Evaluation of Phosphorus Reduction in Wastewater Ponds by Injecting Aluminum Sulfate(Alum) Into A High Flow Solar Powered Circulator

at

Belle Plaine, MN Wastewater Treatment Facility

and

Isle, MN Wastewater Treatment Facility

Report produced by:

Jerry Myers, Applications Engineer, SolarBee / Pump Systems, Inc,
530 25th Ave. East
Dickinson, ND 58601   ph 701-225-4494

Mike Christensen, SolarBee Regional Manager
Wells, MN   ph 507-553-5590

Joel Bleth, Owner, SolarBee / Pump Systems, Inc,
530 25th Ave. East
Dickinson, ND 58601   ph 701-225-4494

Willy Tormaschy, Owner, SolarBee / Pump Systems, Inc,
530 25th Ave. East
Dickinson, ND 58601   ph 701-225-4494

Date: February 23, 2004

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

PAGE

1.0 ABSTRACT

From April to November, 2003, the cities of Belle Plaine, MN and Isle, MN conducted testing to determine the possible benefits of using a solar powered pond circulator to apply alum in order to reduce phosphorus (P) to meet their wastewater discharge permit limits. The circulator was placed in the center of the wastewater pond, and the alum was injected into it from shore using a chemical injection pump.

The primary goal was to reduce effluent P to below 1.0 mg/l. Additional goals were to demonstrate an alum application method which, compared to applying alum with a boat, would: (a) reduce the amount of alum needed, thereby reducing the cost of alum and the rate at which biosolids accumulate in the pond leading to increased dredging costs, and (b) reduce the manpower hours required to apply alum, which is often in short supply in small communities, and (c) increase the safety of applying alum, since alum is a hazardous substance which requires special handling considerations that are made more difficult by applying it in a boat.

Five tests were conducted. Test #1 and #2 were at Belle Plaine, Tests #3, #4, and #5 were at Isle. Test #1 was cut short due to an unexpected algae matting and bloom that was probably caused by injecting the alum at too high of a flow rate. After the first test, each subsequent test was modified to build on what was learned previously and to change one or more factors to improve the results. Various parameters that were evaluated to determine the optimum method of injecting alum into the solar powered circulator, included: (1) Pond Surface Area, (2) Pond Volume, (3) Circulation Time of Pond with SolarBee Before Alum Application, (4) Amount of Alum Applied, (5) Number of Alum Application Cycles, (6) Type of Alum Pumped, (7) Alum Application Rate, (8) Time Period from Final Alum Application to Start of Discharge and (9) Time Period from SolarBee Shut Down to Start of Discharge.

Tests #2, #3, #4, and #5 were successful in meeting the primary goal of reducing effluent P levels to below the cities' wastewater permit level of 1.0 mg/l. Test #1, as mentioned above, was cut short. All tests met the additional goals. Regarding a reduction in alum needed, the two tests at Belle Plaine averaged 3.01 pounds of aluminum required per pound of P reduced. The tests at Isle, after the system was further improved, averaged 2.08 pounds of aluminum required per pound of P reduced. Belle Plaine did not have a prior history of alum application, but in Isle, applying alum with a boat for the three previous years had averaged 4.74 pounds of aluminum required per pound of P reduced, so the testing in Isle resulted in a 56% reduction of alum required. In all tests the alum application involved far fewer manpower hours for the city, and increased safety due to minimal handling of the alum when the alum was injected into the solar powered circulator.

The most important parameters impacting the successful reduction of P below 1.0 mg/l were, in order of importance:

(1) The amount of alum applied, which depends on the starting P concentrations.

(2) The type of alum applied; results improved with the 7% acidic alum.

(3) The alum injection rate; the optimum injection rate was 0.10 to 0.20 gpm, but rates up to 1.50 gpm are effective as well and may be needed to meet application time constraints on large ponds.

(4) The circulation time before the alum was applied; operating the circulator 24 hours before the alum application seemed to improve the success.

(5) The time period between the alum injection and when the pond discharge was begun; after the alum injection is completed, discharge should preferably occur within 1-3 days, and within 10 days maximum.

Application parameters that were not as important were: (1) Pond size and volume, though pond sizes above 12 acres may require an additional circulator for timely application of alum and thorough circulation of the mixed fluid. As long as the correct amount of alum is applied, pond volume had no impact on the successful reduction of P. (2) Number of injection cycles; one continuous injection cycle seemed to have the same impact as several shorter injection cycles with mixing time in-between them.

2.0 BACKGROUND

Alum, or aluminum sulfate, is a flocculent commonly used in wastewater ponds to precipitate soluble phosphorus (P), which is usually in the form of orthophosphate. The chemical reaction of aluminum sulfate with orthophosphate forms a solid, aluminum phosphate, which drops to the bottom of the pond. Since alum causes the settling of many other substances in the pond in addition to P, alum is typically applied in the final pond, having the cleanest water, to reduce the amount of alum required and also the amount of biosolids buildup. Recommended alum amounts and mixing ratios, based on stoichiometric equations, are shown in the Appendix in Sections 8.3.A, 8.4.A, 8.6.A, 8.7.A and 8.8.A. Various vendors of alum offer different concentrations of aluminum, so the number of gallons of alum to apply to a specific pond must usually be based on the vendor's recommendation and the experience level of alum applications by the wastewater operation personnel. The ideal pH for alum precipitation of P is 5.5 to 6.5. The pH in most wastewater is higher than this, so "acidic alum" can be purchased which contains sulfuric acid to help make the alum more effective in a higher-pH environment. In the subject tests, three types of alum were used as indicated in the Appendix 8.1; regular or non-acidic, 2% acidic, and 7% acidic. Because most wastewater ponds will have some algae growth in the final pond, and thus a higher pH during the daylight hours, it seems advisable to use 7% acidic alum in most cases. It costs slightly more per pound of aluminum, but less of it will likely be needed due to its increased effectiveness. All alum requires special handling and safety considerations. The acidic alum, in particular, is very corrosive due to its low pH. See Appendix 8.10 for a typical material safety data sheet (MSDS) for aluminum sulfate.

Alum is usually applied with a boat equipped with a 55 - 500 gallon on-board tank, a chemical feed system, and a boat motor. The alum is applied by either (1) feeding it into the prop wash to create the desired mixing, or (2) spraying it onto the wastewater via spray booms on both sides of the boat.[1] Application of alum with a boat can become manpower intensive and usually requires applying much more alum than theoretically necessary due to difficulties in achieving an even application and thorough mixing. Application with a boat also involves significantly more safety considerations than applying chemicals on land.

Pond #3 at Belle Plaine Wastewater Treatment Facility was used for Test #1 and #2. This pond is 11 acres in size, has a capacity of 23 million gallons, and is typically discharged in the spring and fall of each year. Alum applications had not been performed on this pond prior to the subject testing.

Figure 1: Generator and Pump Trailer and Alum Application Boat at boat dock at Pond #3, Isle, MN. Isle Wastewater Treatment System has a boat equipped with a storage tank with chemical feed equipment and an outboard motor for alum applications. The alum is fed into the prop wash and mixed as a result of the action of the outboard (propeller driven) motor.

Pond #3 at Isle Wastewater Treatment Facility was used for Tests #3, #4, and #5. This pond is 8 acres in size, has a capacity of 17 million gallons, and is also typically discharged in the spring and fall of each year. Alum applications with a boat have been performed on this pond for the last 8 years or more to reduce P below permit level of 1.0 mg/l.

3.0 EQUIPMENT

The circulator used to apply alum in the subject tests, due to the large size of the ponds, was the SolarBee Model SB10000, manufactured by Pump Systems, Inc. (PSI) of Dickinson, N.D. The SB10000 has a flow rate, at full impeller speed, of 10,000 gallons per minute (gpm) leaving the circulator. It was equipped with a 24-hour shore power kit that allows the machine to run on solar power during the day and on shore power at night via a power converter on shore (110 volts a.c. x 2 amps input, 30 volts d.c. x 7 amps output). The circulator is designed to bring water up from a fixed depth in the lower levels in a pond and distribute the water radially across the pond's surface in a long-range near-laminar-flow pattern of up to 40 surface acres per circulator. This allows for thorough mixing of the reservoir and capture of dissolved oxygen produced by photosynthesis and surface re-aeration. Under full sunlight the SB10000 has a direct flow rate of 3,000 gpm up the 36-inch diameter intake hose and an induced flow rate of 7,000 gpm from under the slightly-submerged 72-inch diameter flow dish, for a total flow rate of 10,000 gpm leaving the machine. Solar powered mixers come in a variety of sizes and cost $12,000 to $40,000 depending on the size and application. The circulator and the chemical injection equipment required for the subject tests, was provided by Pump Systems, Inc. (PSI) and had an estimated installed cost of about $33,000.

Figure 2: SolarBee Model SB10000 solar powered circulator. The machine used in the subject tests had an adjustable intake hose length, for 3 to 10 feet deep settings

For the tests at Belle Plaine, the circulator was placed in the center of the 11-acre pond and tethered to shore with two 0.25" stainless steel cables. The circulator was approximately 200 feet from the alum injection station on the shore. The power cord, for nighttime operation, and the alum injection hose were attached to one stainless steel cable. In Test #1 a 3/8-inch diameter alum injection hose was used. But due to high friction losses that caused high pressure at the injection pump, it was replaced with a 1-inch diameter hose for Test #2. The injection hose had no fittings in the end of it, and was attached to the circulator in a manner to allow for alum injection to occur near the center of the impeller and 2 inches beneath the surface of the water. PSI also provided a generator and chemical injection pump. The first pump used was a Wayne Model PLS100 1 hp electric centrifugal pump. But due to the viscosity of alum (25 cp at 70 degrees F, water is 1 cp at same temperature), the motor overloaded. Subsequently this pump was changed out to an Aermotor Model HNAS100 1 hp shallow well jet centrifugal pump. The alum was stored in a 1,600 gallon tank on a 2-ton single axle truck for Test #1, and in two 2,400 gallon semi-trailer tanks for Test #2 (one tank for regular alum and one tank for 2 % acidic alum). These tanks were left on the site near the injection station for the entire duration of the test. A 1-inch diameter suction hose was used to connect the alum tank to the injection pump.

For the tests at Isle, the circulator was placed in the center of the 8-acre pond and tethered to shore with two floating nylon ropes to prevent any possible disturbance to the sediment and to P that had been precipitated in the past. The circulator was approximately 350 feet from the alum injection station on the shore. The power cord, for nighttime operation, and a 1-inch diameter alum injection hose were attached to one on the nylon ropes. Float balls and 2.5 gallon plastic jugs were attached to the nylon ropes for increased buoyancy. The injection hose had no fittings in the end of it, and was attached to the circulator in a manner to allow for alum injection to occur near the center of the impeller and 2 inches beneath the surface of the water. The city provided a 110 volt a.c. power outlet for the circulator shore power kit. Having applied alum in the past, the city already had a 50-foot by 40-foot building that housed two 2,500 gallon alum storage tanks. Alum was gravity fed to the circulator for Test #3 and Test #4. During the last test, Test #5, with the onset of cold temperatures the 1-inch diameter alum injection hose froze up one night. Consequently Test #5 was completed by using a 2 gpm pressure washer piston pump and a replacement 3/8-inch diameter alum injection hose, with the pump operating around the clock until all of the alum had been applied.

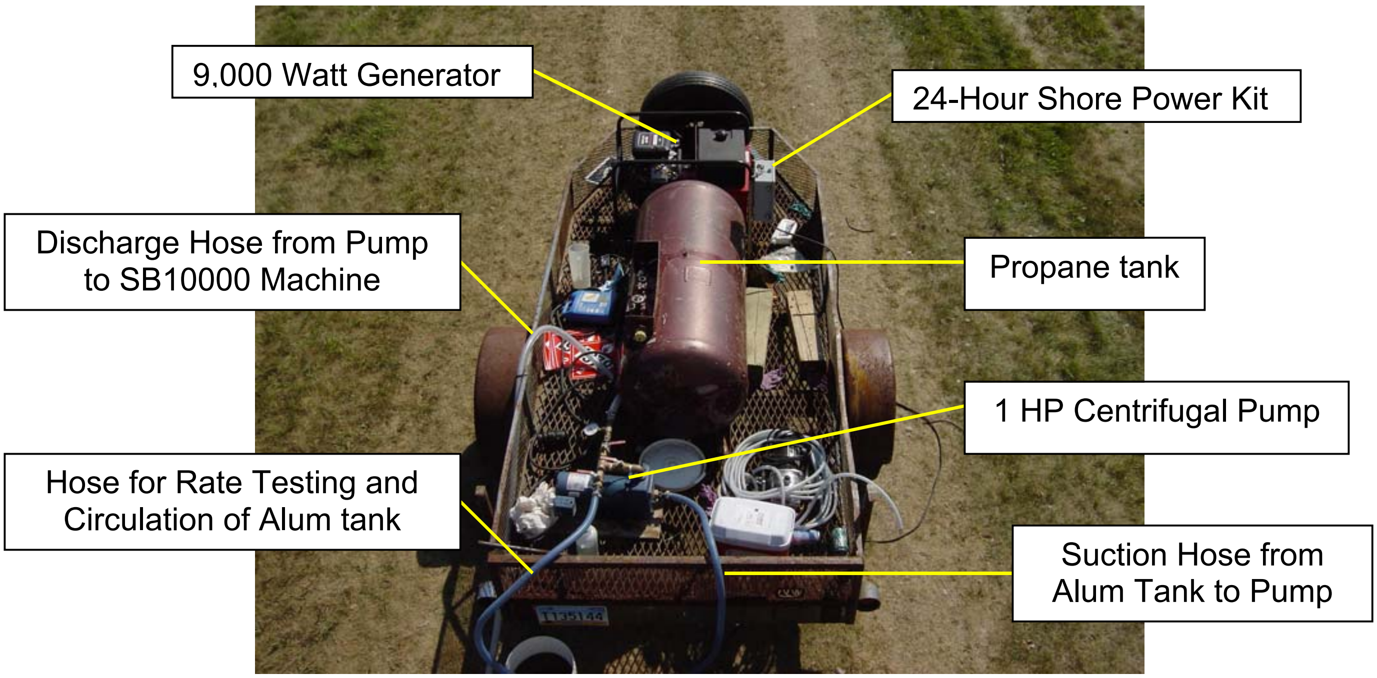

Figure 3: Generator and Pump Trailer at Belle Plaine, MN.

4.0 PROCEDURES

Different pre-treatment, alum injection, and post-treatment procedures were developed and monitored to determine the most effective way to reduce effluent P to below 1.0 mg/l. Water testing was conducted at each step, by certified laboratories, for phosphorus (P), pH, total suspended solids (TSS), Fecal Coliforms, and carbon biochemical oxygen demand (CBOD).

4.1 PRE-TREATMENT PROCEDURE

In each test the circulator was operated in advance of the alum injection for a period of time to thoroughly mix the pond. Just prior to the alum injection, a water sample was taken to the lab to determine the initial level of P.

At Belle Plaine, the pre-treatment was conducted on solar power only, so just sunup-to-sundown mixing was provided. The circulator intake hose was set at 4 feet deep in the 7 feet deep pond during this step.

At Isle, the pre-treatment circulation was conducted 24 hours per day. The circulator intake hose was set at 5 feet deep in the 7 feet deep pond for Test #3, and at 3 feet deep for Tests #4 and #5.

4.2 ALUM APPLICATION PROCEDURE

Alum was either pumped or gravity fed from the tank on shore to the center of the circulator's distribution dish. Discharge of the alum occurred near the circulator impeller and approximately two inches below the surface of the water. Periodic measurements of the alum injection rate were made at the circulator using a calibrated collection jar and a stopwatch. The impeller caused initial alum mixing in the circulator flow dish and then spread the diluted mixture out from the machine in a 360-degree radial pattern. Alum applications were performed in either one long stage or several smaller stages, with the circulator operating 24-hours per day from the beginning of the first alum application to the end of the final application.

4.3 POST TREATMENT PROCEDURE

After all of the alum was applied, the circulator continued to provide circulation until the pond was discharged. During this period the circulator ran on solar power only at Belle Plaine and for 24-hours per day at Isle.

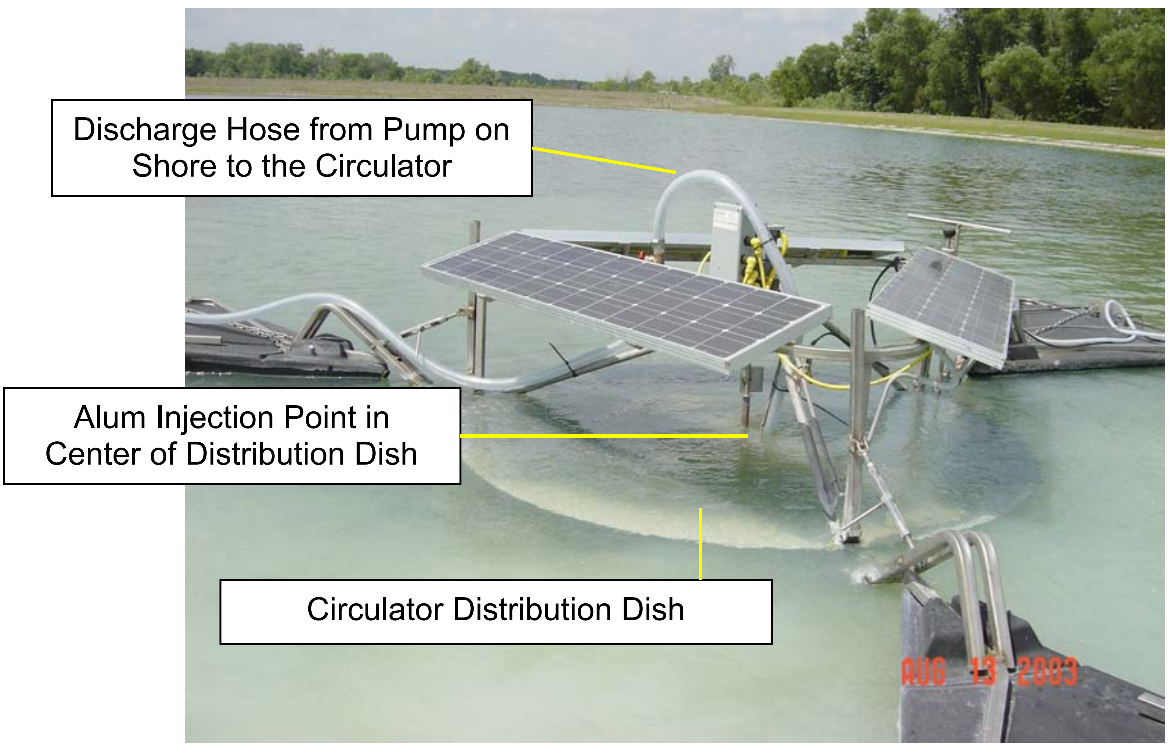

Figure 4: Application of alum with circulator during Test #2 at Belle Plaine, MN. The milky color of the water is the result of the application rate being somewhat high at 1.46 gpm. The alum concentration was 487 mg/l as the water left the circulator.

4.4 SPECIFIC PROCEDURES FOR EACH OF THE FIVE TESTS

Test #1, April - May, 2003, at Belle Plaine: See Appendix 8.3B for results.

(1) Pre-Treatment: Circulator was operated in daylight hours only, for 12 days.

(2) Alum Application: Circulator was operated only when injecting alum. Injected 1,565 total gallons of regular (non-acidic) alum at 0.58 gpm in four applications over 7.3 days. The calculated alum mixing concentration with direct flow of 3,000 gpm at center of circulator distribution dish was 193 mg/l. (This test was cut short before the required amount of alum was injected, due to the formation or large floating algae mats and alum flocs on the surface of the water).

(3) Post Treatment: Circulator was operated in daylight hours only, for 33.5 days after alum was injected. The volume of Pond #3 was 23.2 million gallons. Pond discharge occurred immediately after the circulator was shut down.

The total time period from pre-treatment to discharge was 52.8 days.

Test #2, August, 2003, at Belle Plaine: See Appendix 8.4B for results.

(1) Pre-Treatment: Circulator was operated 24 hours per day for 0.6 days.

(2) Alum Application Treatment: Circulator was operated 24 hours per day. Injected 2,548 total gallons alum, including 948 gallons of 2% acidic alum followed by 1,600 gallons of regular (non-acidic) alum. All alum was injected in one application at the rate of 1.46 gpm over 1.2 days. The calculated alum mixing concentration with direct flow of 3,000 gpm at center of circulator distribution dish was 487 mg/l.

(3) Post Treatment: Circulator was operated 24 hours per day for 0.7 days after alum injected. Volume of Pond #3 for this treatment was 19.5 million gallons. Pond discharge occurred 32 days after circulator was shut down.

Total time period from pre-treatment to discharge was 34.5 days.

Test #3, August - September, 2003, at Isle: See Appendix 8.6B for results.

(1) Pre-Treatment: Circulator was operated 24 hours per day for 14 days.

(2) Alum Application Treatment: Circulator was operated 24 hours per day. Injected 1,000 gallons of 7% acidic alum. All alum was injected in one application at the rate of 0.10 gpm over 6.8 days. The calculated alum mixing concentration with direct flow of 3,000 gpm at center of circulator distribution dish was 33 mg/l.

(3) Post Treatment: Circulator was shut down and pond was discharged immediately after alum was injected. Volume of Pond #3 for this treatment was 17.3 million gallons.

Total time period from pre-treatment to discharge was 20.8 days.

Test #4, September - October, 2003, at Isle: See Appendix 8.7B for results.

(1) Pre-Treatment: Circulator was operated 24 hours per day for 16 days.

(2) Alum Application Treatment: Circulator was operated 24 hours per day. Injected 870 gallons of 7% acidic alum. All alum was injected in two applications at the rate of 0.16

gpm over 14.9 days. The calculated alum mixing concentration with direct flow of 3,000 gpm at center of circulator distribution dish was 53 mg/l.

(3) Post Treatment: Circulator was operated 24 hours per day, for 6 days after alum injected. Volume of Pond #3 for this treatment was 17.3 million gallons. Pond discharge occurred 2 days after circulator was shut down.

Total time period from pre-treatment to discharge was 38.9 days.

Test #5, November, 2003, at Isle: See Appendix 8.8B for results.

(1) Pre-Treatment: Circulator was operated 24 hours per day for 4.3 days.

(2) Alum Application Treatment: Circulator was operated 24 hours per day. Injected 980 gallons of 7% acidic alum. All alum was injected in three applications at the rate of 0.21 gpm over 10.9 days. The calculated alum mixing concentration with direct flow of 3,000 gpm at center of circulator distribution dish was 70 mg/l. Due to severe cold weather during this test the alum was diluted with pond water and the mixture was injected at a higher rate to prevent the discharge line from freezing. Application rate of actual alum was still at 0.20 gpm.

(3) Post Treatment: Circulator was operated 24 hours per day, for 7.9 days after alum injected. Volume of Pond #3 for this treatment was 15.9 million gallons. Pond discharge occurred immediately after the circulator was shut down.

Total time period from pre-treatment to discharge was 23.1 days.

5.0 RESULTS

5.1 PHOSPHORUS REDUCTION ACHIEVED

Test #1, April - May, 2003, at Belle Plaine: The P level was reduced from a pre-treatment concentration of 4.20 mg/l to an average of 2.615 mg/l at discharge. (This test was cut short before the required alum was injected due to large algae mats forming on the surface).

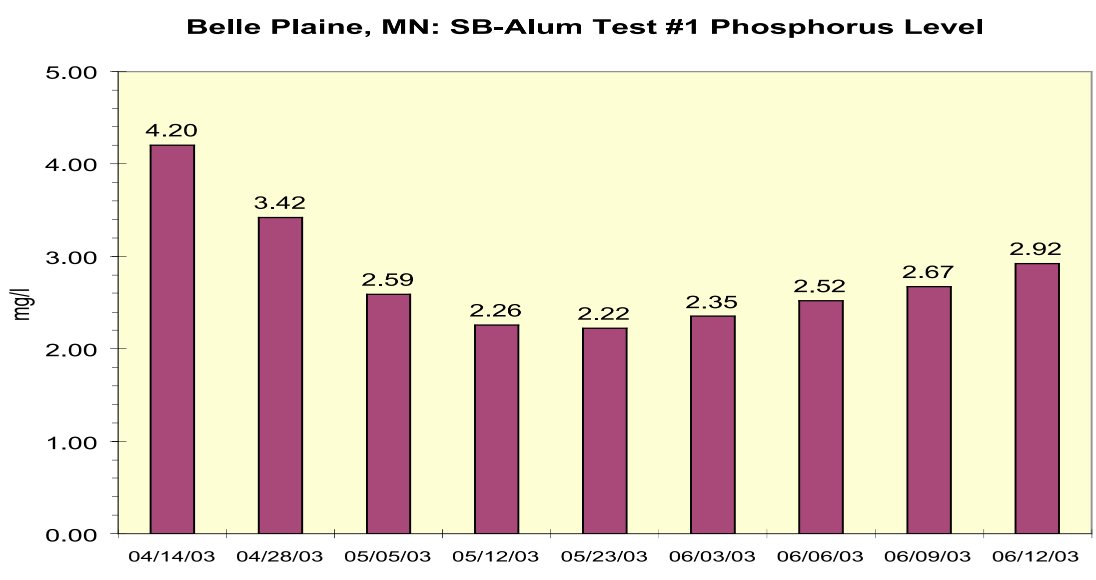

Figure 5: P chart for Test #1 at Belle Plaine.

Test #2, August, 2003, at Belle Plaine: This test was successful in meeting the goal of effluent P < 1.0 mg/l. The P level was reduced from a pre-treatment concentration of 2.93 mg/l to an average of 0.985 mg/l at discharge.

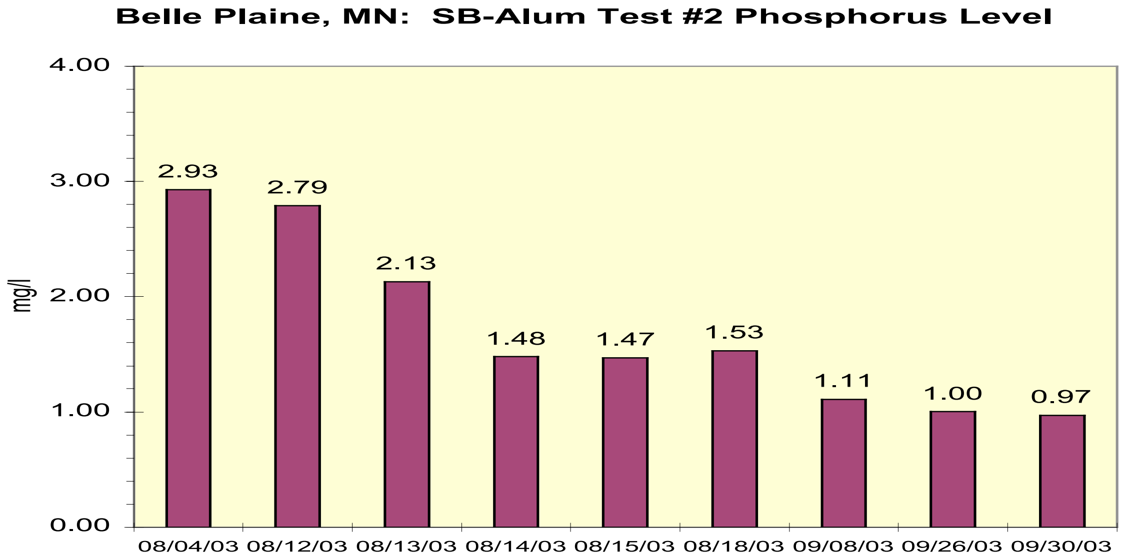

Figure 6: P chart for Test #2 at Belle Plaine.

Test #3, August - September, 2003, at Isle: This test was successful in meeting the goal of effluent P < 1.0 mg/l. The P level was reduced from a pre-treatment concentration of 1.70 mg/l to an average of 0.573 mg/l at discharge.

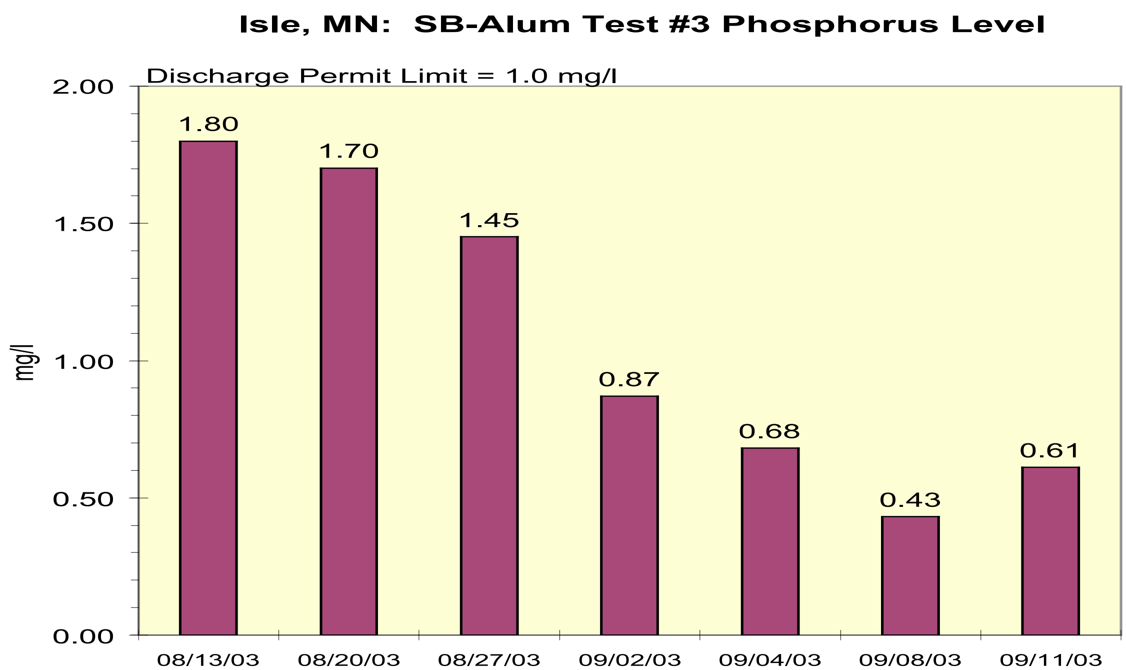

Figure 7: P chart for Test #3 at Isle.

Test #4, September - October, 2003, at Isle: This test was successful in meeting the goal of effluent P < 1.0 mg/l. The P level was reduced from a pre-treatment concentration of 1.60 mg/l to an average of 0.47 mg/l at discharge.

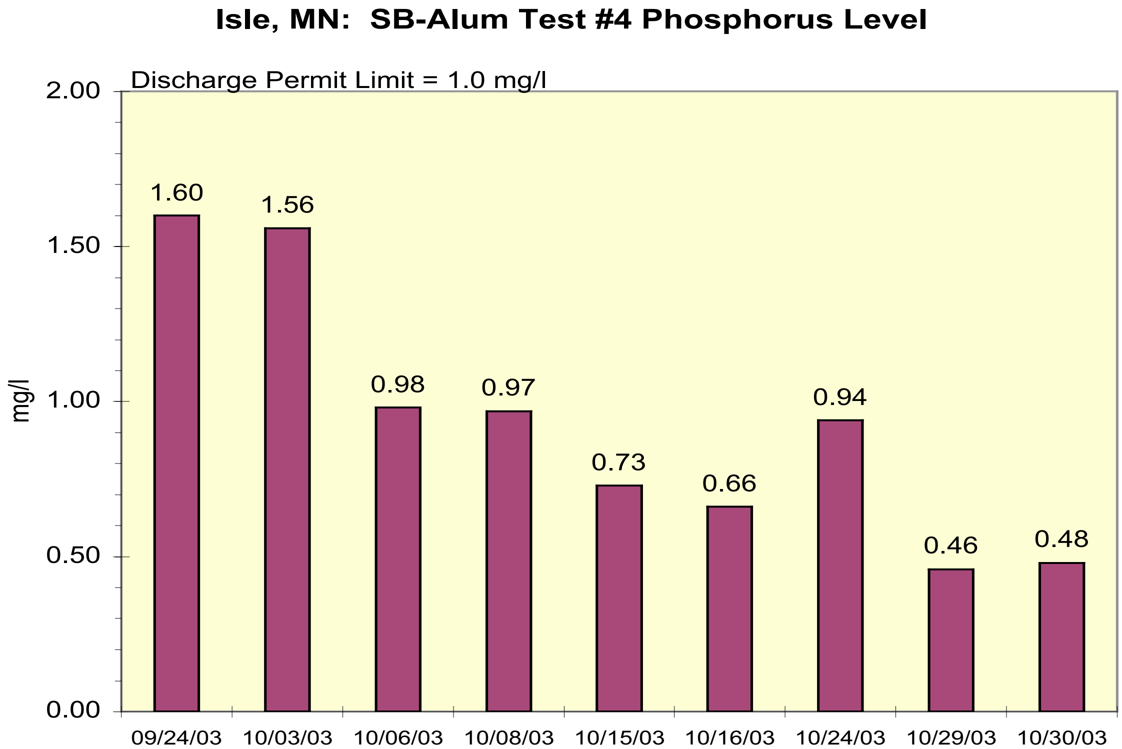

Figure 8: P chart for Test #4 at Isle.

Test #5, November, 2003, at Isle: This test was successful in meeting the goal of effluent P < 1.0 mg/l. The P level was reduced from a pre-treatment concentration of 1.72 mg/l to an average of 0.437 mg/l at discharge.

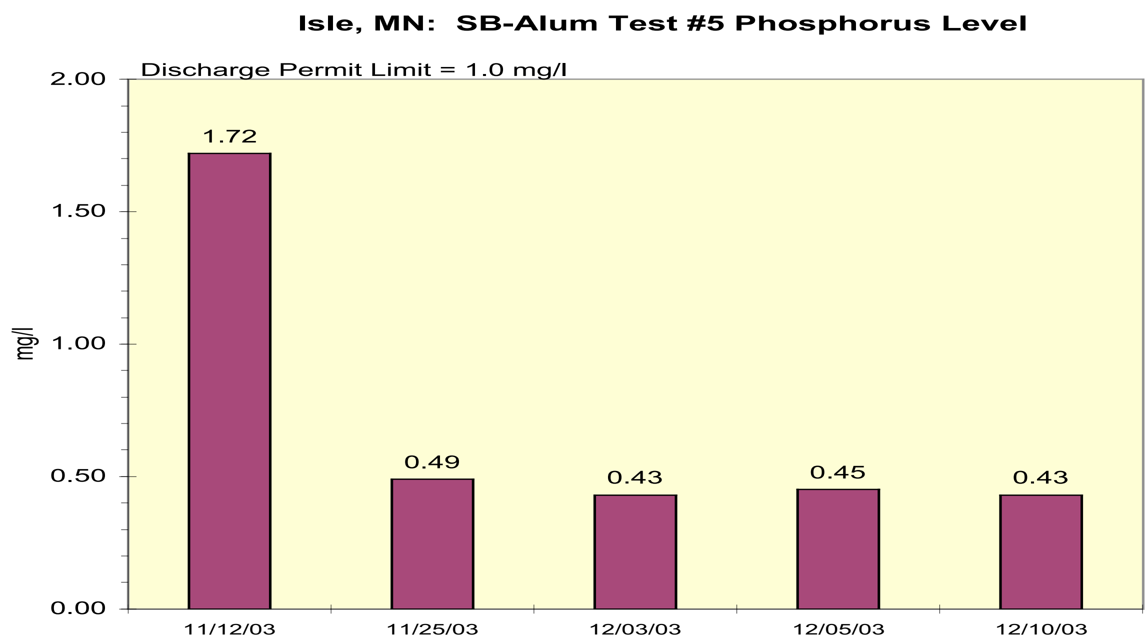

Figure 9: P chart for Test #5 at Isle.

5.2 ALUMINUM REQUIRED FOR PHOSPHIORUS REDUCTION

The amount of aluminum required per pound of P removed is shown in the Appendix, Section 8.1, for all tests. See Section 6.5 for discussion on aluminum content for the different types of alum used on the tests.

At Belle Plaine, approximately 3.01 pounds of aluminum (average of Tests #1 and #2) were required for each pound of P removed. Belle Plaine had not injected alum previously, so no comparisons could be made to any prior application method.

At Isle, approximately 2.08 pounds of aluminum (average of Tests #3, #4, and #5) were required per pound of P removed. This represents a 56% reduction in aluminum from the average of the three prior years when alum was applied with the boat prop method. Isle's alum usage history, as shown in the Appendix, Section 8.5.B, is summarized below:
Fall, 2002 - Boat prop wash application - 4.36 pounds of aluminum per pound of P removed.
Fall, 2001- Boat prop wash application - 3.50 pounds of aluminum per pound of P removed.
Fall, 2000 - Boat prop wash application - 6.37 pounds of aluminum per pound of P removed.

The reduction in aluminum needed with the circulator is most likely due to its mixing action resulting in a much more even distribution of alum throughout the pond volume.

5.2 POND OBSERVATIONS

At Belle Plaine, within a day of starting the alum application for Test #1, algae mats and large alum flocs began forming on the surface of the pond. The test was eventually cut short before the suggested amount of alum was applied in order to determine the cause of the algae matting. Through consultations with the alum supplier and a review of the literature on this subject, it was found that, depending on algae species and concentration, and type and concentration of alum, alum flocculation could apparently trap algae-produced O_2 and/or CO_2 in a manner that creates buoyancy leading to large floating algae mats. Non-acidic alum had been injected in Test #1 at 0.58 gpm. It was decided to conduct Test #2 using 2% acidic alum at the start of the test, followed by non-acidic alum, and to inject at a higher rate of 1.58 gpm, and also to finish the test regardless of whether algae matting re-occurred. Algae matting did occur again in Test #2, but the test was still successful in reducing the P effluent levels to below 1.0 mg/l.

At Isle, no alum flocs or algae mats occurred during any of the tests. Barley straw bales had been placed in the pond in early spring to help control algae growth and the operator indicated that the clarity of the pond, compared to previous years, was much better within five days after the circulator was placed in the pond in the fall. It's possible that the circulator mixing action prior to the injection of alum enhanced the performance of the toxins released by the decaying barley straw. This subject is brought up only to point out the difference in pond conditions between Belle Plaine and Isle, and is not an attempt to provide detailed discussion on barley straw applications in wastewater ponds. Calculated alum application rates were 0.10 gpm on Test #3, 0.16 gpm on Test #4, and 0.21 gpm on Test #5.

The following photos are a good depiction of pond conditions during the various tests.

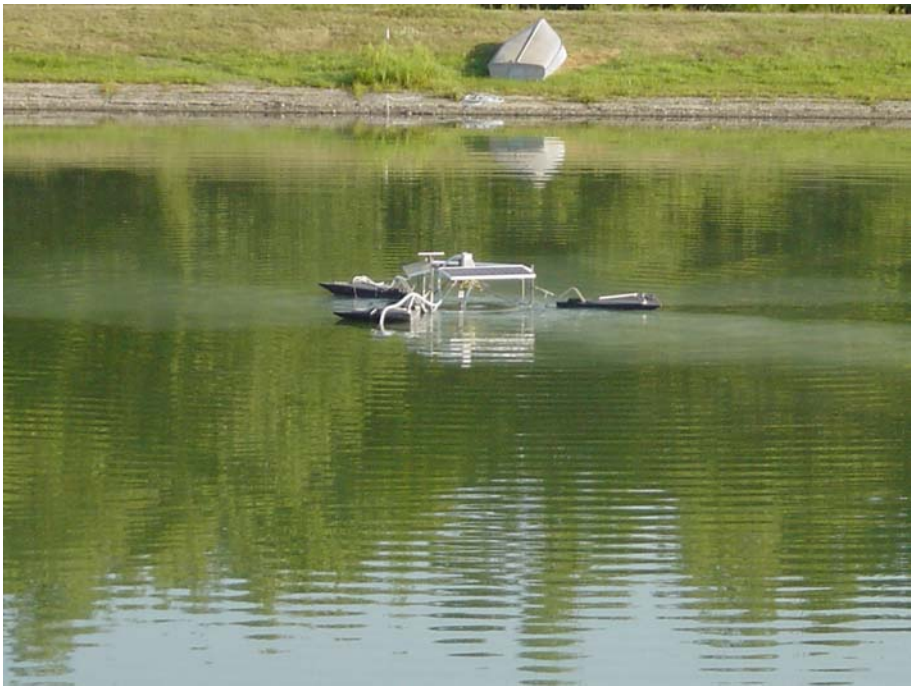

Figure 10: Circulator, during alum application for Test #2 at Belle Plaine.

Figure 11: Alum floc on the bottom of the pond near shore during Test #2 at Belle Plaine. Notice alum floc on pond water surface. The high application rate was a factor in the amount of floc on the bottom and on the water surface.

Figure 12: Alum floc on the pond water surface during Test #2 at Belle Plaine.

Figure 13: Sludge judge sample from the bottom of pond near the circulator, during Test #2 at Belle Plaine. The alum floc on the bottom of the pond was approximately 1.25 feet thick.

Figure 14: Alum floc and possibly blue green algae on the water surface in foreground, and clear water in the background, during Test #2 at Belle Plaine. The alum and algae flocculation is probably the result of the high alum application rate used in this test.

Figure 15: The circulator at Test 3 at Isle. The floats support the discharge hose and 24-hour shore power cord from shore. Floats attached to the hose help suspend it in the water to prevent any disturbance of pond sediment. Alum has not yet been injected in this photo.

Figure 16: Generator and Pump Trailer on boat dock for Test #3 at Isle.

Figure 17: Alum application during Test #4 at Isle. Additional floats were added to keep the injection hose suspended off the bottom of the pond.

6.0 DISCUSSION OF TEST RESULTS

6.1 POND SIZE AND POND VOLUME

Pond surface area and total volume must be considered in determining the amount of alum to apply and the size and number of circulators required for proper mixing. As long as the correct amount of alum and mixing are applied, pond surface area and pond volume have no impact on the successful reduction of P.

6.2 CIRCULATION OF POND BEFORE ALUM APPLICATION

A comparison of the tests indicates that circulating the pond for 24 hours or more before the alum improves the results, though the improvement cannot be quantified. A 24-hour shore power kit for the circulator, though not required, is advised. If electricity is not available at the pond location, then a generator should be provided for both the pre-treatment and the alum injection phases.

6.3 AMOUNT OF ALUM APPLIED

Factors that affect the actual quantity of alum required to attain a specific P reduction in wastewater include (1) the pH, (2) the thoroughness of mixing the alum throughout the pond before it sinks to the bottom, (3) the type of alum used, (4) the alkalinity, (5) the ionic constituents such as sulfate, fluoride, sodium, and others, (6) the quantity and nature of suspended solids, (7) micro-organisms, (8) other physical conditions pertinent to the pond such as sludge depth, shape, suspended solids, wind mixing, and others.

Regarding (1) above, higher pH pond water (around 9.0) requires more alum for a specific P reduction than lower pH pond water(around 7.0). As stated earlier, the ideal pH range for alum precipitation of P is 5.5 to 6.5.

Regarding (2) above, the subject tests were aimed mostly at trying to find a more effective way to apply alum and mix it into the pond. The circulator which was tested will draw approximately 12 to 14 million gallons of pond water through the machine per day with a 24-hour shore power kit, and about 4 million gallons per day on solar-only operation. The near-laminar flow of solar circulators insures that the entire pond is circulated to all the outer edges which results in less alum required.

Regarding (8) above, algae mats formed immediately during both tests at Belle Plaine but not during any of the tests at Isle. It's possible that the higher suspended solids at Belle Plaine, as shown in the water tests in the Appendix, caused more alum to be required (3.01 pounds of aluminum per pound of P removed) than at Isle (2.08 pounds of aluminum per pound of P removed).

6.4 NUMBER OF ALUM INJECTIONS

As long as the total amount of alum injected is the same, the number of injection cycles did not seem to impact the reduction of P. But by injecting the alum in separate cycles, and obtaining a P concentration after each stage, a wastewater treatment facility can fine-tune the alum application procedure and most likely reduce the total amount of alum applied. Utilizing the circulator for a staged alum application is considerably easier and less manpower-intensive than using a boat to apply the alum in various numbers of cycles.

6.5 TYPE OF ALUM INJECTED

Three types of alum were utilized in the various tests. (1) Regular alum, with a typical aluminum content of about 4.16% by weight. (2) Two percent (2%) acidic alum, with a typical aluminum content of about 3.98% by weight. Acidic alum refers to the percent sulfuric acid that is added with regular alum. (3) Seven percent (7%) acidic alum, with a typical aluminum content of about 3.28% by weight. Aluminum content is less with acidic alums but the acid makes the alum more effective in water where the pH is above the optimum level of 5.5 to 6.5.

As shown in the Appendix, regular alum was used on Test #1, a combination of regular alum and 2% acidic alum was used on Test #2, and 7% acidic alum was used on Tests #3, #4, and #5. The best results occurred with the 7% acidic alum.

6.6 ALUM APPLICATION RATE AND MIXING CONCENTRATION

Alum application rates were adjusted on the first three tests to determine an optimum application rate. It was determined that the early injection rates used, up to 1.46 gpm of alum, were too high. Refer to Figures 4, 10, 11, 12 and 13. The milky mixture eventually disappeared after the alum application ended and circulation of pond water was continued. Discussions with alum vendor personnel indicated a lower concentration of alum would provide a better pond treatment for P reduction.

The alum application rate on Test #3 at Isle was lowered to 0.10 gpm. There was no physical evidence of any milky mixture of alum and pond water throughout the test. Application rates on Tests #4 and #5 at Isle were: 0.16 gpm and 0.21 gpm. The results were consistent with Test #3; there was no physical evidence of any milky mixture throughout the tests.

Based on a 3,000 gpm direct flow rate up the intake hose of the circulator, an alum injection rate of 0.10 gpm to 0.20 gpm yields a calculated alum concentration of 33 mg/l to 66 mg/l at the perimeter of the flow dish of the circulator, and 10 mg/l to 20 mg/l at the full machine diameter after the direct flow mixes with the 7,000 gpm of induced flow. The conclusion is that this injection range, combined with the near laminar flow circulation patterns of the circulator, will reduce P levels to below 1.0 mg/l as long as the correct total amount of alum is applied to treat the entire pond volume.

6.7 CIRCULATION AFTER THE ALUM INJECTION

It appears beneficial to operate the circulator for 1-2 days immediately before the pond is discharged. This provides additional mixing for any alum that may have become re-suspended by wind mixing or disassociation in the sediment.

6.8 POND DISCHARGE

Changes in pond biology and events such as pond turnovers may affect the success of the alum application in reducing P. Therefore; the pond should be discharged as soon as possible after lab testing confirms that the required P reduction has been achieved.

6.9 POND OBSERVATION

Laboratory-scale continuous-flow experiments have produced large bacterial-algae flocs with good settling characteristics. Floating algae blankets in the presence of chemical coagulants such as alum have been reported in a 50 gpm pilot plant where a floating algal blanket occurred with alum doses of 125 mg/l to 170 mg/l.[2]

As mentioned above regarding Belle Plaine Tests #1 and #2, blue green algae mats and floating alum flocs formed on the pond surface after the alum was injected. The relatively high-calculated alum concentration in Test #1 (193 mg/l at the flow dish) and Test #2 (487 mg/l at the flow dish) was possibly responsible. Within a day after the alum injection ended, the pond cleared up with no evidence of the algal mats or floating alum flocs. But even though the surface matting occurred, results of the only completed test at Belle Plaine, Test #2, were still acceptable, though more alum was required per pound of P removed than at the Isle tests.

7.0 CONCLUSIONS

A high flow solar powered circulator with near-laminar flow, located in a middle of a wastewater pond, can be used with an on-shore injection pump to apply alum to reduce effluent P in a wastewater lagoon to below 1.0 mg/l. Expected benefits include less alum required, less biosolids buildup, less manpower hours required, and fewer safety risks by reducing the handling of the alum and the need to apply it with a boat. The financial benefits should pay for the circulator system investment relatively quickly; payback should occur between 0.60 to 3.32 years (See Appendix8.10). The safety benefits, though hard to quantify, are also significant.

Five tests were conducted. Test #1 and #2 were at Belle Plaine, Tests #3, #4, and #5 were at Isle. Tests #2, #3, #4, and #5 were successful in meeting the primary goal of reducing effluent P levels to below the wastewater permit level of 1.0 mg/l. Test #1 was cut short due to an unexpected algae matting and bloom that was probably caused by injecting the alum at too high of a flow rate..

Regarding a reduction in alum needed, the two tests at Belle Plaine averaged 3.01 pounds of aluminum required per pound of P reduced. The tests at Isle, after the system was further improved, averaged 2.08 pounds of aluminum required per pound of P reduced. Belle Plaine did not have a prior history of alum application, but in Isle, applying alum with a boat for the three previous years had averaged 4.74 pounds of aluminum required per pound of P reduced, so the testing in Isle resulted in a 56% reduction of alum required. In all tests the alum application involved far fewer manpower hours for the city, and increased safety due to minimal handling of the alum when the alum was injected into the solar powered circulator.

The most important parameters impacting the successful reduction of P below 1.0 mg/l were, in order of importance:

(1) The amount of alum applied, which depends on the starting P concentrations.

(2) The type of alum applied; results improved with the 7% acidic alum.

(3) The alum injection rate; the optimum injection rate was 0.10 to 0.20 gpm, but rates up to 1.50 gpm are effective as well and may be needed to meet application time constraints on large ponds.

(4) The circulation time before the alum was applied; operating the circulator 24 hours before the alum application seemed to improve the success.

(5) The time period between the alum injection and when the pond discharge was begun; after the alum injection is completed, discharge should preferably occur within 1-3 days, and within 10 days maximum.

Application parameters that were not as important were: (1) Pond size and volume, though pond sizes above 12 acres may require an additional circulator for timely application of alum and thorough circulation of the mixed fluid. As long as the correct amount of alum is applied, pond volume had no impact on the successful reduction of P. (2) Number of injection cycles; one continuous injection cycle seemed to have the same impact as several shorter injection cycles with mixing time in-between them.

Future studies should be aimed at:
(a) Devising easy-to-use charts for wastewater operators to follow in determining the amount and type of alum most likely needed, based on water volume, pH, and a number of other water quality parameters. This would allow the wastewater treatment operator to take full advantage of the circulator method of alum application to reduce the amount of alum applied.
(b) Developing a standardized alum storage and injection pump system that makes it simple and convenient for the operator to monitor the alum application.

Appendix 8.1: Summary Sheet for All SolarBee / Alum Tests

PHOSPHORUS REDUCTION IN WASTEWATER PONDS
APPLICATION OF ALUM WITH SOLARBEE CIRCULATION MACHINE

Test #	1	2	3	4	5
Location	Belle Plaine, MN	Belle Plaine, MN	Isle, MN	Isle, MN	Isle, MN
Pond #	3	3	3	3	3
Month / Year	April, 2003	August, 2003	September, 2003	October, 2003	November, 2003
Pond Data:					
Size(Acres)	10.94	10.39	8.14	8.14	8.06
Depth(Feet)	7.0	6.17	7.0	7.0	6.5
Volume(Million Gals.)	23.2	19.5	17.3	17.3	15.9
Volume(Million Lbs.)	193.3	162.8	143.9	143.9	132.9
Alum Application:					
Type of Alum	Regular	2% Acid / Regular	7% Acid	7% Acid	7% Acid
Volume(Gals)	1,565	2,548	1,000	870	980
Wt. Lbs. Per Gallon	11.10	11.10	11.10	11.10	11.10
Wt. % Aluminum	4.160%	4.043%	3.250%	3.250%	3.250%
Aluminum Used(Lbs.)	723	1,143	361	314	354
Rate(GPM)	0.58	1.46	0.10	0.16	0.21
Pumping Time(Days)	1.875	1.208	6.823	3.896	3.250
Method	4 Stages	Continuous	Continuous	2 Stages	3 Stages
SolarBee Data:					
Model Number	SB10000	SB10000	SB10000	SB10000	SB10000
Run time before Alum pumped(days)	12.000	0.625	14.000	16.000	4.250
Run time with Alum pumped(days)	1.875	1.208	6.823	3.896	3.250
Run time between Alum Stages(days)	5.396	0.000	0.000	11.000	7.687
Run time after Alum pumped(days)	33.500	0.667	0.000	6.000	7.920
Total run time (days)	52.771	2.500	20.823	36.896	23.107
Alum Mixing Concentration:	(Based on SB10000 Direct Flow Rate of 3,000 GPM)				
Mixing mg/l	193	487	33	53	70
Application/Discharge Time Data:					
Final Alum to Discharge Time (days)	33.5	32.7	0.0	8.0	7.9
SB Shut Down to Discharge Time (days)	0.0	32.0	0.0	2.0	0.0
Phosphorus (P) Data:					
Pre Treatment(mg/l)	4.20	2.93	1.70	1.60	1.72
Discharge Range(mg/l)	2.35 - 2.92	1.00 - 0.97	0.61 - 0.43	0.46 - 0.48	0.49 - 0.43
Average Discharge(mg/l)	2.615	0.985	0.573	0.470	0.437
Total Reduction(mg/l)	1.585	1.945	1.127	1.130	1.283
Total Reduction(Lbs.)	306	317	162	163	171
Discharge P below 1.0 mg/l?	**NO**	**YES**	**YES**	**YES**	**YES**
Lbs. Aluminum Used / Lbs. P Removed	2.36	3.61	2.22	1.93	2.07
Gals. Alum / mg/l P Reduction	987	1,310	887	770	764
Pond Observations:					
Algae mats present?	YES	YES	NO	NO	NO
Large Alum flocs present?	YES	YES	NO	NO	NO
Barley Straw Used?	NO	NO	YES	YES	YES

Appendix 8.2: Summary Information for Belle Plaine, MN Tests

Appendix 8.2.A Lab Test Data

Belle Plaine, MN
Pond #3 Lab Test Data

Date	P (mg/l)	pH	TSS (mg/l)	Fecal Coliform #/100 ml	CBOD (mg/l)	Comments
	1.000	6 to 9	45	200	25	Discharge Limits
04/14/03	4.200	7.40	52.0	27	24.0	Pre-Treatment, SB running
04/28/03	3.420	8.40	64.0	10	13.0	SB running with Alum
05/05/03	2.590	8.50	72.0	300	10.0	Pre-Discharge, SB running
05/12/03	2.260	8.10	14.0	40	6.0	Pre-Discharge, SB running
05/23/03	2.220		13.0	10	6.0	Pre-Discharge, SB running
06/03/03	2.350	8.10	9.0	296	11.0	Discharge
06/06/03	2.520	8.00	7.0	10	5.0	Discharge
06/09/03	2.670	8.00	6.0	10	4.0	Discharge
06/12/03	2.920	8.10	6.0	10	3.0	Discharge
08/04/03	2.930					Pre-Treatment
08/12/03	2.790					SB running with Alum
08/13/03	2.130					SB running with Alum
08/14/03	1.480					Pre-Discharge, SB running
08/15/03	1.470					Pre-Discharge
08/18/03	1.530					Pre-Discharge
09/08/03	1.110		47.0		8.0	Pre-Discharge
09/26/03	1.000		49.0		3.0	Discharge
09/30/03	0.970	9.40	11.0		3.0	Discharge

Appendix 8.2.B: Alum Usage Review

Belle Plaine, MN
Alum Useage Review

1	2 Discharge	3 Beginning Phosphorus (mg/l)	4 Average Phosphorus at Discharge (mg/l)	5 Phosphorus Reduction (mg/l)	6 Pond #3 Volume (M gals)	7 (C6 X 8.34 X C5) Phosphorus Removed (lbs)	8 Reg Alum Volume (gallons)	9 2% Acidic Volume (gallons)	10 Aluminun Required (lbs)	11 (C10 / C7) Lbs. Al per Lbs. Phos.
Spring, 2003	1	4.200	2.615	1.585	23.18	306	1,565	0	723	2.36
Fall, 2003	1	2.930	0.985	1.945	19.52	317	1,600	948	1,157	3.65

Appendix 8.3: Test #1: Belle Plaine, MN

Appendix 8.3.A: Phosphorus Reduction with Alum Calculation Worksheet

Test #1 Phosphorus Reduction with SolarBee and Alum

Location: Belle Plaine, MN **Pond #:** 3

NOTE: Change **RED** numbers only

STEP 1: Determine Pond Size

Pond Size Information:

Total Depth of Pond	7.00	feet
Length at top of pond, berm edge to berm edge	1,278	feet
Slope on these sidewalls, typically 3:1	3	
Width at top of pond, berm edge to berm dege	373	feet
Slope on ends, typically 3:1	3	
Volume of the pond when full	23.18	million gallons
Surface acres of pond when full	10.94	acres

Pond Size Information , As Operated:

Operating depth of pond	7.00	feet
Estimated average weight bearing sludge depth	0.00	feet
Volume of the pond, as operated, not accounting for weight bearing sludge	**23.18**	million gallons
Volume of the pond, as operated, accounting for weight bearing sludge	**23.18**	million gallons
Surface area of pond as operated	10.94	acres

STEP 2: Determine Volume of Liquid Aluminum Sulfate(Alum) to Use

METHOD 1: Theoretical calculations for amount of liquid Alum:

Initial phosphorus level in water(mg/l or parts per million(ppm))	4.20	mg/l or ppm
Final phosphorus level in water	0.50	mg/l or ppm
Required reduction of phosphorus level in water	3.70	mg/l or ppm
Aluminum required for every pound of phosphorus removed(THEORETICAL)	0.87	pounds
Water to be treated	23.18	million gallons
Water to be treated (gals. X 8.34 ppg)	193.3	million pounds
Total phosphorus to remove	715	pounds
Total aluminum required to remove phosphorus(THEORETICAL)	622	pounds

Pick type of Alum and corresponding Wt % Aluminum from Table: (Use Mid Point Values or data from Spec Sheet)

Alum Type	Aluminum Content Range		
	Low	High	Mid Point
Regular	4.160%	4.370%	*4.265%*
1% Acid	4.000%	4.200%	*4.100%*
2% Acid	3.900%	4.050%	*3.975%*
3% Acid	3.800%	3.900%	*3.850%*
5% Acid	3.500%	3.700%	*3.600%*
7% Acid	3.200%	3.300%	*3.250%*

Aluminum content in liquid Alum — Alum Type: Regular	4.160%	Wt % Al
Liquid Alum required(THEORETICAL)	14,959	pounds
Liquid Alum weight (pounds per gallon, ppg)	11.10	ppg
Liquid Alum required(THEORETICAL - Assumes no reaction with other nutrients)	1,348	gallons

METHOD 2: Rule of thumb calculation for amount of liquid Alum:

Initial phosphorus level in water	4.20	mg/l or ppm
Final phosphorus level in water	0.50	mg/l or ppm
Required reduction of phosphorus level in water	3.70	mg/l or ppm
Water to be treated	23.18	million gallons
Water to be treated	71	acre-ft.
Liquid Alum required per acre-ft per ppm phosphorus reduction:	20	gals./acre-ft/ppm
Liquid Alum required	5,264	gallons
Application factor of Alum when compared to Theoretical volume above	3.91	

METHOD 3: Rule of thumb calculation for amount of liquid Alum:

Initial phosphorus level in water	4.20	mg/l or ppm
Water to be treated	23.18	million gallons
Liquid Alum required per million gallons per ppm phosphorus level:	35	gals./MG/ppm
Liquid Alum required	3,407	gallons
Application factor of Alum when compared to Theoretical volume above	2.53	

STEP 3: Evaluate Volume of Alum Used

Application Dates: 04/22/03, 04/24/03 to 04/25/03, 04/28/03, 04/29/03

Initial phosphorus level in water		4.200	mg/l or ppm
Final phosphorus level in water		2.615	mg/l or ppm
Reduction of phosphorus level in water		1.585	mg/l or ppm
Aluminum required for every pound of phosphorus removed(THEORETICAL)		0.87	pounds
Water treated		23.18	million gallons
Water treated (gals. X 8.34 ppg)		193.3	million pounds
Total phosphorus removed		306	pounds
Total aluminum required to remove phosphorus(THEORETICAL)		267	pounds
Aluminum content in liquid Alum	Alum Type: Regular	4.160%	Wt % Al
Liquid Alum used		1,565	gallons
Liquid Alum weight per gallon		11.10	ppg
Total aluminum used to reduce phosphorus		723	pounds
Aluminum used / pound of phosphorus reduced		2.36	pounds
Application factor in this pond to reduce phosphorus level as listed above		2.71	

Appendix 8.3.B: Alum Application Information

LOCATION: Belle Plaine, MN Pond #: 3

SUBJECT: SolarBee / Alum Test #1

Date / Time	Alum Type	Tank Volume (Gallons)	Total Pumped Vol.(gals)	Pumping Data Elapsed Time(min.)	Volume (gals)	Rate GPM
4/22/03 8:00 AM	Regular	1,565	0	NA	NA	NA
4/22/03 10:00 AM	Regular	1,515	50	120	50	0.42
4/24/03 8:00 AM	Regular	1,515	0	NA	NA	NA
4/25/03 2:30 PM	Regular	672	843	1,830	843	0.46
4/28/03 2:00 PM	Regular	672	0	NA	NA	NA
4/28/03 8:00 PM	Regular	372	300	360	300	0.83
4/29/03 8:00 AM	Regular	372	0	NA	NA	NA
4/29/03 2:30 PM	Regular	0	372	390	372	0.95
		TOTALS	1,565	2,700	1,565	0.58

NOTES:

(1) SolarBee SB10000 machine started on 04/10/03. Running on solar power only.

(2) Fluid intake depth at 4.0 feet from pond surface.

(3) SolarBee SB10000 machine shut down on 06/02/03.

SB10000 Run Times	Days	Comments
Before Alum pumped:	12.000	Solar power only
While Alum pumped:	1.875	Solar power and generator
Between Alum stages:	5.396	Solar power and generator
After Alum pumped:	33.500	Solar power only
TOTAL	52.771	

Appendix 8.4: Test #2: Belle Plaine, MN

Appendix 8.4.A: Phosphorus Reduction with Alum Calculation Worksheet

Test #2 Phosphorus Reduction with SolarBee and Alum

Location: Belle Plaine, MN **Pond #:** 3

NOTE: Change **RED** numbers only

STEP 1: Determine Pond Size

Pond Size Information:

Total Depth of Pond	6.17	feet
Length at top of pond, berm edge to berm edge	1,264	feet
Slope on these sidewalls, typically 3:1	3	
Width at top of pond, berm edge to berm dege	358	feet
Slope on ends, typically 3:1	3	
Volume of the pond when full	19.52	million gallons
Surface acres of pond when full	10.39	acres

Pond Size Information , As Operated:

Operating depth of pond	6.17	feet
Estimated average weight bearing sludge depth	0.00	feet
Volume of the pond, as operated, <u>not</u> accounting for weight bearing sludge	**19.52**	million gallons
Volume of the pond, as operated, accounting for weight bearing sludge	**19.52**	million gallons
Surface area of pond as operated	10.39	acres

STEP 2: Determine Volume of Liquid Aluminum Sulfate(Alum) to Use

METHOD 1: Theoretical calculations for amount of liquid Alum:

Initial phosphorus level in water(mg/l or parts per million(ppm))	2.93	mg/l or ppm
Final phosphorus level in water	0.50	mg/l or ppm
Required reduction of phosphorus level in water	2.43	mg/l or ppm
Aluminum required for every pound of phosphorus removed(THEORETICAL)	0.87	pounds
Water to be treated	19.52	million gallons
Water to be treated (gals. X 8.34 ppg)	162.8	million pounds
Total phosphorus to remove	396	pounds
Total Aluminum required to remove phosphorus(THEORETICAL)	344	pounds

Pick type of Alum and corresponding Wt % Aluminum from Table: (Use Mid Point Values or data from Spec Sheet)

Alum Type	Low	High	Mid Point
Regular	4.160%	4.370%	*4.265%*
1% Acid	4.000%	4.200%	*4.100%*
2% Acid	3.900%	4.050%	*3.975%*
3% Acid	3.800%	3.900%	*3.850%*
5% Acid	3.500%	3.700%	*3.600%*
7% Acid	3.200%	3.300%	*3.250%*

Aluminum content in liquid Alum — Alum Type: 2% Acid / Regular	4.068%	Wt % Al
Liquid Alum required(THEORETICAL)	8,460	pounds
Liquid Alum weight (pounds per gallon, ppg)	11.10	ppg
Liquid Alum required(THEORETICAL - Assumes no reaction with other nutrients)	762	gallons

METHOD 2: Rule of thumb calculation for amount of liquid Alum:

Initial phosphorus level in water	2.93	mg/l or ppm
Final phosphorus level in water	0.50	mg/l or ppm
Required reduction of phosphorus level in water	2.43	mg/l or ppm
Water to be treated	19.52	million gallons
Water to be treated	60	acre-ft.
Liquid Alum required per acre-ft per ppm phosphorus reduction:	20	gals./acre-ft/ppm
Liquid Alum required	2,912	gallons
Application factor of Alum when compared to Theoretical volume above	3.82	

METHOD 3: Rule of thumb calculation for amount of liquid Alum:

Initial phosphorus level in water	2.93	mg/l or ppm
Water to be treated	19.52	million gallons
Liquid Alum required per million gallons per mg/l or ppm phosphorus level:	35	gals./MG/ppm
Liquid Alum required	2,002	gallons
Application factor of Alum when compared to Theoretical volume above	2.63	

STEP 3: Evaluate Volume of Alum Used

Application Dates: 08/12/03 to 08/13/03

Initial phosphorus level in water	2.930	mg/l or ppm
Final phosphorus level in water	0.985	mg/l or ppm
Reduction of phosphorus level in water	1.945	mg/l or ppm
Aluminum required for every pound of phosphorus removed(THEORETICAL)	0.87	pounds
Water treated	19.52	million gallons
Water treated (gals. X 8.34 ppg)	162.8	million pounds
Total phosphorus removed	317	pounds
Total Aluminum required to remove phosphorus(THEORETICAL)	275	pounds
Aluminum content in liquid Alum — Alum Type: 2% Acid / Regular	4.043%	Wt % Al
Liquid Alum used	2,548	gallons
Liquid Alum weight per gallon	11.10	ppg
Total Aluminum used to reduce phosphorus	1,143	pounds
Aluminum used / pound of phosphorus reduced	3.61	pounds
Application factor in this pond to reduce phosphorus level as listed above	4.15	

Appendix 8.4.B: Alum Application Information

LOCATION: Belle Plaine, MN Pond #: 3

SUBJECT: SolarBee / Alum Test #2

Date / Time	Alum Type	Tank Volume (Gallons)	Total Pumped Vol.(gals)	Pumping Data		
				Elapsed Time(min.)	Volume (gals)	Rate GPM
8/12/03 11:00 AM	2% Acid	1,998	0	NA	NA	NA
8/12/03 11:00 PM	2% Acid	1,050	948	720	948	1.32
8/12/03 11:00 PM	Regular	2,050	0	NA	NA	NA
8/13/03 4:00 PM	Regular	450	1,600	1,020	1,600	1.57
		TOTALS	2,548	1,740	2,548	1.46

NOTES:

(1) SolarBee SB10000 machine started at 8:00 p.m. on 08/11/03.

(2) Fluid intake depth at 4.5' from pond surface.

(3) SolarBee SB1000 machine shut down at 8:00 a.m.on 08/14/03.

SB10000 Run Times	Days	Comments
Before Alum pumped:	0.625	Solar power and generator
While Alum pumped:	1.208	Solar power and generator
After Alum pumped:	0.667	Solar power and generator
TOTAL	2.500	

Appendix 8.5: Summary Information for Isle, MN Tests

Appendix 8.5.A: Lab Test Data

Isle, MN
Pond #3 Lab Test Data

Date	P (mg/l)	pH	TSS (mg/l)	Fecal Coliform #/100 ml	CBOD (mg/l)	Comments
	1.000	6 to 9	45	200	25	Discharge Limits
04/05/00	4.900					Pre-Discharge
04/14/00	2.100	7.70	17	<10	6.5	Pre-Discharge
04/28/00	1.400	9.70	10	<10	7.6	Pre-Discharge
05/03/00	1.300	8.50	23	<10	3.6	Pre-Discharge
05/04/00	1.300	8.20	<4	<10	<2	Pre-Discharge
05/08/00	0.540	7.20	5	<10	2.8	Discharge
05/10/00	0.760	7.00	<4	<10	2.6	Discharge
05/23/00	6.000					Pre-Discharge
06/11/00	1.800	8.60	10		5.4	Pre-Discharge
06/18/00	1.200	8.00	6	<10	6.9	Pre-Discharge
06/19/00	1.500	8.00	12	<10	5.6	Pre-Discharge
06/19/00	1.000					Pre-Discharge
06/26/00	0.920	7.90	20	10	3.5	Discharge
06/30/00	0.630	8.50	27	<10	7.7	Discharge
08/10/00	2.900					Pre-Discharge
08/31/00	0.860	7.30	7.5	<10	3.3	Pre-Discharge
09/06/00	0.880	7.60	6.3	<10	2.4	Discharge
09/07/00	0.880	7.50	14	<10	6.3	Discharge
09/12/00	0.910	8.10	22	15	17	Discharge
09/14/00	0.820	8.60	35	<10	13	Discharge
10/10/00	0.960	7.60	<4	15	<2	Pre-Discharge
10/18/00	0.820	7.80	<4	<10	<2	Discharge
10/19/00	0.840	7.70	<4	<10	10	Discharge
10/24/00	0.980	8.50	<4	<10	10	Discharge
04/12/01	6.300					Pre-Discharge
04/23/01	2.100	7.10	5	130	4.9	Pre-Discharge
04/26/01	2.130					Pre-Discharge
04/29/01	0.960	7.10	<4	<10	2.9	Discharge
05/03/01	0.840	7.70	4.4	2	<2	Discharge
05/10/01	4.290		35		27.7	Pre-Discharge
05/17/01	0.830		13	8	3.6	Discharge
05/22/01	1.800	8.80	11	190	5.2	Discharge
05/24/01	0.080		6.4	<1	4	Discharge
05/31/01	2.060		18	<1	4.2	Pre-Discharge
06/10/01	1.000	7.50	<4	45	2.2	Discharge
06/14/01	0.460		8	25	<2	Discharge
06/16/01	0.630	7.20	4.6	10	<2	Discharge
08/22/01	1.400		10.4		2.1	Pre-Discharge
09/04/01	0.540	8.50	14	<10	<2	Discharge
09/06/01	0.570					Discharge

Date	P (mg/l)	pH	TSS (mg/l)	Fecal Coliform #/100 ml	CBOD (mg/l)	Comments
	1.000	6 to 9	45	200	25	Discharge Limits
09/07/01	0.550	8.00	7.2	<10	2.2	Discharge
09/08/01	0.620	8.50	5.8	<10	<2	Discharge
09/20/01	0.620		5.2	<1	3.2	Discharge
09/24/01	0.930	7.90	11	10	5	Discharge
09/27/01	0.810		4.8	<1	4.5	Discharge
10/10/01	3.310		11.6	<2	3.8	Pre-Discharge
10/18/01	0.470		6	6	3.8	Discharge
10/22/01	0.530	7.30	<4	10	<2	Discharge
10/25/01	1.250		24	8	4.9	Discharge
04/17/02	3.000		10	128	7.2	Pre-Discharge
04/25/02	1.000		9.2	<2	4.8	Discharge
04/30/02	0.960	8.50	18	<10	7.4	Discharge
05/02/02	0.650	9.30	35.3	<4	12.8	Discharge
05/10/02	2.900	8.90	33	31	14	Pre-Discharge
05/16/02	2.320	9.20	33.3	20	6.2	Pre-Discharge
05/23/02	1.220					Pre-Discharge
05/30/02	0.540		4.4	<1	5.4	Discharge
06/04/02	0.750	7.50	<4	8	<2	Discharge
06/06/02	0.480		6.4	2	5.6	Discharge
06/14/02	1.900	7.40	28	44	6	Pre-Discharge
06/20/02	0.520	7.50	7.2	10	6.2	Discharge
06/25/02	0.820	8.30	17	<2	4.7	Discharge
02/27/02	0.830		16	2	6	Discharge
08/14/02	1.630					Pre-Discharge
08/21/02	2.210		42.4	2	7.1	Pre-Discharge
09/05/02	0.800		<1	1,100	6.4	Discharge
09/09/02	0.470	8.60	24	<2	<2	Discharge
09/12/02	0.780		32.4	<2	6.4	Discharge
09/26/02	1.320		19.2	4	5.2	Pre-Discharge
10/03/02	0.200		6	<2	<2	Discharge
10/07/02	0.150	7.60	7.2	6	<2	Discharge
10/10/02	0.240		4.8	<2	3.8	Discharge
10/22/02	1.300	7.80	13	12	3.3	Pre-Discharge
10/29/02	0.240	7.10	<4	<2	<2	Discharge
10/31/02	0.240		<1	<2	2.8	Discharge
11/04/02	0.210	7.60	<4	2	<2	Discharge
04/17/03	2.500		46.7	240	12.8	Pre-Discharge
04/25/03	1.070	7.79	38.0	<10	9.2	Pre-Discharge
04/28/03	0.846	8.93	34.0	28	9.5	Discharge
04/28/03	0.798					Discharge
05/01/03	1.200		21.0	<2	7.0	Discharge
05/05/03	0.753	8.90	16.8	4	5.8	Discharge

Date	Phosphorus (mg/l)	pH	TSS (mg/l)	Fecal Coliform #/100 ml	CBOD (mg/l)	Comments
	1.000	**6 to 9**	**45**	**200**	**25**	**Discharge Limits**
05/15/03	0.920	9.40	26.7	<2	8.1	Pre-Discharge
05/22/03	0.460	8.60	12.4	10	2.8	Pre-Discharge
05/27/03	0.407	8.33	8.8	2	<2.0	Discharge
05/29/03	0.490		14.4	2	<2.0	Discharge
06/12/03	1.500		7.2	4	6.6	Pre-Discharge
06/19/03	0.690		12.0	<2	8.1	Discharge
06/23/03	0.801	7.79	22.0	32	4.3	Discharge
06/26/03	0.950		21.2	<2	13.7	Discharge
08/13/03	1.800					Pre-Treatment
08/20/03	1.700	8.50	13.2	38	7.0	Pre-Treatment, SB running
08/27/03	1.450					SB running with Alum
09/02/03	0.870					SB running between Alum stages
09/04/03	0.680		4.8	2	4.7	Discharge
09/08/03	0.430	9.08	6.8	6	3.4	Discharge
09/11/03	0.610		2.0	86	5.7	Discharge
09/24/03	1.600	7.30	4.8	6	2.5	Pre-Treatment, SB running
10/03/03	1.560					SB running with Alum
10/06/03	0.980					SB running between Alum stages
10/08/03	0.970					SB running between Alum stages
10/15/03	0.730					SB running between Alum stages
10/16/03	0.660	7.75	<4	6	<2	Pre-Discharge, SB running
10/24/03	0.940	8.07	4.8	844	4.3	Pre-Discharge
10/29/03	0.460		2.8	64	2.5	Discharge
10/30/03	0.480	7.78	<4	8	<2	Discharge
11/12/03	1.720	8.62	14.0	18	14.0	Pre-Treatment, SB running
11/25/03	0.490					Pre-Discharge
12/03/03	0.430	7.61	6.4	3	6.5	Discharge
12/05/03	0.450	7.64	6.0	<2	6.8	Discharge
12/10/03	0.430	8.15	11.0	<2	10.0	Discharge

Appendix 8.5.B: Alum Usage Review

Isle, MN
Alum Useage Review

1	2	3	4	5	6	7	8	9	10	11
	Discharge	Beginning Phosphorus (mg/l)	Average Phosphorus at Discharge (mg/l)	Phosphorus Reduction (mg/l)	Pond #3 Volume (M gals)	(C6 X 8.34 X C5) Phosphorus Removed (lbs)	Reg Alum Volume (gallons)	7% Acidic Volume (gallons)	Aluminun Required (lbs)	(C10 / C7) Lbs. Al per Lbs. Phos.
Spring, 1999	1			0.000	17.26	0				
	2			0.000	17.26	0				
	3			0.000	17.26	0				
				SPRING, 1999 TOTALS		0	7,969	0	3,680	#DIV/0!
Fall, 1999	1			0.000	17.26	0				
	2			0.000	17.26	0				
	3			0.000	17.26	0				
				FALL, 1999 TOTALS		0	4,401	0	2,032	#DIV/0!
Spring, 2000	1	4.900	0.650	4.250	17.26	612				
	2	6.000	0.775	5.225	17.26	752				
				SPRING, 2000 TOTALS		1,364	12,999	0	6,002	4.40
Fall, 2000	1	2.900	0.873	2.028	17.26	292				
	2	0.960	0.880	0.080	17.26	12				
				FALL, 2000 TOTALS		303	4,188	0	1,934	6.37
Spring, 2001	1	6.300	0.900	5.400	17.26	777				
	2	4.290	0.903	3.387	17.26	488				
	3	2.060	0.697	1.363	17.26	196				
				SPRING, 2001 TOTALS		1,461	9,715	0	4,486	3.07
Fall, 2001	1	1.400	0.570	0.830	17.26	119				
	2	2.230	0.787	1.443	17.26	208				
	3	3.310	0.750	2.560	17.26	369				
				FALL, 2001 TOTALS		696	2,190	3,955	2,438	3.50
Spring, 2002	1	3.000	0.870	2.130	17.26	307				
	2	2.900	0.590	2.310	17.26	333				
	3	1.900	0.723	1.177	17.26	169				
				SPRING, 2002 TOTALS		809	660	8,121	3,234	4.00
Fall, 2002	1	1.630	0.683	0.947	17.26	136				
	2	1.320	0.197	1.123	17.26	162				
	3	1.300	0.230	1.070	17.26	154				
				FALL, 2002 TOTALS		452	990	4,197	1,971	4.36
Spring, 2003	1	2.500	0.899	1.601	17.26	230				
	2	0.920	0.590	0.330	17.26	48				
	3	1.500	0.449	1.051	17.26	151				
				SPRING, 2003 TOTALS		429	0	8,047	2,903	6.76
Fall, 2003	1	1.700	0.573	1.127	17.26	162	0	1,000	361	2.22
	2	1.600	0.470	1.130	17.26	163	0	870	314	1.93
	3*	1.720	0.437	1.283	15.94	171	0	980	354	2.07
				FALL, 2003 TOTALS		495	0	2,850	1,028	2.08

* 1,070 gals of 7% Acidic Alum was gravity feed to edge of pond to empty tanks before severe winter weather. Used 980 gallons with SolarBee.

Appendix 8.6: Test #3: Isle, MN

Appendix 8.6.A: Phosphorus Reduction with Alum Calculation Worksheet

Test #3 Phosphorus Reduction with SolarBee and Alum

Location: Isle, MN **Pond #:** 3

NOTE: Change **RED** numbers only

STEP 1: Determine Pond Size

Pond Size Information:

Total Depth of Pond	7.00	feet
Length at top of pond, berm edge to berm edge	750	feet
Slope on these sidewalls, typically 3:1	3	
Width at top of pond, berm edge to berm dege	473	feet
Slope on ends, typically 3:1	3	
Volume of the pond when full	17.26	million gallons
Surface acres of pond when full	8.14	acres

Pond Size Information , As Operated:

Operating depth of pond	7.00	feet
Estimated average weight bearing sludge depth	0.00	feet
Volume of the pond, as operated, not accounting for weight bearing sludge	**17.26**	million gallons
Volume of the pond, as operated, accounting for weight bearing sludge	**17.26**	million gallons
Surface area of pond as operated	8.14	acres

STEP 2: Determine Volume of Liquid Aluminum Sulfate(Alum) to Use

METHOD 1: Theoretical calculations for amount of liquid Alum:

Initial phosphorus level in water(mg/l or parts per million(ppm))	1.45	mg/l or ppm
Final phosphorus level in water	0.50	mg/l or ppm
Required reduction of phosphorus level in water	0.95	mg/l or ppm
Aluminum required for every pound of phosphorus removed(THEORETICAL)	0.87	pounds
Water to be treated	17.26	million gallons
Water to be treated (gals. X 8.34 ppg)	143.9	million pounds
Total phosphorus to remove	137	pounds
Total Aluminum required to remove phosphorus(THEORETICAL)	119	pounds

Pick type of Alum and corresponding Wt % Aluminum from Table: (Use Mid Point Values or data from Spec Sheet)

Alum Type	Aluminum Content Range Low	High	Mid Point
Regular	4.160%	4.370%	*4.265%*
1% Acid	4.000%	4.200%	*4.100%*
2% Acid	3.900%	4.050%	*3.975%*
3% Acid	3.800%	3.900%	*3.850%*
5% Acid	3.500%	3.700%	*3.600%*
7% Acid	3.200%	3.300%	*3.250%*

Aluminum content in liquid Alum — Alum Type: 7% Acid	3.250%	Wt % Al
Liquid Alum required(THEORETICAL)	3,661	pounds
Liquid Alum weight (pounds per gallon, ppg)	11.10	ppg
Liquid Alum required(THEORETICAL - Assumes no reaction with other nutrients)	330	gallons

METHOD 2: Rule of thumb calculation for amount of liquid Alum:

Initial phosphorus level in water	1.45	mg/l or ppm
Final phosphorus level in water	0.50	mg/l or ppm
Required reduction of phosphorus level in water	0.95	mg/l or ppm
Water to be treated	17.26	million gallons
Water to be treated	53	acre-ft.
Liquid Alum required per acre-ft per ppm phosphorus reduction:	20	gals./acre-ft/ppm
Liquid Alum required	1,006	gallons
Application factor of Alum when compared to Theoretical volume above	3.05	

METHOD 3: Rule of thumb calculation for amount of liquid Alum:

Initial phosphorus level in water	1.45	mg/l or ppm
Water to be treated	17.26	million gallons
Liquid Alum required per million gallons per ppm phosphorus level:	35	gals./MG/ppm
Liquid Alum required	876	gallons
Application factor of Alum when compared to Theoretical volume above	2.66	

STEP 3: Evaluate Volume of Alum Used

Application Dates: 08/28/03 to 09/04/03

Initial phosphorus level in water		1.700	mg/l or ppm
Final phosphorus level in water		0.573	mg/l or ppm
Reduction of phosphorus level in water		1.127	mg/l or ppm
Aluminum required for every pound of phosphorus removed(THEORETICAL)		0.87	pounds
Water treated		17.26	million gallons
Water treated (gals. X 8.34 ppg)		143.9	million pounds
Total phosphorus removed		162	pounds
Total Aluminum required to remove phosphorus(THEORETICAL)		141	pounds
Aluminum content in liquid Alum	Alum Type: 7% Acid	3.250%	Wt % Al
Liquid Alum used		1,000	gallons
Liquid Alum weight per gallon		11.10	ppg
Total Aluminum used to reduce phosphorus		361	pounds
Aluminum used / pound of phosphorus reduced		2.22	pounds
Application factor in this pond to reduce phosphorus level as listed above		2.56	

Appendix 8.6.B: Alum Application Information

LOCATION: Isle, MN Pond #: 3

SUBJECT: SolarBee / Alum Test #3

Date / Time	Alum Type	Tank Volume (Gallons)	Total Pumped Vol.(gals)	Pumping Data Elapsed Time(min.)	Pumping Data Volume (gals)	Pumping Data Rate GPM
8/28/03 12:15 PM	7% Acid	2,040	0	NA	NA	NA
8/29/03 1:00 PM	7% Acid	1,940	100	1,485	100	0.07
9/2/03 10:00 AM	7% Acid	1,340	600	5,580	600	0.11
9/3/03 10:00 AM	7% Acid	1,240	100	1,440	100	0.07
9/4/03 8:00 AM	7% Acid	1,040	200	1,320	200	0.15
		TOTALS	1,000	9,825	1,000	0.10

NOTES:

(1) SolarBee SB10000 machine started on 08/14/03.

(2) Fluid intake depth set at 4.92' from pond surface on 08/14/03.

(3) Fluid intake depth set at 3' from pond surface on 08/28/03.

(4) SolarBee SB10000 machine shut down at 8:00 a.m.on 09/04/03.

SB10000 Run Times	Days	Comments
Before Alum pumped:	14.000	Solar and shore power
While Alum pumped:	6.823	Solar and shore power
After Alum pumped:	0.000	
TOTAL	20.823	

Appendix 8.7: Test #4: Isle, MN

Appendix 8.7.A: Phosphorus Reduction with Alum Calculation Worksheet

Test #4 Phosphorus Reduction with Alum and SolarBee

Location: Isle, MN **Pond #:** 3

NOTE: Change **RED** numbers only

STEP 1: Determine Pond Size

Pond Size Information:

Total Depth of Pond	7.00	feet
Length at top of pond, berm edge to berm edge	750	feet
Slope on these sidewalls, typically 3:1	3	
Width at top of pond, berm edge to berm dege	473	feet
Slope on ends, typically 3:1	3	
Volume of the pond when full	17.26	million gallons
Surface acres of pond when full	8.14	acres

Pond Size Information , As Operated:

Operating depth of pond	7.00	feet
Estimated average weight bearing sludge depth	0.00	feet
Volume of the pond, as operated, <u>not</u> accounting for weight bearing sludge	**17.26**	million gallons
Volume of the pond, as operated, accounting for weight bearing sludge	**17.26**	million gallons
Surface area of pond as operated	8.14	acres

STEP 2: Determine Volume of Liquid Aluminum Sulfate(Alum) to Use

METHOD 1: Theoretical calculations for amount of liquid Alum:

Initial phosphorus level in water(mg/l or parts per million(ppm))	1.60	mg/l or ppm
Final phosphorus level in water	0.50	mg/l or ppm
Required reduction of phosphorus level in water	1.10	mg/l or ppm
Aluminum required for every pound of phosphorus removed(THEORETICAL)	0.87	pounds
Water to be treated	17.26	million gallons
Water to be treated (gals. X 8.34 ppg)	143.9	million pounds
Total phosphorus to remove	158	pounds
Total Aluminum required to remove phosphorus(THEORETICAL)	138	pounds

Pick type of Alum and corresponding Wt % Aluminum from Table: (Use Mid Point Values or data from Spec Sheet)

Alum Type	Aluminum Content Range		
	Low	High	Mid Point
Regular	4.160%	4.370%	*4.265%*
1% Acid	4.000%	4.200%	*4.100%*
2% Acid	3.900%	4.050%	*3.975%*
3% Acid	3.800%	3.900%	*3.850%*
5% Acid	3.500%	3.700%	*3.600%*
7% Acid	3.200%	3.300%	*3.250%*

Aluminum content in liquid Alum	Alum Type: 7% Acid	3.250%	Wt % Al
Liquid Alum required(THEORETICAL)		4,239	pounds
Liquid Alum weight (pounds per gallon, ppg)		11.10	ppg
Liquid Alum required(THEORETICAL - Assumes no reaction with other nutrients)		382	gallons

METHOD 2: Rule of thumb calculation for amount of liquid Alum:

Initial phosphorus level in water	1.60	mg/l or ppm
Final phosphorus level in water	0.50	mg/l or ppm
Required reduction of phosphorus level in water	1.10	mg/l or ppm
Water to be treated	17.26	million gallons
Water to be treated	53	acre-ft.
Liquid Alum required per acre-ft per ppm phosphorus reduction:	20	gals./acre-ft/ppm
Liquid Alum required	1,165	gallons
Application factor of Alum when compared to Theoretical volume above	3.05	

METHOD 3: Rule of thumb calculation for amount of liquid Alum:

Initial phosphorus level in water	1.60	mg/l or ppm
Water to be treated	17.26	million gallons
Liquid Alum required per million gallons per ppm phosphorus level:	35	gals./MG/ppm
Liquid Alum required	967	gallons
Application factor of Alum when compared to Theoretical volume above	2.53	

STEP 3: Evaluate Volume of Alum Used

Application Dates: 10/01/03 to 10/04/03, 10/15/03 to 10/16/03

Initial phosphorus level in water		1.600	mg/l or ppm
Final phosphorus level in water		0.470	mg/l or ppm
Reduction of phosphorus level in water		1.130	mg/l or ppm
Aluminum required for every pound of phosphorus removed(THEORETICAL)		0.87	pounds
Water treated		17.26	million gallons
Water treated (gals. X 8.34 ppg)		143.9	million pounds
Total phosphorus removed		163	pounds
Total Aluminum required to remove phosphorus(THEORETICAL)		142	pounds
Aluminum content in liquid Alum	Alum Type: 7% Acid	3.250%	Wt % Al
Liquid Alum used		870	gallons
Liquid Alum weight per gallon		11.10	ppg
Total Aluminum used to reduce phosphorus		314	pounds
Aluminum used / pound of phosphorus reduced		1.93	pounds
Application factor in this pond to reduce phosphorus level as listed above		2.22	

Appendix 8.7.B: Alum Application Information

LOCATION: Isle, MN Pond #: 3

SUBJECT: SolarBee / Alum Test #4

Date / Time	Alum Type	Tank Volume (Gallons)	Total Pumped Vol.(gals)	Pumping Data Elapsed Time(min.)	Volume (gals)	Rate GPM
10/1/03 11:30 AM	7% Acid	3,000	0	NA	NA	NA
10/2/03 11:30 AM	7% Acid	2,750	250	1,440	250	0.17
10/3/03 11:30 AM	7% Acid	2,500	250	1,440	250	0.17
10/4/03 9:00 AM	7% Acid	2,330	170	1,290	170	0.13
10/15/03 9:00 AM	7% Acid	2,330	0	NA	NA	NA
10/16/03 9:00 AM	7% Acid	2,130	200	1,440	200	0.14
		TOTALS	870	5,610	870	0.16

NOTES:

(1) SolarBee SB10000 machine started on 09/15/03.

(2) Pond depth at 5' when SB10000 machine started.

(3) Fluid intake depth set at 3' from pond surface.

(4) SolarBee SB10000 machine shut down at 9:00 a.m. on 10/22/03.

SB10000 Run Times	Days	Comments
Before Alum pumped:	16.000	Solar and shore power
While Alum pumped:	3.896	Solar and shore power
Between Alum stages:	11.000	Solar and shore power
After Alum pumped:	6.000	Solar and shore power
TOTAL	36.896	

Appendix 8.8: Test #5: Isle, MN

Appendix 8.8.A: Phosphorus Reduction with Alum Calculation Worksheet

Test #5 Phosphorus Reduction with Alum and SolarBee

Location: Isle, MN **Pond #:** 3

NOTE: Change **RED** numbers only

STEP 1: Determine Pond Size

Pond Size Information:

Total Depth of Pond	7.00	feet
Length at top of pond, berm edge to berm edge	750	feet
Slope on these sidewalls, typically 3:1	3	
Width at top of pond, berm edge to berm dege	473	feet
Slope on ends, typically 3:1	3	
Volume of the pond when full	17.26	million gallons
Surface acres of pond when full	8.14	acres

Pond Size Information , As Operated:

Operating depth of pond	6.50	feet
Estimated average weight bearing sludge depth	0.00	feet
Volume of the pond, as operated, <u>not</u> accounting for weight bearing sludge	**15.94**	million gallons
Volume of the pond, as operated, accounting for weight bearing sludge	**15.94**	million gallons
Surface area of pond as operated	8.06	acres

STEP 2: Determine Volume of Liquid Aluminum Sulfate(Alum) to Use

METHOD 1: Theoretical calculations for amount of liquid Alum:

Initial phosphorus level in water(mg/l or parts per million(ppm))	1.72	mg/l or ppm
Final phosphorus level in water	0.50	mg/l or ppm
Required reduction of phosphorus level in water	1.22	mg/l or ppm
Aluminum required for every pound of phosphorus removed(THEORETICAL)	0.87	pounds
Water to be treated	15.94	million gallons
Water to be treated (gals. X 8.34 ppg)	132.9	million pounds
Total phosphorus to remove	162	pounds
Total Aluminum required to remove phosphorus(THEORETICAL)	141	pounds

Pick type of Alum and corresponding Wt % Aluminum from Table: (Use Mid Point Values or data from Spec Sheet)

Alum Type	Aluminum Content Range		
	Low	High	Mid Point
Regular	4.160%	4.370%	*4.265%*
1% Acid	4.000%	4.200%	*4.100%*
2% Acid	3.900%	4.050%	*3.975%*
3% Acid	3.800%	3.900%	*3.850%*
5% Acid	3.500%	3.700%	*3.600%*
7% Acid	3.200%	3.300%	*3.250%*

Aluminum content in liquid Alum	Alum Type: 7% Acid	3.250%	Wt % Al
Liquid Alum required(THEORETICAL)		4,342	pounds
Liquid Alum weight (pounds per gallon, ppg)		11.10	ppg
Liquid Alum required(THEORETICAL - Assumes no reaction with other nutrients)		391	gallons

METHOD 2: Rule of thumb calculation for amount of liquid Alum:

Initial phosphorus level in water	1.72	mg/l or ppm
Final phosphorus level in water	0.50	mg/l or ppm
Required reduction of phosphorus level in water	1.22	mg/l or ppm
Water to be treated	15.94	million gallons
Water to be treated	49	acre-ft.
Liquid Alum required per acre-ft per ppm phosphorus reduction:	20	gals./acre-ft/ppm
Liquid Alum required	1,194	gallons
Application factor of Alum when compared to Theoretical volume above	3.05	

METHOD 3: Rule of thumb calculation for amount of liquid Alum:

Initial phosphorus level in water	1.72	ppm
Water to be treated	15.94	million gallons
Liquid Alum required per million gallons per ppm phosphorus level:	35	gals./MG/ppm
Liquid Alum required	960	gallons
Application factor of Alum when compared to Theoretical volume above	2.45	

STEP 3: Evaluate Volume of Alum Used

Application Dates: 11/12/03 to 11/13/03, 11/20/03, 11/21/03 to 11/23/03

Initial phosphorus level in water		1.720	mg/l or ppm
Final phosphorus level in water		0.437	mg/l or ppm
Reduction of phosphorus level in water		1.283	mg/l or ppm
Aluminum required for every pound of phosphorus removed(THEORETICAL)		0.87	pounds
Water treated		15.94	million gallons
Water treated (gals. X 8.34 ppg)		132.9	million pounds
Total phosphorus removed		171	pounds
Total Aluminum required to remove phosphorus(THEORETICAL)		148	pounds
Aluminum content in liquid Alum	Alum Type: 7% Acid	3.250%	Wt % Al
Liquid Alum used		980	gallons
Liquid Alum weight per gallon		11.10	ppg
Total Aluminum used to reduce phosphorus		354	pounds
Aluminum used / pound of phosphorus reduced		2.07	pounds
Application factor in this pond to reduce phosphorus level as listed above		2.38	

Appendix 8.8.B: Alum Application Information

LOCATION: Isle, MN

Pond #: 3

SUBJECT: SolarBee / Alum Test #5

				Pumping Data			
Date / Time	Alum Type	Tank Volume (Gallons)	Total Pumped Vol.(gals)	Elapsed Time(min.)	Volume (gals)	Total Rate GPM	Alum Rate GPM
11/12/03 4:00 PM	7% Acid	2,050	0	NA	NA	NA	NA
11/13/03 4:00 PM	7% Acid	1,900	150	1,440	150	0.10	0.10
11/20/03 12:30 PM	Mix 1	2,200	0	NA	NA	NA	NA
11/20/03 10:00 PM	Mix 1	2,050	150	570	150	0.26	0.08
11/21/03 6:00 PM	Mix 1	2,050	0	NA	NA	NA	NA
11/22/03 9:00 AM	Mix 1	800	1,250	900	1,250	1.39	0.44
11/22/03 9:30 AM	Mix 2	5,000	0	NA	NA	NA	NA
11/23/03 3:00 PM	Mix 2	3,000	2,000	1,770	2,000	1.13	0.22
		TOTALS	3,550	4,680	3,550	0.76	0.21

NOTES:

(1) SolarBee SB10000 machine started at 10:00 a.m. on 11/08/03.
(2) Pond depth at 6.5' with 5" ice when SB10000 machine started.
(3) Fluid intake depth set at 3' from pond surface.
(4) 500 gallons of 7% Acid Alum was gravity feed to the edge of the pond on 11/18/03 after injection line to SolarBee machine froze.
(5) Had pump problems on 11/20/03 due to low temperatures and hgh viscosity of 7% Acid Alum.
(6) Diluted 700 gallons 7% Acid Alum with 1,500 gallons pond water(Mixture 1-31.8% 7% Acid Alum) on 11/20/03.
(7) Installed new pump on 11/21/03.
(8) Mixed 800 gallons of Mixture 1 with 700 gallons 7% Acid Alum and 3,500 gallons pond water for total of 5,000 gallons(Mixture 2-19.1 % 7% Acid Alum) on 11/22/03.
(9) Pump failed and injection line to SolarBee froze due to low temperatures on 11/23/03.
(10) 3,000 gallons of Mixture 2 was gravity feed to the edge of the pond on 11/26/03.
(11) Total of 980 gallons of 7% Acid Alum was pumped or gravity feed to SB10000 machine.
(12)Total of 1,070 gallons of 7% Acid Alum was gravity feed to edge of pond. City needed to empty tanks before severe winter weather.
(13) SolarBee SB10000 machine shut down at 9:00 a.m. on 12/03/03.

SB10000 Run Times	Days	Comments
Before Alum pumped:	4.250	Solar and shore power
While Alum pumped:	3.250	Solar and shore power
Between Alum stages:	7.687	Solar and shore power
After Alum pumped:	7.920	Solar and shore power
TOTAL	23.107	

Appendix 8.9: Typical Material Safety data Sheet (MSDS) for Aluminum Sulfate

Aluminum Sulfate, Liquid

Material Safety Data Sheet

Section 1 - Chemical Product and Company Identification

Product/Chemical Name: Aluminum Sulfate, Liquid
Chemical Formula: $Al_2(SO_4)_3 \bullet 14(H_2O)$
CAS Number: 10043-01-3
General Use: Water Treatment Chemical
Emergency Contact: **800-424-9300**
Chemtrec

Manufacturer:

HMIS
H 1
F 0
R 0
PPE†
†Sec. 8

Section 2 - Composition / Information on Ingredients

Ingredient Name	CAS Number	% wt
Aluminum Sulfate	10043-01-3	27.8
Water	7732-18-5	72.2

	OSHA PEL		ACGIH TLV		NIOSH REL		NIOSH
Ingredient	TWA	STEL	TWA	STEL	TWA	STEL	IDLH
Aluminum Sulfate	2 mg/m^3 *as aluminum*	none estab.	none estab.	none estab.	none estab.	none estab.	none estab.

Toxicity Data:

Section 3 - Physical and Chemical Properties

Physical State: liquid
Appearance and Odor: colorless, clear amber or light green
Odor Threshold: negligible odor
Vapor Pressure: NA
Vapor Density (Air=1): NA
Density:
Specific Gravity (H_2O=1, at 4 °C): 1.32
pH: 2.1 ± 0.5

Water Solubility: Complete
Other Solubilities:
Boiling Point: 109° C/228° F
Freezing/Melting Point: -13° C/9° F
Viscosity:
Surface Tension:
% Volatile: NA

Section 4 - Fire-Fighting Measures

Flash Point: NA
Burning Rate: NA
Autoignition Temperature: NA
LEL: NA
UEL: NA

NFPA

Flammability Classification:
Extinguishing Media: NA
Unusual Fire or Explosion Hazards: If evaporated to dryness and exposed to temperatures greater than 1400°F aluminum sulfate will decompose generating toxic and corrosive gas.
Hazardous Combustion Products: See Section V
Fire-Fighting Instructions: Do not release runoff from fire control methods to sewers or waterways.

Section 5 - Stability and Reactivity

Stability:	Aluminum Sulfate, Liquid is stable at room temperature in closed containers under normal storage and handling conditions.
Polymerization:	Hazardous polymerization cannot occur.
Chemical Incompatibilities:	Alkalies and water-reactive materials.
Conditions to Avoid:	N/A
Hazardous Decomposition Products:	Thermal oxidative decomposition of Aluminum Sulfate occurs at temperatures greater than 1400°F and can produce sulfur oxides.

Section 6 - Health Hazard Information

Potential Health Effects

Primary Entry Routes:	Ingestion
Target Organs:	N/A
Acute Effects	No unusual
Eye:	May cause a burning feeling.
Skin:	May cause a skin rash or burning feeling.
Ingestion:	
Carcinogenicity:	IARC, NTP, and OSHA do not list Aluminum Sulfate, Liquid as a carcinogen.
Medical Conditions Aggravated by Long-Term Exposure:	None reported.
Chronic Effects:	There is no evidence that aluminum sulfate causes cancer or affects reproduction.

Emergency and First Aid Procedures

Inhalation:	(mist or spray) Remove from exposure, seek medical treatment if any symptoms occur.
Eye Contact:	Immediately flush with large amounts of water for at least 15 minutes, occasionally lifting upper and lower lids. Seek medical attention.
Skin Contact:	Remove contaminated clothing and wash contaminated skin with water.
Ingestion:	Do not induce vomiting, drink milk or water and immediately seek medical attention.

After first aid, get appropriate in-plant, paramedic, or community medical support.

Section 7 - Spill, Leak, and Disposal Procedures

Spill /Leak Procedures:	Spill procedures are dictated by site wastewater flow controls and will vary from site to site. General procedures are provided in this document, but authorization for any wastewater discharge must be obtained prior to the discharge.
Small Spills:	If directed to an industrial sewer, wash down with large volumes of water. Spills can be neutralized and absorbed with soda ash or lime, but neutralization will release carbon dioxide, which can generate a breathing hazard.
Large Spills	For large spills, dike far ahead of liquid spill for later disposal. Do not release into sewers or waterways. Pump residue into storage containers or neutralize with lime or soda ash. Neutralization will release carbon dioxide, which can generate a breathing hazard.
Containment:	
Cleanup:	Wash or neutralize impacted areas after liquid removal to remove residues.
Regulatory Requirements:	Follow applicable OSHA regulations (29 CFR 1910.120).
Disposal:	Contact your supplier or a licensed contractor for detailed recommendations. Follow applicable Federal, state, and local regulations.
Container Cleaning and Disposal:	

Ecological Information:

EPA Regulations:

RCRA Hazardous Waste Number:	Not listed (40 CFR 261.33)
RCRA Hazardous Waste Classification	(40 CFR 261.??): Not classified
CERCLA Hazardous Substance (40 CFR 302.4)	listed CWA, Sec. 311 (b)(4)
CERCLA Reportable Quantity (RQ)	5,000 lbs (2,270 kg) as $Al_2(SO_4)_3$ 17,900 lbs (8,120 kg) as a 27.8% solution
SARA 311/312 Codes:	immediate (acute) health hazard
SARA Toxic Chemical (40 CFR 372.65):	Not listed
SARA EHS (Extremely Hazardous Substance) (40 CFR 355):	Not listed

OSHA Regulations:

Air Contaminant (29 CFR 1910.1000, Table Z-1, Z-1-A):	Not listed
OSHA Specifically Regulated Substance (29CFR 1910.????)	Not listed

State Regulations:

Section 8 - Exposure Controls / Personal Protection

Engineering Controls:

Ventilation: Under normal conditions, liquid alum will not generate mists or vapors. No special ventilation is recommended.

Administrative Controls:

Respiratory Protection: Seek professional advice prior to respirator selection and use. Follow OSHA respirator regulations (29 CFR 1910.134) and, if necessary, wear a MSHA/NIOSH-approved respirator. Select respirator based on its suitability to provide adequate worker protection for given working conditions, level of airborne contamination, and presence of sufficient oxygen. For emergency or non-routine operations (cleaning spills, reactor vessels, or storage tanks), wear an SCBA. *Warning! Air-purifying respirators do not protect workers in oxygen-deficient atmospheres.* If respirators are used, OSHA requires a written respiratory protection program that includes at least: medical certification, training, fit-testing, periodic environmental monitoring, maintenance, inspection, cleaning, and convenient, sanitary storage areas.

Protective Clothing/Equipment: Wear chemically protective gloves, boots, aprons, and gauntlets to prevent prolonged or repeated skin contact. Wear protective chemical safety goggles, per OSHA eye- and face-protection regulations (29 CFR 1910.133). Contact lenses are not eye protective devices. Appropriate eye protection must be worn instead of, or in conjunction with contact lenses.

Safety Stations: Make emergency eyewash stations, safety/quick-drench showers, and washing facilities available in work area.

Contaminated Equipment: Separate contaminated work clothes from street clothes. Launder before reuse. Remove this material from your shoes and clean personal protective equipment.

Comments: Never eat, drink, or smoke in work areas. Practice good personal hygiene after using this material, especially before eating, drinking, smoking, using the toilet, or applying cosmetics.

Section 9 - Special Precautions and Comments

Handling Precautions:

Storage Requirements:

DOT Transportation Data (49 CFR 172.101):

Shipping Name:	Aluminum Sulfate	**Packaging Authorizations**	
Shipping Symbols:	G	**a) Exceptions:**	173.155
Hazard Class:	9	**b) Non-bulk Packaging:**	173.203
DOT No.:	UN3082	**c) Bulk Packaging:**	173.241
Packing Group:	III	**Quantity Limitations**	
Label:	Class 9	**a) Passenger, Aircraft, or Railcar:**	no limit
Special Provisions (172.102):	8, T1	**b) Cargo Aircraft Only:**	no limit
		Vessel Stowage Requirements	
		a) Vessel Stowage:	A
		b) Other:	

Prepared By:
Revision Notes:

Disclaimer: The information presented herein is believed to be accurate and reliable, but is given without guaranty or warranty, expressed or implied. The user should not assume that all safety measures are indicated so that other measures may not be required. The user is responsible for assuring that the product and equipment are used in a safe manner that complies with all appropriate legal standards and regulations.

Appendix 8.10: Cost of Ownership

SolarBee Circulator / Alum Application vs. Boat / Alum Application

FOR: ALUM APPLCATION	SCENARIO 1 INPUTTED VALUES:	SCENARIO 1 CALCULATED VALUES:	SCENARIO 2 INPUTTED VALUES:	SCENARIO 2 CALCULATED VALUES:	SCENARIO 3 INPUTTED VALUES:	SCENARIO 3 CALCULATED VALUES:
MOTORBOAT APPLICATION						
MISC. MAJOR COSTS:						
Boat, dock, alum application equipment	$100,000		$70,000		$40,000	
Alum/Year	$15,000		$15,000		$15,000	
Manpower/Year	$2,500		$2,500		$2,500	
SUBTOTAL, THESE ITEMS:		***$ 117,500***		***$ 87,500***		***$ 57,500***
MAINTENANCE, $/YR	$150		$150		$150	
MAINTENANCE		***$ 150***		***$ 150***		***$ 150***
TOTAL COST(BOLD#S)		***$ 117,650***		***$ 87,650***		***$ 57,650***
SOLARBEE APPLICATION:						
QUANTITY OF SOLARBEES	1		1		1	
W/ 200 WATT SHORE POWER?	YES		YES		YES	
INSTALLED SB COST, EACH	$33,000		$33,000		$33,000	
INSTALLED SB COST, TOTAL		***$ 33,000***		***$ 33,000***		***$ 33,000***
MAINTENANCE OF SB(S), $/YR		***$ 200***		***$ 200***		***$ 200***
SB ELECTRICAL COST, $/YR		***$ 120***		***$ 120***		***$ 120***
MISC. MAJOR COSTS:						
Alum/Year	$9,750	(35% reduction)	$9,750	(35% reduction)	$9,750	(35% reduction)
Manpower/Year	$1,250	(50% reduction)	$1,250	(50% reduction)	$1,250	(50% reduction)
SUBTOTAL, THESE ITEMS:		***$ 11,000***		***$ 11,000***		***$ 11,000***
TOTAL COST(BOLD#S)		***$ 44,320***		***$ 44,320***		***$ 44,320***
SAVINGS:						
$ SAVINGS WITH SB(S)		**$ 73,330**		**$ 43,330**		**$ 13,330**
PAYBACK TIME WITH SB, YEARS:		**0.60**		**1.02**		**3.32**

9.0 REFERENCES

1 **Municipal Wastewater Lagoon - Phosphorus Removal** by Charles Pycha and Ernesto Lopez, Environmental Engineers, Technical Support Section, Water Compliance Branch, U.S. EPA 5WCT-15-J, Chicago, Illinois.

2. **Design Manual - Municipal Wastewater Stabilization Ponds** by U.S. Environmental Protection Agency, Office of Research and Development, Municipal Environmental Research Laboratory, Center for Environmental Research Information, Office of Water and Office of Water Program Operations, October, 1983, Section 5.2.5.

10.0 ACKNOWLEDGEMENTS

SolarBee / Pump Systems Inc. appreciated the opportunity to work with the following individuals and groups on this project. We want to thank them for all the manpower, time, information gathering and discussions required to make these successful tests for alum application with the floating, solar powered, high flow circulation machine.

Larry Anderson of Short, Elliott, Hendrickson, Inc., St Paul, MN.

Al Fahey and other city employees at Belle Plaine MN, Wastewater Treatment Facility.

David Sawatsky, David Oslin and other city employees at Isle, MN Wastewater Treatment Facility.

Ben Shultes, Chris Lind and other employees at General Chemical Syracuse Technical Center at Syracuse, NY.

Mike Boersma, Dave Lupo and other employees of SolarBee / Pump Systems, Inc. Installation and Service Crews.

Harvestland Cooperative in Morgan, MN, alum distributor.

11.0 ADDITIONAL NOTES

Please contact our SolarBee by Pump Systems, Inc. main office in Dickinson, North Dakota at 1-866-437-8076 with any question concerning information presented in this report or if you would like a copy of this report.

Information on the SolarBee floating, solar powered high flow circulation machines can be found on our website at www.solarbee.com.