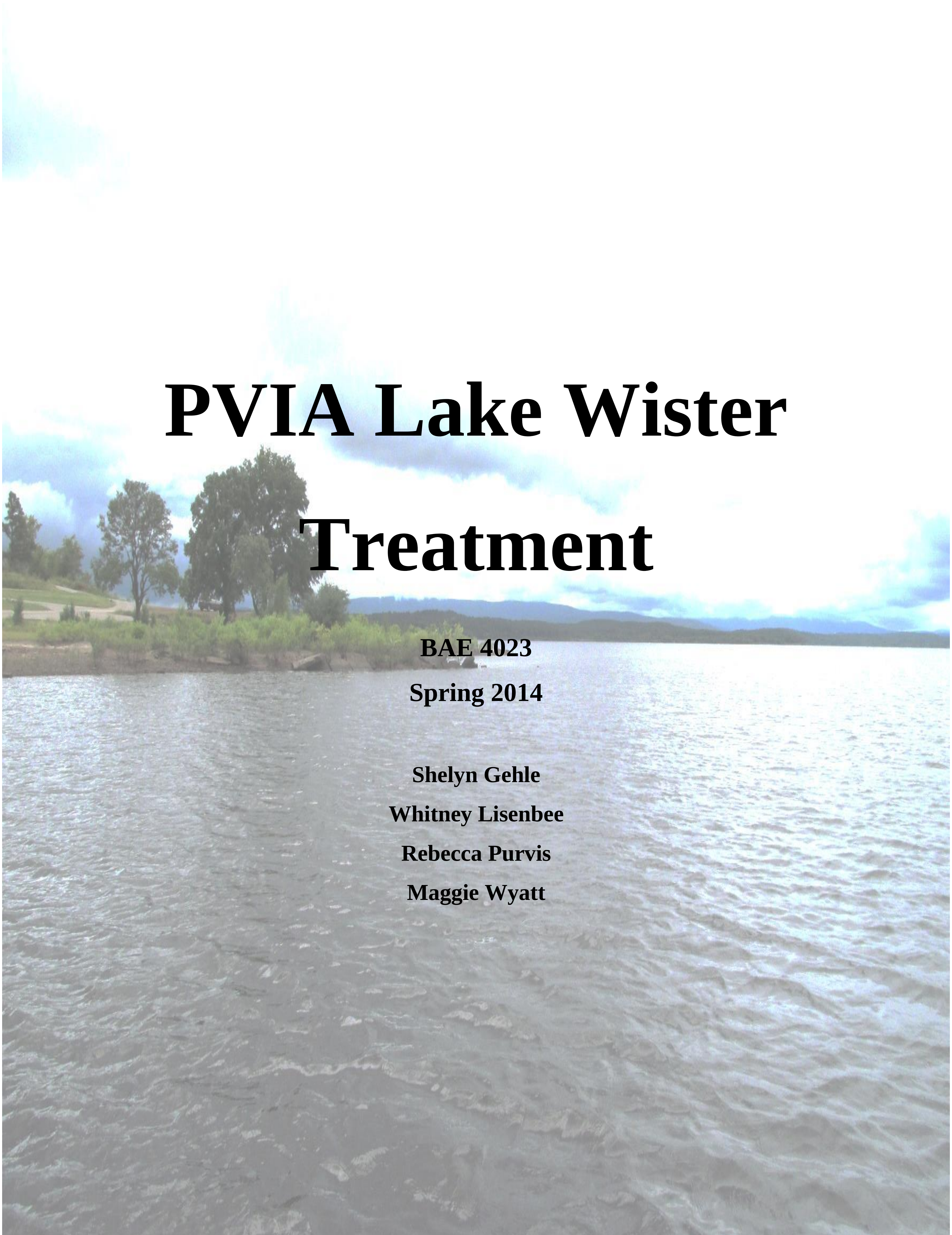

PVIA Lake Wister Treatment

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Abstract

The Poteau Valley Improvement Authority (PVIA) is looking for a solution to reduce the dissolved phosphorus level in Lake Wister. PVIA treats and distributes water to about 80% of LeFlore County in Oklahoma. The treatment system will be implemented in Quarry Island Cove, the location of the water intake station. The removal of phosphorus will reduce the amount of algae in the lake and therefore, reduce the disinfection by-products (DBPs), the result of organic matter reacting with chlorine, in the treated outflow. This system is designed to mix alum with lake water using a bubble curtain. The alum then reacts with phosphorus and creates a flocculant that will settle to the bottom of the lake. This bubble curtain will be produced by multiple diffusers or bubble tubing, placed across the length of the cove, so that as water enters the cove it is treated before being pumped to the water treatment plant. The aeration will be powered by the current compressor, located at the intake facility. Liquid alum will be distributed through pipes using chemical injectors and a variable speed pump to adjust the release rate. Alum chemistry analysis was completed to determine the amount of alum that should be used and how to adjust the amount based on cove pH and alkalinity. The aeration products were tested to determine which will provide better mixing with the alum. Diffuser discs and bubble tubing were tested at various pressures in a pool 8ft deep. Testing showed that the bubble tubing provided better mixing throughout the pool. After cost analysis, the bubble tubing system was cheaper than the diffuser disc system. It is recommended to use two rows of bubble tubing with a single line of alum down the center.

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Background on PVIA

PVIA stands for the Poteau Valley Improvement Authority. The PVIA treats and distributes water to about 80% of Le Flore County in Oklahoma. Le Flore County is located in east-central Oklahoma. Efforts were focused in Wister, OK, where Lake Wister is located (Figure 1). On average, six million gallons of water a day (MGD) are pumped out of Lake Wister for treatment and distribution through the drinking water supply system. The maximum capacity for the treatment plant is twelve MGD. The intake is located in Quarry Island Cove (Figure 2) on the northeast side of the lake. The cove contains about 2 percent of the total volume of the lake, totaling 1418 ac-ft, and the depth across the cove is on average fifteen feet. Our design will be implemented in Quarry Island Cove, allowing for the water to be treated before being pumped to the treatment plant.

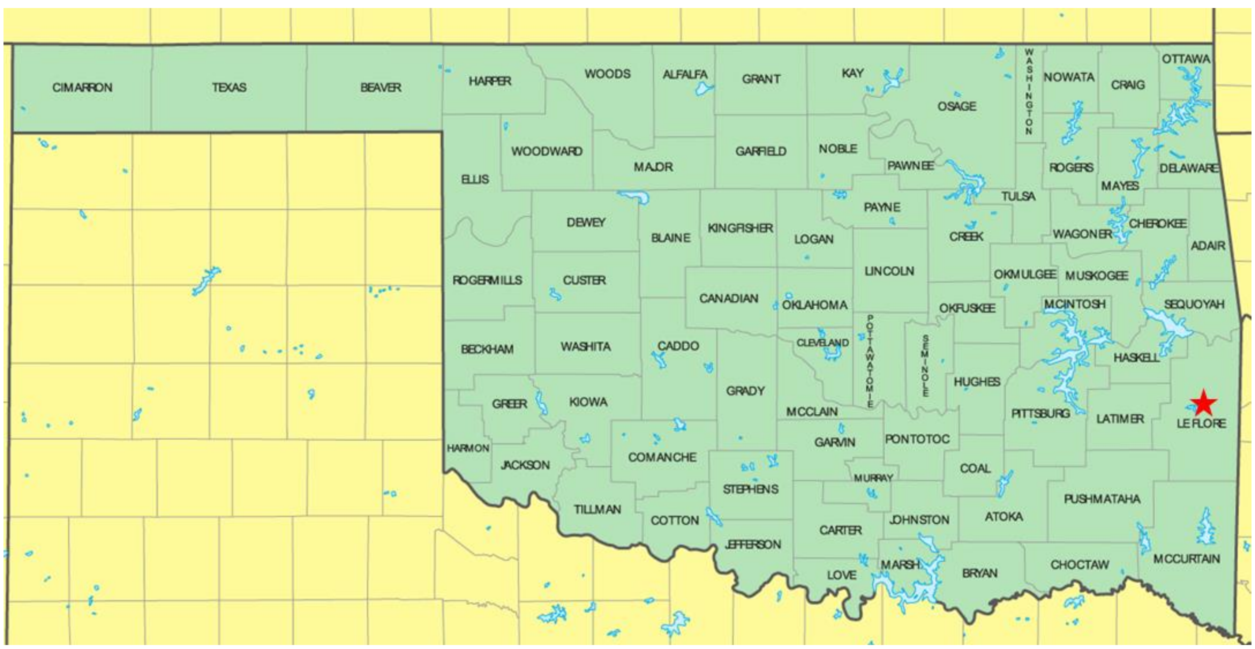


Figure 1: Map of Oklahoma; Lake Wister is represented by a red star.

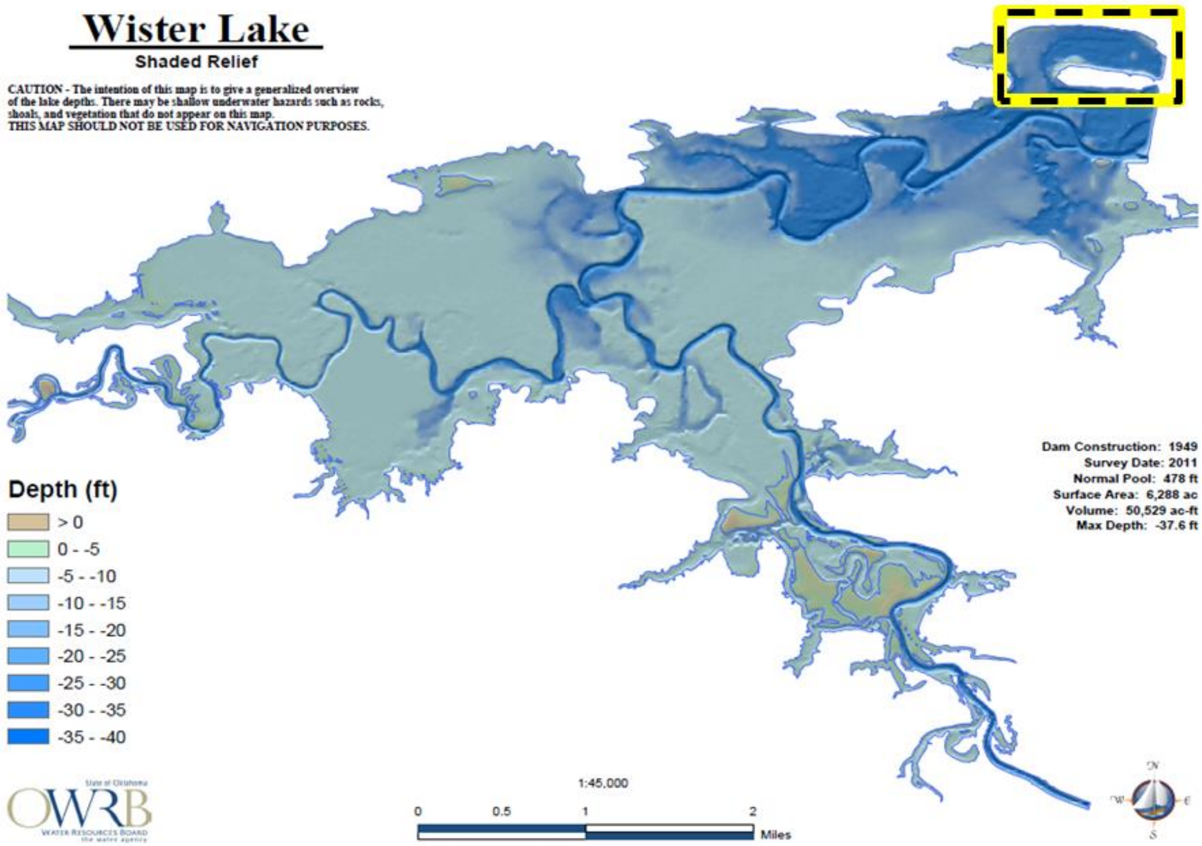


Figure 2: Map of Lake Wister; yellow box represents Quarry Island Cove where the water is drawn for treatment.

Problem Statement

Current Problem

Lake Wister has a very high level of dissolved phosphorus, which is released from the lake bedrock, with little to no contribution from agricultural runoff. Phosphorus is the limiting nutrient for algal growth. Therefore, an increase in phosphorus concentration results in an increased level of algae within the lake. A high level of phosphorus within the lake can create a eutrophic environment, where oxygen is limited and algae blooms encourage fish kills or other detrimental conditions. To ensure that the lake is mesotrophic, rather than eutrophic, the phosphorus level needs to be below 24 µg/L (Appendix A). One way to monitor the phosphorus level within the lake is to quantify the chlorophyll-A level, which is a component of algae photosynthesis. There are no standards for phosphorus, but the Oklahoma Department of Environmental Quality (ODEQ) has set the chlorophyll-A standard to not exceed 10 µg/L.

Current Procedure

The PVIA water treatment plant must remove phosphorus from the water by adding aluminum sulfate, commonly called alum. PVIA uses approximately 5,000 gallons of alum per week, at a cost of one dollar per gallon. Currently, alum is added immediately after the water reaches the treatment plant. Alum reacts with phosphorus in the water to create a precipitant of aluminum phosphate. The water is then put through three clarifiers, which allows the flocculation precipitant to settle to the bottom, creating sludge. A large volume of sludge, or "water treatment residual", is created over time that must be properly removed and disposed of by PVIA. The residual material is pumped to a nearby pasture and spread out. The disposal of this material makes up one-twelfth of their total labor cost; with one employee whose primary focus is on sludge removal. The current disposal site may not always be available for the PVIA, which would require them to haul the sludge to a landfill or find an alternative treatment solution.

Proposed Chemical Treatment

Our project objective is to create an Alum Microfloc Curtain. Essentially, this curtain is created by a line of aeration components on the bottom of the lake with an alum component placed over the top. The aeration components move air bubbles from the bottom to the lake surface while alum is injected above the aeration system. The curtain provides direct contact between the alum and phosphorus laden water as the alum is brought to the surface. The mixing creates a flocculation precipitant that settles to the bottom of the lake to form a protective barrier against the re-suspension of dissolved phosphorus from the sediments. This curtain will allow for a continuous decrease in phosphorus concentration in the water as it enters the cove. The reduction in phosphorus will in turn reduce the algae and cyanobacteria (blue-green algae) levels. The reduction in algae will also help reduce the level of toxic disinfection by-products in the treated outflow. Disinfection by-products are the result of chlorine reacting with the organic matter, such as dead algae, in the water treatment process. This in-lake treatment will help the PVIA keep Lake Wister under the state standards for chlorophyll-A.

Current in-lake alum applications

Alum can currently be sprayed over the water surface and then sink to the bottom causing the phosphorus to attach to it, but it is not extremely effective because of the lack of mixing and alum to phosphorus contact. Putting alum into a lake environment is not toxic to the aquatic ecosystem because aluminum is only detrimental when it is a free ion, not when it is bound to phosphorus. The previously discussed flocculant also compacts to prevent free aluminum ions from escaping. It is a safe and effective way to reduce phosphorus in the lake.

Water Balance

Quarry Island Cove has a volume of 1418 ac-ft. A steady state accumulation equation was used to see how much water would be entering the cove each month to be treated. This volume affects how much alum would be needed each month to treat the incoming lake water. Lake water entering the cove was determined using Equation 1,

$$A = I - O \tag{1}$$

where A is the cove accumulation, I is cove inflow, and O is cove outflow. For inputs, it was assumed that the precipitation was negligible as the annual rainfall spread over the entire lake surface would have very little accumulation in the cove. For outputs, it was assumed that evapotranspiration was 4 ft/yr and that the water treatment intake pumped out 6 MGD. Accumulation of water in the cove was set to zero because it is a steady state equation. This equation was solved to find that 600 ac-ft (740 ML) of water per month would be entering the cove for treatment.

Constraints

There are many different constraints and all need to be taken into account when creating potential designs.

Cove Constraints

Quarry Island Cove has a quarter mile (1320 ft) wide opening which the design needed to span across in order to effectively treat all incoming water. The lake has an alkalinity range from 8 to 42 mg/L as $CaCO_3$ with an average of 19 mg/L as $CaCO_3$ and a pH range from 6.5 to 9.5. Low alkalinity and pH within the cove creates a corrosive environment that could interfere with how effectively the structure functions. At least 316 series stainless steel needed to be used to withstand potential corrosion. Lake conditions vary throughout the year causing sporadic algae blooms that need to be addressed. Due to these seasonal changes, a system that allows for varying rates of alum injection was required to ensure that proper treatment takes place. Finally, the cove has a high level of recreational boating and fishing. Any design needed to be on the bottom of the cove to ensure no interference between the treatment and boats. Buoys or signs will need to be set up to ensure that no fish hooks or anchors get caught on the pipes.

Power Constraints

The current compressor station is 45 horsepower and has 48 connections (units). Should the final design need more power or require more units, a new compressor must be purchased to ensure proper function. The compressor needs to be at least 30 ft above the lake floodplain to avoid any potential flooding. In addition, there is limited power access, so the compressor needs to be near the water intake station. The final design would be near the power supply to reduce piping and allow for easy maintenance access.

Alum Chemistry

As mentioned in the constraints, the lake can have low alkalinity and pH creating an undesirable environment. The addition of alum to water consumes alkalinity (Equation 2) and the addition to water containing phosphorus creates an aluminum phosphate precipitant (Equation 3).

$$Al_2(SO_4)_3 \cdot 14H_2O + 6HCO_3^- \rightleftharpoons 2Al(OH)_{3_{(s)}} + 6CO_2 + 14H_2O + 3SO_4^{2-} \tag{2}$$

$$Al_2(SO_4)_3 \cdot 14H_2O + 2PO_4^{3-} \rightleftharpoons 2AlPO_4 + 3SO_4^{2-} + 14H_2O \tag{3}$$

Aluminum phosphate precipitant has no known toxic effects on aquatic and human life (North American Lake Management Society, 2004). Based on lab tests it has been found that the precipitant settles at a rate of 1 ft/5 minutes. With a maximum depth of eighteen feet it will take the precipitant 90 minutes to reach the cove bottom, but nearby water mixing could increase this time. If the intake station is approximately 500 ft from the system, the flowrate in the lake would have to be 1420 MGD to be concerned about flocculant being pulled into the intake station.

Therefore, the PVIA should be able to run the system continuously as they have a maximum capacity of 12 MGD. Although changes in temperature and water density can make the flowrate increase slightly, it will never overcome 1420 MGD and therefore, the focculant will not be pulled into the water intake station.

For every mole of the liquid alum solution added, six moles of alkalinity (HCO_3^-) is consumed within the system (Equation 2). Concern arises as to how much alkalinity is consumed based on the site-specific alum dosage and the effects an alkalinity reduction will have on the cove system. In order to determine if there are any negative effects within this system the alum dosage must be calculated. Treatment is working to reduce P levels to below the mesotrophic level of 0.024 mg/L. Calculating the dosage of liquid alum solution needed requires the difference in the current P levels and the mesotrophic level. Based on two years of phosphorus data it was found that the worst scenario had 0.11 mg/L of P within the lake. Characteristics of the alum solution being added are necessary in calculating the amount of effective solution present. General Chemical provided a chemical product sheet for liquid alum as seen in Appendix B. Relationships between the Al and P as well as the percent of Al present in the solution were used to calculate the dosage of liquid alum solution required for the worst case scenario (U.S. EPA, 1976). The dosage rate can be converted into mg/L as $CaCO_3$, which directly shows how much alkalinity is consumed by the addition (Appendix C).

Alkalinity consumption causes a change in the water chemistry, which could be dangerous to aquatic life and would interfere with the efficiency of the alum injection. In order to return the system back to the initial alkalinity and maintain an adequate pH, lime would need to be added in the same quantity of alkalinity consumed. For example, at an incoming P level of 0.11 mg/L the required alum dosage is 3.87 mg/L of liquid and would consume 1.95 mg/L as $CaCO_3$. To return the alkalinity to the initial value, 1.95 mg/L of lime would need to be added to the cove. Alkalinity of the cove needs to be closely monitored. If the starting alkalinity is sufficient then a buffer may not need to be added after treatment. However, if there becomes an insufficient level of alkalinity available then Al and P react differently and one of the products is sulfuric acid. Although consuming alkalinity can lead to a decrease in pH, the creation of sulfuric acid would have a more drastic effect and would require a much larger quantity of lime to neutralize the cove.

In order to determine the effect a reduction in alkalinity has on the pH, the Deffeyes diagram (Appendix D) needs to be used. From this diagram, the initial alkalinity and pH can be used to find the starting point of the system. From here the point can be moved vertically down based on the reduction in alkalinity. This point will give the new pH of the system. Based on the quantity of lime added, the point will be moved over for the addition of carbonate and up for an increase in alkalinity. The final point will be the new starting pH of the system.

Aeration Components

Diffusers Discs

Product Information

Diffuser discs are membranes, typically 9 to 12 inches in diameter, that release a steady stream of bubbles. These allow for good aeration and mixing when compressed air flows through the disc. Diffuser discs are weighted, so a support system to keep them on the lake bottom was not necessary. Using this product ensures that there is no interference with cove recreation. PVIA previously used diffuser discs for cove aeration.

Product Problems and Solutions

Current mass-produced diffuser discs cannot be placed in series (Figure 3a). Each disc only has an inlet tube, but no outlet. This means that each diffuser has to be considered a single unit on the compressor. One potential solution to this problem was to create a new diffuser model that has both an inlet and outlet tube. Such design would allow a portion of air to be released from one diffuser with the rest continuing to the next. Each diffuser would require a pressure regulator to ensure that the same volume of air was released from each diffuser, creating a constant air curtain (Figure 3b). The problem with this design was that failure of a single unit resulted in complete system failure. Should a diffuser in the middle malfunction and need to be removed, it would cause the rest of the diffuser line to be cut off from the air supply until repaired. A more effective design (Figure 3c), was created to have a main air pipe and branched diffusers. Each diffuser required a pressure regulator, but the air pipe was one unit; each disc acted individually off of the main pipe. This reduced the amount of pipe and necessary units, and allowed for easy maintenance of diffusers.

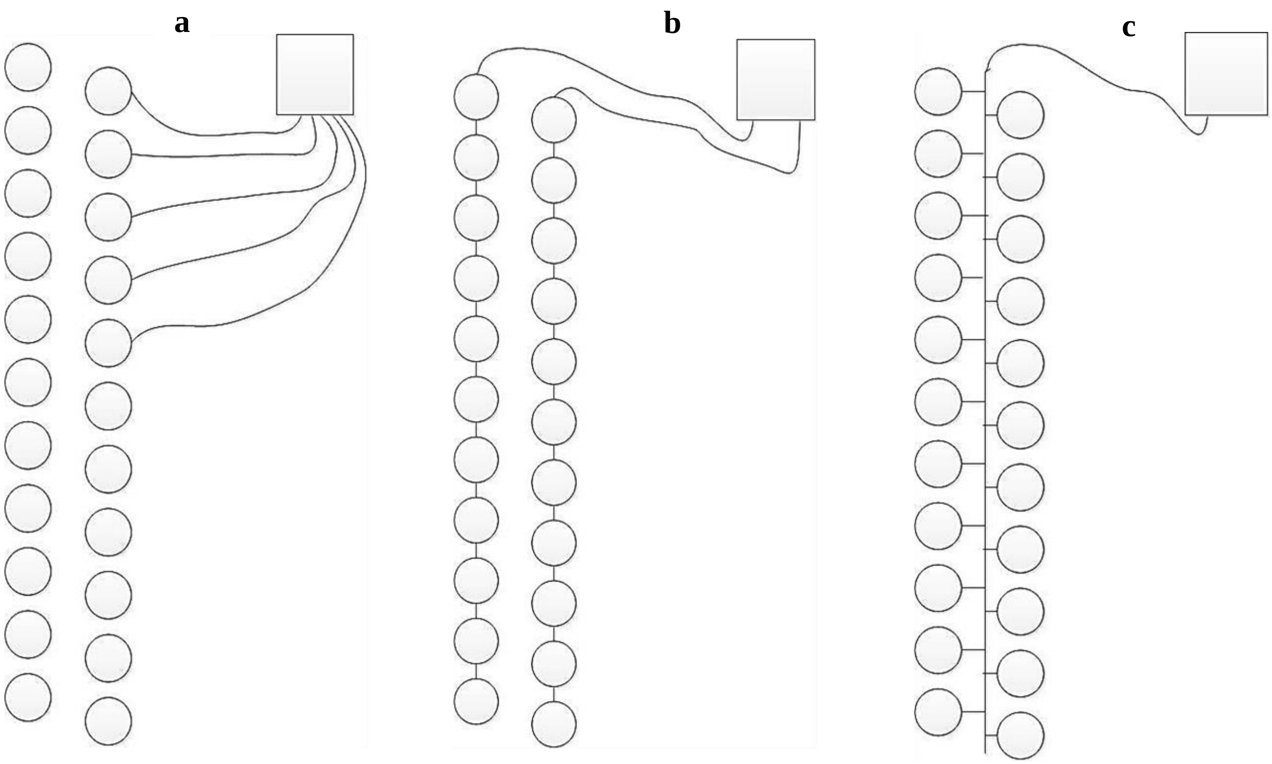


Figure 3: Problems with connecting diffuser discs; a) each diffuser connected individually; b) diffusers connected in series; c) diffusers branching off a main air supply pipe.

Bubble Tubing

Bubble tubing comes in two main varieties. One consists of a weighted pipe on the bottom and a flexible, porous pipe on top that allows for the release of air bubbles. Another is weighted rubber tubing with uniform perforations. Since both products are weighted, a weighted structure would not be necessary. However, a support system to ensure the pipe did not roll over and block air flow was considered. Should a blockage develop within the pipe, a solvent could be pumped through following which the air supply could resume as normal. The bubble tubing can potentially create a more effective curtain because there is no spacing between bubble streams. Currently there is only small diameter tubing with a maximum of 1.5 inch OD. However, verification with bubble tubing distributers confirmed that bubble tubing with 1 inch OD would be sufficient for the cove size treated.

OctoAir-10 Industrial Diffuser

The OctoAir-10 Industrial Diffuser is 4 ft in diameter with 100 ft of bubble tubing coiled inside. Due to the size, a large volume of bubbles can be produced and fewer diffusers (5 or 6) would need to be placed across the cove. However, these are costly at $1,700 each. Although they create a large bubble supply, they were not economically feasible for this project.

Porous PVC

Porous PVC is very similar to the bubble tubing; however, it is not a weighted system. A weighted support to hold down this tubing would be needed. This pipe is rigid, unlike bubble tubing, so it cannot conform to the cove bottom. Potential options included having multiple sections that act as individual units off of the compressor or attaching fittings to span the cove. Porous PVC is available in diameters up to 30 inches, which gave options in determining the desired bubble volume for the curtain.

Alum Components

There are two types of alum that were considered for this system: liquid alum and solid alum.

Liquid Alum

Liquid alum would be distributed through a continuous pipe across the cove. This pipe would be placed above the aeration components so that the alum is carried to the lake surface by the bubble stream. Release of liquid alum could be achieved through the use of chemical injectors. Kenco Chemical Injectors were specifically chosen due to many features (Appendix E). These injectors can be oriented in any direction. They would be placed facing upward and out of the pipe to inject alum into the lake. They also have check valves, preventing water from entering the pipe. This is important because backflow would react with the alum to form a precipitant that would clog the pipe. This brand is more durable because it minimizes chemical build-up. Finally, they function under a wide range of pressures and flowrates (Appendix F). The alum pipe would be connected to a variable speed pump in order to regulate the release of alum. This will allow for the system to counteract any seasonal or unpredicted chemical changes.

Solid Alum

Solid alum is available in 40 lb blocks called ChemLogs. ChemLogs would be held above the diffusers using a bracket system. An advantage of using solid alum is that it is easily released by the movement of the bubbles produced by the diffusers. However, this means that the alum may not be released consistently and there is no way to fluctuate the alum dispersal to account for changes in lake conditions. Using solid alum would reduce the equipment needed; as dispensing liquid alum requires piping, injectors and a pump. This means that a solid alum system would have a lower initial cost than a liquid alum system. However, solid alum is more expensive than liquid alum and would need to be replaced often. Dry alum costs 50% more than the equivalent liquid alum (Davis and Cornwell, 1998, pg.173). This would lead to increased operating costs using a solid alum system.

Layouts

Three possible layouts of the system within the cove were developed. In each of these layouts, the diffuser discs could be exchanged for bubble tubing as the aeration component. The orange box shown in Figures 4-6 represents the current water intake station.

Layout 1

The first layout (Figure 4) consists of two staggered rows of diffuser discs with an alum pipe above each row, placed at the cove entrance. The staggered method allows for better mixing, increasing the alum contact with phosphorus and preventing phosphorus from passing through the system untreated.

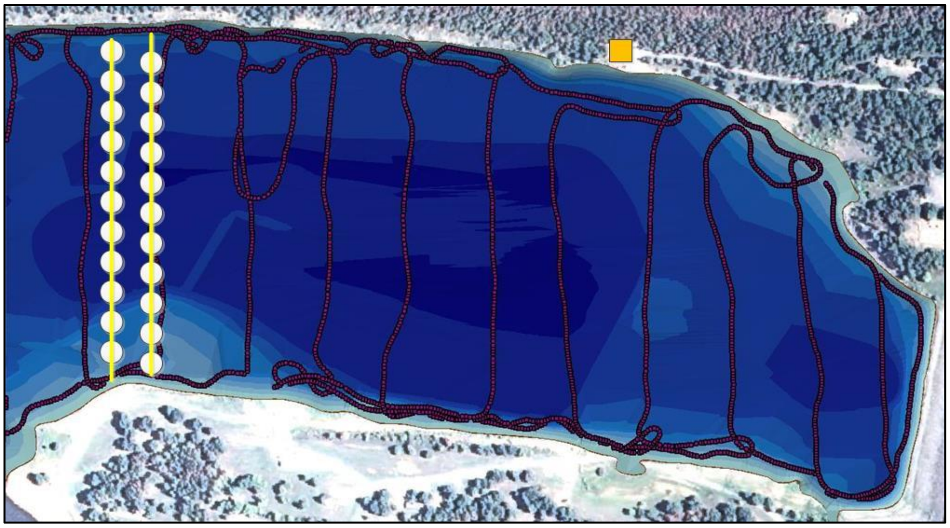


Figure 4: Layout 1

Layout 2

The second layout option (Figure 5) is comprised of a primary and secondary treatment system. The primary system consists of a single row of diffuser discs across the entrance to the cove. The secondary system also contains a single row of diffusers but is located closer to the water intake station. A single alum release system will be attached above each aeration row. This layout allows the water to be treated as it enters the cove and again as it approaches the intake. Two individual systems allow for a back-up treatment, so should one system fail, the water would still be treated by the other.

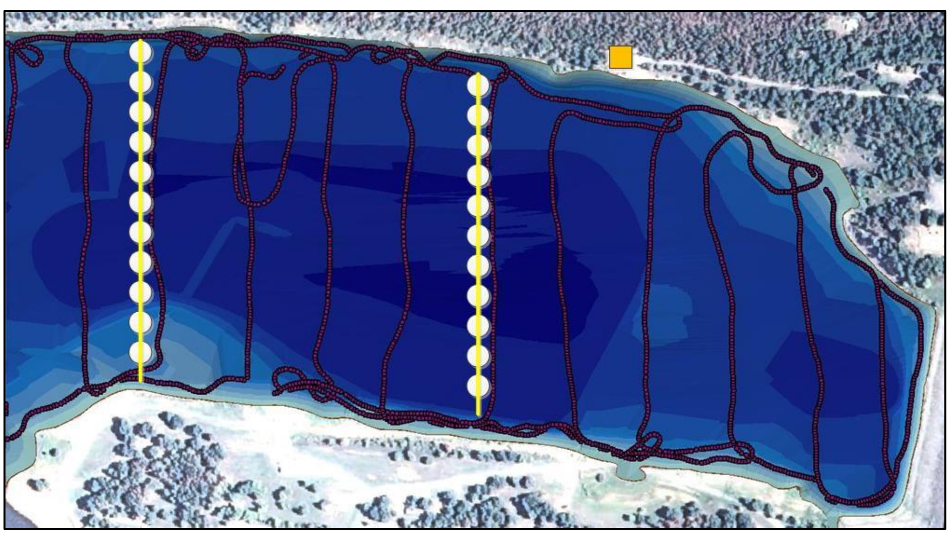


Figure 5: Layout 2

Layout 3

The third layout (Figure 6) is similar to the second in that it has a primary and secondary system, but the secondary system is located directly around the water intake station in a semicircle design. The main consideration with this layout is that the volume of water inside the secondary system must be larger than the maximum volume of water extracted by the intake station, in order to avoid catching alum flocculant in the intake pipe.

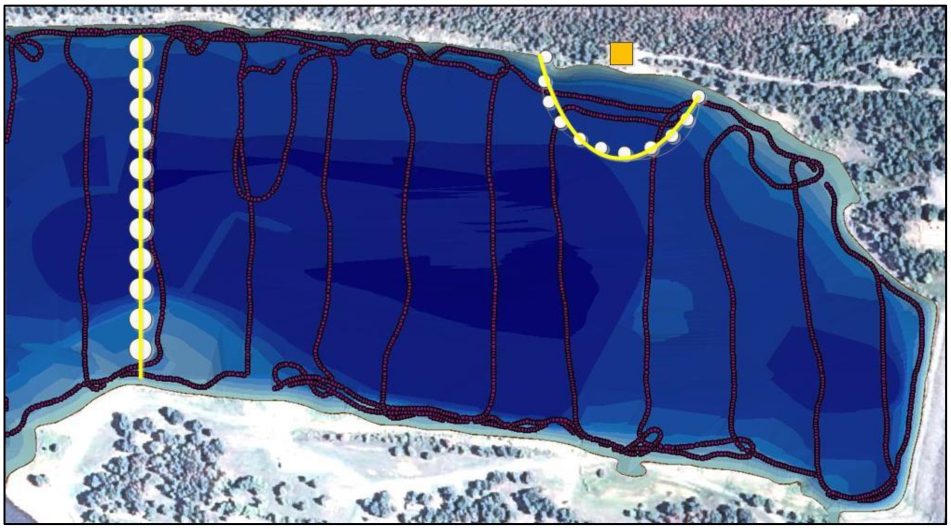


Figure 6: Layout 3

PVIA Layout Recommendations

After further discussion with PVIA, it was recommended that the system in Layout 1 should be utilized, but moved closer to the water intake station due to power availability and potential use of the compressor located at the station to power the diffusers. Layout 2 and Layout 3 were eliminated based on the availability of power.

Patents

Current Patents

Patent No. 7,074,328 was found to be similar to the branched diffuser system. It describes a bubble curtain that was created by attaching diffusers in a branching method and using pressure regulators to ensure an even pressure distribution to each diffuser. However, this patent does not include the alum components present in this system. If the PVIA decided to use this formation of diffusers they will have to ask permission from the patent holder.

Potential Patents and Steps

Currently, no patents regarding the process of in-lake alum addition with an aeration component have been found. Before implementing this system, more in-depth patent searches will need to be conducted to be certain that the process of adding alum into a lake in this way has not been previously patented. The results of this search will determine if the patent process will be completed with the OSU Technology Development Center.

Testing Materials List

Bulkhead construction:

1. 140 ft – 2” x 10” boards
2. 96 sq ft – 1 ” thick plywood
3. Caulking
4. Screws and concrete fasteners

Testing materials:

- 15 ft – Pentair PerfAerated Diffuser Tubing
    - Weighted tubing has 3/8" inside diameter and an operating range of .15–.6 cfm. Sold by the foot, max 100'. Weighs .2 lb/foot.
- 4 – Vertex Membrane Diffuser Discs, provided by PVIA
    - 9 inch diameter
- 20 ft – Clear vinyl tubing
- 1” OD PVC tubing and appurtenances
- 5 – pressure gauges
- 5 – ball valves
- Air compressor and air hose

Testing

Testing Set-up

Testing Pool

In order to test the aeration products, a large pool had to be constructed that would allow us to visualize the effect of the spacing between diffusers. The USDA-ARS Hydraulics Lab at Lake Carl Blackwell in Stillwater, OK provided the best opportunity for this set up. Within the 96 ft outdoor concrete flume, we constructed two 8 ft tall bulkheads to create a 12 ft long section which included a window for visualizing the bubbles created by the aeration products. The final dimensions of the pool were 12”x6”x8”. The bulkheads were constructed using 2”x10” boards and plywood, then sealed using caulking. It was preferred to use tap water to fill the pool so that the water would be clear; however, the flowrate was not enough to overcome the rate of leaking due to minor cracks. Instead, the pool was filled with water from Lake Carl Blackwell because a higher flowrate could be maintained. The estimated volume of water within the section was 4310 gallons.

Aeration Product Layout

An air supply assembly was created using 1” OD PVC pipe, ball valves, and pressure gauges (Figure 7).

Figure 7: Air Supply Assembly

Fifteen feet of bubble tubing was connected to one line of the air supply. The four diffusers were connected separately to the air supply using clear vinyl tubing. The aeration products were arranged to be able to test multiple different distances of spacing (Figure 8). Spacing was determined by an estimate based upon previous research. This research suggested one foot of spacing per foot of water depth (Yum, Kim and Park, 2007). The testing pool would have to be very large to accommodate this spacing and it was decided that this spacing would use too many diffusers when scaled to the lake. Therefore, the testing spacing was as follows:

- 3.5 ft between diffusers on the same line
- 2 ft between the individual lines

The diffusers were placed within the pool, such that they were at least 3 ft from each end and 2 ft from each wall to avoid interference with the bubbles.

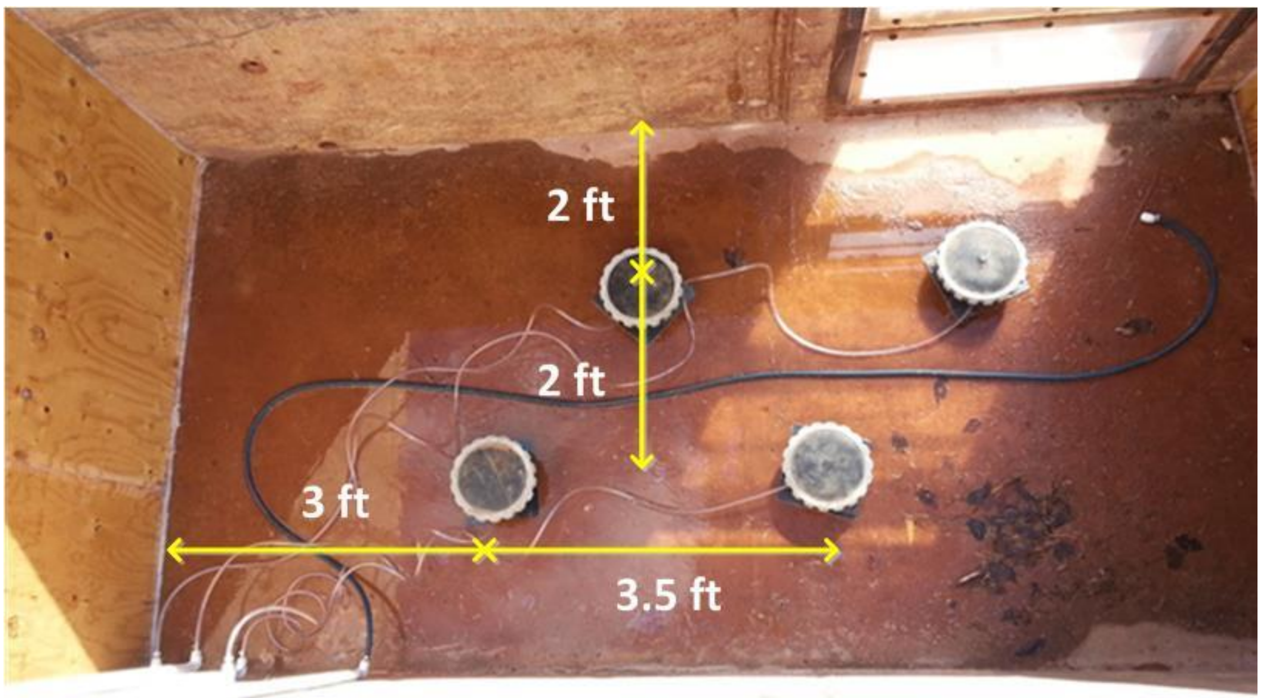


Figure 8: Testing set-up before being filled with water.

Compressor Testing

Lab testing was done on a single diffuser disc to determine the required amount of air flow (in cfm) at various pressures (in psi). A 13 inch ID PVC pipe was placed around the diffuser and was 8 ft in height. A screw compressor was connected to the diffuser at the base of the PVC pipe. A pressure gauge measured the pressure entering the diffuser (Figure 9). A hole was placed 7.73 ft from the ground for the velocity probe, far enough from the diffuser to better ensure laminar flow. The velocity of air from the diffuser was recorded at various pressures, and then it was multiplied by the area of the PVC pipe to determine the flowrate at each pressure tested. From this data, a graph was created to represent the flowrate with respect to the pressure (Appendix G). To adjust for the pressure head of the water on top of the diffuser, the static head was added to the pressure found during testing. This was done for an 8 ft and 15 ft static head to represent the testing pool and lake depth (Appendix H). From this testing, it was determined that the diffuser needed a large amount of airflow at a small pressure. For further testing of diffusers in the pool, a Sullair 185 cfm, 100 psig diesel compressor was used to guarantee enough air flow to the diffusers. The pressure was controlled manually with ball valves and pressure gauges on the air supply assembly.

Figure 9: Testing of compressor requirements.

Testing Procedure

The diffusers were not in the same place they were laid because of error during filling and previous attempts at testing. However, the reported results were based off the estimated diffuser placing (Figure 10).

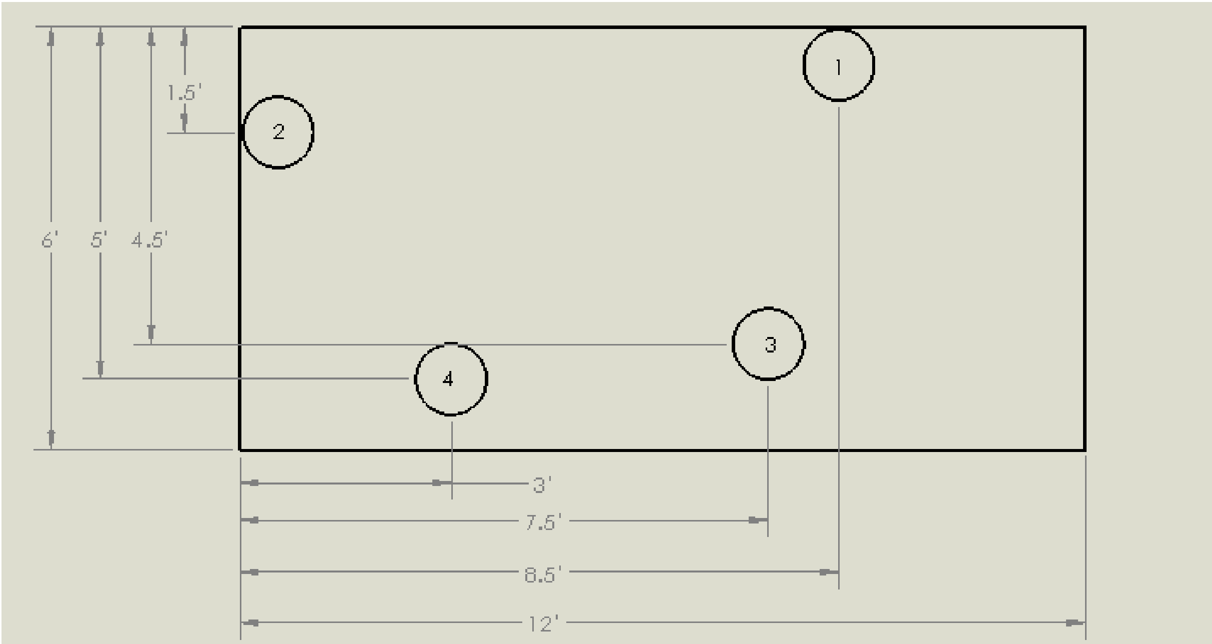


Figure 10: Testing set-up after being filled with water. Diffusers were moved into different locations from the original set-up.

The following procedure was used during testing:

- Turn on compressor with all valves closed. Record initial valve readings.

Diffusers

- Adjust diffuser #1 to 2.5 psi. Record observations.
- Adjust diffusers #1 and #3 to 2.5 psi. Record observations.
- Adjust Diffusers #1, #3, and #4 to 2.5 psi. Record observations.
- Repeat steps 2-4 at 4, 6, and 8.5 psi.
- Adjust diffuser #3 to 10 psi. Record observations.

Bubble Tubing

- Adjust bubble tubing to 1 psi. Record observations.
- Repeat step 7 at 2.5, 4, 6, 8, 9, 10, and >15 psi (completely open valve).

Diffuser #2 was not used due to its placement against the wall of the pool. Although Diffuser #1 was also close to a wall, it was in front of a window so it was easier to observe. Recorded observations for each testing set can be seen in Appendix F.

Testing Results (Appendix I)

Diffusers

From testing observations, it was determined that 8 psi was the minimum pressure to get consistent bubbling that mixed the water. At 8.5 psi, it was estimated that the bubbles would reach the surface when placed in the 15 ft lake. However, the diffuser bubbles were concentrated in a vertical column when released from the diffuser and did not begin mixing until they had risen to 3 ft from the surface (Figure 11).

Figure 11: View of the diffuser through the window.

It is recommended that each diffuser receive 8-10 psi to have sufficient mixing. Diffuser #3 deviated some from its original location during the testing. It is suggested that this movement was due to the wave motion created from other diffusers turned on at the same time. It might be necessary for a heavier base to be connected to the diffusers to prevent any movement of the diffusers in the lake. The spacing of diffusers was tested by looking at the interactions between diffusers across and diagonal from each other. This spacing was determined to be sufficient because at the recommended pressures the diameter of the most concentrated bubbles were almost touching. This demonstrates strong mixing between the diffusers (Figure 12).

Figure 12: Diffuser #1 and #3 running at 8.5 psi, significant overlapping occurred.

<u>Bubble Tubing</u>

Bubble tubing behaved similarly to the diffuser discs, but showed more consistent mixing from the bottom to the top of the pool (Figure 13). The minimum pressure recommended for the bubble tubing was 9 psi but higher pressures would be recommended for sufficient mixing when placed in the lake. At these pressures, the bubble tubing width reached 6 ft to the end of the tank but two lines of bubble tubing is recommended because the bubble curtain created is not as thick as that of the diffuser disc (Figure 14). The bubble tubing began to meander as the air was supplied and had to be secured at the far end so that the tubing remained across the length of the pool. This movement led to the idea that using a curved line of bubble tubing instead of two straight lines may be more efficient, while still providing enough bubble mixing.

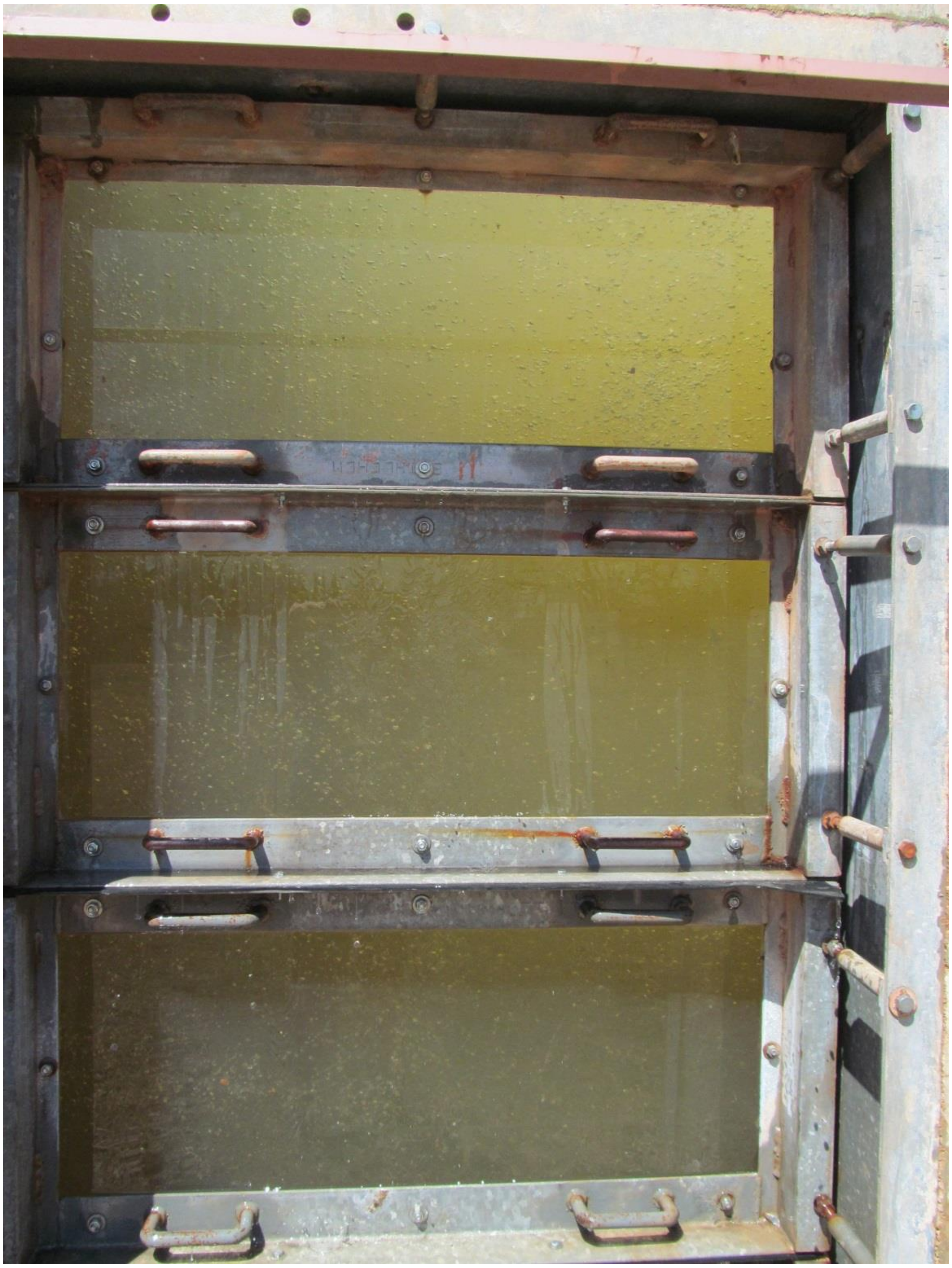


Figure 13: View through the window of mixing created by the bubble tubing.


Figure 14: Top view of the bubble tubing testing.

Final Design Alternatives

In order to select the best option for PVIA to implement, multiple design options were explored and a financial analysis was created for each different design option.

Alternative #1: Bubble Tubing

<u>Layout</u>

If using bubble tubing, two lines should be laid 1 ft apart, with the alum line running down the middle. The alum injectors should be placed every 10-15 ft to ensure even distribution of alum. A weighted stand would need to be constructed using 316 series stainless steel, in order to hold the bubbling tubing and alum lines at least 1 ft from the bottom of the lake. This stand can be constructed using 1/8" T angle stock, with hose clamps holding the bubble tubing and alum line in place. Since the bubble tubing is only available in 100 ft sections, weighted connector tubing, with various lengths, must be connected to the compressor with pressure regulators. This set-up would require the use of 26 units on the compressor.

Product Breakdown

The bubble tubing recommend is Pentair PerfAerated Diffuser Tubing. This is weighted tubing that has 3/8" inside diameter and an operating range of 0.15–0.6 cfm. It is sold by the foot, with a maximum section length of 100 ft and it weighs 0.2 lb/ft. PVIA will need to purchase 2600 ft of this bubble tubing. In addition, in order to connect the bubble tubing to the compressor, approximately 28,600 ft of weighted connector tubing will need to be purchased. This is to ensure that the pressure distribution across the entire cove is the same.

Alternative #2: Diffusers

Layout

If using diffuser discs, one line of Schedule 80 PVC would connect the diffusers in a staggering formation. Each diffuser would be 4 ft from the last and branched on the opposite side of the pipe as seen in Figure 3c. Pressure regulators would be necessary on each diffuser to ensure consistent air flow to every diffuser. The total estimated number of diffuser discs is 325. A line of alum injectors would be placed above the row of diffusers furthest from the intake. In other words, an injector would be placed above every other diffuser. A stand to hold the alum pipe would need to be constructed out of at least 316 series stainless steel. This set-up would require only one unit on the compressor, but the compressor would need to be able to supply 650 cfm in order to achieve the optimum 2 cfm per diffuser disc. Therefore, more than one compressor would be necessary for proper aeration.

Product Breakdown

Two brands of diffuser discs have been considered. The Matala brand contains a 9 or 12 in membrane through which the air flows. The diffuser discs come with a base that can be self-weighted using gravel or sand. The Environmental Dynamics International (EDI) brand diffuser disk also comes with either a 9 or 12 in. membrane. This diffuser does not include a base but can be mounted using their Universal Diffuser Mount. The connection for both of these products is a

3/4” NPT male threaded fitting. Environmental Dynamics International provides an Operating Pressure Diagram (Appendix J). This was important to see the airflow at various pressures.

Alum Delivery

With either diffusers or bubble tubing, the alum delivery system would be recommended as follows:

- use Schedule 80 PVC pipe to carry the alum from the pump to the lake
- use Kenco Mini Chemical Injectors
  - product: KINJM – 316 SS
  - cost: $70/injector
- use a variable speed pump to control the rate of alum release
  - required: 2 gpm @ 50 ft head
  - product: Pentair IntelliFlo Variable Speed Pump

Product sheets for the chemical injectors and the injection flowrates can be seen in Appendices E and F. The pump curve for the variable speed pump is shown in Appendix K.

Financial Analysis

The estimated installation cost for bubble tubing was created to show to the PVIA (Table 1). Two options for connector tubing were evaluated: self-weighted and unweighted polyethylene. The length of tubing was estimated based on the line being set 500 ft from the intake on the lake bottom. The costs for keeping the unweighted tubing from interfering with cove recreation are not included in this analysis. Based on these calculations and practical decisions based on quality, self-weighted aeration tubing is the best option if bubble tubing is chosen.

Table 1: Bubble Tubing Cost Analysis

Materials	Description	Number	Unit Price	Total Price
Bubble Tubing	2 lines - 1250' each; Pentair PerfAerated Diffuser Tubing	26 sets of 100'	$174.00	$4,524.00
Connector Tubing options	3/8" Self Weighted Airline	572 sets of 50'	$51.49	$29,452.28
	3/8" Polyethylene Tubing (unweighted)	143 sets of 200'	$55.58	$7,947.94
Pressure regulators	Pneumatic Regulator, Nonrising, Locking Knob; 3/8" NPT, 95 cfm	26	$87.80	$2,282.80
Weighted Stand	Angle Stock, 316SS, 1/8 In T, 1 In Leg, 7 ft	390	$39.05	$15,229.50
	Hose Clamp, SS, Min.Dia.3/4, SAE 20, PK10	130 (10/pack)	$9.19	$1,194.70
	Hose Clamp, Min.Dia.1, SAE 24, PK10	26 (10/pack)	$13.01	$338.26
	Other materials and Labor			$4,500.00
Alum Tubing	3/4" Sch. 80 PVC	130 sets of 10'	$0.65	$845.00
Alum Injectors	KINJM 316 SS	130 @ 10' apart	$70.00	$9,100.00
Alum Storage Tank		1	$4,000.00	$4,000.00
Variable Flow Pump		1	$1,000.00	$1,000.00

Total based on connector tubing used	
Weighted	Unweighted
$72,466.54	$50,962.20

The estimated installation cost for diffuser discs was created to show to the PVIA (Table 2). Two options for diffuser discs were evaluated: weighted and unmounted. The cost of filling the weighted diffuser disc bases with sand or gravel and the cost of mounting the other diffuser discs are not included in this analysis. Based on these calculations and practical decisions based on quality, the weighted diffusers are the best option if diffuser discs are chosen.

Table 2: Diffuser Disc Cost Analysis

Materials	Description	Number	Unit Price	Total Price
Diffuser options	Matala Air Base W/9-in. Air Disc (weighted)	325 @ 4' apart	$76.95	$25,008.75
	Membrane Pond Air Diffuser (19" Diameter) (unmounted)	325 @ 4' apart	$44.50	$14,462.50
Weighting/Mounting Options	Matala- Sand or Gravel		$20/ton	$600.00
	Universal Diffuser Mount	325	$90.00	$29,250.00
Alum Brackets	Angle Stock, 316SS, 1/8 In T, 1 In Leg, 7 ft	260	$39.05	$10,153.00
	Hose Clamp, Min.Dia.1, SAE 24, PK10	26 (10/pack)	$13.01	$338.26
	Other materials and Labor			$4,500.00
Connector Tubing	3/4" Sch. 80 PVC	132 sets of 10'	$0.65	$858.00
Pressure regulators	Pneumatic Regulator, Nonrising, Locking Knob; 3/4" NPT, 100 cfm	325	$87.80	$28,535.00
Alum Tubing	3/4" Sch. 80 PVC	130 sets of 10'	$0.65	$845.00
Alum Injectors	KINJM - 316 SS	162	$70.00	$11,340.00
Variable Flow Pump	Pentair IntelliFlo Variable Speed Pump	1	$1,000.00	$1,000.00
Alum Storage Tank		1	$4,000.00	$4,000.00

Total based on diffuser used	
Weighted	Unmounted
$87,178.01	$105,281.76

Final Design Recommendation

After testing, it was determined that the bubble tubing fulfilled the requirements of the project better than diffuser discs. In addition, the compressor requirements of diffuser discs make the option nearly impossible. Therefore, based on the overall cost and effectiveness of the products, the best option for PVIA would be bubble tubing with self-weighted connector tubing.

Treatment Schedule

In order to assist in determining the amount of liquid alum solution that is required for each treatment period, a spreadsheet (Table 3) was created that allows PVIA to directly input the P level of the incoming water. The system will automatically calculate the amount of solution that needs to be released from the alum injection system, the $CaCO_3$ equivalent of this injection, and the amount of lime that would need to be added to maintain the alkalinity.

Table 3: Example calculation for the amount of alum, with 100% effectiveness, and lime required to be added, based on current phosphorus levels.

Current P Level	**0.11**	**mg/L as P**
Mesotrophic P Level	**0.024**	**mg/L as P**
P For Removal	**0.086**	**mg/L as P**
Alum Liquid Needed	**3.870**	**mg/L as liquid**
Alum $CaCO_3$ equivalent	**1.955**	**mg/L as $CaCO_3$**
$CaCO_3$ to Return to initial Alkalinity	**1.955**	**mg/L as $CaCO_3$**
Water Pumped Out	**6.00E+06**	**gal/day**
	2.27E+07	**L/day**
Total Alum Required	**8.79E+07**	**mg liquid**
Total Alum $CaCO_3$ equivalent	**4.44E+07**	**mg as $CaCO_3$**
Total $CaCO_3$ to Return to initial Alkalinity	**4.44E+07**	**mg as $CaCO_3$**

Permits

The Oklahoma Department of Environmental Quality does not require a permit for partial lake treatments with alum; however, the following suggestions were made:

- must not exceed 50 µg/L dissolved aluminum in the lake,
- the lake pH must remain between 6.5 and 9.0 during the application,
- a buffering solution, such as sodium aluminate or sodium carbonate, shall be available to use with alum if a decrease in pH is observed.

The U.S. Army Corps of Engineers may require a 404 Dredge and Fill permit. However, this would depend if the flocculant is considered “discharge” or not. The law states:

> "The basic premise of the program is that no discharge of dredged or fill material may be permitted if: (1) a practicable alternative exists that is less damaging to the aquatic environment or (2) the nation's waters would be significantly degraded. In other words, when you apply for a permit, you must first show that steps have been taken to avoid impacts to wetlands, streams and other aquatic resources; that potential impacts have been minimized; and that compensation will be provided for all remaining unavoidable impacts." (U.S. EPA, Section 404 Permitting)

It is a known fact that alum would not be harmful to the environment, but one could argue that a practicable alternative would be to only treat water with alum after it enters the water treatment plant instead of in the lake.

Feasibility

In order to determine the feasibility of this final design option, a worst case scenario was set up. It was assumed that the phosphorus level was 0.11 mg/L, which is the highest seen in the two years of given data, the maximum withdrawal capacity of 12 MGD, and only a 20% efficiency of the alum. Under these conditions it was found that monthly costs would be around $5,200 for alum and $3,000 for lime. This brings total monthly costs to $8,200. Currently, PVIA spends, on average, $20,000 on alum each month. This does not include the cost of activated carbon that they add to help maintain a steady pH. PVIA may still need to add small amounts of alum in the treatment plant to remove residual P, but the cost will be a fraction of current spending. Even if they had to add up to half of the amount of alum they currently use, there will still be a total reduction in monthly treatment costs. In conclusion, under the worst case scenario for this system, it is still cost effective compared to current treatment expenses.

Acknowledgements

- Steve Patterson, PhD.: Environmental Consultant
- Don Goforth: Manager – Water Treatment Plant
- David Wyatt, P.E.: Consulting Engineer – PVIA
- Dr. Ken Hammond: Chairman – PVIA
- Keith Wright: Board Member – PVIA
- Mick LaFevers: Secretary Treasurer – PVIA
- Sherry Hunt, PhD.: USDA-ARS Hydraulics Lab
- Kem Kadavy, P.E.: USDA-ARS Hydraulics Lab
- Wayne Kiner: OSU BAE Lab
- Carl Parrott, P.E.: ODEQ Water Quality Division
- Dr. Garey Fox
- Dr. Paul Weckler
- Dr. Dan Storm
- Dr. Dan Thomas

References

Davis, M. L., and D. A. Cornwell.1998. *Introduction to Environmental Engineering*. 3rd ed. Boston, MA: McGraw Hill.

North American Lake Management Society. “Position 2 Statement: THE USE OF ALUM FOR LAKE MANAGEMENT.” February 26, 2004.

“Process design manual for phosphorus removal.” 1976. U.S. Environmental Protection Agency. *EPA* 625/1-76-001a.

"Section 404 Permitting." *Water: Discharge of Dredged or Fill Materials (404)*. U.S. Environmental Protection Agency. <http://water.epa.gov/lawsregs/guidance/cwa/dredgdis/>.

Yum, K., S. H. Kim, and H. Park. 2007. Effects of plume spacing and flowrate on destratification efficiency of air diffusers. *Water Research*. 42: 3249-3262.

Figure 1: http://mapsof.net/map/counties-map-of-oklahoma#.U0wmHfnIZgg

Figure 2: provided by PVIA

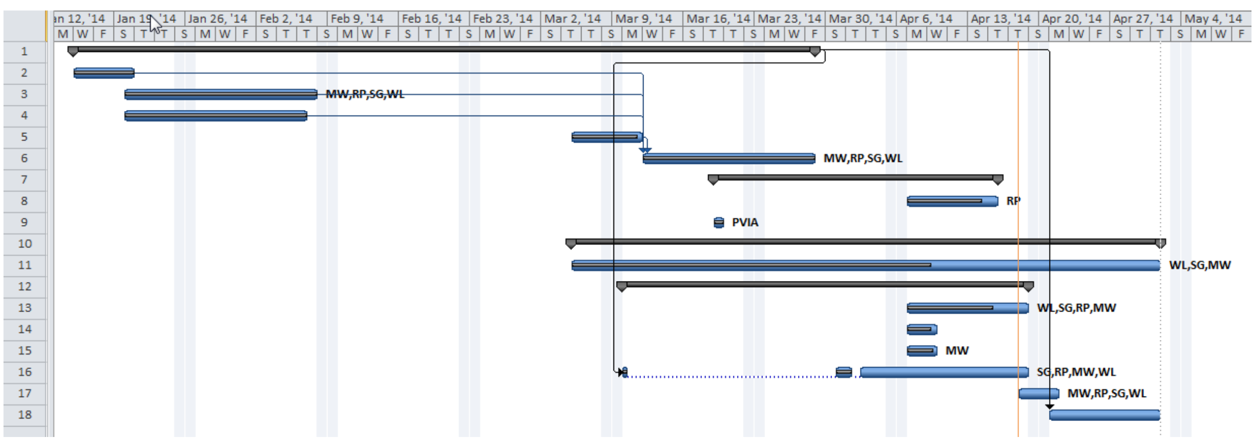
Figure 5, 6, and 7: background photo provided by PVIA

Appendix A: graphs provided by PVIA

Appendices

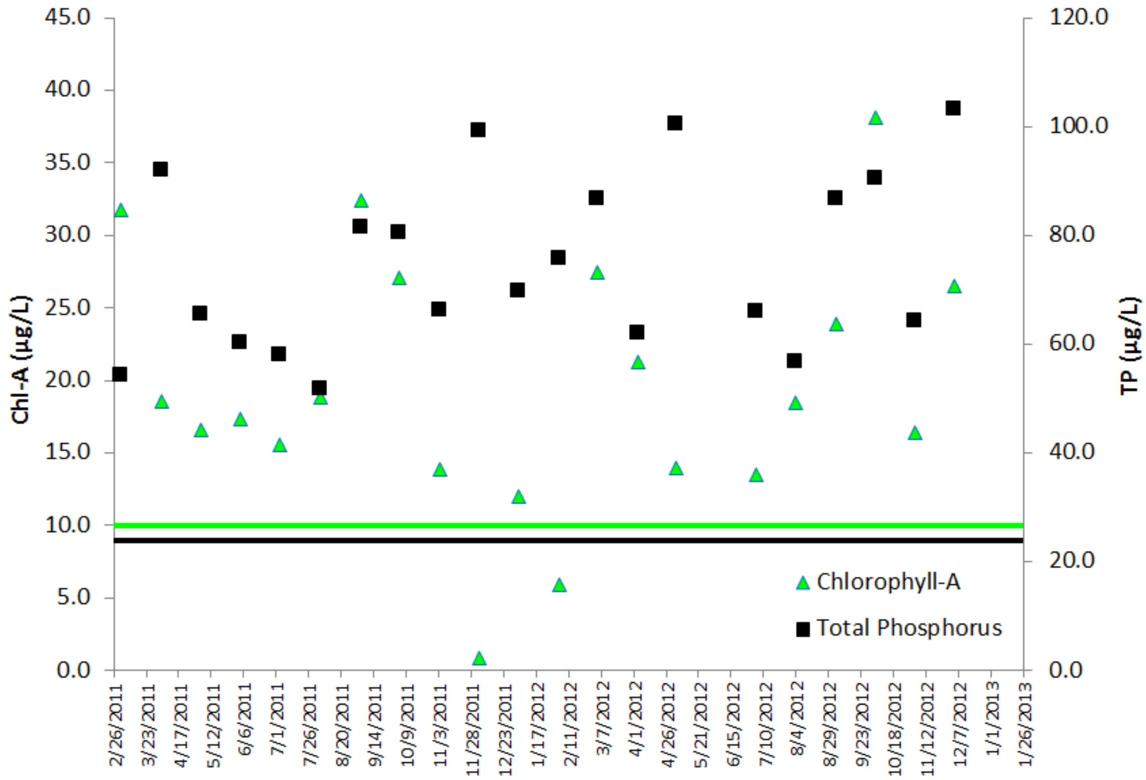
Project Schedule

	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1	**Testing**	**53 days**	**Wed 1/15/14**	**Fri 3/28/14**		**MW,RP,SG,WL**
2	Determine Purchase List	4 days	Wed 1/15/14	Mon 1/20/14		
3	Find Testing Facility	15 days	Mon 1/20/14	Fri 2/7/14		MW,RP,SG,WL
4	Purchase Testing Materials	14 days	Mon 1/20/14	Thu 2/6/14		
5	Cost Analysis for Testing	5 days	Wed 3/5/14	Tue 3/11/14		
6	Test Products	13 days	Wed 3/12/14	Fri 3/28/14	2,3,4,5	MW,RP,SG,WL
7	**Water Chemistry Analysis**	**20 days**	**Wed 3/19/14**	**Tue 4/15/14**		
8	Chemistry Analysis	7 days	Mon 4/7/14	Tue 4/15/14		RP
9	Alum Setting Test	1 day	Wed 3/19/14	Wed 3/19/14		PVIA
10	**Deliverables**	**42 days**	**Wed 3/5/14**	**Thu 5/1/14**		
11	Website	42 days	Wed 3/5/14	Thu 5/1/14		WL,SG,MW
12	**Final Report**	**30 days**	**Mon 3/10/14**	**Fri 4/18/14**		
13	Final Report	10 days	Mon 4/7/14	Fri 4/18/14		WL,SG,RP,MW
14	Research Patents	3 days	Mon 4/7/14	Wed 4/9/14		
15	Permitting	3 days	Mon 4/7/14	Wed 4/9/14		MW
16	Total Cost Analysis	15 days	Mon 3/10/14	Fri 4/18/14	1	SG,RP,MW,WL
17	Presentation	2 days	Fri 4/18/14	Mon 4/21/14		MW,RP,SG,WL
18	Prepare Demonstration	9 days	Mon 4/21/14	Thu 5/1/14	1	



Task list and Gantt chart for completing this project.

Appendix A: Chlorophyll-a and total phosphorus levels



Graph of chlorophyll-A and total phosphorus levels in Lake Wister.

Appendix B: Alum specification sheet

General Chemical (800) 631-8050 www.GeneralChemical.com

Liquid Alum

PRODUCT DATA SHEET

CHARACTERISTICS

Liquid Alum is a clear, light green or yellow to colorless solution. It is a cationic inorganic coagulant and flocculant suitable for industrial and municipal water and wastewater treatment applications.

NSF/ANSI Standard 60: Drinking Water Chemicals - Health Effects; Certified

TYPICAL PROPERTIES

Formula:	Aqueous solution of aluminum sulfate	
C.A.S.	10043-01-3 (Aluminum sulfate)	
	pH (neat)	2.0 - 2.4
	Specific Gravity @ 70°F (21°C)	1.335
	Freezing Point	4°F (-16°C)
	Density, lbs/gal., U.S.	11.14
	Aluminum as Al, %	4.2 - 4.4
	Aluminum as Al_2O_3, %	8.0 - 8.4
	Aluminum as $Al_2(SO_4)_3 \cdot 14H_2O$ (Dry Alum), %	46 - 49

PRODUCT USES

Municipal and industrial water and wastewater treatment for the removal of turbidity, color, suspended solids and phosphorus. Sludge compaction and volume reduction. Lagoon treatment. Oily wastewater clarification and dissolved air flotation. Emulsion breaking. Fixing rosin sizes on paper fibers. Paper machine drainage and retention aid. Paper machine pitch control.

SHIPPING CONTAINERS

Bulk transport	Bulk car
275 gal. one way container	55 gal. plastic drum

SHIPPING REGULATIONS

DOT Classification: Corrosive Liquid, Acidic, Inorganic, N.O.S. (Contains Aluminum Sulfate)
Hazard Class: 8 DOT ID Number: UN 3264 Packing Group: III
RQ = 5000 Lbs. (CASRN formula basis)

PRODUCT SAFETY INFORMATION

Liquid Alum may cause irritation to the skin, eyes and respiratory tract. Avoid contact with skin, eyes and clothing. Anyone procuring, using or disposing of these products or their containers must be familiar with the appropriate safety and handling precautions. Such information may be found in the **Material Safety Data Sheets (MSDS)** for these products or you may contact General Chemical Technical Service. In the event of an emergency with these products, call the 24 hour **Emergency Number: USA (CHEMTREC) 800-424-9300** or **Canada (CANUTEC) 613-996-6666**. For additional information contact:

Syracuse Technical Center
(315) 478-2323
(800) 255-7589 Outside NY

Water Chemicals Group
(973) 515-0900
(800) 631-8050 Customer Service

Revision Date: May 1, 2013

Appendix C: Alum dosage calculations

Alum Dosage Calculations

Liquid Alum Solution contains: $\approx 46\%$ dry Alum
$\approx 4.2\%$ Al

Reaction:

$$Al_2(SO_4)_3 \cdot 14H_2O + 6HCO_3^- \rightleftharpoons 2Al(OH)_{3\,(s)} + 6CO_2 + 14H_2O + 3SO_4^{2-}$$

Mole Ratio Al:P = 1:1
Weight Ratio Al:P = 0.87:1

Aluminum required per mg/L of P $= \dfrac{0.87}{0.042} = 20.7$ mg/L Al

Solution required with 46% dry alum $= \dfrac{20.7 \text{ mg/L}}{0.46} = 45$ mg/L liquid solution

45 mg/L liquid alum solution removes 1 mg/L of P

Based on two-years of data:
Worst level of P = 0.11 mg/L
Mesotrophic P level = 0.024 mg/L
$\Delta P = 0.11 - 0.024 = 0.086$ mg/L of P to be removed

$$\frac{45 \text{ mg/L liquid}}{1 \text{ mg/L P}} = \frac{X}{0.086 \text{ mg/L P}} \qquad X = 3.87 \text{ mg/L liquid solution required per day}$$

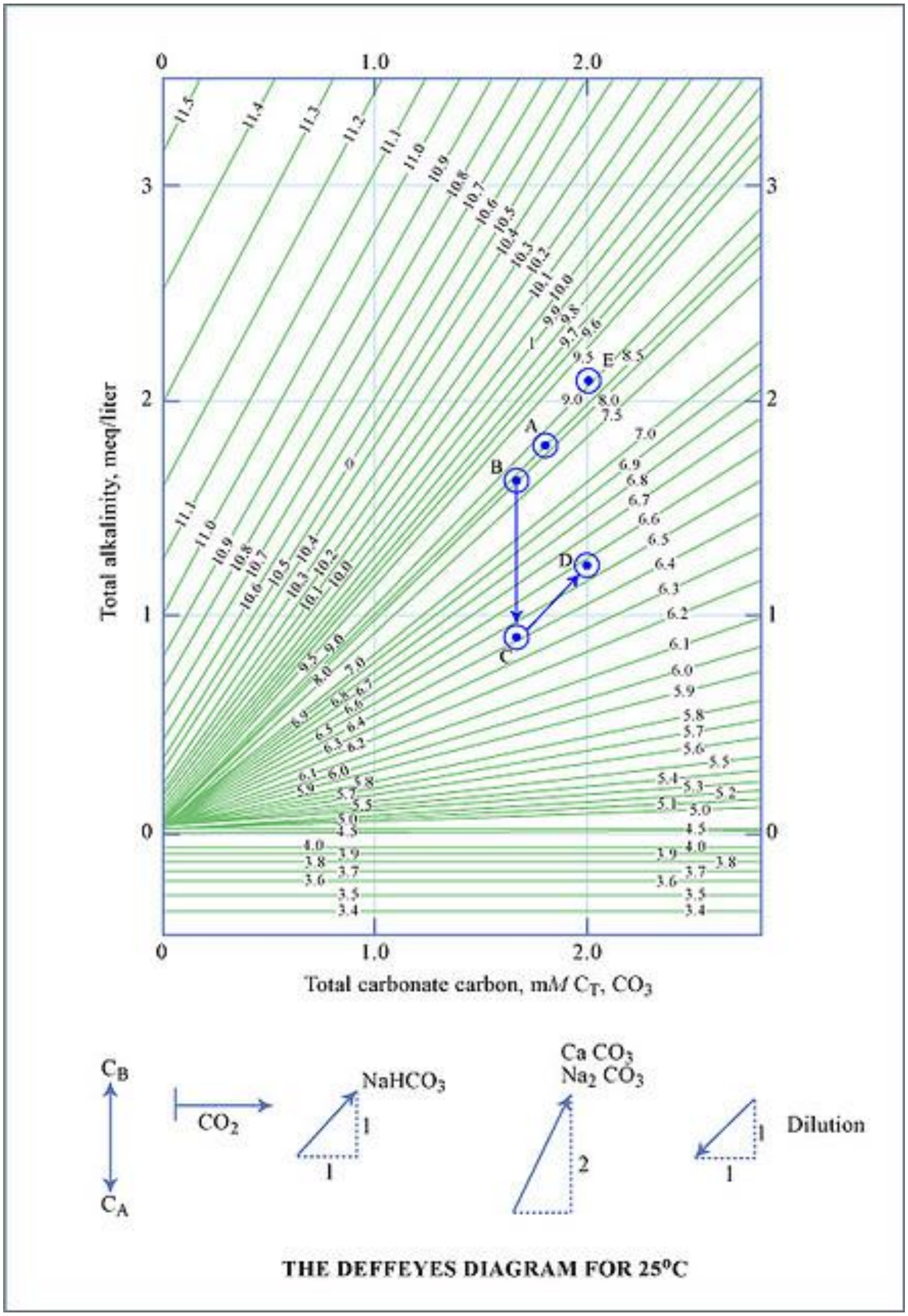
Alkalinity consumed:

$$3.87 \text{ mg/L liquid} \left(\frac{50 \text{ mg } CaCO_3}{99 \text{ mg Solution}}\right) = 1.95 \text{ mg/L as } CaCO_3$$

This dosage consumes 1.95 mg/L as $CaCO_3$.

To return to initial alkalinity this amount of lime (1.95 mg/L) would need to be added to the cove.

Appendix D: Deffeyes Diagram



The Deffeyes diagram characterizes the relationship between alkalinity, pH, and total carbonate carbon.

Appendix E: Kenco chemical injector data sheet

KENCO ENGINEERING

KENCO CHEMICAL INJECTORS

INDUSTRIES SERVED: Natural Gas Transmission and Distribution • Oil and Gas Production and Refining
Petrochemical • Water Treatment • Fluid Processing • Pulp & Paper Processing

PATENT NO. 7,137,569

KENCO CHEMICAL INJECTORS

APPLICATION

Kenco chemical injectors are designed to inject and properly atomize corrosive chemicals into the turbulent stream of a process system pipeline. The Kenco chemical injector will minimize the possibility of corrosive chemical build-up on the walls of the pipeline.

FEATURES

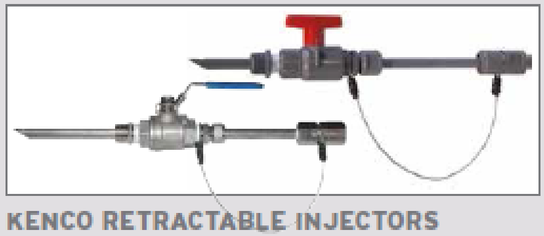
- Patented aspirator tip design on injector disperses chemical evenly into process stream and away from pipe walls
- Check valve in injector eliminates backflow
- Injector is ideal for high pressure applications up to 6000 psig
- Injector has been designed so that it can be mounted in any orientation
- Standard insertion lengths available up to 24" long. Custom sizes also available.
- Injector available in 316 Stainless Steel, Hastelloy C-276, and CPVC
- Ball-check material in 316 Stainless Steel injectors is 316 Stainless Steel and ball-check material in CPVC and Hastelloy injectors is ceramic.
- Ball-check spring material in 316 Stainless Steel and CPVC injectors is Inconel. Ball-check spring material in Hastelloy injectors is Hastelloy.
- Standard Injector chemical feed port is 1/2" NPT and process connection is 1/2" or 3/4" NPT.

MINI-INJECTOR

- "Mini" injector assembly atomizes chemical in smaller pipelines and/or lower flowrates
- Available in 316 Stainless Steel only
- Standard Injector chemical feed port and process connection is 1/8" or 1/4" NPT

MODELS KINJ & KINJM *TEMPERATURE & PRESSURE RATINGS*

Injector Material	Maximum Working Pressure	Maximum Operating Temperature
316 SS	6000 psig	800°F
Hast C-276	6000 psig	800°F
CPVC	340 psig @ 73°F; 150 psig @ 150°F	200°F



KENCO RETRACTABLE INJECTORS

APPLICATION

Kenco retractable injectors allow for injector insertion or removal without interrupting the main process in the pipeline.

FEATURES

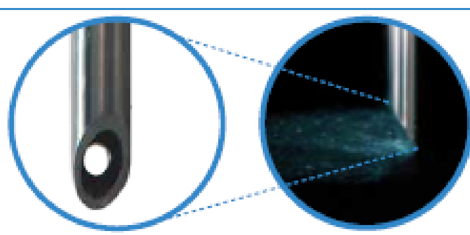
- Patented aspirator tip design on injector disperses chemical evenly into process stream and away from pipe walls
- Ball valve assembly isolates pipeline from injector assembly when injection is not required
- Compression seal holds the assembly from back pressure
- Safety line prevents the injector assembly from being completely withdrawn and protects against blowout
- Standard ball valve assemblies available in 316 Stainless Steel, Alloy 20, CPVC and Brass. Standard Injector Nozzle assemblies available in 316 Stainless Steel, Hastelloy C-276 and CPVC.
- Ball-check material in 316 Stainless Steel injectors is 316 Stainless Steel and ball-check material in CPVC and Hastelloy injectors is ceramic.
- Ball-check spring material in 316 Stainless Steel and CPVC injectors is Inconel. Ball-check spring material in Hastelloy injectors is Hastelloy.
- Optional spring loaded check valve available. Check valve available with body bleed valve.
- Standard Retractable Injector chemical feed port is 1/2" NPT. Process connection is 3/4" NPT.

MODEL KRINJ *TEMPERATURE & PRESSURE RATINGS*

Valve Material	Maximum Working Pressure	Maximum Operating Temperature
Brass	150 psig	up to 350°F
316 SS	150 psig	up to 400°F
Alloy 20	150 psig	up to 400°F
CPVC	150 psig @ 73°F 100 psig @ 150°F	up to 180°F

* Note: maximum operating temperature dependent on compression seal material

KENCO Chemical Injectors have a unique design engineered to minimize the possibility of corrosive chemical build-up on the walls of the pipeline.



This photograph of a KENCO injector illustrates the misting created by the unique design.

Appendix F: Kenco chemical injectors flowrates

MAXIMUM INJECTION FLOWRATES

STANDARD INJECTOR – KINJ

4 GPM	**240 GPH**	**15.14 LPM**	**908.5 LPH**

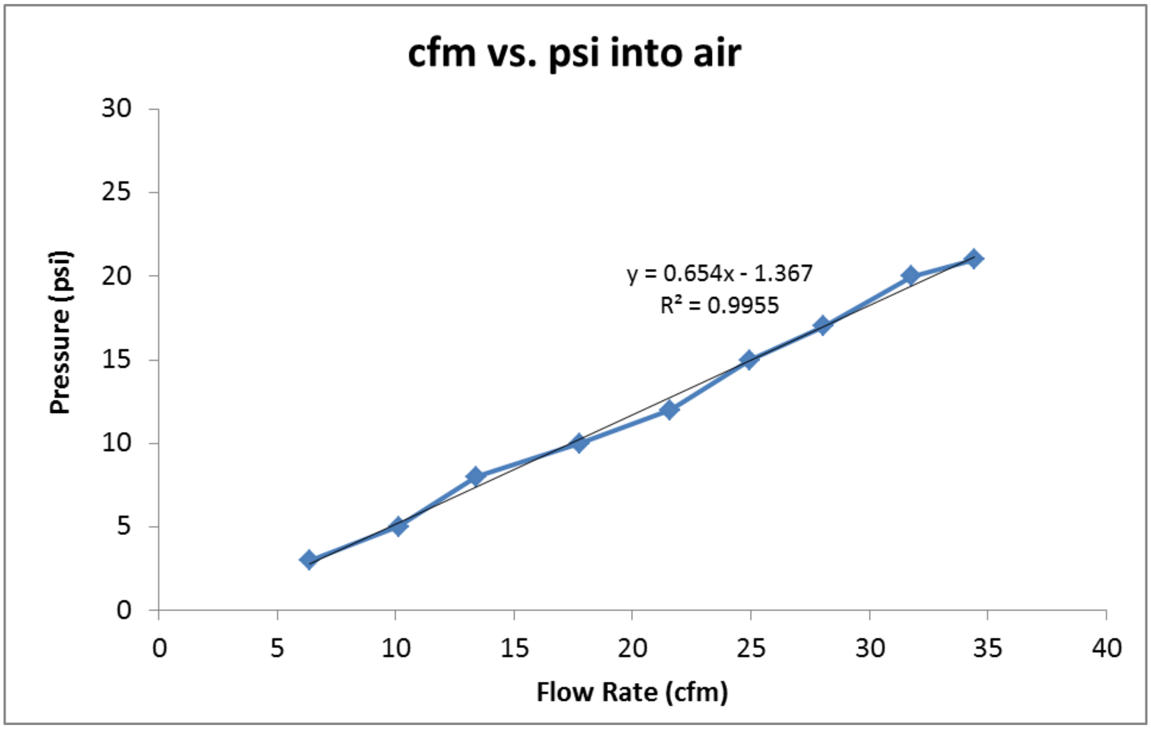
MINIATURE INJECTOR – KINJM

0.6 GPM	**36 GPH**	**2.27 LPM**	**136.3 LPH**

RETRACTABLE INJECTOR – KRINJ

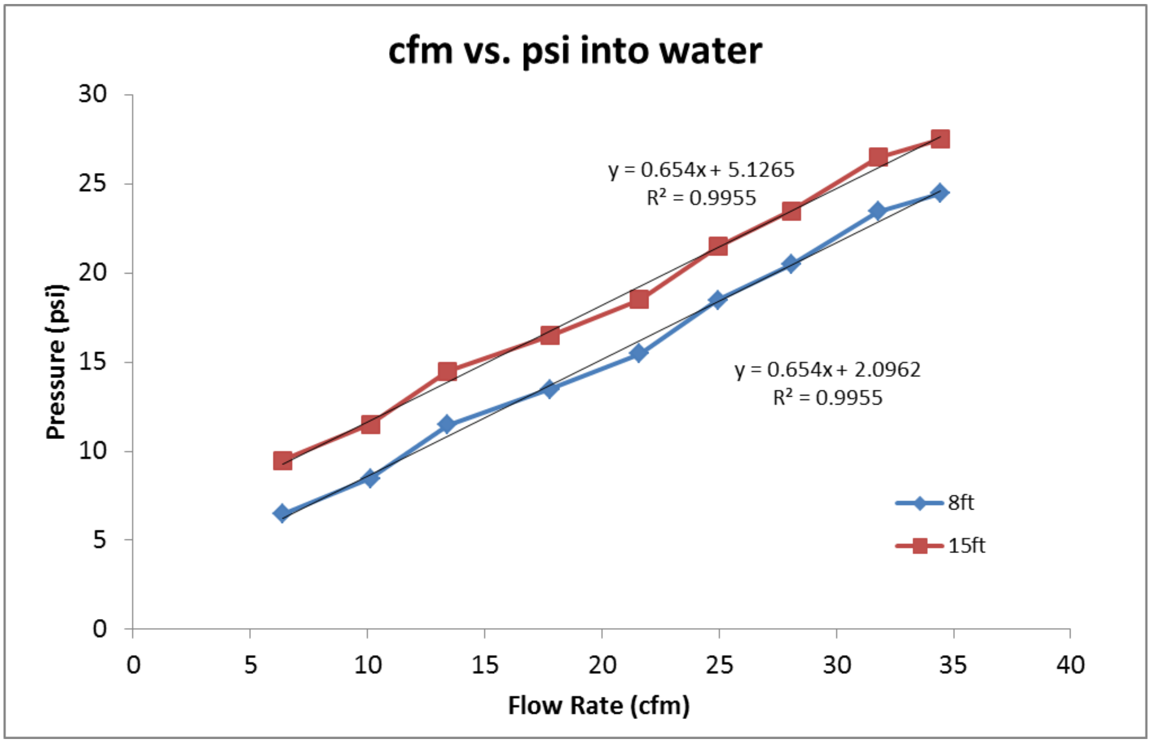
4 GPM	**240 GPH**	**15.14 LPM**	**908.5 LPH**

Appendix G: Compressor testing



Graph generated from diffuser flowrate testing into air.

Appendix H: Static pressure head for testing and in-lake



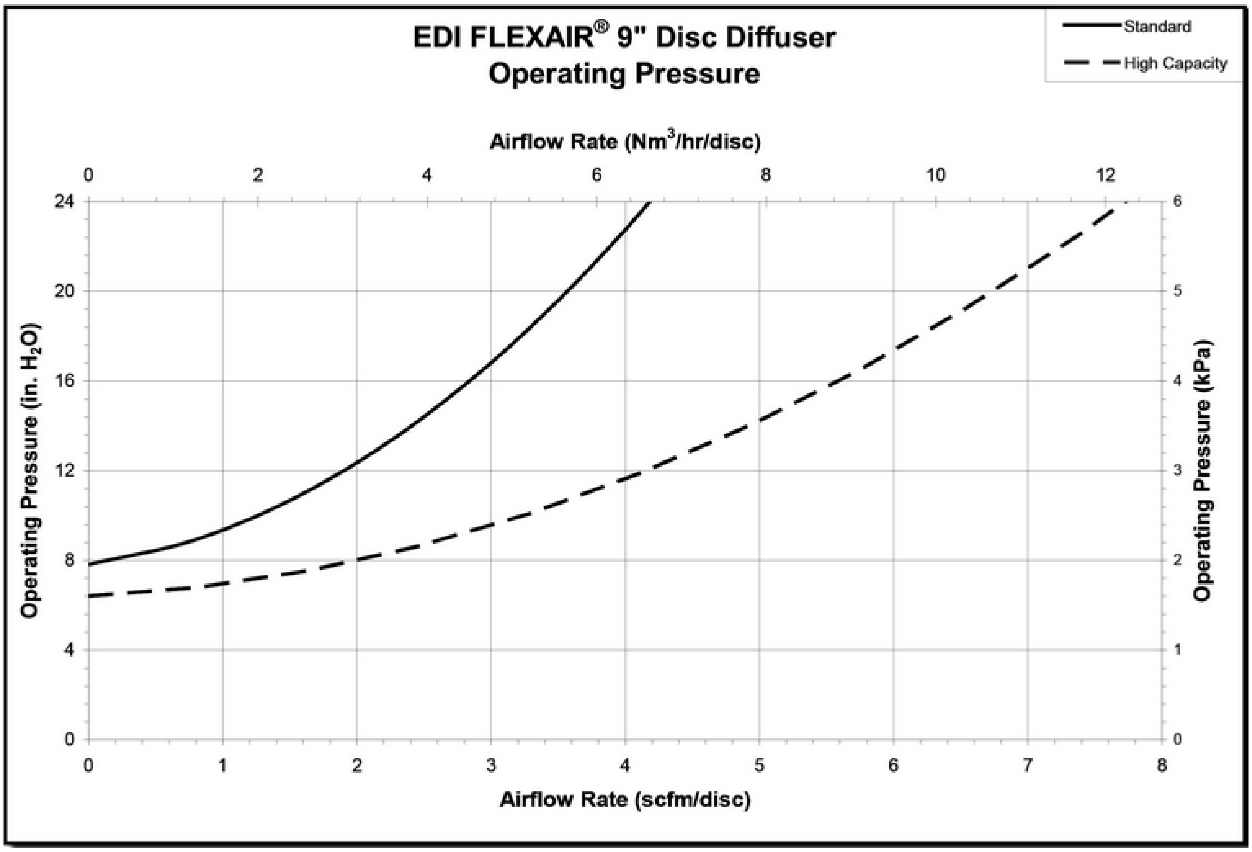
Graph generated by adding static pressure head of 8 ft and 15 ft of water to the corresponding air pressure.

Appendix I: Testing data

Diffuser Discs				
Pressure (psi)	**Diffusers used**	**Bubble diameter (in)**	**Spacing (in)**	**notes**
1	1	12		minimal bubbling
2.5	1,3	15	45 diagonal	slight bubbling, bubbles straight up
2.5	1,4	15	60 diagonal, 36 horizontal	
2.5	1,3,4	15	overlap 3-6	good bubbles but not mixing a lot
4	1,3,4	24	overlap-6-9	more overlap
4	1,4	24	slight overlap	slight overlap
4	1,3	24	better overlap	slightly better overlap, when not mixing water still, then but when mixing it seems better than before
6	1,3,4	30		
6	1,4	30	overlap-6-9	
6	1,3	30		inconsistent mixing
8	1,3	36		diameters almost touching, bubbles mixing instead of turbulence
8.5	1,3	36		can probably make it to the top of 15 ft, mixing at least 7-8 ft up but straight bubble stream at bottom
10	3	48		good bubbling, bubbles reach wall
30	3	144		extremely turbulent

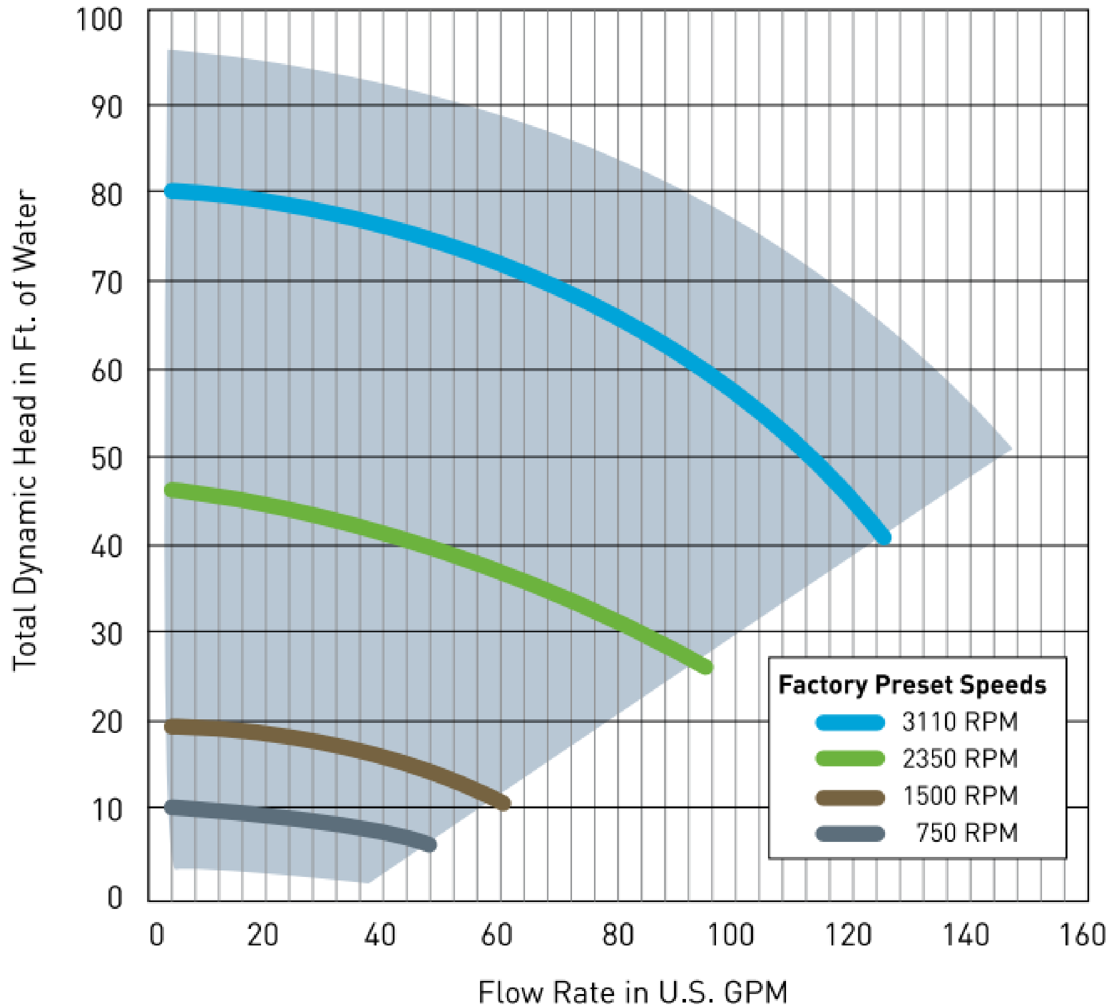
Bubble Tubing		
Pressure (psi)	**Bubble width (ft)**	**Notes**
1	0.5-1	similar to 1 psi with diffusers
2.5	1	more turbulent
4	1-1.5	mixing visible, turbulence at surface
6	1.5	better mixing
8	end of tank	good mixing
9	end of tank	sufficiently turbulent at surface
10	hitting walls	really mixing, bubbles hitting walls
>15 (full blast)		

Appendix J: Disc diffuser operating pressure diagram



The diagram used to determine the optimal operating pressure for the diffuser discs.

Appendix K: Pentair IntelliFlo Variable Speed Pump performance curve



NOTE: The chart above demonstrates performance rates at factory preset speeds of 750 RPM, 1500 RPM, 2350 RPM and 3110 RPM. However, flow rates can also be custom programmed between the ranges of 400 RPM and 3450 RPM as indicated by the blue tint.

Appendix L: Testing invoice

PVIA Senior Design Team INVOICE

Biosystems & Ag Engineeering Dept.
111 Ag Hall
Oklahoma State University
Stillwater, OK, 74074
Dr. Weckler: 405-744-8399

DATE: April 17, 2014

FOR: *Testing materials*

Bill To:
Poteau Valley Improvement Authority

25768 US Highway 270
Wister, OK, 74966
918-655-7500

DESCRIPTION	AMOUNT
Fastenal	$ 14.51
	$ 31.77
Lowes	$ 84.52
	$ 253.77
	$ 35.45
	$ 47.99
	$ 116.23
	$ 14.47
	$ 11.10
Pentair Aquatic-Bubble Tubing	$ 38.95
Grainger	$ 21.09
TOTAL	$ 669.85

Make all checks payable to: **OSU-Biosytems & Ag Engineering Dept.**
If you have any questions concerning this invoice, Dr. Paul Weckler, 405-744-8399, paul.weckler@okstate.edu

THANK YOU!

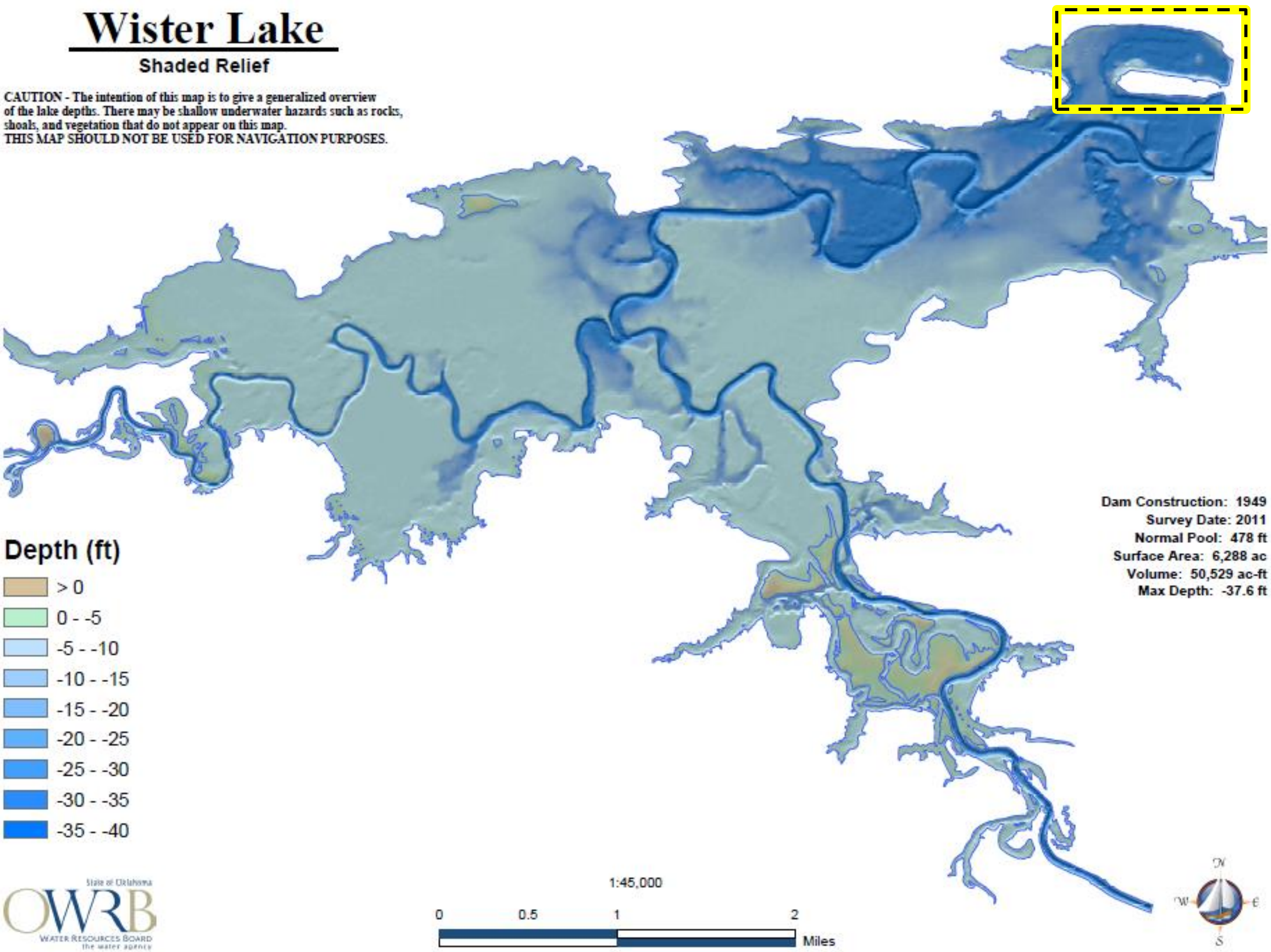
PVIA Lake Wister Water Treatment

Shelyn Gehle, Whitney Lisenbee, Rebecca Purvis, and Maggie Wyatt

Background on PVIA

- Poteau Valley Improvement Authority (PVIA) Water Treatment Plant
- Treats and distributes water to about 80% of LeFlore County, OK
- Water source: Lake Wister
- Pulls on average 6 million gallons of water/day

Site Location


Wister Lake
Shaded Relief
CAUTION - The intention of this map is to give a generalized overview of the lake depths. There may be shallow underwater hazards such as rocks, shoals, and vegetation that do not appear on this map.
THIS MAP SHOULD NOT BE USED FOR NAVIGATION PURPOSES.
Depth (ft)
> 0
0 - -5
-5 - -10
-10 - -15
-15 - -20
-20 - -25
-25 - -30
-30 - -35
-35 - -40
Dam Construction: 1949
Survey Date: 2011
Normal Pool: 478 ft
Surface Area: 6,288 ac
Volume: 50,529 ac-ft
Max Depth: -37.6 ft
1:45,000
0
0.5
1
2
Miles
State of Oklahoma
OWRB
WATER RESOURCES BOARD
the water agency

Water Balance

- Quarry Island Cove Volume = 1418 ac-ft

Accumulation = Inputs – Outputs

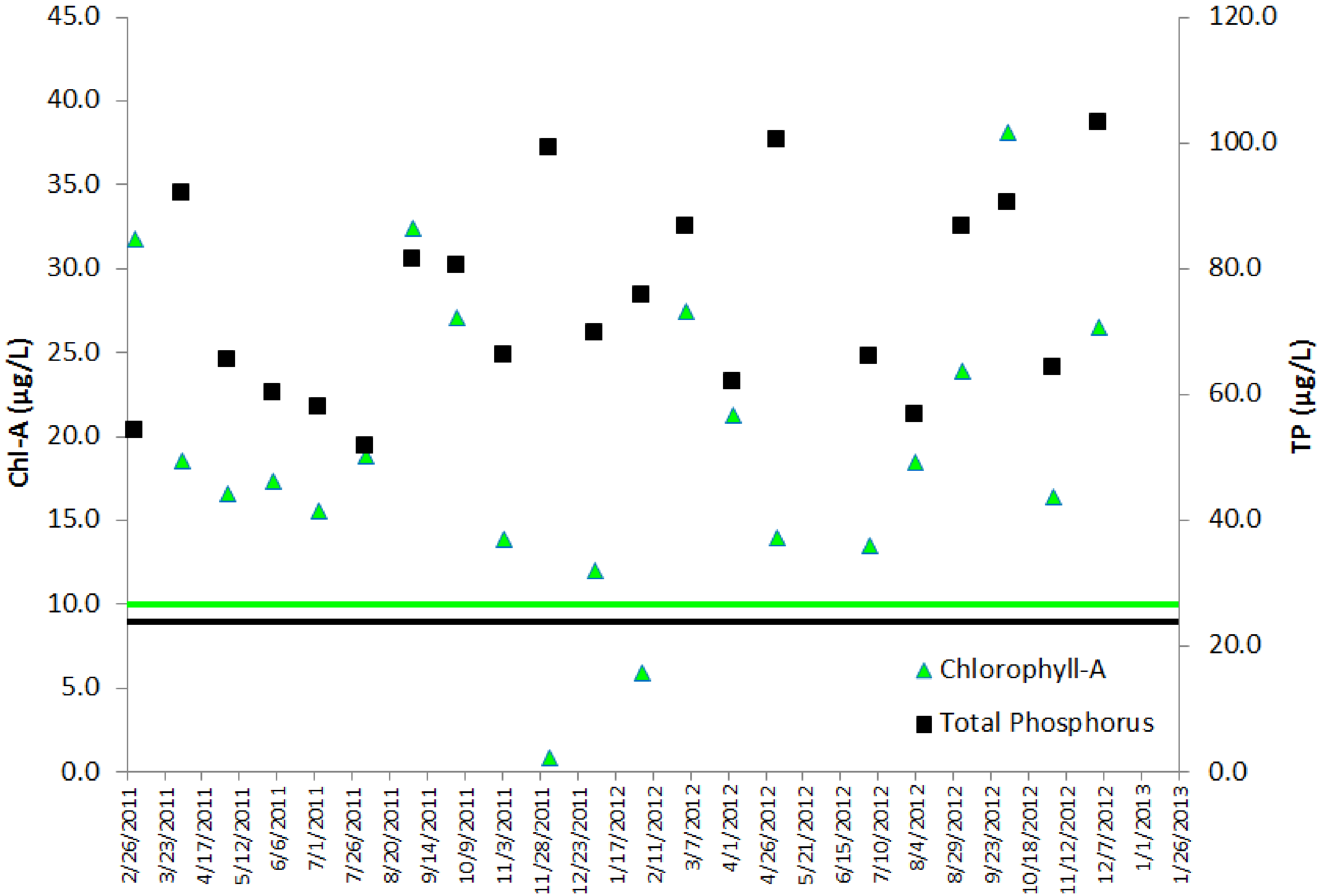
  - assume steady-state

- Inputs:
  - Precipitation = assume zero
  - Water entering cove from lake
- Outputs: 588 ac-ft/month (725 ML/month)
  - Evapotranspiration = 4ft/yr
  - Pumped out = 6MGD (22.7 ML/day)

Current Problems

- High phosphorous and algae levels in the lake
- P is the limiting nutrient for algal growth
- P concentration is indicated by levels of Chlorophyll-A in lake
  - Must not exceed ODEQ standards of 10 µg/L for Chlorophyll-A

Phosphorous and Chlorophyll-A Levels



Alum Treatment

- Aluminum Sulfate [$Al_2(SO_4)_3$]
  - Reacts with phosphorus and creates an aluminum phosphate precipitant
  - Precipitant settles at rate of 1 ft/5 min

- PVIA Treatment Plant has to remove P by adding Alum

Current Alum Application

- Currently only used in treatment plant
  - Treatment uses 5,000 gallons of Alum/week
  - Alum cost: $1/gallon

- Creates large volumes of “water treatment residual” (sludge) during treatment process
  - Pumped to nearby pasture and spread out
  - 1/12 of labor costs
  - Current procedure subject to change

Mixing/Settling of Alum

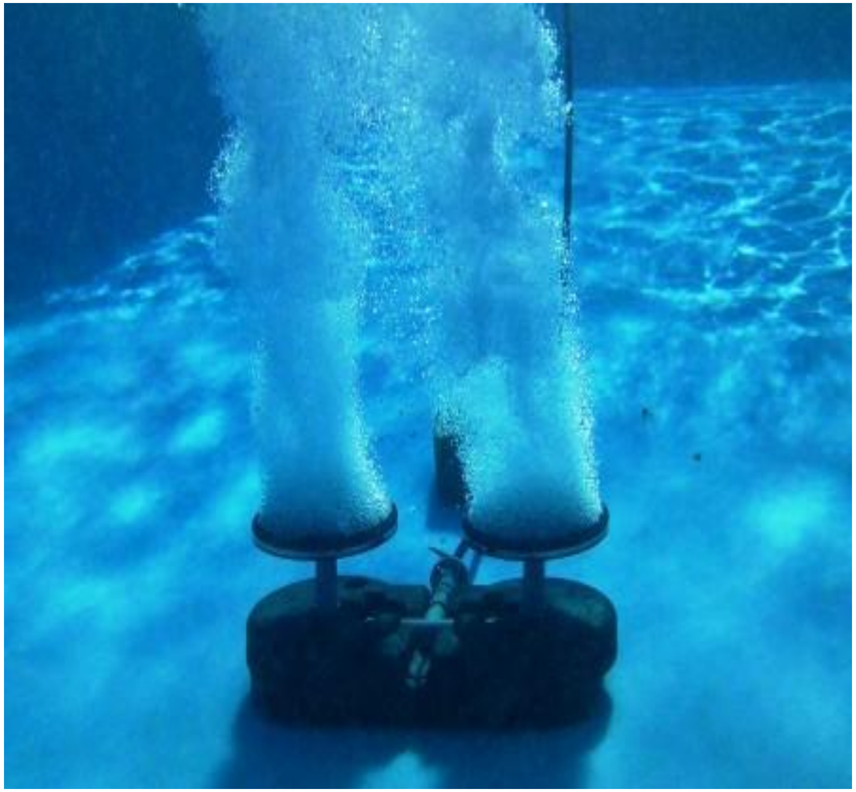
Project Objectives

- Create an Alum Microfloc Curtain
  - Alum and aeration components
- Allow for continual decrease in P concentration
  - Reduce algae and cyanobacteria levels
  - Reduce Disinfection By-Products (DBP) and toxins in treated outflow
  - Keeping below state regulations for Chlorophyll-A
- Determine dosage rates

Constraints

- ¼ mile cove opening
- Materials must withstand highly corrosive lake
- Compressor must be above floodplain
- Compressor depends on number of running units
- Power availability limited by road access
- Treatment varies by season
- Cannot interfere with cove recreational activities

Diffuser Discs



https://www.outdoorwatersolutions.com/store/dual-disc-rubber-membrane-diffuser-with-base-and-risers-p-248.html

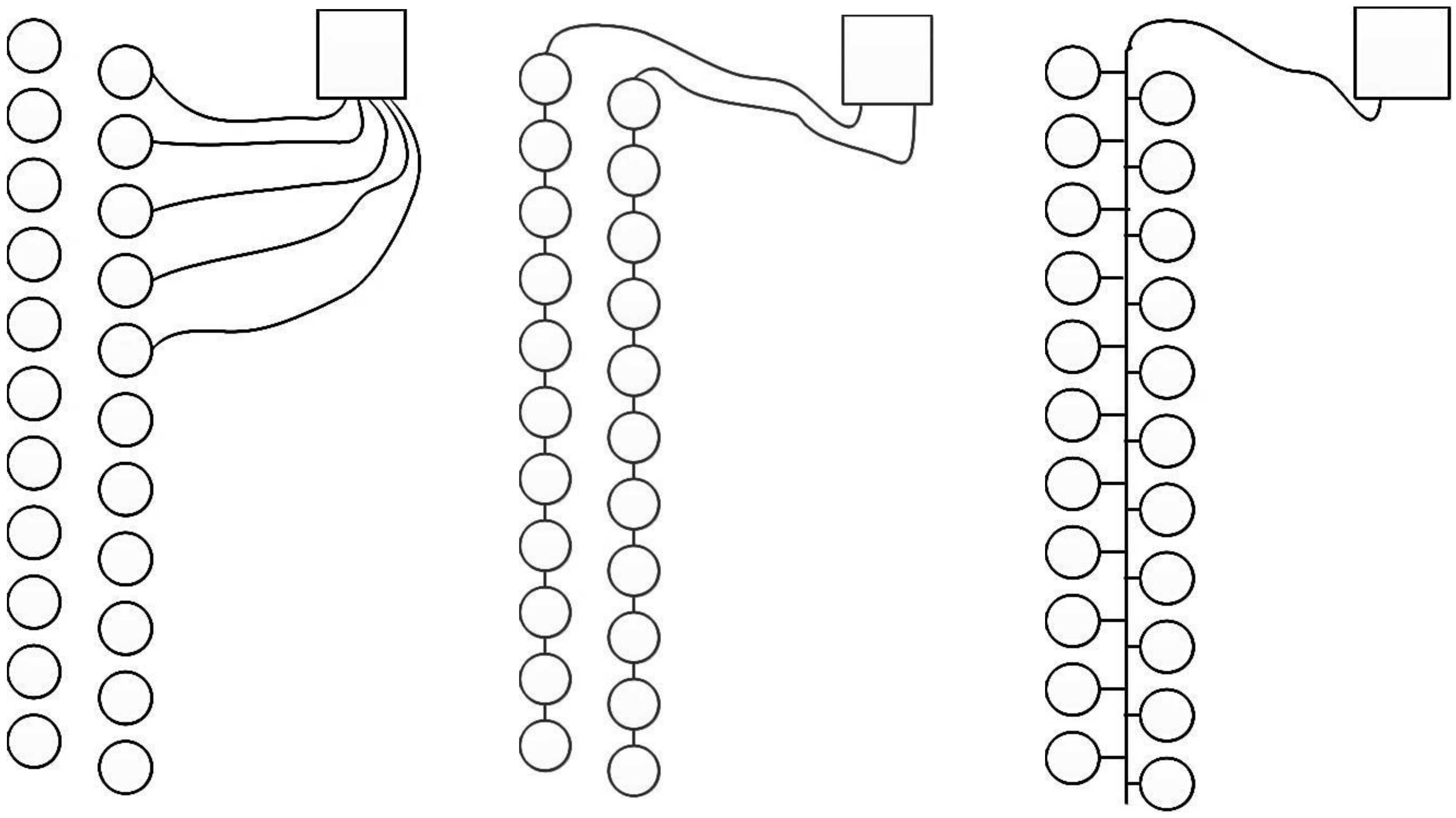
Pros

- Common
- Weighted
- Good aeration
- Familiarity

Cons

- Cannot be in series
- Pressure regulators
- Moderately expensive

Problems with Diffuser Discs



Bubble Tubing

http://pentairaes.com/perfaerated-diffuser-tubing-101.html

Pros

- Weighted
- Continuous curtain
- Easy installation
- Easy maintenance

Cons

- Needs supports

Potential Materials

OctoAir-10 Industrial Diffuser

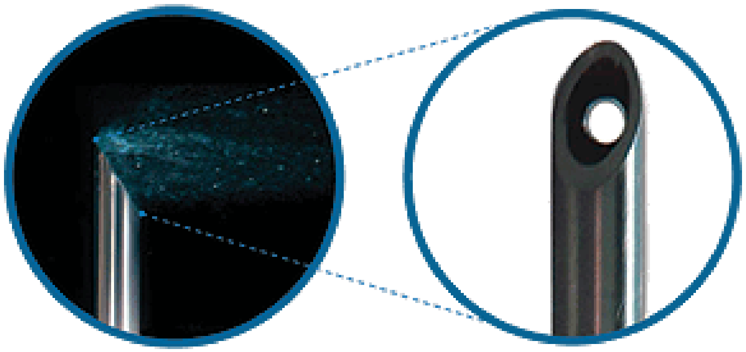
http://www.canadianponds.ca/en/octoair-10-diffuseur-industriel-octoair-2?cc=bubbletub

Porous PVC

http://www.alita.com/diffuser/polyethylene.php

Liquid Alum Release

Kenco Chemical Injectors



http://kenco-eng.com/product-info/chemical-injectors

- Connected to continuous Alum pipe
- Placed above diffusers
  - Oriented in any direction
  - Check valves
  - Minimize chemical build-up
  - Function under wide pressure range
  - High flow rate

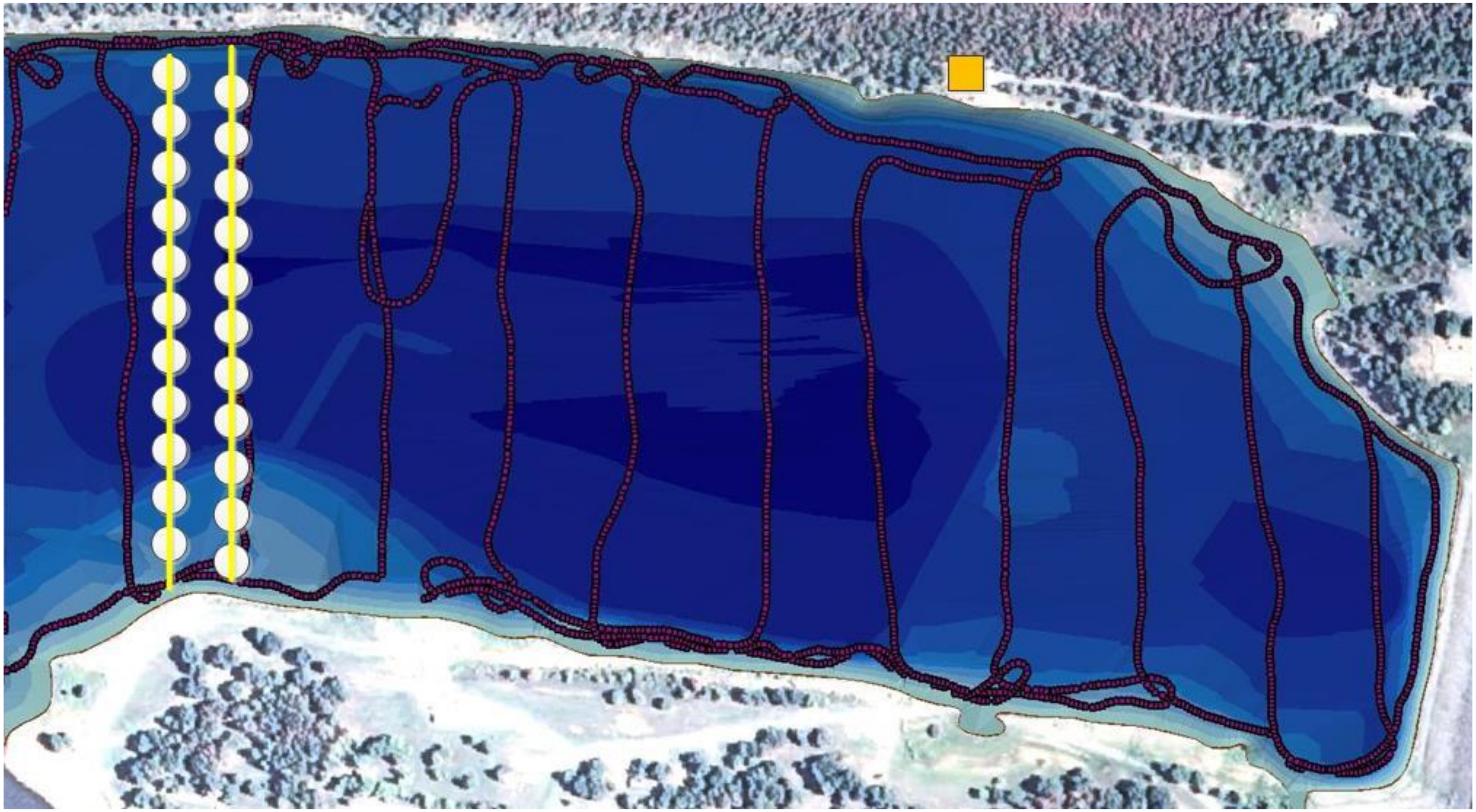
Solid Alum Release

- ChemLog
  - 40 lb blocks
  - Held above diffusers

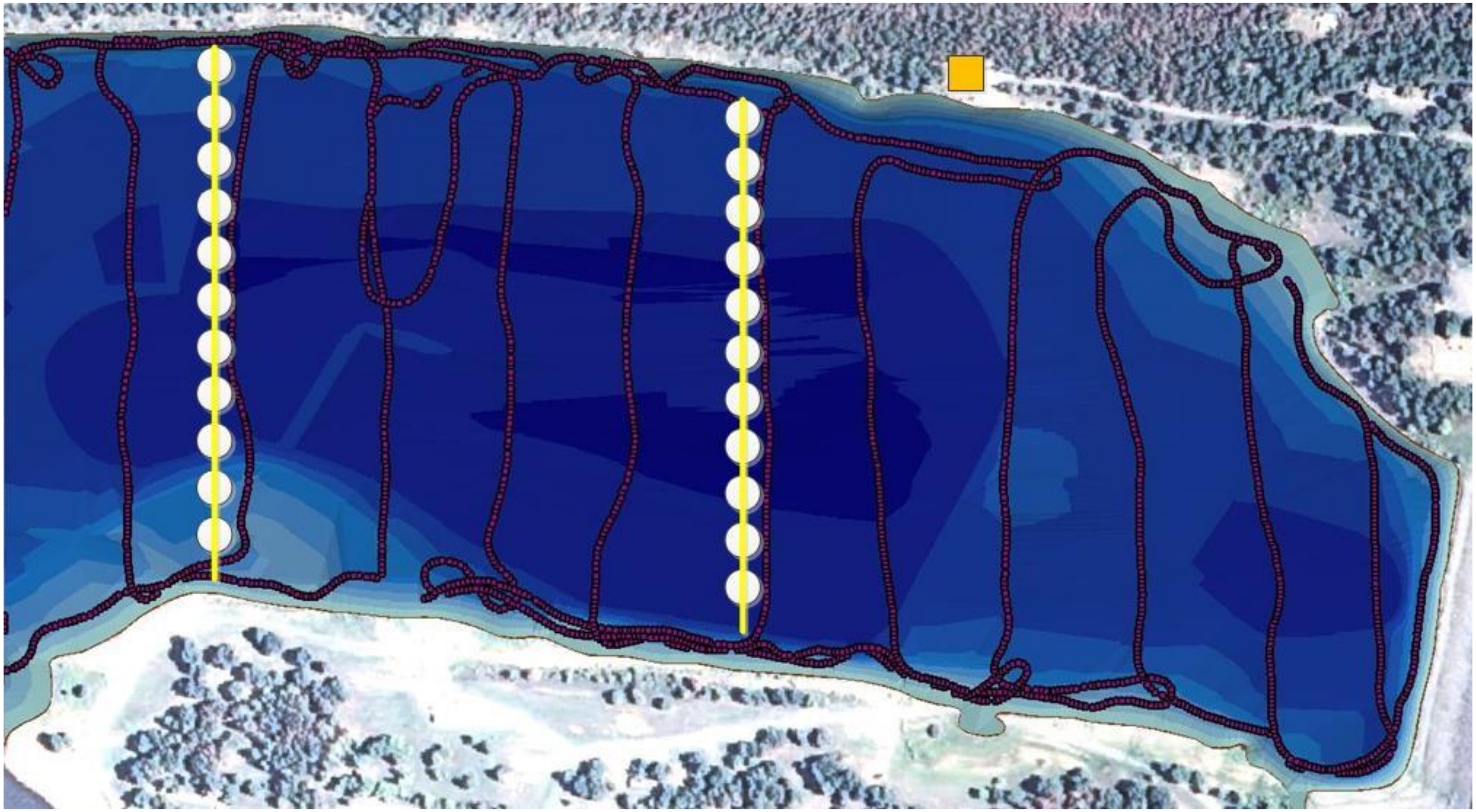
Pros:
  - Easy release
  - Less equipment

Cons:
  - Must replace often
  - Not consistent
  - Costs 50% more

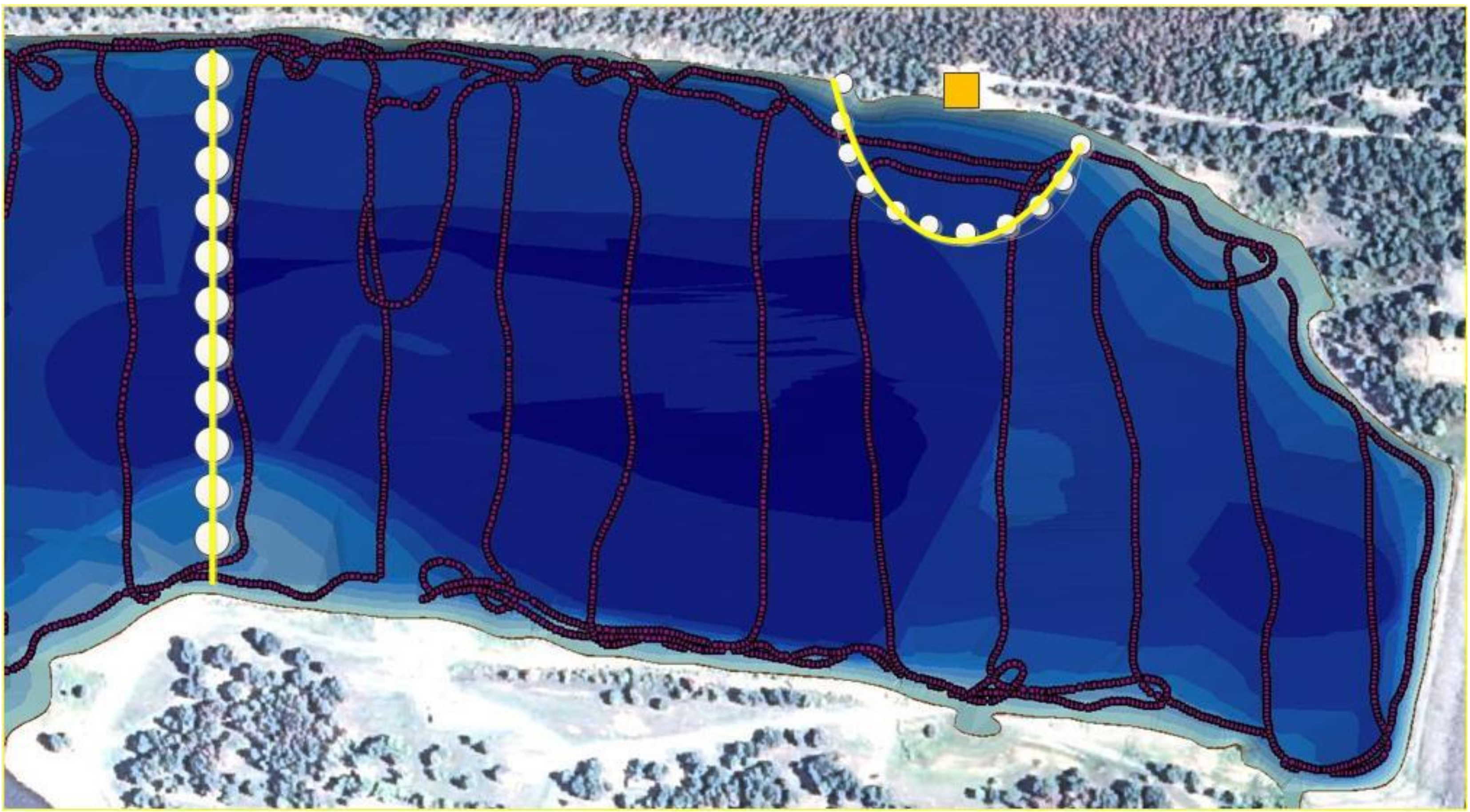
Layout 1



Layout 2



Layout 3



Patents and Permits

- Patent No. 7,074,328
  - Connects diffusers in branches using regulators
  - Does not have Alum components
- Potentially patent process

- No permit required by ODEQ to add alum

- US Army Corps of Engineers "404 Dredge and Fill" permit may be necessary

Alum Chemistry

- Low alkalinity and pH creates a corrosive lake
  - Alkalinity: avg. 19 mg/L as $CaCO_3$ (range 8-42)
  - pH: 6.5 to 9.5
- Alum reacts with current lake chemistry
  - Reduces alkalinity of lake
  - Lime addition

Alum Spreadsheet

Current P Level	0.11	mg/L as P
Mesotrophic P Level	0.024	mg/L as P
P For Removal	0.086	mg/L as P
Alum Liquid Needed	4.838	mg/L as liquid
Alum $CaCO_3$ equivalent	2.443	mg/L as $CaCO_3$
$CaCO_3$ to Return to initial Alkalinity	2.443	mg/L as $CaCO_3$
Water Pumped Out	1.20E+07	gal/day
	4.54E+07	L/day
Total Alum Required	2.20E+08	mg liquid
Total Alum $CaCO_3$ equivalent	1.11E+08	mg as $CaCO_3$
Total $CaCO_3$ to Return to initial Alkalinity	1.11E+08	mg as $CaCO_3$

Alum Recommendations

- Schedule 80 PVC pipe
- Kenco Mini Chemical Injectors
  - Product: KINJM – 316 SS
- Variable speed pump
  - Required: 2 gpm @ 50 ft head
  - Product: Pentair IntelliFlo Variable Speed Pump

Testing Location

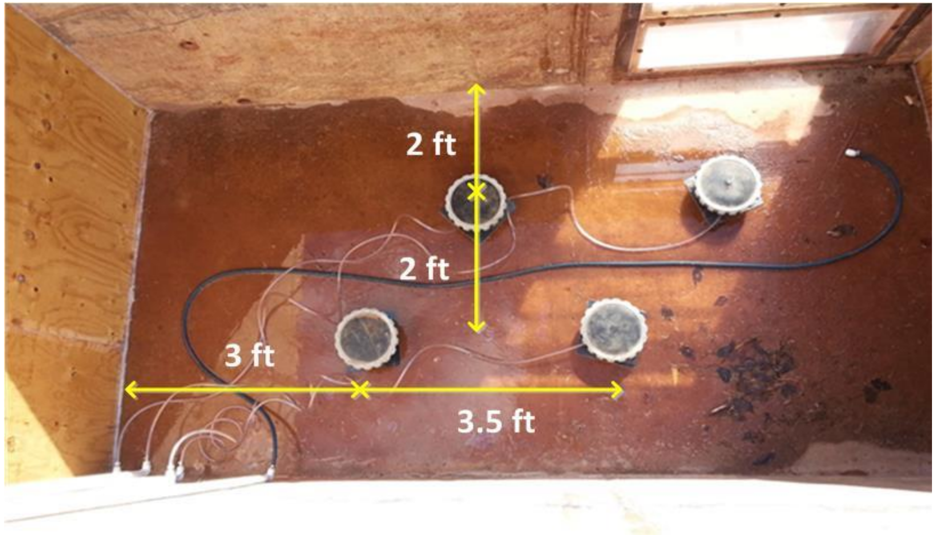
USDA ARS Hydraulics Lab Flume

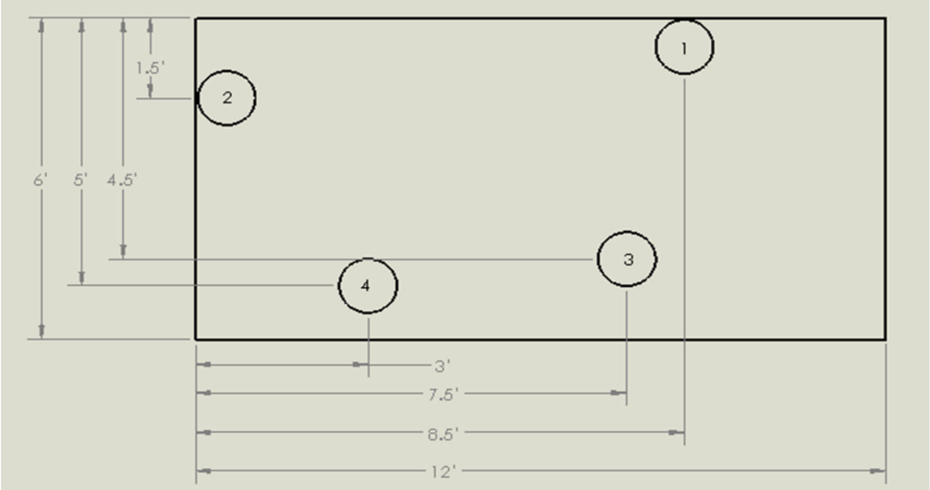
Testing Setup

Right Top: Designed diffuser spacing

Right Bottom: Actual diffuser spacing

Below: Air supply unit





Testing Procedure

Turn on compressor with all valves closed. Record initial valve readings.

<u>Diffusers</u>

- Adjust diffuser #1 to 2.5 psi
- Adjust diffusers #1 and #3 to 2.5 psi
- Adjust Diffusers #1, #3, and #4 to 2.5 psi
- Repeat steps 2-4 at 4, 6, and 8.5 psi
- Adjust diffuser #3 to 10 psi

<u>Bubble Tubing</u>

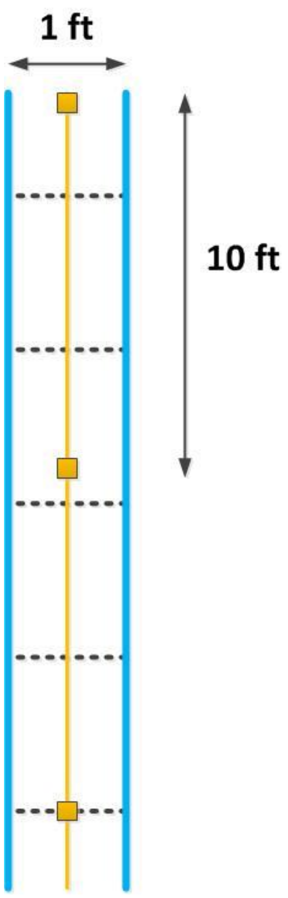
- Adjust bubble tubing to 1 psi
- Repeat step 7 at 2.5, 4, 6, 8, 9, 10, and >15 psi (completely open valve)

Testing Results

Diffuser Discs	Bubble Tubing
	

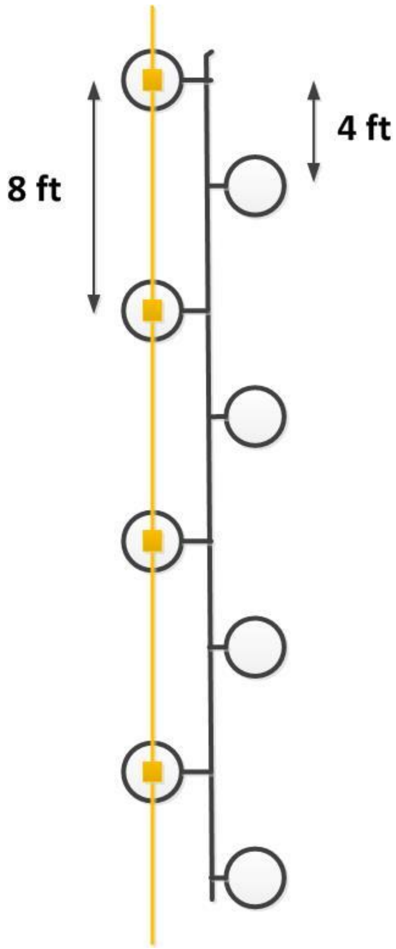
Alternative #1: Bubble Tubing

- Pentair PerfAerated Diffuser Tubing
  - 3/8" inside diameter
- 26- 100 ft lengths of bubble tubing
  - Two lines 1 ft apart
- 28,600 ft of weighted connector tubing
- Weighted stand
- Compressor: 5-20 cfm
  - 26 units on the compressor
- Alum injectors every 10-15 ft



Alternative #2: Diffusers

- 325 Matala or Environmental Dynamics International (EDI) diffuser discs
  - 9 or 12 in. membrane
  - Weighted base
    - Sand/gravel or Universal Diffuser Mount
- One line of Schedule 80 PVC
  - Branched formation-4 ft apart
- Pressure regulator on each diffuser
- Compressor- 650 cfm
  - One unit on the compressor
- Alum injectors- every other diffuser



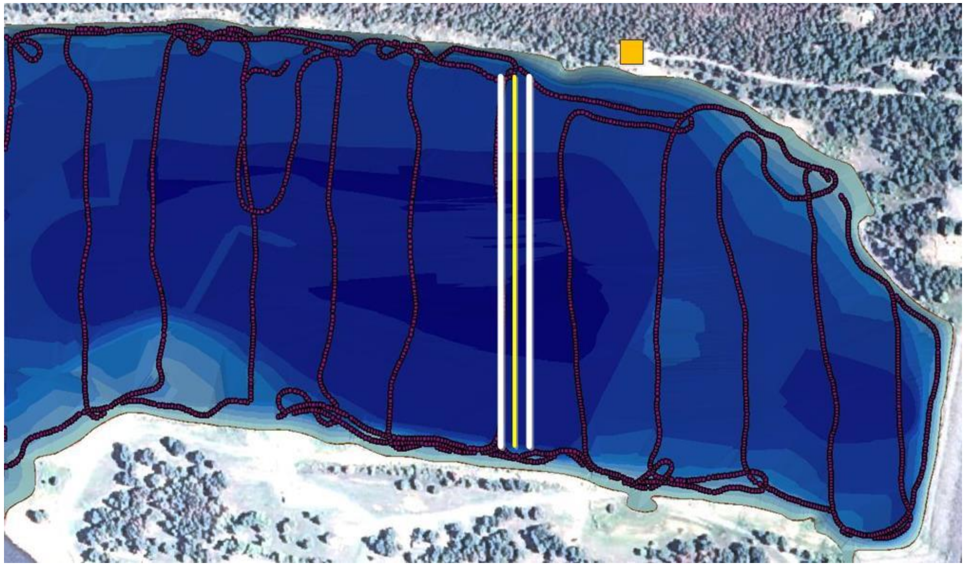
Financial Analysis – Materials

- Bubble Tubing
  - Unweighted Connector Tubing - $50,962.20
  - Weighted Connector Tubing - $72,466.54
- Diffuser Discs
  - Universal Diffuser Mount- $105,281.76
  - Weighted Base- $87,178.01

- Cost for all options includes: aeration components, piping, injectors, pump, and pressure regulators, brackets

Final Recommendations

- Alternative #1- bubble tubing
  - Meets compressor requirements
  - Better mixing
  - Cost-effective
  - Fewer components
  - Run for at least 1 hour
  - Allow for 2 hours settling time



Acknowledgements

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- Keith Wright: Board Member – PVIA
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- Wayne Kiner: OSU BAE Lab
- Carl Parrott: ODEQ Water Quality Division
- Dr. Garey Fox
- Dr. Paul Weckler
- Dr. Dan Storm
- Dr. Dan Thomas

References

- Davis, M. L., and D. A. Cornwell.1998. *Introduction to Environmental Engineering*. 3rd ed. Boston, MA: McGraw Hill.
- "Section 404 Permitting." *Water: Discharge of Dredged or Fill Materials (404)*. U.S. EPA. <http://water.epa.gov/lawsregs/guidance/cwa/dredgdis/>.
- Yum, K., S. H. Kim, and H. Park. 2007. Effects of plume spacing and flowrate on destratification efficiency of air diffusers. *Water Research*. 42: 3249-3262.
- Oklahoma map: http://mapsof.net/map/counties-map-of-oklahoma#.U0wmHfnIZgg
- Wister map: provided by PVIA
- Layout background photo: provided by PVIA
- Chlorophyll-A/phosphorus graphs: provided by PVIA
- USDA ARS Hydraulics Lab satellite view: https://www.google.com/maps/@36.1370948,-97.1890865,380m/data=!3m1!1e3

Questions?

Project website: http://osuseniordesign.wix.com/pvia-lake-wister

Diffusers

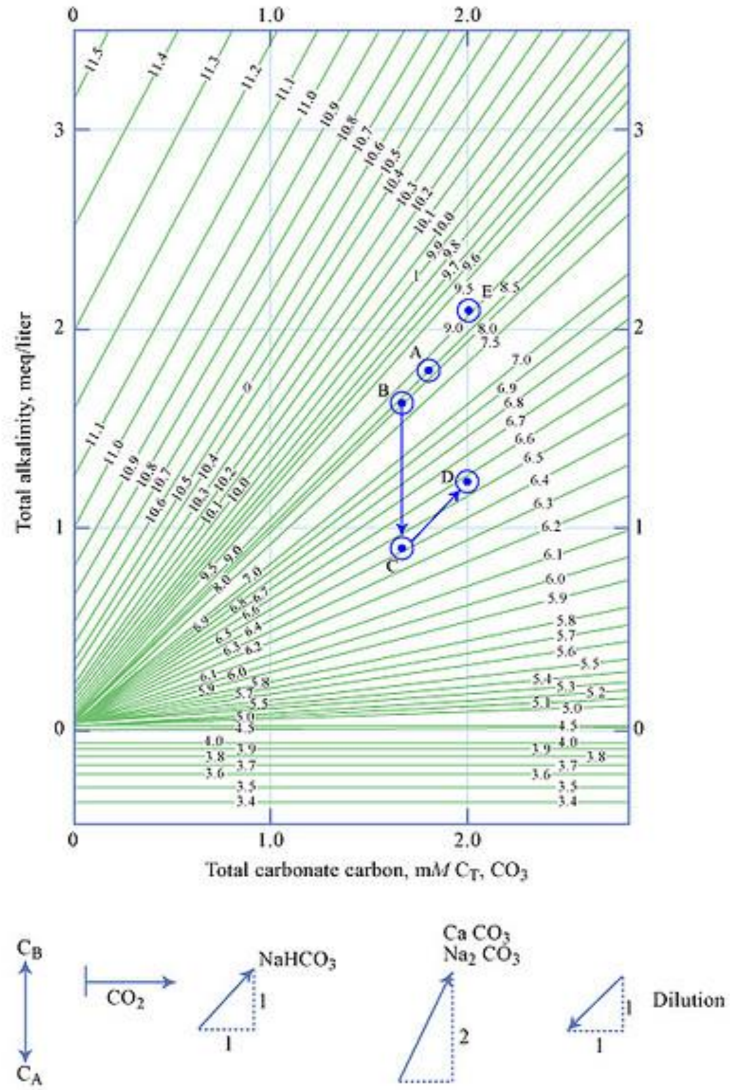
Materials	Description	Number	Unit Price	Total Price
Diffuser options	Matala Air Base W/9-in. Air Disc (weighted)	325 @ 4' apart	$76.95	$25,008.75
	Membrane Pond Air Diffuser (19" Diameter) (unmounted)	325 @ 4' apart	$44.50	$14,462.50
Weighting/Mounting Options	Matala- Sand or Gravel		$20/ton	$600.00
	Universal Diffuser Mount	325	$90.00	$29,250.00
Alum Brackets	Angle Stock, 316SS, 1/8 In T, 1 In Leg, 7 ft	260	$39.05	$10,153.00
	Hose Clamp, Min.Dia.1, SAE 24, PK10	26 (10/pack)	$13.01	$338.26
	Other materials and Labor			$4,500.00
Connector Tubing	3/4" Sch. 80 PVC	132 sets of 10'	$0.65	$858.00
Pressure regulators	Pneumatic Regulator, Nonrising, Locking Knob; 3/4" NPT, 100 cfm	325	$87.80	$28,535.00
Alum Tubing	3/4" Sch. 80 PVC	130 sets of 10'	$0.65	$845.00
Alum Injectors	KINJM - 316 SS	162	$70.00	$11,340.00
Variable Flow Pump	Pentair IntelliFlo Variable Speed Pump	1	$1,000.00	$1,000.00
Alum Storage Tank		1	$4,000.00	$4,000.00

Bubbling Tubing

Materials	Description	Number	Unit Price	Total Price
Bubble Tubing	2 lines - 1250' each; Pentair PerfAerated Diffuser Tubing	26 sets of 100'	$174.00	$4,524.00
Connector Tubing options	3/8" Self Weighted Airline	572 sets of 50'	$51.49	$29,452.28
	3/8" Polyethylene Tubing (unweighted)	143 sets of 200'	$55.58	$7,947.94
Pressure regulators	Pneumatic Regulator, Nonrising, Locking Knob; 3/8" NPT, 95 cfm	26	$87.80	$2,282.80
Weighted Stand	Angle Stock, 316SS, 1/8 In T, 1 In Leg, 7 ft	390	$39.05	$15,229.50
	Hose Clamp, SS, Min.Dia.3/4, SAE 20, PK10	130 (10/pack)	$9.19	$1,194.70
	Hose Clamp, Min.Dia.1, SAE 24, PK10	26 (10/pack)	$13.01	$338.26
	Other materials and Labor			$4,500.00
Alum Tubing	3/4" Sch. 80 PVC	130 sets of 10'	$0.65	$845.00
Alum Injectors	KINJM 316 SS	130 @ 10' apart	$70.00	$9,100.00
Alum Storage Tank		1	$4,000.00	$4,000.00
Variable Flow Pump		1	$1,000.00	$1,000.00

Feasibility

- Worst Case Scenario
  - 0.11 mg/L of P
  - 12 MGD
  - 20% efficiency
- Monthly alum and lime costs
  - $5219 (in-lake)
  - Additional at plant
- Total system cost
  - $80,000
- Current monthly alum costs
  - $20,000



THE DEFFEYES DIAGRAM FOR 25°C

PVIA Lake Treatment

BAE 4012

Fall 2013

Shelyn Gehle, Whitney Lisenbee, Rebecca Purvis, Maggie Wyatt

Background on PVIA

PVIA stands for the Poteau Valley Improvement Authority; they treat and distribute water to about 80% of Le Flore County in Oklahoma. Le Flore County is located in east-central Oklahoma. Our efforts were focused in Wister, OK, where Lake Wister (Figure 1) is located. On average, six million gallons a day are pumped out of Lake Wister for treatment and distribution. The maximum capacity for the treatment plant is twelve million gallons per day. The intake is located in a small cove on the northeast side of the lake. The cove is only about 2 percent of the total volume of the lake and the depth across the cove is on average fifteen feet. Our design will be implemented in Quarry Island Cove, the location of the water intake station, allowing for the water to be treated before being removed.

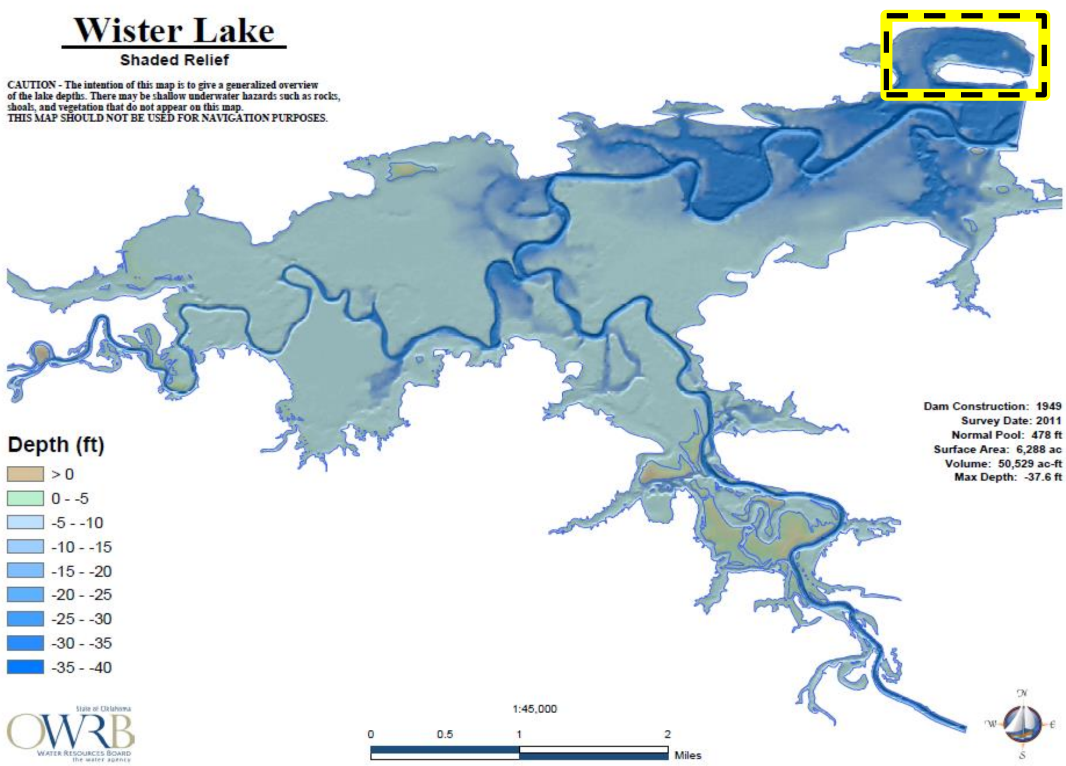
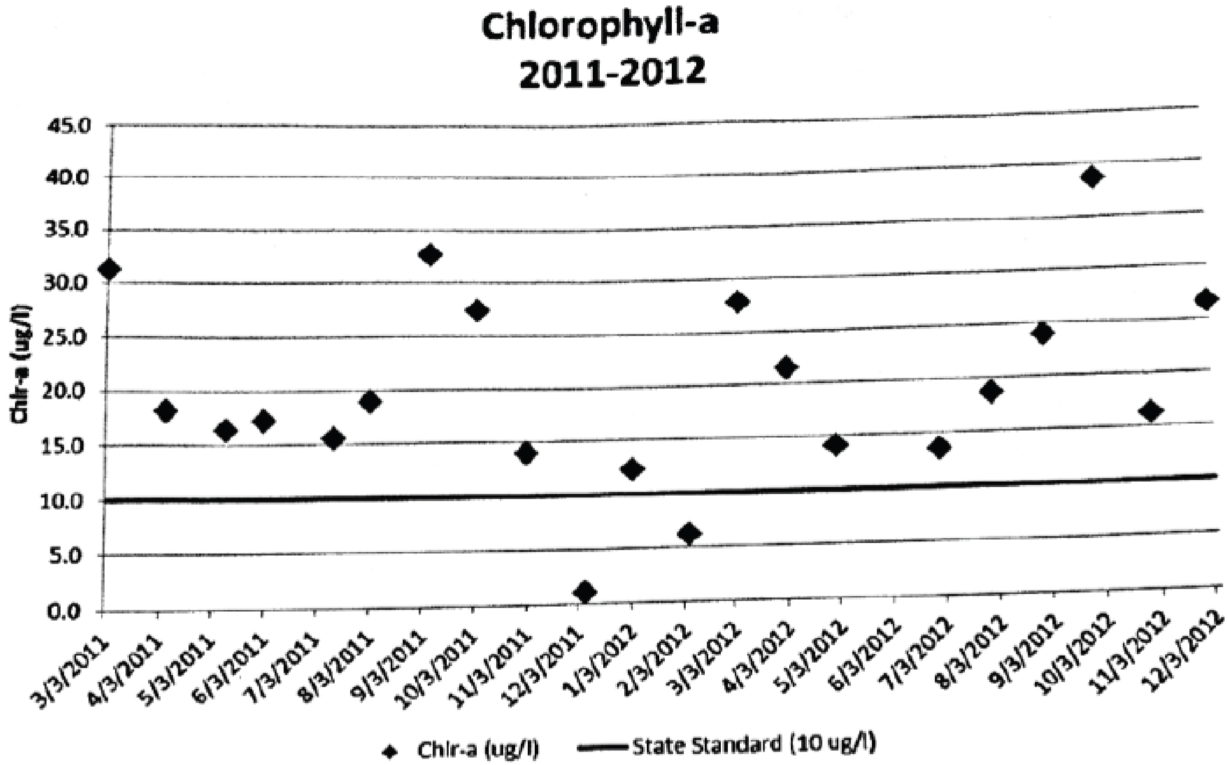


Figure 1. Map of Lake Wister; yellow box represents Quarry Island Cove where the water is drawn for treatment

Problem Statement

Lake Wister has very high levels of phosphorus. Phosphorus is the limiting nutrient for algal growth. Therefore, an increase in phosphorus concentration results in increased levels of algae within the lake. High levels of phosphorous within the lake can create a eutrophic environment. To ensure that the lake is mesotrophic, rather than eutrophic, phosphorous levels need to be below 24 µg/L (Figure 2). One way to monitor phosphorous levels within the lake is to quantify Chlorophyll-A levels, which is part of algae photosynthesis. There are no standards for phosphorous, but the Oklahoma Department of Environmental Quality has set a Chlorophyll-A standard to not exceed 10 µg/L.

Our project objective is to create an Alum Microfloc Curtain. Essentially, this is a line of diffusers with an alum component placed over the top. This will allow the alum to be brought to the surface to mix with incoming water. Alum reacts with phosphorous to create a precipitant which will sink to the cove bottom and form a protective residual layer.This curtain will allow for a continuous decrease in phosphorus concentration in the water as it enters the cove. The reduction in phosphorus will in turn reduce the algae and cyanobacteria (blue-green algae) levels. The reduction in algae will also help reduce the level of disinfection by-products in the treated outflow. Disinfection by-products are the result of chlorine reacting with the organic matter, such as dead algae, in the water treatment process. This initial treatment will help the PVIA keep Lake Wister under the state standards for Chlorophyll-A within the lake.



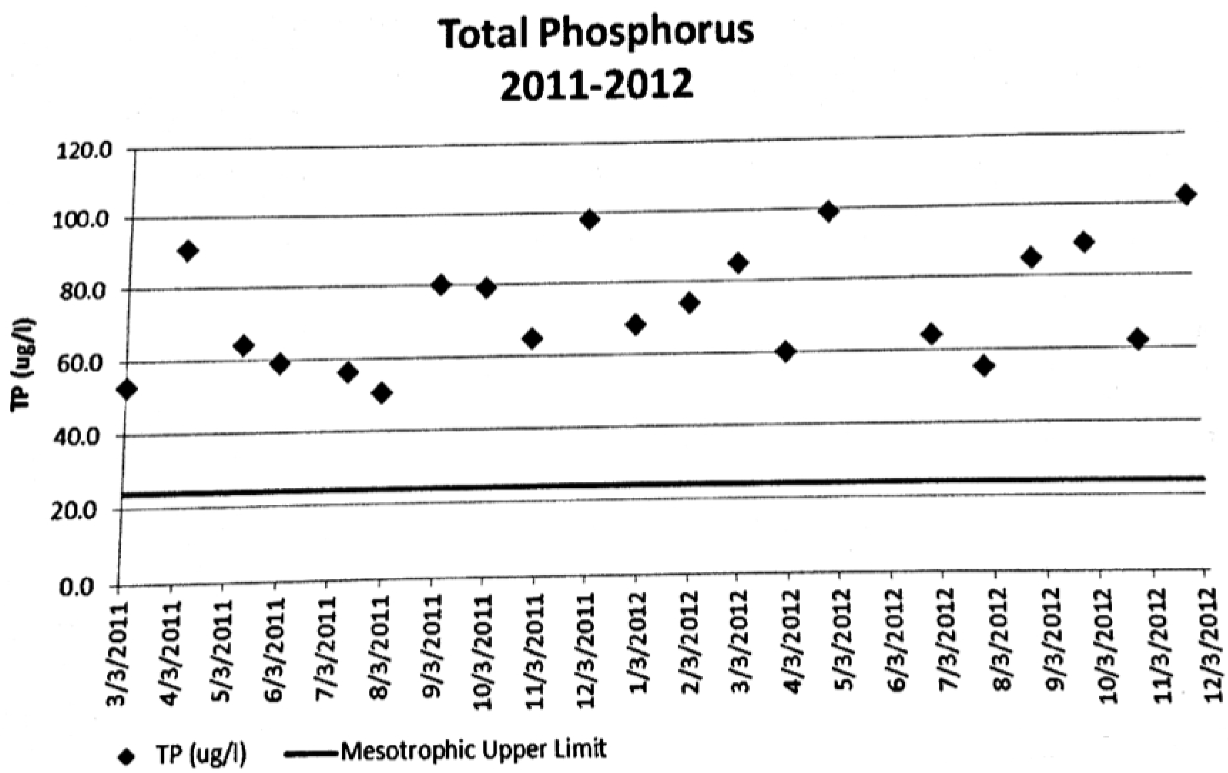


Figure 2. Graph of chlorophyll-a and total phosphorous levels in Lake Wister

Alum is the common name for aluminum sulfate. Alum reacts with phosphorus to form a precipitant of aluminum phosphate. This flocculation precipitant settles to the bottom of the lake to form a protective barrier against the re-suspension of dissolved phosphorus from the sediments.

The PVIA water treatment plant has to remove phosphorus from the water by adding alum. Currently, alum is only applied once the water reaches the treatment plant. They use about 5,000 gallons of alum per week, at a cost of about one dollar per gallon. The water is then put through three clarifiers, which allows the sludge to settle to the bottom. A large volume of this sludge, or "water treatment residual," must then be disposed of by the treatment plant. The residual material is pumped to a nearby pasture and spread out. The disposal of this material make up about one-twelfth of their total labor cost; there are twelve full-time employees, one of which spends most of his time dealing with the sludge. There is no guarantee that this practice will always be available, which would require them to haul the sludge to a landfill.

Another method of applying alum is a water surface application. The alum is sprayed on top of the water, which allows it to settle to the bottom, trapping phosphorus as it moves through the water. This application method would not be feasible for our project because it would interfere with cove recreational activities and add to the labor cost for the plant.

Water Balance

The Quarry Island Cove has a volume of about 1418 ac-ft. A steady state accumulation equation was done to see how much water would be returning to the cove each month to be treated. This will help in the calculation of how much alum will be needed each month to treat the new lake water. The equation is simply the accumulation rate, which is equal to the inputs of water minus the outputs of water. For inputs, it was assumed that the precipitation was negligible as the annual rainfall spread over the entire lake surface would have very little accumulation in the cove. The volume of water entering the cove is what is to be determined. For outputs, it was assumed that evapotranspiration was 4 ft/yr and that the water treatment intake pumped out 6 MGD. The accumulation would go to zero because it is a steady state equation. This equation was solved to find that about 600 acre-feet of water per month would be returning to the cove to treat.

Constraints

There are many constraints that need to be taken into account before creating a solution for reducing the phosphorus levels. Quarry Island Cove has an opening of a quarter mile that our design will need to span across, in order to effectively treat all incoming water. The lake has an alkalinity range from 8 to 42 mg/L as $CaCO_3$ with an average of 19 mg/L as $CaCO_3$ and a pH ranging from 6.5 to 9.5. Low alkalinity and pH within the cove can create a corrosive environment that could affect how effectively our structure functions. At least a 400 series stainless steel would need to be used to withstand potential corrosion.

The current compressor station has 45 horsepower and the ability to have 48 units branching off. Should our final design need more power or have more units, a new compressor will need to be purchased to ensure proper function. A new compressor would need to be at least 30 ft above the lake floodplain to avoid any potential flood problems. In addition, there is limited power access, so a new compressor would need to be near the existing or across the cove at the other potential power source. The final design should also be near the power supply to reduce needed piping and to allow for easy access for maintenance.

Lake conditions vary throughout the year and there could be random occurrences of algae blooms that will need to be addressed. Due to these ever changing conditions, a system that allows for varying rates of alum injection will be needed to ensure that proper treatment is taking place. Finally, the cove has a high level of recreational boating and fishing. Any design would need to be on the bottom of the cove to ensure no interference between the treatment and boats. Buoys or signs may need to be set up to ensure that no fish hooks get caught on the pipes. There are many different constraints and all need to be taken into account when creating potential designs.

Alum Chemistry

As mentioned in the constraints, the lake can have low alkalinity and pH creating an undesirable environment. When placed in the lake to react, 1 mg of alum will consume 0.5 mg of alkalinity ($CaCO_3$). If the alkalinity in the lake is too low, then the reaction will create an acid, further reducing the lake's pH and available alkalinity. First the volume of alum needed to reduce phosphorus to 24 mg/L will need to be calculated. Once this volume has been determined, an analysis of the lake's carbonate system can be carried out to determine the effects of this alum addition. Should there not be enough alkalinity, our design may require the addition of lime or sodium aluminate to act as a buffer. The addition of alum and a buffer will need to be continuously monitored with changing lake conditions.

Aeration Components

Diffusers

Diffuser discs are membranes (typically between 9 and 12 inches in diameter) that release a steady stream of bubbles, allowing for good mixing, when compressed air is pumped in. Diffuser discs are weighted, so a separate system to keep them on the lake surface would not need to be created. Having them on the lake bottom keeps the system from interfering with cove recreation. This product is easily available and well known, with PVIA already using some for lake mixing. However, current manufactured diffuser discs cannot be placed in series. Each system only has an inlet tube, but no outlet. This means that each diffuser would have to be considered a single unit on the compressor.

One potential solution to this problem is to create a new diffuser that has both an inlet and outlet tube, allowing for air to continue passing through. Each diffuser would have a pressure regulator to ensure that the same volume of air is being released from each diffuser, creating a constant air curtain. The problem with this design arises in the event that a diffuser fails. Should a diffuser in the middle fail and need to be removed, it could cause the rest of the diffuser line to be cut off from the air supply until repaired, resulting in the malfunction of a large part of the curtain.

A more effective design would be to have a main air pipe and branch off the diffusers. Each diffuser would still need a pressure regulator, but the air pipe would only be one unit and each diffuser can act individually off of this main pipe. This cuts down on needed pipe and units, as well as allowing for each maintenance and repairs of diffusers. These diffuser connections can be seen in Figure 3.

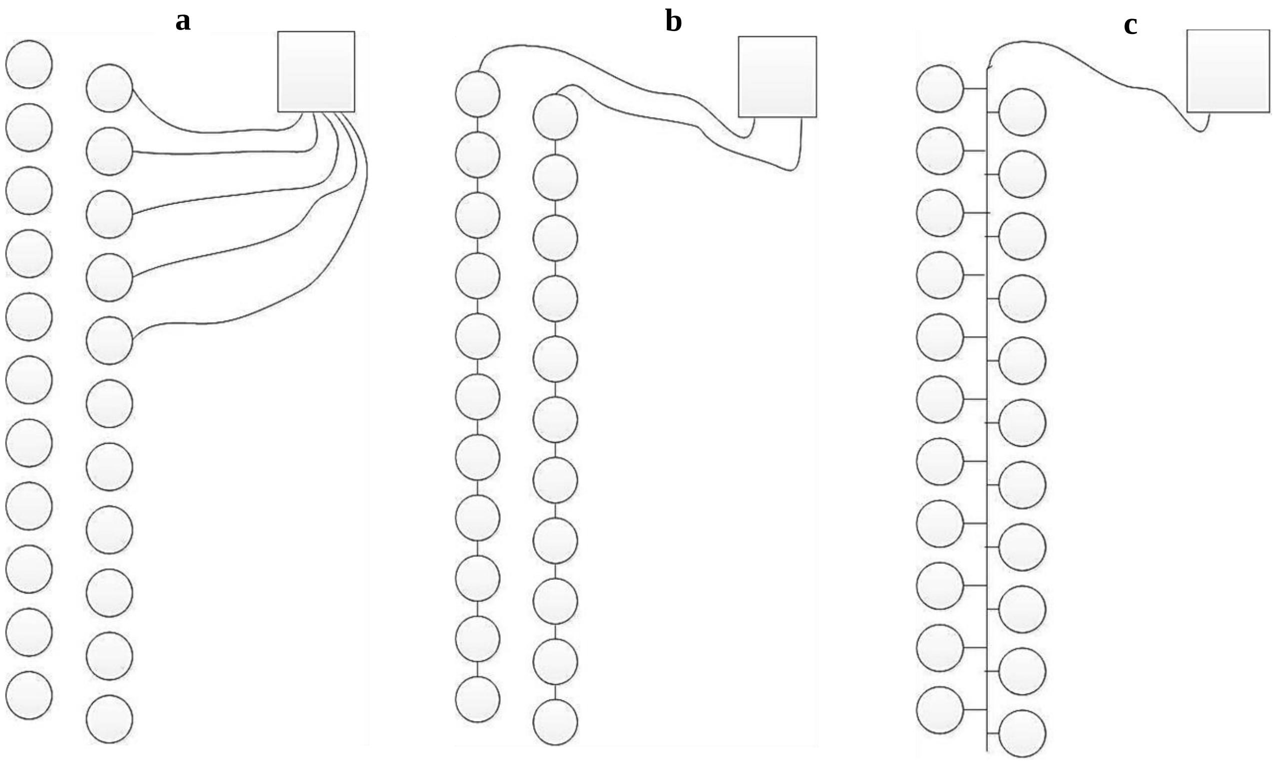


Figure 3. Problems with connecting diffuser discs; a) each diffuser connected individually; b) diffusers connected in series; c) diffusers branching off a main air supply pipe

Bubble Tubing

Bubble tubing consists of a weighted pipe on the bottom and then a flexible, porous pipe on top that allows for the release of air bubbles. Since this product is already weighted, a different system would not need to be created to do this; a support system to ensure the pipe does not roll over and block air flow may also be needed. Unlike the diffuser, this system will allow for a continuous air curtain with no potential gaps. Should a blockage develop within the pipe, a solvent can be pumped through and then the air supply can resume as normal. Although potentially creating a more effective curtain, bubble tubing will need a high pressure to ensure that the bubble supply is the same on both ends. Currently there is only small diameter tubing with a maximum of 1.5 inch OD, which may not provide the needed bubble volume.

OctoAir-10 Industrial Diffuser

The OctoAir-10 Industrial Diffuser is 4 ft in diameter with 100 ft of bubble tubing coiled inside. As this diffuser is a much larger scale, we will get a very large volume of bubbles; and due to the size, may need fewer placed across the cove. However, due to the size, these could be very costly. Although they may create a large bubble supply, they may not be economical for this project.

Porous PVC

Porous PVC is very similar to the bubble tubing; however, it is not a weighted system. A weighted support to hold down this tubing would be needed. This pipe is also rigid, so it cannot conform to the cove bottom. Potential options include having multiple sections that act as individual units off of the compressor or attaching fittings to span the cove. Porous PVC is available in diameters up to 30 inches, which would give options in determining the desired volume for the curtain.

Alum Components

There are two types of alum that can be used in this system: liquid alum and solid alum. Liquid alum will be distributed through a continuous pipe across the cove. This pipe will be placed above the diffusers so that the alum will be carried to the lake surface by the bubbles released from the diffusers.

The Kenco Chemical Injectors were specifically chosen due to many features. These injectors can be oriented in any direction; they can be placed facing out of the pipe to inject alum into the lake. They also have check valves that prevent water from entering the pipe. This is important to avoid water entering the alum pipe, which will react with the alum to form a precipitant that can clog the pipe. These injectors are also more durable because they are able to minimize chemical build-up. Finally, they function under a wide range of pressures and high flow rates. This will allow the alum pipe to be connected to a variable flow pump, in order to regulate the flow of alum with seasonal changes.

Solid alum is available in 40 lb blocks called ChemLogs. These ChemLogs will be held above the diffusers using a bracket system. An advantage of using solid alum is that it is easily released by the movement of the water produced by the diffusers. However, this means that the alum may not be released consistently and there is no way to fluctuate the alum dispersal to account for changes in the lake. Using solid alum reduces the equipment needed; as dispensing liquid alum requires piping, injectors and a pump. This means that a solid alum system will have a lower initial cost than a liquid alum system. However, solid alum is also more expensive than liquid alum and must be replaced often. This would lead to increased operating costs using a solid alum system.

Layouts

The current water treatment intake station is located in the cove where this system will be placed. Three possible layouts of this system within the cove were developed. In each of these layouts, the diffuser discs can be exchanged for bubble tubing if that is chosen as the aeration component and solid alum if that is the chosen type of alum used.

The first layout (Figure 4) consists of two staggered rows of diffuser discs with an alum pipe above at the entrance to the cove. The staggering method allows for better mixing which increases the alum contact with phosphorous and prevents phosphorous from passing through the system untreated. After further discussion with PVIA, it was recommended that the system should be moved closer to the water intake station due to power availability and to potentially use the compressor located at the station to power the diffusers.

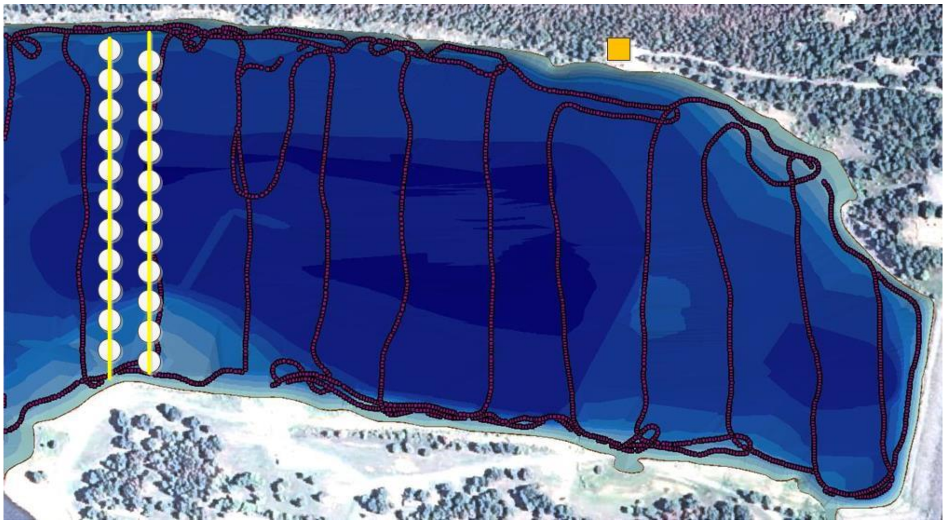


Figure 4. Layout 1

The second layout (Figure 5) option is comprised of a primary and secondary treatment system. The primary system consists of a single row of diffuser discs across the entrance to the cove. The secondary system also contains a single row of diffusers but is located closer to the water intake station. This layout allows the water to be treated as it enters the cove and treated again as it approached the intake. This also provides a back-up system. In the case that one system failed, the water would still be treated by the other system.

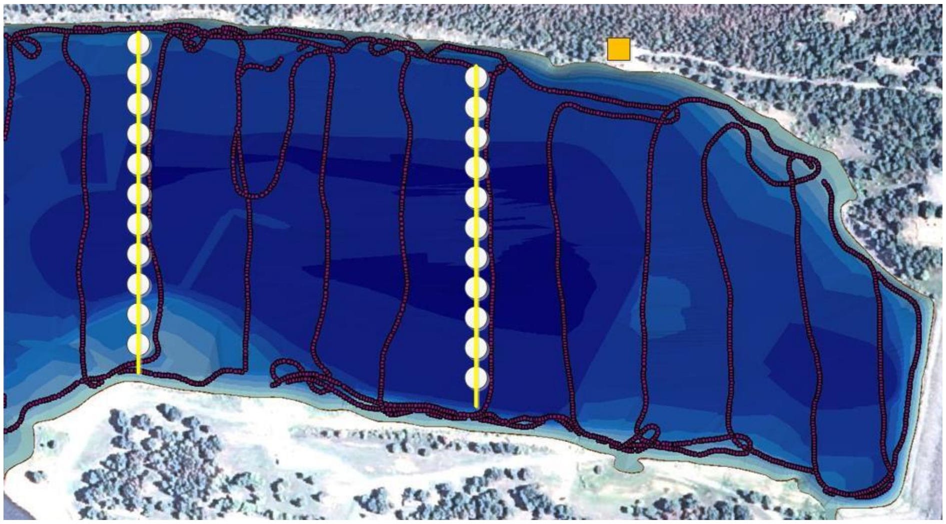


Figure 5. Layout 2

The third layout (Figure 6) is similar to the second in that it has a primary and secondary system, but the secondary system is located directly around the water intake station in a semicircle design. The main consideration with this layout is that the volume of water inside the secondary system must be larger than the maximum volume of water extracted by the intake station, in order to avoid catching alum flocculant in the intake pipe. These layouts will be reevaluated when the final design is determined.

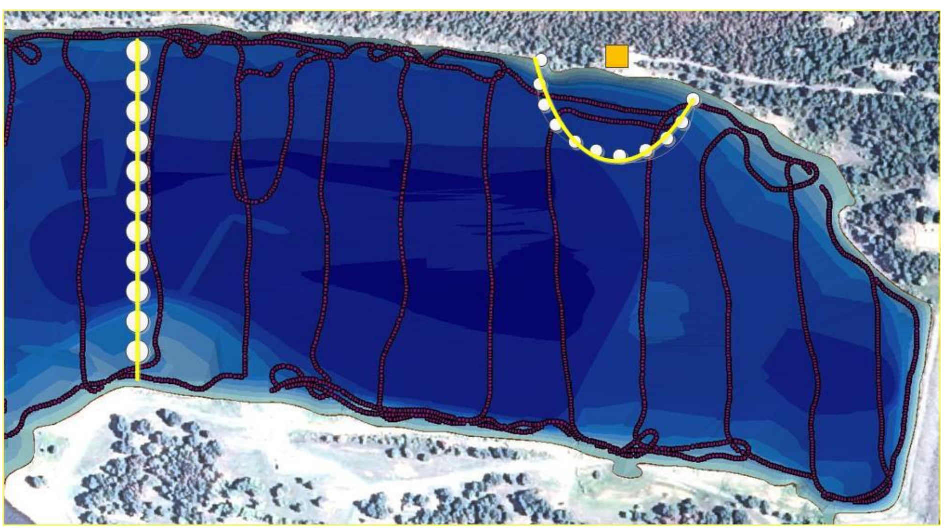


Figure 6. Layout 3

Patent

Patent No. 7,074,328 was found to be similar to this system. It describes a bubble curtain that was created by attaching diffusers in a branching method and using pressure regulators to ensure an even pressure distribution to each diffuser. However, this patent does not include the alum components present in this system. This could allow for the final design and process used in this system to be patented.

Next Steps

The spring semester will be spent building and testing different design components for comparison. The first step is to purchase or construct the various diffuser systems that have been considered. The PVIA has provided some disc diffusers to work with; however, the other systems will need to be purchased. Wayne Kiner in the BAE lab has offered to help design and construct a disc diffuser system that will connect in series with regulators, should that be the desired design. The next step is to find testing facilities to test the diffusers and/or the alum dispersion. Lastly, alum disturbs the lake chemistry, so calculations need to be done to assure that the lake remains neutral.

The facility that will be used to test the diffusers will need to be at least 15 feet deep, in order to simulate the depth of the lake across the cove. We are looking to use a large pool or empty reservoir in the Stillwater area to meet this testing constraint. While testing the diffusers, bubble movement, velocity, and mixing will be observed. The bubbles need to be able to reach the surface of the water; the mixing needs to be consistent, so that the maximum amount of phosphorus comes in contact with the alum. In addition, a small compressor or blower will need to be donated or purchased to use for the implementation this pilot test.

The alum will need to be tested in a different facility because the flocculant would be difficult clean out of a pool. We also need to be able to visualize the flocculant settling. Currently, the best solution for this problem is building a large Plexiglas box for testing. About thirty gallons of raw water was collected from Lake Wister; it would be possible to use this water for alum testing within the test box. Ultimately, we would like to be able to see the flocculant settling, in order to calculate the settling velocity and determine the sludge production.

Final Steps

An analysis of the units and power requirements for each potential design will need to be carried out to determine if the current compressor will meet the needs. If not, research will need to be carried out to find a more appropriate power source. There is potential to use a blower instead, as it requires less power.

A general treatment schedule will be created to reflect the annual changes in lake conditions. Continuous monitoring of the lake conditions can allow for changes in alum flow rate and potential buffer addition to be made as necessary.

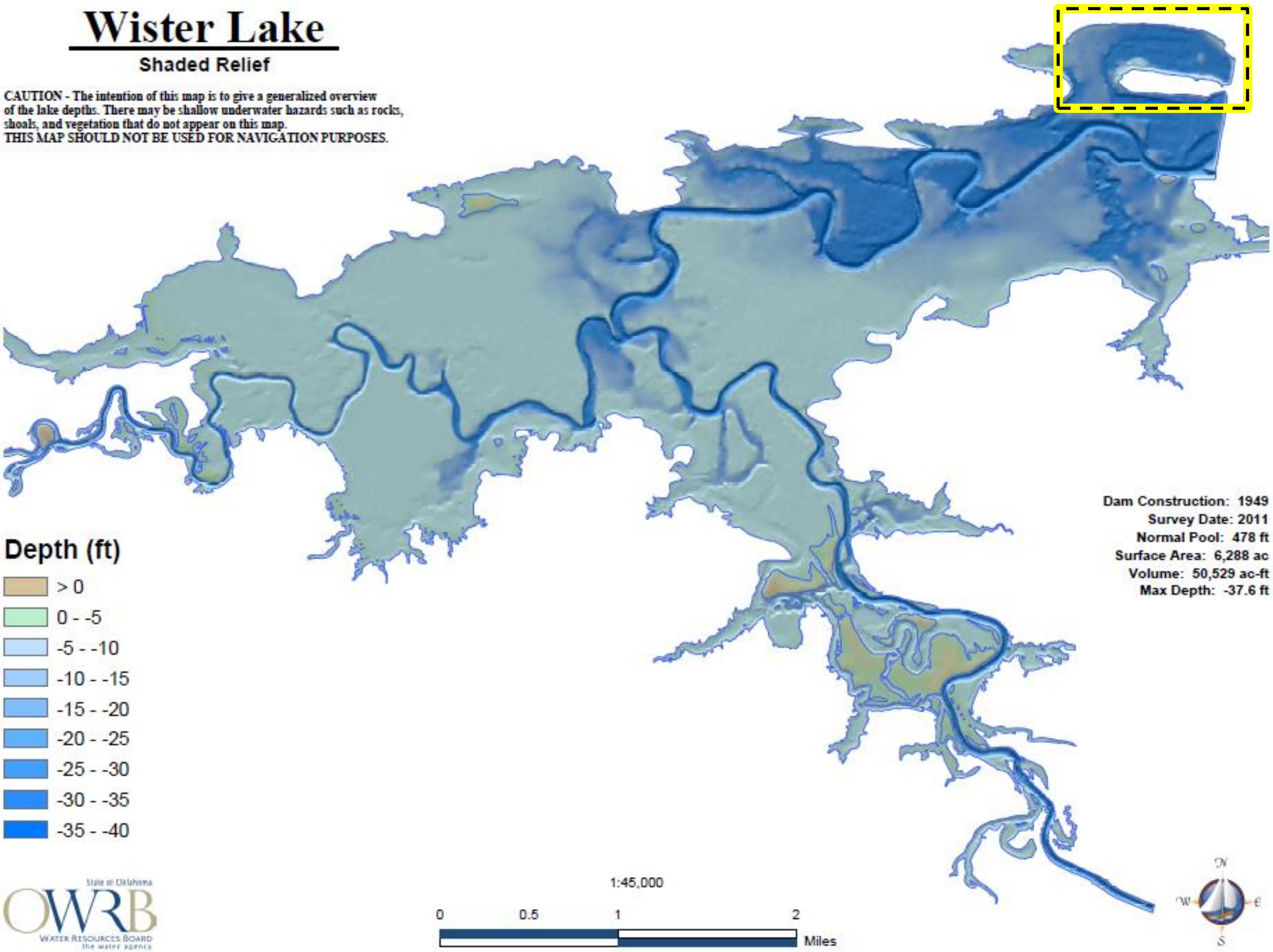
A cost-benefit analysis of each design will be carried out and proposed to PVIA to show how each differs in potential effectiveness in reducing phosphorus compared to the cost of products, running, and potential maintenance. Designs may require regulatory permits for installation and running. Research into these will be carried out and passed on to PVIA to ensure they know all necessary aspects of each design.

PVIA Lake Wister Water Treatment

Shelyn Gehle, Whitney Lisenbee, Rebecca Purvis, and Maggie Wyatt

Background on PVIA

- Poteau Valley Improvement Authority (PVIA) Water Treatment Plant
- Treats and distributes water to about 80% of LeFlore County, OK
- Water source: Lake Wister
- Pulls on average 6 million gallons of water/day


Wister Lake
Shaded Relief
CAUTION - The intention of this map is to give a generalized overview of the lake depths. There may be shallow underwater hazards such as rocks, shoals, and vegetation that do not appear on this map.
THIS MAP SHOULD NOT BE USED FOR NAVIGATION PURPOSES.
Depth (ft)
> 0
0 - -5
-5 - -10
-10 - -15
-15 - -20
-20 - -25
-25 - -30
-30 - -35
-35 - -40
Dam Construction: 1949
Survey Date: 2011
Normal Pool: 478 ft
Surface Area: 6,288 ac
Volume: 50,529 ac-ft
Max Depth: -37.6 ft
1:45,000
0
0.5
1
2
Miles
State of Oklahoma
OWRB
WATER RESOURCES BOARD
the water agency
N
W
E
S

Water Balance

- Quarry Island Cove Volume = 1418 ac-ft

Accumulation = Inputs – Outputs

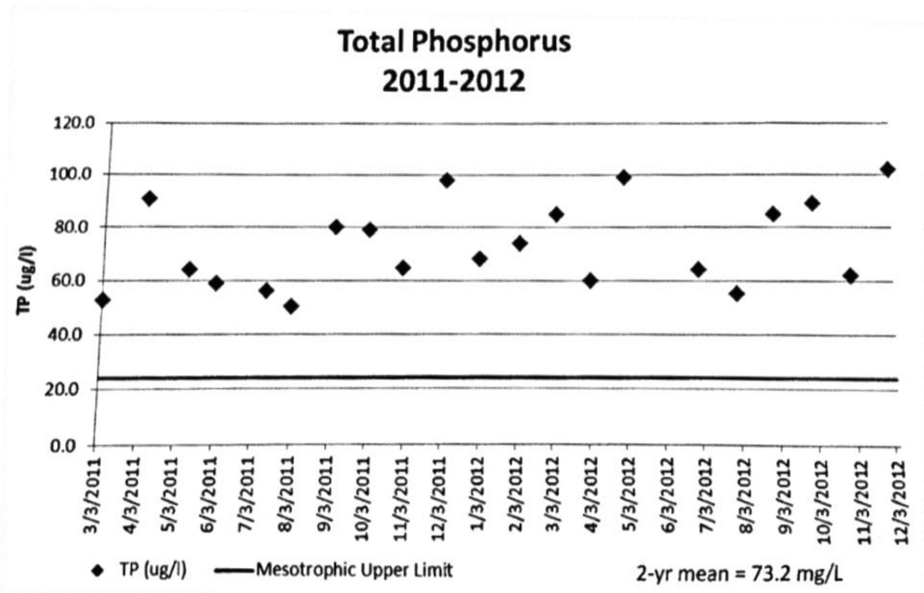
  - assume steady-state

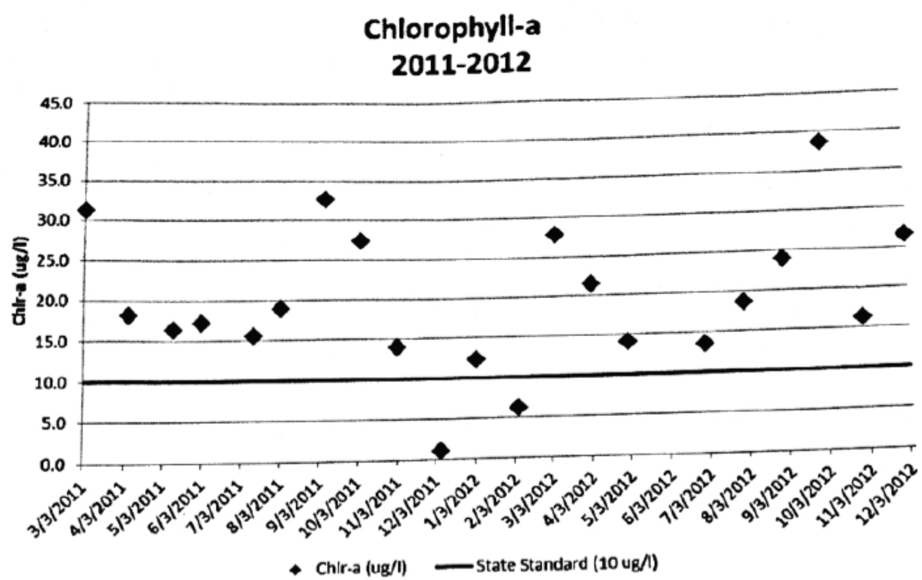
- Inputs:
  - Precipitation = assume 0
  - Water entering cove from lake
- Outputs: 588 ac-ft/month
  - Evapotranspiration = 4ft/yr
  - Pumped out = 6MGD

Current Problems

- High phosphorous and algae levels in the lake
- P is the limiting nutrient for algal growth
- P concentration is indicated by levels of Chlorophyll-A in lake
    - Must not exceed DEQ standards of 0.01 mg/L for Chlorophyll-A

Phosphorous and Chlorophyll-a Levels





Current Problems

- PVIA Treatment Plant has to remove P by adding Alum

- Creates large volumes of "water treatment residual" (sludge) during treatment process
  - Pumped to nearby pasture and spread out
  - 1/12 of labor costs
  - Current procedure subject to change

Alum Treatment

- Aluminum Sulfate [$Al_2(SO_4)_3$]
  - Reacts with phosphorus and creates a precipitant
  - Precipitant settles

- Currently only used in treatment plant
  - Treatment uses 5,000 gallons of Alum/week
  - Alum cost: $1/gallon

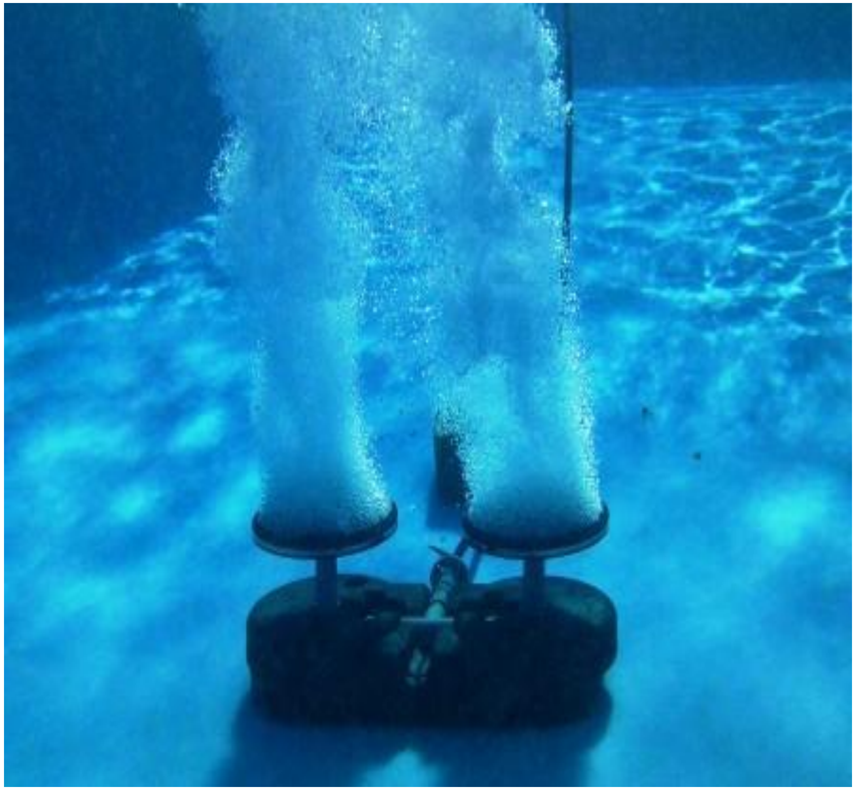
Project Objectives

- Create an Alum Microfloc Curtain
- Allow for continual decrease in P concentration
  - Reduce algae and cyanobacteria levels
  - Reduce Disinfection By-Products (DBP) and toxins in treated outflow
  - Keeping below state regulations
- Develop a treatment usage schedule

Constraints

- ¼ mile cove opening
- Materials must withstand highly corrosive lake
- Compressor must be above floodplain
- Compressor depends on number of running units
- Power availability limited by road access
- Treatment varies by season
- Cannot interfere with cove recreational activities

Diffuser Discs



https://www.outdoorwatersolutions.com/store/dual-disc-rubber-membrane-diffuser-with-base-and-risers-p-248.html

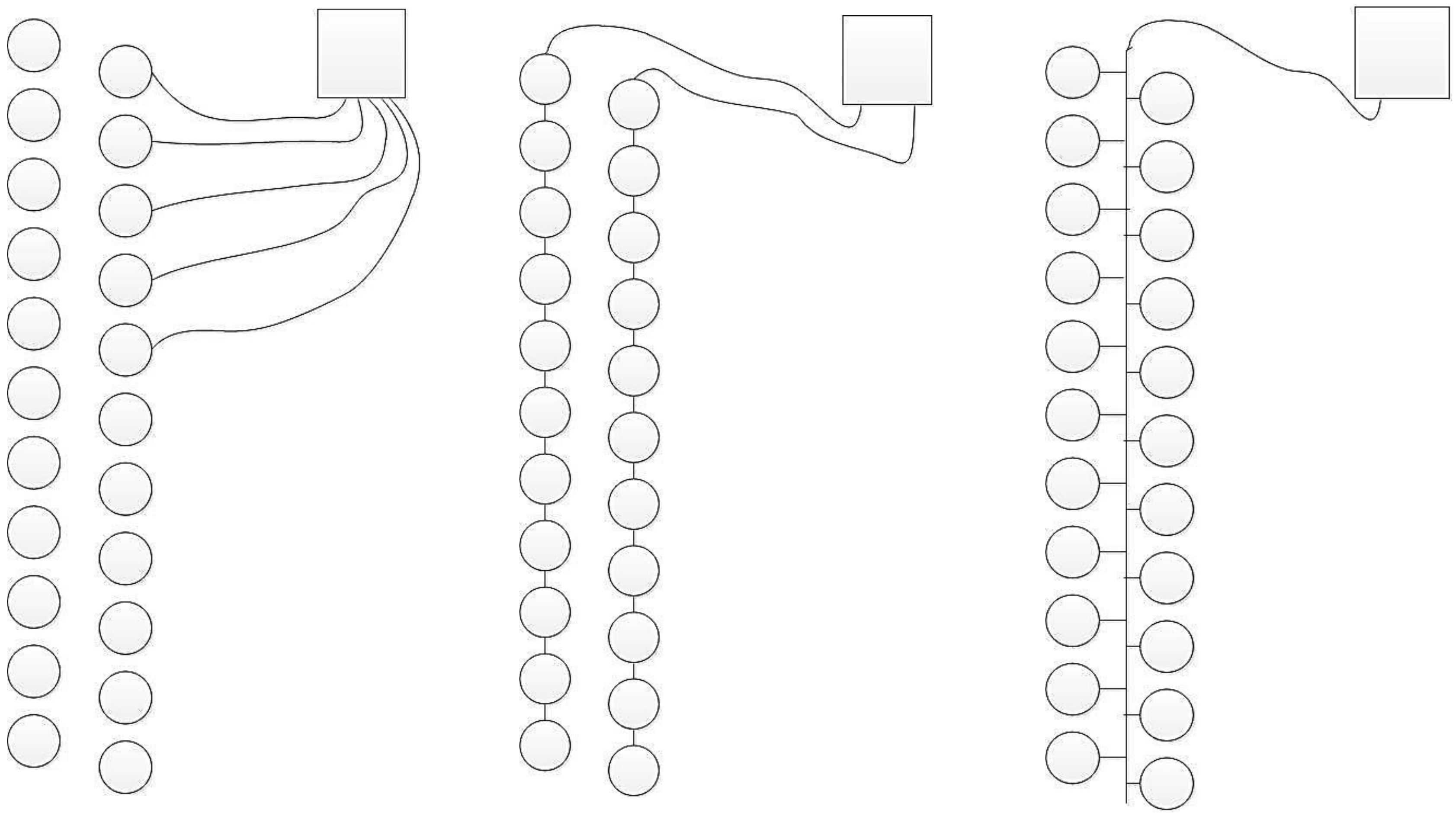
Pros

- Common
- Weighted
- Good mixing
- Familiarity

Cons

- Cannot be in series
- Pressure regulators
- Moderately expensive

Problems with Diffuser Discs



Bubble Tubing

http://www.canadianponds.ca/Bubble-Tubing-linear-industrial-diffuser.aspx

Pros

- Weighted
- Continuous curtain
- Easy installation
- Easy maintenance

Cons

- High Pressure
- Small OD
- Needs supports

Potential Materials

OctoAir-10 Industrial Diffuser

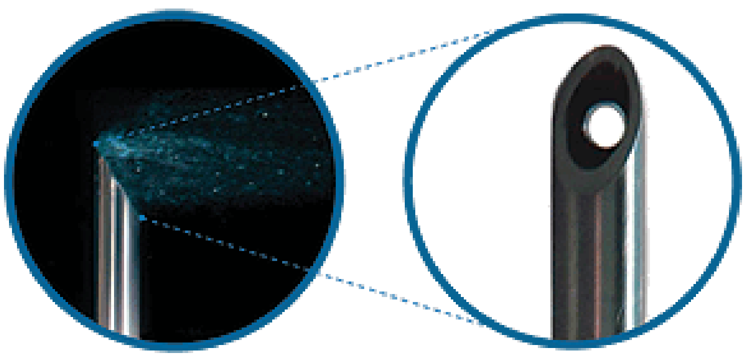
http://www.canadianponds.ca/en/octoair-10-diffuseur-industriel-octoair-2?cc=bubbletub

Porous PVC

http://www.alita.com/diffuser/polyethylene.php

Liquid Alum Release

Kenco Chemical Injectors



http://kenco-eng.com/product-info/chemical-injectors

- Connected to continuous Alum pipe
- Placed above diffusers
  - Oriented in any direction
  - Check valves
  - Minimize chemical build-up
  - Function under wide pressure range
  - High flow rate

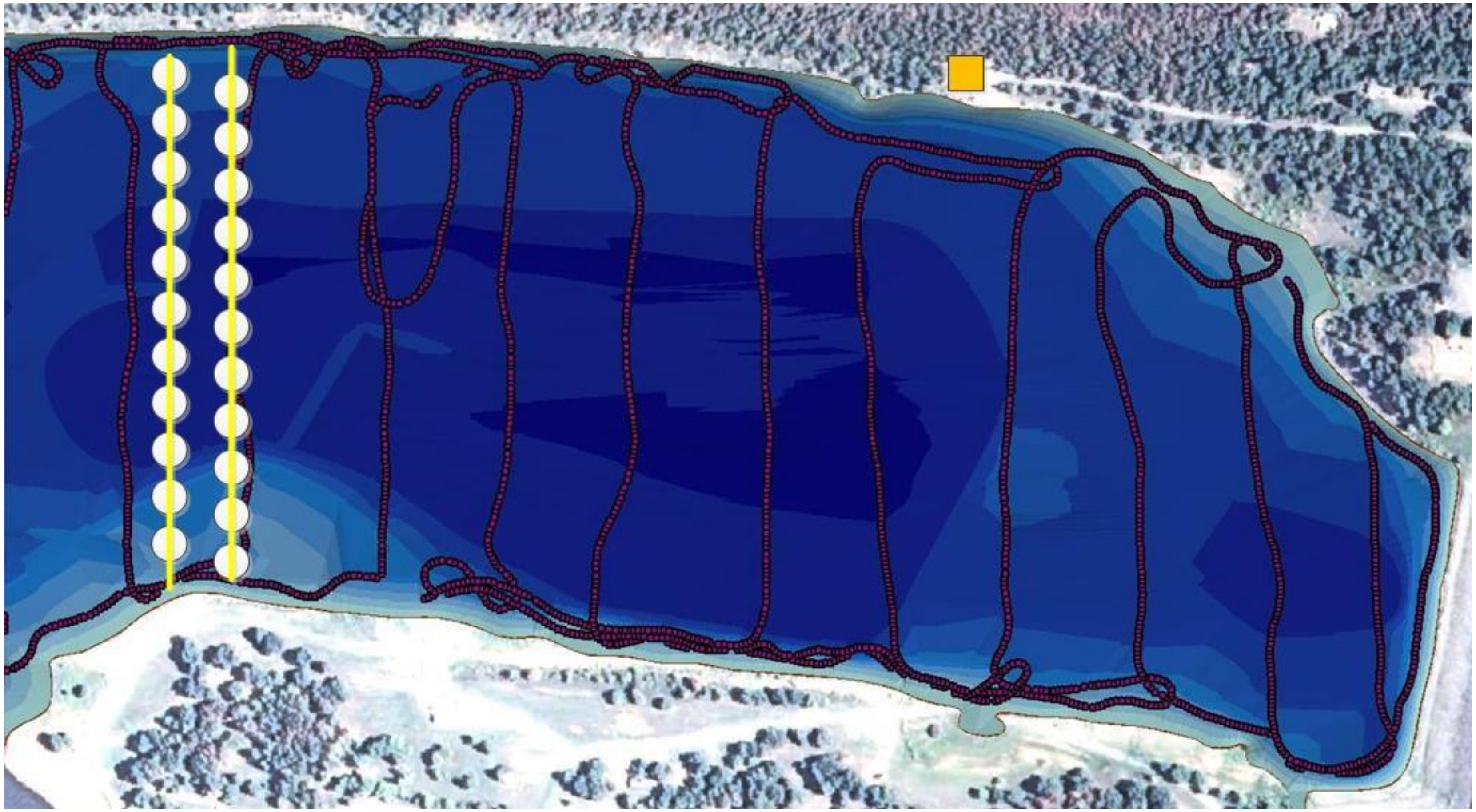
Solid Alum Release

- ChemLog
  - 40 lb blocks
  - Held above diffusers

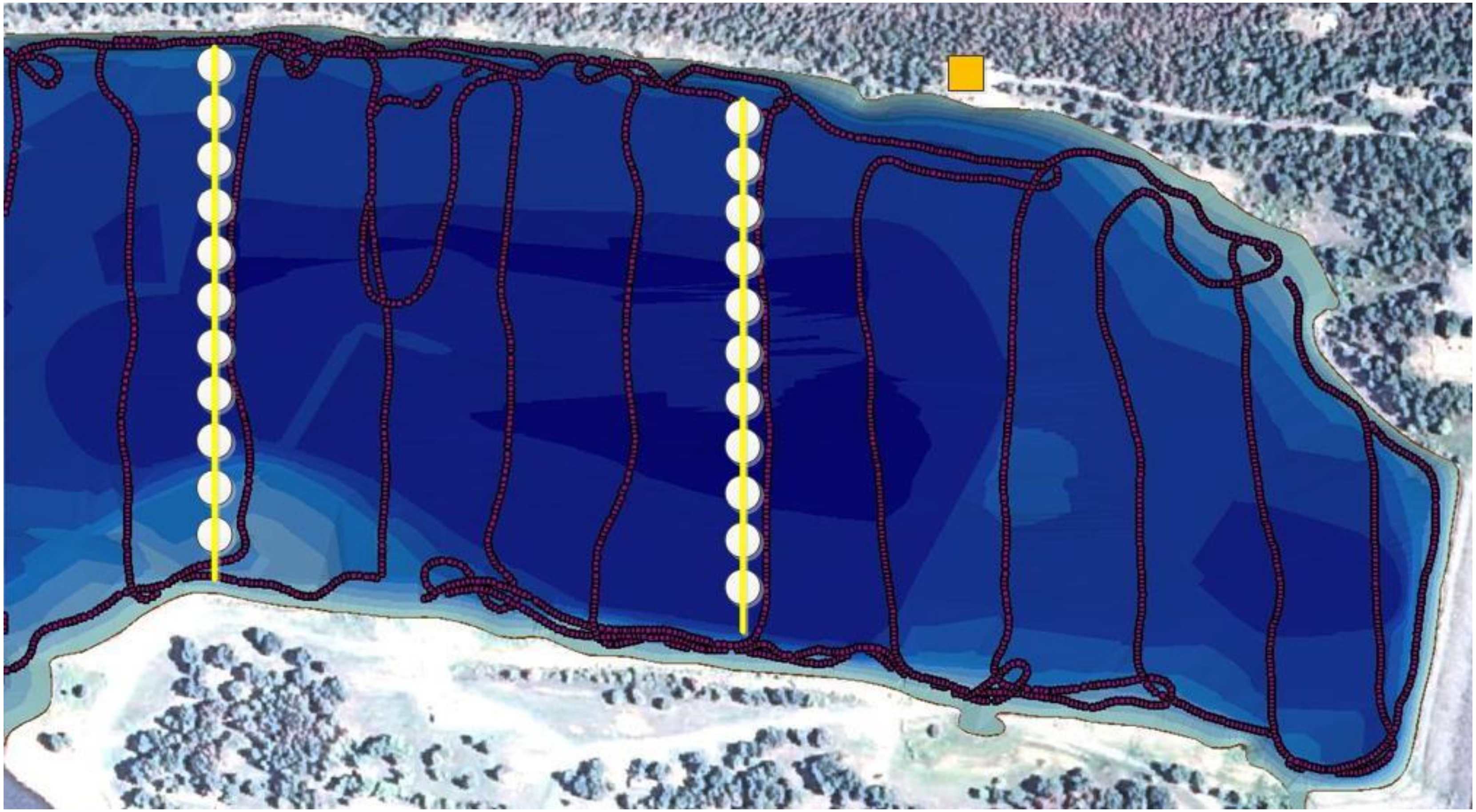
Pros:
  - Easy release
  - Less equipment

Cons:
  - Must replace often
  - Not consistent
  - More expensive

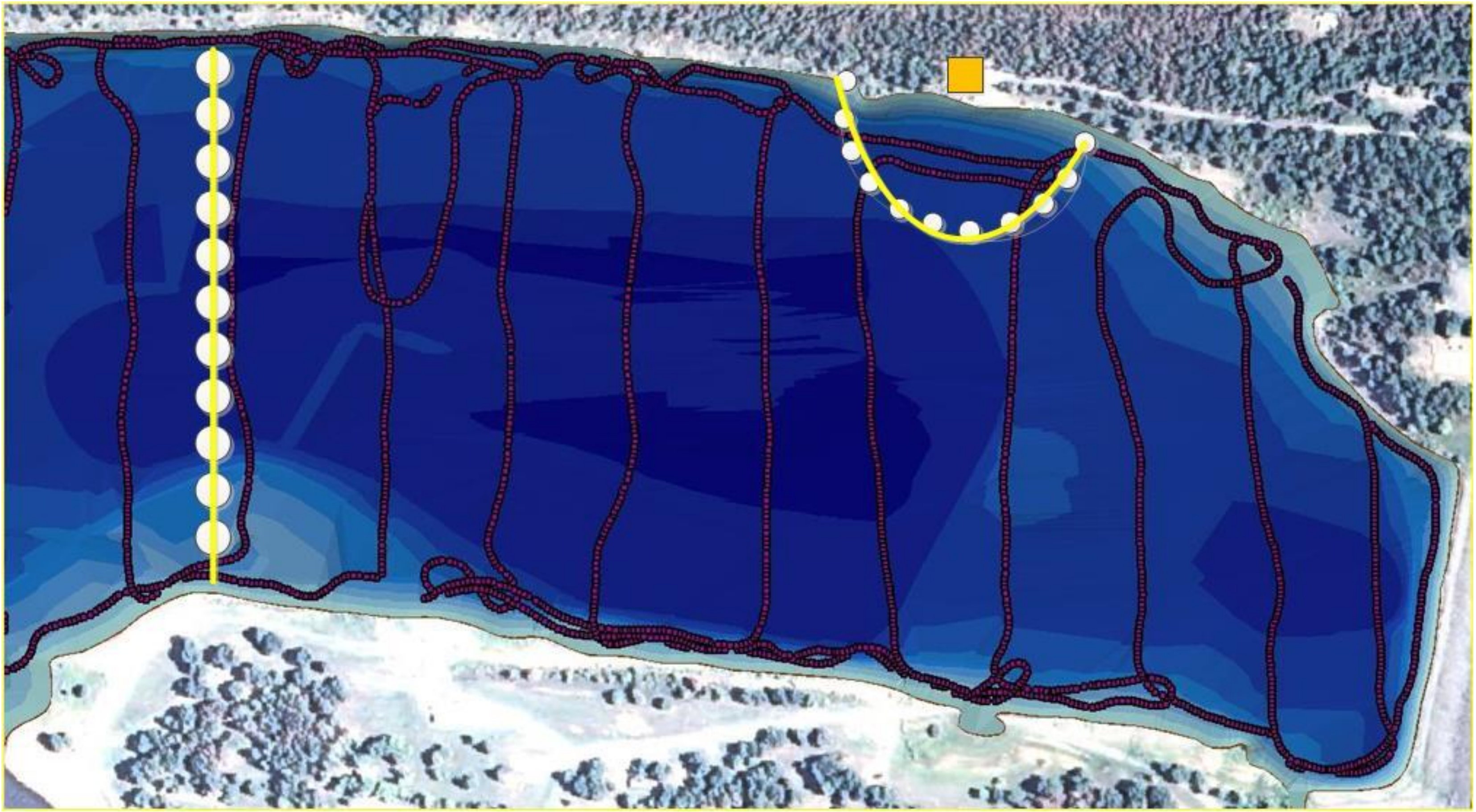
Layout 1



Layout 2



Layout 3



Patents

- Patent No. 7,074,328
  - Connects diffusers in branches using regulators
  - Does not have Alum components
- Potentially patent process and final design

Next Steps

- Find large test facility
- Purchase or construct various diffuser systems
- Test Alum dispersion and effectiveness
- Determine effects on lake chemistry

Testing Procedures - Diffusers

- Test facility:
  - At least 15 ft deep
- Use small compressor/blower
- Implement pilot test system
- Observe:
  - bubble movement
  - velocity
  - mixing

Testing Procedures - Alum

- May need a different facility
- Currently determining best way to observe dispersion
- Mix with raw water samples
  - Determine sludge production
  - Calculate settling velocity

Alum Chemistry

- Low alkalinity and pH creates a corrosive lake
  - Alkalinity: avg. 19 mg/L as $CaCO_3$ (range 8-42)
  - pH: 6.5 to 9.5
- Alum reacts with current lake chemistry
  - Reduces alkalinity of lake
  - May need to add lime
- Each reaction affects other reactions
  - Carbonate system analysis

Final Tasks

- Determine compressor/blower requirements
- Treatment usage schedule
- Complete cost-benefit analysis on each design
- Regulatory permits

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- Keith Wright
  - Board Member – PVIA
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Questions?


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