Compromised Water Quality at Milford Lake and Potential Remediation Strategies

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Introduction

Milford Lake, located in Wakefield and Milford, Kansas, provides visitors with a wide range of recreational opportunities both directly on and next to the lake. Visitors come to fish, boat, water ski, tube, swim, kayak, and canoe directly on the water. Visitors also can camp at several sites surrounding the lake including Milford State Park, Acorn Resort, Timber Creek, Wakefield Campgrounds, and various other locations.

Throughout the years, Milford Lake has seen a dangerous rise in toxic algal blooms, resulting in the shutdown of the lake. There are multiple contributors to what is causing these algal blooms, including agricultural runoff, infrastructure, and other human activities causing pollution. With the increase of toxic algal blooms comes harm to visitor experience, recreation-based economy, and health and safety of both humans and animals.

This report looks at how the water quality at Milford Lake has been negatively impacted. The water quality has been affected by the overloading of nutrients in the reservoir by upstream and local sources. Not only are there too many nutrients coming into the lake but the reservoir and dam design capture and prevent sediment that holds these nutrients from being released further downstream. When ideal weather conditions and the overloading of nutrients combine, large algae blooms are likely to occur. Algae use these nutrients for food, which leads to large blooms that impact the lake in multiple ways. Once the algae blooms start to die off in the fall and winter they release harmful toxins and nutrients back into the water and then they are held by the sediment. This recycling of nutrients and the addition of new nutrients lead to the algae blooms at Milford Lake. Milford Lake has experienced algae blooms for multiple years and is monitored by the Kansas Department of Health and Environment. They continually monitor the Lake due to the negative impacts that are associated with the algae blooms. This report looks at how the water quality negatively affects recreation-based economies, visitor experiences, local perspective, health & safety, and wildlife. Potential management strategies are explored due to the wide range of impacts that accompany algae blooms.

Visitor Experience

The visitor experience is negatively impacted when locals and those traveling from far away have a bad experience or their expectations are not met. Those visiting can have negative experiences when the lake is in the midst of a bloom due to the bad smell and impaired aesthetic that blooms cause the water to have. In instances that the lake closes due to microcystin toxin levels being too high, those who come to the lake to recreate will be let down. If their motivation for coming to visit the lake was to go out and recreate, they will be disappointed.

Recreation-Based Economy

Visitors help contribute to local economies by spending their money in those local communities. When lakes are experiencing algal blooms, visitors can still recreate and get in the water if microcystin toxin levels aren’t too high, and the lake remains open. However, even if microcystin toxin levels are low enough to remain open to the public, some visitors still may avoid getting in the water due to the water having a bad odor or looking dirty. This depends on a person's own determination if the lake water is clean enough to swim in. A person's own beliefs on whether the water is or is not clean enough affects their willingness to participate in recreational activities in and around the water. When the water quality does not meet the expectations of visitors and they choose not to recreate, the industries that provide these services don't make any profits. Not only might they choose not to recreate but they may decide to go somewhere else that will meet their expectations.

In an article looking at harmful algae blooms at Lake Erie, scientists found evidence that the blooms negatively affected the surrounding economies. They were able to determine a negative effect on the economy by measuring algae levels and monthly fishing license sales. The data was collected by the Ohio Department of Natural Resources Fishing License and Permit Sales database, then separated by counties. They collected data between 2011 and 2014. Researchers found that "fishing license sales drop between 10% and 13% when algal conditions surpass the World Health Organization's moderate health risk advisory threshold of 20,000 cyanobacteria cells/mL" (Wolf, 2017). When Lake Erie was experiencing harmful algae blooms, there were around 3,600 fewer fishing licenses sold in the surrounding counties. The estimated economic loss from this is approximately $2.25 million to $5.58 million. This shows that the number of cyanobacteria found in Lake Erie has a negative impact on local communities, the economy, and anglers. The reason that fewer licenses were sold may be due to the blooms harming native fish populations, or loss of motivation to fish due to impacted experience. People that go fishing want to catch fish. If the blooms are affecting the fish population, then anglers will be less motivated to go fishing.

In order to determine if there was any evidence of economic loss due to the algal blooms at Milford Lake, we contacted Kyle Hoover. Hoover is the Director at Milford State Park and has first-hand knowledge about the effects that the blooms have on the park. When asked how visitation to the park was affected during times of algal blooms, Hoover stated, "When the lake is in a warning BGA status we definitely notice a decline in the park visitation. We also start to receive more phone calls for cancellations for camping or cabin reservations during this time too." Although this is only the report of one state park director, it shows that surrounding economies around Milford Lake are being affected by the algae blooms. More research should be conducted to determine the magnitude of the impact being made.

Local Perspective

While algae blooms affect those that come to the lake to visit during their stay, people who live in the surrounding area are affected the most. The two towns right by Milford Lake are Wakefield and Milford. These towns are relatively small with few businesses. Most locals have lived there for years and tend to boat and recreate at the lake. Locals use the lake to fish and hunt throughout the year. The lake is the perfect way to escape the heat on a hot summer day. However, locals may not be able to recreate at the lake or even have the desire to go out on the water depending on the status of the lake's algae bloom. When there is an algae bloom, locals are affected by the odor that comes with the blooms and the aesthetic of the lake is destroyed by the green slick that covers the water's surface. There has been little to no study on the perceptions of the locals surrounding Milford Lake. To best understand how they are being affected by the blooms, researchers and lake managers need to meet with local communities.

In 2015 researchers used focus groups to explore the public perceptions of water-related environmental concerns in northwest Ohio. The study was conducted on Ohio residents in Lucas County after a do-not-drink advisory related to a harmful algal bloom in the summer of 2014. There were 93 people included in the sample; the majority of the participants were white females between the ages of 40 and 59. Focus groups used 90-minute sessions each time and were videotaped to be professionally transcribed to maximize data capture and facilitate data analysis. The perception from the public includes themes such as “(1) avoiding the use of tap water due to concerns about water quality, (2) mourning the loss of a precious resource and their childhood recreational activities, (3) believing there are financial impacts associated with water problems, (4) distrusting the actions and decisions of persons in authority, (5) wanting to stop fighting about who is to blame and determine the problem’s real cause, and (6) desiring actions and planning by authorities to prevent future problems” (Ames, 2019). There is a wide range of problems and thoughts brought up by the participants but it shows that the algae blooms were affecting their lives in a negative way. These types of observations would be useful in studying the perceptions of local residents around Milford Lake since they both experienced algae blooms that can have a negative impact on their lives.

Health & Safety

Studies should be conducted to understand the perceptions of local communities on the algae blooms. Additionally, health and safety brochures should be distributed to locals to inform them of the hazards associated with the blooms. The local residents need reliable information in order to best protect themselves and their families. While the Kansas Department of Health and Environment (KDHE) tests the lake's toxin levels regularly and issues lake warnings, watch advisories, and closures based on these levels, it is best to provide the public with as much information as possible regarding the risks that come with exposure. Even if a lake warning or watch advisory is in effect, locals and lake visitors may not understand how the algae blooms can affect their health. Knowing how exposure to algae blooms may affect their health, lake users are able to make an informed decision on whether or not they want to participate in recreational activities in or around the water. Locals should be informed of health and safety concerns based on recent scientific literature regarding algae blooms. In the Journal for Nurse Practitioners, researchers investigate the current knowledge for the assessment, treatment, clinical management, and prevention of algal bloom–related illness.

There are many ways that people can be exposed to cyanobacterial toxins found in algae blooms. A few exposure pathways include inhalation, direct skin contact, incidental ingestion, and food contamination (*The Journal for Nurse Practitioners*, 2020). This exposure can result from recreational activities on or around water sources that are experiencing harmful algal blooms. Not only can people be exposed by directly touching the algae when swimming or recreating on the water but by being around it. Exposure can occur by just being around water sources that are experiencing harmful algal blooms due to Aerosolized toxins. Aerosolized toxins come from fine spray or colloidal suspension in the air. They can become suspended in the air when waterways are disturbed by recreational activities such as boating and skiing, or even high winds. Once suspended in the air, toxins can be carried by wind and come into contact with people. Populations living near impacted waterways are at a greater risk of exposure (*The Journal for Nurse Practitioners*, 2020). For those who recreate in impacted water sources, accidental ingestion, and direct skin contact may occur during swimming or during water sports. The most common exposure to cyanobacteria is associated with pruritic skin rashes and gastrointestinal symptoms (*The Journal for Nurse Practitioners*, 2020). This journal also lists the ingestion of contaminated fish as another form of exposure but does not go into detail on the effects this may have on a person. It is important to note that there are different levels of exposure depending on the amount of time one is exposed and the recreational activities being done.

The level of exposure will determine the impact on one's health. People who come in contact with blue-green algae yearly, like the local communities near Milford Lake, experience chronic exposure. While there is very little data regarding chronic exposure to cyanotoxins, it is thought that it may be damaging to the liver, colon, kidneys, and brain in animals and humans (*The Journal for Nurse Practitioners*, 2020). This article points out that in a review of nonalcoholic liver disease in the United States, rates of disease were highest in areas with a history of cyanobacteria algal blooms, and there might be a potential link between exposure to the blue-green algal toxin β-N-methylamino-L-alanine (BMAA) and multiple neurodegenerative diseases. Additionally, antibodies to microcystin have been identified in the research setting and are being explored as a potential biomarker of organ damage (*The Journal for Nurse Practitioners*, 2020). Milford Lake has experienced harmful blue-green algae blooms for several years now and the people that visit and live near the lake may experience health problems due to the algae blooms depending on their levels of exposure. Lake managers should do their best to inform the public of the potential impacts that the algae blooms can have on their health.

Wildlife

As research continues to be done on the health effects that algae blooms can have on local communities and those that visit the lake, more needs to be done on the impacts on wildlife. Milford Lake provides a habitat for wildlife both in and around the lake. Research has found algae blooms to negatively affect human health and the same should be assumed for wildlife until proven otherwise. To find out if there is any evidence of fish and or other wildlife populations being affected by algal blooms, we conducted an interview with Clint Thornton, a biologist for the Kansas Department of Wildlife and Parks (KDWP). When asked if there was any evidence, Thornton said, “I am sure blue-green algae has affected wildlife around the lake, but we do not have any evidence of this that I am aware of. I've heard of someone's dog getting sick on a couple of different occasions, but you don't hear about wildlife… it's very hard to get data on this.” While he believes that the algal blooms have affected wildlife, there is not enough data to support this claim or to show the magnitude of its effect. With that being said, there is data that shows that dogs can get sick and die from exposure to algae blooms.

In the article “Investigation of a Microcystis aeruginosa cyanobacterial freshwater harmful algal bloom associated with acute microcystin toxicosis in a dog,” the authors Deon van der Merwe, Lionel Sebbag, Edward Carney, and other contributing authors share their findings on how blue-green algae was responsible for the death of a dog. The dog that they are reporting their findings on was a 6-year-old, intact female Briard dog, weighing 35.5 kilograms. The dog and its owners were visiting Milford Lake. They were walking along the lakeshore at a swimming beach close to the town of Milford when the dog began drinking water from the lake. In the evening the dog started to get sick. It lost its appetite, vomited green-colored fluid, and developed diarrhea, according to its owners. The owners took the dog to Veterinary Medical Teaching Hospital at Kansas State University at 12:30 pm on September 25, 2011. This was only 24 hours after it drank water from the lake. Eleven hours after presentation and four hours after placing the urinary catheter, no additional urine had been produced. The dog was then euthanized at 2:00 am, using pentobarbital sodium (Merwe, 2012). The veterinarians, along with the owners, decided to euthanize the dog as it was in pain, showing no signs of improvement, and the likelihood of recovery was extremely low. After the dog's death, a necropsy was performed, and samples of tissue in the liver, kidney, spleen, lungs, myocardium, mesentery, uterus, stomach and intestines, bladder, skeletal muscle, tonsils, salivary glands, and brain were taken (Merwe, 2012). The diagnosis of microcystin poisoning was supported by the finding of liver failure and gastroenteritis and associated gross and microscopic postmortem lesions (Merwe, 2012). While it is not known how other animals are affected by microcystin found in algal blooms, there should be more research done to come to a full conclusion. The microcystin that can be found in algal blooms can also be harmful to wildlife not only due to the toxins they release into the water but by what they take out of the water as well.

Dam Design

Issues causing toxic algal blooms are the dam and reservoir infrastructure of Milford Lake. Milford Lake Dam was built in 1966 by the U.S. Army Corps of Engineers (Huggins & Howick, 1998). Most dams are built with a clay core and are set on top of the alluvial material that is deposited by the river connected to the dam (Huggins & Howick, 1998). However, Milford Lake is a special case because the alluvial material was not found at the location where the dam and reservoir were being built, making the sediments beneath the Milford Dam more porous (Huggins & Howick, 1998). This allows more water to seep under the dam and be absorbed by the underlying aquifer into the groundwater compared to other dams. The alluvial material found at the bottom of the Milford Reservoir and below the dam are composed of mostly medium to coarse sand, gravel and silty sand, and small fragments of clay (Huggins & Howick, 1998).

Reservoir Design

The Milford Reservoir contains 73 wells to relieve pressure when water is at extremely high levels (Huggins & Howick, 1998). The water that is collected from these wells flows to a lake located near the reservoir. This lake is used for the fish hatchery located at Milford (Huggins & Howick, 1998). 50% of the water for the pressure relief lake comes from Milford Reservoir, while the rest of the water comes from the groundwater (Huggins & Howick, 1998). The pressure relief lake was found to have dangerously high levels of ammonia, nitrate plus nitrite, and phosphorus, making it extremely eutrophic (Huggins & Howick, 1998). Scientists suggest that this contamination comes directly from the bottom sediments of Milford Reservoir since these sediments release large amounts of nutrients and are therefore a nutrient source (Huggins & Howick, 1998).

Toxic algal blooms that occur each year at Milford Lake make negative impacts on multiple factors, including visitor experience, recreation-based economy, local perspective, health and safety, and wildlife. There are many causes of these algal blooms including dam and reservoir infrastructure, water runoff, and other human activities. Our research group began searching for possible solutions to this growing issue by first conducting tests on water samples taken directly from Milford Lake.

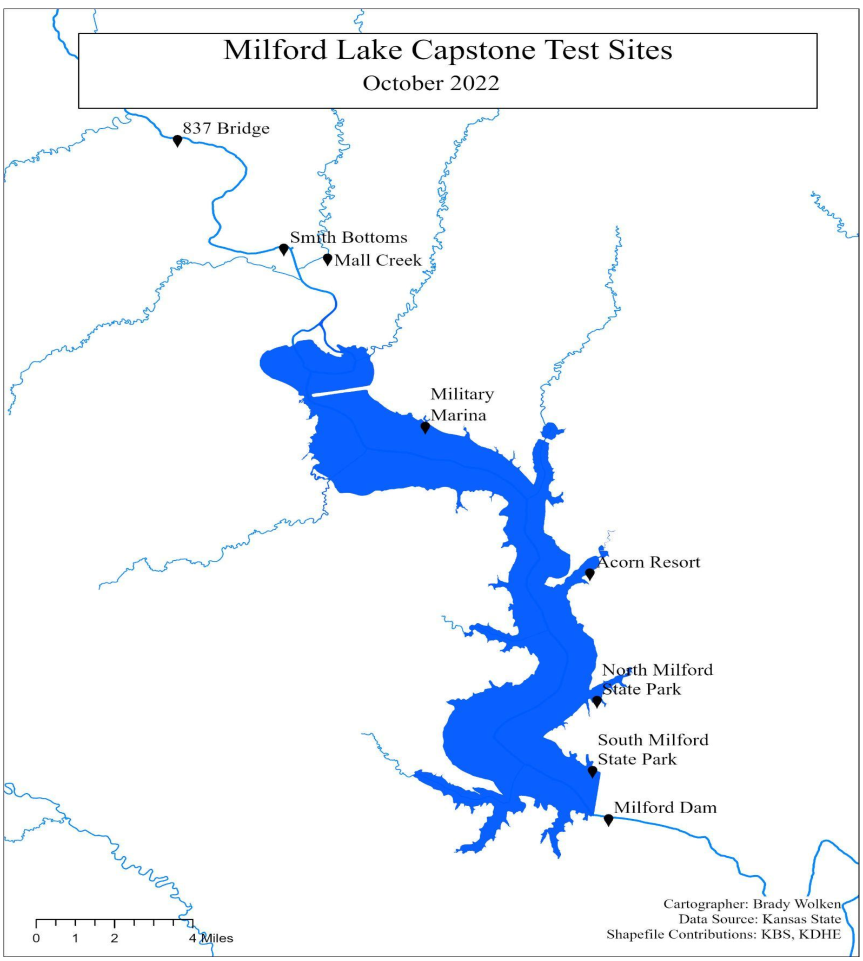
Methods

A total of eight sites, found on Figure 1 below, were tested and analyzed. Each site was tested for concentrations of ammonium, nitrate, orthophosphate, total phosphorus, total nitrogen, and total suspended solids. Two water samples from each site were collected on October 16th, 2022. Alongside our physical test samples that we obtained for testing, at each site a YSI EXO 3 Multiparameter Sonde was used to collect data on chlorophyll, observed dissolved oxygen, total algae (chlorophyll + phycocyanin), turbidity, and temperature. The algal blooms were slowing down at this time, but a freeze had not yet occurred, so there was not a complete die-off of algae. One set of samples was tested directly by our research group, while the second set of samples was sent to the Kansas State University Soils Testing Lab, located in Throckmorton Hall.

To better understand the history and quality of the Milford Lake Watershed we contacted industry professionals that have experience with the lake. We contacted Kyle Hoover KDWP Milford State Park Manager, Brett Miller KWDP District Fisheries Biologist, Clint Thornton KDWP Biologist, and Dr. Elizabeth Smith KDHE Environmental Scientist.

Figure 1

Milford Lake, KS Capstone Test Sites



Sample Testing

To test for nitrate, phosphate, and ammonium, we used a water quality chemical testing kit with a color disc. Each test required the addition of specific chemicals that would detect the concentrations of certain ions, so each test needed to be done separately. Figure 2 shows the testing procedure that the group conducted for nitrate, phosphate, and ammonium.

Figure 2

Nitrate, phosphate, and ammonium testing

To test for total suspended solids, the research group put each sample through a vacuum filtration system to collect all particles in the sample and remove as much water as possible. The samples from each collection site were placed in an oven and removed after 24 hours. The samples were then weighed and recorded. Figure 3 shows the samples from each site in the oven.

Figure 3

Samples being dried in the oven for total suspended solids concentrations

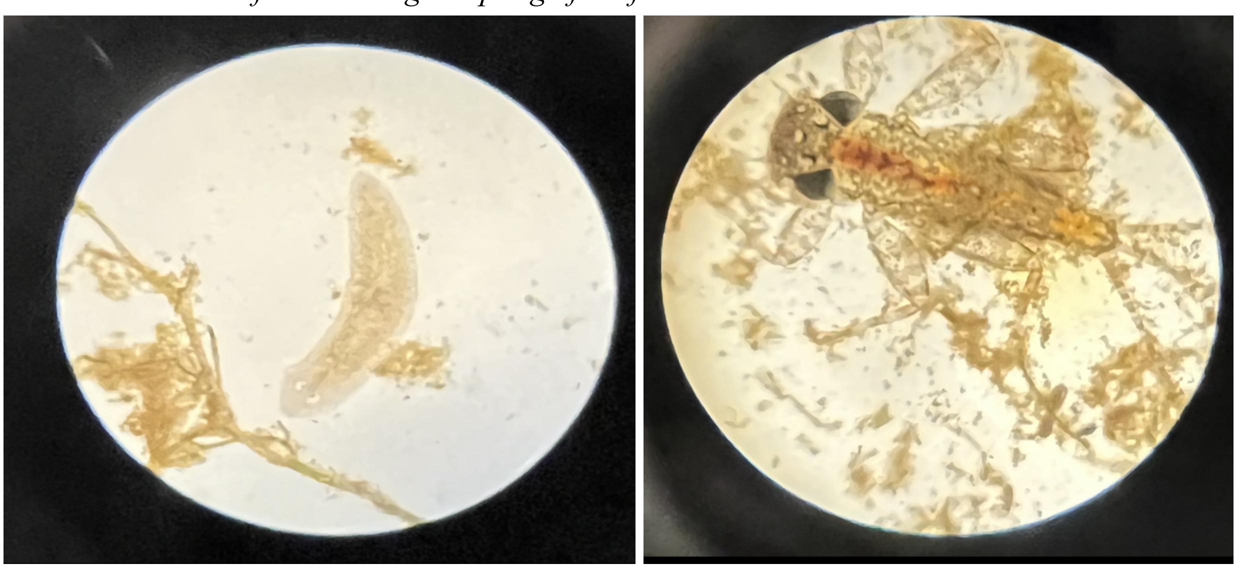
Macroinvertebrate Sampling and Identification

Our research group did an aquatic macroinvertebrate survey at two different points and found there to be similar insects at both points. The two points we surveyed were South Milford State park and Milford Damn. We found *Diporeia* which is a tiny shrimp-like organism also known as Scud. We also identified Tadpole shrimp (*Notostraca*), springtail (*Collembola*), Flatworm (*Planaria*), Riffle Beetle (*Elmidae*), Darner dragonfly larvae (Aeshnidae), Mayfly larvae (*Ephemeroptera*), snails (*Gastropod)*, Zebra mussel (*Dreissena polymorpha*), Water boatman (*Corixidae*), and mosquito larvae (*Culicidae)*. Pictures of our samples can be found in Figure 4.

The ability to locate and identify aquatic invertebrates correlates with water quality of streams and bodies of water. A diversity of intolerant macroinvertebrates or an absence of them can indicate water quality. Macroinvertebrates are broken up into three groups and are based on the invertebrate's ability to survive or not survive in polluted waters. In group one, the invertebrates do not tolerate polluted waters. Group one consists of macroinvertebrates such as stoneflies, mayflies, riffle beetles, and caddisflies. These species are also known as indicator species since their presence “indicates” water quality. Group two invertebrates are “facultative” which means they can tolerate limited pollution. Some of the invertebrates in group two consist of damselflies, aquatic sowbugs, scud, dragonflies, and crayfish. Group three consists of pollutant-tolerant organisms, but they can be found in any quality of water. Some of the organisms found in group three can be aquatic worms, leeches, and pond snails (USDA NRCS, 2004). We identified two species in group one, two in group two, and one in group three.

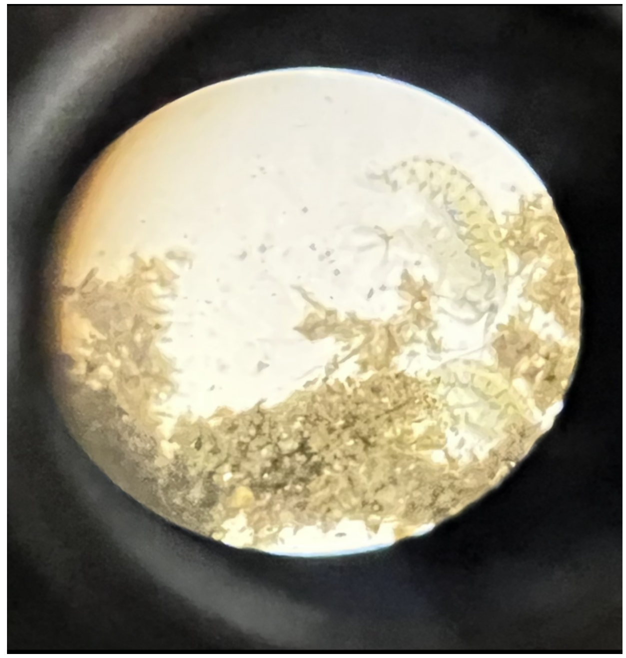
Figure 4

Macroinvertebrates found during sampling of Milford Lake

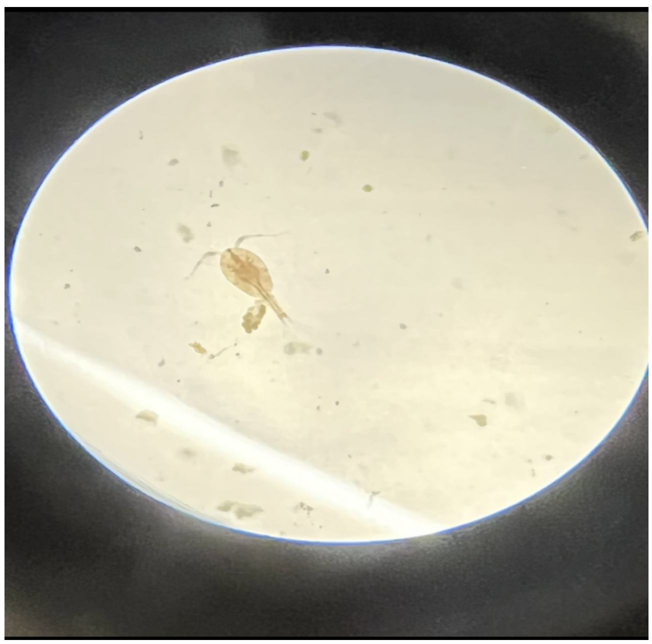


Flatworm (*Planaria*)   Mayfly larvae (*Ephemeroptera*)

Scud (*Diporeia*)



Springtail (*Collembola*)



Tadpole Shrimp (*Notostraca*)

Results And Discussion

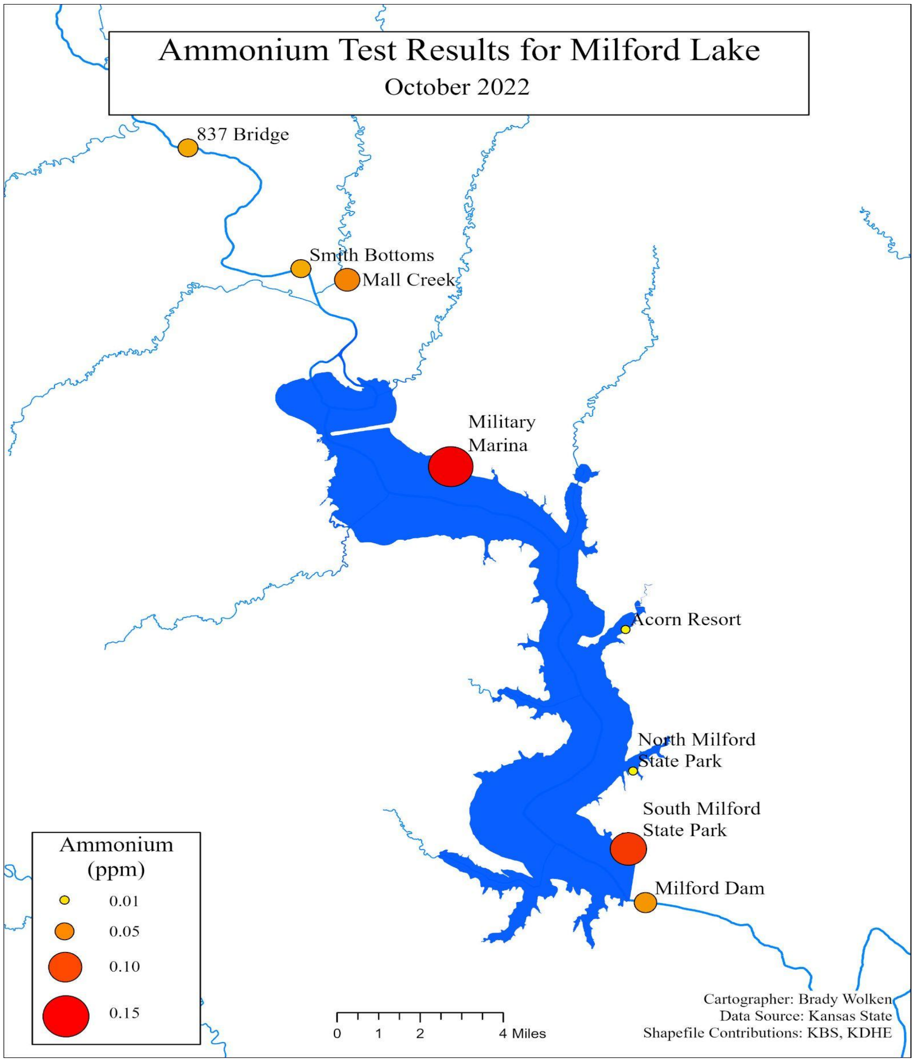
While testing was done by both the research group and the Soils Testing Lab, the data from both tests did not correlate. Since this was the research group’s first time running water quality tests, data from the Soils Testing Lab was used instead to ensure precise measurements with accurate results. Each set of results has been added to maps below to show the correlation between site location and concentrations.

Ammonium Concentrations

The highest concentrations of ammonium were found at Military Marina and South Milford State Park. These locations are at opposite ends of Milford Lake. Ammonium is commonly found when decomposition of organic materials has occurred (Janke, R et al. 2006). Locations with more algae will more commonly have less ammonium. The nutrient readings that were collected correlates with our visible observations. We observed minimal algae at all test sites except for the North Milford State Park and Acorn Resort testing sites. All data can be seen in Appendix A. Ammonium concentrations at each testing site can be found in Figure 5.

Figure 5.

Ammonium Concentrations at each testing site

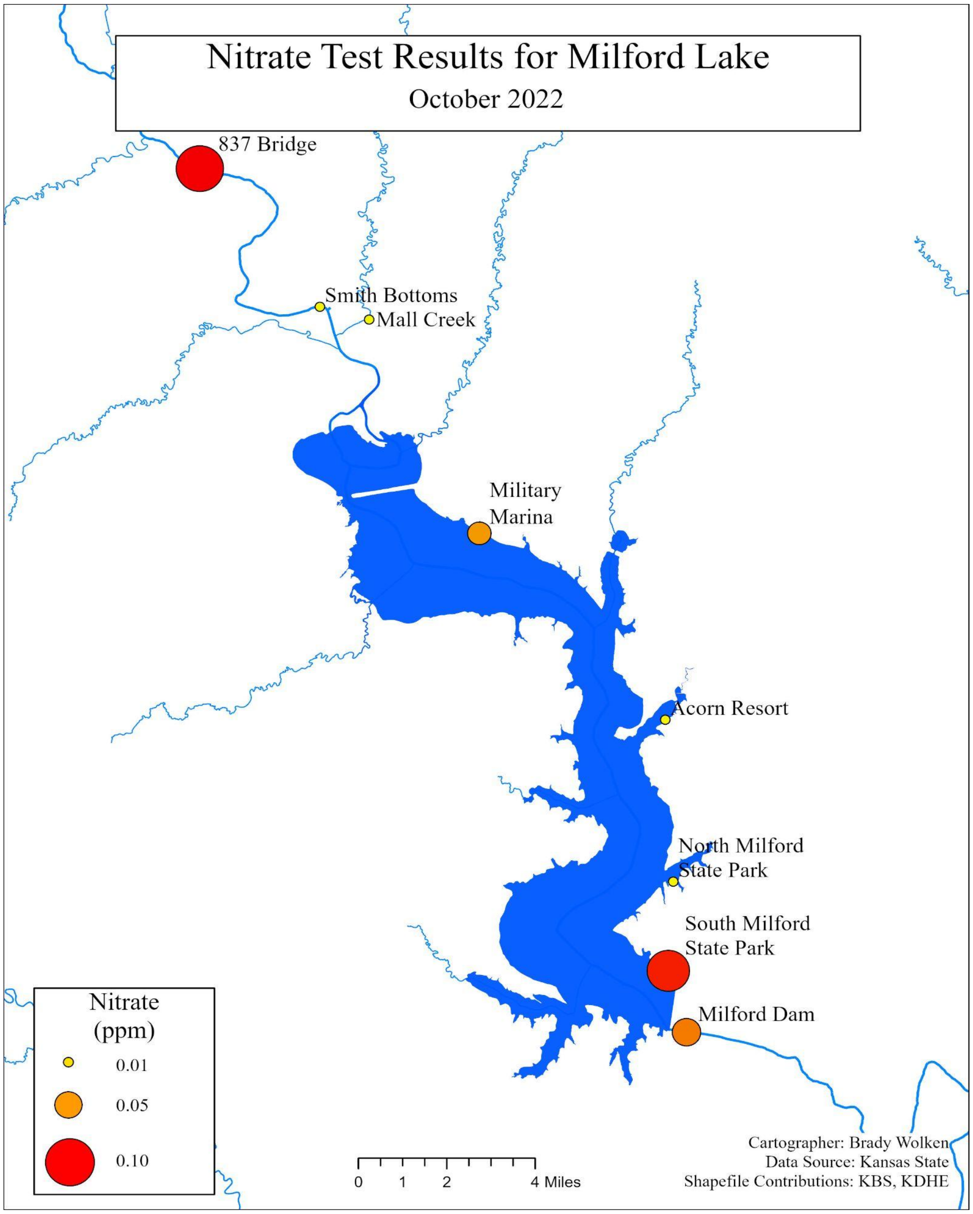


Nitrate Concentrations

Nitrate is most commonly found from field and animal waste runoff (Janke, R et al. 2006). Our test results found that nitrate concentrations were the highest at the 837 Bridge and at South Milford State Park. We believe that for the 837 bridge test site the reason for the high nitrogen amount is due to agricultural run off from the upstream watershed. All data can be seen in Appendix A. Nitrate concentrations at each testing site can be found in Figure 6 below.

Figure 6.

Nitrate concentrations at each testing site

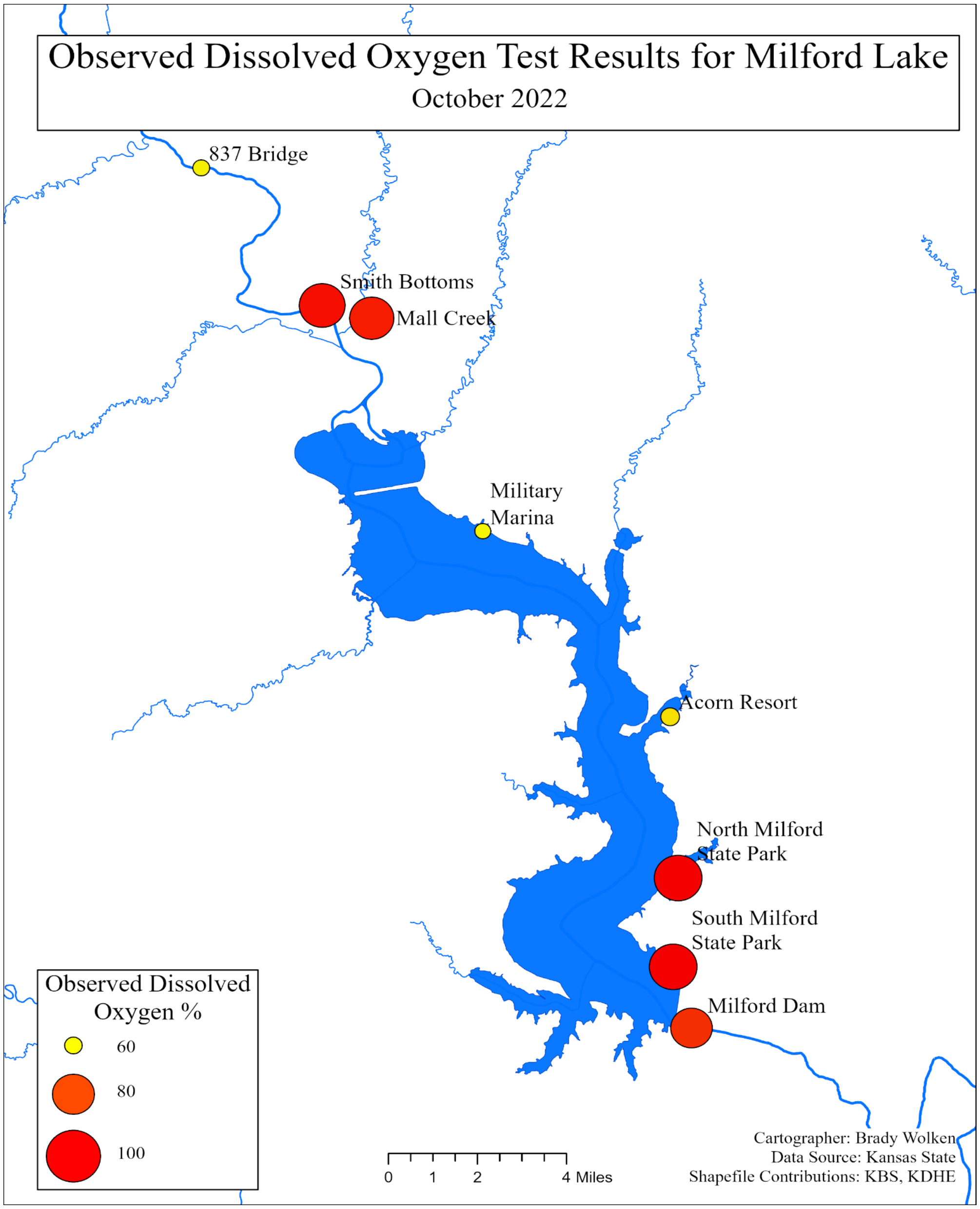


Observed Dissolved Oxygen Concentrations

Dissolved oxygen readings allow us to measure the amount of oxygen that is present in the water. Healthy Observed Dissolved Oxygen ratings span from 80- 120% (Department of Environment and Natural Resources, n.d). Acorn Resort, Military Marina, and the 837 Bridge all had very low concentrations of dissolved oxygen, which means in many of the locations there is enough oxygen for more algae to grow. This is dangerous for surrounding wildlife and plant life found in the lake. All data can be seen in Appendix A. Figure 7 below shows observed dissolved oxygen concentrations at each testing site.

Figure 7.

Observed dissolved oxygen at each testing site

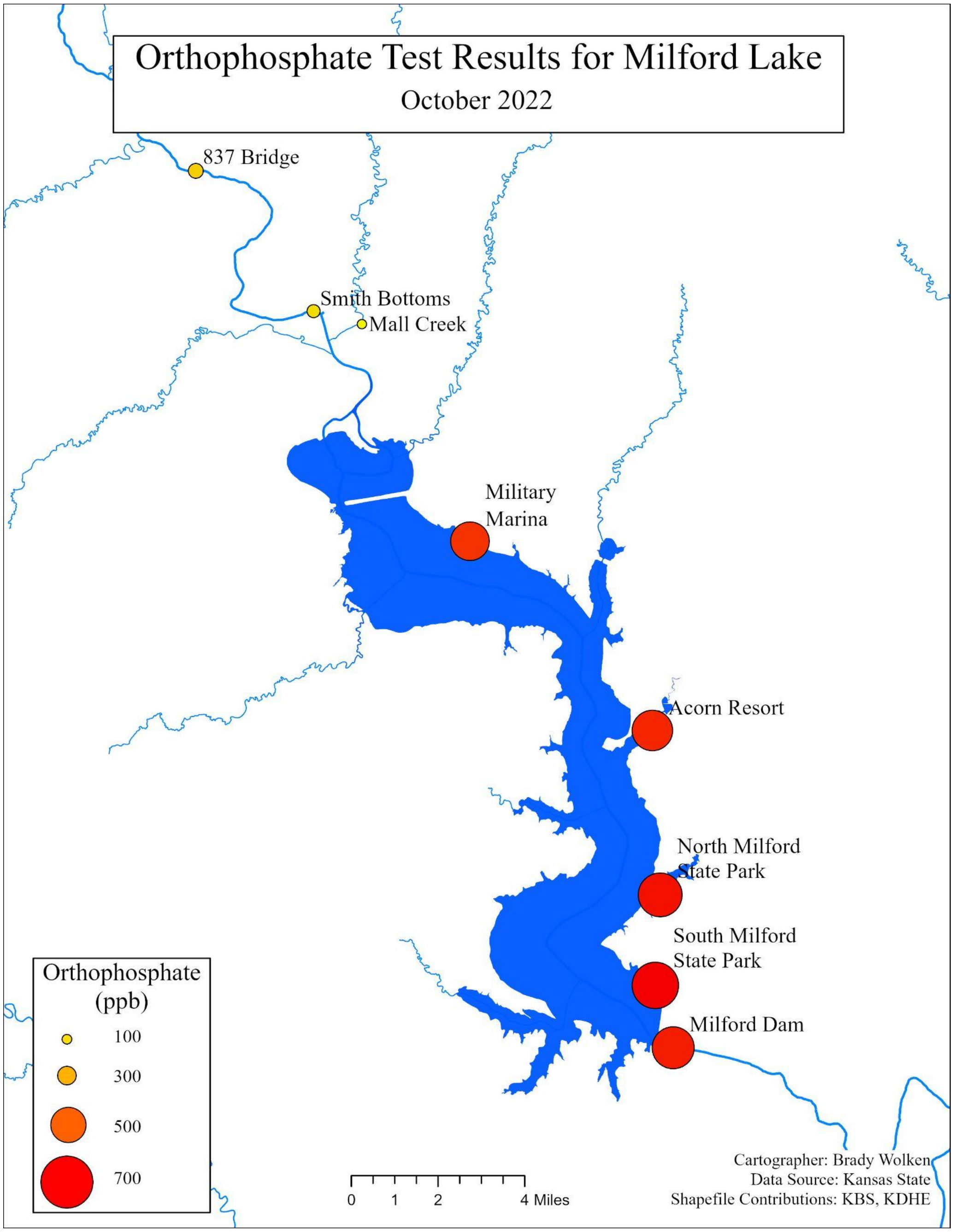


Orthophosphate Concentrations

High levels of orthophosphate were found all throughout Milford Lake. When phosphorus is available in lakes or streams it is most commonly orthophosphate. Orthophosphate is a plant available soluble that comes from aquatic animals and plant outputs that is a growth-limiting nutrient for aquatic plants (Janke, R et al. 2006). All data can be seen in Appendix A. Orthophosphate concentrations at each testing site can be found below in Figure 8.

Figure 8.

Orthophosphate concentrations at each testing site

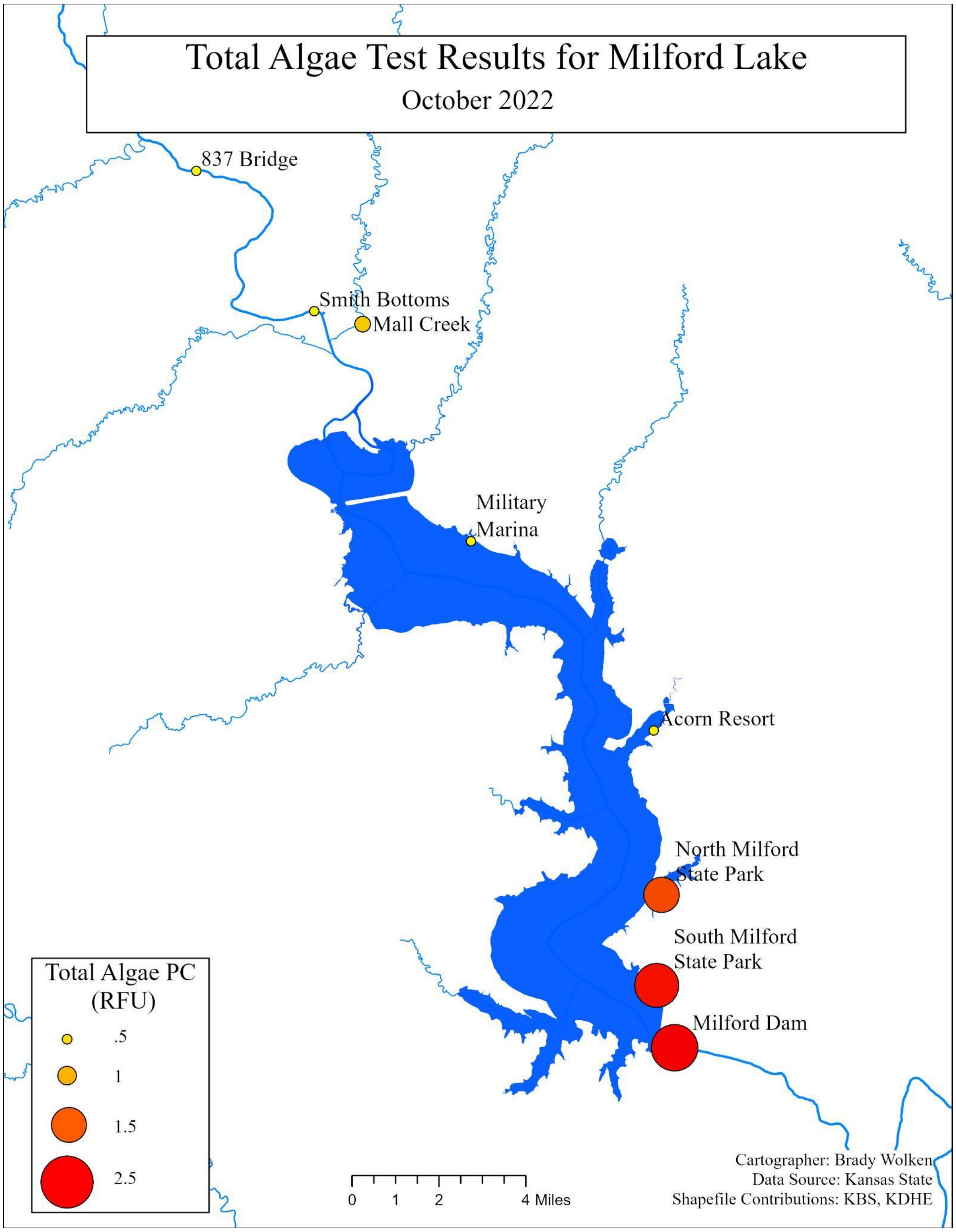


Total Algae Concentrations (phycocyanin)

High levels of total algae were found at the bottom of Milford Lake as shown below. This could be due to the sediments traveling toward the dam and then being trapped there when the sediments cannot travel any further downstream. All data can be seen in Appendix A. Figure 9 shows total algae at each testing site.

Figure 9.

Total algae concentrations at each testing site

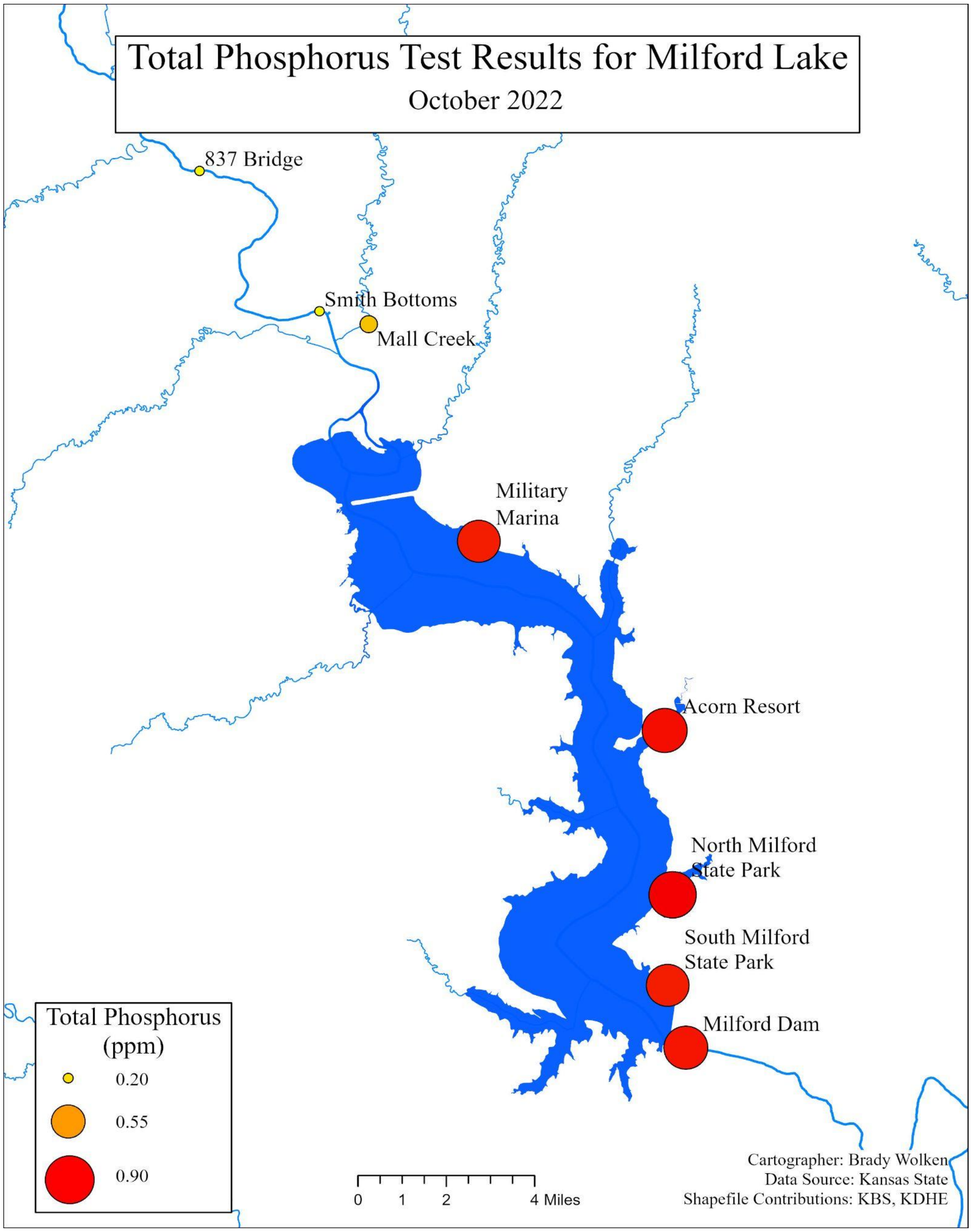


Total Phosphorus Concentrations

Total phosphorus measures every type of measurable phosphorus based nutrient. Many of these nutrients are common growth-limiting nutrients for aquatic plants including algae (Janke, R et al. 2006). While testing lower amounts of phosphorus was found in the northern stream testing sites, all test sites in Milford Lake were significantly higher. All data can be seen in Appendix A. Figure 10 shows total concentrations of phosphorus at each site.

Figure 10.

Total phosphorus concentrations at each testing site

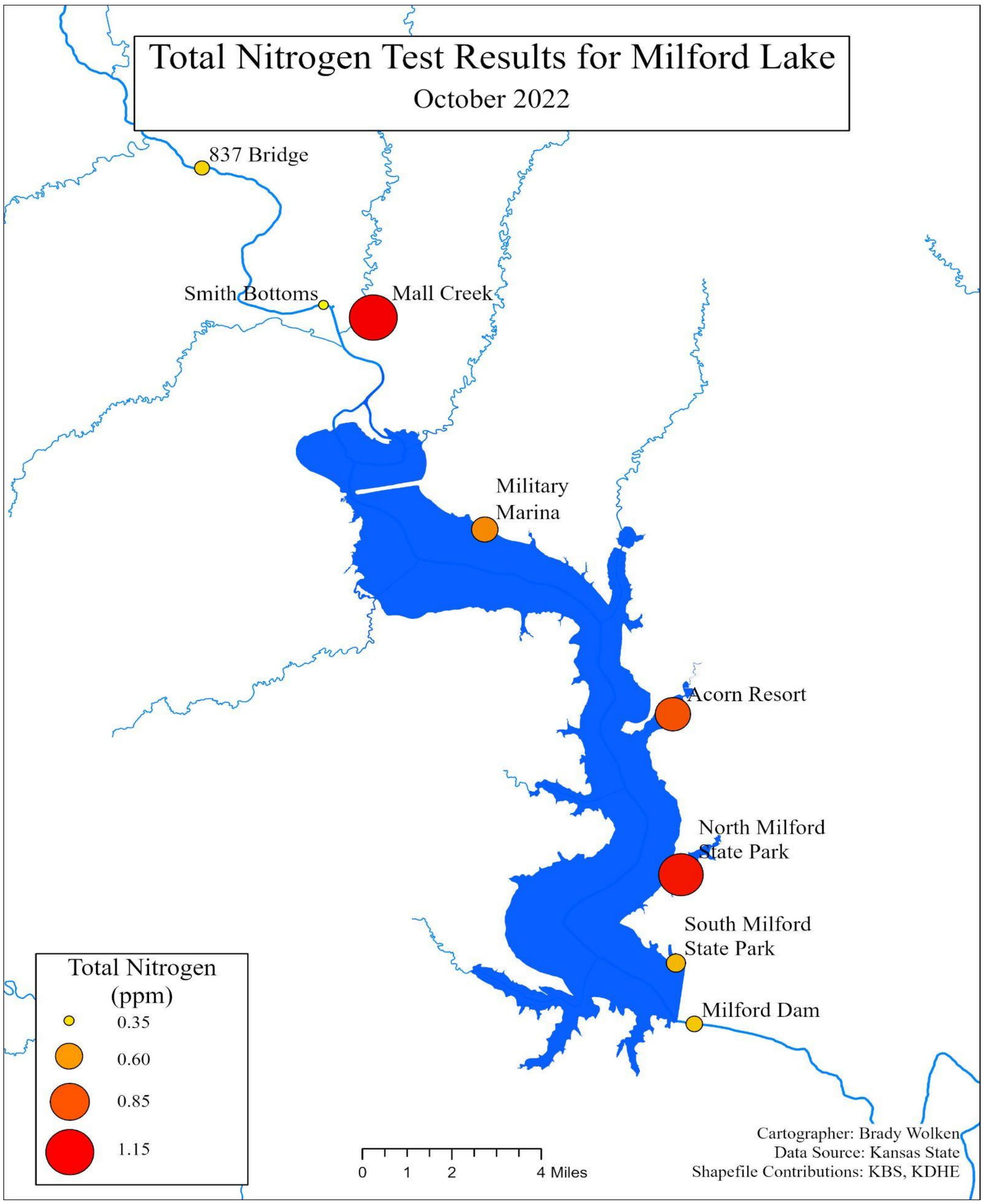


Total Nitrogen Concentrations

Total nitrogen measures for every measurable nitrogen based nutrient. Many of these nutrients are common growth-limiting nutrients for aquatic plants including algae. Levels of total nitrogen are influenced by organic decomposition, agricultural runoff, and animal output (Janke, R et al. 2006). While testing, we found fluctuating amounts of total nitrogen. All data can be seen in Appendix A. Total nitrogen concentrations at each testing site can be found in Figure 11 below.

Figure 11.

Total nitrogen concentrations at each testing site

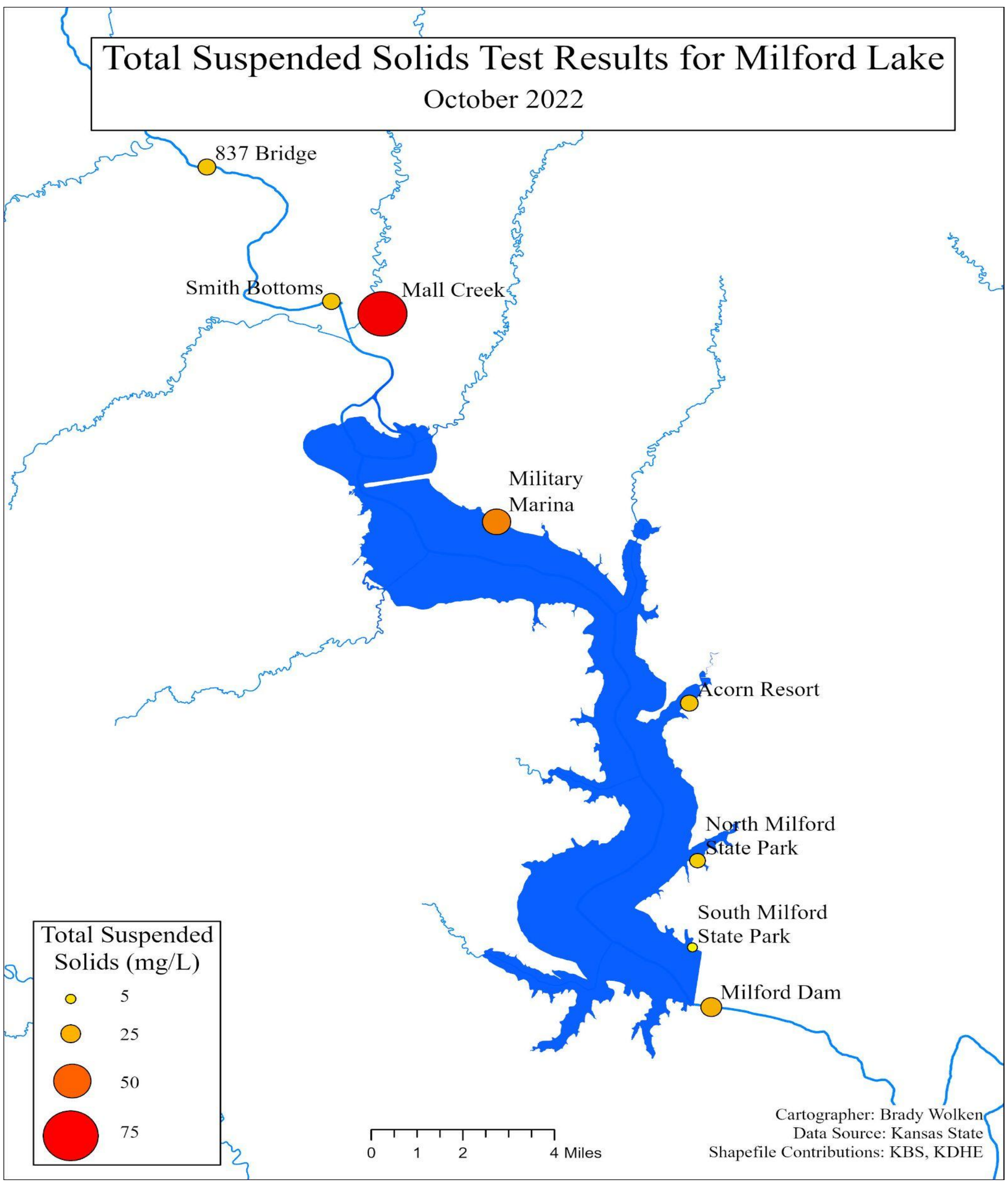


Total Suspended Solids

Total suspended solids readings are very closely related to turbidity, both of these readings refer to how cloudy bodies of water are. Total suspended solids can be affected by soil erosion, algae growth and plant or animal output. Vey high ratings of suspended solids are not good for aquatic life because suspended nutrients block sunlight and can cause water to warm (Janke, R et al. 2006). In our tests Mall Creek showed the highest concentrations of suspended solids. This can also be seen in Figure 3. All data can be seen in Appendix A. Concentrations of total suspended solids are found in Figure 12.

Figure 12.

Total suspended solids concentrations at each testing site



While this is only a small portion in time, we compared our data to USGS data and found that it correlates with annual variation found on the USGS database (See in Appendix A). Based on our results, the high levels of nutrients, especially phosphorus, will continue to be cycled through the reservoir if nothing is done to filter it out. This will cause algal blooms to most likely continue in the future. From the figures, we can also see that the reservoir is receiving nutrient sources from upstream as well.

Potential Management Strategies

Strategies to reduce the size and frequency of algal blooms should be considered based on the effectiveness and costs associated with action or implementation. Management strategies that are less effective in controlling algae blooms but have other benefits such as supporting biodiversity, increasing town and city aesthetics, and having the potential for local economic growth and reduction in pollutants should be considered.

Geotextiles Filter Media

Geotextiles are made up of synthetic polymers and are available in two types; woven and non-woven. The use of Geotextiles to filter water and remove algae on the surface could be useful to reduce microbial mineralization. Microbial mineralization comes from the dead algae after each summer. The dead algae release nutrients into bodies of water and surface sediment. The nutrients serve as a source for the bloom in the next spring (Veetil et al., 2021). While limiting or preventing an overload of nutrients would also reduce harmful algae blooms, this could be a useful management tool when blooms do happen to occur. A study on using filtration to improve the surface water quality of a eutrophic lake was done at Lake Caron, located in Quebec, Canada. The researchers explored the “effectiveness of non-woven geotextiles as a filter media for surface water treatment and the subsequent improvements in surface water quality in terms of nutrient, turbidity and suspended particle removal” (Veetil et al., 2021). A total of 14 filtration experiments were conducted using various combinations of filter sizes. The results using geotextiles as a filter media to remove algae on the surface had good results. The abundance of phytoplankton before and after filtration found an algal removal of 97% (Veetil et al., 2021). Not only was this effective at removing the algae, but it was able to remove the total amount of algae by varying percentages of different algae species. Phytoplankton were removed in “the first four days and their removal was 88% Cyanophyecae, 69% Chrysophyecae, 100% Cryptophycae, and 70% others” (Veetil et al., 2021). This could be useful since some phytoplankton species are necessary to support healthy ecosystems and their complete removal may not be necessary. This study also determined that “68% of the cost was associated with the electricity used and a part of this amount can be offset by running the system on solar energy” (Veetil et al., 2021). This could be a cost-effective solution to reduce the number of nutrients that get recycled year to year. This could help restore the aesthetics of water sources by reducing the amount of green slick on the water's surface. The biggest problem associated with this management strategy would be the filter getting clogged and needing to be replaced.

Rain Gardens

Surface runoff is an important transport mechanism for many pollutants**.** During Storms or light rains, pollutants can easily be transported by stormwater and into other bodies of water.

Surface runoff carries debris, fertilizers, herbicides, and pesticides into water sources (Pearson et al., 2018). These pollutants are a contributor to the degradation of water quality in lakes, wetlands, estuaries, and groundwater. The local community's infrastructure in the town of Wakefield and Milford both contribute to water pollution through surface runoff that ends up in the lake. Road debris can include a collection of soil, plant matter, and waste materials that accumulate along the edge of roadways and eventually find their way into waterways. If road debris or other pollutants like fertilizers that nitrogen (N) and phosphorus (P) are able to leach into water reservoirs, water quality degradation would likely occur and create an ideal environment for eutrophication (Pearson et al., 2018). A solution to reduce the amounts of pollutants entering the lake that come directly from Wakefield and Milford would be to create rain gardens. Water From Wakefield’s sewer drains, shown on the left in Figure 13, runs into the lake along this route. The image on the right in Figure 13 shows where a rain garden could actually be installed to reduce their local contributions.

Figure 13.
Sewer drains in Wakefield, Kansas on the left and possible rain garden system on the right

Research shows that rain gardens provide a wide range of benefits to local communities and the surrounding environment. These benefits include stormwater preservation, reduction of runoff and flood protection, groundwater pollution prevention, biodiversity enhancement, and microclimate control (Kasprzyk et al., 2022). A rain garden is “(i) a shallow depression with free-draining soil, (ii) a planted depression designed to collect, store, infiltrate and filter stormwater runoff on a small-scale, especially in urban areas, or (iii) a vegetated area into which runoff is drained, attenuated and stored and water infiltrates into the ground or is taken up by plants” (Castellar et al., 2021; Dickie et al., 2010; Graham et al., 2012). The filtering of the water before it reaches bigger bodies of water can have a profound impact on the quality due to the reduction of pollutants entering it. Rain gardens act as a filter because of the Hydrophyte plant's ability to remove many pollutants from rainwater. Hydrophyte plants have the ability to filter out or reduce the amount of nitrogen and phosphorus compounds, heavy metals, and oil derivatives found in water runoff (Kasprzyk, 2022). Nitrogen and phosphorus are leading causes of algae blooms and can be reduced by the use of rain gardens. Plants are able to do this through their roots and rhizomes. The plants loosen up the soil, take up biogenic compounds such as nitrogen, phosphorus, and heavy metals, and provide the necessary nutrients, including oxygen for bacteria and fungi present in the root system (Kasprzyk, 2022). The bacteria and fungi present in the root system also support the process of the decomposition of harmful substances (Kasprzyk, 2022). Not only are the plants able to reduce the number of nutrients and pollutants from reaching other bodies of water, but they also promote biodiversity.

The use of native plants and wildflowers can help animals and insects like pollinators survive and thrive in urban environments. Additionally, the use of native plants and wildflowers in towns is aesthetically pleasing due to their natural beauty. A rain garden was installed along a roadside in Seattle and is shown in Figure 14.

Figure 14.
Rain garden found in Seattle, Washington

Rain gardens will cost more money depending on the degree of labor and costs associated with planting. To reduce costs, towns should seek grants for funding and use volunteers to cut the cost of labor. Using volunteers would help engage and educate community members on the benefits of rain gardens and would promote their sense of accomplishment at the end of the project.

Biomanipulation

The term "biomanipulation" can be described as a type of engineering that uses living things to manipulate the surrounding environment. At Milford, the stocking of tilapia could be a management strategy to reduce the size and frequency of algal blooms. In a research project at Lake Yuehu, China, researchers studied the use of tilapia to control algae blooms. They found that tilapia is among the very few fish species which are capable of digesting blue-green algae. tilapia have the ability to digest blue-green algae since they can secrete gastric acid at a pH as low as 2.5 to 1.0 (Lu et al., 2006). Not only are the tilapia able to digest the algae, but they found that they can help control or prevent blue-green algal blooms, improve transparency, and optimize phytoplankton community structure (Lu et al., 2006). These results were consecutive for three years. When considering the use of tilapia in water systems that they are not native to, it is important to think about the long-term consequences of their introduction.

If the introduction of a species has a negative effect on an ecosystem it may cause more harm than good. Picking species that are unable to take over ecosystems and do not cause harm to native species is the best option. Tilapia prefer warm waters, according to ichthyologist and hatchery owner, Nicholas James. James states that the tilapia "O. mossambicus from warmer regions appears to have a lower tolerance for cold; a 1978 cold front in KZN, during which water temperatures fell below 13°C for some days, caused mass mortalities" (James, 2017). The selection of tilapia, which have a low tolerance to cold, may be useful in selecting a fish to control algae blooms since Milford Lake in Kansas experiences cold temperatures in the winter and will prevent a complete takeover of the species. Tilapia would mostly be able to survive during the late spring and into the hot summer months when algae blooms also occur. During this time they would help minimize the size of the blooms by using the algae as a food source. Further research would need to be conducted to figure out when to stock tilapia into the lake and how many are needed to have the best impact on controlling algae blooms. Additionally, more information is needed to ensure that the use of tilapia as a management strategy wouldn't cause a negative impact on native wildlife.

Scheduled Sediment Release

Because sediment plays a major role in nutrient absorption and release, it is necessary to develop a system or process to improve sediment flow and release in reservoirs. Too much sediment accumulation in reservoirs can lead to a multitude of issues including a decrease in reservoir benefits, environmental damage, and an increase in cost of maintenance and management (Shelley, Hotchkiss, Boyd, & Gibson, 2022). Authors Shelley, Hotchkiss, Boyd, and Gibson conducted research on different sediment release methods that have worked successfully at different reservoirs in the United States. The study conducted closest to Milford Lake takes place at Spencer Dam located in northeast Nebraska (Shelley et al., 2022). While the dam failed in 2019 due to issues with ice, observations and studies were done prior to this event (Shelley et al., 2022). This reservoir had high levels of fine sand sediment that flowed from the Niobrara River through the Sandhills region of Nebraska (Shelley et al., 2022). Issues began once the reservoir started filling with this sandy sediment, similar to Milford Lake sediments, as discussed above. Engineers and project managers developed a plan to release sediments by performing a semiannual, two-week drawdown flush (Shelley et al., 2022). This process allowed sediments and water overflow from the reservoir to flow downstream freely for two weeks straight. It created sandbars downstream that naturally eroded away by the time the next flush was due (Shelley et al., 2022). While profit loss is a negative effect of this procedure, since no hydropower can be produced during this two-week process, it would cost a great deal more to have to hire professionals to clean out the sandy sediments that would eventually block important valves and piping systems. Another concern that authors in this article found was fish killing due to a rapid release of stagnant water with low levels of dissolved oxygen (Shelley et al., 2022). Fortunately, this problem can be solved. Engineers of the Spencer Dam resolved the conflict by slowing down the initial drawdown to decrease the impacts of water with low dissolved oxygen levels (Shelley et al., 2022). In conclusion, sediment release is an important process to keep stagnant water and sediment fluxes constant so that there is not an excess buildup of these sediments and the nutrients that they absorb and release. Figure 15 shows sediments traveling from Spencer Reservoir during a flush.

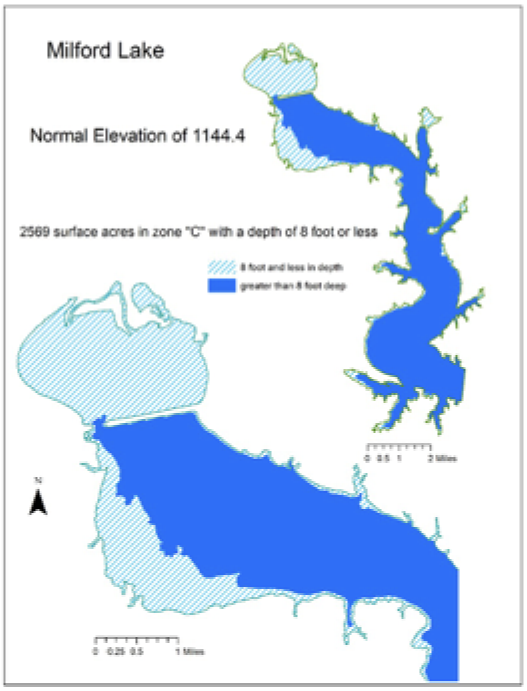
Figure 15.
Sediments traveling from the lake during a flush (Shelley et al., 2022)

Floating Wetlands

Much like rain gardens, floating wetlands are a good solution to remove nitrogen, phosphorus, and other pollutants from water sources. Floating wetlands can be used in areas where water is too deep for plants to grow and thrive. These wetlands can be installed on top of any water surface, and then anchored down. Since they are anchored they can be moved if necessary. The International Institute for sustainable development conducted research on using floating wetlands to treat eutrophic freshwater lakes. In this study they used cattail plants to treat the water and remove excess nutrients. In order to remove the nutrients from the water fully, management action would be necessary to remove plant materials at the end of the growing season. The removal of these plants from the floating wetlands would ensure that the plant matter and the nutrients stored within them would not be cycled back into the water. The results of this research and previous research found that the removal of plant matter should occur in August or September, in order for the plants to survive the cold winter months (Grosshans 2014; Grosshans 2019). Floating wetlands may also help reduce algae blooms by reducing the water temperature. Since the wetland will float on the surface of the water, this will create a barrier in between the sun and the water's surface. The Minnesota Pollution Control agency states that "Blue-green algae prefer warm, calm, sunny weather and water temperatures higher than 75°F" (*Blue-green algae and harmful algal blooms, 2022*). Reducing the amount of available nutrients is going to be the biggest factor in controlling algae blooms but lowering the water temperatures still will also be helpful. A picture of a floating wetland is shown in Figure 16.

When considering where to install floating wetlands at Milford lake, it may be necessary to install them where water enters the lake. Additionally, wetlands should be placed in areas of the lake that are more shallow as identified in Figure 16. Placing them in areas that are more shallow will have the biggest effect on lowering the water temperature.

Figure 16.
Floating wetland found in a lake (Kansas department of Health and Environment)



<u>Conclusion</u>

Our research group recommends the following methods to reduce algal blooms and remediate Milford Lake in Kansas:

1) Conduct research on how algal blooms in Milford Lake specifically affect the local economy and townspeople and their daily life.
2) Provide more detailed and up-to-date information to locals of the harm that algal blooms can cause and when they are at their peak concentrations.
3) Conduct further research on impacts of health and safety to both humans and wildlife in Wakefield and Milford, Kansas.
4) Design and install rain gardens and floating wetlands where they will create the most positive impacts on Milford Lake and the surrounding land.
5) Conduct an annual or semi-annual sediment release to allow for the movement of stagnant water and sediments in Milford Lake.

Conducting further research will bring about more awareness to the people living in close proximity to Milford Lake and to visitors of the lake. It would also bring attention to a serious issue that affects everyone in the community either directly or indirectly. Furthermore, rain gardens can be designed and installed along the sewage systems of Wakefield and Milford. Not only will these rain gardens absorb pollutants in water runoff from storms, but it will also bring more jobs to these small communities through rain garden construction and ongoing maintenance. Installing floating wetlands to Milford Lake can bring about more jobs as well as another source of profits through tourism. Many lakes do not have floating wetlands, so this tactic will bring tourists of all types while it also cleans and filters the lake water. Finally, annual or semi-annual sediment release can benefit plants and wildlife at Milford Lake. Sediments will not be trapped and can travel downstream, bringing nutrients from the Republican River into the Kansas River and preventing the buildup of excess nutrients in Milford Lake that in turn cause toxic algal blooms.

Using all of these methods would be the most cost effective and proactive solution to a serious problem by providing more jobs to a small community, bringing more tourism to the area, and by cleaning and filtering Milford Lake. When the cleanliness of the lake improves, plant and wildlife diversity will increase, making Milford Lake even healthier and human and animal friendly. Tourists and locals will be able to enjoy recreation at Milford Lake like they once did before toxic algal blooms took over.

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Appendix A

Table 1

Total Nitrogen Test Results at Milford Lake

Location	Data Source	Date	Total Nitrogen (ppm)
837 Bridge	Capstone Team	October 2022	0.47
	USGS	July 2017	1.40
Smith Bottoms	Capstone Team	October 2022	0.35
	USGS	July 2017	1.80
Mall Creek	Capstone Team	October 2022	1.22
	USGS	July 2017	1.50
Military Marina	Capstone Team	October 2022	0.73
	USGS	October 2018	1.80
	USGS	August 2018	0.96
	USGS	July 2018	0.93
Acorn Resort	Capstone Team	October 2022	0.93
North Milford State Park	Capstone Team	October 2022	1.14
	USGS	October 2018	1.20
	USGS	August 2018	0.72
	USGS	July 2018	0.64
South Milford State Park	Capstone Team	October 2022	0.57
	USGS	October 2018	1.20
	USGS	August 2018	0.88
	USGS	July 2018	0.69
Milford Dam	Capstone Team	October 2022	0.51
	USGS	October 2018	1.20
	USGS	August 2018	0.89
	USGS	July 2018	0.61

Table 2

Orthophosphate Test Results at Milford Lake

Location	Data Source	Date	Orthophosphate (ppb)
837 Bridge	Capstone Team	October 2022	164
	USGS	July 2017	147
Smith Bottoms	Capstone Team	October 2022	136
	USGS	July 2017	158
Mall Creek	Capstone Team	October 2022	80
	USGS	July 2017	155
Military Marina	Capstone Team	October 2022	515
	USGS	October 2018	595
	USGS	August 2018	548
	USGS	July 2018	361
Acorn Resort	Capstone Team	October 2022	542
North Milford State Park	Capstone Team	October 2022	590
	USGS	October 2018	557
	USGS	August 2018	423
	USGS	July 2018	316
South Milford State Park	Capstone Team	October 2022	629
	USGS	October 2018	606
	USGS	August 2018	426
	USGS	July 2018	335
Milford Dam	Capstone Team	October 2022	564
	USGS	October 2018	567
	USGS	August 2018	401
	USGS	July 2018	345

Table 3

Observed Dissolved Oxygen Percentage Test Results at Milford Lake

Location	Data Source	Date	Observed Dissolved Oxygen Percentage
837 Bridge	Capstone Team	October 2022	66.9
	USGS	July 2017	74.0
Smith Bottoms	Capstone Team	October 2022	96.6
	USGS	July 2017	97.0
Mall Creek	Capstone Team	October 2022	94.8
	USGS	July 2017	92.0
Military Marina	Capstone Team	October 2022	66.0
	USGS	October 2018	79.0
	USGS	August 2018	171
	USGS	July 2018	193
Acorn Resort	Capstone Team	October 2022	69.0
North Milford State Park	Capstone Team	October 2022	98.5
	USGS	October 2018	90.0
	USGS	August 2018	213
	USGS	July 2018	153
South Milford State Park	Capstone Team	October 2022	98.3
	USGS	October 2018	86.0
	USGS	August 2018	257
	USGS	July 2018	170
Milford Dam	Capstone Team	October 2022	92.4
	USGS	October 2018	93.0
	USGS	August 2018	259
	USGS	July 2018	184

Table 4

Total Algae PC Test Results at Milford Lake

Location	Data Source	Date	Total Algae (RFU)
837 Bridge	Capstone Team	October 2022	0
	USGS	July 2017	1.64
Smith Bottoms	Capstone Team	October 2022	0
	USGS	July 2017	1.98
Mall Creek	Capstone Team	October 2022	0.37
	USGS	July 2017	1.67
Military Marina	Capstone Team	October 2022	0
	USGS	October 2018	0.21
	USGS	August 2018	1.04
	USGS	July 2018	1.03
Acorn Resort	Capstone Team	October 2022	0
North Milford State Park	Capstone Team	October 2022	1.51
	USGS	October 2018	1.30
	USGS	August 2018	4.30
	USGS	July 2018	1.50
South Milford State Park	Capstone Team	October 2022	1.99
	USGS	October 2018	0.09
	USGS	August 2018	1.73
	USGS	July 2018	0.31
Milford Dam	Capstone Team	October 2022	2.51
	USGS	October 2018	0.21
	USGS	August 2018	1.37
	USGS	July 2018	0.46

Table 4

Total Algae PC Test Results at Milford Lake

Location	Data Source	Date	Total Algae (RFU)
837 Bridge	Capstone Team	October 2022	0
	USGS	July 2017	1.64
Smith Bottoms	Capstone Team	October 2022	0
	USGS	July 2017	1.98
Mall Creek	Capstone Team	October 2022	0.37
	USGS	July 2017	1.67
Military Marina	Capstone Team	October 2022	0
	USGS	October 2018	0.21
	USGS	August 2018	1.04
	USGS	July 2018	1.03
Acorn Resort	Capstone Team	October 2022	0
North Milford State Park	Capstone Team	October 2022	1.51
	USGS	October 2018	1.30
	USGS	August 2018	4.30
	USGS	July 2018	1.50
South Milford State Park	Capstone Team	October 2022	1.99
	USGS	October 2018	0.09
	USGS	August 2018	1.73
	USGS	July 2018	0.31
Milford Dam	Capstone Team	October 2022	2.51
	USGS	October 2018	0.21
	USGS	August 2018	1.37
	USGS	July 2018	0.46

Table 5

Turbidity Test Results at Milford Lake

Location	Data Source	Date	Turbidity (FNU)
837 Bridge	Capstone Team	October 2022	0.46
	USGS	July 2017	36.0
Smith Bottoms	Capstone Team	October 2022	42.3
	USGS	July 2017	39.0
Mall Creek	Capstone Team	October 2022	331
	USGS	July 2017	37.0
Military Marina	Capstone Team	October 2022	.427
	USGS	October 2018	50.0
	USGS	August 2018	7.70
	USGS	July 2018	6.2
Acorn Resort	Capstone Team	October 2022	0.45
North Milford State Park	Capstone Team	October 2022	33.2
	USGS	October 2018	9.80
	USGS	August 2018	3.10
	USGS	July 2018	2.00
South Milford State Park	Capstone Team	October 2022	13.8
	USGS	October 2018	9.40
	USGS	August 2018	3.70
	USGS	July 2018	2.30
Milford Dam	Capstone Team	October 2022	29.3
	USGS	October 2018	7.90
	USGS	August 2018	3.40
	USGS	July 2018	2.60

Table 6

Temperature Test Results at Milford Lake

Location	Data Source	Date	Temperature (C°)
837 Bridge	Capstone Team	October 2022	26.0
	USGS	July 2017	27.4
Smith Bottoms	Capstone Team	October 2022	17.7
	USGS	July 2017	28.0
Mall Creek	Capstone Team	October 2022	17.6
	USGS	July 2017	28.0
Military Marina	Capstone Team	October 2022	26.0
	USGS	October 2018	13.1
	USGS	August 2018	28.7
	USGS	July 2018	30.5
Acorn Resort	Capstone Team	October 2022	26.0
North Milford State Park	Capstone Team	October 2022	14.4
	USGS	October 2018	17.0
	USGS	August 2018	29.4
	USGS	July 2018	31.3
South Milford State Park	Capstone Team	October 2022	14.3
	USGS	October 2018	16.5
	USGS	August 2018	29.5
	USGS	July 2018	30.9
Milford Dam	Capstone Team	October 2022	14.6
	USGS	October 2018	17.5
	USGS	August 2018	30.4
	USGS	July 2018	30.0

Table 7

Nitrate Test Results at Milford Lake

Location	Data Source	Date	Nitrate (ppm)
837 Bridge	Capstone Team	October 2022	0.09
Smith Bottoms	Capstone Team	October 2022	0.01
Mall Creek	Capstone Team	October 2022	0.01
Military Marina	Capstone Team	October 2022	0.04
Acorn Resort	Capstone Team	October 2022	0.01
North Milford State Park	Capstone Team	October 2022	0.01
South Milford State Park	Capstone Team	October 2022	0.08
Milford Dam	Capstone Team	October 2022	0.05

Table 8

Ammonium Test Results at Milford Lake

Location	Data Source	Date	Ammonium (ppm)
837 Bridge	Capstone Team	October 2022	0.05
Smith Bottoms	Capstone Team	October 2022	0.05
Mall Creek	Capstone Team	October 2022	0.07
Military Marina	Capstone Team	October 2022	0.14
Acorn Resort	Capstone Team	October 2022	0.01
North Milford State Park	Capstone Team	October 2022	0.01
South Milford State Park	Capstone Team	October 2022	0.11
Milford Dam	Capstone Team	October 2022	0.06

Table 9

Total Phosphate Test Results at Milford Lake

Location	Data Source	Date	Total Phosphate (ppm)
837 Bridge	Capstone Team	October 2022	0.21
Smith Bottoms	Capstone Team	October 2022	0.21
Mall Creek	Capstone Team	October 2022	0.35
Military Marina	Capstone Team	October 2022	0.81
Acorn Resort	Capstone Team	October 2022	0.85
North Milford State Park	Capstone Team	October 2022	0.89
South Milford State Park	Capstone Team	October 2022	0.81
Milford Dam	Capstone Team	October 2022	0.83

Table 10

Total Suspended Solids Test Results at Milford Lake

Location	Data Source	Date	Total Suspended Solids (mg/L)
837 Bridge	Capstone Team	October 2022	18.97
Smith Bottoms	Capstone Team	October 2022	19.19
Mall Creek	Capstone Team	October 2022	68.83
Military Marina	Capstone Team	October 2022	36.26
Acorn Resort	Capstone Team	October 2022	19.15
North Milford State Park	Capstone Team	October 2022	16.48
South Milford State Park	Capstone Team	October 2022	6.82
Milford Dam	Capstone Team	October 2022	24.39