Influences of Nutrient Accumulation, Sedimentation Loading, and Organic Matter on Water Quality in Marion County

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1. Abstract

The purpose of this study is to conduct research on the water quality status of Marion County Lake including summarizing results from previous assessments in order to recommend management strategies to promote public safety within the community. The objectives of this report are: i) to assess nutrient accumulation, ii) to quantify sedimentation loading, and iii) to analyze concentration of organics by conducting a thorough limnological study of Marion County Lake. Biological, chemical, and physical lake characteristics were studied to determine existing conditions and assist in the development of lake management plans. After extensive interpretation of the test results as well as information provided by the Kansas Department of Health and Environment (KDHE), it was concluded that the lake is eutrophic. The water samples which were processed contained relatively low concentrations of potentially dangerous chemicals. However, the data provided by KDHE implies that the total coliform concentration exceeded the Maximum Contaminant Level (MCL) established by the U.S. Environmental Protection Agency. The chlorophyll-a content was high compared to the Kansas and Federal lake benchmarks and the total algal cell count was alarmingly high, suggesting that current conditions pose a risk of algal blooms in the season in which the temperature of the lake is at a maximum.

2. Introduction

In this particular study, the potential effects of agricultural production, sediment loading, and organic matter concentrations on water quality were analyzed as part of the limnological assessment of Marion County Lake. Limnology is defined most generally as the study of freshwater bodies. Typically, limnological studies include analysis the qualitative and quantitative properties of lakes or bodies of water. Natural and anthropogenic eutrophication of the lake is raising concern, as the lake is frequently used for recreational activities.

Several parameters can be considered when conducting limnological studies. For example, water depth, pH, dissolved oxygen, soluble forms of nutrients, and algal growth are commonly tested to ensure environmental safety for plants, animals, and humans. These characteristics can have a profound impact on lake water quality. Nutrients such as nitrogen and phosphorus are important to analyze in limnological studies, especially in areas where the primary land use is agricultural production. Depending on fertilizer application, composition of animal food, methods of animal waste disposal, soil types, and nutrient loss risk factors, these elements can accumulate in groundwater or surface water. Accumulations of these nutrients to the point of eutrophication is a public health concern, as poor water quality can cause growth of harmful bacteria. Testing nitrite and nitrate nitrogen water levels is essential to promote environmental safety of lake water. Further, soluble phosphorus is another nutrient that can contaminate lake water. Phosphorus is immobile in soils, but can pool at the soil surface and flow into lakes via water runoff. Soluble phosphorus, typically occurring in the form of orthophosphate, is then readily available for uptake by algae. This is how phosphorus can help cause eutrophication of lakes and promote growth of algal blooms.

This report consists of an assessment of previously collected data and new water quality sample results that were analyzed at the Kansas State University Soil Testing Lab. The parameters measured in the Marion County Lake water samples include total suspended solids (TSS), total dissolved solids (TDS), electrical conductivity (EC), pH, Total Nitrogen, Total Phosphorus, Ammonia (NH4), Nitrate (NO3), and Ortho Phosphorus.

3. Literature Review

3.1 Nutrient Accumulation

3.1.1 Nutrient Accumulation below Feedlot Pens in Kansas

Livestock are fed excess amounts of phosphorus, urea (which contains nitrogen), and other soluble salts in order to maximize the average daily gain per animal. These nutrients are necessary for growth but are not completely absorbed by the animal and are excreted into the surrounding area. Since environmental impacts of feedlot cattle waste studies have been conducted previously for air, water, and surface soil quality, Vaillant, et al. (2009) decided to measure the effects to subsurface nutrient accumulation in the surrounding areas of feedlots in Kansas specifically. To conduct this analysis, four feedlots in Kansas were used and ranked in order from west to east, each having different rates of rainfall, and subsequently different soils. Table 3.1 (from the article) below displays nitrogen loading comparing two of the pens that were evaluated in the study, displaying a similar trend in nitrogen intake, retention, and excretion.

Table 1. Nitrogen loading found at pen surface for six pens each at two different commercial feedlots, Feedlot 1 and Feedlot 2. The Daily N Retention values come from Kissinger et al. (2007).

Item	Feedlot 1 Avg.	Feedlot 2 Avg.
Average weight, kg	478	435
Head per pen, hd	254	66.0
Area per head, m^2 hd^{-1}	16.8	29.1
Daily N intake, as fed, g hd^{-1} d^{-1}	221	211
Daily N retention, g hd^{-1} d^{-1}	28.0	28.0
Daily N excretion, g hd^{-1} d^{-1}	193	183
Daily pen N excretion, kg m^{-2} d^{-1}	0.0115	0.0063
Yearly pen N excretion, kg m^{-2} yr^{-1}	4.2	2.3

Soil core samples were taken from several pens of each feedlot and measured for soil moisture, pH, and total Nitrogen and Carbon content. Nutrient deposition rates include measurements of ammonium, organic nitrogen, nitrate, chloride/pH, and phosphorus content variability among feedlots. It was concluded that since there had been compaction of the surface soil, that reduces infiltration and diffusion of minerals, meaning that leaching does not contribute significant amounts of nitrogen and phosphorus to groundwater while in use. Although, they did mention that if the feedlots were closer together and the soil were allowed to dry, then there is potential for groundwater contamination from mineralization and nitrogen leaching. Therefore, if there are not any feedlots currently around a water body, it does not necessarily mean that there are not problems with leakage of nutrients from other areas that were previously used as confined feeding operations. Figure 3.2 from the article shown below a similar trend between all the pens that were evaluated for pH, Chlorine, and Phosphorus profiles for each feedlot.

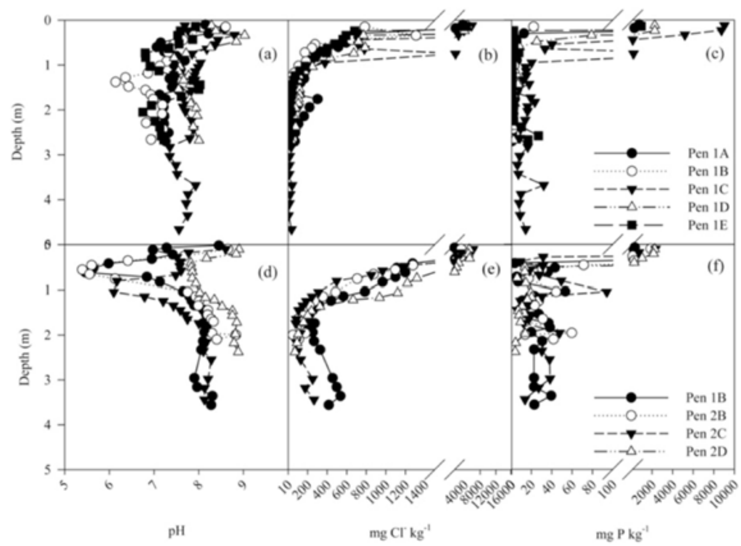

Figure 1. pH, Cl-, and P profiles for Feedlot 1 (a, b, and c) and Feedlot 2 (d, e, and f). The profiles for Feedlot 1 are similar for Feedlots 3 and 4.

3.1.2 Spatiotemporal distribution of Nutrients below Abandoned Feedlots

How nutrients from cropland and feedlot operations were assessed for their influence in the spatial and temporal distribution of nutrients from an abandoned feedlot move into surface water and groundwater through preferential pathways that ultimately can cause problems in the future (Gbolo, P. & Gerla, P.J. J. 2015). Both Nitrogen and Phosphorous are common minerals that are released as waste form these operations. Nitrogen is a short-term contaminator, but Phosphorus is both a short term and long term contaminator. The study was conducted using 15 O horizons, 63 composite O and A horizons, and 61 B horizons to composite a collection of samples within northwest Minnesota feedlot that is adjacent from wetlands.

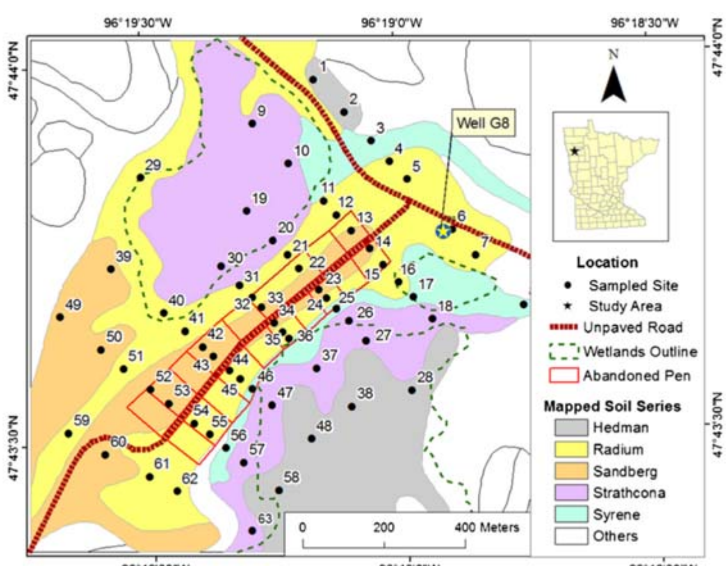

Figure 2. Study area showing soils, pen location, sampled sites, and outline of wetlands

Soil samples were analyzed for Phosphorus, nitrate, and ammonium. A deep-monitoring well was also used to examine the change in the groundwater nutrient concentration over time. The distribution of nutrients indicated in the results a high concentration of phosphorus from the well-drained soil that had been previously been used for feedlots and showed a lower concentration in the nearby wetlands. Interestingly, nitrate showed higher concentrations in the wetlands than the soil, indicating that nitrate is capable of moving further in the plain than phosphorus. Conclusively, there is long term problems with a high concentration of phosphorus accumulation because of the immobile quality of phosphorous. Phosphorus is mainly moved only if erosion and runoff occur.

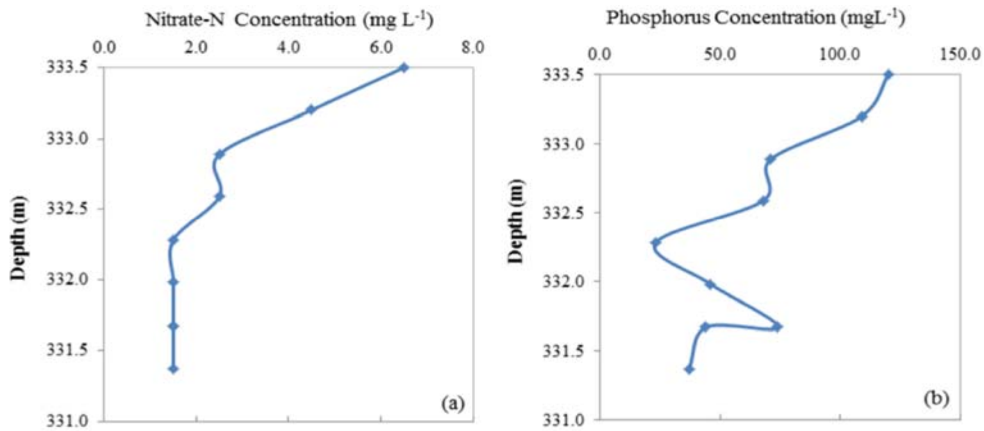

Figure 3. Vertical distribution of the concentrations of NO3-N (a) and P (at sample site 35)

3.1.3 Trends of Nutrient and Sediment Retention in Great Plains Reservoirs

We understand that nutrient accumulation can occur due to surrounding environment contributions; now it is necessary to know how the nutrients are held in water bodies in Kansas. The reservoirs efficiency of nutrient cycling in six reservoirs in Kansas due to agriculture and other anthropogenic processes was investigated in [Cunha, D. G., Fernandes, Do, C. C., & Dodds, W. K. (2014]. A thirty-year time series discharge, total phosphorus, nitrate and the total suspended solids among six different reservoirs. The testing included correlations among retention, discharge, and how they change over time. Since Kansas has a range of precipitation rates in different areas, the reservoirs selected were in different areas, depths, and residence times. Data was collected upstream and downstream reservoirs of total phosphorus, total suspended solids, total nitrates on a bimonthly basis from 1972 to 2010 by the Kansas Department of Health and Environment. Discharge was monitored by the United States Geological Survey. To analyze the data, a confidence of 95% and then linear regression to analyze the differences in discharge, retention, paired nitrogen and total nitrogen. All reservoirs showed that they removed solids and nutrients from upstream to downstream at a rate that was statistically significant. The average reduction of the total phosphorus was between 42 and 74%, the total suspended solids was between 0 and 93%, and the total nitrates were between 11 and 56%. The ability to remove the minerals did not change over time. The article explains that the difference in discharge significantly influenced the retention of nutrients in the reservoir. Understanding the trends of how nutrients are known to be retained in the reservoirs are important to understand because reservoirs cycle nutrients at a constant rate and if there are additions that are continuously being incorporated from nearby feedlots, the reservoir would not be capable of removing it.

Figure 4. Map of several lakes north of Marion County, Kansas

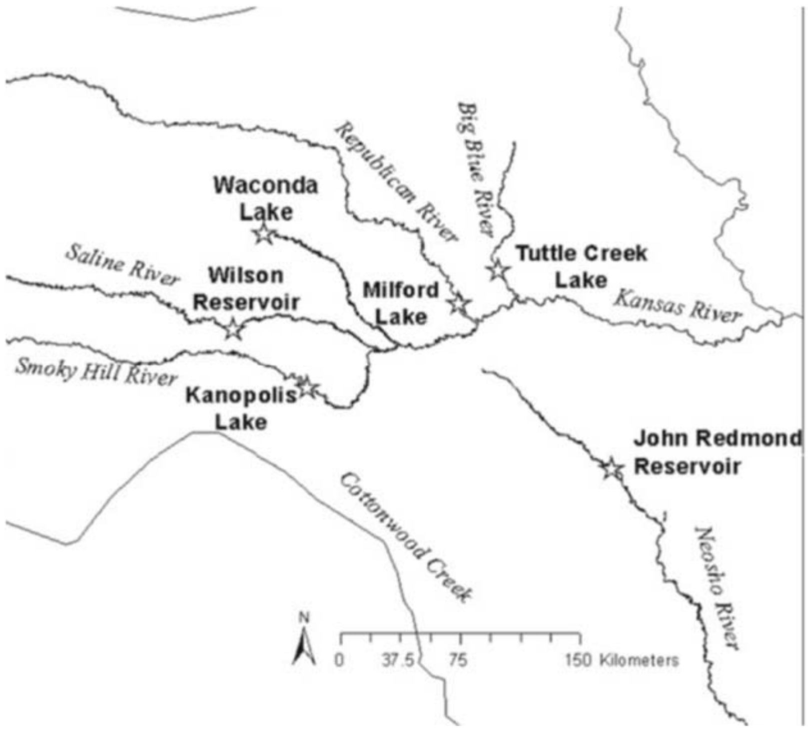

Table 2. Mean reduction (%) for total phosphorus (TP), total suspended solids (TSS), and nitrate (NO3-) from upstream to downstream each of the studied reservoirs: Kanopolis, John Redmond, Wilson, Tuttle Creek, Milford and Waconda

Variable reservoir	TP (%)	TSS (%)	NO_3^- (%)
Kanopolis	67	83	14
John Redmond	67	72	56
Wilson	50	64	39
Tuttle Creek	74	93	11
Milford	63	86	33
Waconda	42	–	48

All shown percentages of reduction were considered statistically greater than zero ($p<0.05$, MANOVA)

– no reduction

3.1.4 Dissolved Organic Nitrogen in Wastewaters from Animal Feedlots

Because algae blooms have caused a wide range of problems it was deemed necessary to determine dissolved organic nitrogen and bioavailable dissolved organic nitrogen levels from two different sources and the response that they have when inoculated with different levels of algae and/or bacteria. The livestock that was held during the sampling period were sheep, pigs, and predominantly cattle. S. Jingyi, et al. (2017) used six grab samples each week from April until October 2014. For each of these samples and their duplicates the average and standard deviation values were determined immediately after the water was filtered. Wastewater samples were also taken below the lagoons surface. Two algal species were obtained to inoculate the water and incubated for 21 days to determine the limitations of what algae can be grown from different water sources. Dissolved nitrogen was measuring using a second derivative ultraviolet spectrophotometric method to detect concentrations within a certain range. A statistical analysis was then conducted to evaluate the statistical difference under different inoculation conditions. Total dissolved nitrogen mostly contained ammonia and dissolved organic nitrogen which were utilized by the algae and bacteria for growth. Bioavailability of dissolved organic nitrogen proved to be similar regardless of wastewater sources. Also, the bioavailability of the dissolved organic nitrogen was between 36 and 79% available to either algae or algae and bacteria inoculum. Since algae requires more nitrogen for growth, these results were said to be predictable. The article explains that the possible reasons for the high nitrite accumulation in the samples were pH variation, lack of oxygen (due to high NH3 content), and inadequate nitrite oxidizing bacteria. It also mentions that dissolved organic nitrogen should receive more attention in livestock wastewater management along standard water quality parameters. A summary of the summary is shown in the graphical abstract below:

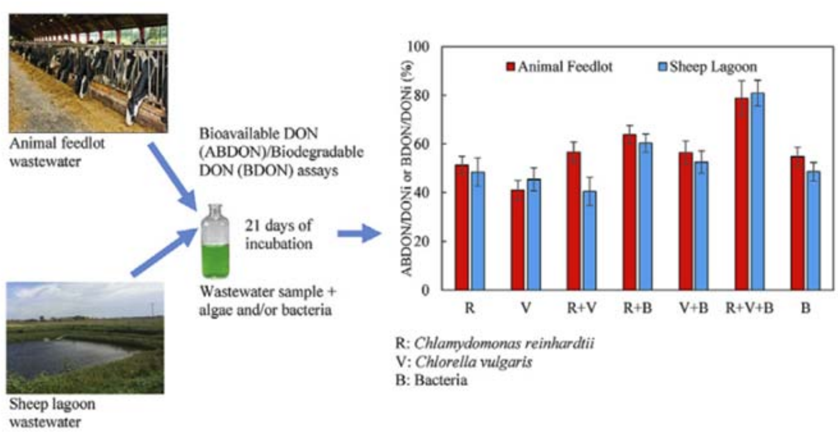

Figure 5. Different types of bacteria detected using a Bioavailable DON (ABDON) or biodegradable DON (BDON) assay for animal feedlots and sheep lagoons

3.1.5 Effect of Phosphorus Loadings on Lake Quality

In the study (Song et al. 2017) determined how much phosphorus that is internally released from the sediment of hypereutrophic lakes, how much do internal phosphorus loads contribute to lake water quality compared to external loads, and the factors that regulate the release and retention of phosphorus in the sediment. Four lakes were selected in Nebraska to study the internal and external phosphorus loads. External loads are phosphorus carried with water through rivers and stream channels in watersheds to downstream lakes or reservoirs. Water quality samples were collected biweekly at the deepest locations of lake water using a “Van Dorn sampler” and were collected at the same location from June to November 2014. External phosphorus loadings were quantified through inflow water samples feeding the lakes were collected as well through base flow water sampling and storm water sampling.

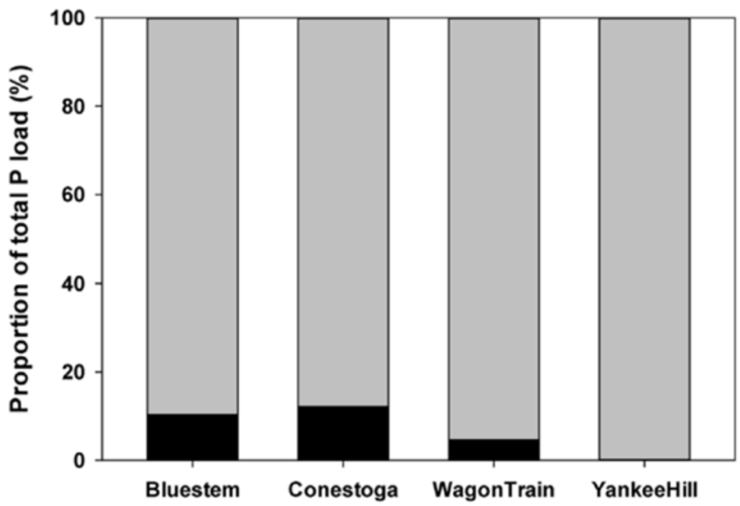

Figure 6. Relative contribution of annual external (grey) and internal P (black) loads into total P input to the study reservoirs

Internal phosphorus loadings were quantified by measuring the phosphorus release rate under aerobic and anaerobic conditions, how long anoxia conditions occurred when taking core samples of the soil. The article indicates that agricultural reservoirs are vulnerable to eutrophication with the greatest source of Phosphorus being transferred from the surrounding area. It was also seen that external phosphorus loadings contribute to up to 96% of the total input into reservoirs and 4-12% of the total phosphorus loads from internal phosphorus.

3.1.6 Summary

This research of feedlots proved their contribution to nutrient accumulation at different degrees in the underlying soil. Accumulation was shown to be quite severe especially in the shallow bedrock in this area. Also, depending on the compaction of the soil that is beneath the animal waste, the amount of nutrients that would be infiltrated and diffused of minerals would be reduced. This indicates that leaching would not contribute significant amounts of nitrogen and phosphorus in groundwater while in use. Although, if feedlots are closer together, and the soil was allowed to dry, groundwater contamination from mineralization and nitrogen leaching would be a possibility. Cations such as Ammonium-N were absorbed by soil clays in Kansas that were below the compacted liner and didn’t accumulate greater than three meters in depth. Ammonium nitrogen concentrations were greatest in the first half meter of soil. Well-drained soil that had been previously been used for feedlots and showed a lower concentration in the nearby wetlands.

Nitrate showed higher concentrations in the wetlands than the soil, indicating that nitrate is capable of moving further in the plain than phosphorus. There are long term problems with a high concentration of phosphorus accumulation because of the immobile quality of phosphorous. Phosphorus is mainly moved only if erosion and runoff occur. Also, in regard to Marion County lake and reservoir, that if there is phosphorus accumulation in the water, it must be due to separate forces than only the deposition from animal excreta. Agricultural reservoirs would then be most vulnerable to eutrophication with the greatest source of Phosphorus being transferred from the surrounding area due to fertilizer runoff from irrigation. Bioavailability of dissolved nitrogen is highly available to algae and bacteria inoculum due to the algae's large requirements for nitrogen. High nitrite accumulations were shown by pH variations, lack of oxygen due to nitrite content, and inadequate nitrite oxidizing bacteria in the water. Since there is some conflicting data, it would be ideal to study the soils surrounding the feedlot at various distances to understand the capability nutrients have of traveling to the nearby lake or what is causing them to travel; whether it may be runoff or erosion.

3.2 Sedimentation and Sediment Loading

3.2.1 Introduction

When one thinks of problems associated with reservoirs and lakes, many usually think of fish die-offs, or algae blooms. Many don't think about the root causes for these problems, those causes being sedimentation and sediment loading. Though natural, these two systems can have a huge adverse impact on the environment when one considers the effect humanity has had on both the climate and land use around these water systems. This literature review will quickly summarize some of the major points concerning sedimentation and sediment loading.

3.2.2 Background

a. Climate

To begin to understand why sedimentation and sediment loading are an issue, one must first look at the immediate climate for the area affected. This is due to the interconnected nature of climate and freshwater quality. Any change in climate systems will have an effect on freshwater ecosystems and the areas surrounding them. According to a study done in Switzerland, some possible effects of climate changes are changes in streamflow, rises in water temperature, and changes in biochemical reactions (Fant 2017). These changes can have large effects on the rates of sedimentation, and through several other processes, sediment loading.

b. Sedimentation and Sediment Loading

Sedimentation and sediment loading can therefore become serious threats to lakes and reservoirs. Both are natural occurrences and are usually not harmful to natural ecosystems. However, human intervention such as human-accelerated climate change has caused these natural systems to become harmful to water bodies. Sedimentation in reservoirs causes sediment to slowly fill several important layers in the water body. These layers, once filled, mean that the reservoir must be dredged, or turned into a wetland. Sediment loading on the other hand is a much larger problem. Normally, trace amounts of minerals and elements are in the water flow at any one time, and this is normal. With an increase in fertilizer usage via agricultural purposes, the amount of nitrogen and phosphorous have increased drastically.

Once in the water system via sedimentation, nutrients can be absorbed by sediments, hence 'sediment loading'. This is possibly the highest risk for deteriorating water quality. It was once thought that phosphorus loads in sediment and the water system could be as high as the phosphorus inputs into the system, especially near agricultural areas. However, there is a frightening lack of data studying current, or internal, phosphorus loads compared to input, or external, phosphorus loads and what factors regulate the release and retention of phosphorous once it's in these systems. From preliminary studies, such as one done by Song et al. (2017), it appears that the majority of internal loading occurs during the summer, when lakes/reservoirs experience anaerobic conditions. Comparing the two types of phosphorous loading, the report found external loading made up 98% of total phosphorus inputs into the system, accounting for large internal loads during the summer.

c. Stratification

Another factor that needs to be taken into account is the stratification of the water body being studied. Stratification refers to the separation of lakes into three layers: the Epilimnion, the top of the lake; the Metalimnion, or Thermocline, the middle layer (which may change depth depending on temperatures); and the Hypolimnion, the bottom layer. These stratification layers refer to the change in temperature at differing depths. A report from Acton Lake, UT, measured sediment nutrient loads at two points: one thermally stratified and the other unstratified. From these two measurement points, it was found that waters that are more stratified release more phosphorus into the waters than non-stratified sites. Nutrients released from these lake sediments has a heavy influence on the quality of the water and the activity of plankton. Implementation of better management strategies and practices are therefore required to manage the amount of loaded nitrogen and phosphorus entering the water systems.

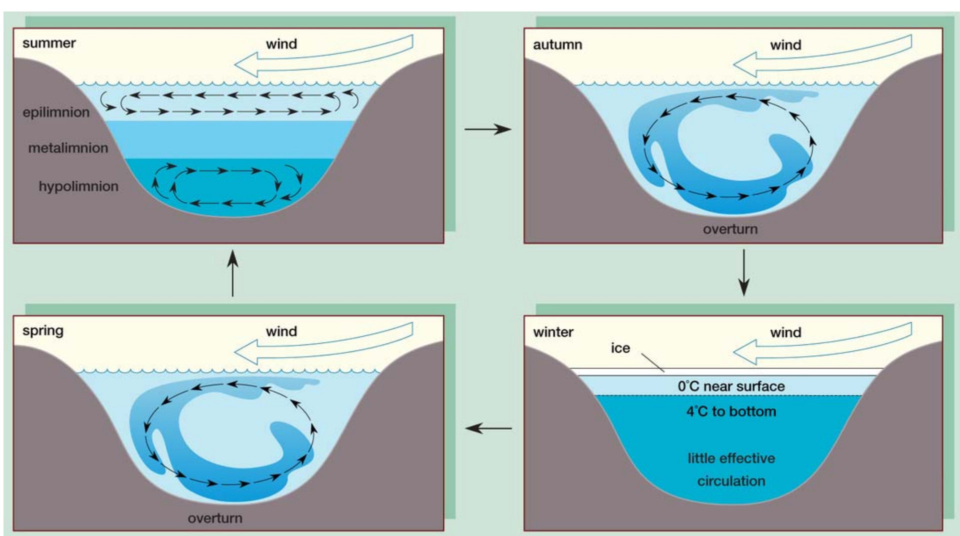

Figure 7. Stratification levels during different seasons

d. **Trophic Levels**

Trophic levels are determined by the amount of nitrogen, phosphorus, and other biological nutrients in the water. Nitrogen and phosphorous are considered 'limiting resources', with increased concentrations resulting in increased plant growth. Lakes/reservoirs with low nutrient levels will be considered 'Oligotrophic' and have low algae production and very clear waters. Lakes/reservoirs with and intermediate amount of nutrients are considered Mesotrophic and are commonly clear water lakes or ponds. Eutrophic water bodies however have a very high amount of nutrients in the waters and are usually covered in algae or aquatic plants. When an abnormally large amount of nutrients is concentrated in lake waters, the process of eutrophication may occur, becoming so enriched with nutrients that bacteria and algae completely take over the top layer of the water body. When these algae die, they sink to the bottom, where the process of decomposition occurs. This process involves a massive intake of oxygen though, and the water body may soon become deprived of dissolved oxygen as a result.

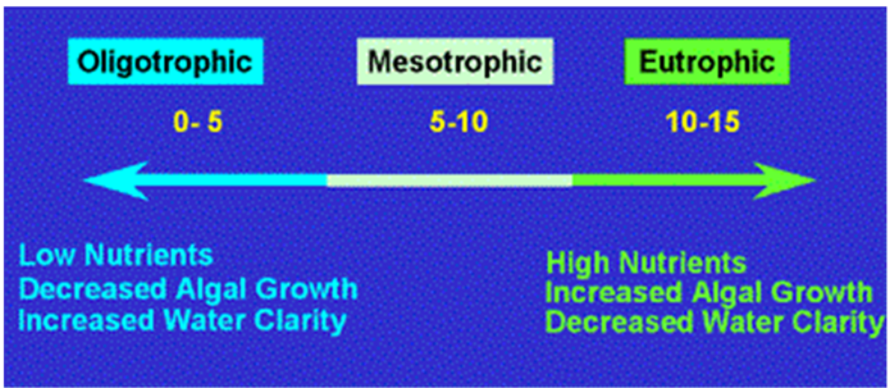

Figure 8. The three trophic levels, and some associated features.

For example, according to a report (Song and Burgin 2017), nearly half of all lakes and reservoirs in the United States are impaired. The causes of this impairment are the result of excessive nutrient loading and the resulting eutrophication. The authors set out to answer two questions: What are the underlying causes controlling internal phosphorus loading and retention; and how does trophic state affect internal phosphorus loading? Internal phosphorus loading seems to be related to trophic levels. In less eutrophic lakes, chemicals and sediment-bound phosphorous seemed to determine internal loading. In more eutrophic lakes on the other hand, biological variables such as plankton and other biomass caused internal loading. This difference was caused due to the high levels of sediment-bound phosphorus being broken down by plankton, which amplified the internal phosphorous release, creating a perpetual cycle of internal loading.

3.2.3 Methods and Case Studies

a. **Switzerland ~ C. Fant**

To understand the intricacies that climate change may have on sediment systems, complex studies must be undertaken to understand the interconnectedness of these systems. For example, a case study from Switzerland used a complex series of water quality measuring systems, climate models, and greenhouse gas mitigation policies to put together a potential assessment of water quality conditions in the United States out to the year 2100. To properly account for the complexity of the studied area, multiple considerations were used as water quality parameters: water temperature, dissolved oxygen content, total nitrogen content, and total phosphorous content. Taken into account, the study found that water quality will worsen across the country, with the eastern states deteriorating quicker than the western states. Together, these changes in water quality will cost between 1.2–b2.3 billion USD/year in 2050, and 2.7 – 4.8 billion USD/year in 2090 (Fant 2017).

3.2.4. Strategies and Management

a. Best Management Practices

Implementation of wide-scale watershed management efforts with a variety of best management practices (BMP's), are required in order to mitigate and manage sedimentation and sediment loading of lakes and reservoirs. An example of such practices can be found in a paper studying nutrient loading on lakes and reservoirs by R.E. Lizotte, where an assessment of a lake (Beasely Lake) in a 625 ha watershed surrounded by intensive row-crop style agriculture activity. The area was monitored over a 14 year period from 1996 – 2009. 87 ha's were implemented into a BMP program, with total phosphorus, soluble reactive phosphorus, ammonium, and nitrate being measured biweekly during the years of the project. The results of the switch to BMP's showed that the program was successful, with a marked decrease in the measured nutrients. Notable BMP's that worked the most effectively in reducing sedimentation and sediment loading were vegetative buffers and conservation tillage.

Apart from BMP's, another part of any water management plan related to BMP's would be construction of a 'phosphorous budget', or a set amount of phosphorous that the plan would allow into the lake/reservoir/watershed at any given time. Part of the plan should also be dedicated to biological processes and dissolved oxygen availability, measuring these parameters and making sure that lakes/reservoirs remain at a stable level capable of supporting the local ecosystem.

3.2.5 Summary

Sedimentation and sediment loading are a problems that must to be addressed. Since the magnitude and rate of sedimentation and sediment loading depend on the climate, temperature, and trophic state, managing these concerns can be a daunting task. Many preliminary research efforts have shown that mitigation and management is indeed possible if time and effort are dedicated to research individual water bodies (as every water body is different). Through various management programs and practices, individuals and organizations can mitigate the amount of nutrients that are deposited into water bodies.

3.3 Organic Matter and Water Quality

3.3.1 Biological Attributes

The presence of organic matter in soil promotes growth and development of plants, supports soil health, and stimulates nutrient cycling. However, organic matter in water is more complex, as the accumulation of nutrients can cause growth of harmful substances. Algal blooms are arguably the most important factor to consider regarding lake toxicity and public health hazards. Algal growth is stimulated by warm temperatures, which is why algae is typically of the most concern during summer months. Two effective methods of identifying algal blooms are cyanobacteria cell counts and chlorophyll concentrations, according to the World Health Organization (WHO) (Cong 2015). Marion County Reservoir, a freshwater body that is geographically similar to Marion County Park and Lake, contains much higher levels of nutrients and chlorophyll compared to the benchmarks recommended by the Kansas Department of Health and Environment (KDHE). Multiple methods have been developed for detecting cyanotoxins in water, including mouse bioassays, immunological assays, biochemical assays, and chromatographic techniques (Cong 2015). For this particular research project, water and soil samples were collected by the group members then analyzed for several parameters by the Kansas State University Soil Testing Lab.

Table 3. Secchi depth and concentration of total nitrogen, total phosphorus, and chlorophyll a for Marion Lake, federal reservoirs, and 105 Kansas freshwater bodies

Median trophic values of Marion Lake in comparison with other reservoirs and Kansas trophic benchmarks (reference conditions). The Kansas benchmark values were derived from 105 lakes and reservoirs, based on the data collected between 1985 and 2002.

Trophic Indicator	Marion Lake	Federal Reservoirs	Kansas Benchmarks
Secchi depth (cm)	64	95	129
TN (µg/L)	1,190	903	625
TP (µg/L)	80	76	23
Chlorophyll *a* (µg/L)	15	12	8

The table above was compiled by the KDHE and shows the following measurements taken form 105 Kansas freshwater bodies between 1985 and 2002 and compares the values to the benchmarks for federal reservoirs. The parameters for Marion County are compared with the Kansas values and the federal values. The table shows that the total concentrations of nitrogen, phosphorus, and chlorophyll for Marion Lake are greater than the benchmark values for Kansas and federal freshwater bodies.

3.3.2 Summary

Marion County Park and Lake is an integral part of the local community and of the greater Flint Hills region. The lake serves as an ecosystem service, so the water quality of the lake is essential to preserve the safety and public health of the community. Since the park and lake are not currently managed sufficiently, the goal of this research project is to collect data and develop a management plan for the property. After a site investigation, soil and water sampling and analysis, and interpretation of results, the research team has proposed strategies to prevent contamination and treat existing water quality problems. The examined parameters consist of pH, nutrient concentrations, dissolved oxygen, zooplankton population, and algal growth. Expected management strategies will be to relocate nearby animal production operations, implement no-till cultivation, and promote governmental regulation of disposal of wastewater and solid waste.

4. Methods

4.1 Study Sites

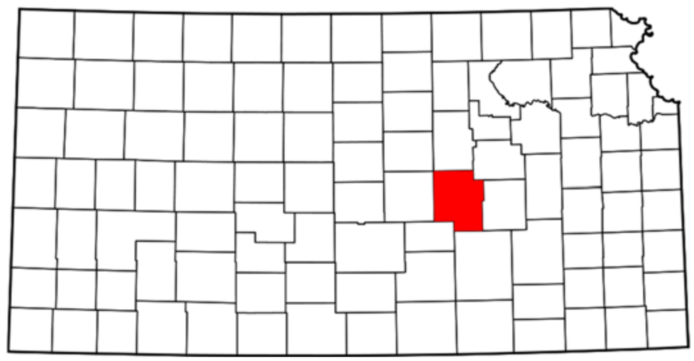

Figure 9. Map of Kansas delineating Marion County

Marion County Park and Lake is the area of interest for this particular study. The park contains approximately 300 acres of land, 150 acres of water, and is surrounded by about 200 homes. The lake falls within the Upper Cottonwood sub-basin, and the associated drainage area for the lake is approximately 6.2 square miles. Marion County Lake is located in the Flint Hills region of Kansas, which has a designated use of primary and secondary recreation as well as aquatic life support and food procurement.

All lake uses are currently impaired by eutrophication. At conservation pool levels, the lake has an area of 134.4 acres, a maximum depth of 10.0 meters, an average depth of 3.4 meters, and a retention time of 1.2 years. The county-owned park and lake opened in May, 1940 in Marion County, Kansas, located in the western Flint Hills. The park manager resigned in 2017, resulting in a need for a new management plan for the park and lake. The history of data collection from Marion Lake has been inconsistent and incomplete. However, KDHE has been tasked with gathering previously compiled information and assessing this data as it relates to the current status of the lake. Soil and water data has been extracted from several sources to construct a more complete image of the environmental conditions in the area.

Currently, the Lake is considered to be fully eutrophic, with a trophic state index of 56.39. The trophic state index (TSI) is derived from the chlorophyll a concentration in the lake waters. Trophic state assessments of algal activity are based on chlorophyll a concentrations, nutrient levels, and consideration of the TSI. At this time, the lake is listed for dissolved oxygen impairment alongside eutrophication.

Table 4. Range of trophic levels and their respective TSI

Trophic Level	TSI
Oligotrophic	< 40
Mesotrophic	40 – 49.99
Slightly Eutrophic	50 – 54.99
Fully Eutrophic	55 – 59.99
Very Eutrophic	60 – 63.99
Hypereutrophic	> 64

4.1.1 Upper Cottonwood Watershed

Although the study area of Marion County Park and Lake is about 450 acres, the property is only a fraction of the surrounding watershed. A watershed, defined by the United States Geological Survey (USGS), is an area of land that drains all of the streams and rainfall to a common outlet such as the outflow of a reservoir, mouth of a bay, or any point along a stream channel. Then name of the watershed to which Marion County Lake belongs is the Upper Cottonwood watershed. The map shown in Figure 10 contains 6.2 square miles of drainage area, referring to the area of land that gathers in Marion Lake after rainfall events.

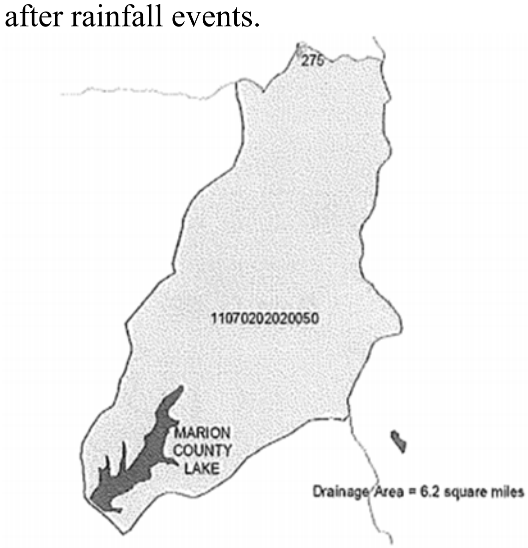

Figure 10. Map of the Upper Cottonwood Watershed showing the corresponding drainage area and Marion County Lake

The U.S. Environmental Protection Agency (USEPA) provides information from annual reports from each state regarding the causes of impairment for each watershed. In 2016, the state reported five causes of impairment in Upper Cottonwood watershed area. Atrazine, total suspended solids (TSS), total phosphorus, sulfate, and eutrophication were the five parameters which were reported as not meeting water quality standards.

Table 5. Causes of impairment and number of causes reported in the Kansas Upper Cottonwood watershed for the 2016 reporting year

Cause of Impairment	Number of Causes Reported
Atrazine	15
Total Suspended Solids (TSS)	10
Phosphorus, Total	5
Sulfate	4
Eutrophication	1

4.1.2 Soil Map

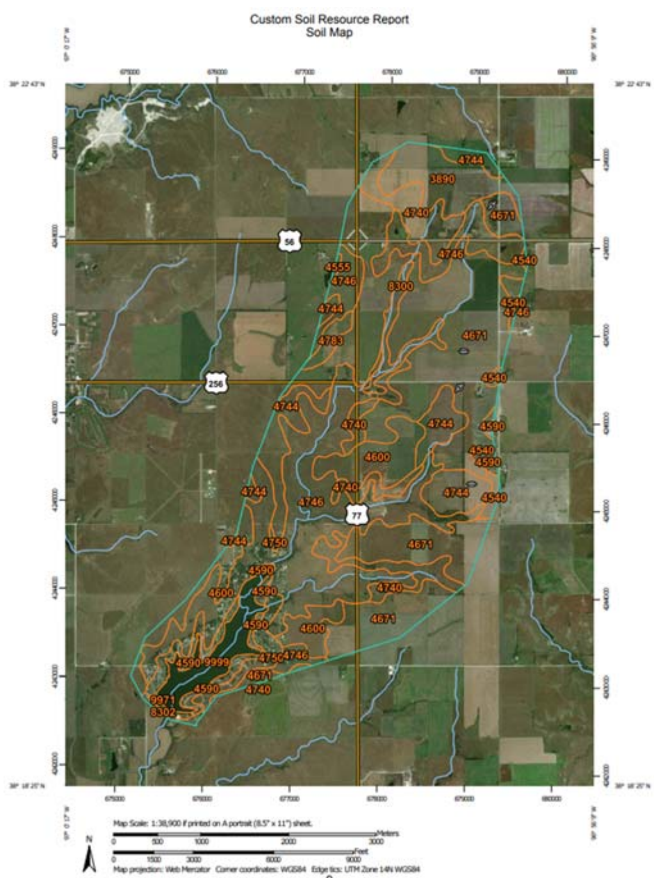

Figure 11. Soil map of Marion County Lake and surrounding watershed

4.1.3 Soil Classification

The custom soil map provided by the Natural Resource Conservation Service (NRCS) Web Soil Survey shows the portion of the Upper Cottonwood watershed which drains into Marion Lake. The soil map indicates two predominant soil mapping units in the area of interest: the Irwin Silty Clay Loam and the Labette-Sogn silty clay loam. The characteristics of these soils are important to consider when conducting environmental research, as soils have a profound impact on water translocation, infiltration, erosion, and other properties of water movement. The Irwin Silty Clay Loam comprises 33.7% of the area of interest. This mapping unit ranges from 980 ft to 1660 ft in elevation and receives 31 to 38 inches of annual precipitation. The mean annual air temperature of this mapping unit is 54 to 57 degrees Fahrenheit. This soil is moderately well drained and belongs to the “high” runoff class. The height of available water in this soil profile is typically about 9.7 inches, which is characterized as “high” storage capacity. A common soil profile of the Irwin Silty Clay Loam has an Ap surface horizon, indicating dark color, high organic matter, and tillage. Next is a thick illuvial B horizon with the accumulation of silicate clays . which may contain carbonate . Below the B horizons is a C horizon with little or no indication of weathering.

4.2 Sampling

4.2.1 Marion County Water Analysis

On April 14th, 2018, water was collected at four separate locations on the lake in order to gain a understanding of the contents of Marion County Lake water at this current time. Four 250 mL samples were collected using Nalgene Bottles from Fisher Scientific. The samples were submerged in the water to achieve the maximum amount of water the bottle can hold for analysis. Post-collection, the samples were subsequently labeled to correspond with the location in which they were collected displayed in the satellite imagery used below:

Figure 12. Map of Marion County Lake Water Sample Collection

The four samples were then taken to the Kansas State University (KSU) Soil Testing Lab for water analysis. The parameters measured include total suspended solids (TSS), total dissolved solids (TDS), electrical conductivity (EC), pH, Total Nitrogen, Total Phosphorus, Ammonia (NH4), Nitrate (NO3), and Ortho Phosphorus.

4.3 Analysis

Table 6. KSU Soil Testing Lab Water Analysis Results

Lab # (s)	Sample Name	TSS mg/L	TDS mg/L	EC mS/cm	pH	Total N ppm	Total P ppm	NH4-N ppm	NO3-N ppm	Ortho P ppb
502794	1	19	244	0.35	8.00	0.95	0.02	0.04	0.15	144
502795	2	25	246	0.35	8.20	1.04	0.03	0.06	0.13	41
502796	3	35	258	0.37	8.12	0.96	0.03	0.09	0.10	10
502797	4	184	247	0.35	8.18	2.28	0.17	0.04	0.14	<5

4.3.1 Test Result Analysis

When first viewing these results, it is notable that the 4th sample seams be substantially higher than the other samples in total suspended solids, total nitrogen and total phosphorus. According to the article *Interpreting Water Tests for Ponds and Lakes* (Swistock n.d.) nitrate-nitrogen concentrations above 3 mg/L and any detectable amounts of total phosphorus above 0025 mg/L may be an indication of pollution from various sources, such as, fertilizers, manures, or other nutrient rich wastes. Total Nitrogen ranged from 0.95-2.28 ppm and Total Phosphorus ranged from 0.02-0.17. With the understanding that 1 ppm = 1 mg/L, it is shown that total phosphorus content from 3 of the 4 samples is in the range of polluting quantities. Only the fourth sample at a total nitrogen of 2.28 showed an increase in the amount of pollution. When collecting the samples, it was noted that foam was seen in the water, as well as algal growth on the nearby bedrocks of the lake. Orthophosphate is the plant available form of phosphate that is said to be the most stable and is often referred to as “reactive phosphorus”. Orthophosphate is produced during natural process such as sewage. (Murphy n.d.) Interestingly, the greatest amount of orthophosphate was in the first sample. Electrical Conductance of the water measures how well water can conduct an electrical current, and increases with increasing amounts of mobility of ions (Murphy n.d.). These range and do not have regulatory levels. Measurements of total dissolved solids is regulated as an indicator of the conductance of the water.

Water quality is a concern when quantities of total dissolved solids (TDS) are above 1000 mg/L (B. Swistock). All four samples are well below this limit. Total suspended solids are defined as solids that can be trapped by a filter, and are known to be able to block sunlight from reaching vegetation that is submerged within the water. A reduction in the rate of photosynthesis would subsequently lead to less oxygen respiration into the water by plants. A high TSS could also indicate larger amount of bacteria, nutrients, pesticides, and metals in the water. (Murphy n.d.) Although, according to the same article, the EPA does not have regulations for TSS. When taking pH into consideration, the US Environmental Protection Agency set a standard for ph levels should be between 6.5 and 8.5. The pH from the four samples averaged to 8.125, which is higher on the spectrum but within range. The pH is a representation of the concentration of hydrogen ions in the water. The presence of calcite (CaCO3) can cause the release of carbonates (HCO3, CO3), resulting in increased alkaline waters. (Murphy n.d.) Since calcite is known to be present in the soils in the Midwest, this could be the reason there is an increase in pH of the waters in Marion County Lake.

4.3.2 Water Contaminants

One aspect that must be studied for a complete understanding of water quality is the concentration of water contaminants. Water contaminants exist in many different categories, including organic chemicals, inorganic chemicals, metals, herbicides, and bacteria. These substances are regulated by the U.S. Environmental Protection Agency (USEPA), which has specific maximum contaminant levels (MCL) for drinking water. The historical data provided by the KDHE indicates that most parameters are below the aforementioned MCL's, but there are a few notable contaminants that are present at levels unsafe for drinking water. One of these parameters is total coliforms. The maximum recorded total fecal coliform found in Marion Lake was 10 cfu/100mL, with 7.14% of samples testing positive. This percentage exceeds the 5% MCL regulation for drinking water. Although total coliform does not directly threaten human health, it often serves as an indicator of the presence of potentially harmful bacteria (USEPA). Even if the local water municipality does not use water from Marion Lake to provide water to the community, the presence of the coliform could pose a health risk for those in contact with the water for recreational purposes.

Additionally, algal cell counts from Marion Lake indicate that the water is unsafe to drink because the algae concentration exceeds the MCL allowed by USEPA and the World Health Organization (WHO). Referring to the data provided the KDHE, it was found that the maximum cyanobacteria cell count was 520,380 cell/mL. This value was recorded on August 9, 2017 at 10:48 A.M. The correlation between warm weather and cyanobacterial growth observed in literature is supported by this data source, as the maximum levels occur in late summer. However, it is important to realize that high cyanobacteria concentrations are not always directly related to high safety risk. According to the WHO, "Worldwide, about 60% of cyanobacterial samples investigated contain toxins (...) The toxicity of a single bloom may, however, change in both time and space. Demonstrations of toxicity of the cyanobacterial population in a given lake do not necessarily imply an environmental or human hazard as long as the cells remain thinly dispersed. Mass developments and especially surface scums pose the risks." The health risk of cyanobacteria is complicated and incorporates many factors into the environmental assessment. As a general guideline, "a level of 100,000 cyanobacterial cells/ml (which is equivalent to approximately 50 mg chlorophyll-a/litre if cyanobacteria dominate) represents a guideline value for a moderate health alert in recreational waters" (WHO). Table 7 below shows the trophic designations of water bodies based on chlorophyll-a content. Lakes or reservoirs with a chlorophyll-a concentration between 7.21 and 30.0 ug/L are considered eutrophic.

Table 7. Trophic designation by concentration of chlorophyll-a (ug/L) in lake or reservoir water

Lake or reservoir trophic designation	TSI	Chlorophyll-a
Oligo-mesotrophic:	0-39	≤ 2.50 ug/L
Mesotrophic:	40-49	2.51-7.20 ug/L
Eutrophic:	50-63	7.21-30.0 ug/L
Hypereutrophic:	> 63	> 30.0 ug/L
Argillotrophic:	n/a	n/a

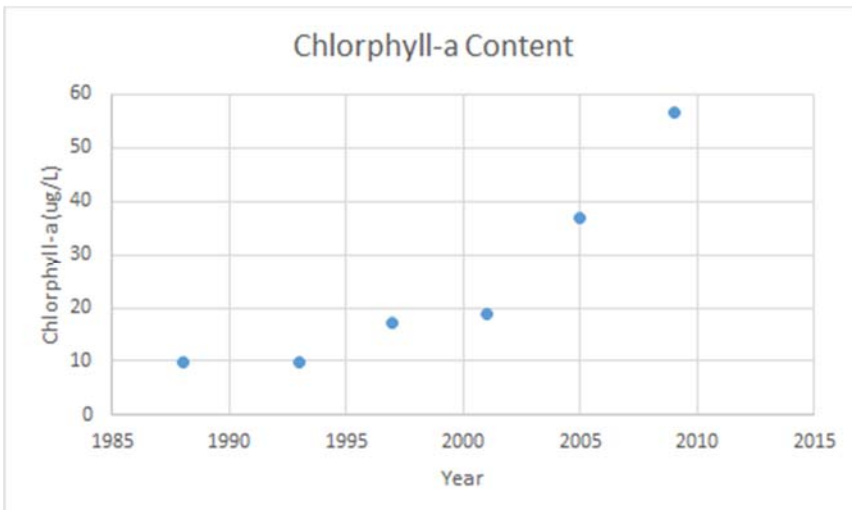

Figure 13. Chlorophyll-a concentration (ug/L) of water found in Marion County Lake from 1988 to 2009.

With the information provided by KDHE which is shown in Figure 13, it can be seen that the chlorophyll-a concentration in Marion County Lake is increasing rapidly. Additionally, the 2009 value of 56.7 ug/L classifies the lake as hypereutrophic. Additionally, alternative data sources indicate eutrophic conditions of the lake. As previously stated in Table 6, the chlorophyll-a concentration in Marion Lake exceeds the benchmark for Kansas freshwater bodies and for Federal reservoirs. The reported chlorophyll-a value was 15 ug/L, which is concerning from a water quality perspective. Although Marion Lake and Marion County Lake are separate bodies of water, they both belong to the Upper Cottonwood watershed and likely share common land uses and management practices. Therefore, to an extent, the parameters reported from Marion Lake can be compared with the concentrations present in the area of interest for this research project.

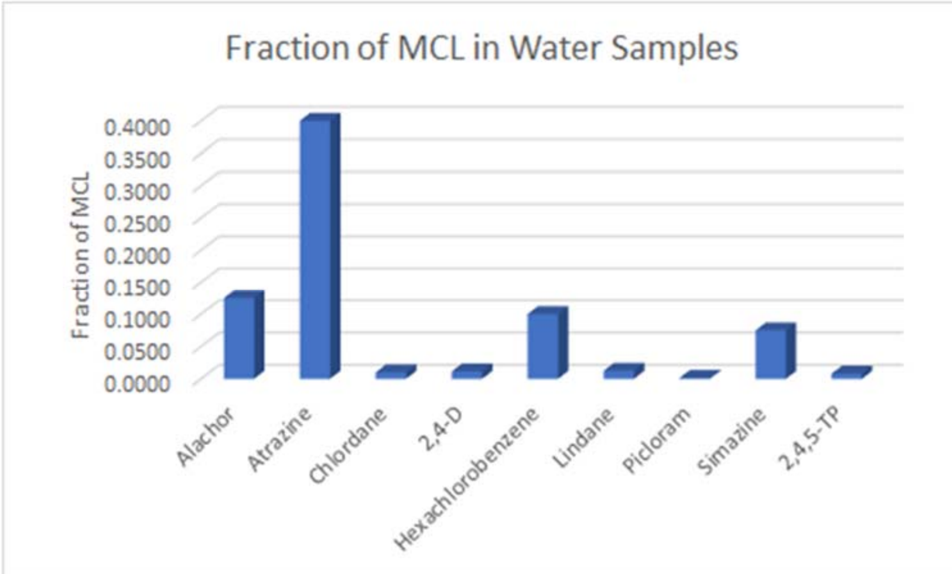

Figure 14. Fraction of the maximum value of several inorganic water contaminants found in Marion Lake compared to the corresponding maximum contaminant level (MCL) established by the USEPA for drinking water

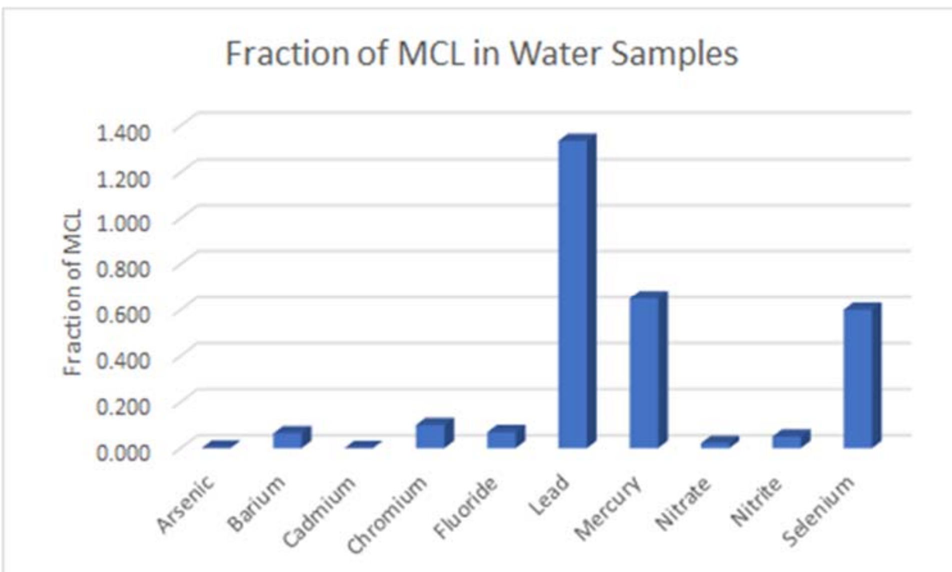

Figure 15. Fraction of the maximum value of several organic water contaminants found in Marion Lake compared to the corresponding maximum contaminant level (MCL) established by the USEPA for drinking water

Although a few water quality parameters exceeded the MCL values for drinking water, most of the contaminants were detected at significantly lower levels. Each of the analyzed inorganic and organic chemicals in the lake were present at 1% of the drinking water MCL or less. The tables above compare test values of some notable parameters with the MCL's established by the USEPA.

5. Discussion

An interdisciplinary approach must be taken to rectify the current water quality problems in Marion County Park and Lake. Since the primary source of the eutrophication in the lake is nutrient contamination from agricultural operations, farm managers should implement the government-suggested BMP's regarding fertilizer application, tillage, and animal waste removal. Animal operations should be located a safe distance from the lake shore to avoid solid waste contamination. Nearby farmers should implement no-till cultivation to prevent erosion and runoff of soluble nutrients such as phosphorus and nitrogen. Surface water and lake sediment should be sampled frequently and according to a regulated procedure and sent to a lab to be processed to test for excess nutrients and toxins. Both farmers and governmental policy are responsible for solving environmental issues and supporting public health of communities. Therefore, regulation of wastewater and proper removal of solid waste is equally as important as individual contributions. The most favorable solution for the water quality issues in the area of interest is to prevent contamination using the discussed BMPs. However, prevention of water contamination is not always cost-effective or even possible. Several methods have been developed to treat harmful nutrients and toxins in lake water. For example, "using activated carbon can efficiently remove (…) cyanotoxins, but the carbon will be exhausted within a short time thus needed to be re-applied frequently" (Cong 2015).

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