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SolarBee Experience in Controlling Submersed Macrophytes

(updated October 6, 2006)

1. Background

Pump Systems, Inc. (PSI) has been in the water movement business since 1978, and developed the solar-powered water circulation technology in 1998 for the primary purpose of enhancing dissolved oxygen (DO) distribution in wastewater ponds using renewable energy. In September 2001, PSI named this technology the "SolarBee". The earliest machines pumped 2,500 GPM and were applied mostly in wastewater ponds, though a few were deployed in lakes up to 63 acres of surface area. In mid-2002, the flow rate was increased to 10,000 GPM enabling broader applications in a variety of lakes. The SolarBee's near-laminar flow reaches out long distances, up to 35 acres or more per machine; the circulation effect is additive, and we are now in over 160 ponds, lakes and reservoirs from less than 2 acres to more than 12,000 acres in size. The ability to completely mix 100s of acre-feet with one machine has been proven by dye tests conducted by the EPA in Ohio (see <http://www.solarbee.com/ww.shtml>), and by chlorine tracer tests performed in an 11 acre x 90 MG potable water tank in San Francisco, CA.

In lakes, each SolarBee is deployed in one of two ways, depending on the goals of the owner: (a) with the intake hose shallow, to mix just the upper waters (epilimnion) to control blue-green algae (cyanobacteria) blooms. Typical results of mixing the epilimnion include noticeable improvements in water clarity, in part because of increased autoflocculation and/or because algal nutrients are now being taken up by more digestible algae (rather than toxic, inedible blue-greens); zooplankton populations and fish communities thrive with the additional food source, thus reducing algal densities in the water column, or (b) with the intake hose deep, to provide hypolimnetic (bottom water) oxygenation and mixing in order to limit the upward progression of anoxic conditions from the lake bottom, and to minimize inorganic chemical release from the sediments. By October 2006, SolarBees had been deployed successfully in 160+ lakes for one or both of the above-mentioned purposes.

2. Chronology of Observed SolarBee Impacts on Submersed Macrophyte Growth

In 2000, the lake manager from Mirror Lake (North Dakota), one of the first lakes to use the original 2,500 GPM units, reported that submersed aquatic weed growth appeared to be less than in years past. This was not something we had envisioned as a potential impact of circulation, but we filed away this unsolicited observation. We heard similar unsolicited comments from a few other lake owners in 2001 and 2002, but nothing dramatic. In the summer of 2002 we installed 2 SolarBees in a 7-acre raw water supply reservoir in Lloyd, NY. The town's objective was to reduce the buildup of organic substances on the bottom of the lake, which they deemed responsible for imparting a taste

and odor to the water that rendered it totally unusable for the city's drinking water supply. An extremely dense crop of Eurasian watermilfoil (EWM) hindered the installation, almost preventing the use of a flat-bottom boat to deploy the units. A year after installing the units (late 2003), the lake manager reported that water clarity and quality were great; the reservoir was now back on line as a source of water, and, to their surprise, the milfoil had all but disappeared (although still widely prevalent in the other four lakes in their system.) One employee stated that "the weeds were so thick, you couldn't get an oar through them - now there are only sporadic traces." That got our attention, and we took notice when more and more lake owners reported submersed macrophyte reductions in 2003 and 2004.

By the end of 2004 there were SolarBees in about 75 lakes nationwide, with about ten of them reporting some degree of submersed macrophyte growth inhibition. Also noteworthy was that in all the lakes there was a varying degree of water clarity improvement due to the suppression of cyanobacteria blooms. In some cases, maximum Secchi depths went from a few feet to over 10 feet. The standard paradigm in lake management has been: 1) poison the algal community with a copper-based algaecide, 2) the water clears up as the dead algae settle to the bottom, 3) the submersed macrophytes rapidly takeover, 4) herbicides are then applied to the macrophytes, and 5) macrophytes die off and cyanobacteria blooms return. This never-ending cycle can be quite costly – both to the lake owner and to the lake's ecology. Nevertheless, the paradigm had been that once the waters were clearer, macrophytes took over. But in the 75+ (now 160+) lakes where water clarity has improved, invasive weeds have rarely made a significant presence. And if there were invasive weeds already, noticeable reductions were observed by lake owners. Consistent with this apparent inhibition was the lake in Lloyd, NY, as well as other lakes that had reported EWM reductions in previous years, that continue to report sustained EWM reductions each subsequent year. These independent observations suggest that the paradigm assumption of light limitation of submersed macrophyte growth may not be valid - since there was/is plenty of water clarity, yet invasive weed growth has not become a significant problem in any treated lake where the SolarBees are properly deployed consistent with the working hypothesis below.

3. Working Hypothesis of the Possible Mechanism for Impacting Macrophytes

The SolarBee pulls water from all directions at the depth of the intake hose. So if the intake hose is set at 10 feet, water will be pulled to the machine from the shoreline down to 10 feet in the water column. These near-shore surface waters that are pulled along the lake sediments down to 10 feet, and then back to the machine, are naturally enriched with dissolved oxygen from algal photosynthesis and oxygen transfer across the air-water interface. This slow, but constant movement of oxygen-rich water over the littoral zone sediments has been demonstrated in dye studies and empirically shown to reduce sludge in wastewater ponds, improve sediments for fish spawning, and promote sediment compaction.

We believe that this slow, but continual oxidation of near-shore lake sediments is the likely key to submersed macrophyte control through circulation. Based on consultations with leading aquatic macrophyte scientists with the Army Corps of Engineers and a review of relevant literature, our working hypothesis is the following:

The continual oxidation of littoral sediments and overlying waters negatively impacts the health and growth of invasive submerged aquatic plants by limiting ammonia-N availability.

To properly examine this comprehensive working hypothesis, we must break it down into sub-issues.

- 1) *Are sediments the major source of nutrients for submersed macrophytes?*
Yes: well-established in the scientific literature (e.g., Barko and Smart 1981),
- 2) *Can ammonium-N availability limit the growth of submersed macrophytes?*
Yes: well-established in the scientific literature (e.g., Nichols and Keeney 1976; Anderson and Klaff 1986; "Thus, unlike P, the availability of N may under some circumstances limit the growth of [EWM]" Smith and Barko 1990),
- 3) *Can enhanced oxygen availability promote the oxidation of ammonium-N to nitrate-N?*
Yes: well-established in the scientific literature (e.g., any basic microbiology or limnology text book describes bacteria-mediated nitrification),
- 4) *Can SolarBee-induced circulation oxidize littoral sediments?*
Yes: empirical evidence supporting that the near-laminar return flow of oxygen-rich water back to the machine oxidizes littoral sediments include: EPA dye study, sludge digestion in wastewater ponds, sediment compaction along lake shores, dramatic increases in fish spawning in littoral areas, and
- 5) *Is there any empirical evidence that SolarBee-induced circulation negatively impacts submersed invasive macrophytes?*
Yes: Yellowing and subsequent death of plants, consistent with severe nitrogen deficiency; effective, sustainable aquatic weed reduction (as a secondary benefit) with SolarBees in about 20 lakes since 2000; negative impact on lightly-rooted invasives, but not effective on plant species with deeper roots or rhizomes, e.g., water shield (*Braenia schreberi*) and white lily (*Nymphaea* sp.) or emergent plants such as cattail (*Typha* sp.); in the 160+ lakes and reservoirs where SolarBees have significantly improved water clarity since 2000, invasive aquatic macrophytes have rarely made a significant presence and have been apparently inhibited; and, a Canadian company sells an up-flow, wind-powered circulator that has been reported to effectively control EWM in 20-30 lakes and ponds since 1999 (but with a much smaller affected area per machine).

The sub-issues above, together with the brief bibliography below, clearly illustrate that the ammonia-N limitation working hypothesis does not create any new theory or new science requiring peer-review for acceptance. Every single relevant issue has been either long established in the peer-reviewed scientific literature, inherently logical, and/or is well established in the empirical evidence - the only new issue we raise is the scope or sphere of influence. But the concept of controlling certain invasive aquatic macrophyte species by limiting sediment ammonia-N availability through sediment modification and/or oxidation already has very strong support in the published scientific literature. This is also consistent with the long-held paradigm described above, except that the real reason why submersed macrophytes experience rapid growth after the blue-green algae are killed is because decomposing algae provide a significant input of ammonia-N to the sediments, thus fertilizing the aquatic weeds. So, one ancillary benefit of blue-green algae bloom control through epilimnetic circulation is to reduce N inputs to the sediments for aquatic plant uptake (which is part

of the slow approach for macrophyte control).

The following are among the peer-reviewed, scientific articles relevant to the inhibition of some submersed aquatic macrophyte species through sediment modification and ammonia-N limitation:

Anderson, M.R. and J. Kalff (1986). Nutrient limitation of *Myriophyllum spicatum* growth in situ. *Freshwater Biol.* 16: 735-743.

Barko, J.W. and R. M. Smart, (1981). Sediment-based nutrition of submersed macrophytes. *Aquatic Botany*, 10: 339-352.

Barko, J.W. and R. M. Smart, (1986). Sediment-related mechanisms of growth limitation in submersed macrophytes, *Ecology*, 67(5): 1328-1340.

Barko, J.W. et al. (1991). Sediment interactions with submersed macrophyte growth and community dynamics. *Aquatic Botany*, 41: 41-65.

Barko, J.W. et al. (1986). Environmental factors and their consideration in the management of submersed aquatic vegetation: a review. *J. Aquat. Plant Manage.* 24: 1-10.

Barko, J.W. et al. (1988). Interrelationships between the growth of *Hydrilla verticillata* (L.f.) Royle and sediment nutrient availability. *Aquatic Botany*, 32: 205-216.

James, W.F. et al. (2004). Impacts of sediment dewatering and rehydration on sediment nitrogen concentration and macrophyte growth. *Can. J. of Fish. and Aquatic Sc.*, 61(4): 538-546.

Lillie, R.A. and J.W. Barko (1990). Influence of sediment and groundwater on the distribution and biomass of *Myriophyllum spicatum* L. in Devils Lake, Wisconsin, *J. of Freshwater Ecology*, 5(4): 417-426.

Nichols, S.A. and D.R. Keeney (1976). Nitrogen nutrition of *Myriophyllum spicatum* uptake and translocation of ¹⁵N by shoots and roots. *Freshwater Biol.* 6:145-154.

Smith, C.S. and J.W. Barko (1990). Ecology of Eurasian watermilfoil, *J. Aquatic Plant Manage.*, 28: 55-64.

4. Comments on a Few Case Studies

PSI has initiated a number of *in-situ* tests at several lakes throughout the country. The following is a brief synopsis of a few of the tests.

Tahoe Keys Marina was a 2.5-year test conducted at our expense, which we have just now completed. The test was a successful learning experience, and a number of local residents noticed better water quality and some weed reductions in the marina - they also have expressed regret that the SolarBees have been removed due to the conclusion of the test. The test was a success not because we eliminated EWM in the marina, because we did not. The test was successful because we learned more definitively that if the weeds are growing below the level of the intake of the SolarBee, the SolarBee does not have much impact on them. SolarBee circulation effectively oxidizes the

sediments above the level of the intake, but not below. At Tahoe Keys Marina we were mandated to keep the intake hoses about 3-4 feet above the bottom because of concerns of sediment resuspension. The marina bathymetry is such that there is more relatively flat bottom than sloping sides, so SolarBee circulation did not impact as much of the marina sediments as hoped for. However, the water clarity was improved so plants at the bottom did grow, but not as high as before. Marina personnel also reported frequent removal of loose EWM from the marina, which is significant evidence as EWM does not typically release from the sediments during summer growth, and much of the EWM that was being collected did not appear to be very healthy - we have seen the exact same effect in a number of other lakes as well. In contrast, hydrologically-connected Beaver Lagoon, with more gently sloping sides, did show significant reductions of EWM following SolarBee installation. In years past, EWM completely covered the surface of Beaver Lagoon to the extent that birds could walk on it without sinking - now the surface is essentially free of EWM. We gained valuable information (e.g., the importance of basin bathymetry with respect to SolarBee intake depth) with the Tahoe test, and every single result was consistent with the ammonia-N limitation working hypothesis.

Monona Bay (Madison, WI) is an on-going test that began in May 2005. Monona Bay is about 160 acres with a relatively flat bottom. Six SolarBees were installed at the end of May 2005, with the intake hoses set about 2 feet off the bottom due to concerns of sediment resuspension – similar to Tahoe Keys Marina (note: as the flow back to the machine is very slow, it is virtually impossible for the SolarBee to cause sediment resuspension when deployed properly). Local residents reported better water clarity, no significant blue-green algae blooms, and no noxious odors. However, the EWM was already near the water surface when the units were installed. Similar to Tahoe Keys Marina, and other lakes where SolarBee installations took place in early summer, some of the macrophytes turned sickly, released from the sediments, and came to the surface. Visually this was not attractive, but we were informed that the EWM was negatively impacted in parts of the lake. But because of the fairly flat basin bathymetry, a significant part of the bottom sediments were below the level of the SolarBee intake hoses and therefore not effectively oxidized. Results from 2006 were similar to 2005 for similar reasons – permitting issues prevented the units from being redeployed until late May after the EWM had already been well-established. Although these results confirmed the importance of bathymetry with SolarBee deployment, it is hoped that both the time of deployment and the depth of the intake hoses will be adjusted for 2007 for more effective treatment.

Lake Steilacoom, a 320-acre lake in Washington, demonstrated the different results that can be achieved when units are deployed in the fall rather than the spring or summer. In 2005, aquatic weeds and blue-green algae blooms covered the lake, with Secchi depth visibility around 1-3 feet – typical summer conditions for many years. In November 2005 we installed 9 SolarBees with the intake hoses set around 12 feet deep. During the summer of 2006 there were no significant algal blooms, water clarity often reached down to the bottom at 17 feet, and submersed aquatic weeds were only sporadically present from 0-12 feet in depth, though there were some present below 12 feet. Apparently there was significant ammonia-N depletion in the sediments before the growing season started. The homeowners association honored a previously scheduled herbicide application in late June, but the applicator reported being surprised that there were so few weeds there to kill.

There are over twenty ponds, lakes and reservoirs since 2000 reporting significant reductions of one or more invasive submersed aquatic macrophyte species, and we have independent testing for several more lakes scheduled for 2007. Plant species that have been specifically observed to be

negatively impacted include Eurasian watermilfoil (*Myriophyllum spicatum*), curly leaf pond weed (*Potamogeton crispus*), sago pondweed (*Potamogeton pectinatus*), coontail (*Ceratophyllum demersum*), American elodea (*Elodea canadensis*), and hydrilla (*Hydrilla verticillata*). These are all relatively lightly-rooted plants susceptible to being impacted by sediment oxidation and modification. On the other hand, testing has shown little impact on more deeply-rooted species such as water lilies (*Nymphaea* sp.) and water shield (*Braenia schreberi*). This is viewed as a positive aspect as many native species tend to be more deeply rooted, and thus not inhibited by oxidizing the superficial sediments.

Finally, we presented our working hypothesis, together with empirical data and photographic evidence of sickly plants collected from several lakes to help explain the ecological relationships consistent with observations made in over 160 lakes, in a technical presentation at the national Aquatic Plant Management Society's (APMS) annual meeting in July 2006. Appreciating that presenting at the national APMS annual meeting is a form of peer-review, we specifically asked the audience if anyone could find in the scientific literature or from their own professional experience any shred of evidence that would otherwise contradict any aspect of our working hypothesis, or provide any alternative explanation for the consistent observations made by independent lake owners. The silent response from the room full of aquatic plant management scientists affirmed our conclusions; this was not surprising considering the strong empirical and scientific literature support for ammonia-N limitation of growth.

Summary

We have considerable confidence that SolarBee-induced circulation can reduce and inhibit the growth of certain invasive aquatic weeds in freshwater lakes over time. Although we are still fine-tuning SolarBee deployment parameters, best results have occurred when the units were installed in the fall and the intake hoses were placed below the depth of the macrophyte beds. Evidence of ammonia-N limitation is very strong, and there are university-based studies and other independent tests currently under way to document the physiological mechanisms involved, and to indicate how to deploy SolarBees for optimal and/or predictable control. Additionally, we are collecting data on other aquatic macrophyte species that may also be impacted. We do not anticipate the same impact for all submersed aquatic species as we have seen for EWM, and there may be some plants whose physiology is unaffected by SolarBee-induced circulation. We hope to be able to fine tune this application so targeted areas can be best addressed without necessarily impacting other macrophyte communities that provide important ecological functions in the lake.

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