MEMORANDUM

To: Vic Lucero, Water Quality Supervisor, City of Thornton

From: Christopher F. Knud-Hansen, Ph.D.

Date: December 8, 2003

Re: Evaluation of SolarBees for blue-green algae control in East Gravel Lake 4

Introduction

The City of Thornton uses the South Platte River as a primary source for drinking water following the river's partial diversion into the East Gravel Lake (EGL) system via the Burlington Canal (Pontius Water Consultants 2003). The EGL system consists of four lakes connected by gated conduits. South Platte River water diverted through the Burlington Canal first enters EGL2, then goes into EGL3, then EGL1, and finally into EGL4 all by gravity flow. Water from EGL4 is then pumped into the Columbine Water Treatment Plant (CWTP) for processing, treatment, and ultimate distribution.

South Platte River water entering EGL2 through the Burlington Canal typically contains a considerable percentage of secondary effluent from the wastewater treatment plant for the Cities of Littleton and Englewood, and to a lesser extent from Centennial's wastewater treatment plant. This effluent is rich in soluble nitrogen (N) and phosphorus (P), and can stimulate algal blooms under favorable temperature and light conditions. In recent years during the summer months, blooms of blue-green algae (i.e., cyanobacteria) have occurred in the EGL system - including EGL4 - resulting in significant chemical costs (primarily for copper sulfate and powdered carbon) to deal with taste and odor problems associated with blue-green blooms.

The SolarBee (Figure 1; manufactured by Pump Systems, Inc., Dickinson, ND) is a solar-powered device which pumps water from a specific depth up to the surface of a pond or lake, effectively creating a continuous circulation pattern in the waters above the intake depth. Because blue-green algae require quiescent waters for optimal growth, they do not do well when the lake's surface is continually disturbed (Pearl 1995).

On April 25, 2003, three SB10000F SolarBee units were installed in EGL4 (Figure 2) with the goal of managing or eliminating blue-green blooms in the lake. This technical memorandum evaluates the performance of the SolarBees for the period of May - September 2003, and reviews relevant EGL4 water quality data in order to provide recommendations for the placement of existing SolarBees, and the potential utility of additional SolarBees to the CWTP.

Figure 1. Photo of a SolarBee unit similar to the three units installed in EGL4.

Figure 2. Photo (by V. Lucero) showing one of the SolarBee units operating in EGL4 (the pump station can be seen in the background).

Materials and Methods:

SolarBee installations and adjustments: EGL4 is somewhat rectangular in shape with the long axis following a north-south orientation. On April 25, 2003, three SolarBee SB10000F units were installed mid-lake and linearly along the north-south axis of EGL4 (Figure 3). Intake levels were set initially at about 18'. Field measurements indicated thermal stratification and bottom water deoxygenation in June, so the intakes were lowered to be just off the bottom to promote whole lake mixing. However, the anchors that came with the SolarBees did not hold fast, and all three units slowly drifted eastward during May and June. On June 30th the SolarBees were moved back to their original locations, and secured with additional anchorage. On July 22nd the intake levels for all three units were raised back to 18', or at the approximate level of the thermocline. This was done because EGL4 had thermally stratified with the shifting of the SolarBee units to the east, and four SolarBee units were considered necessary to completely mix the lake once it had stratified (as opposed to maintaining spring mixed conditions throughout the summer). Therefore, the intakes were raised to 18' in order to keep the upper waters sufficiently turbulent to prevent blue-green algae blooms.

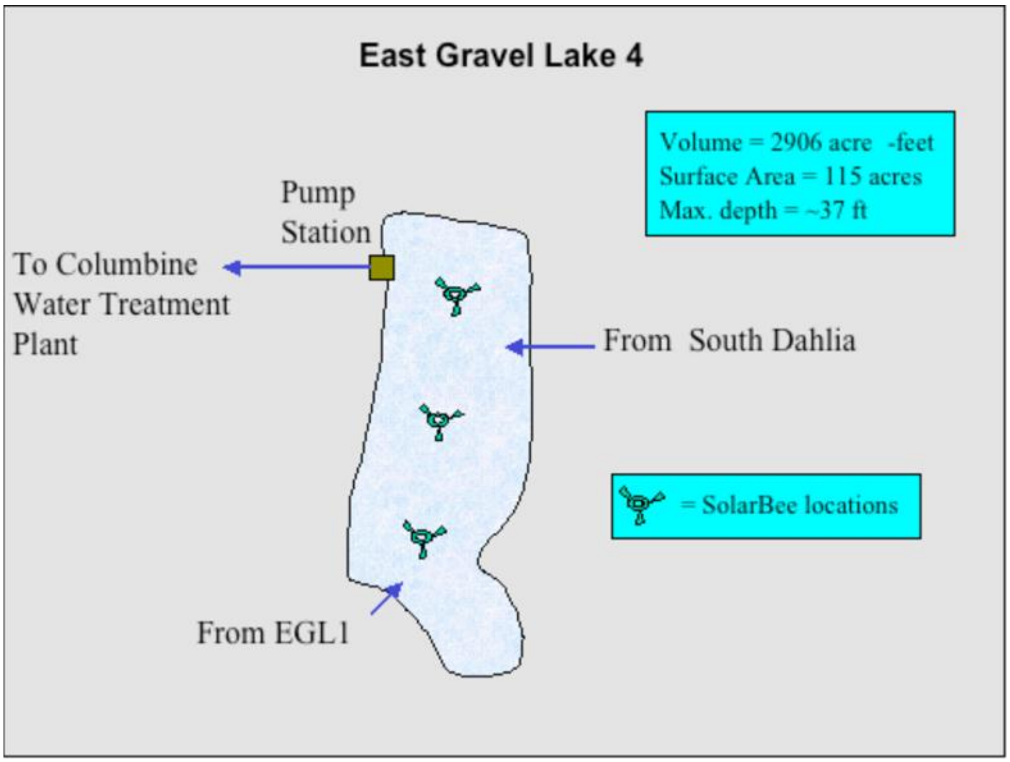

Figure 3. Schematic drawing of EGL4 showing locations of the three SolarBees.

Field measurements: Field measurements were taken weekly by CWTP personnel at three in-lake stations beginning on March 31, 2003. The three field stations were about 50' away from each SolarBee, and were designated EGL4_SBS (near the south SolarBee and the conduit from EGL1), EGL4_SBM (near the middle SolarBee), and EGL4_SBN (near the north SolarBee and the pump station into the CWTP). Variables measured were Secchi depth, and vertical profiles of water temperature, dissolved oxygen (DO), pH, and conductivity. Measurements for vertical profiles were made at the surface and at 5' intervals down to 5' from the bottom with a Yellow Springs Instrument (YSI) equipped with a submersible multi-parameter probe.

Water quality measurements: Water samples were collected every 2-3 weeks at three depths at each of the three in-lake stations. The three sample depths were 1) surface, 2) a mid-depth, and

3) a few feet off the bottom. Water quality measurements relevant to evaluating the SolarBees' performance were the following: algal counts, chlorophyll *a*, nitrate-N, ammonia-N, and ortho-P. All analyses were performed at the CWTP's water quality laboratory.

Results and Discussion:
Although considerable data were collected, the scope of this report is limited to only those results that help evaluate the SolarBees' performance and their utility towards reducing blue-green algae blooms. Therefore, the focus of discussion below is on 1) water column thermal stability, 2) DO distribution, and 3) algal productivity.

Thermal stability/mixing: Figure 4 below provides the vertical temperature profiles from March - September 2003. From March into early May, EGL4 remained fairly well-mixed naturally while the water temperature increased from about 7EC to about 13EC. From early May to early June the lake exhibited thermal stratification below about 10', with the upper 10' of the water column remaining well-mixed. In early June the intakes were lowered to just off the bottom to promote whole-lake mixing; but in fact, mixing was incomplete as indicated by associated DO profiles (Figure 5). As the SolarBees slowly drifted to the east during May and June, they were

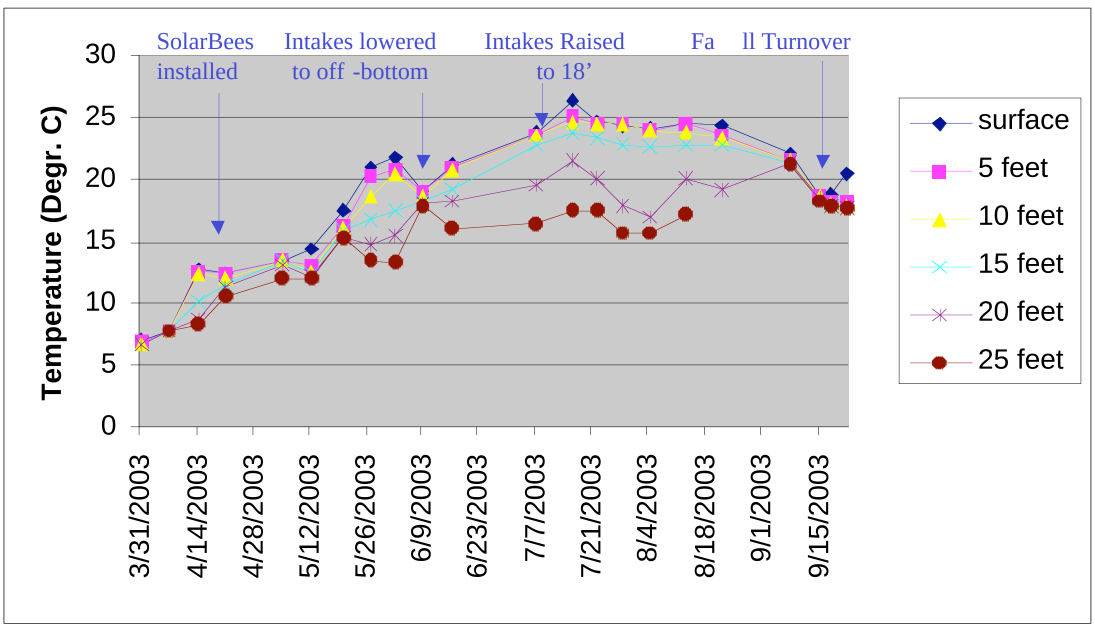

Figure 4. Temperature vertical profiles in EGL4 during March - September 2003.

unable to totally destratify the lake following the lowering of the intakes in early June. Once the intake levels were raised back to 18' on July 18th, the upper 15' of the water column remained well-mixed while the bottom waters remained thermally stratified. This condition lasted until September 14th, when nighttime temperatures were sufficiently cold to increase surface water density to where this water sank to the bottom. This annual event is called the fall turnover. As long as the lake remains ice free, the lake will continue to mix naturally until the spring when surface water temperatures warm again.

Dissolved oxygen distribution: Vertical profiles of dissolved oxygen (DO) concentrations often illustrate stratified conditions in a lake more clearly than do thermal profiles. From early April until mid-June the SolarBee intake levels were set at 18'. During this period, DO concentrations were essentially identical from the surface down to about 20' (Figure 5). At the same time, DO concentrations at the 25' depth were always less than the waters above, though bottom water DO concentrations varied together with variations in surface waters. That is, oscillations in DO concentrations during this period were observed throughout the water column, even though bottom water concentrations remained consistently lower than surface water values. This result suggests that the SolarBees were effective at mixing the water column down to the intake levels, but still influenced DO concentrations down to the 25' depth.

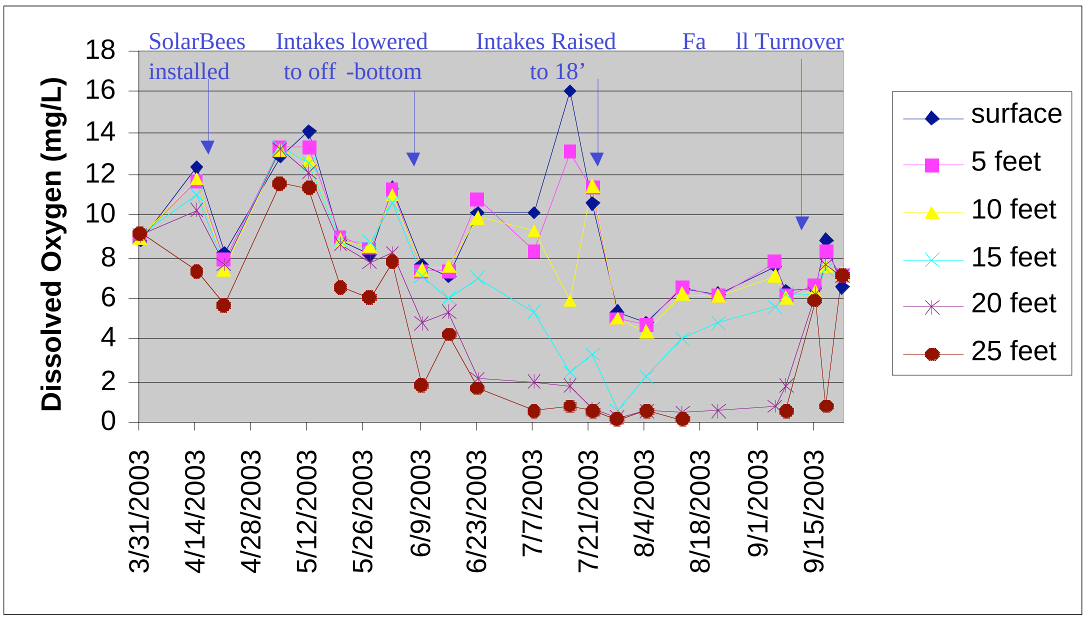

Figure 5. Dissolved oxygen vertical profiles in EGL4 during March - September 2003.

When the SolarBee intakes were lowered to just off the bottom in early June, however, DO concentrations at the 20' and 25' depths generally remained below 2 mg L^{-1} for the remainder of the summer. DO concentrations at the 15' depth also steadily declined until the SolarBee intakes were raised to 18' in July. Figure 5 shows that following this raise in intake levels, DO concentrations at 15' steadily increased, though not quite reaching the uniform levels measured in the upper 10' of water. This rise in DO concentrations at the 15' level illustrates the SolarBees' ability to mix DO-rich surface waters down to - but not necessarily below - the intake level.

The difference between the mixing effect of the three SolarBees set at 18' during the April to early June period (i.e., influencing DO concentrations at 25') versus the mid-July to September period (i.e., influencing DO concentrations down to 15') reflects the different water density gradients between spring and summer. Water density is a function of water temperature, and the temperature/density gradient (i.e., resistance to mixing) was greater during the summer than during the spring (Figure 4). Nevertheless, both Figures 4 and 5 clearly indicate that the SolarBees were able to keep the top 10' in EGL4 well-mixed throughout both the spring and summer.

Algal productivity: With sufficient light and suitable water temperatures, algae will grow in response to a supply of soluble nitrogen (N) and phosphorus (P). The most common indicator used to assess algal biomass is through the measurement of chlorophyll *a* concentrations, the predominant algal pigment used for capturing light energy for photosynthesis.

Figure 6 shows the variations of chlorophyll *a* concentrations in EGL4 from January through September 2003. Observed increases in EGL4 algal biomass correlate very well to known water

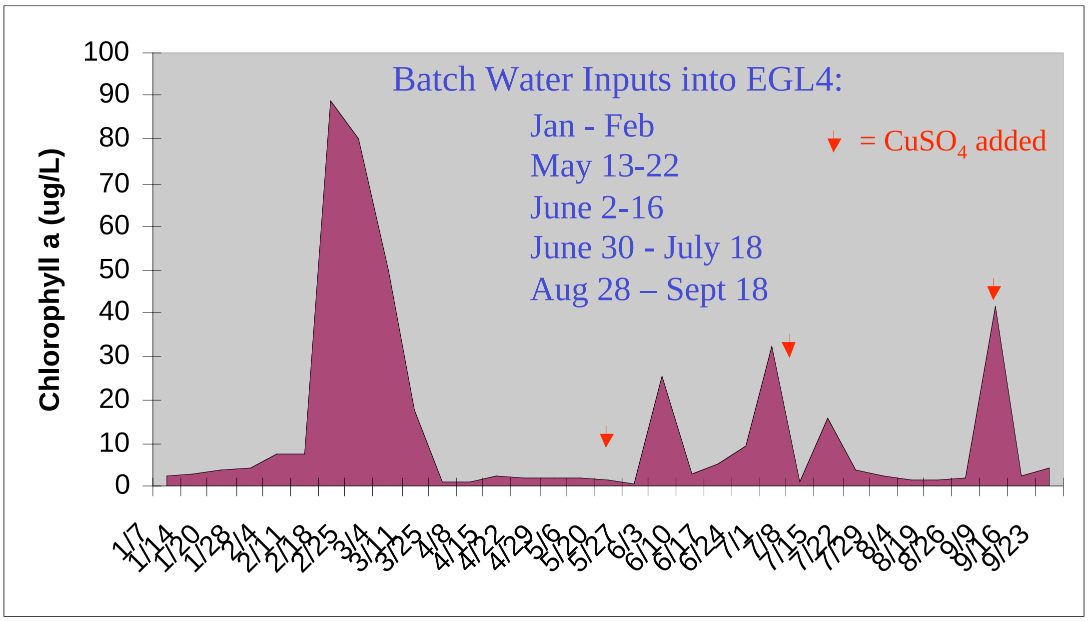

Figure 6. Chlorophyll *a* concentrations measured in EGL4 during 2003.

inputs from EGL1. Unlike previous years, when the conduit between EGL1 and EGL4 was left open and the two lakes were allowed to "float" together, during the summer of 2003 the gate remained closed except for periods when water from EGL1 was permitted to flow into EGL4. Because water from EGL1 has higher N and P concentrations than EGL4 (Pontius Water Consultants 2003), algal production in EGL4 increased following each batch input of water from EGL1. The February-March chlorophyll *a* peak reflects the substantial volume of secondary treated effluent diverted into the EGL system from the Burlington Canal during January-February to help prepare for drought conditions.

It is worth noting that even though there were batch nutrient inputs from EGL1, the summertime total algae counts measured in EGL4 were noticeably smaller in 2003 than comparative summertime values for 2001 and 2002 (Figure 7). It is not clear whether the SolarBees were responsible for the lower algal counts in 2003, but their mixing effect would logically promote dispersal of the soluble N and P coming from EGL1 within EGL4's water column. Following this logic, there would be less N and P from EGL1 available for algal uptake in EGL4's photic zone (i.e. the upper part of the lake that receives solar radiation). Without a more rigorous nutrient loading evaluation, however, this explanation should be considered more hypothetical than conclusive.

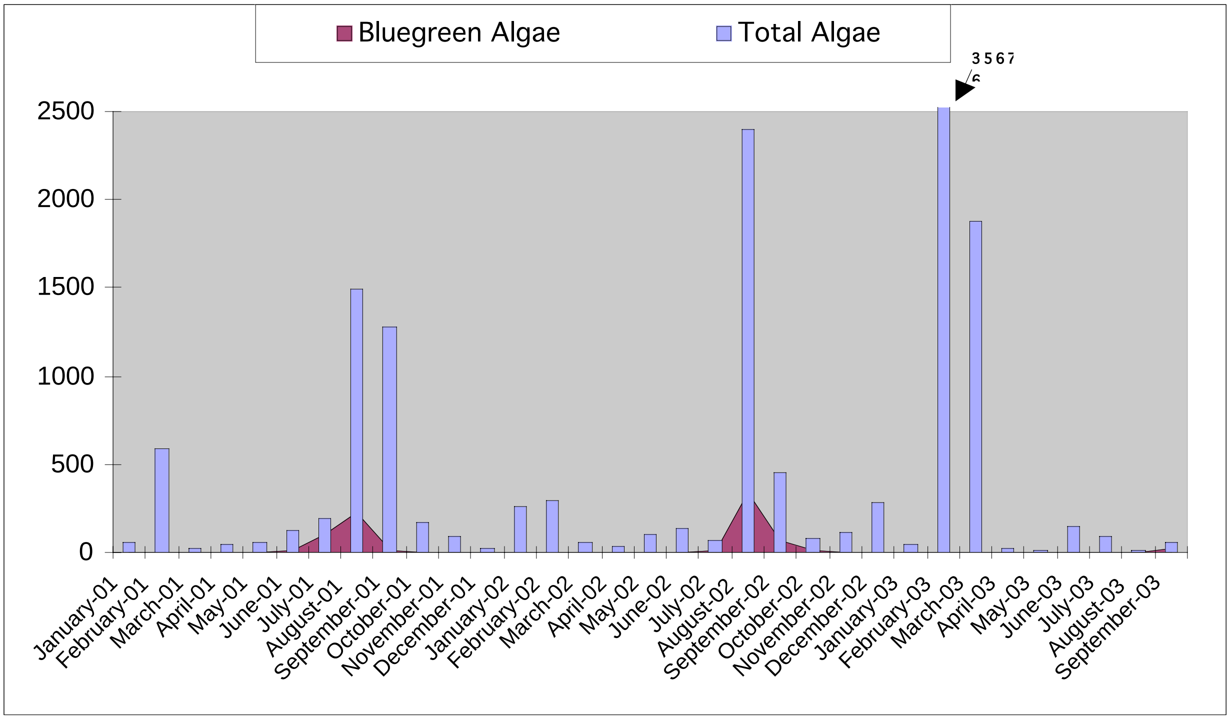

Figure 7. Total algal and blue-green algal counts (counts per mL) in EGL4 from 2001-2003.

Although the nutrient chemistry data collected at the three in-lake stations do not provide any direct assistance towards evaluating the effectiveness of the SolarBees, there are a few interesting observations worth noting. First, there were no systematic differences in N or P concentrations between the three in-lake stations - an observation consistent with lake water circulation and mixing via SolarBees. There were also no systematic differences in water quality with depth, with the exception of elevated soluble P, ammonia-N, iron and manganese concentrations in bottom waters that had become anoxic. As for seasonal differences, soluble P concentrations in EGL4 remained about 0.1 - 0.3 mg L^{-1} from March through September. In contrast, nitrate-N was about 3.5 mg L^{-1} in early spring, and decreased steadily to about 1 mg L^{-1} by September. This decreasing trend in nitrate-N concentrations is curious, and not readily explained by either algal growth or nutrient loading data.

Another curious observation was that chlorophyll *a* concentrations generally remained low (< 3 Φg L^{-1}) even though there was plenty of soluble N, soluble P, and light (Secchi depth measurements were frequently between 2-4 meters, except under bloom conditions). Algae in EGL4 apparently responded to nutrient inputs from EGL1 (Figure 6), but why summertime algal growth was not greater with ample soluble N, P, and light availability is not clear. It is also not clear whether or not the SolarBees were responsible in some way for this low algal growth in what would otherwise be considered favorable growing conditions.

Pertinent to the SolarBee evaluation, however, was the near absence of blue-green algae during 2003 (Figure 7). Figure 8 below presents the same blue-green algal count data as monthly averages. This figure indicates that there were blue-green algae observed in EGL4 during September 2003. However, these algae were most likely imported from EGL1, which was experiencing a major blue-green algae bloom at the time when water was moved into EGL4 (i.e, August 28 - September 18).

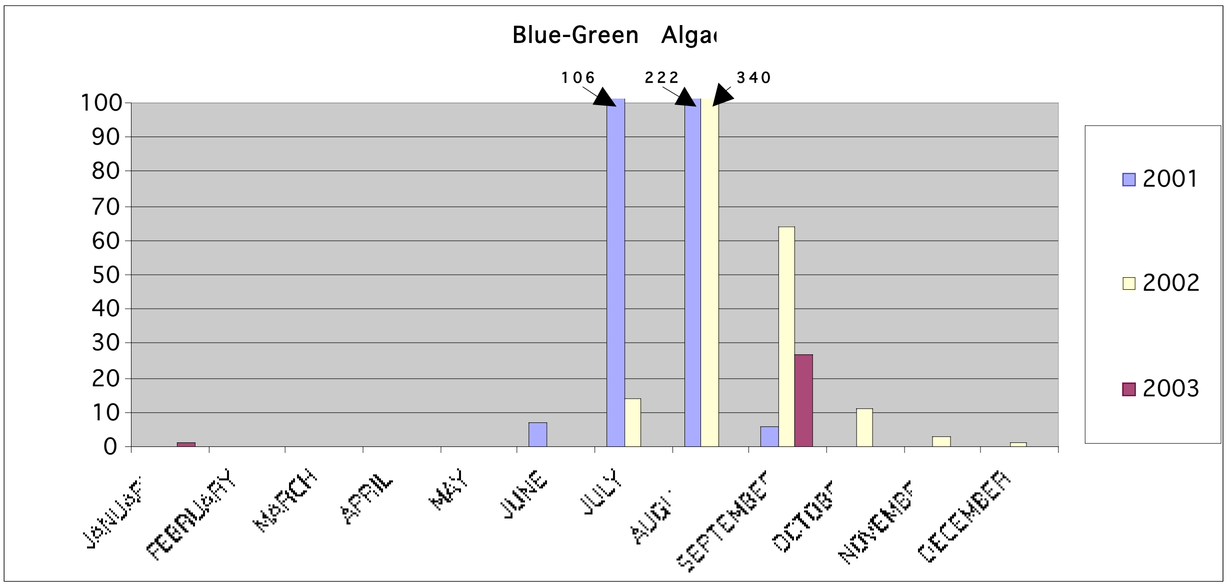

Figure 8. Total algal and blue-green algae counts (counts per mL) in EGL4 from 2001-2003.

The absence of blue-green algae in EGL4 can be directly attributed to the surface water turbulence created by the SolarBees. Of the dominant environmental factors favoring blue-green algal growth (e.g., high nutrient concentrations, warm temperatures, and quiet waters), the presence of calm, flat water is perhaps the most important (Pearl 1995). Blue-greens are not fast growers, but they are able to regulate their buoyancy and float to the surface when waters are calm. Staying on the surface gives them greater access to light, carbon dioxide, and atmospheric N - a competitive advantage over other planktonic algal species. When surface waters are turbulent, however, blue-greens lose this important ecological advantage and are unable to out compete the non-blue-green algal community.

Nevertheless, copper sulfate was added to EGL4 three times during the summer of 2003 (Figure 6). The additions made in May and July were precautionary, however, and were carried out in response to perceived algal (though not blue-green) blooms. The September copper sulfate addition was in response to the blue-greens observed in EGL4 which had been imported from EGL1.

The ability of SolarBees to effectively eliminate blue-green blooms by maintaining surface water turbulence has been well-documented in other lakes where they have been installed. In Colorado, for example, the City of Englewood had typically applied copper sulfate 1-2x per week in their drinking water reservoir, but has not used copper sulfate since SolarBees were installed in June 2002. St. Charles Mesa Water District, Pueblo, had four years of taste and odor problems due to blue-green algae, and has had no taste and odor issues since SolarBees were installed in March 2001. In the City of Lafayette, SolarBees installed in November 2002 improved the water quality in the reservoir used as a source for drinking water. And, Jefferson County also reported that the SolarBees installed May 2001 resolved their blue-green algae problems in their drinking water reservoir. The apparent success of SolarBees eliminating blue-green blooms in EGL4, therefore, is entirely consistent with ecological principles as well as results reported from other municipalities.

Conclusions and Recommendations:

The following *conclusions* can be reasonably derived from the water quality data:

- Three SolarBees kept surface waters in EGL4 mixed down to 10-15' throughout the spring and summer, until fall turnover mixed the whole lake on September 14th.
- For maintaining surface water turbulence, SolarBee locations appear to be fairly robust since surface waters remained well-mixed even when the SolarBees drifted eastward during May and June.
- Algal blooms observed in EGL4 during the summer of 2003 were associated with batch nutrient inputs from EGL1.
- Algal productivity in EGL4 was lower and more consistent in summer of 2003 as compared to 2001 and 2002 - even with the batch nutrient inputs from EGL1. It is not yet clear whether the SolarBees were in part responsible for the relatively low algal growth observed during the summer of 2003.
- The summer blue-green algae bloom typically observed in EGL4 was essentially eliminated in 2003, most likely due to the surface water turbulence created by the SolarBees. Blue-green algae blooms were observed in the three other EGL lakes where SolarBees were not installed.

The following are *recommendations* based on the above conclusions:

- Three SolarBee units are sufficient for controlling blue-green algae blooms in EGL4, and all three should be retained in current locations in order to eliminate the need for costly copper sulfate and powdered carbon additions in the future.
- The City of Thornton may wish to consider additional SolarBees for:
  - EGL4, if whole lake mixing is desired for the oxidation of lake sediments to control the release of soluble phosphorus, iron, and manganese.
  - EGL1, to eliminate blue-green blooms in EGL1 that could otherwise get transported into EGL4.
  - EGL2 and EGL3, to create whole-lake circulation to: 1) provide additional water treatment through enhanced oxygenation of the water column and lake bottom sediments, 2) eliminate blue-green blooms in these lakes, and 3) reduce or eliminate the potential for significant short circuiting of water

as Burlington Canal water travels through the EGL system (Pontius Water Consultants, 2003). If EGL2, EGL3, and EGL1 are combined into one large reservoir as proposed, SolarBees could still provide the same lake management benefits described above to ensure that good quality water is sent to EGL4.

Literature Cited:

Pearl, H.W., 1995. Ecology of Blue-Green Algae in Aquaculture Ponds. Journal of the World Aquaculture Society, 26 (2): 109-131.

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