Medora Corporation

SolarBee Experience in Inhibiting Submersed Macrophyte Growth

1. Background

SolarBee technology was developed starting in 1998, and by 2002 the flow rate had been quadrupled to 10,000 gallons per minute (gpm) leaving each machine. The ability to achieve long distance circulation of 100s of acre-feet with one machine has been proven by dye tests conducted by the EPA in Ohio, Chlorine Tracer Tests performed in an 11 acre 90 MG potable water tank in San Francisco, CA, Nitrification Study by Glendale, CA, a Wastewater Mixing Study by Bennett, CO, a dye test in Bella Vista, AR and others.

SolarBees are now used in over 400 lakes, reservoirs and ponds, from < 1 acre to nearly 12,000 acres in size, and for both partial-lake and whole-lake applications.

In a few lakes, SolarBee machines are set for hypolimnetic circulation, with the intake near the bottom of the lake, to reduce methymercury, iron, manganese, and sulfides. See http://lakes.medoraco.com/hypolimnetic-deployment for details.

However in most lakes, SolarBee machines are set for epilimnetic circulation, with the intake at only 5-10 feet deep, for the purpose of reducing or eliminating cyanobacteria (blue-green algae) blooms, as shown at http://lakes.medoraco.com/epilimnetic-deployment. It was in these lakes that the effects SolarBees have on macrophytes were first noticed. (See Figure 1).

2. Chronology of Observed LDC Impacts on Submersed Macrophyte Growth

<u>Mirror Lake, Hettinger, ND.</u> In 2000, the lake manager from Mirror Lake (North Dakota), one of the first lakes to use the original 2,500 gpm units for epilimnetic circulation, reported that submersed aquatic weed growth was noticeably less than in years past.

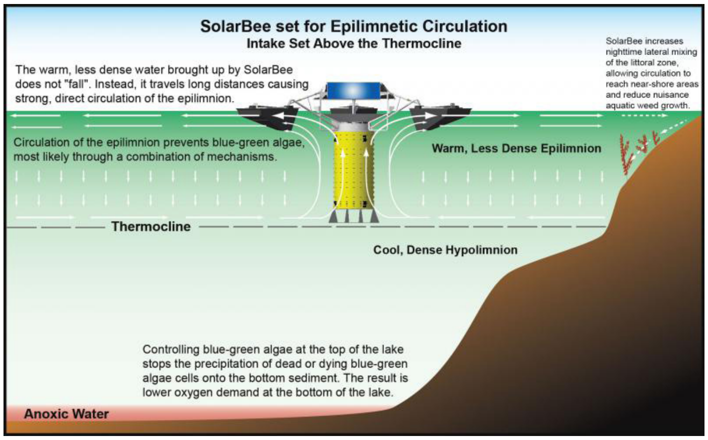

Figure 1: Diagram of epilimnetic mixing.

<u>Highland Reservoir #5, Lloyd, NY.</u> In the summer of 2002, one SolarBee was installed into each of two lobes of 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 greatly improved; the reservoir was now back on line as a source of water, and, to their surprise, the EWM 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."

<u>Others.</u> 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. In all of these 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 17 feet.

3. A Problem for the Light Limitation Theory.

For many years, the standard paradigm in lake management has been: 1) apply copper- based algaecide, 2) the water clears up as the dead algae settle to the bottom, 3) with increased light, submersed macrophytes rapidly take over, 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. But in the hundreds of SolarBee-treated 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.

Improved water clarity, occurring simultaneously with reduced EWM growth, challenges the long-assumed theory that the growth of submerged macrophytes is mostly light-limited.

4. Working Hypothesis of the Possible Mechanism for Impacting Macrophytes

Based on consultations with leading aquatic macrophyte scientists with the Army Corps of Engineers, and a review of relevant literature, the working hypothesis on why the SolarBees reduces EWM is the following:

When set for epilimnetic circulation, a SolarBee increases the nighttime lateral mixing of the littoral zone as shown in the above diagram. This causes increased oxidation of littoral sediments, and negatively impacts the health and growth of invasive submerged aquatic plants by limiting ammonia-N availability.

To properly examine this comprehensive working hypothesis, it must be broken 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., basic microbiology and limnology text books describes bacteria-mediated nitrification),

4) Can SolarBee flow oxidize littoral sediments?

Yes: empirical evidence supporting increased oxidization of littoral sediments includes the Ohio EPA dye study, sludge digestion on sidewalls of wastewater ponds, sediment compaction along lake shores, and dramatic increases in fish spawning in littoral areas.

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) in over 30 lakes utilizing SolarBees; 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 300+ 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 also 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 relevant issue is long established, the only new issue raised is the scope or sphere of influence of a SolarBee machine.

Based on the above, the main reason for EWM reduction after cyanobacteria is controlled by SolarBees may be that there is no longer a continuously decomposing cyanobacteria crop contributing ammonia-N to the sediments and fertilizing the aquatic weeds. In short, with less cyanobacteria, there will be less aquatic weeds.

There are over 30 ponds, lakes and reservoirs since 2000 reporting significant reductions of one or more invasive submersed aquatic macrophyte species due to SolarBee circulation. 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), and American elodea (Elodea canadensis). 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 superficial sediments. Unfortunately, the aquatic weed hydrilla (Hydrilla verticillata) also has roots and runners several inches below the sediment surface, and testing in Florida has not yet demonstrated a similar inhibitory impact as with lightly-rooted submersed plants.

The SolarBee effects on lake clarity in over 170 lakes, along with the reduction of EWM growth in many lakes and the increase of EWM in none of the lakes, was presented at the national Aquatic Plant Management Society's (APMS) annual meeting in July 2006. Figure 2a and 2b are slides from that presentation.

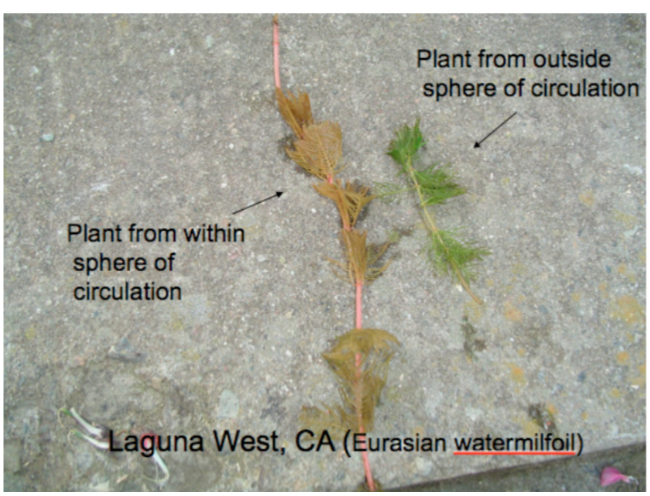

Figure 2a: Eurasion watermilfoil plamt comparison.

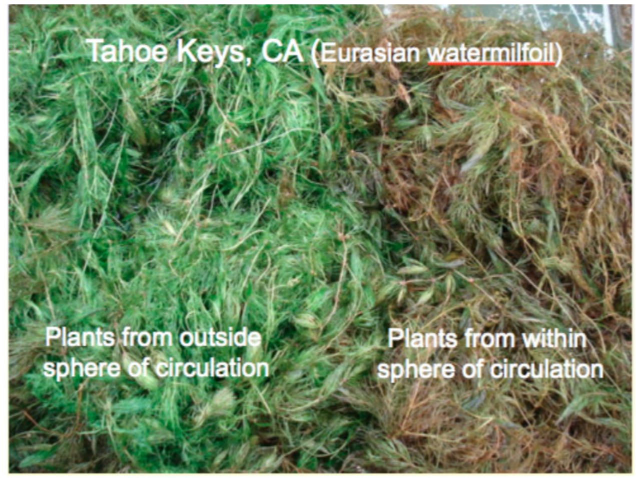

Figure 2b: Eurasion watermilfoil plamt comparison.

Appreciating that presenting at the national APMS annual meeting is a form of peer-review, Dr. Chris Knud-Hansen specifically asked the audience if anyone could find in the scientific literature, or from their own professional experience, any contradiction to the SolarBee ammonia-N limitation theory. There were none.

The following peer-reviewed papers are 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. Aquatic 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 Mange., 28: 55-64.

5. Application Guidelines & Ongoing Research

This is what has been learned so far about applying SolarBee machines to reduce invasive macrophytes:

1) Invasive macrophyte reduction with SolarBee is more effective in whole-lake treatments than in partial-lake treatments. When treating just one cove of a large lake, it's possible that the lack of return flow to the SolarBee from the main part of the lake negatively impacts the macrophyte reduction.

2) Macrophyte reduction is better at smaller SolarBee spacing. For large SolarBee machines, that means 10-15 acres per unit instead of 35 acres usually used for cyanobacteria control.

3) Macrophyte reduction with SolarBees is better after the first fall and winter of circulation. If machines are installed in late spring or early summer, macrophyte growth is not immediately inhibited. However, as the summer progresses plants frequently become unhealthy, dislodge from the sediment substrate, and float to the lake surface. These dislodged plants can be so thick on the surface that the SolarBee requires more computerized "reverses" to clean the impeller, or else even some manual cleaning. But as long as SolarBee circulation continues throughout the year, aquatic weed suppression also continues unabated into subsequent years.

4) It is important to distinguish the machine from the mechanism. The hypothesized mechanism is ammonia-N limitation through sediment oxidation, and through a reduction of continuously dying cyanobacteria which had previously been supplying the macrophytes with ammonia-N. If ammonia-N does not become limiting, then plants will continue to grow. For example, if there are significant ammonia-rich groundwater inputs, oxidizing superficial sediments will not be effective. It is also possible that substantial leaf litter accumulation on the lake sediments can contain high ammonia concentrations in the interstitial water, also making submersed macrophyte control via sediment oxidation difficult.

5) There have been numerous tests conducted where SolarBee units were provided at no cost to the lake owner(s). The results, although variable, are completely consistent with the working hypothesis.

For example, Tahoe Keys Marina, CA has a relatively flat bottom. Authorities mandated, because of misguided concerns of sediment re-suspension, that the SolarBee intake plates be two to three feet above the bottom. The results were that bottom sediments which were below the intake plate were not oxidized, and EWM bottom growth was not prevented in those areas. But EWM in shallower waters was impacted as indicated by the photo above, and significant EWM reductions were observed at the adjacent Beaver Cove, a shallower part of Tahoe Keys Marina.

A 2-year demonstration at Monona Bay, WI showed similar results when the SolarBee intake plates were required by authorities to be 3 ft above the bottom. Results there were further compromised by the fact that units were installed at the end of May and removed in October of each year, though homeowners around Monona Bay still reported visible aquatic weed reductions in shallower near-shore areas.

At Lake Cochituate, MA, 2 units were installed in fall of 2006, but one unit was moved during the winter and the other did not run for 4 months. Also, these were cove, partial lake treatments where most of the flow did not return to the SolarBee machine, and the results showed that EWM was not impacted significantly.

At Conesus Lake, NY, measureable EWM reductions occurred in treated areas (i.e., in littoral waters above the depth of the SolarBee intake hose) in both years (2006-07) of the study. This is a case where only half the recommended units were used in the pilot study because of budgetary constraints. And although EWM reductions were noted, the consultant for the study concluded that because observed differences did not meet a 95% confidence level, EWM reductions could not be attributed to SolarBee-induced circulation. Not only was the 95% threshold for an ecological pilot study unreasonable, the consultant also incorrectly assumed that EWM growing at depths beneath the SolarBee intake hose should be also impacted.

The best documented SolarBee macrophyte study to date was conducted in Tinmouth Pond, VT. This is where one SolarBee was installed in 2006 to treat one half of a 78-acre lake. Detailed transect mapping of both invasive and native plants conducted prior to and after the installation showed EWM reductions only in the treated half of the lake, while native species (including rare and protected species) did well. Water clarity and overall lake health was also noticeably better in the treated half. So, in 2008 the lake has owners acquired a second unit to complete treatment of the whole lake. There have not been any cyanobacteria blooms and water clarity has noticeably improved since both units were installed. With improved water clarity and shallow depths throughout the lake, there has been a reemergence of native aquatic plants. Annual transect mapping has documented that native plants which accounted for 47% of the coverage in 2005 increased to 94% in 2009. And by 2009 the EWM covered only 3.4% of the lake and many remaining plants looked scrawny and unhealthy, consistent with ammonia-N limitation. So although EWM still has a small presence in Tinmouth Pond, it is neither dominating nor outcompeting native plants.

6. Summary

Since 2002, Medora Corporation has gained considerable confidence that SolarBee-induced circulation can reduce and inhibit the growth of certain invasive aquatic weeds in freshwater lakes over time.

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