Spring 2015

Utilizing Ultrasonic Technology to Manage Algal Blooms in Lake Rockwell

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Honors Project
5/1/2015

Introduction

Lake Rockwell is the main source of drinking water for the greater Akron area in Northeast Ohio. Lake Rockwell is located in Kent, Ohio and is fed by the Cuyahoga River. The lake functions as a reservoir, containing a dam at the south end where the lake feeds into the Akron Water Treatment Plant. The Cuyahoga River then continues to flow past the dam. One of the greatest issues threatening the water quality and safety of Lake Rockwell is algae blooms.

The algae species most affecting Lake Rockwell is cyanobacteria. Cyanobacteria, or blue-green algae, rely on photosynthesis for energy production and growth. Cyanobacteria release toxins in the water, many of which cannot be removed by conventional water treatment processes in a cost-efficient manner [5]. In order to remove these toxins before they are released into the drinking water supply, a time and money consuming filtering process must occur. Even after filtering, some of the algae and toxins remain in the water.

The easiest way to prevent the cyanobacteria toxins from entering the drinking water is to eliminate the algae problem in Lake Rockwell, before it enters the water treatment plant. The proposed solution for this problem is an ultrasonic algae control system. This system monitors different water quality parameters while also working to prevent the growth of algae. The system is made up of sensors (master buoys) and transmitters (slave buoys) that are placed at various locations throughout the lake. The transmitters emit an ultrasonic frequency, which disrupt the algae and cause them to sink in the water. This prevents the algae cells from engaging in photosynthesis, so the algae dies [1]. This paper will explore the effectiveness of ultrasonic algae control in other bodies of water and the application of such a system in Lake Rockwell.

Ultrasonic Algae Control Systems

In order to deal with the algae problem in Lake Rockwell and prevent an occurrence at the Akron Water Treatment Plant, our proposed solution is an ultrasonic algae control system. The system we have chosen to use is manufactured by LG Sonic and consists of master transmitter buoys and slave buoys. The master buoys relay a signal to the slave buoys that tells them to emit the ultrasonic waves. The master buoys are also capable of measuring and logging pH, turbidity (total suspended solids), chlorophyll a (algae), phycocyanin (blue-green algae), dissolved oxygen, and temperature. Based on the readings, the system can then change the vibration pattern to address the specific issues in the water [2]. Each one of the buoys is equipped with solar panels, so they require no additional energy input.

When the buoys emit the ultrasonic waves, they disrupt the structure of the algae cells. The waves cause the gas vesicles in the cells to rupture, making the entire cell sink to the bottom of the water. A comparison of the algae cells before and after they are subjected to vibration can be found in the picture below.

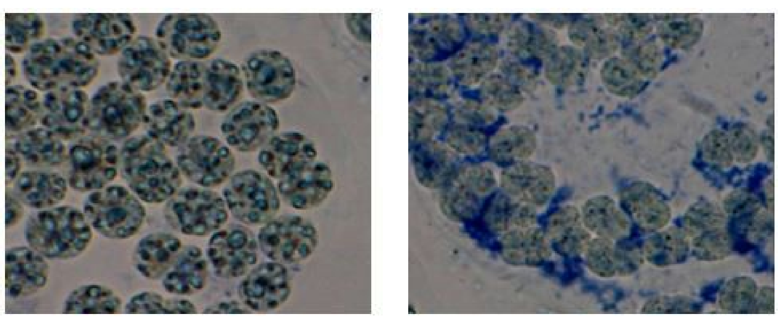

Figure 1: The gas vesicles in algae cells (highlighted in blue) before and after ultrasonic treatment. The vesicles are intact on the left, before being subjected to vibrations. The image on the right shows the cells after treatment, with the gas vesicles destroyed [2].

An additional positive point: the vibrations emitted by the buoy system are not harmful to any other aquatic life. They all lie within the ultrasonic range, so they are inaudible and not disruptive to animals or other plant life [2]. The vibrations do not destroy the cell organelles in more complex plant species. Cyanobacteria release toxins when they decompose [4]. Because the algae cells die gradually, there is not a large release of toxins into the water. The algae also does not reproduce as quickly as before ultrasonic treatment, so the concentration of potential toxins introduced to the water is minimized [1]. With less algae growth, healthy bacteria are able to consume nutrients in the water, controlling phosphorous and nitrate levels. The combination of algae death and healthy bacterial growth gradually improves the overall quality of the water.

Relevant Case Study

The effectiveness of ultrasonic algae control has been proven in a study at Canoe Brook Reservoir in New Jersey, a lake similar in size and depth to Lake Rockwell [3]. The Canoe Brook Reservoir study used an ultrasonic system in May through November of 2013 to treat periodic algae blooms that were affecting the taste and odor of the water in nearby Short Hills, NJ. The problem at Canoe Brook Reservoir is very similar to the one at Lake Rockwell because the algae problem was periodic. Algae is not found in high concentrations at all times of the year, so the treatment method had to be one that was adjustable. One of the main species of algae targeted was also cyanobacteria. At the conclusion of the study, Canoe Brook Reservoir experienced significantly reduced taste and odor compounds and algae levels coming into the water treatment plant [3]. As a result, less alum was needed to treat the water. A map of the chlorophyll levels in Canoe Brook Reservoir, both pre- and post-treatment can be seen below.

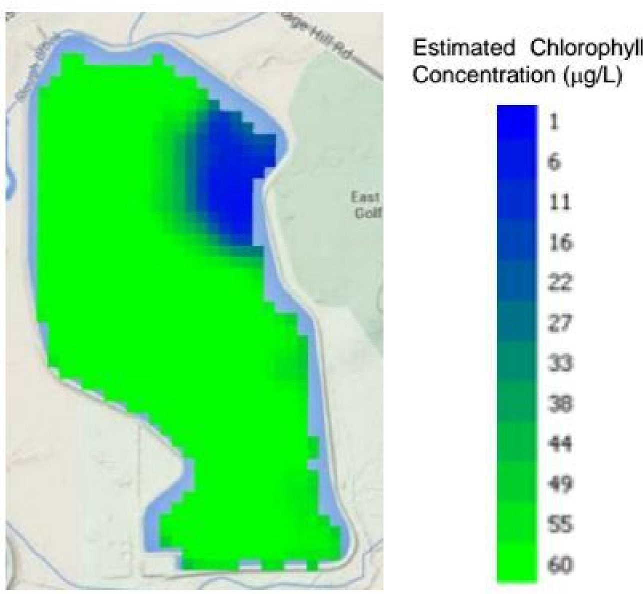

Figure 2: Chlorophyll concentrations in Canoe Brook Reservoir in August 2013, before the ultrasonic treatment system was initiated [3].

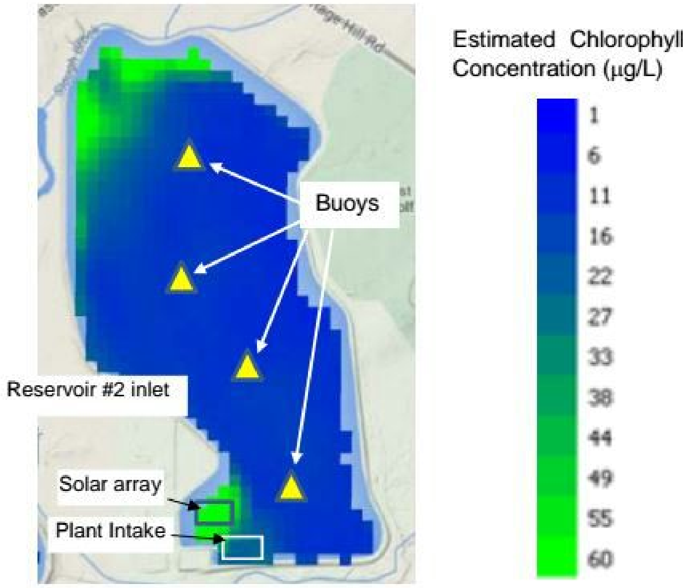

Figure 3: Chlorophyll concentrations in Canoe Brook Reservoir in August 2014, after the ultrasonic treatment system had been utilized for one season [3].

Implementation of System and Success Rates

According to LG Sonic's specifications, the effective radius of coverage for each buoy is 250 meters [2]. This means that the total area that can be covered by any one buoy is 196,350 m^2. In order to accurately calculate the total area of Lake Rockwell, satellite images were used in addition to an area calculator. The area calculator syncs with the data in Google Maps and allows the user to create a free form shape layered onto the map to determine the desired area. The following figure developed from the web-based software showcases the shape used to estimate the area of Lake Rockwell.

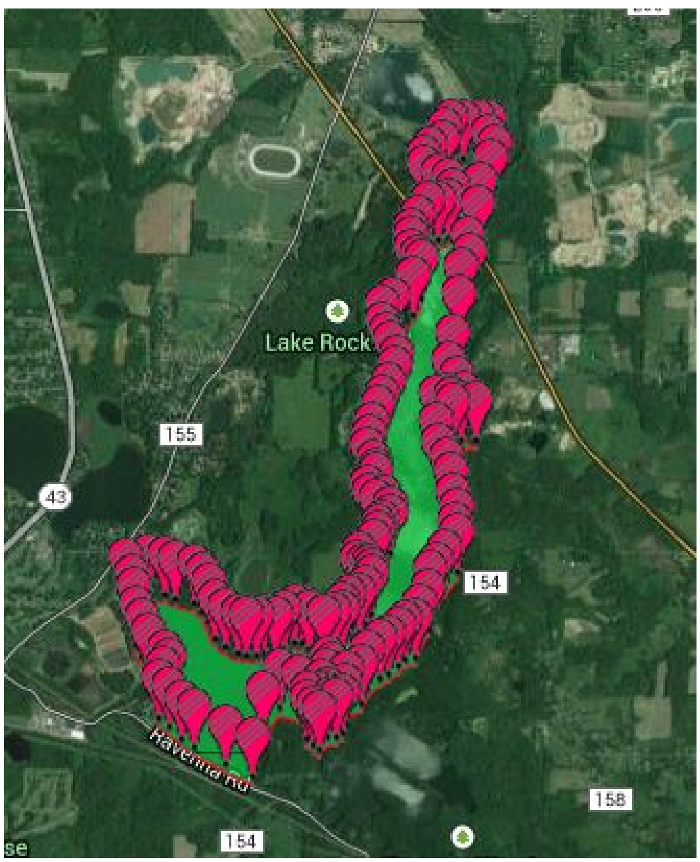

Figure 4: Area of Lake Rockwell with the data points used by the area calculator

The software calculated the area of the lake to be 2,534,212 m^2. Dividing the area of Lake Rockwell by the area of coverage of the buoys gave an estimate of how many buoys it would take to have complete coverage.

This initial estimation assumes that the lake has no area lacking coverage between buoys, as well as no coverage extending into the surrounding landscape. Because Lake Rockwell is not uniformly shaped, this assumption does not necessarily hold true. A more exact calculation is needed to ensure there are zero gaps in ultrasonic coverage, and also to delete any superfluous buoys.

Utilizing the area of coverage of each buoy and the specifications for the LG Sonic System, a layout of the proposed ultrasonic algae control system is shown below.

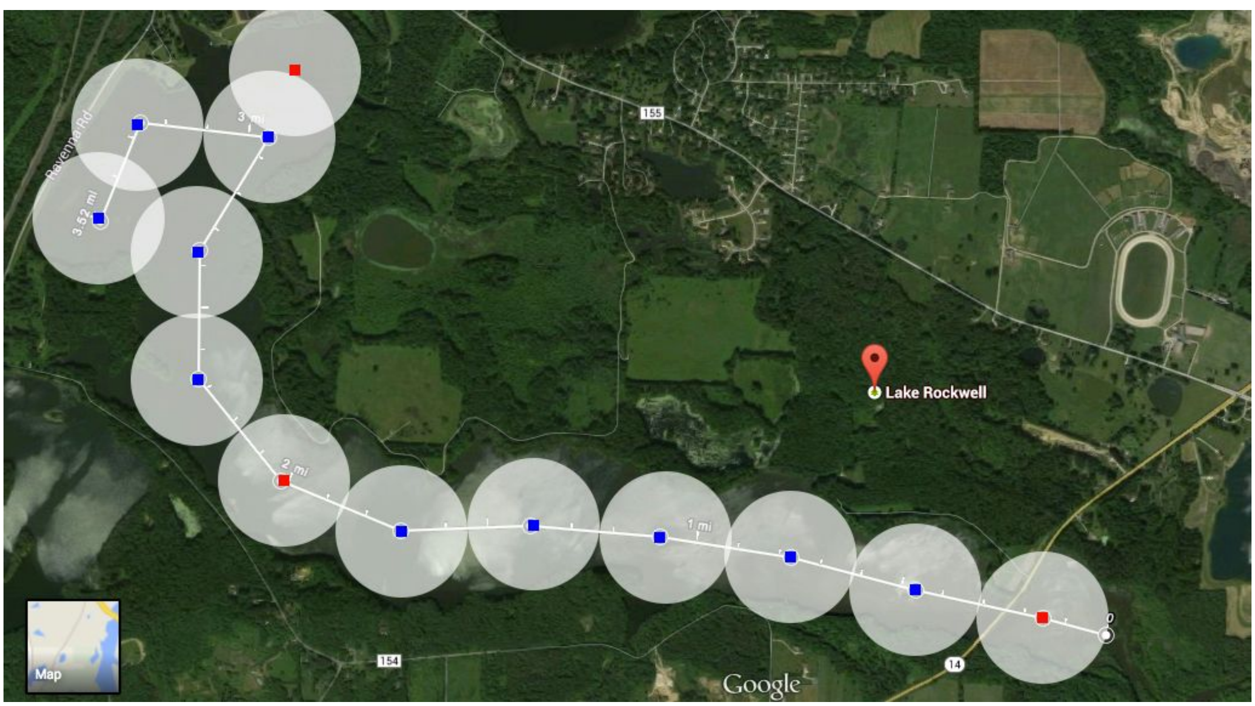

Figure 5: Locations of the master buoys, shown in red, and the slave buoys, shown in blue. The white circle shows the coverage area for each individual buoy.

Each circle in the figure represents the coverage area one single buoy. The buoys were placed 500 meters apart from each other (the sum of two radii). This placement brings the total number of buoys to thirteen.

The master buoys include sensors for blue-green algae, green algae, dissolved oxygen, turbidity, temperature, and pH level [2]. As mentioned before, these readings are relayed to a computer and can be used to adjust the frequency of the vibrations emitted from the buoys. Currently, samples are periodically taken and tested at various locations throughout the lake for all of the water quality measures previously listed. The current testing program has sampling occur at both ends of the lake and near the middle, where the bend is located. In order to keep a similar sampling pattern, placing three master buoys in those locations would be necessary maintain the current water quality testing program. A revised placement of buoys was considered, but the success rate is increased and the cost estimate is decreased with the three master buoy system and placement shown above.

In order to fully explore the tradeoffs of less buoys, and therefore less ultrasonic coverage, and the anticipated success rate, multiple combinations of slave and master buoys were considered. Two different measures were used to determine the overall success of the system: the probability of full coverage of the lake and the probability of 100% algae treatment and elimination in the lake. The probability of full coverage of the lake changes because the lake is not uniform in shape. As the number of buoys are varied, where and how much coverage there is on the lake changes depending on whether it was a master or slave buoy that was changed. This probability has the greatest effect on the overall cost of the system over a set period of years.

An equation was developed that links the number of buoys to the overall success rate of the system. Because the master buoys are outfitted with sensors that relay water quality parameters that can also be used to predict algal events, they were weighted more in the success equation than the slave buoys. In addition to this assumption, it was also assumed that, based on the probability of full coverage, that the maximum amount of buoys that the system would utilize would be 14. If the system used more than 14 buoys, then there would be an unnecessary overlap in the coverage area that would be inefficient for the system. As the number of master buoys and slave buoys were varied, the overall probability of success of the system increased. At a certain point, however, the effectiveness of adding another buoy to the system began to plateau. This is due to the assumption mentioned before, that the system becomes inefficient once there are more than 14 buoys (with any combination of masters and slaves) in the lake.

(Eq. 1)

(Eq.2)

Equation 1 shows the probability full coverage in the lake. *M* and *C* represent the number of master and slave buoys, respectively. Using the total area of the lake and dividing it by the total coverage of one buoy, it is determined that each buoy is capable of covering 7.75% of the surface area of the lake. Because Lake Rockwell is not uniformly shaped and coverage area of each buoy extends in a circle, it is determined that a maximum of 85% of the lake can be covered without overlap in coverage area of the buoys.

The total success rate of the system is represented as a piecewise function, with the upper limit of success at 80% based on a system that consists of 14 or more buoys. This is based off of the probability of full coverage previously determined. The second part of the equation weights the master buoys slightly more than the slave buoys because of their ability to detect different algae indicators with the sensors that each one has installed on its body. A graphical representation of the probability of full coverage and the overall success rate can be seen below.

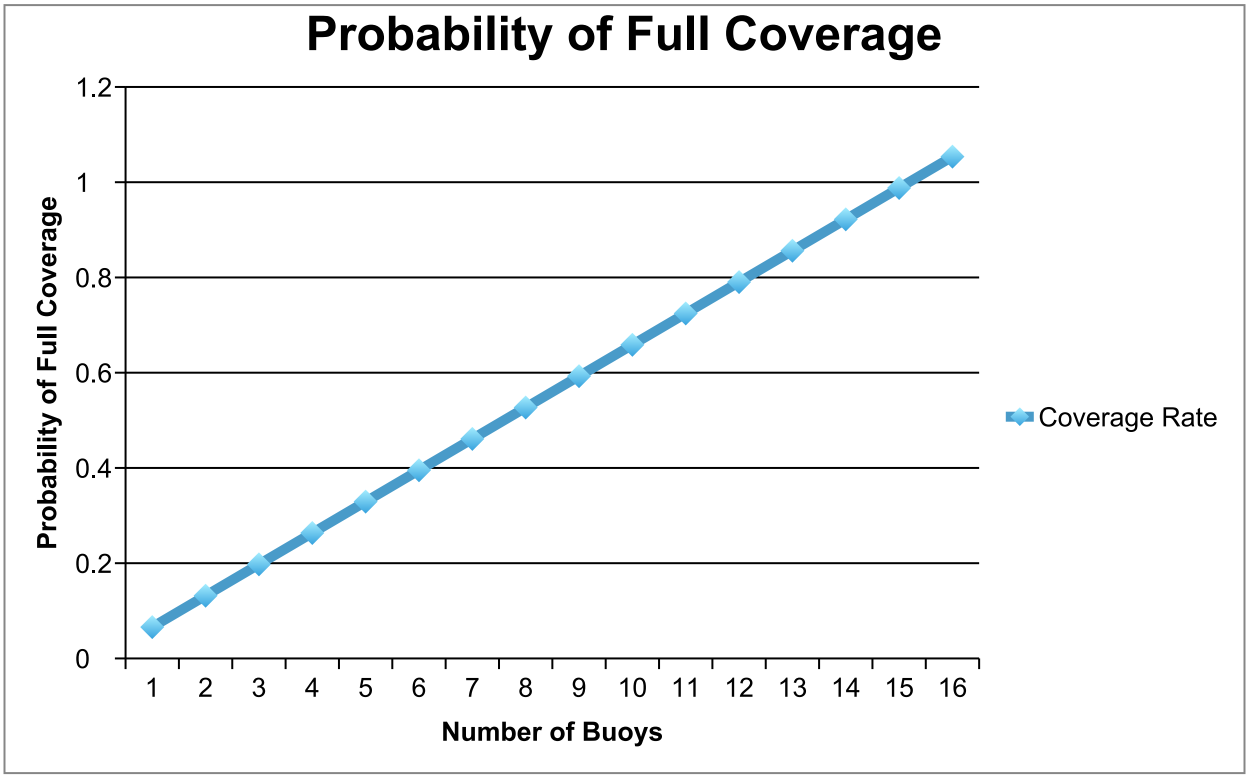

Figure 6: As seen by the graph above, once the number of buoys approaches fourteen, the probability of full coverage approaches 100%. Using more than fourteen buoys in the system starts to become inefficient.

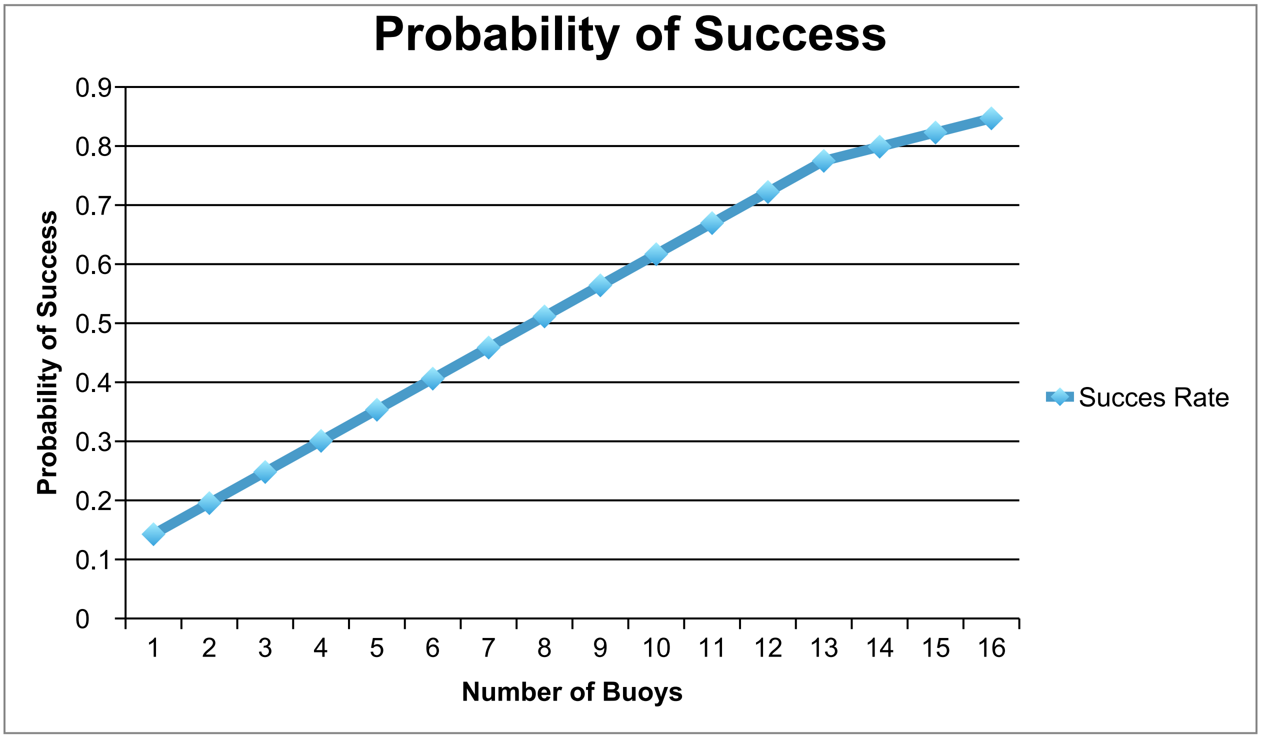

Figure 7: At a number of thirteen buoys, the probability of success of the system begins to plateau.

As shown by Figure 7, the success of the system does not continue to increase at the same rate after thirteen buoys. In combination with the probability of full coverage that was determined and shown in Figure 6, it is determined that the most efficient number of buoys is thirteen. This supports the conclusion the results that were initially determined and discussed earlier in the paper. After varying the combinations of master slave buoys within the range of thirteen total buoys, it is determined that the greatest success rate is seen when there are three master buoys and ten slave buoys. The probability of success of the system with this combination is approximately 68.9% within the first five years.

In order to fully explore the probability of success of the system, we also varied the effective radius of each buoy. The working radius of the system is said to be 250m [2]. However, this 250 meters does not take into account varying water conditions. If the water is more turbulent or there are other obstructions in the water, the working radius may be decreased. A working radius of 200 meters was also considered. With this changed radius, the probability of success is much lower and the amount of buoys for effective coverage is far higher. Due to this, we decided to use the original layout, assuming a radius of 250 meters. The comparison of the probability of success for the two different radii can be seen below.

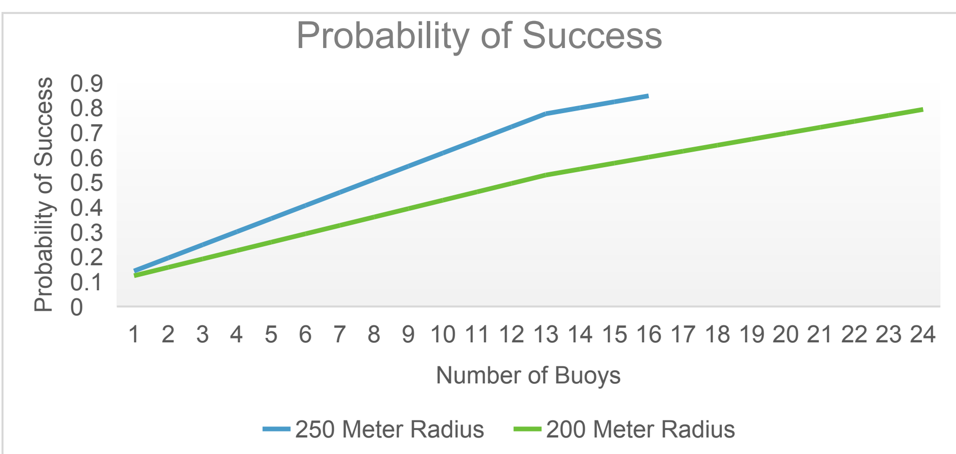

Figure 8: The probability of success for the two varying radii can be seen above.

Cost of the System

To estimate the total cost of implementing the system, the unit cost of multiple combinations of master and slave buoys, in addition to maintenance and potential replacement costs were balanced together. Total cost was determined using the LG Sonic system and the prices given by that manufacturer. The cost of a master buoy is $35,000 while the cost of a slave buoy is $25,310 [2]. The total cost to the project could then easily be discovered by utilizing the following equation:

The total cost of purchasing the buoys comes to $358,100.

This yearly estimate would equal the amount of time the buoys would last divided by the total cost of putting the buoys in service. It must also include any maintenance cost per year the buoys incur. It was found that each buoy, on average, had maintenance fees totaling $300 per year [2]. The equation used to find the total cost per year was developed by the group and is listed below.

As an example, using three master buoys, ten slaves, and a five-year in-service use for the buoys we can discover our yearly cost:

Ultrasonic algae control is a new technology that has only been available on the market for a short time. Because of this, the life of a single buoy or system has not been determined. In order to account for the lack of information on the life cycle of the system, multiple values for the cost per year have been calculated. The products from LG Sonic have at least a two year warranty, so the costs per year assume that the hardware and software of the system will last at least that long. The variability in the cost per year is shown in the table below. This varying cost also takes into the account the probability of success for the system that was earlier discussed.

Table 1: The varying cost per year is shown, depending on the amount of time the buoys stay in service. These costs also include a basic interest rate.

In-Service Use (yrs)	Cost per year ($)	Total Cost ($)
2	$192,829.30	$385,658.60
3	$133,251.27	$399,753.80
4	$103,514.90	$414,059.60
5	$85,715.20	$428,576.00
6	$73,883.83	$443,303.00
7	$65,462.94	$458,240.60
8	$59,173.60	$473,388.80
9	$54,305.29	$488,747.60
10	$50,431.70	$504,317.00

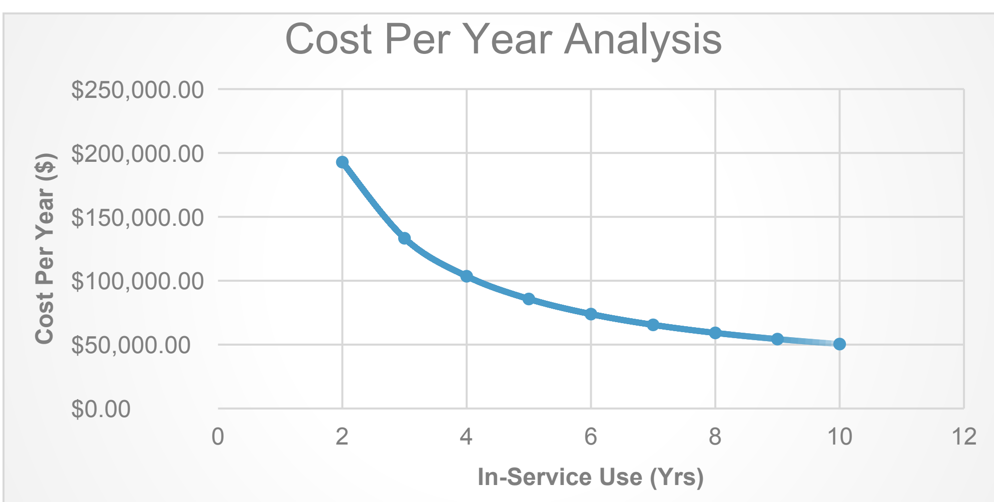

Figure 9: A graphical representation of the cost per year is shown above.

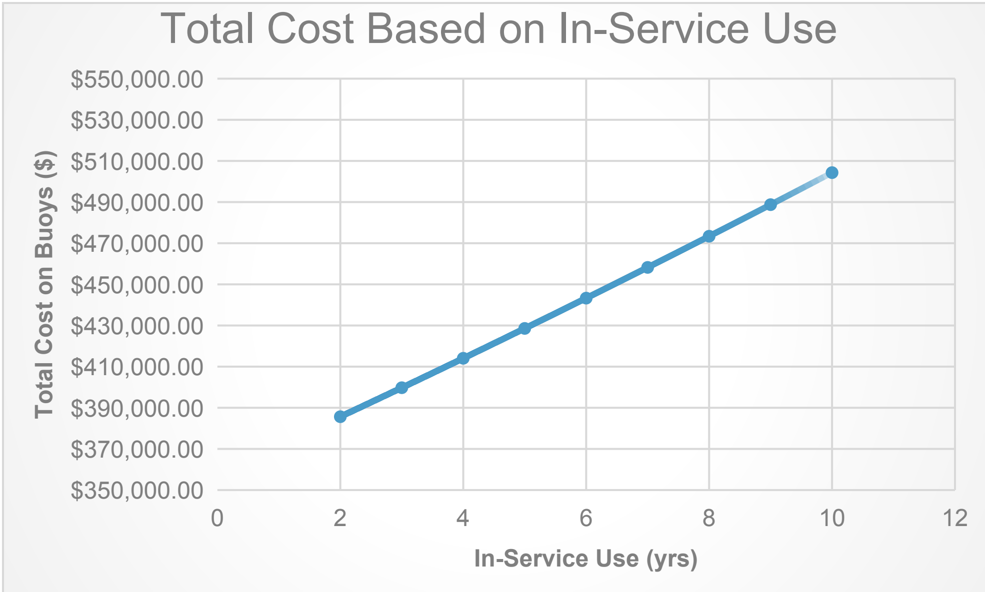

Figure 10: A graphical representation of the total cost of the system, based on the amount of time the buoys are in service is shown above.

In the Canoe Brook Reservoir study, the total algae control and monitoring cost for the water treatment plant was $85,000 per year. Using similar calculations for cost per year of the system, they determined that it would take approximately 1.8 years for a payback on the system to occur [3]. Canoe Brook Reservoir and Lake Rockwell are both sources of drinking water and have similar algae control problems, both targeted at cyanobacteria. The treatment processes in both locations are the same. Based on this, it is assumed that the payback of an LG Sonic system installed in Lake Rockwell would also be two years.

Conclusion

Ultrasonic algae control has been proven to be an effective method of improving water quality. The ultrasonic system that has been developed for Lake Rockwell will not only reduce the concentration of algae blooms in the lake, but also the toxins entering the City of Akron Water Treatment Plant. This will eliminate the additional cost to treat the water with alternatives, such as alum and copper sulfate, and improve the efficiency of the filters and backwash program. The one-time cost of implementing the system and minimal yearly maintenance costs will benefit the taxpayers and increase the overall efficiency of the treatment plant. Utilizing the LG Sonic product line will create a healthier ecosystem in the lake and make the water quality monitoring program easier for the City of Akron. The ultrasonic system in Lake Rockwell will provide lasting results and make widespread algae problems a thing of the past.

Works Cited

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