the private sector is unlikely to find enough incentive to pursue such a bold and aggressive program.

Like the space program of the last half of the twentieth century, a concept like **HCMHS** could well return benefits yet unknown. Certainly, it would create meaningful jobs, and would likely improve the fishery and the integrity of the aquatic ecology. But before the program is implemented on a large scale, in-field demonstration would be required. Suggested is a 50 acre (one track) designated area to be managed as sustainable as described within this text, for a period of two years. During this time the targeted crop will be monitored for growth rate, recovery, and nutrient content. Additional monitoring will be included to determine composting effectiveness and compost value, equipment efficiency, logistical efficiency, ecological impacts and other parameters of concern. It is suggested such a demonstration be conducted as a public-private effort to adequately assess concept feasibility.

Considering the value of the services the **HCMHS** could provide in protecting and restoring the quality of Florida's lakes and rivers, and the possibility of generating a new economic driver in Florida, this concept is worth investigating further. It is recommended that implementation of the proposed in-field demonstration program proceed as soon as practical and be commensurate with development of a **Pay-for-Performance** program.

Table ES-1

HCMHS Preliminary Cost Estimate West Lake Tohopekaliga Conceptual Program

CONCEPTUAL LEVEL
Cost Estimate West Lake Tohopekaliga
At Build-out (12,000 acres)

CAPITAL COSTS	Unit Price	Unit	Number	Cost
1.5 acre/hr harvester with GPS autopilot	$ 300,000	each	100	$ 30,000,000
On-water chopping units with conveyors	$ 65,000	each	100	$ 6,500,000
Transport barges/boats	$ 100,000	each	300	$ 30,000,000
Receiving/Processing Station--Land	$ 100,000	acre	400	$ 40,000,000
Receiving Station Development/Equipment	$ 1,500,000	per station	7	$ 10,500,000
Engineering/Surveying/Permitting	$ 3,000,000	lump sum	1	$ 3,000,000
Monitoring Equipment	$ 800,000	lump sum	1	$ 800,000
SUB TOTAL				**$ 120,800,000**
Contingency 15%				**$ 18,120,000**
TOTAL CAPITAL				**$ 138,920,000**

Annual Operating, Maintenance and Monitoring Costs	Unit Price	Unit	Number	Cost
Direct Labor (circa 500 employees)	$ 35	hour	1,164,800	$ 40,768,000
Indirect Labor	$ 2,000,000	Lump Sum	1	$ 2,000,000
Fuel Harvesting	$ 4	gallon	400,000	$ 1,600,000
Fuel Water Transport and Miscellaneous	$ 4	acre	50,000	$ 200,000
Maintenance 2% of Equipment Capital	$ 117,800,000	per station	0.02	$ 2,356,000
Product Transport	$ 500	load	35,000	$ 17,500,000
Laboratory	$ 20,000	month	12	$ 240,000
Consultant (Fisheries, Aquatic Biologist, Accounting, Tax etc.)	$ 2,500,000	lump sum	1	$ 2,500,000
SUB TOTAL				**$ 67,164,000**
Contingency 15%				**$ 10,074,600**
TOTAL ANNUAL OPERATING, MAINTENANCE AND MONITORING COSTS				**$ 77,238,600**

ANNUAL SALES	Unit Price	Unit	Number	Cost
Pay for Performance Fee Phosphorus removal	$ 100	pound	1,011,700	$ 101,170,000
Harvesting Fee	$ 200	acre	12,000	$ 2,400,000
Product Sales (compost)	$ 30	cy	550,000	$ 16,500,000
TOTAL SALES				**$ 120,070,000**
ANNUAL RETURN				**$ 42,831,400**
20 year Internal Rate of Return (IRR)				**30.7%**
Profit Margin				**35.7%**

PROPOSED CONCEPT

Contemplated is a management strategy for Hydrilla to be applied to Florida lakes presently experiencing severe overgrowth of Hydrilla. This strategy which can be called the **Hydrilla Cultivation Mechanical Harvesting Strategy** or **HCMHS**, is based upon the predominant use of mechanical harvesting to sustain a reasonable and acceptable standing crop, such that Hydrilla is retained as a resource at levels beneficial to the aquatic ecology, while avoiding interference with boat traffic or ecological degradation from overgrowth. While this represents a notable paradigm shift from the present approach adopted and practiced by the aquatic plant management sector in Florida, which is largely represented by governmental agencies, academic support groups, herbicide manufacturers and herbicide applicators, it is a strategy congruent with the concept of "pulse stabilization" as described by Eugene Odum and as alluded to by his brother, H.T. Odum[6], in developing the field of Systems Ecology at the University of Florida. An example of a natural system which is pulse stabilized would be a tidally flushed salt marsh community by which a significant portion of net productivity and associated nutrients are removed through tidal flows, thereby pushing the system closer to a stable near-equilibrium dynamic.

In using mechanical harvesting of Hydrilla to emulate pulse stabilization, human efforts through harvesting represent grazing of net productivity, with the beneficial component of nutrient removal rather than internal nutrient recycling. What is interesting about such an approach is that net Hydrilla production would be increased by maintaining standing crop at a range within the log phase of growth to ensure both effective removal of targeted pollutant(s) (e.g. phosphorus) and avoidance of undesirable standing biomass levels. This approach is commonly used in wastewater treatment design such as with activated sludge to sustain optimal sludge density and production measured as Mixed Liquor Suspended Solids (MLSS)[7], or with nutrient reduction using aquatic plants as first described by Musil and Breen[8] in South Africa, and later by HydroMentia and others[9] [10] in expanding the application of Managed Aquatic Plant Systems or MAPS[11], as a means of removing and recovering nutrients from wastewaters and impaired surface waters.

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[6] Odum, W.E., Odum, E.P. & Odum, H.T. Estuaries (1995) 18: 547. https://doi.org/10.2307/1352375

[7] Metcalf and Eddy, Inc. Revised by George Tchobanoglous 1991 Wastewater Engineering: Treatment, Disposal and Reuse" McGraw-Hill ISBN 0-07-041690-7

[8] Musil, C.F. and C.M. Breen (1977) "The application of growth kinetics in the control of *Eichhornia crassipes* (Mart) Solms through nutrient removal by mechanical harvesting." Hydrobiologia 53:165

[9] Stewart, E.A.; D.L. Haselow and N.M. Wyse (1984) "A practical model for water hyacinth based wastewater management, design and operation." 679-702 Future of Water Reuse Proceedings: Water Reuse Symposium III. San Diego, Calif.

[10] Algal Turf Scrubber ® Design Model as described in Appendix 2 of STA-1W Algal Turf Scrubber® Pilot 2008-2009 Final Performance Report prepared for the South Florida Water Management District.

[11] A review of the MAPS concept may be found at https://docs.wixstatic.com/ugd/ada4f8_8c4942d4f6f2407aa5dba8d9930f9325.pdf In-lake harvesting to facilitate water quality and habitat reclamation may be consider *in-situ* MAPS.

Nutrient removal and recovery are critical components of the **HCMHS** concept, as documented and verified nutrient removal through harvest—particularly phosphorus—would contribute significantly to efforts related to Total Maximum Daily Load allocations (TMDL) and the attendant efforts to meet these allocations through the Basin Management Action Plans or BMAPS. In large basins such as the Kissimmee-Okeechobee-Everglades (KOE) basin, phosphorus removal is a critical task associated not only with BMAPs but also regional restoration efforts such as the Comprehensive Everglades Restoration Plan (CERP) and the Northern Everglades and Estuaries Protection Program (NEEPP). The Northern Everglades Basin, which includes the Lake Okeechobee Watershed, extends northward from Lake Okeechobee into the Kissimmee Chain of Lakes and the west region of Orange County (Orlando) known for its Theme Parks with their high level of tourist visitation. It also includes the circa 22,000-acre West Lake Tohopekaliga, a lake impacted by Hydrilla overgrowth and which is presented as a case model in this discussion. The Northern Everglades Basin extends over more than 4,500 square miles, and as noted by the University of Florida Water Institute in a 2015 report[12] the basin is burdened with an accumulation of over 110,000 metric tons of available phosphorus, which is labelled as legacy phosphorus within the 2015 report[13]. As noted in the Water Institute report:

"legacy P in the Lake Okeechobee watershed could sustain contemporary P loading rates, i.e. 500 metric tons per year, for more than two centuries. Clearly, there is a need to fully recognize the potential contribution of legacy P to any future P-loading scenario----Legacy P in the Lake Okeechobee watershed is of concern because current efforts to achieve the Lake Okeechobee TMDL have proven inadequate. None of the current BMAPs for the Lake Okeechobee, St. Lucie or Caloosahatchee watersheds will achieve their respective TMDLs within the next 5 years----beyond existing and planned approaches, the substantial reservoir of legacy phosphorus in the Northern Everglades watersheds will necessitate new and more aggressive strategies to combat the mobility of phosphorus."

The urgency of managing legacy phosphorus was also expressed recently by the Blue-Green Algae Task Force[14] in their Consensus Report.

"Legacy nutrients, as indicated previously, are a concern in the South Florida landscape and the task force recommends that their contribution to loading figure prominently in the Lake Okeechobee, Caloosahatchee and St. Lucie River and Estuary BMAPs. The task (force) further recommends that projects with the demonstrated potential to

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[12] UF water Institute 2015 Options to Reduce High Volume Freshwater Flows to the St. Lucie and Caloosahatchee Estuaries and Move More Water from Lake Okeechobee to the Southern Everglades an Independent Technical Review by the University of Florida Water Institute March 2015 Prepared for Florida Senate

[13] A more appropriate name for this stored phosphorus would be rogue phosphorus or Stored Excess Anthropogenic Phosphorus or SEAP

[14] The Blue-Green Algae Task Force was established by Florida's Governor to investigate and help resolve issues within the NEEPP area related to extensive blooms of Blue-Green Algae (Cyanobacteria) https://floridadep.gov/Blue-GreenAlgaeTaskForce

expedite legacy nutrient removal merit special attention and be designated as priority projects."

It is suggested that **HCMHS** qualifies as a project with a potential to expedite legacy nutrient removal and hence should be consider for *"designation as a priority project"*. It is further suggested that the environmental service which would be provided to the BMAP effort has value, and compensation could be provided through a **Pay-for-Performance** program, with payment based upon a dollar amount for each pound of phosphorus removed. A review of the **Pay-for-Performance** concept can be found at https://www.pasop.org/a-plan-for-the-kissimmee-okeechobee .

Incorporation of economic credit for phosphorus removal is essential to the viability of the **HCMHS** proposed within this text. As legacy phosphorus is present largely in the soils and sediments of the basin, Hydrilla is well suited for its removal, as much of the direct phosphorus uptake is associated with the available legacy phosphorus held within lake sediments. If the Hydrilla can access this sediment phosphorus, then this phosphorus must be classified as available and hence part of the legacy store. Should at some time Hydrilla deplete this phosphorus, two issues will have been resolved—the invasive expansion of Hydrilla, and the availability of legacy phosphorus.

DESIGN AND OPERATIONAL CONSIDERATIONS

Introduction

HydroMentia modified the Musil and Breen model to accommodate the engineering design of MAPS units, and this modeling approach is applicable to the **HCMHS** strategy presented here. At question is the expected biomass density of Hydrilla at "top-out" as dry-g m^{-2}; the reasonable range of expected net growth rate (d^{-1}); and the rate of vertical growth (inches d^{-1}). Typically, net growth rate is a function of the innate production capabilities of the targeted organism; optimal temperature and the impacts of temperature changes on growth rate as expressed through the V'ant Hoff-Arrhenius Relationship[15]; the extent of grazing and disease impact; and the availability of controlling factors, such as nutrients, space or sunlight.

Net production over time is typically exponential during the expansive phase of development. Once a paucity of necessary resources (e.g. nutrients or sunlight or space) occurs, net productivity will approach zero, and often the rate of tissue necrosis and sloughing will match development of new growth. At such a time the crop becomes a "carbon pump", actively moving atmospheric or dissolved carbon to the sediments,

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[15] $\mu_{T1}/\mu_{Topt} = \Theta^{(T_1 - Topt)}$ with μ as specific growth rate $time^{-1}$; T as water temperature C°; T_{opt} the optimal temperature for maximizing growth rate; and Θ is the temperature coefficient usually between 1.01 and 1.10. When $T_1 \leq T_{opt}$
Myszograf, S "Reaction rate coefficient k20 and temperature coefficient Θ in organic waste thermal disintegration" University of Zielona Góra, Faculty of Civil Engineering, Architecture and Environmental Engineering, Poland

where it can impose a sizable oxygen demand and expand the vertical rise of the sediments[16]. The goal then is to maintain an optimal standing crop biomass through periodic harvesting.

Net productivity within this range of exponential growth may be expressed as $Z_t = (Z_0)\, e^{\mu t}$ where Z_t is the biomass on a dry weight basis at time t, and Z_0 is biomass at time zero; μ is the net growth rate as t^{-1}.

It needs to be recognized that the values applied in this analysis are taken from available literature, but there is of course quite a bit of variation within the literature. Therefore, actual applicable values will need to be determined through full-scale field demonstration studies, as detailed in later sections of this text.

Standing Crop

Information related to the standing biomass associated with Hydrilla is limited, although based on discussion by persons with experience in managing Hydrilla, there is thought that Hydrilla could grow to densities of about 20 wet tons per acre, or at 8% solids about 3,200 dry pounds per acre. This equates to about 360 dry g m^{-2}. This is similar to values reported by Bricefno[17], which ranged from 390 to 420 dry g m^{-2} as maxima within the tropical environment of Panama. He also noted the solids content was about 8%, with ash at about 15% of dry weight. This standing crop density is below standing crop levels often reported for water hyacinths, which have typically been maintained in MAPS facilities[18] at about 100-150 wet tons per acres at 5% solids, or about 1,120 – 1,680 dry g m^{-2}.

Net Growth Rate

While the standing crop density for Hydrilla might be comparatively low, it demonstrates high net growth rates. Water hyacinth maximum net growth rate (μ_{max}) used in design of hyacinth based MAPS is between 0.04 and 0.05 d^{-1} Hydrilla rates are reported within the field to approach or exceed 0.10 d^{-1}. Also, while hyacinths are influenced significantly by nutrient levels within the water column, Hydrilla is not so restrained because of its ability to readily access available nutrients within the sediments, which typically show less fluctuation in nutrient levels.

In a US Fish and Wildlife Service pamphlet[19] it is stated that Hydrilla can double its biomass in two weeks—or a net growth rate of 0.05 d^{-1}. This is considerably lower than

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[16] From an ecological perspective this may be considered an acceleration of successional processes which transform a lacustrine system to marsh and eventually climax forest.

[17] Bricefno, J (1990) Morphological variation and ecological status of Hydrilla verticillata in Gatun Lake, Panama. Dissertation University of North Texas, Denton Texas

[18] HydroMentia, Inc. (2005) S-154 Pilot ATS™-WHS™ Aquatic Plant Treatment System Final Report. South Florida Water Management District, Contract C-13933 West Palm Beach, Fl

[19] https://www.fws.gov/columbiariver/ans/factsheets/Hydrilla.pdf

values presented by Glomski and Netherland[20] of 0.08 to 0.22 d^{-1}, with an average of 0.19 d^{-1}. Bianchini et.al.[21] suggested the biomass doubling time for rooted Hydrilla ranged from 2.5 to 11 days, or a net growth rate of 0.06 to 0.28 d^{-1}. Recognizing the net growth rate will need to be adjusted based upon some future data collected during a full-scale demonstration program, it seems reasonable for this initial evaluation to use some value between these ranges—such as 0.15 d^{-1}.

Vertical Growth Rate

In a summary of the Florida Fish and Wildlife Commission's position on Hydrilla management[22], it is reported that the apical stem of Hydrilla can exceed one inch per day vertical growth. Bricefno[23] offers similar numbers. This parameter is of little scientific value but does give some insight into the spacing of harvests, as discussed later in this text. For purposes of this report 3-4 inches per day vertical rise is assumed.

Preliminary Design of Proposed Concept

West Lake Tohopekaliga is about 22,000 acres and is located just south of the City of Kissimmee. It contributes flow to the Kissimmee Chain of Lakes to the south, which in turn moves into Lake Okeechobee through the Kissimmee River—now C-38. West Lake Tohopekaliga or simply West Lake, is within the Kissimmee-Okeechobee-Everglades (KOE) Watershed. West Lake itself receives much of its flow from runoff and seepage from the western reaches of the Orlando Metropolitan Area as well as the City of Kissimmee. West Lake has been profoundly impacted by Hydrilla overgrowth, and therefore would be a logical target for a large-scale application of **HCMHS**.

The littoral zone appears to occupy at least 15% of the lake area. The intent would be to protect the littoral areas as well as maintain an additional 30% of the total lake surface in topped-out Hydrilla to benefit birdlife and other aquatic organisms which either feed on the exposed Hydrilla or use it for cover and breeding habitat. This means the **HCMHS** would target up to 55% of the lake area or just over 12,000 acres.

The first phase of implementation would be to remove the topped-out biomass over the targeted 12,000 acres to a depth of about 5 feet below the surface. It would be impractical to expect this could be done over a short time period. Rather it is suggested that the 12,000 acres be segmented into management modules of an average of about 300 acres each—i.e. circa 40 modules. At a standing crop of 350 dry g m^{-2} at 8% solids, and with 80% of the biomass in the first couple of feet when the Hydrilla is topped out, about 16 wet tons per acre or a total of 800 wet tons total would need to be removed per module, leaving about 70 dry g m^{-2} residual crop.

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[20] Glomski, L.M. and M.D. Netherland (2012) Does Hydrilla grow an inch per day? Measuring short-term changes in shoot length to describe invasive potential. J. Aquat. Plant Manage. 50: 54-57

[21] Bianchini, I, M.B. Cunha-Santino, and J.A.M. Milan (2010) Growth of Hydrilla verticillata (L.f.) Royle under controlled conditions Hydrobiologia 644(1):301-312

[22] http://myfwc.com//media/1386750/Hydrilla-Mgmt-Position.pdf

[23] IBID footnote 17

Considering a net growth rate of 0.15 d^{-1}, the crop will recover to a harvest target of about 300 dry g m^{-2} in about 10 days. If the initial depth is 5 feet, and the vertical gain is 3-4 inches each day, then in 10 days the top of the biomass will be 20-30 inches below the surface. In ten days then, after the first cut the crop will again be harvested to five feet below the surface. It can be expected that the remaining standing crop will exceed the initial 70 dry g m^{-2} as the crop below the topped-out Hydrilla will have responded to the access to sunlight by expanding laterally. Recognizing this, it is assumed the standing crop after this first harvest will be about 120 dry g m^{-2}, which will be the targeted standing crop. Consequently, the next harvest, and subsequent harvests need to occur at a frequency of about every six days during the growing season from April through October. Therefore, maximum harvest requirements for the 300-acre module are about 50 acres each day. If harvesting is done as two 8 hr. shifts, then enough machinery will be required to do about 3 acres per hour. The operational cycle is presented schematically as Figure A.

To summarize, at build-out (12,000 acres) a system capable of managing Hydrilla over 55% of West Lake would require 40 modules of 300 acres each, each with enough equipment to harvest 3 acres per hour over a 16-hour day, 7 days a week. This would be the expected rate during the growing season from April through October. This would be reduced during the cooler period from November through March. The targeted standing crop density would be 120 dry g m^{-2} with depth to the top of biomass to be no less than 2 feet at time of harvest. The targeted harvest crop density would be 300 dry g m^{-2}. Projected wet biomass harvest at build-out of all 40 modules, is just over 20,000 tons per day during the growing season (190 days) and just over 6,000 tons per day during the cool season (175 days), or a total annual wet harvest of 4,864,000 tons. This equates to 389,100 dry tons per year, which contain about 0.13% phosphorus. Hence the projected annual phosphorus removal is 1,011,700 pounds or 506 tons. If the unit value of this phosphorus through a **Pay-for-Performance** agreement is $100 for each pound[24], then the annual return would be $101,170,000. The **Pay-for-Performance** commitment therefore is a critical component of the **HCMHS.**

Initial Full-Scale Demonstration

Implementation will begin with one test module track (50 acres) as a full-scale demonstration to be operated and monitored for at least two continuous years. During the demonstration period, critical parameters, such as net growth rate, temperature coefficient, impact of frequent disruption from harvesting activity, and vertical growth rate will be established. In addition, ecological and water quality parameters will be monitored such as fishery response, comparative change in diversity, Secchi depth and

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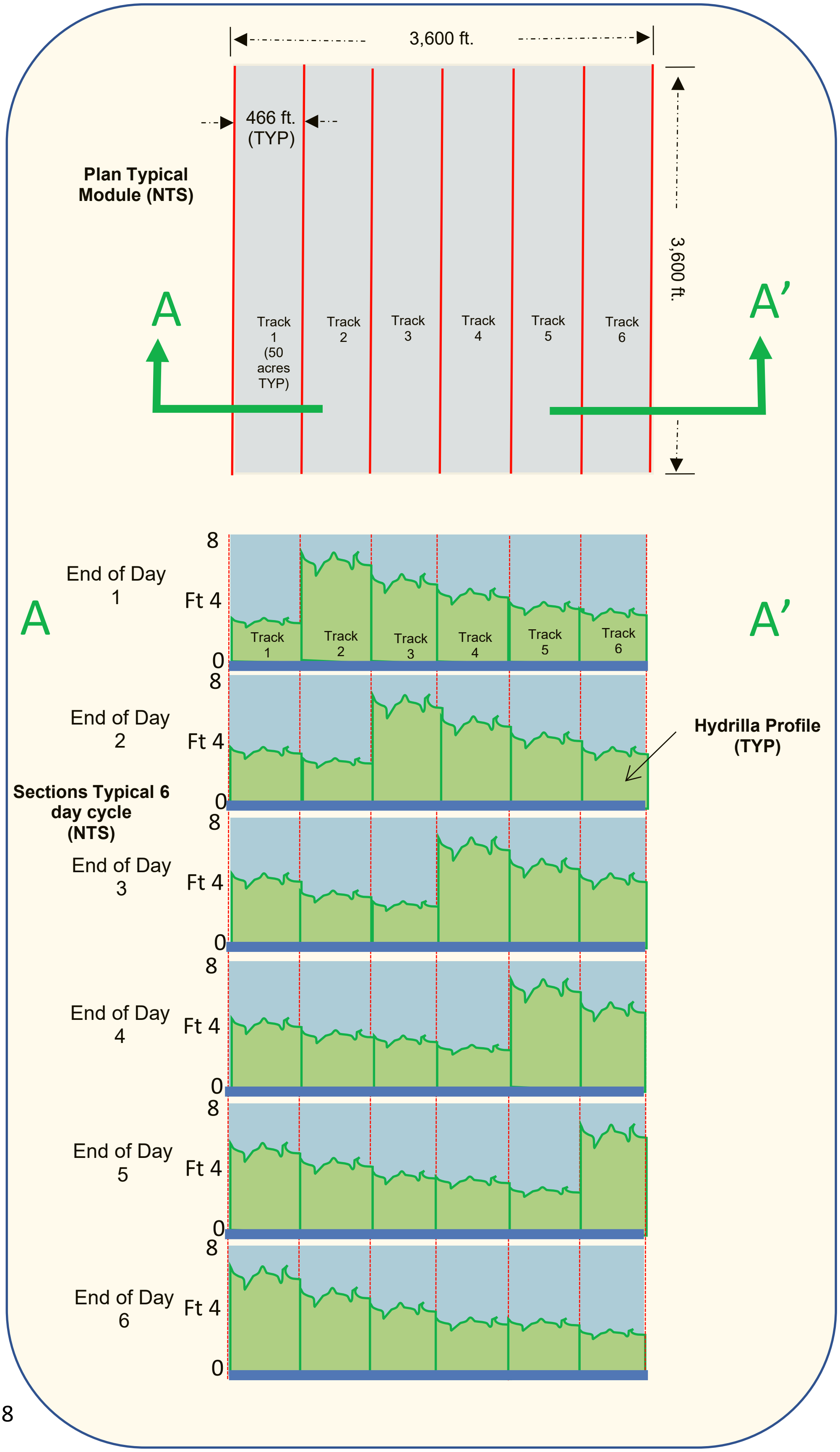
[24] The rate of $100 per pound of phosphorus removed is reasonable and is below what the South Florida Water Management District is typically paying for each pound of phosphorus removed based upon a 50 yr.-present worth analysis done by Sano D., A. Hodges, and R. Degner. 2005, Economic Analysis of Water Treatments for Phosphorus Removal in Florida University of Florida IFAS, Gainesville, Florida.

Figure A: Schematic of Conceptual Module Layout and Operational Cycle (Growing Season)



turbidity, nutrient levels, alkalinity and hardness, heavy metal screening, pesticide and herbicide screening, dissolved oxygen, Cyanobacteria qualitative and quantitative and associated toxins, pH, water temperature, and conductivity. Also harvest wet weight will be monitored and percent solids determined, along with critical qualitative parameters such as nitrogen, carbon and phosphorus content, protein, fiber, and other parameters as may be deemed necessary in determining the potential value of the crop.

The full-scale demonstration will also serve to more clearly identify logistical needs and to incorporate refinements in terms of equipment efficiency, maintenance demands, personnel scheduling, weather impact, and harvest management, transport, processing and deposition.

HARVEST MANAGEMENT

Removing Hydrilla from the water column is but one step in an integrated process train, which is essential for a successful program. How will the harvest be transported to a collection/deposition site? Will volume reduction and homogenization (chopping) be done at the module immediately after harvest, or will it be done at the deposition site(s)? Will additional processing be done, such as composting, blending, anaerobic digestion, pressing, drying, pelletizing etc.? If so, what is the cost and added value of this additional processing? If products are made, what is their value and the extent of the market? What are the regulatory restraints? With almost 5 million tons of wet material to be handled each year at the 12,000-acre build-out, these are critical concerns that must be addressed during the full-scale demonstration.

Based upon previous experiences, it might be expected that wet Hydrilla will have a density of perhaps as much as 500 lb yd^{-3}. Therefore, the annual volume at build-out would be estimated at 19,500,000 yd^3. Chopping *in-situ* at the module would increase density to about 1,620 lb yd^{-3}, thereby reducing the annual volume for transport to about 6,000,000 yd^3. Chopping would also render the material more amenable to further processing, and for quantitative and qualitative monitoring. However, additional on-water equipment would be required.

If the chopped material were to be composted, assuming 25% of volatile solids loss through aerobic (windrow) metabolism, and moisture reduction to 40%, the estimated annual compost production would be 511,000 tons, or an approximate volume of about 550,000 yd^3 or nearly 35,000 truckloads (@16 yd^3). This is based upon the assumption that the chopped material can be windrow composted without addition of bulking material.

There are of course other processing options beyond composting, which could result in higher value products. These need to be thoroughly investigated during the full-scale demonstration, and beyond. The potential products might include:

- Bulk Compost

- Container mix for the nursery/foliage industry with compost as an ingredient
- Livestock, pet and fish feed; mineral supplements; bedding material
- Fiber products and biodegradable plastics
- Biogas, Hydrothermal Liquefaction and other renewable energy products
- Extracts and allelopathic chemicals (e.g. Cyanobacteria inhibition or insect repellents)
- Other specialty products (cosmetics, health supplements etc.)

While during the early stages of the full-scale demonstration material may simply be deposited on one of the nearby “islands” as has been done in the past, later stages must include serious evaluation of long-term alternatives which would provide a reliable environmentally sound outlet of harvested material that would ensure nutrients would not return to the water column.

OTHER OPERATIONAL FACTORS

There are several other somewhat less tangible, but no less relevant issues—both positive and negative—which need to be considered during the full-scale demonstration. These include:

- How does Hydrilla respond to the proposed frequent harvest? Will it become susceptible to disease or infestation? Will it have the energy reserves necessary to respond with regrowth after extensive maintenance? Ironically, if the Hydrilla regrowth is impeded one objective of physical control will have been met, but nutrient removal benefits will be greatly diminished.
- What is the impact on the fisheries and the overall aquatic ecology? Does frequent mechanical disruption of the crop have impact not only through by-catch loss, but also interference of spawning patterns or food sources. The creation of viable habitat may well have positive impact upon fisheries and the aquatic ecology and hence off-set any losses from by-catch. Such is one of the anticipated benefits, but the long-term effects need careful and objective assessment by experienced experts during the two-year full-scale demonstration.
- Are there social concerns regarding noise, odors, vandalism, appearance, and boating safety? Ten percent of the open water will be under harvest during the growing season (April through October). Will this level of activity interfere with public use? How will property values be impacted?
- Provisions must be included to ensure viable Hydrilla propagules are not accidentally transported to other surface waters.
- What provisions are needed to avoid spills of fuel and oil during refueling and maintenance of equipment?
- What provisions are needed to protect equipment and personnel from severe weather events? What level of insurance should be considered?
- How will water quality be impacted? How much turbidity will be generated during the harvest activity? How will diurnal cycles of pH, water temperature, and DO be

impacted? Will conductivity be impacted or alkalinity levels? Will a reduction in nutrients be observed?
- How will maintenance of open water influence development of Cyanobacterial as well as other phytoplankton.
- How will the **HCMHS** influence movement of water, to include changes in hydraulic detention time, overall water depth, short circuiting, or development of currents, gyres or seiches?
- Will the Hydrilla uptake heavy metals or pesticides sequestered within the sediments? How would this impact product value and deposition?

ECONOMIC CONSIDERATIONS

A major economic driver regarding **HCMHS** is the level of recovery through the **Pay-for-Performance** agreement. Negotiations for the unit environmental service fee per pound of phosphorus removed will revolve around the costs the involved agencies expect to pay to meet the removal needs related to legacy phosphorus and the extent to which such removal is deemed necessary. As noted, the Blue Green Algae Task Force and the University of Florida Water Institute have clearly stated the urgency of this need.

Based upon the removal estimates stated previously of about 1,011,700 pounds of phosphorus annually, the value at $100 per pound removed would return $101,170,000 annually. Mechanisms for paying this fee would likely be through some authority granted by the legislature to assess fees to users—much like a sewer or water authority. While over $101 million may sound excessive, it needs to be recognized that much of the legacy phosphorus within the KOE is attributable to activity associated with the Orlando Metropolitan Area with its Theme Parks and Convention Centers, which receive over 72 million visitors per year[25]. Assessment of under $2 per visitor would cover the expense and would be a legitimate fee. Of course, all users, including residential, commercial, agricultural and industrial would also be assessed. Considering this model, the financial burden on the individual citizen and visitor would be minimal.

If the $101 million-dollar environmental service fee were collected, could it off-set the operational costs? Over the 12,000 acres, the $101 million represents an annual allocation of $8,475 per acre. At first glance this appears to be more than enough, but this proposed **HCMHS** scope goes well beyond typical one-time mechanical harvesting projects, which may cost from $600-$2,000 per acres, depending upon the scope.

Because the **HCMHS** involves continuous operation, the cost of frequent launching and removing of harvesters and support equipment is not an issue. Therefore, very large harvesting units can be considered, as once they are set in the lake it is expected that they would not be removed for the project duration. This would result in savings over the long-term. Nonetheless, at build-out at least 80-100 large harvesters will be needed that can harvest 1.5 acres per hour. If these costs $300,000 each, the capital expenditure

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[25] https://attractionsmagazine.com/visit-orlando-75-million-visitors-2018/

would approach $30 million. Considering support equipment, unloading stations, processing facilities including land costs, monitoring equipment, engineering and permitting, and 15% contingency the capital costs could be as high as $140,000,000, as shown in Table 1.

Direct labor is estimated at 400-500 employees or about 1,164,000 man-hours annually, at a cost over $40 million. Total estimated operating, maintenance and monitoring costs as noted in Table 1 are estimated at over $77 million annually.

Table 1

HCMHS Preliminary Cost Estimate West Lake Tohopekaliga Conceptual Program

CONCEPTUAL LEVEL
Cost Estimate West Lake Tohopekaliga
At Build-out (12,000 acres)

CAPITAL COSTS	Unit Price	Unit	Number	Cost
1.5 acre/hr harvester with GPS autopilot	$ 300,000	each	100	$ 30,000,000
On-water chopping units with conveyors	$ 65,000	each	100	$ 6,500,000
Transport barges/boats	$ 100,000	each	300	$ 30,000,000
Receiving/Processing Station--Land	$ 100,000	acre	400	$ 40,000,000
Receiving Station Development/Equipment	$ 1,500,000	per station	7	$ 10,500,000
Engineering/Surveying/Permitting	$ 3,000,000	lump sum	1	$ 3,000,000
Monitoring Equipment	$ 800,000	lump sum	1	$ 800,000
SUB TOTAL				**$ 120,800,000**
Contingency 15%				**$ 18,120,000**
TOTAL CAPITAL				**$ 138,920,000**

Annual Operating, Maintenance and Monitoring Costs	Unit Price	Unit	Number	Cost
Direct Labor (circa 500 employees)	$ 35	hour	1,164,800	$ 40,768,000
Indirect Labor	$ 2,000,000	Lump Sum	1	$ 2,000,000
Fuel Harvesting	$ 4	gallon	400,000	$ 1,600,000
Fuel Water Transport and Miscellaneous	$ 4	acre	50,000	$ 200,000
Maintenance 2% of Equipment Capital	$ 117,800,000	per station	0.02	$ 2,356,000
Product Transport	$ 500	load	35,000	$ 17,500,000
Laboratory	$ 20,000	month	12	$ 240,000
Consultant (Fisheries, Aquatic Biologist, Accounting, Tax etc.)	$ 2,500,000	lump sum	1	$ 2,500,000
SUB TOTAL				**$ 67,164,000**
Contingency 15%				**$ 10,074,600**
TOTAL ANNUAL OPERATING, MAINTENANCE AND MONITORING COSTS				**$ 77,238,600**

ANNUAL SALES	Unit Price	Unit	Number	Cost
Pay for Performance Fee Phosphorus removal	$ 100	pound	1,011,700	$ 101,170,000
Harvesting Fee	$ 200	acre	12,000	$ 2,400,000
Product Sales (compost)	$ 30	cy	550,000	$ 16,500,000
TOTAL SALES				**$ 120,070,000**
ANNUAL RETURN				**$ 42,831,400**
20 year Internal Rate of Return (IRR)				**30.7%**
Profit Margin				**35.7%**

Sales are dominated by the **Pay-for-Performance** fees estimated at $100 per pound of phosphorus, with 1,011,400 pounds removed resulting in over $101 million received annually. The product sales at $16,500,000 are based upon bulk compost and are a minor component of sales. In fact, return from compost sales will be close to the cost of transport as noted in Table 1. Included in sales is a $200 per acre fee for clearing and maintaining 12,000 acres free from topped-out Hydrilla.

Based upon these costs and sales, as shown in Table 1, the Internal Rate of Return for 20 years is estimated at 30.7% with a profit margin of 35.7%.