Proposed Methods to Improve the Lake Thunderbird Water Quality

Prepared by

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(COMCD)

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Executive Summary

Lake Thunderbird is facing water quality issues and is listed on the 303(d) list of impaired waters. Water quality issues have risen due to rapid urbanization and stormwater runoff leading to an increase in nutrient levels. Excess nutrients have caused increases in phosphorus, nitrogen, and chlorophyll-a and a dramatic decrease in dissolved oxygen. These impairments are important to address as the lake is an essential waterbody providing municipal water supply, recreation and fish and wildlife propagation. To address these issues, the objectives of this project are to evaluate water quality data, compare and assess the in-lake and watershed-level technologies, and develop a recommended design. The water quality data and their changes over time were analyzed through the performance of various statistical analyses. The in-lake and watershed treatment methods were extensively assessed through the research of literature, an initial screening, and an in-depth decision matrix which aided in the selection of solutions. Six decision criteria were evaluated and scored from a 1-4 ranking system in the matrix: effectiveness, capital costs, operation and maintenance commitments, public acceptance, and environmental performance. The treatment methods with the highest scores were further analyzed and a designed solution was developed. Final recommendations included treatment wetlands and pervious pavement which had the highest rated rankings overall while the other methods can be considered as alternatives. The treatment wetlands have a removal efficiency of 10-50% of nutrients with cost estimates ranging from 4 – 20 million. Estimates of nutrients for pervious pavement were found to be 30-85% and the estimated costs were 20 - 31 million.

Introduction

Lake Thunderbird is a 5,377-acre reservoir located in South Central Oklahoma. The reservoir has a capacity of 105,942 acre-foot and resides in a 256 square mile watershed in Cleveland County (OWRB, 2020). As of 2010, the national census reported the population within the watershed to be approximately 99,600 people. Designated uses of Lake Thunderbird include municipal water supply, flood control, recreation, and fish and wildlife propagation (ODEQ, 2013). The reservoir's water usage is supervised by the Central Oklahoma Master Conservancy District (COMCD). Lake Thunderbird is the primary public water supply for Norman, Midwest City, and Del City (ODEQ, 2013). The Oklahoma Water Resources Board (OWRB) has monitored and provided water quality services for COMCD from 2000 to present. Data presented by the OWRB have frequently documented a history of water quality issues. **Figure 1** contains the site map of Lake Thunderbird showing where water quality samples have been collected by the OWRB.

This document describes the current state of Lake Thunderbird and provides in-depth recommendations for water quality improvement. The reservoir's history and previous water quality improvement efforts are summarized, and the water quality parameters of concern are addressed. These parameters are elevated chlorophyll-a (Chl-a) concentrations, low dissolved oxygen (DO), and elevated turbidity. Water quality objectives are discussed, and treatment methods are provided.

Background

Site History and Management

"The Norman Project," today known as Lake Thunderbird, was initiated with the intent of flood control on the Little River. The design plans for the Norman Reservoir included current and future water demands for the surrounding communities including Midwest City, Norman, Del City, Moore, and Tinker Air Force Base, and a provision was added to allow for the allocation of any surplus water to Oklahoma City (OKC). However, Moore, Tinker Air Force Base, and OKC currently get no water from the lake. This plan was determined to be economically feasible, and "The Norman Project" was authorized under Public Law 86-529. It was signed into law in 1960 with subsequent planning and construction funding provided by the Works Appropriation Bills by 1962 (Simonds, 1999).

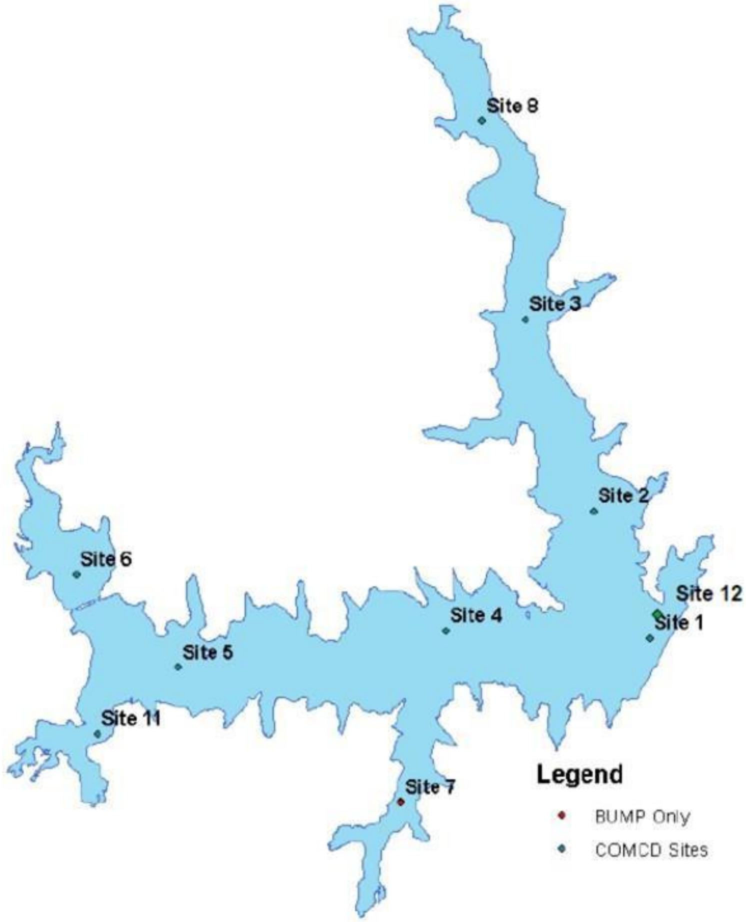

Figure 1: Site Map of OWRB Sampling Locations for Lake Thunderbird (OWRB, 2020)

Construction of the dam began in 1962 which included construction of a spillway, outlet works, reservoir, re-lift pumping station, reservoir clearing operations, and recreation infrastructure. The 2,456-hectare (6,070 acre) reservoir was completed in mid-1965. Water use began in 1966, and the reservoir was renamed as Lake Thunderbird.

Operation and maintenance of Lake Thunderbird was transferred from the US Bureau of Reclamation (BOR) to the COMCD in 1966 just after water deliveries began. COMCD consists of a seven-member board with three members each from Norman and Midwest City and one from Del City. They oversee management and operations at the lake in collaboration with BOR, the title holder, and the Oklahoma Department of Tourism and Recreation, responsible for Lake Thunderbird State Park.

Physical Characteristics and Hydrologic Budget

Lake Thunderbird is located at the confluence of Little River and Hog Creek and is approximately 13 miles east of central Norman. Mean and maximum water depths are 15.4 and 58 meters, respectively. Lake Thunderbird has approximately 138.4 kilometers of shoreline at the conservation pool water surface elevation as of 2020 (OWRB, 2020; Tetra Tech Inc., et al., 2010). The conservation pool storage volume is 105,942 acre-feet at an elevation of 1039 feet, and the flood control pool storage volume is 182,195 acre-feet at an elevation of 1,049 feet (USACE, 2020).

Lake Thunderbird uses a five-stage water conservation system ranging from 100% to 37% capacity shown in **Table 1** (City of Norman, 2016). Level 1 conservation efforts are considered everyday efforts that citizens can practice at home. The other conservation levels depend on Lake Thunderbird's percent capacity.

Table 1: Summary of Five-Stages of Water Conservation for Lake Thunderbird (OWRB, 2020)

Stage	% Capacity	Water Elevation (feet)
1	Not Applicable	Not Applicable
2	69	1033
3	60	1031
4	50	1028.56
5	37	1025

Figure 2 shows the monthly water budget for Lake Thunderbird for 2019. Inputs include direct precipitation and inflow from the tributaries including surface runoff in the basin (OWRB, 2020). Outputs include gated dam releases, water supply withdrawals, and evaporation (OWRB, 2020). Inputs and outputs were comparable throughout the year with some seasonal differences. For example, the highest amount of water input was in the spring, which is the rainiest part of the year, while the highest amount of water output was during the summer when demands and evaporation are highest.

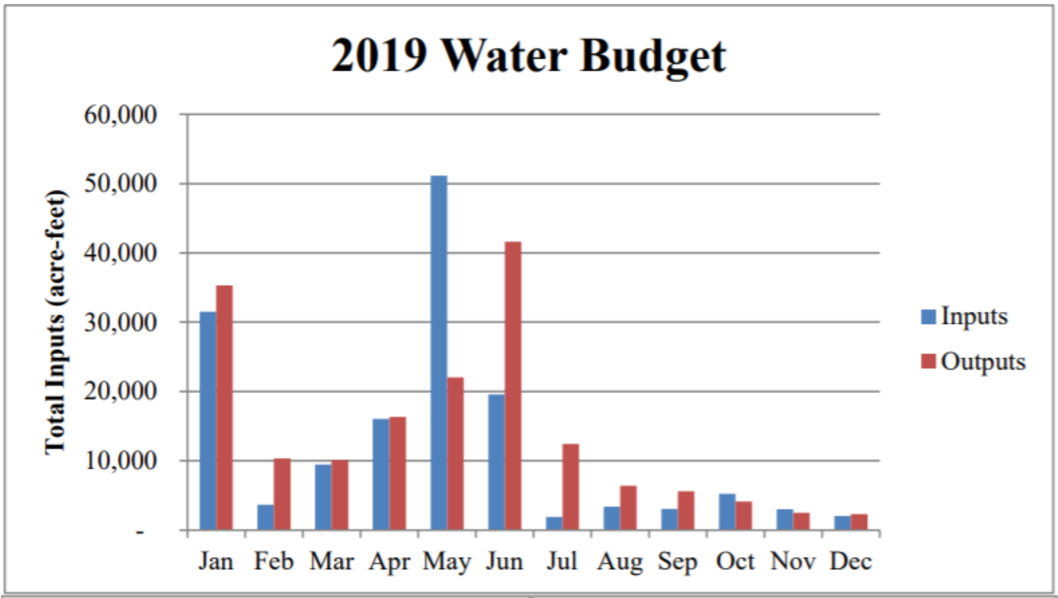

Figure 2: 2019 Lake Thunderbird Water Input and Output Sources by Month (OWRB, 2020)

Lake Thunderbird has a municipal water allocation of 21,600 acre-feet annually (Tetra Tech Inc. et al., 2010). The water supply contract allocations between Norman, Midwest City, and Del City are 43.8 percent, 40.4 percent, and 15.8 percent, respectively (Tetra Tech Inc. et al., 2010).

Watershed

Within the watershed, there are 5 major tributaries that contribute to inflowing water. USGS StreamStats provides data estimations on flow rates of these tributaries (USGS StreamStats, 2021). The data are tabulated in **Table 2.** The watershed is in the Central Great Plans and Cross Timbers ecoregions where it covers an area of 163,840 acres (OCC, 2008). Some of the major tributaries that flow into the watershed include the Little River entering from the West and Hog Creek from the North, as well as other tributaries shown in **Figure 3** (OWRB, 2020). The watershed is dominated by grasslands and deciduous forests and consists of 60% agricultural land and 40% residential area (OWRB, 2019; OCC, 2008). In the past 30 years, the agricultural regions of the watershed have decreased due to the rapid urbanization caused by population growth and increased recreation. Since 2016, there is a decreased percentage of open spaces, evergreen forests, grasslands, and cultivated regions which show as a negative percent change in **Table 3**.

Table 2: USGS Watershed Tributary Inflow Rates (USGS StreamStats 2021)

USGS watershed tributary inflow rates				
Tributary	100 Year Peak Flow (ft^3/s)	Flow (%)	Corresponding OWRB Sampling Site	Watershed Area (mi^2)
Hog Creek	18,700	26.3	8	48.4
Little River	29,600	41.7	6	110
Clear Creek	5,180	7.30	7	5.77
Jim Blue	6,240	8.80	11	7.83
Dave Blue	11,200	15.8	11	20.2
Total	70,920	100	N/A	192.5

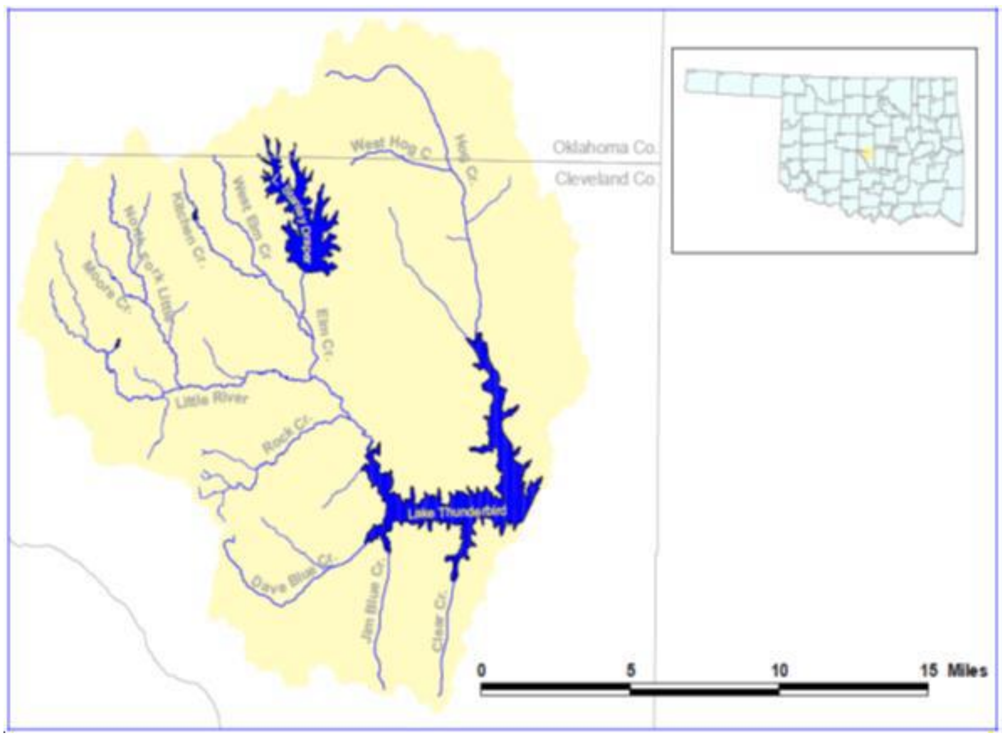

Figure 3: Map of Lake Thunderbird Watershed (OCC, 2008)

Beneficial Uses

Most of the watershed's drainage comes from the city of Norman as it covers half of the watershed's area. 38% of the watershed area consists of Oklahoma City, and 8% of the watershed area consists of Moore. Some of the municipalities in the watershed can be seen in **Figure 4**. The Little River State Park on Lake Thunderbird has a variety of recreational activities such as fishing, hunting, boating, and swimming; thousands of visitors come every year (Simonds, 1999). Many people have direct contact with the lake through swimming, jet skiing, fishing, and other activities. According to the latest fishing report submitted by the Oklahoma Department of Wildlife Conservation, some of the fish species at the lake include bass, catfish, and crappie (2021). Flood control is another significant use of Lake Thunderbird. Flood control operations of the Norman Dam follow the regulations provided by the Army Corps of Engineers. The construction of the Norman Dam has saved over $33,250,000 of flood damages from occurring along the Little River tributary since 1965 (Simonds, 1999).

Table 3: Lake Thunderbird Watershed Land Use, Percent of Watershed, and Percent Change in Land Use from 2011-2019 (OWRB, 2020)

Category	Acreage	Percent of Watershed	Percent Change
Open water	8359	5.08	+0.76
Developed, open space	12474	7.58	-1.82
Developed, low intensity	9182	5.58	+1.24
Developed, medium intensity	6080	3.7	+1.71
Developed, high intensity	1376	0.84	+0.41
Barren land	238	0.14	+0.13
Deciduous forest	61607	37.45	+2.16
Evergreen forest	322	0.2	-0.03
Mixed forest	163	0.1	
Shrub scrub	2842	1.73	
Grassland/herbaceous	55237	33.58	-4.76
Pasture/hay	4926	2.99	-0.5
Cultivated crops	1533	0.93	-1.21
Emergent herbaceous wetlands	20	0.01	+0.01
Total watershed	164505	100	100

Water Quality

Water quality data collected by the OWRB have shown increased levels in Chl-a, phosphorus, nitrogen, and turbidity, as well as a decrease in DO. The increase in nutrient levels could be due to runoff of stormwater from residential areas, road construction, and agricultural areas, and leakage from septic systems and other nonpoint sources (OCC, 2008). Excess nutrient loadings have adversely impacted the quality of water in Lake Thunderbird. Lake Thunderbird is currently designated as a sensitive water supply. The lake is on the state list of impaired waters (303(d) list) as stated by the Clean Water Act (OWRB, 2020). **Table 4** below shows the total nutrient loading contributions by city within the watershed, and **Figure 4** illustrates relative contributing areas by municipality.

Table 4: Total Nutrient Loading Contribution by City (OWRB, 2020)

City	TP (%)	TN (%)
Norman	38.0	39.5
Oklahoma City	31.1	32.4
Moore	28.1	25.4
Other	2.80	2.60

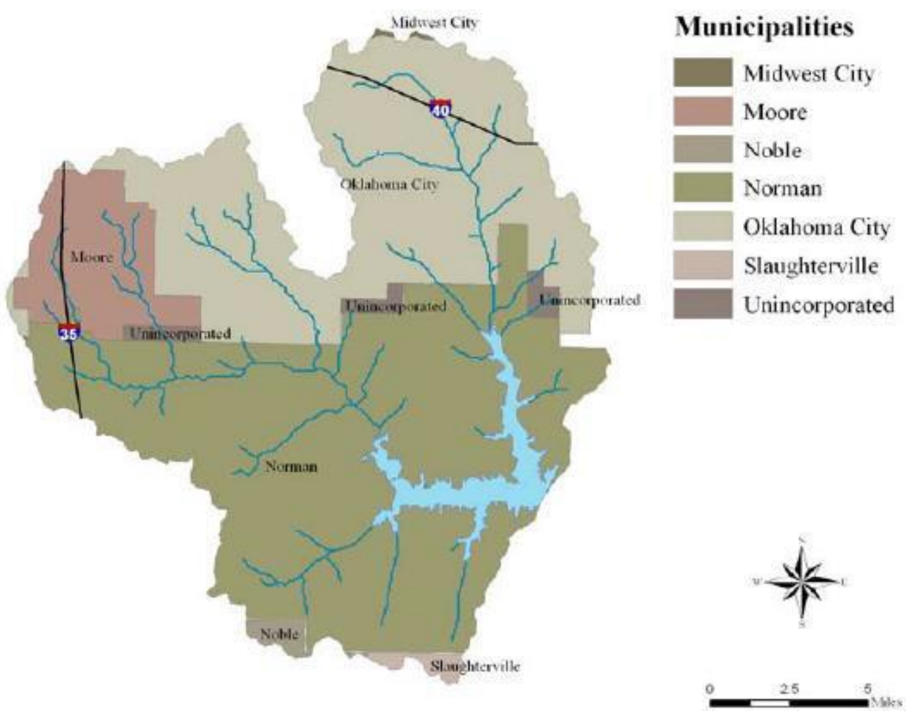

Figure 4: Municipalities Located in the Lake Thunderbird Watershed (OCC, 2008; Vieux, 2007)

ODEQ has determined that Lake Thunderbird is not supporting its designated uses for Fish & Wildlife Propagation (FWP) and public water supply due to excessive levels of turbidity and Chl-a in addition to insufficient levels of DO (ODEQ, 2013). Elevated levels of turbidity and Chl-a are responsible for taste and odor complaints from residents in the City of Norman.

Thermal stratification occurs annually when the lake's surface becomes warmer throughout the spring and summer months. The OWRB reports that Lake Thunderbird's stratification period typically occurs between May and October. During thermal stratification, an upper, less dense layer of water called the epilimnion forms over a denser, cooler layer called the hypolimnion.

When temperatures dramatically decrease, the two layers are separated by a third layer called the metalimnion. In 2018, the OWRB found that the hypolimnion and the metalimnion experience hypoxic conditions during the stratification period. Hypoxia occurs in the lower regions of the lake which signifies low DO levels. This could be due to a large oxygen demand of the lake sediment caused by high organic matter concentrations. Excessive Chl-a levels in the epilimnion during stratification could also contribute to this (OWRB, 2019).

Previous Restoration Efforts

Although there have been several previous restoration efforts for Lake Thunderbird, its water quality is still greatly impaired. Previous projects and studies such as the supersaturated oxygen aeration system (SDOX) and floating wetlands have been unsuccessful or inconclusive. A summary of previous efforts can be found in **Table 5**.

Table 5: Previous Lake Thunderbird Restoration Efforts

Year	Project
2012	Lake Thunderbird Water Reuse Feasibility Study
2013	Total Maximum Daily Load (TMDL) Study
2013	Trailwoods Neighborhood Best Management Practices (BMP) Project
2013	Plans to Reduce Sediment and Nutrient Loadings
2014	Rain Gardens and BMPs at Kitchen Lake
2014	Bio-retention and Green Infrastructure strategies in the Thunderbird basin
2018	Floating Wetland Studies

Objectives

The objectives of this project were to evaluate the reservoir’s water quality data, assess and compare in-lake and watershed-based technologies, and develop a designed solution to propose to the OWRB and the COMCD to address water quality concerns. The reservoir’s environmental data from the past twenty years were analyzed to identify changes in the water quality parameters over time. In-lake and watershed technologies were evaluated relative to 6 decision criteria: effectiveness, capital costs, operation and maintenance commitments, public acceptance, and environmental performance. The comprehensive analysis of the environmental data and comparisons of in-lake and watershed technologies were used to select optimal technologies and develop conceptual designs.

Methods

An initial screening of possible treatment technologies was conducted for both watershed and the in-lake treatment methods. Priority was given to methods that treat low DO, high turbidity, and high Chl-a. After an initial screening of the methods, a qualitative comparison matrix was developed to identify methods for further consideration. Detailed information regarding six the decision criteria for each method was collected for each method on the list. This information was used to inform rank values of the 6 criteria for each method in a quantitative weighted-ranking matrix. The highest scoring in-lake method and watershed-level method were selected for conceptual designs.

In-Lake Treatment Methods: Initial Screening

In-lake technologies can be used to target specific water quality issues by implementing actions within the actual lake water body. Within the broad topic of in-lake treatment, H_2OU reviewed ecological, chemical, and physical treatment processes. Ecological treatment methods generally use ecosystem functions and principles of ecological engineering to improve water quality and address parameters of concern. Unlike traditional engineering approaches, these methods are generally more cost effective, require minimal maintenance, and are not as easily manipulated or controlled (Bergen et al., 2001). An understanding of the performance of technologies from previous studies in similar biogeographical regions is key to determining the effectiveness of such methods. In-lake chemical methods use the addition of chemical agents for removal of excess nutrients, including phosphorus and nitrogen compounds, and limit algae growth. Physical approaches to in-lake water treatment consist of methods that use the movement or displacement of certain components to improve water quality such as filtration or dredging. The methods found in the initial screening of in-lake treatment methods are in **Appendix B**.

Watershed-Level Methods: Initial Screening

Watershed-level management practices are technologies located outside of the lake but within the watershed that help reduce nutrient loadings into the lake**.** A healthy watershed can result in improved ecosystems, economic benefits, and physical and mental health benefits (USEPA, 2015). H_2OU looked at watershed-level practices that range from implementing systems directly into the watershed to everyday in-home practices to reduce pollutants. The methods found in the initial screening of watershed-level methods are in **Appendix B**.

Method Ranking

Based on the initial screening, H_2OU Engineering eliminated technologies from further evaluation due to high cost and limited scalability. The remaining methods were evaluated relative to cost, effectiveness, lifetime, maintenance, scale, and public acceptance **(Appendix C)**. A weighted decision matrix was made using the data identified from the literature review and, in the case of public acceptance, the consensus and perceptions of H_2OU Engineering personnel. The decision matrices are shown in **Tables 6 and 7**. The technologies are ranked on a scale of 1 to 4, where 1 is the lowest rank and 4 is the highest. The weight of each criterion can be seen in **Figure 5.**

In-Depth Method Analysis

Methods of Consideration

From the decision matrix, H_2OU Engineering conducted additional research for methods that had a total score above 3. For in-lake treatment methods, this included biomanipulation, treatment wetlands, shoreline revegetation, breakwater systems, P inactivation using alum, and down flow bubble contact systems. For watershed BMPs, rain gardens and permeable pavement were chosen for further research.

Criteria for Analysis

Each of the considered methods was further analyzed for the five criteria of cost (including capital (CAPEX) and operational (OPEX)), effectiveness, lifetime, public acceptance, and environmental impact. CAPEX includes construction, planning, site preparation, physical assets, and all initial costs. OPEX includes labor, operation and maintenance, spare and replacement parts, and annual taxes and fees. Effectiveness is gauged by the ability of the method to improve DO, turbidity, and/or Chl-a. Lifetime is an estimated time period in which the method is expected to remain viable assuming appropriate operation and maintenance are provided. Public acceptance is estimated from aesthetic quality of the method, land use/change, ubiquity, and public knowledge of the technology. Environmental impact includes direct pollution of air, water, or soil, or ecological impacts caused by the technology that disrupt biodiversity and ecosystem health.

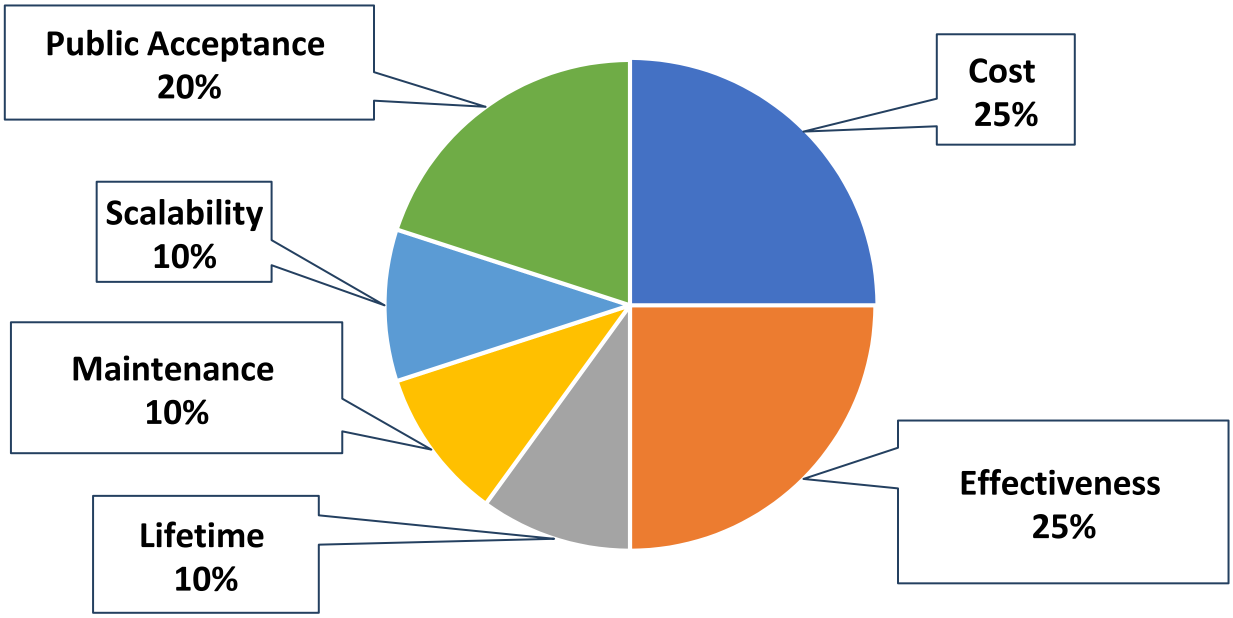

Figure 5: Criteria Weightings

Table 6: H_2OU's In-Lake Treatment Methods Decision Matrix

Method	Cost	Effectiveness	Lifetime	O&M	Scale	Public Acceptance	Total
Biomanipulation	4	2	3	3	4	4	3.3
Treatment wetlands	3	4	3	4	3	3	3.35
Shoreline Revegetation	4	2	4	3	3	3.5	3.2
Breakwater Systems	4	2	3	3	3	3.5	3.1
P Inactivation	4	4	2.5	2	2	3	3.25
Sediment Oxidation	2	2.5	3	2	1	2	2.13
Coagulation Magnetic Separation	4	3	2.5	2	1	3	2.9
Down Flow Bubble Contact System	2	3.5	2.5	2	4	4	3.0
Sediment Dredging	1	4	2.5	3	4	1	2.4

Table 7: H_2OU's Decision Matrix Watershed Level Methods

Method	Cost	Effectiveness	Lifetime	O&M	Scale	Public Acceptance	Total
Erosion Control Logs	3	3	3	4	4	3.5	3.1
Rain Gardens	3	2	4	4	3	4	3.25
Pervious Pavement	4	4	3	4	3	3	3.6
Green Roofs	2	2	4	4	3	4	2.9
Catch Basin Filter	2	1	2	1	2	2	1.7

Phosphorus Inactivation

Introduction

Many urban lakes are impacted with poor water quality due to excess nitrogen or phosphorus loadings caused by nonpoint sources (Charboneau, 1999). Phosphorus is the limiting nutrient controlling algae growth and causing eutrophication in surface waters (Preptas et al., 1990). Phosphorus inactivation has been an effective in-lake chemical treatment method used to reduce internal phosphorous loadings and is commonly used in water and wastewater treatment (ENSR 2016). In-lake treatment with alum has been more widely studied and applied to various lakes than other methods due to its applicability, cost-effectiveness, and proven success (Welch and Cooke, 1999).

Phosphorus inactivation involves the use of the coagulant aluminum sulfate (alum) or sodium aluminate, which are added to the surface of the lake. The chemical coagulant binds to the dissolved phosphorus in the water column to form an insoluble precipitate (Steiman and Ogdal, 2008). The insoluble precipitates will gradually undergo settling until they reach the sediments at the bottom of the lake (Bankowska-Sobczak et al., 2020). This method inactivates the phosphorus from being released into the lake which reduces the internal phosphorus loading.

Dose Determination

Determining an accurate alum dose is vital to producing the most effective results in reducing phosphorus. The alum dose typically ranges between 1-5 mg/L and is 10-20 times the phosphorus concentration (NE, 2018). The treatment depth typically ranges from 10 cm to 20 cm from the surface of the lake (ENSR, 2016). To determine the correct dose, laboratory experiments are performed and parameters such as the available sediment phosphorus, solids fraction, treatment depth or targeted ratio of Al-P are identified. Small amounts of alum are added to a lake water sample until a desired amount of alum forms a precipitate and removes the phosphorous (Charboneau, 1999). The ratio of the alum bound to the phosphorous can then be determined by plotting the phosphorous concentrations against the alum doses. Using the ratios, the phosphorous binding efficiency can be evaluated to determine the proper alum dose (Pilgrim et al., 2007). In a study for Cedar Lake, Indiana, **Equation 1** was used to calculate the alum dose (ENSR, 2016):

$$Al\ Dose = (ASP) \times (SG) \times (SF) \times (TD) \times (Al{:}ASP) \quad \text{[Equation 1]}$$

Where:
Al Dose = Alum concentration (g/m2)
ASP = Available Sediment P (mg/kg dry weight)
SG = Specific Gravity (g/cm3)
SF = Solids Fraction or % solids/100
TD = Treatment depth (m)
Al:ASP = Targeted ratio of Al to ASP for treatment

Cost Information

The amount of alum varies depending on area of treatment. The approximate cost for the alum treatment can range from $500-$1,500/acre (ENSR, 2016). For the study conducted at Cedar Lake, Indiana, the total cost of alum was approximately $270,123 for a treated lake area of 400 acres (ENSR, 2016). Long-term water monitoring and re-dosing of alum will require additional costs.

Effectiveness

Past studies have shown successful results with the addition of alum. The average reduction efficiencies for all 7 lakes in **Table 8** were 80% for phosphorus and 57% for Chl-a upon dosing.

Table 8: Lake Characteristics, Dosage, and Application Depth of Alum for Selected Lakes. (Lewtas et al., 2015; Welch and Cooke, 1999)

Lake	Dose (gm Al/m3)	Application Depth	Lake Area (km2)	Max Depth (m)	Mixes
Annabessacook, ME	25	Hypolimnion	5.75	12	Dimictic
Kezar, NH	30	Hypolimnion	0.74	8.2	Dimictic
Morey, VT	11.7	Hypolimnion	2.2	13	Dimictic
Irondoquiot Bay, NY	28.7	Hypolimnion	6.79	23.7	Dimictic
Dollar, OH	20.9	Hypolimnion	0.02	7.5	Dimictic
West Twin, OH	26	Hypolimnion	0.34	11.5	Dimictic
Mirror, WI	6.6	Hypolimnion	0.05	13.1	Dimictic
Shadow, WI	5.7	Hypolimnion	0.17	12.4	Dimictic
Eau Galle, WI	4.5	Hypolimnion	0.6	9	Dimictic
Long, Port Orchard, WA	5.5	Surface	1.4	3.7	Polymictic
Long, Turnwater, WA	7.7	Surface	1.3	6.4	Polymictic
Erie, WA	10.9	Surface	0.45	3.7	Polymictic
Campbell, WA	10.9	Surface	1.5	6	Polymictic
Pattison, WA	7.7	Surface	1.1	6.7	Polymictic
Wapato, WA	7.8	Surface	0.12	3.5	Polymictic

Lifetime

In the same study conducted by (Welch and Cooke 1999), the longevity of the alum treatment was documented to range from 4 to 21 years in stratified lakes and 1 to 11 years in shallow lakes. The longevity of the treatment, however, is largely dependent on the rate of phosphate (PO_4) release and the application dose (Gibbs et al., 2011). The alum treatment may not be as effective in the long term if there is continual release of external P loadings into the lake. Without a reduction in the external P loadings, a return of internal P loadings will occur within the lake, which will require future re-doses of alum thus extending the treatment (Huser et al., 2016). Longevity is also dependent on an accurate dosing, as underdosing may require future re-doses or overdosing may cause ecological impacts to aquatic biota (Huser et al., 2016).

Public Acceptance

Public acceptance of P inactivation using alum may be low due to the idea that the addition of a chemical to a lake may be unsafe and cause ecological impacts. However, this perspective may be changed through public education through dissemination and publishment of laboratory results. However, alum is generally safe for humans and will not pose human health risks as people do not drink untreated lake water (Nalms, 2014). Additionally, alum concentrations for the lake will not exceed EPA standards and will be under safe drinking regulations (Nalms, 2014).

Environmental Impact

Potential environmental impacts may include toxicity to aquatic biota if the pH is not kept in the range between 6 and 8. Alum may reduce the pH of the lake and at low-alkaline pH levels, soluble Al^{3+} is the predominant species, which is toxic to aquatic biota (Charboneau, 1999). Low concentrations of even 0.1 to 0.2 mg Al/L at a pH of 5 or lower can be toxic (Lewtas et al., 2015). If the pH does decrease, however, buffers may be used to keep the pH in range. $CaCO_3$ or $NaAl(OH_4)$ may be used as the buffer to prevent pH reduction during alum hydrolysis (Nogaro et al., 2013; Lewtas et al., 2015). Additionally, some other studies have seen short term ecological effects in species richness of benthic invertebrates immediately following an alum application. However, those short-term effects were followed by long-term recovery with the improvement of water quality (Steinman & Ogdahl, 2008).

Treatment Wetlands

Introduction

Wetlands are a natural solution to the eutrophication impairment of large nutrient loads. Treatment wetlands are man-made wetland systems designed and proven to be effective at addressing problems such as nutrient loading and suspended solids (USEPA, 1999).

Treatment wetlands rely on abiotic and biotic transformations catalyzed by substrate and biota to treat water. Plant uptake of nutrients, absorption, volatilization, and biodegradation also factor into how a constructed wetland effectively processes stormwater. There are two major categories of treatment wetlands: surface flow (horizontal) and subsurface flow (USEPA, 2020). Surface flow wetlands allow stormwater to flow horizontally through the system. These wetlands are open to the atmosphere, can be cost effective, and are particularly suited for larger areas.

Subsurface flow wetlands require intakes to be constructed under the surface which allow the influent to pass through substrate and plant roots. This method is best suited for small water bodies (USEPA, 2020).

Effectiveness

Treatment wetlands have been used to restore water bodies internationally. Perhaps one of the best pilot studies of a constructed wetland in the United States is at Lake Apopka in Florida. This is a large lake with a surface area of 30,800 acres and an average depth of 4.7 meters with approximately five times the volume of Lake Thunderbird (Dunne et al., 2012). Apopka's horizontal flow wetland was designed to maximize the removal of Total Phosphorus (TP) and Total Suspended Solids (TSS). Apopka's wetland consists of four independently flowing systems totaling nearly 700 acres in area (Dunne et al., 2012). Lake Apopka's hydraulic inflows were between 29 and 160 times greater than rainfall, additionally outflow volumes exceeded evaporation by factors of 27 to 66 (Dunne et al., 2012). The results of removal efficiency for TP and TSS are tabulated in **Table 9**.

Cost

The cost of implementing a constructed wetland varies considerably depending on design parameters and nutrient loading. However, generally they are more cost effective than comparable treatment methods. Major design cost factors lie in the substrate and aquatic life within the desired location. If a wetland previously existed in the chosen location, then it is

Table 9: Lake Apopka Removal Efficiency of TP and TSS (2003 - 2007) (Dunne et al., 2012)

Lake Apopka removal efficiency of TP and TSS (2003 - 2007)	
Parameter	**Removal Rate (%)**
TP	30
TSS	91

possible to restore a wetland. The USDA provides an estimated first year cost of restoring a wetland to be $10,200 per acre and ranging from $300 to $3,300 per acre to maintain the wetland in the following years (Tyndall, 2016). Installing a wetland in an area where substrate and plant species need to be completely redesigned provides a first-year cost estimation between $30,000 - $65,000 per acre and $300 to $3,300 per acre after installation (USEPA, 1999).

Lifetime

Treatment wetlands generally have a lifetime of 10 to 30 years. The lifetime of a treatment wetland is determined by the nutrient loading rates, the capacity of the wetland to remove and store contaminants, and the rate of detritus build up (Davis, 1994). A wetland should be monitored routinely to assess its effectiveness. The capacity of the wetland to remove contaminants may decrease with time. However, long term data provided by the EPA show that wetland systems can maintain treatment performance for 20+ years if the loading rates are reasonable and the wetland system is designed, built, and maintained properly for the body of water (Davis, 1994). The nutrient loading rates, sedimentation rate, and theoretical wetland capacity will be further evaluated to provide an approximate design life.

Public Acceptance

Public acceptance of a constructed wetland will likely depend on location and size. A constructed wetland in Lake Thunderbird would take up significant surface area that would take away from recreational activities. A larger number of smaller wetlands upstream would likely be better perceived. Either way, a constructed wetland should be reasonably accepted by the community because there would be no required chemical dosing or perceived harmful effects.

Environmental Impact

Treatment wetlands do not pose an appreciable negative environmental impact. Wetlands require natural systems that enhance the biodiversity, wildlife habitats, and aesthetics of the lake. The systems are constructed to reduce nitrogen, phosphorous, and TSS without producing harmful gases such as methane. Wetland systems are designed to maximize vegetative species diversity without increasing invasive species (USEPA, 2016). The project should consider depth-flow variability, local vegetation, sediment accumulation, and plans to control undesirable species.

Downflow Bubble Contact System

Introduction

A Downflow Bubble Contact System (DBCS), also known as a Speece cone, is a type of hypolimnion oxygenation system. The Speece cone consists of a submersible pump and chamber in the shape of an inverted cone, suspended by support cables attached to a floating raft at the water surface. Oxygen gas from onshore storage is injected into the top of the cone. Anoxic water is also injected into the top of the cone from a submersed intake. The water and pure oxygen move down the cone suspending rising oxygen bubbles in the cone and allowing for approximately 90% oxygenation (Mobley et al., 2015). The oxygenated water is then discharged from the bottom of the cone horizontally to not disrupt thermal stratification. DBCS's directly aim to elevate DO levels in the hypolimnion while also suppressing sediment nutrient flux in the water column, effectively limiting eutrophication.

Effectiveness

The Camanche Reservoir in California is a lake similar to Lake Thunderbird utilizing a DBCS. The California water body's area is approximately 30% larger than Lake Thunderbird. The Camanche Reservoir was eutrophic and characterized by having low water clarity, high Chl-a and blooms of cyanobacteria associated with internal nutrient loading from anoxic sediments before the implantation of a DBCS in 1993. After 5 years of DBCS operation, Chl-a decreased by 73% and soluble phosphate from the sediment pool declined by 84%. Water clarity and quality was improved over the course of operation; Secchi disk depth rose from 0.5m to 10m at peak in 2004 (Horn et al., 2019). The pilot study was able to deem the hypolimnion oxygenation system a long-term success. **Figure 6** displays Chl-a concentrations over time. HOS is when the Speece cone was introduced.

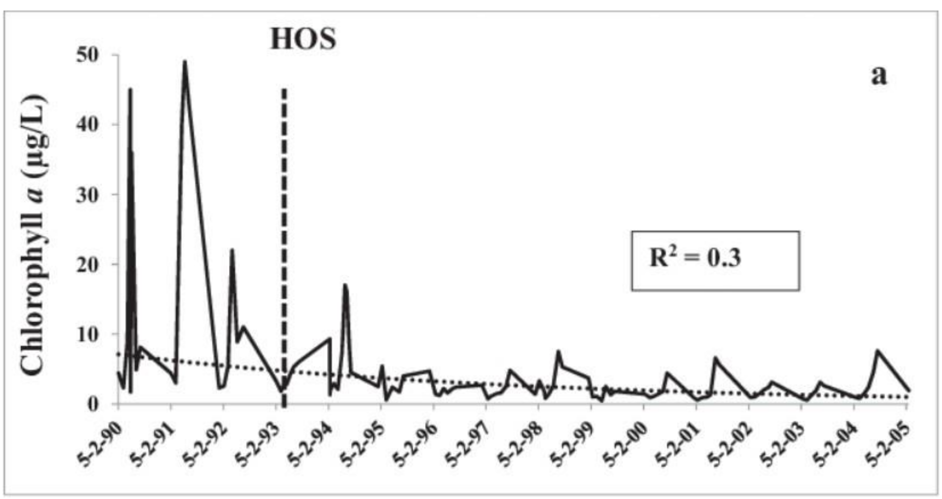

Figure 6: Chl-a Concentration vs Time. (Horn et al. 2019)

Cost

Cost estimates will be drawn from the Camanche Reservoir project due to the size of the lake and success of the operation. In California, the DBCS utilized a 30m long, 0.5m diameter horizontal diffuser and oxygen gas flux rate of $4.6 m^3/min$ for approximately 160 days per year (Horn et al., 2019). **Table 10** summarizes the cost for installing and maintaining a DBCS in Lake Thunderbird.

Table 10: DBCS Cost Summary

DBCS Cost Summary	
Capital Cost	$3,349,000
Annual O&M	$270,000
Annual Power & Oxygen	$74,000
Total Cost (10 yr life)	$6,789,000

Lifetime

The cost estimation was based off a ten-year life for the DBCS system. Case studies done at the Camanche Reservoir and Newman Lake, in California and Washington, respectively provide data that show DBCS is capable of reversing a eutrophic lake within this time period (Horn et al., 2019). The lifetime of a DBCS system is at least ten years, and with proper maintenance the equipment will remain functional for a longer period if necessary.

Public Acceptance

The public acceptance of a DBCS should be high compared to other methods because this system will operate out of the public's perception. The Speece cone and submersible pump are designed to be implemented above the sediment, and operational hoses will run through the sediment to the surface. The cone will also be located in the deepest waters of the lake, ensuring minimal public interaction.

Environmental Impact

The negative environmental impact is estimated to be negligible for a DBCS. The pump and cone will be contained and designed to remain in place. There are no harmful chemicals or reactions that would negatively affect the water quality or impact species present in the lake.

Lake Breakwater and Revegetation Systems

Introduction

Shoreline revegetation involves the planting of native aquatic plants in the littoral zone and shoreline area. Natural and biodegradable materials may also be used to further vegetation establishment. The three main types of shoreline revegetation are (1) protection of existing vegetation; (2) natural colonization of shoreline over time; and (3) accelerated revegetation. Of these three, accelerated revegetation was chosen for further evaluation because it is the most time efficient (UWSP, 2009). Breakwater systems may also include shoreline revegetation, but can also include stone, rock, geotextile, or wood buttresses and barriers. Floating wetlands or vegetative plant beds are a form of small-scale water treatment and breakwater that can be made of synthetic or natural buoyant materials such as foam, water bottles, logs, bamboo, or burlap sacks. They are anchored to the lake's bottom with a durable chain or rope. The floating body extends into the water with poles to ensure wave energy is lowered, both at the surface and below the surface, upon collision with the structure (Fitriadhy et al., 2017). These can be vegetated with aquatic plants to take up excess nutrients and utilize sunlight to prevent algal growth.

Cost

Most of these methods require manual labor to install and maintain. This could be done through the use of volunteers, interns, or employees. Materials needed include a dump truck, an excavator with bucket and backhoe attachments, a flatbed truck, augers, shovels, work gloves, poles, plants, rocks, geotextile materials, and wood. Floating wetlands are versatile and have varying costs. The estimated capital cost is $1 per square foot if homemade from recycled materials or $24 per square foot if purchased from a commercial source (Sample et al., 2020).

In an analysis of California's Lake Elsinore, the cost of shoreline revegetation and natural wave attenuation was estimated to be $35,000 per converted acre. Over a 25-year period, this would amount to a cost of $200,000/year (SAWPA, 2020). This estimate included vegetation establishment, labor, installation, and plant costs. Lake Thunderbird has approximately six times the shoreline of Lake Elsinore, but many materials could be sourced for free through foraging. The use of volunteered labor, as well as donated or foraged material (fallen branches and trees, willow saplings), could further lower costs, although these free methods should not be expected preemptively.

Effectiveness

Revegetation efforts are used to stabilize the soil, support an aquatic ecosystem, and sequester excess nutrients into more stable biomass. Roots from the plants help to mitigate erosion and aquatic biomass attenuates waves to reduce physical sediment resuspension (Moss, 1990). In addition, plants uptake nutrients like phosphorous and nitrogen and release oxygen to improve water quality (Slembrouck et al., 2018). Plants would also compete with algae for sunlight and nutrients and thus prevent excessive algal growth and Chl-a levels (Carpenter et al., 1995). Elevated landside foliage can also provide shade that limits sunlight and could provide localized cooler temperatures. In addition to these benefits, increased foliage also provides habitat to support fish and wildlife (Kornis et al., 2017). The presence of piscivorous fish further improves water quality by supporting zooplankton grazers that consume algal biomass and thus lower Chl-a concentrations (Carpenter et al., 1995).

Floating wetlands have been found to be effective at reducing nitrogen concentrations from ammonia, nitrate, and nitrite. They may also increase DO (Zhang et al., 2020). An ongoing research project at Lake Thunderbird is measuring the wave attenuation ability of various designs.

Lifetime

Revegetation approaches require minimal maintenance but could take 40+ years to establish and reach full functioning (Spears et al., 2011). Species best suited for the environment will persist and establish themselves over time and remain unless disturbed without maintenance. Breakwater systems have varying lifetimes. Rocks are more permanent and require minimal maintenance, while branch boxes and vegetative approaches require more maintenance and repair. Floating wetlands, however, have shorter lifetimes and will need annual repair or replacement.

Public Acceptance

Revegetation and breakwater systems should be acceptable to the public. Stone and geotextile options may be less aesthetically favorable, but revegetation may be favored for increasing aesthetic quality of shorelines. These systems are relatively low-cost and easily understood by the public. Floating wetlands should be covered with foliage to increase aesthetic quality but may cause near-shore navigation challenges which could impact acceptability.

Environmental Impact

Revegetation efforts that introduce new species have the potential to disrupt local ecology. Animals may become enmeshed in geotextile or landscaping fabric. Floating wetland plastic or foam will disintegrate over time and pollute lake water. Placement of rocks may also disrupt local ecology.

Biomanipulation

Introduction

Biomanipulation is a method of biological treatment that works by controlling the population of strategic species within a lake's ecosystem to restore a buffered food chain (Carpenter et al., 1995). A common application is for decreasing the population of planktivorous fish that eat zooplankton. This allows the zooplankton grazer populations to increase and results in a decrease of their food source: planktonic algae biomass. In this process, Chl-a concentrations are effectively lowered (Søndergaard et al., 2010; Tang et al., 2015). This can be accomplished through stocking a lake with piscivorous fish that consume planktivorous fish. Alternatively, populations of planktivorous fish can be decreased through the promotion of fishing of these species.

Fishery manipulation has other beneficial side-effects that also improve water quality (Zhang et al., 2020). Fishery manipulation has been shown to foster competitive microorganisms for phytoplankton and this competition causes phytoplankton populations to decrease (Van Donk et al., 1990).

Cost

For Lake Thunderbird, there are 5 major fish species (**Table 11**). With consideration of these fish species, fish stocking could be done through the introduction of more bass and catfish or promote crappie fishing. Of these two approaches, the latter is free, and the former would cost approximately $55 per 100 catfish or $90 per 100 bass from Dunn's Fish Farm, which supplies to Oklahoma (Dunn's Fish Farm, January 20, 2021).

Table 11: Fish Types and Trophic Status for Lake Thunderbird (Oklahoma Wildlife Department, 2021)

Fish Type	Trophic Type
Largemouth Bass	Piscivore
Channel Catfish	Piscivore
Saugeye	Piscivore
Black Crappie	Planktivore
White Crappie	Planktivore

Effectiveness

Biomanipulation has been shown to be effective at lowering nutrient concentrations and turbidity in lakes (Klinge et al., 1995; Mäler, 2004). The reduction in planktonic algae also reduces algal turbidity. Additionally, fish uptake nutrients like phosphorous and carry them out of the lake when they are fished (Wang et al., 2017).

Lifetime

Biomanipulation should follow principles of ecology and population dynamics. Initial monitoring is needed to ensure that artificially increased or decreased fish populations are sustained. This is necessary until desired conditions have been reached. In one study, unmonitored planktonic fish populations rapidly increased and biomanipulation was not effective at improving water quality (Gulati and Donk, 2002).

Public Acceptance

Biomanipulation is estimated to be highly acceptable to the public, as it encourages recreational fishing. The cost of fish may be of concern. It is also possible that the public may not understand biomanipulation and deem this method as ineffective and wasteful of time, money, and energy. To combat this, education about the method can be provided in the form of flyers and online guides.

Environmental Impact

Biomanipulation focuses on the population dynamics of a few species. Introduction of fish or a decrease in fish populations could cause unintended disruptions to lacustrine food webs. For example, birds that consume fish may also be impacted. It is important to consider the niche of fish and plankton and how changes will impact other species. Significant pollution of air, water, or soil are not of concern with this method.

Watershed-Level Method Analysis

Rain Gardens

Introduction

Rain gardens provide an area for storm water to filter directly into the ground instead of flowing over impervious areas into storm sewers that discharge into tributaries of Lake Thunderbird. Rain gardens are located at low terrain and consist of vegetation that simulate a prairie environment (Beier, 1995). The plants remove the pollutants from the storm water by absorbing and filtering them through the roots. Putting in rain gardens is a low cost, low-maintenance, and low-effort method to improve the overall water quality of Lake Thunderbird.

Cost

The initial cost of a residential rain garden would range from $3 to $4 per square foot, and for commercial, industrial, and institutional sites the cost would range between $10 to $40 per square foot (Coffman et al., 1999). Rain gardens can reduce the amount of storm water drainage pipes which can be cost saving. In Maryland, a medical building reduced the storm drainpipe length by 60% and saved $24,000 by putting in rain gardens (USEPA, 1999). Maintenance for rain gardens is minimal, and the cost varies on the conditions of the rain garden each year. The first three years of the rain garden's life will be the costliest in-terms of maintenance until proper ground cover is formed (Cahill et al., 2018).

Public Acceptance

Despite the environmental improvements rain gardens provide, educating the public on the importance of rain gardens can be a challenge. Public knowledge about the importance of rain gardens and water quality can be achieved by putting signs of hydrologic benefits around the rain garden areas. However, the aesthetics of the rain gardens provide high public acceptance. Rain garden education could also prompt citizens to create their own rain gardens in their neighborhoods or residential areas.

Environmental Impacts

Rain gardens positively impact their surrounding environment due to the introduction of native vegetation, wildlife, and natural nutrient filtration. Rain gardens can filter 80 to 99% of rainwater depending on the location. Phosphorus removal rates are between 25 to 50% and nitrogen removal is between 40 to 60% (CWP, 2008).

Pervious Pavement

Introduction

Pervious or permeable pavement is a method of paving in which there are layers of gravel or other high-porosity material underneath the visible top layer. The void spaces underneath the pavement surface allow for stormwater to be retained beneath the surface instead of running off into water bodies or storm sewers. This retention stops the water from collecting excess nutrients and allows it to soak back into the soil instead of contributing to the nutrient loadings in nearby lakes and streams (CTC & Associates LLC, 2012). There are multiple types of pervious pavements, each having different infiltration rates, void spaces, and appearances.

Cost

Cost of pervious pavement construction depends on the pavement material. The average cost ranges from $12 to $34 per square foot (The State University of New Jersey, n.d.). The maintenance cost annually for pervious pavement includes biannual vacuum sweeping and other maintenance such as picking up trash and filling holes. The average maintenance cost is $800 per acre (CTC & Associates LLC, 2012).

Public Acceptance

Pervious pavement is publicly acceptable because it looks like impervious pavement. However, if pavers are used, the public may not like the aesthetic of the new public areas. However, if educational programs are implemented to show the public why pervious pavement is needed, the public may accept the new project more.

Environmental Impacts

Pervious pavement reduces nutrients seeping down to the water table by filtration. It can filter out TSS, TP, and nitrate by 85, 85 and 30% respectively (StormwaterPA, 2006). This can reduce the amount of nutrients into Lake Thunderbird and give the lake an overall better water quality.

Water Quality Testing and Analysis

Water Quality Testing

Representatives from each firm (H_2OU Engineering, Jay Engineering, and Enviro-Shield) conducted one field sampling event on March 20th, 2021. Water samples from Sites 1, 2, 4, 5, 6 and 11 from Lake Thunderbird were sampled for the following water parameters: temperature, pH, DO (concentration and percent saturation), specific conductance, conductivity, resistivity, total dissolved solids, salinity, oxidation-reduction potential, chlorophyll-a, turbidity, nitrate, nitrite, soluble reactive phosphorous, and TP. In situ measurements included the use of the YSI 6920v2 sampling probe which measured the temperature, pH, conductivity, ORP and other parameters. The Secchi Disk was used to measure the transparency of the lake water and Hach kits were used to measure hardness and alkalinity. One-liter samples were collected at each site, while a field blank and duplicate were collected at a random site. The lake samples were further analyzed for nutrient concentrations such as total nitrogen (TN) and TP, as well as using the Hach method in the laboratory. The results from the laboratory analyses can be seen in **Tables 12-15.** All sampling and analysis protocols, as well as quality control and quality assurance measures, found in the Sampling and Analysis Plan (SAP) and the Quality Assurance Project Plan (QAPP) (**Appendix A**) were followed.

All field samples needed from each site were collected successfully. However, one messenger was lost from the Van Dorn sampler. Although this was unforeseen, an extra messenger had been packed and brought to the site so sampling could proceed. A potential source of human error is the contamination of samples. The field and lab blanks had nonzero values when analyzed, implying some contamination. Photos from the sampling date are included in **Figures 7-10.**

Figure 7-Figure 8: In-Situ Testing for Alkalinity

Figure 9: Secchi Dish Depth Measurement; Figure 10: Van Dorn Sampler Collection of Water Sample and Sample Labeling

Laboratory results for TN are presented in **Table 12.** These concentrations are much higher than the OWRB data values. The detectable range for this test is 1 to 16 mg/L. Reported values outside of this range are denoted with an asterisk (*).

It should be noted that the field blank was measured to have a TN concentration above the recommended sampling range. This suggests that sampling or testing was erroneous, as the field blank contains only DI water and should have no measurable nitrogen concentrations. Because of this, collected TN data were not considered for further analysis.

Table 12: Laboratory Test Results for Nitrogen

Sample Name	**TN (mg/L)**
Lab Blank	14.5
Site 5	7.45
Site 1	26.8*
Site 6 Field Dupe	22.5*
Field Blank	24.4*
Site 11	14.7
Site 6	7.74
Site 2 Lab Dupe	43.9*
Site 4 Field Dupe	16.1*
Site 2	10
Site 4	12.4

TP concentrations were determined by following the Hach method for TP. TP concentrations are recorded in **Table 13**. It should be noted that these concentrations are under the measuring range and were very low in comparison to the OWRB data. The field and laboratory blanks also indicated contamination as seen in **Table 13** as those values were negative. Thus, the TP data proved to be insufficient to compare with the previous OWRB data.

Samples taken during the sampling trip were also analyzed for TSS. These data were not considered in design recommendations, however, because there were issues with the mass balance causing the data to likely be skewed.

YSI results were also not used in design considerations due to sampling limitations and error. For sites 1, 3 and East Bridge, the DO and Chl-a data were incorrect due to technical problems with the YSI 6000. The East and West Bridge sites were too high above the water to accurately measure Secchi disk depth.

Table 13: Laboratory Test Results for Phosphorus

Sample Name	TP (mg/L)
Site 1	0.027
Site 2	0.022
Site 4	0.021
Site 5	0.015
Site 6 (west bridge)	0.026
Site 11	0.030
Field Blank	-0.027
Site 4 Dupe	0.013
Site 6 (east bridge)	0.017
Lab Dupe	-0.016
Lab Blank	-0.036

In-Lake Water Quality Data

Statistical Analyses

Statistical analyses were conducted to better understand correlations between measured nutrients as well as between depths, seasonality/time, and location in the lake. This information was used to identify viable treatment methods.

Data Provided in Appendix

Water quality data measuring provided by the OWRB was analyzed and findings are included in Appendices D through H. These parameters include ammonia, turbidity, Secchi disk depth, TSS Chl-a, inorganic nitrogen, total Kjeldahl nitrogen (TKN), total organic carbon (TOC), orthophosphate (Ortho-P), pheophytin-a, phosphorous, temperature, DO (concentration and percent saturation), pH, oxidation reduction potential (ORP), salinity, specific conductivity, and total dissolved solids, iron, manganese, sulfate, and lake elevation.

Data Selected for Analysis

Of the data provided, only the values for ammonia, turbidity, Secchi disk depth, TSS, Chl-a, inorganic nitrogen, TKN, TOC, Ortho-P, phosphorous, DO (concentration), pH, and lake elevation were chosen for analysis. ORP, salinity, specific conductivity, and total dissolved solids, iron, manganese, sulfate, pheophytin-a, and temperature were not analyzed.

Data Limitations

The data given were limited in certain aspects. For example, certain parameters were not sampled for on consistent dates. The time between sampling events was inconsistent, meaning that directly comparing parameters at specific times was not feasible. Instead, H_2OU opted for seasonal comparison and larger trends over time. Another limitation with the data was that certain parameters were not sampled for over periods of years. This meant that the 2000-2016 dataset and the 2017-2019 dataset had different parameters that did not necessarily overlap. For example, turbidity was only measured for the 2000-2016 dataset. Because of these limitations, H_2OU only analyzed data for certain parameters until or since 2016.

Chlorophyll-a

Notes about data

All measurements were taken at a depth of 0.5 meters. This is within the trophic zone for turbid lakes because it allows for sunlight penetration (Brinkmann, 2018). Additionally, Chl-a was not measured at sites 7, 9, and 10. None of the datasets were found to be normally distributed.

Trends and Tests

Time-related

Sampling for Chl-a was conducted from April to November. Concentrations generally peak in August but are elevated from July to October (**Appendix D**). When measured by year, it was found that Chl-a concentrations measured in 2018 and 2019 were lower than 2017 concentrations. 2016 measurements did not differ with the 2017, 2018, or 2019 measurements (**Appendix D.2**).

Location-related

Chl-a concentrations were consistent for the measured sites, but site 12 had a lower average measure concentration and a greater variance. There was no significant difference between sites, but sites 11 and 12 were closest to having a significant difference (**Appendix D.1**).

Comparison to Total Phosphorus

There was negligible correlation found between TP and Chl-a concentrations (R^2=0.016). However, there is a lag relationship between phosphorus and Chl-a concentrations. Data were not collected at regular intervals, so a regular lag time could not be used in the data analysis. To account for lag, the date data were moved down one space. For example, the Chl-a data from the former sampling date were graphed as data from the next sampling date. Although this lag time was irregular, the implementation of the lag time doubled the correlative relationship between TP and Chl-a (R^2=0.0284) (**Appendix D. 3**).

Turbidity

Notes about data

Measurements were made at sites 7, 9, or 10. Only TSS and turbidity were measured at site 1. From 2000-2015, TSS was measured, but not turbidity. From 2016-2019, turbidity was measured, but not TSS. No overlap between data sets was provided, so a linear regression could not be developed. Instead, the TSS and turbidity were compared to test whether they are similar. No depths were reported for turbidity measurements between 2016-2019 so a standard depth was assumed.

Trends and Tests

Location-related

Turbidity was found to be highest at site 6 and lowest at sites 2, 4, and 12. To account for variation, median values for each site were compared. Median values of tested sites generally did not differ from each other (**Appendix E.1**).

TSS concentrations were found to be highest at site 6 and 11 and lowest at site 3. To account for variation, median values for each site were compared. Median values of tested sites generally did not differ from each other (**Appendix E.2**).

TSS and turbidity were found to generally follow the same trends by location (**Appendix E.3**).

Dissolved Oxygen

Notes about data

DO was not measured at sites 9 or 10. Over 17,000 data points for DO were provided and used in analysis.

Trends and Tests

Location-related

Median DO concentrations ranged from approximately 4 to 8 mg/L and there is a significant difference in median concentrations between sites (**Appendix F.1**) DO was found to consistently have higher concentrations at shallower depths, and lower concentrations at deeper depths (R^2=0.405) (**Appendix F.3**).

Time-related

DO was measured between February and September of each year (**Appendix F.2**). There was great variance between months 4-8 (April through August), so these months were further used to look at DO by depth.

Comparison of DO concentration to Percent Saturation

DO concentration in mg/L was used for all the above DO tests. However, data on DO percent saturation were provided. When DO concentration is plotted against percent saturation, there is a weak relationship (R^2=0.391) between the two parameters (**Appendix F.4**)

Other Parameters

Trends and Tests

Nitrogen Analysis

Four types of nitrogen were provided: NH_3, TKN, NO_3^-, and NO_2^-. Linear regression analysis was used to test for relationships between these parameters to check if any could be used as surrogates for others (**Appendix H.1**). There was a strong relationship between NH_3 and TKN (R^2=0.876). TKN had a weak relationship to NO_3^- (R^2 = 0.0314) and NO_2^- (R^2 = 0.00807). Nitrite and nitrate also had a weak relationship (R^2 = 0.00529). TKN can be used as a surrogate for NH_3, but no other nitrogen parameters could be used as surrogates.

Phosphorus Analysis

Two types of phosphorus data were provided: TP and Ortho-P. Linear regression analysis was used to test for a relationship between these parameters to check if they could be used as surrogates for each other (**Appendix H.2**). A strong relationship was found between TP and Ortho-P (R^2=0.766); thus, TP was used as a surrogate for Ortho-P.

Lake Thunderbird Mass Loading

The mass loading rates, and respective percentages of the total mass loading for TP and TN were calculated using water quality data provided by the OWRB and flow measurements derived from StreamStats for the two major watersheds for Lake Thunderbird. The calculated values are shown in (kg/yr) in **Table 16**. These data were compared against TMDL data in order to determine the final design criteria.

Table 14: Phosphorous and Nitrogen Annual Mass Loading by Tributary

Watershed	Hog Creek	Little River	Jim Blue	Dave Blue	Total
TP (kg/yr)	846	4,098	239	620	5,803
TP (%)	15	71	4	11	N/A
TN (kg/yr)	13,439	32,256	2,189	5,665	53,549
TN (%)	25	60	4	11	N/A

Results and Recommendations

Treatment wetlands and pervious pavement were the final chosen recommendations for treating Lake Thunderbird's water quality due to their high scores in the decision matrix. Conceptual design, reduction percentages and costs for each method are outlined below. Costs and reduction percentage evaluations are based on similar projects, and the actual numbers may be different depending on the design modifications.

Treatment Wetlands

Design

The conceptual design for the Lake Thunderbird treatment wetland was developed by evaluating OWRB data, USGS StreamStats data, and data provided from existing treatment wetland sites. The process began by evaluating the average daily flow for each of the 5 contributing watersheds contained within the Lake Thunderbird watershed. The flow data were then paired with the average concentration of TP and TN in the OWRB data set to calculate an estimated loading percentage for each tributary.

The Lake Thunderbird TMDL report states the loading rates for TP and TN are 63.25 (kg/day) and 322.02 (kg/day), respectively. These values were calculated using HSPF model framework to generate nutrient loading runoff within the lake. The TMDL report includes a safety factor and future accumulation adjustments that permit these data to be used as design criteria (Dynamic Solutions, 2013).

There are many variables that determine a treatment wetland's nutrient removal efficiency. For the conceptual design, nutrient removal efficiencies per acre were determined based off data analyzed from wetland studies. Land et al. (2016), estimate removal to be in the range of 10 – 40 (g/m^2yr) for nitrogen and 0.5 – 5 (g/m^2yr) for phosphorus, for non-point source runoff. The approximated TMDL loading rates and removal rates used as design criteria are found in **Table 17**.

Table 15: Total Nitrogen and Phosphorus Mass Loading Rates

Nutrient	TMDL Loading Rates (kg/yr)	Removal Rates (kg/acre yr)
TN	117,537	64.8
TP	23,086	8.1

The removal rates were used in the conceptual design to calculate the areas necessary for different percent reductions of the TMDL loading rates (**Table 18**). Phosphorus was determined to have a greater influence over the design criteria because it required more area.

Table 16: Area Requirements for Mass Loading Reduction Amounts

TMDL Loading Reduction (%)	Area Required TN (acre)	Area Required TP (acre)
10%	182	285
25%	454	713
50%	908	1,425
75%	1,361	2,138

Median removal efficiencies in successful treatment wetlands for TN and TP are 37% and 46% respectively (Land et al., 2016). To ensure these treatment goals are met at Lake Thunderbird the conceptual design was based off the total area required for 50% removal of TP, 1,425 acres. The total area was then distributed according to the inflow percentage for the corresponding watersheds. **Table 19** displays the inflow percentages and area requirements for each watershed categorized by the inflow tributary. The Dave Blue and Jim Blue tributaries were evaluated as a single tributary and watershed because they enter the lake near each other.

Table 17: Area Requirements for 50% Removal by Tributary

Tributary	Flow Percent (%)	Area (acre)
Hog Creek	27	387
Little River	59	834
Dave Blue/Jim Blue	14	204

Large scale wetlands have longer hydraulic residence times, typically of a week or greater. Small scale wetlands have shorter hydraulic residence times, typically only hours or days. Studies have shown that the TP removal efficiency increases with the hydraulic residence time of a system (Nairn, 2014). For this reason, the preferred system is implanting three large scale treatment wetlands near the inflow of each of the tributaries in **Table 18**. Suggested locations are indicated with black circles in **Figure 11**.

There are various plant species that have been used for the treatment wetlands as shown in **Table 20**. According to the soil data from the USDA Soil Survey, the common soil type surrounding Lake Thunderbird varies from sandy loam, silty, to clayey loams. Due to the fluctuation of seasons and variable weather patterns in the state, it is recommended that the plants chosen for the treatment wetlands be tolerant to changes of weather. Due to the soil characteristics and weather conditions, the most recommended plant species would include bulrushes, spike rushes, pickerelweeds, or sweet flag. These plants can thrive in dry or wet soil conditions and are appropriate for sandy, silt or clayey loams.

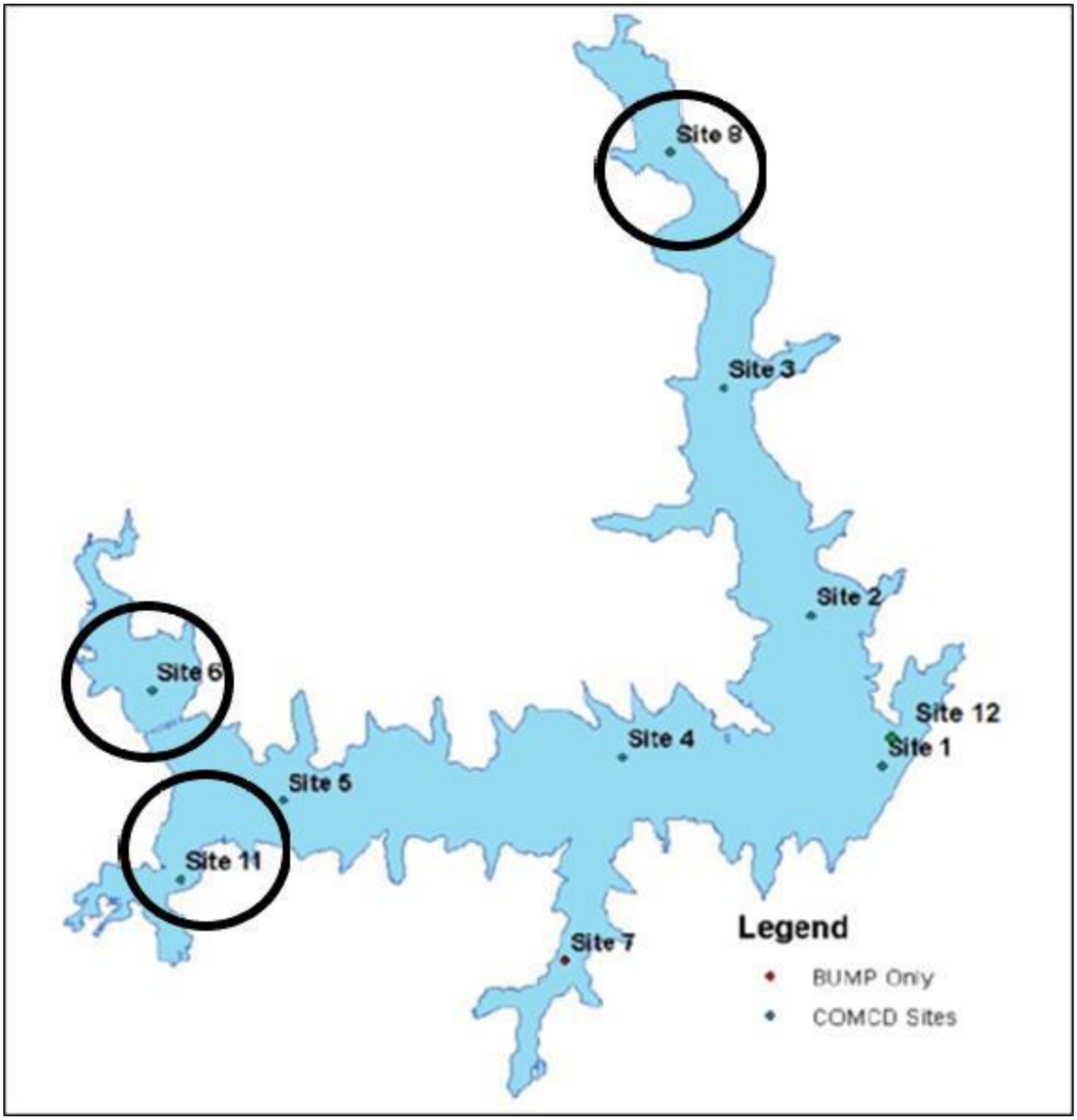

Figure 11: Suggested Locations for 3 Large Scale Treatment Wetlands

Cost

The overall costs for the treatment wetlands include capital expenditures (CAPEX) and O&M (OPEX) costs annualized over a projected 20-year lifetime. The costs were calculated after the determination of the wetland area needed for treatment. Tyndall's wetland cost overview was used to calculate the cost of implementation for the conceptual design. The cost for constructing a basin and the addition of weir plate were subtracted from Tyndall's value. The unit capital cost is approximately $3,500 per acre and the annual maintenance cost is roughly $550 per acre

(Tyndall, 2016). As seen in **Table 21**, the total cost is estimated to be $20.6 million for the conceptual design of 1,425 acres over a 20-year life span.

Table 18: Common Plant Types used for Treatment Wetlands

Common Name	Scientific Name	Plant Type	Soil Conditions	Soil Type
Bulrushes	Scirpus	emergent plant	dry or wet	fine clays, silt loams, sands
Spikerush	Eleocharis palustris	emergent plant	dry or wet	sandy, loamy or clay
Softrush	Juncus effusus	emergent plant	moist to wet soils	sandy, loamy or clay
Sedges	Cyperus	emergent plant	wet soils	sandy, loamy or clay
Arrow arum	Peltandra virginica	emergent plant	semi-dry, moist to wet soils	heavy loams, unconsolidated silts
Arrowhead/Duck potato	Saggitaria latifolia	emergent plant	wet soils	unconsolidated organic and silty wet soils
Blue flag iris	Iris versicolor	emergent plant	moist to wet soils	clay, loamy soils
Lizard's tail	Saururus cernuus	emergent plant	wet soils	sandy, loamy or clay
Pickerelweed	Pontedaria cordata	emergent plant	dry, wet preferred	sandy, silty loam, clays
Sweet flag	Acorus calamus	emergent plant	dry, wet preferred	sandy to heavy clayey soil

Table 19: Projected Costs for Treatment Wetlands

Projected Treatment Wetland Cost			
Capital	O&M (annual)	Total (20 yrs.)	Average annual cost
$4,802,510	$790,918	$20,620,867	$1,031,043

Effectiveness

Treatment wetlands have been shown to be effective in reducing TP, TN, and TSS concentrations. Removal efficiencies, however, greatly vary for each lake and have been reported to range from as low as 30% to over 90% (Haberl et al., 1995). For the Lake Thunderbird, the removal rates were estimated to be 8.1 (kg/acre yr.) for TP and 64.8 (kg/acre yr.) for TN (Land et al., 2016). The conceptual design was constructed to reduce TMDL loading rates by approximately 50% for both TP and TN.

Lifetime

Treatment wetlands commonly have a design lifetime between 10 and 30 years (Davis, 1994). Certain wetlands have had an effective design lifetime of 40+ years. The lifetime of a treatment wetland is dependent on factors such as nutrient loading rates, hydraulic retention time, removal capacity, and the rate of deposit development (Davis, 1994). Generally, a wetland's removal efficiency decreases with time. Efforts to extend a treatment wetland's lifetime efficiency include occasional operation and maintenance focused on ecosystem health and detritus removal. However, this can become costly as a wetland ages. Thus, the lifetime of the conceptual design was estimated as 20 years.

Pervious Pavement

Pervious pavement is a stormwater BMP that filters stormwater and runoff through pavement surface voids. The water then proceeds to seep through an underlying layer of rock before infiltrating into the underlying soil. Benefits of pervious pavements include reducing the rate of runoff, filtering pollutants from the stormwater, and recharging groundwater. Pervious pavement is designed to capture rainfall on pavement surfaces but can also withstand run-off from other impervious areas.

Design

To construct an appropriate pervious pavement conceptual design, a 1-inch 24-hour rainfall event was analyzed. The Little River watershed was selected for analysis because it has the largest percentage of impervious area. The water quality volume (WQv) for this watershed was calculated from the total area and percent impervious area. This information was from the Stormwater Toolbox. Total and percent impervious area were found from USGS StreamStats. The design infiltration rate (f_d) was calculated with **Equation 2** where f is the soil permeability of the Little River watershed from USGS StreamStats.

(VDOT, n.d.): $f_d = 0.5f = 0.5(1.03in/hour) = 0.515in/hour$ [Equation 2]

The next design element was the maximum allowable reservoir depth during a given amount of time (**Equation 3**). This ensures that the reservoir can completely empty within a maximum number of hours following a storm.

$$\text{(VDOT, n.d.): } d_{max} = \frac{f_d \times T_{max}}{V_r} \quad \text{[Equation 3]}$$

d_{max} = maximum allowable reservoir depth (ft)

f_d = design infiltration rate (in/hr)

T_{max} = maximum allowable drain time (hours)

V_r = void ratio of the gravel (0.4)

The maximum allowable reservoir depth for drainage times of 24, 48, and 72 hours are 2.575, 5.15, and 7.725 feet, respectively. To determine the minimum allowable reservoir depth, the frost line Oklahoma code must be considered (VDOT, n.d.). This is the average depth to which soil freezes. Therefore, the bottom of the gravel layer must extend to a depth of at least 20 inches (1.75 ft) below the finished surface of the pavement (Posey, 1984).

The maximum loading ratio, defined as total drainage area to infiltration area, is generally restricted to 6:1 (VDOT, n.d.). The total impervious area of Little River is 5,000 acres (USGS StreamStats, 2021). Therefore, the minimum surface area of the stone infiltration reservoir is 834 acres as computed in **Equation 4**.

$$\text{(VDOT, n.d.): } A_{min} = \frac{5000\,ac \times \frac{43{,}560\,ft^2}{ac}}{6} = 36{,}300{,}000\,ft^2 = 834\,acres \quad \text{[Equation 4]}$$

The surface area of the gravel reservoir, along with its depth, must provide storage for the computed WQv. Employing the minimum reservoir surface area, the depth of the stone reservoir can be computed as 2.01 ft, as shown in **Equation 5**.

$$\text{(VDOT, n.d.): } d = \frac{WQv}{V_r A_{min}} = \frac{29{,}112{,}600\,ft^3}{0.4(36{,}300{,}000 ft^2)} = 2.005\,ft \quad \text{[Equation 5]}$$

The depth is greater than the frost line, so this is an acceptable depth for the reservoir. This depth was used in the Stormwater Toolbox to calculate the storage volume of the reservoir, given a fixed area, to find the percent reduction of runoff (**Table 22**).

Table 20: 2.005 ft Reservoir Depth

Depth of Reservoir (ft)	2.005	
Surface Area of Pavement (acres)	Reservoir Storage Volume (ft^3)	Reduction of Runoff (%)
2.3	80,200	0.275
23	802,000	2.75
230	8,020,000	27.5

The maximum allowable reservoir depth during a 24-hour maximum drainage time was also put into the Stormwater Toolbox (**Table 23**). The 0.57-foot difference between the two reservoirs increased the amount of runoff reduction by 129%. This increase shows that the larger the depth of the reservoir, the more runoff reduction occurs.

Table 21: 2.575 ft Reservoir Depth

Depth of Reservoir (ft)	2.575	
Surface Area of Pavement (acres)	Reservoir Storage Volume (ft^3)	Reduction of Runoff (%)
2.3	103,000	0.354
23	1,030,000	3.54
230	10,300,000	35.4

Pervious pavement construction consists of four layers, as shown in **Figure 12**. Layer 1 is the pervious paving material of choice. The depth of this layer depends on what material is used. Layers 2 and 3 consist of the reservoir with a void ratio of 40% or more. The reservoir depth depends on the WQv, and layer 2 is one third the depth of layer 3. Layer 2 includes fine aggregate, and layer 3 consists of course aggregate. These layers provide a filtering effect for the water into the final layer. Layer 4 is the natural soil where the water percolates down to the water table (StormwaterPA, 2006).

Location

Pervious pavement works well for parking lots, walkways, playgrounds, sports courts, and other similar public areas. Driveways can also be pervious if the homeowner chooses. Pervious pavement roadways have seen wider application in Europe and Japan than in the United States, but aquifer recharge is no less important in the United States (VDOT, n.d.). An experimental stretch of highway in Arizona that is made of pervious pavement was built in 1986, and it is still

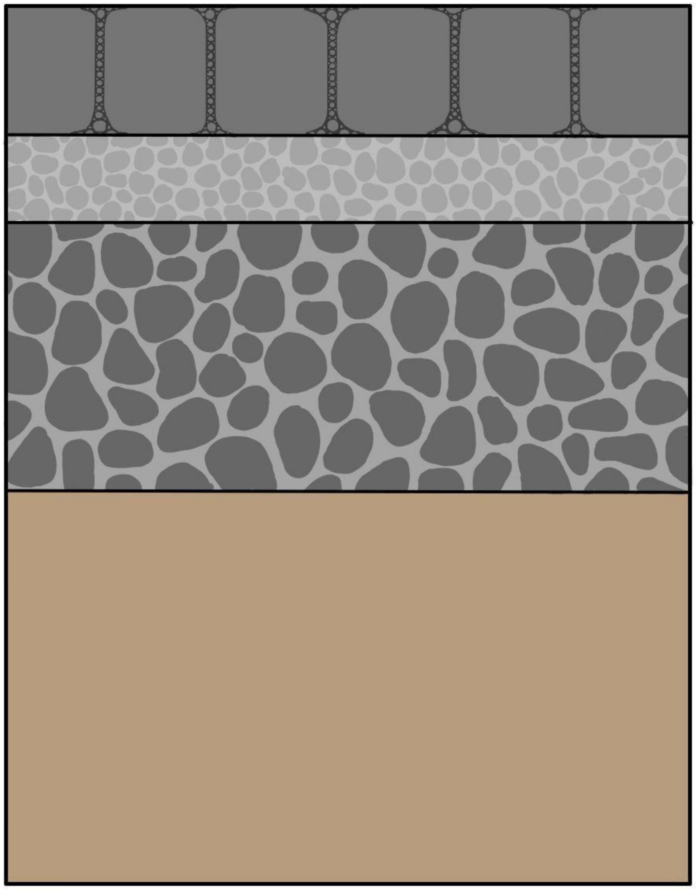

Figure 12: Cross-Section of Pervious Paver and Soil

in use today with an infiltration rate only slightly less than when first constructed (VDOT, n.d.*)*. When considering building with pervious pavement, a low slope and areas with low water tables are preferred (The State University of New Jersey, n.d.). In the cities surrounding Lake Thunderbird, a construction code that requires pervious pavement for all new construction could be implemented to ensure the technology is reaching the desired area for runoff removal.

Cost

Costs of pervious pavement depend on the project range and the material type. The State University of New Jersey's Water Resources Program produced a table showing the cost of different pervious pavements. This cost analysis includes demolition of existing pavement, excavation and disposal of existing soil, placement of stone reservoir layers, installation of under drain piping and cleanouts, and paving materials (The State University of New Jersey, n.d.).

Table 22: Pervious Pavement Construction Cost (The State University of New Jersey, n.d.)

Pavement Type	Low Cost (per ft^2)	High Cost (per ft^2)
Porous Asphalt	$12.00	$22.00
Pervious Concrete	$18.00	$28.00
Permeable Pavers	$22.00	$34.00
Grass Pavers	$16.00	$18.00

Maintenance costs for vacuum sweeping is $800 per acre annually, and the 25-year life-cycle cost of a 40,000-square-foot parking lot constructed with block paver (including installation, biannual vacuum sweeping and other maintenance) is $190,200 compared to $275,875 for impervious asphalt (CTC & Associates LLC, 2012). The lifetime for pervious concrete and block pavement is 20 to 30 years and 15 to 20 years for porous asphalt (CTC & Associates LLC, 2012). **Table 25** shows the 20-year cost of each type of pervious pavement material including the maintenance cost annually. The construction cost was taken from the medium cost from **Table 24** and multiplied by the largest proposed area (230 acres). The most cost-efficient paver material is porous asphalt or grass pavers. However, grass pavers would be difficult to implement in large public areas due to the unevenness which can cause tripping hazards.

Table 23: H_2OU Engineering's 20-Year Cost for Different Pervious Pavement Types with 230 Acre Area

Paver Type	Construction Cost	Annual Maintenance Cost	20 Year Cost
Porous Asphalt	$17,000,000	$184,000	$20,680,000
Pervious Concrete	$23,000,000	$184,000	$26,680,000
Permeable Pavers	$28,000,000	$184,000	$31,680,000
Grass Pavers	$17,000,000	$184,00	$20,680,000

Effectiveness

As shown above, the use of pervious pavement around Lake Thunderbird could have an effectiveness as high as 35.4% reduction in runoff. The highest chosen area of 10,000,000 square feet is approximately 230 acres, which is less than the total impervious area in the Little River watershed.

Lifetime

Because road construction and re-paving of surfaces is relatively common in the area, H_2OU suggests that pervious pavement be implemented when paved surfaces must be redone. Because of the gradual nature of this implementation strategy, there would not be a one-time financial burden. There also would not be a fixed project lifetime since pavements would continually be replaced by pervious pavement. Specific installations of pervious pavement have an estimated lifetime of 20 years, which means that there would be a 20-year gap between replacements at the same site.

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Appendix

Appendix A: Project Documents

Project Work Plan

for

Evaluation of Watershed-Level and In-Lake Options to Address Lake Thunderbird Water Quality

Prepared by

H_2OU Engineering

Rachel Bandy, Monica Ha, Paige Hardman,

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Prepared for

Central Oklahoma Master Conservancy District

(COMCD)

November 9th, 2020

Table of Contents

List of Figures

1.0 **Introduction**

An effective Project Work Plan (PWP) clearly outlines assigned tasks and deadlines to ensure successful execution and completion of a project. This document will assign specific responsibilities to each team member and clarifying milestones and deadlines of the project. The Health and Safety (HSP), Sampling and Analysis (SAP), and Quality Assurance Project Plans (QAPP) that accompany this document will detail tasks, strategies, and objectives of the plan to deliver satisfactory results.

In this document, the project and scale will be defined. Lake Thunderbird and the surrounding watershed will be introduced as the study site and the intended goals of the project will be outlined. A plan of action to achieve H_2OU's specific goals will be provided through general task assignments and a timeline of key deadlines will be provided.

2.0 Project Overview

2.1 Site History

"The Norman Project," today known as Lake Thunderbird, was initiated with the intent of flood control management along the Little River. The design plans for the Norman Reservoir included current and future water demands for the surrounding communities including Midwest City, Norman, Del City, Moore, and Tinker Air Force Base, and a provision was added to allow for the allocation of any surplus water to Oklahoma City. This plan was determined to be economically feasible and "The Norman Project" was authorized under Public Law 86-529 and signed into law by President Eisenhower in 1960 with subsequent planning and construction funding provided by President Kennedy's Works Appropriation Bills by 1962 (Simonds, 1999).

Construction of the dam began in 1962 by Cosmo Construction. Spillway and outlet works were constructed by the L&A Construction Company, the reservoir and relift pumping plant were constructed by the Lee-Emmert Corporation, clearing operations for the reservoir were managed by Schutt Construction Company, and recreation infrastructure was managed by the Pool Construction Company (Simonds, 1999). Construction of the 2456-hectare (6070 acre) reservoir was completed in mid-1965. The Norman reservoir was renamed as Lake Thunderbird and water use began in 1966.

Operation and maintenance of Lake Thunderbird was transferred from the US Bureau of Reclamation (BOR) to the Central Oklahoma Master Conservancy District (COMCD) in 1966 just after water deliveries began. Maintenance has included resolving pipe vibration (1969), relocation of a Del City pipeline segment (1974), and several small breaks (Simonds, 1999). The reservoir continues to supplement water for surrounding communities and prevent flooding today.

2.2 Current Status

Today, Lake Thunderbird is ranked as Priority 1 and in Category 5a of Oklahoma's 303(d) list. This classification indicates impaired water quality and failure to meet designated uses (DEQ 2013). The Department of Environmental Quality (DEQ) has further designated the lake as a Sensitive Water Supply (SWS) that fails to meet requirements for Fish & Wildlife Propagation (FWP) for a Warm Water Aquatic Community and Public Water Supply uses (OCC, 2008). Reasons for impairment include low sub-thermocline dissolved oxygen levels, high turbidity, and high chlorophyll-a concentrations (OWRB, 2019). These parameters also cause the water to have aesthetic concerns and raise water treatment costs (OWRB, 2011).

Figure 1 is a map of the lake and **Figure 2** depicts the watershed.

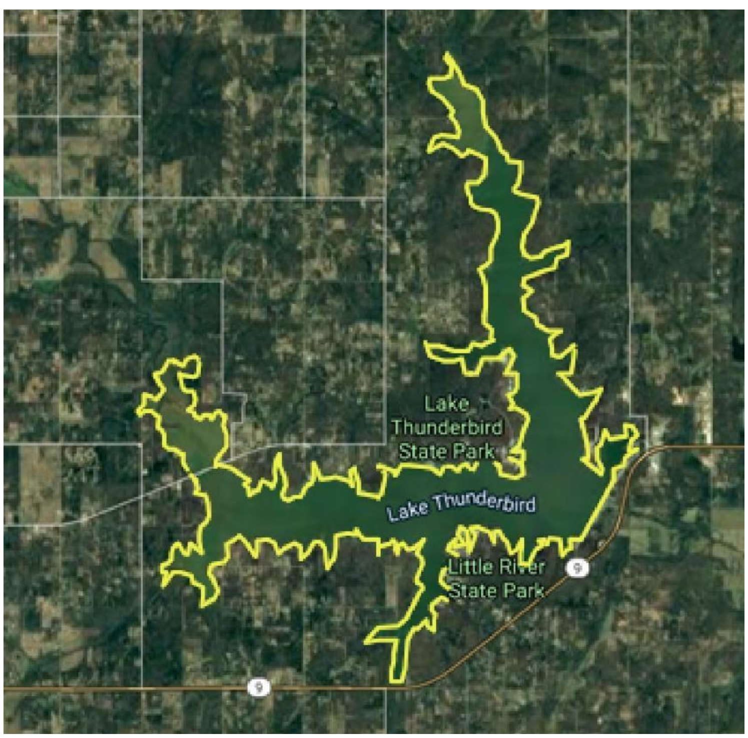

Figure 1: Satellite Image of Lake Thunderbird (Google Maps, 2020)

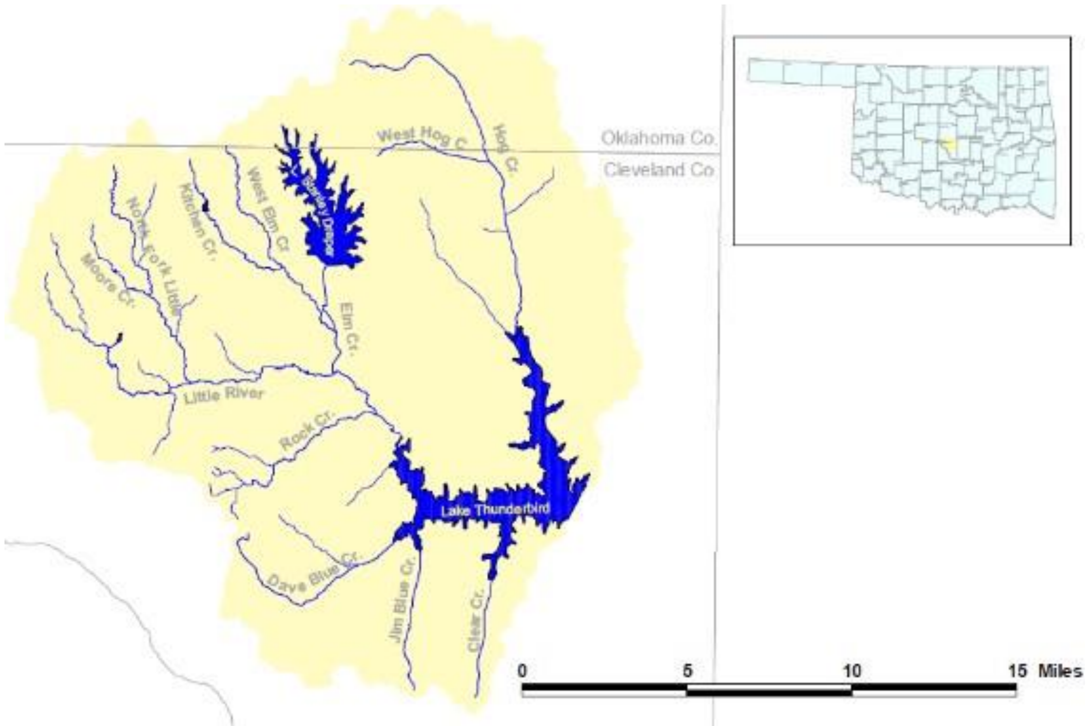

Figure 2: Map of Lake Thunderbird Watershed (OCC, 2010)

2.3 Purpose and Scope

Lake Thunderbird is an important body of water to many in Oklahoma. Because it is used for drinking water, recreation, and animal habitats, it is imperative to preserve the health of the lake and its surroundings. Accordingly, proposed technologies should not interfere with the functions or appearance of the lake. Within these parameters, H_2OU plans to examine treatment methods for both the lake and the watershed as a whole. Exploring options at both the lake- and watershed-level will allow H_2OU to develop a holistic plan to address water quality concerns affecting Lake Thunderbird.

2.4 Issues of Concern

Lake Thunderbird has several water quality concerns, but the most pressing of these are high turbidity, low dissolved oxygen, and high levels of chlorophyll-a. High turbidity means that there are high concentrations of sediments suspended in the water. This can be from suspension of sediments such as clay or elevated concentration of other solids, including phytoplankton. Turbidity causes water to appear dirty and can interfere with sunlight penetration. It can also indicate high algal concentrations (algal turbidity) and increase treatment costs in the production of drinking water.. Low dissolved oxygen (DO) is caused by eutrophic conditions and high temperatures. Under such conditions, there are often elevated chlorophyll-a concentrations. Algal growth expands when limiting nutrients (often phosphorous for surface waters) are added and this leads to DO depletion and chlorophyll-a level augmentation. Low DO is aconcern because biota in the lake need higher DO levels to thrive. Finally, high levels of chlorophyll-a indicate undesirable levels of algae in the water. The SAP contains a more elaborate explanation of these water quality concerns.

2.5 Identification of Key Stakeholders

Central Oklahoma Master Conservancy District: COMCD manages the operation and maintenance of Lake Thunderbird under authorization from BOR and consists of appointed representatives from each of the three municipalities that receive water from the lake.

Bureau of Reclamation: BOR is the federal agency within the U.S. Department of the Interior that organized construction of Lake Thunderbird. BOR's primary objective is provision of water throughout the western United States.

City of Norman: Norman, Oklahoma is a city with an estimated 2019 population of approximately 124,880 (US Census Bureau, 2020). Its sources of water include 21,600 acre-feet annually from Lake Thunderbird and 31 water wells, and an additional 1 MGD that is purchased from Oklahoma City (City of Norman, 2016).

City of Midwest City: Midwest City, Oklahoma is a city with an estimated 2019 population of approximately 57,407 (US Census Bureau, 2020). Its sources of water include 18 wells and an annual share of Lake Thunderbird's water (Midwest City, 2020).

City of Del City: Del City, Oklahoma is a city with an estimated 2019 population of approximately 21,461 (US Census Bureau, 2020). Its sources of water include 12 wells and an annual share of Lake Thunderbird's water (Del City, 2020).

3.0 Project Objectives

The H_2OU team has identified objectives related to safety, sample collection, final documents, and final presentation. Each of these categories has short- and long-term objectives that will be important to keep in mind throughout the project.

3.1 Safety Objectives

Safety is of utmost importance when collecting samples and working in the laboratory. The overall objective of the H_2OU team is to have zero health or safety concerns related to this project. However, in the event of any health or safety incident, H_2OU will refer to the HSP to effectively handle the situation. The HSP has information such as emergency contact information, site descriptions, and potential hazard information. All H_2OU members will thoroughly review the HSP before participating in any sample collection or laboratory work.

3.2 Sample Collection Objectives

Because sample collection is an important aspect of this project and a potential source of error, H_2OU plans to take a preventative approach that minimizes any possible errors. This will be accomplished through adherence to the QAPP, which has sections on Sampling Methods and Data Acquisition Requirements, as well as adherence to the SAP, which contains a specific approach for the sampling events. Due to time constraints, only one sampling event is currently planned. It is important to make the most of this event by adhering to these plans.

3.3 Final Document and Presentation Objectives

H_2OU will consistently update project documents as work proceeds on the project. Each team member will participate to the extent that they are designated and will work under their individual areas of expertise when applicable. The final document will be edited, professionally formatted, and organized to clearly demonstrate each aspect of the project. The final document will accurately reflect H_2OU's research, data collection, analysis, and conclusions. Similarly, the final presentation will be consistent, professional, and easy to understand. Each H_2OU team member will participate in its creation and work to ensure it clearly summarizes all relevant aspects of this project.

4.0 **Resources and Constraints**

There are several resources that H_2OU can use in the completion of this project. First, H_2OU may consult and coordinate with Dr. Knox and Dr. Nairn throughout the project. Additionally, the physical resources that are available to H_2OU are the laboratory and data collection resources provided by the Center for Restoration of Ecosystems and Watersheds (CREW) laboratory.

There are certain constraints that H_2OU must work within to complete this project successfully. One major constraint is time since the project began in August 2020 and must be completed by

April 2021. Another constraint is the COVID-19 pandemic, which greatly limits face-to-face interactions and requires extra care when doing in-person tasks such as sampling and laboratory work. Finally, although Lake Thunderbird is within a relatively accessible distance, there is only one sampling episode planned.

5.0 Project Tasks and Timeline

Tasks were assigned due to relevant experience and interest. However, project tasks are inclusive of all team members and a collaborative environment will be maintained through assignment flexibility and communication. Additional team members were assigned to tasks that were expected to require more effort. Figure 3 shows is the general team structure, detailing topics of specialization for each member..

Figure 3: Team Organization and Positions

5.1 Sampling Tasks

Figure 4 shows sampling locations throughout Lake Thunderbird. Water quality parameters will be measured at sites 1, 2, 4, 5, and 6. In-situ measured parameters include temperature, pH, dissolved oxygen (concentration and percent saturation), specific conductance, conductivity, resistivity, total dissolved solids, salinity, oxidation-reduction potential, total alkalinity, total hardness, and turbidity. A YSI 6920v2 sampling probe will be used to measure temperature, pH, conductivity, and oxidation reduction potential (OPR) and an optical sensor will be added to the multiprobe to measure dissolved oxygen and chlorophyll-a. A Hach 2100P turbidimeter will be used to measure turbidity, test kits will be used to measure total alkalinity and hardness, and a Secchi disk will be used to measure clarity and turbidity.

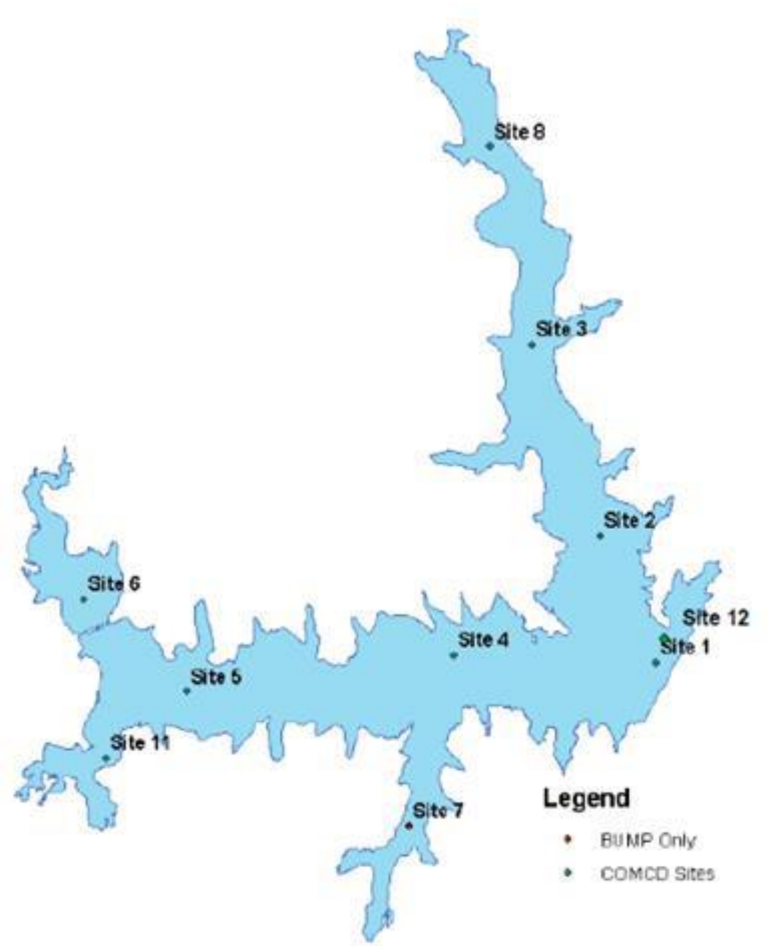

Figure 4: Lake Thunderbird Monitoring Sites (OWRB 2019)

5.2 Laboratory Tasks

A SEAL Analytical AQ300 Automated Direct Analyzer will be used to measure anions such as sulfate, orthophosphate, nitrate, nitrite, and chloride. Total nitrogen and total phosphorous will be analyzed with HACH TNT kits.

5.3 Report and Presentation Tasks

Monica Ha will act as the Final Report Lead while Paige Hardman and Kaleb Schwab will act as the Oral Presentation Leads. Within this general leadership structure, each team member will participate in creating the report and presentation, giving input based on their specific areas of expertise. The report will delineate the improvement technologies the H_2OU team recommends for Lake Thunderbird. The goal for the oral presentation will be to convey this information clearly and effectively to the stakeholders of this project.

5.4 Timeline

This capstone project started in September of 2020. H2OU team members divided each project task into sub-tasks and decided on deadlines for each. The final task of this project is the presentation, which will be given in May of 2021. Figure 5 shows the preparation and preliminary steps such as the literature reviews and project documents. Figure 6 shows larger project steps such as sampling, analysis, and design, as well as creating the final report and oral presentation. For the written report, H2OU's goal is to have 33% completed by February 16th, 66% completed by March 11th, and the final draft due on April 20th. H2OU plans to provide the oral presentation on April 22nd.

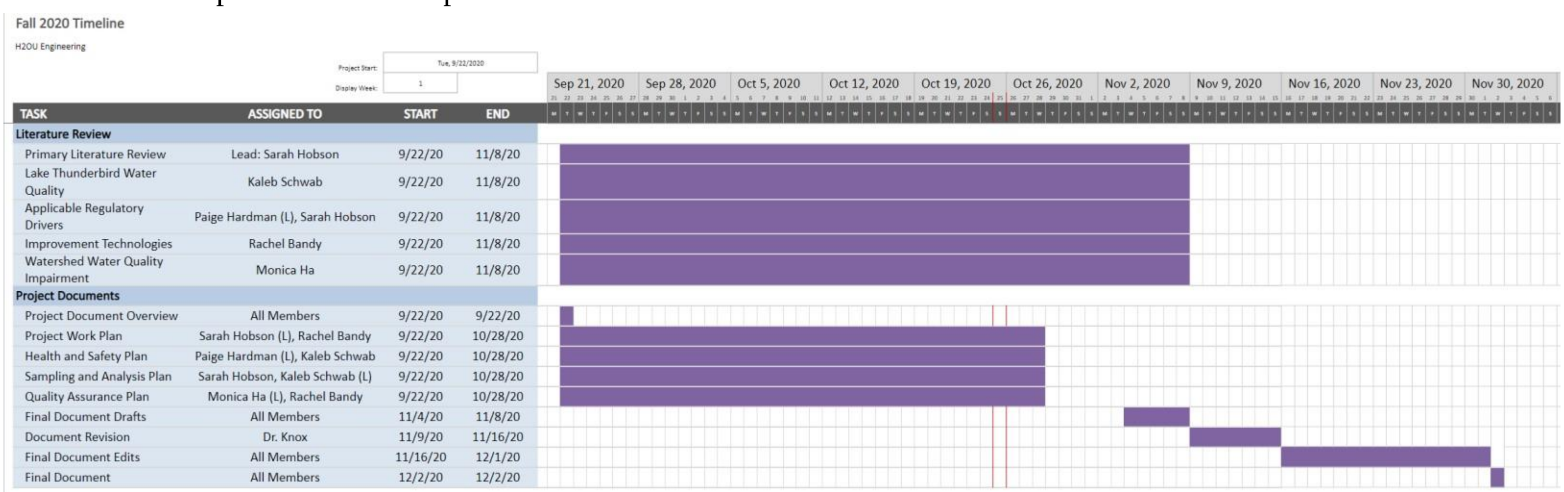

Figure 5: Fall Gantt Chart

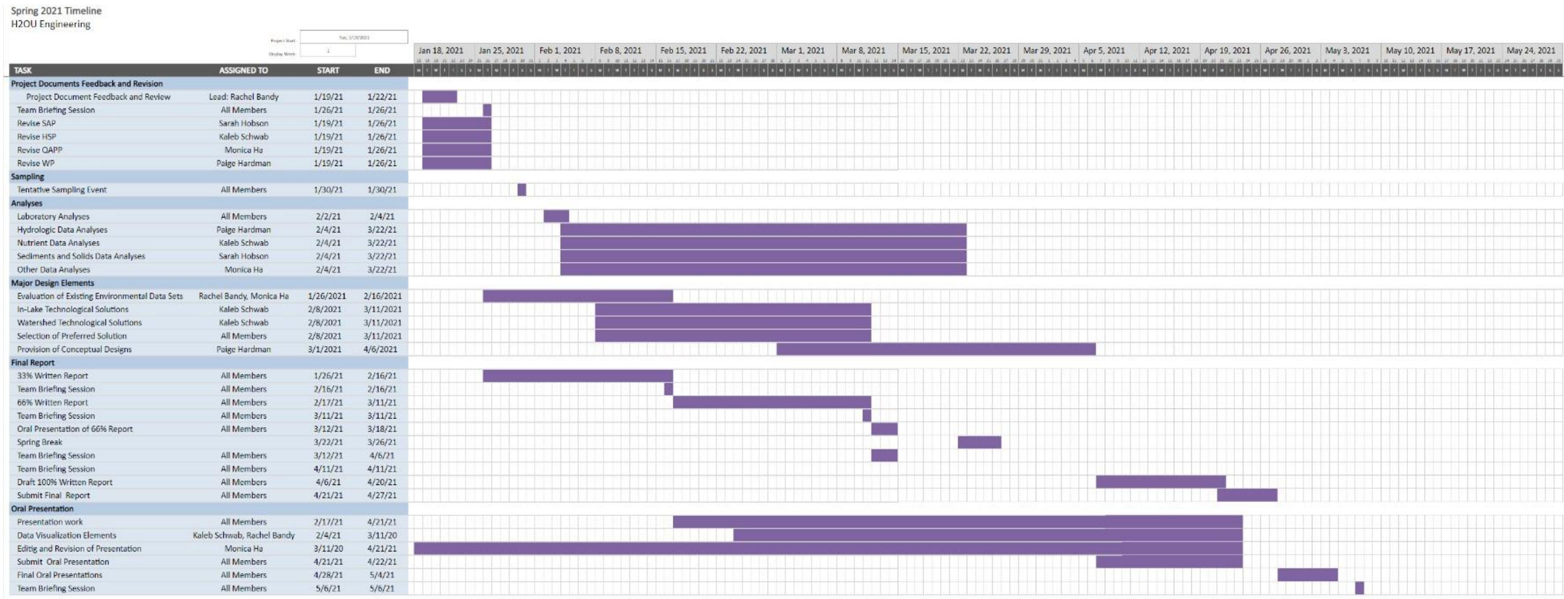

Figure 6: Spring Gantt Chart

6.0 Strategy

The most important strategy for this project will be the team's collective agreement to adhere to the Gantt charts as best as possible. Observing small deadlines within the larger scale of the project will help H_2OU successfully create the report. It will also be important to adhere to the QAPP, HSP, and SAP. These documents provide a framework for sampling and laboratory events. Communication, deadline adherence, and observance of documented procedures will all be important in creating a successful report. Additionally, dividing the workload as evenly as possible will set the H_2OU team up for success and equal participation.

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Sampling and Analysis Plan

for

Evaluation of Watershed-Level and In-Lake Options to Address Lake Thunderbird Water Quality

Prepared by

H_2OU Engineering

Rachel Bandy, Monica Ha, Paige Hardman,

Sarah Hobson, and Kaleb Schwab

Prepared for

Central Oklahoma Master Conservancy District

(COMCD)

November 9th, 2020

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1.0 Site-Specific Information

1.1 Background

Lake Thunderbird, previously called the "Norman Project," was opened for operation in 1965 under provision of the US Bureau of Reclamation. Operations were subsequently transferred to the Central Oklahoma Master Conservancy District. The lake has designated uses of flood control, municipal water supply, recreation, and fish and wildlife propagation for the surrounding municipalities. Water quality issues due to factors such as a high stormwater intake have caused the lake to be uncompliant with designated use requirements (Simonds, 1999). Today, the lake is ranked as Priority 1 and in Category 5a of Oklahoma's 303(d) list. This classification indicates impaired water quality and failure to meet designated uses (ODEQ, 2013). The Oklahoma Water Resources Board (OWRB)) has further designated the lake as a Sensitive Water Supply (SWS) that fails to meet requirements of the Fish & Wildlife Propagation (FWP) for a Warm Water Aquatic Community and Public Water Supply uses (OCC, 2008). Reasons for impairment include low sub-thermocline dissolved oxygen (DO) levels, high turbidity, and high chlorophyll-a concentrations (OWRB, 2019). These parameters also cause the water to have aesthetic concerns and raise water treatment costs (OWRB, 2011).

1.2 Objective

Lake Thunderbird serves as the primary municipal water supply for the cities of Norman, Del City and Midwest City and is being targeted for water quality improvement for failure to meet public/private water supply and warm water aquatic community beneficial use criteria (ODEQ 2018). Elevated chlorophyll-a, turbidity, and Total Maximum Daily Loads (TMDLs) for nutrients, as well as low dissolved oxygen are cited as reasons for impairment (OWRB 2020). Lake Thunderbird is recognized as a sensitive water supply (SWS) by the state of Oklahoma thus requiring additional protection from pollution events. There are no point-source discharges into Lake Thunderbird. Urban stormwater and agricultural inputs are responsible for major nutrient contributions (ODEQ, 2018). The principal impounded stream is the Little River, and major direct tributaries to the lake include Hog Creek, Dave Blue Creek, Jim Blue Creek and Clear Creek (**Figure 1**). The COMCD desires enduring and sustainable solutions to Lake Thunderbird water quality concerns. Samples will be collected to measure water quality parameters such as: nitrate (NO_3^-) nitrite (NO_2^-), total phosphorus (TP), and total nitrogen (TN). These were selected because they indicate water quality impairment by eutrophication and are related to dissolved oxygen and chlorophyll-a concentrations.

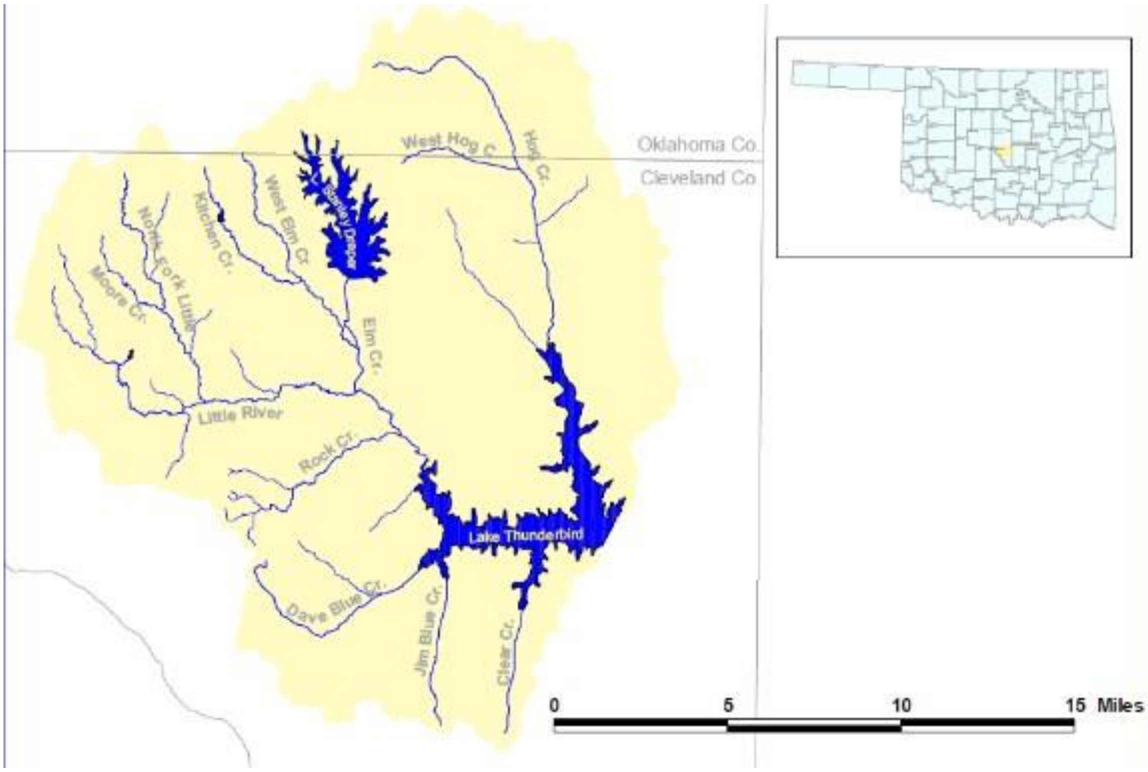

Figure 1: Lake Thunderbird Watershed and Tributary Map (OCC 2010)

2.0 Sampling Approach

2.1 Sampling Area Description

Lake Thunderbird covers approximately 25 square kilometers (6070 acres) in surface area and has a mean and maximum depth of 6 and 18 meters, respectively. It is part of the Little River watershed that consists of 663 square kilometers (256 square miles) of predominantly deciduous forest and grassland/herbaceous vegetation that is mainly agricultural (USACE, 2020). The lake impounds Hog Creek and the Little River (**Figure 2**) at their intersection in Northeast Cleveland County and includes a total of 18 total classified water body segments (ODEQ 2013). It is in a semi-arid climate and has deep clayey soils and a high drainage density (Martin-Mikle et al., 2015).

2.2 Sampling Rationale

In this study, water quality samples will be taken at 5 locations at OWRB test sites 1,2,4,5, and 6 time allowing, as shown in **Figure 2**. At site 1, samples will be taken at 4-meter intervals from 0 to 12 meters below the surface. At all other locations, samples will only be collected from the surface. These locations were selected to represent the varying bathymetric elevations of the lake as well as locations of major influence and effluence of water. At each location, temperature, pH, DO, SC, conductivity, resistivity, total dissolved solids, salinity, oxidation-reduction potential, chlorophyll-a, turbidity, nitrate, nitrite, soluble reactive phosphorous, and total phosphorous will be measured and compared with measurements from previous years.

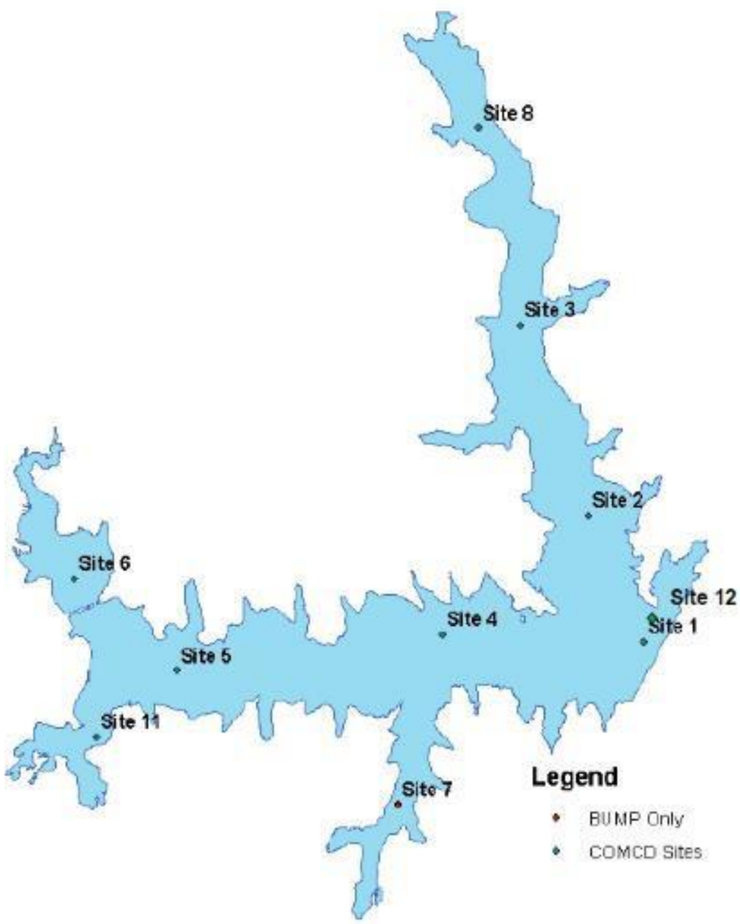

Figure 2: Lake Thunderbird Monitoring Sites (OWRB 2019)

2.3 Field Sampling and Laboratory Sampling Equipment

Sampling equipment will be divided into in situ measurements and sampling for laboratory analyses.

Field Equipment: A YSI 6920v2 sampling probe will be used to measure temperature, pH, conductivity, and ORP and an optical sensor will be added to the multiprobe to measure dissolved oxygen and, and chlorophyll-a. A Hach 2100P turbidimeter will be used to measure turbidity, a Secchi disk will be used to measure turbidity and clarity, and test kits will be used to measure total alkalinity and total hardness. A Van Dorn sampler will be used to measure depths at site 1. **Table 1** displays field sampling equipment to be utilized.

Laboratory Equipment: A SEAL Analytical AQ300 Automated Direct Analyzer (DA) will be used to measure NO_3^- , NO_2^- , SRP and TP.

Other Supplies: Waterproof notebooks for recording of field data (2), indelible ink pens (2), Sterile 150 mL plastic bottles (20), a squeeze bottle of RO water (250 mL), a box of Kimwipes, nitrile glove (1 box, large), dropper vials of 180 mL of H_2SO_4 (1:1, 48%) as preservatives (15 mL/bottle), a clipboard with copies of the chain of custody, sample documentation, and in-situ data collection sheets, a sharpie and waterproof sample labeling tape, ice chests (2, 30 gallon), and a boat for water transportation.

Equipment for Decontamination Considerations: The YSI will be cleaned with DI water between sites, the turbidimeter flask will be rinsed with DI water and wiped with a Kim wipe between uses, turbidity and alkalinity test kits will be disposed of after uses, and new or acid-washed tubes will be used in the DA (USEPA, 2015).

Table 1: Equipment to Bring While Field Sampling

Sampling Equipment		
Van Dorn sampler (horizontal)	Ice chests (2, 30gal)	Sharpie and waterproof sample labeling tape
Nitrile gloves	Sterile 150 mL plastic bottles (20)	Sterile 500 mL plastic bottles (15)
Secchi disk	Sterile 2L containers (4)	H_2SO_4 (1:1), 48%, 180 mL (15 mL/bottle)
Walkie talkies	GPS	YSI 6920v2 with optical sensor multiprobe
Clipboard with documentation sheets	Hach 2100P turbidimeter and 2 flasks	Kimwipes (1 box)

2.4 Sample Parameters

Variables to be recorded/measured at each location are listed in **Table 2**. Samples will be collected to measure general water quality, nutrients, and in-situ measurements.

Table 2: In-Situ Data Collected and Sample Parameters Measured

Sample Variables	
Parameter	**Equipment**
Temperature	YSI 6920v2 Probe
Chlorophyll-a	YSI 6920v2 Optical sensor
Conductivity	YSI 6920v2 Probe
Salinity	YSI 6920v2 Probe
Total Dissolved Solids (TDS)	YSI 6920v2 Probe
pH	YSI 6920v2 Probe
Oxidation Reduction Potential (ORP)	YSI 6920v2 Probe
Specific Conductance	YSI 6920v2 Probe
Resistivity	YSI 6920v2 Probe
Optical Dissolved Oxygen	YSI 6920v2 Optical sensor
Turbidity	HACH 2100P Turbidimeter, Secchi disk
Alkalinity	Test kit - HACH Method 8203
Hardness	Test kit - EDTA Titration
Nitrate (NO_3^-)	SEAL Analytical AQ300 Automated Direct Analyzer (DA)
Nitrite (NO_2^-)	SEAL Analytical AQ300 Automated Direct Analyzer (DA)
Total Nitrogen (TN)	SEAL Analytical AQ300 Automated Direct Analyzer (DA)

Total Phosphorus (TP)	SEAL Analytical AQ300 Automated Direct Analyzer (DA)
Soluble Reactive Phosphorus (SRP)	SEAL Analytical AQ300 Automated Direct Analyzer (DA)

2.5 Sampling Methods

All sampling for surface water will use methods approved by the EPA. Sampling methods approved by the EPA include Van Dorn sampler use and dipping using swing sampler and container. The Van Dorn sampler will be used to collect samples at 4-, 8-, and 12-meter intervals for site 1 (EPA 2013).

Dipping using swing sampler and container

A swing sampler will have a sampling container attached to its end and be used to sample surface water from the boat. Surface samples should be collected prior to any depth sampling or use of Secchi disk as to not disturb water or sediment. The sampler should attempt to face upstream if there is a current. Samplers should take care not to disturb sediment while sampling if the area is shallow. If containers are to be pre-preserved the sampler should not displace the preservative from the container (EPA 2013).

Discrete Depths Sampler

A Van Dorn sampler will be used to take samples at depths. The Van Dorn sampler is a plastic cylinder with rubber stoppers meant to be lowered in a horizontal position. When lowered the stoppers are open on each end allowing for water to pass through. A messenger is sent down a rope when the sampler is at the designated depth to cause the stoppers to close. The cylinder is then raised, and water is then removed through a valve to fill respective sample containers. Care should be taken not to disturb the sediment which can pollute the sample (EPA 2013).

2.6 Field QA/QC

To maintain the utmost quality and the most accurate data in experimental results, quality control and assurance measures will be taken. To assess the potential likelihood of field contamination, quality control samples will be taken through the collection of field blanks, where deionized water samples will be transported and treated as a field sample. For quality assurance, field replicates will be collected in addition to the field samples to analyze any potential discrepancies and compare the results in the field data. For the laboratory analysis portion, laboratory blanks and replicates will also be measured to assess whether outside factors may have contaminated the results. Two field blanks will be transported to the site and sampling locations. This blank will serve as a baseline contamination measure and all samples will be adjusted to account for baseline contamination if it is detected in the field blank. The EPA suggests that at least 10% of samples collected should be duplicate samples (1996). To satisfy this there will be a duplicate sample collected for every ten samples taken. The two total duplicate sites will be randomly chosen and include one surface water collection and one depth collection that will be taken with the Van Dorn sampler. Duplicates will be treated as normal samples and will be collected following the procedures outlined in section 2.5 but will be distinguished from other samples in their labeling (see section 2.9). In the laboratory, duplicates are to be treated and tested as any other sample in order to analyze field variability among ideally identical samples. All quality control and assurance measures are further outlined in the Quality Assurance Project Plan (QAPP) for more details.

2.7 Sample Labeling

All collected samples will be labeled with a clear and concise standardized format to prevent data loss and increase data acquisition efficiency. Each sample will correlate to a pre-defined unique location and parameter of measurement. At a minimum, each sample label shall contain collection location, date and time, team name, sampler initials, parameter to be measured, sample site number, sample identification number (required only at site 1 for samples of differentiating depths) and preservation method. Sample labels will be made of standard waterproof lab tape and be written with permanent marker in a clear and legible print.

2.8 Sampling Documentation and Chain-of-Custody

Samples will be documented in the field with a clipboard, pen, and printed out sample documentation sheet. This sheet will contain all information included in sample labels (see section 2.7) and a box to check off once that sample was collected. Each sample will also be documented in the chain of custody sheet as shown in **Table 3**. All samples will be documented using chain-of-custody forms as the field samples are being transported. The use of chain-of-custody forms will record what samples are being transported, where they are being delivered, and who is in custody of the field samples. Chain-of-custody forms are necessary in providing all the information that was obtained from the time of sample collection, transport, storage, and to the point where it is being disposed. Chain-of-custody forms will provide a form of evidence and documentation for all the field samples that are collected. This will ensure the integrity of the samples and minimize any possible mistakes or potential tampering.

Table 3: Example Chain of Custody Form

Chain of Custody				
Item #	Date/Time	Released by (Signature)	Received by (Signature)	Comments/Location

3.0 Analytical Approach

3.1 Analytes

Parameters to be measured in the field include temperature, conductivity, pH, ORP, dissolved oxygen, turbidity, and chlorophyll-a. Additionally, total nitrogen (TN), nitrate (NO_3^-), nitrite (NO_2^-), soluble reactive phosphorous (SRP), and total phosphorous (TP), will be measured via collected samples in a laboratory.

3.2 Storage, Containers, Preservatives, and Hold-Time

All samples will be taken using nitrile gloves and preserved and stored in coolers. Samples will be stored and transported with their chain of custody documentation. Samples will be collected and preserved to measure NO_3^-, NO_2^-, SRP, TP, and TN, as noted in **Table 4**.

Table 4: Collected Field Sample Containers, Preservatives, and Hold Times

Analytical Parameter and/or Field Measurements	Sample Volume (mL)	Containers (number, type, size/volume)	Preservation Requirements (chemical, temperature, light protection)	Maximum Holding Time
Nitrate-Nitrogen	100	Plastic or Glass	Cool to 4°C	48 hours
Nitrite-Nitrogen	50	Plastic or Glass	Cool to 4°C	48 hours
SRP	50	Plastic or Glass	H_2SO_4 to pH<2 and cool to 4°C	28 days
Total Phosphorus	50	Plastic or Glass	H_2SO_4 to pH<2 and cool to 4°C	28 days
Total Nitrogen	400	Plastic or Glass	H_2SO_4 to pH<2 and cool to 4°C	28 days

3.3 Analytical Procedures

Analytical procedures will be required for the following parameters: NO_3^- , NO_2^-, N, SRP, and TP. Anions will be measured using a Seal Analytical AQ 300 Automated Discrete Analyzer. Laboratory analysis procedures will follow the EPA methods shown in **Table 5.**

Table 5: EPA Method, Detection level, and Parameter Measured Summary

Analytical Methods		
Method	**Parameter**	**Detection Level**
EPA 353.1	Nitrate (NO_3^-)	0.03 mg N/L (Range: 0.2 to 5.0 mg N/L)
EPA 353.2 Ver 2	Nitrite (NO_2^-)	0.0008 mg N/L (Range: 0.015 to 1.5 mg N/L)
HACH Method 10208	Total Nitrogen (N)	0.03 mg N/L (Range: 0.25 to 15 mg)
EPA 365.1 Ver 2	Soluble Reactive Phosphorus (SRP)	0.003 mg P/L (Range: 0.01 to 1.0 mg P/L)
HACH Method 10209/10210	Total Phosphorus (TP)	0.006 mg P/L (Range: 0.065to 5.0 mg P/L)

3.4 Disposal of Materials

The following section and Table 2 are taken directly from the US EPA (2014). **Table 6** describes general and specific procedures and considerations to be used and observed when managing investigation derived waste (IDW) generated during the course of hazardous waste site investigations.

Materials which may become IDW include, but are not limited to:

- Personal protective equipment (PPE) - This includes disposable coveralls, gloves, booties, and life jackets
- Disposable equipment and items - This includes plastic ground and equipment covers, aluminum foil, conduit pipe, composite liquid waste samplers (COLIWASAs), Teflon® tubing, broken or unused sample containers, sample container boxes, tape, etc.
- Cleaning fluids such as spent solvents and wash water.
- Packing and shipping materials.

Table 6: IDW management procedures

TYPE	HAZARDOUS	NON - HAZARDOUS
PPE-Disposable	Containerize in plastic 5-gallon bucket with tight-fitting lid. Identify and leave on-site with permission of site operator, otherwise return to FEC for proper disposal.	Place waste in trash bag. Place in dumpster with permission of site operator, otherwise return to FEC for disposal in dumpster.
PPE-Reusable	Decontaminate as per SESD Operating Procedure for Field Equipment Cleaning and Decontamination, SESDPROC-205, if possible. If the equipment cannot be decontaminated, containerize in plastic 5-gallon bucket with tight-fitting lid. Identify and leave on-site with permission of site operator, otherwise return to FEC for proper disposal.	Decontaminate as per SESDPROC-205, and return to FEC.
Disposable Equipment	Containerize in DOT-approved container or 5-gallon plastic bucket with tightfitting lid. Identify and leave on-site with permission of site operator, otherwise arrange with program site manager for testing and disposal.	Containerize in an appropriate container with tight-fitting lid. Identify and leave on-site with permission of site operator, otherwise arrange with program site manager for testing and disposal. If unfeasible, return to FEC for disposal in dumpster.
Trash	N/A	Place waste in trash bag. Place in dumpster with permission of site operator, otherwise return to FEC for disposal in dumpster.

** These materials may be placed on the ground if doing so does not endanger human health or the environment or violate federal or state regulations.

4.0 **Health and Safety**

H_2OU Engineering will obey the protocols identified in the Health and Safety Plan (HSP) for the duration of this project. For reference, emergency contact information for the H_2OU Engineering team can be found in **Table 7.**

Table 7: Emergency Contact Information

Name	Address	Phone Number	Emergency Contact Name	Emergency Contact Number
Paige Hardman	1208 W Havenwood Dr. Midwest City, OK 73110	918-712-0070	Jaclyn Gaulding	918-807-2138
Monica Ha	2200 Classen Blvd, Norman, OK 73071	405-568-9258	Joseph Ha	405-520-3638
Sarah Hobson	1325 Commerce Drive, Norman, OK 73071	405-802-2333	Liz Bergey	405-609-7854
Kaleb Schwab	1300 Steamboat Way, Norman, OK 73071	918-720-8219	Sherri Schwab	918-200-2399
Rachel Bandy	510 S University Blvd, Apt. 2, Norman, OK 73069	701-204-1491	Anthony Wilkinson	405-637-4449
Robert Nairn	1629 Wilderness Drive, Norman OK73071	405-388-8819	Kathryn Amanda Nairn	405-664-0989
Robert Knox	824 S. Flood Avenue, Norman, OK 73071	405-505-2355	Linda Goeringer	405-349-8893

5.0 **References**

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Quality Assurance Project Plan

for

Evaluation of Watershed-Level and In-Lake Options to Address Lake Thunderbird Water Quality

Prepared by

H_2OU Engineering

Rachel Bandy, Monica Ha, Paige Hardman,

Sarah Hobson, and Kaleb Schwab

Prepared for

Central Oklahoma Master Conservancy District

(COMCD)

November 9th, 2020

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1.0 Project Management

1.1 Approvals Page

______________________________________Date:____________________

Dr. Robert Knox, Project Advisor

______________________________________Date:____________________

Dr. Robert Nairn, Project Advisor

______________________________________Date:____________________

Sarah Hobson, Team Leader

1.2 Distribution List

Table 1 lists the project advisors, the team members of H_2OU Engineering, their position, and contact information.

Table 1: Distribution List and Contact Information

Name	Position	Contact Information
Robert Knox	Project Advisor	rknox@ou.edu 405-550-2355
Robert Nairn	Project Advisor	nairn@ou.edu 405-888-3812
Sarah Hobson	Team Leader	shobson@ou.edu 405-802-2333
Monica Ha	Watershed Specialist	monica.ha@ou.edu 405-568-9258
Rachel Bandy	Data Analysis Lead, Project Document Editor	rachel.j.bandy-1@ou.edu 701-204-1491
Paige Hardman	Community and Regulations Specialist	paigehardman@ou.edu 918-712-0070
Kaleb Schwab	In Lake Specialist	Kaleb.J.schwab-1@ou.edu 918-720-8219

1.3 Project Organization

H_2OU Engineering is comprised of five environmental engineers. H_2OU, along with project advisors Dr. Robert Knox and Dr. Robert Nairn, will conduct an evaluation of water-shed level and in-lake options to address the Lake Thunderbird water quality issues.

The roles and responsibilities for the project personnel are described below. Refer to the organizational chart displayed in **Figure 1**.

Sarah Hobson is the Project Manager and lead communicator. She was the literature review lead and worked on reviewing applicable regulations and improvement technologies for the literature review. She co-wrote the Project Work Plan (PWP) and Sampling and Analysis Plan (SAP) project documents and was the design lead for the PowerPoint presentations. As with all other members, she assisted on all other tasks that needed help in addition to these primary roles.

Monica Ha is the watershed specialist and has focused on reviewing the literature involving watershed water quality and evaluated the best management practices for Lake Thunderbird. She will be the physical parameter and biota analyst and will interpret any other parameters that are needed when analyzing water quality. She will be assisting Sarah with field sampling and Kaleb for evaluating the environmental performance of in-lake water quality improvement technologies. She is also the final report lead and will be responsible for ensuring all project documents and presentations are finalized on time. She has also developed the Quality Assurance Project Plan (QAPP).

Rachel Bandy is the data analysis lead and will have the responsibility of dealing with any coding and/or data sets that the team may encounter. She will also be the primary editor for the project documents and be responsible for any images or charts that need to be produced such as the Gantt chart or team logo. Her primary areas of focus in the literature review are in-lake water quality and improvement technologies, which will allow her to advise on which improvement technologies to implement.

Kaleb Schwab is the in-lake specialist lead and has the responsibility of identifying in situ practices to improve water improvement. He is assisting the team with sampling technology as defined in the Sampling and Analysis Plan (SAP) and the oral presentation. He assisted in writing the Health and Safety Plan (HASP) and the SAP. His primary focus will be on in-lake water quality and improvement technologies.

Paige Hardman is one of the oral presentations leads and will have the responsibility of giving an effective oral presentation in May 2020 over the results of the team's research. She will help Sarah with the applicable regulatory drivers and site-specific community related issues. She assisted in writing the Health and Safety Plan (HASP) and Quality Assurance Project Plan (QAPP). Paige will investigate costs, design and modeling, sustainability, and public acceptance. She is also the hydraulics data analyst and calculations editor.

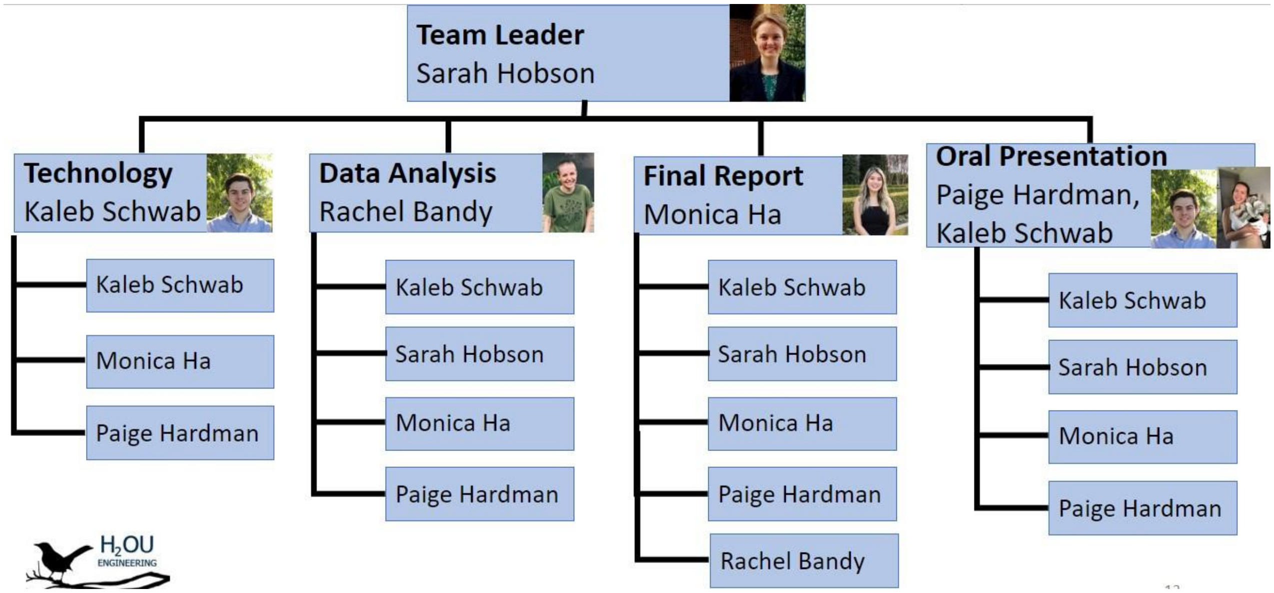

Figure 1: Team Organizational Chart and Defined Roles for Members of H_2OU Engineering

1.4 Project Background

Lake Thunderbird is a recreational area known for a wide range of popular water activities and is an important reservoir for supplying municipal water for the cities of Del City, Midwest City, and Norman. The lake is located approximately 13 miles east of central Norman and has a volume of 120,000 acre-feet and a surface area of 6,070 acres. The lake is also located in the Central Great Plains and Cross Timbers ecoregions and is in a 256 square mile drainage area of the upper Little River Watershed (**Figure 2**, DEQ 2013). The watershed's land use consists of 60% agricultural area and 40% residential area (OCC 2008). Over the past 30 years, recreational use of the lake and an increase in population growth has led to the rapid urbanization of the agricultural area (OCC 2008). As shown in **Table 2**, there is a decreased percent change for the agricultural categories since 2016. Water quality data monitored by the Oklahoma Water Resources Board (OWRB) has shown increased levels in chlorophyll-a, phosphorus, nitrogen, and turbidity and a decrease in dissolved oxygen levels. The increase in these nutrient levels has been caused by the runoff of stormwater from residential areas and road construction, agricultural runoff from the grazing of livestock, leakage from septic systems and other nonpoint sources (OCC 2008). Due to the excess in nutrient loadings, Lake Thunderbird is known as a sensitive water supply lake and is on the state list of impaired waters or 303(d) list as stated by the Clean Water Act (OWRB 2019).

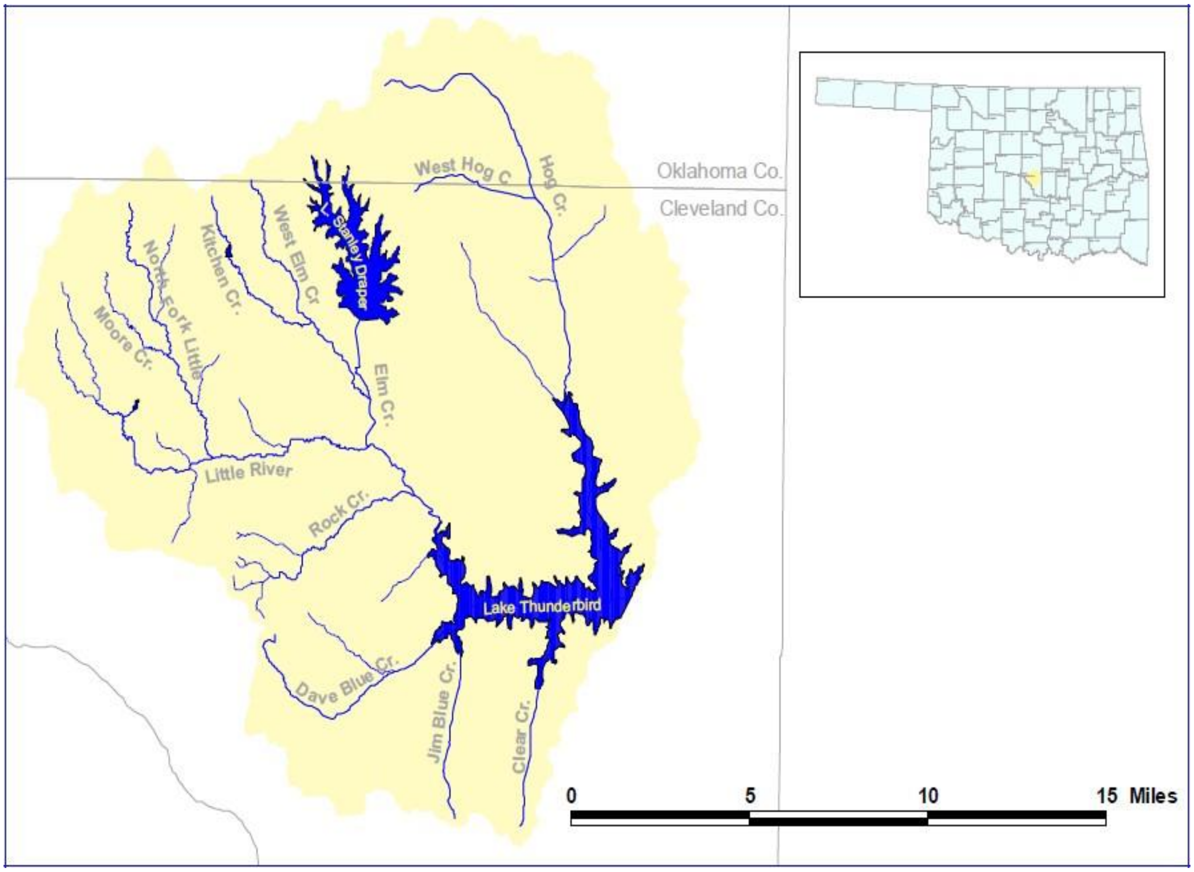

Figure 2: Map of Lake Thunderbird Watershed in Norman, Oklahoma (OCC 2008)

Category	Acreage	Percent of Watershed	Percent Change
Open water	8,359	5.08%	+0.76%
Developed, open space	12,474	7.58%	-1.82%
Developed, low intensity	9,182	5.58%	+1.24%
Developed, medium intensity	6,080	3.70%	+1.71%
Developed, high intensity	1,376	0.84%	+0.41%
Barren Land	238	0.14%	+0.13%
Deciduous Forest	61,607	37.45%	+2.16%
Evergreen Forest	322	0.20%	-0.03%
Mixed Forest	163	0.10%	
Shrub Scrub	2842	1.73%	
Grassland/Herbaceous	55,237	33.58%	-4.76%
Pasture/Hay	4,926	2.99%	-0.50%
Cultivated Crops	1,533	0.93%	-1.21%
Emergent Herbaceous wetlands	20	0.01%	+0.01%
Total Watershed	164,505	100%	100.00%

Table 2: Lake Thunderbird Watershed Land Use, Percent of Watershed, and Percent Change in Land Use from 2011 – 2019 (OWRB 2019)

1.5 Project Schedule

This water quality project will be broken down into two phases and will be occurring over a one-year time period. The project is set to start beginning of Fall 2020 and estimated to be completed in the Spring 2021. In the first phase, H_2OU focused on a preliminary literature review and the development of project documents including the HSP, SAP, QAPP, and the PWP. In the second phase, H_2OU will collect water quality samples and review existing environmental data sets in order to identify water quality issues affecting Lake Thunderbird and identify different technologies to address those water quality issues. **Figures 3** and **4** display the Gannt chart for the project for Fall 2020 and Spring 2021, respectively.

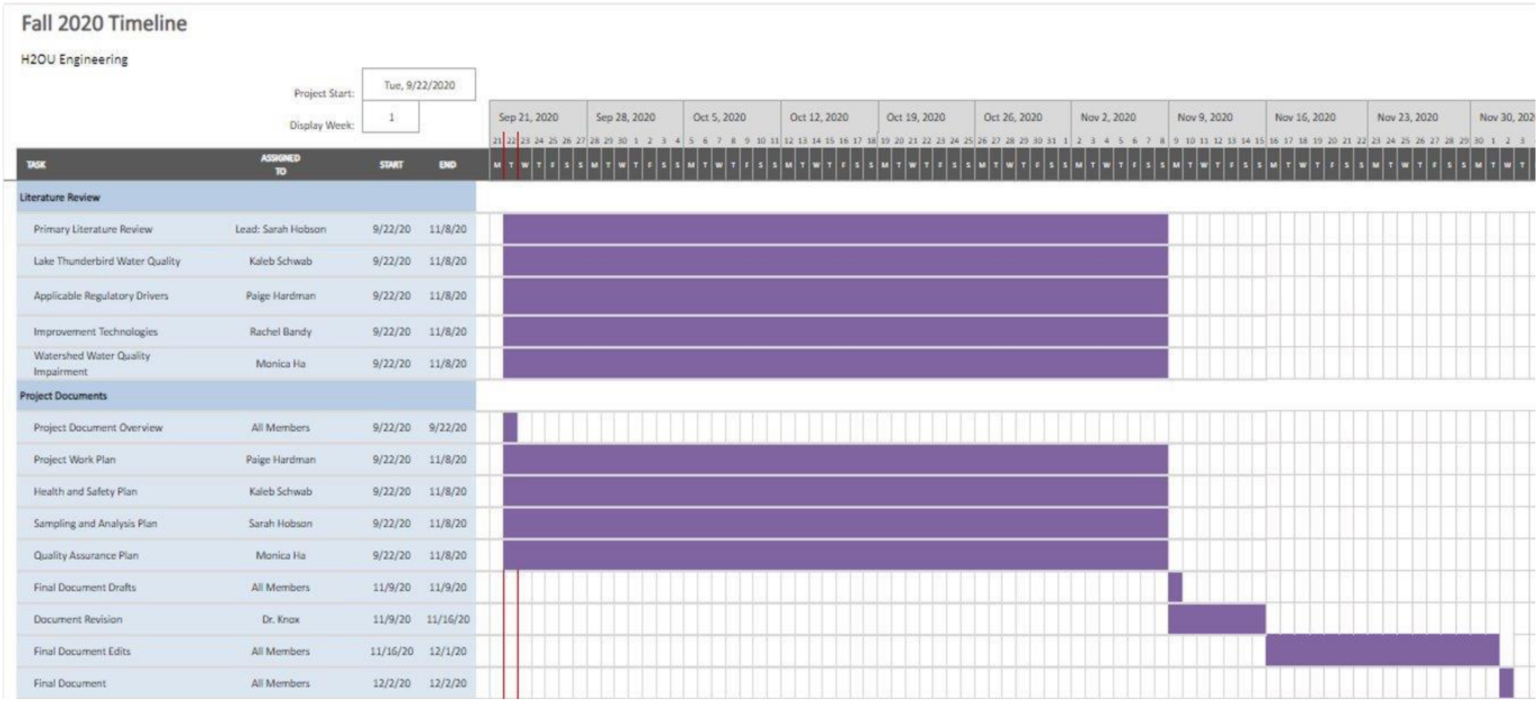

Figure 3: Fall 2020 Gannt Chart

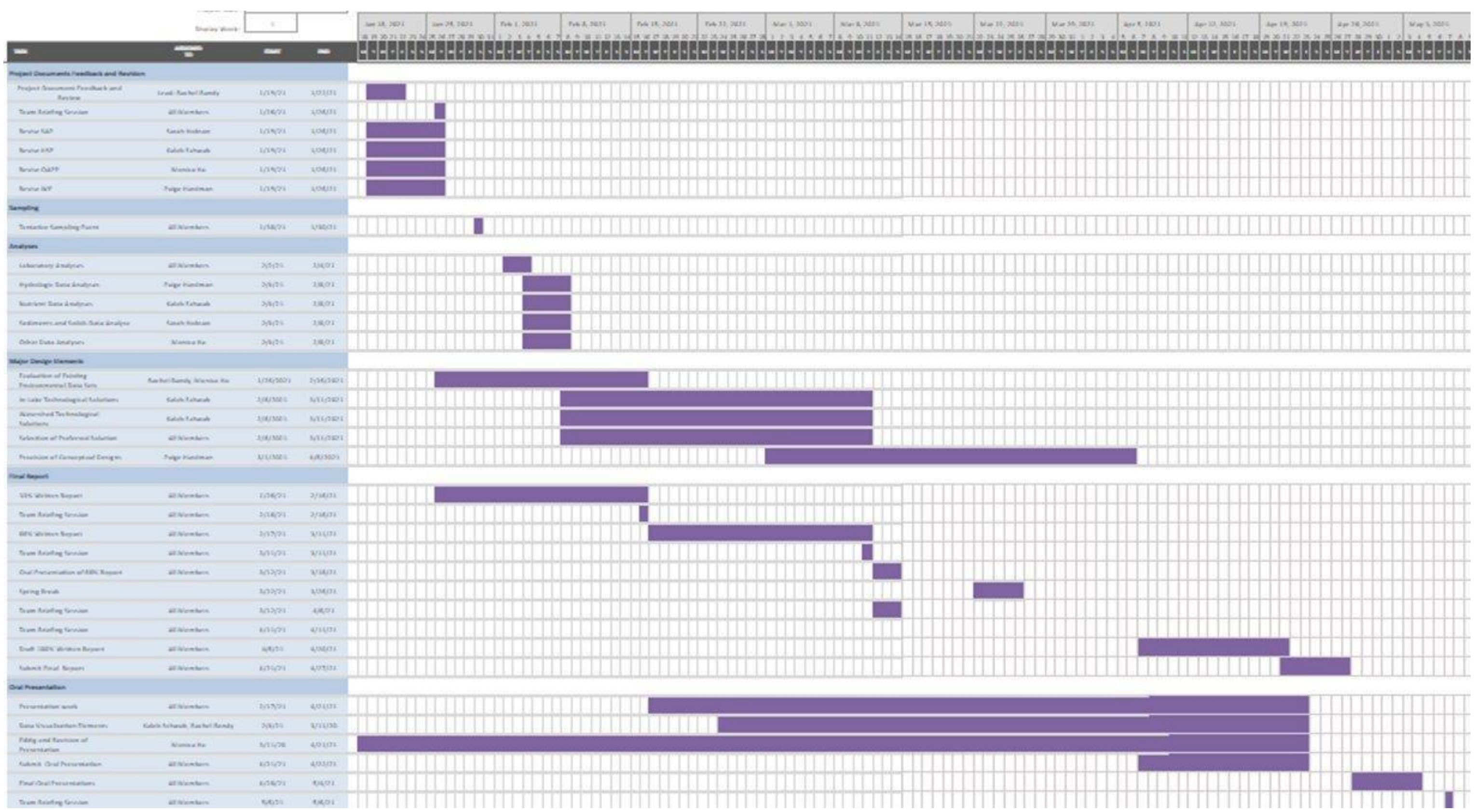

Figure 4: Spring 2021 Gannt Chart

1.6 Project Goals and Approach

Lake Thunderbird is an important water body that the cities of Del City, Midwest City, and Norman largely depend on as a drinking water resource. The lake is also home to fish populations and other forms of aquatic life that are susceptible to changes in the lake's water quality. Due to excessive nutrient loadings, high turbidity, and low dissolved oxygen levels, the lake has impacted the taste and odor of drinking water, as well as affected the lake's ability to support fish and wildlife propagations (OCCC 2008). As an impaired body of water, it is the purpose of this project is to provide solutions to the Central Oklahoma Master Conservancy District (COMCD) to address Lake Thunderbird's poor water quality. The main objectives of this project are to evaluate the reservoir's water quality data, assess and compare watershed-based and in-lake technologies, and develop a designed solution to address these concerns.

H_2OU Engineering will collect water samples from sites 1, 2, 4, 5, and 6 throughout Lake Thunderbird and analyze for nutrients, sediments and solids content. The data collected will be compared to the environmental dataset collected in the previous years. Based on the results of the these analyses, the most suitable watershed-level or in-lake technologies will be proposed, and the best management practices identified. H_2OU Engineering will assess the environmental performance, the capital costs, the operation and maintenance costs and the overall sustainability and public acceptance of the technologies. H_2OU Engineering will also develop conceptual designs and diagrams for the selected solutions. The final written and oral deliverables will be provided to the COMCD and stakeholders.

1.7 Quality Assurance Objectives and Criteria

1.7.1 Objectives and Project Decisions

The Data Quality Objectives (DQOs) of this project are to ensure the data collection is precise, accurate, representative, complete, and is able to be compared across each sample and sampling location (EPA 1996). To achieve this, quality assurance and quality control (QA/QC) measures will be implemented. To ensure the QA of the data, all team members will thoroughly review the standard operating procedures (SOPs) of the SAP, QAPP, PWP and HASP and the associated manuals of the field equipment before use. The geographic locations and the varying depths of the lake will be verified prior to the sampling date. Specific procedures will be followed regarding the documentation, labeling, calibration of the field equipment and the acid-washing and blanking of the Van Dorn samplers. More information on these QA measures is described in the respective sections below.

QC measures are applied to the sample collection process to limit source of errors and potential contamination from occurring. The QC measures require the collection of QC samples in addition to the water samples already being collected. QC samples will include the collection of one field blank and duplicate in-situ and will be analyzed in the laboratory in the same manner as the other water samples. Similarly, laboratory blanks, duplicates and spikes will be taken during the laboratory analysis. Field blanks are used to detect any contamination that may occur during the sampling process, storage, transportation, and analysis of the samples. To assess field variability, field duplicates will be taken in-situ to measure the accuracy of the sampling methods, and to ensure accurate representation between them. During the sample analysis, laboratory blanks and more than two duplicates will be analyze to allow for the statistical analyses of the standard deviation, relative standard deviation, and relative percent difference. Performing these statistical analyses will indicate variability over a range of measurements. In the laboratory, spiked samples will also be taken to test for measurement accuracy. The spiked sample will determine if there is a difference between the original measurement and spiked measurement (EPA 1996).

1.8 Documents and Records

Documentation and identification of all field samples is critical. Improper or missing documentation and sample labeling will result in inaccurate results and ineffective sampling. Therefore, all field data will utilize proper labeling, chain of custody forms, and be recorded in field notebooks along with any other additional field notes. All field information will be transferred and logged electronically into an Excel spreadsheet. The Excel sheet will be transferred to an online source, such as Google Docs, and all team members will have access. Laboratory data will be recorded separately and logged electronically into an Excel spreadsheet.

1.8.1 Field Data Sheets

Field data sheets will be used to record all information necessary when collecting field samples. The sample collection data sheet will include all information that is recorded on sample labels (collection location (longitude and latitude), collection date and time (in military time), team name, sampler initials, parameters to be measured, sampling identification number, site number

(1-12), type of sample, (field sample, blank or replicate) the preservation method, and a field notes and observations section. An in-situ measurement sheet will be used to record collected data from the YSI sampling probe and Secchi Disk. This second sheet will also include location (longitude and latitude), sampling site number, time and date, and current weather conditions from the nearest Mesonet location.

1.8.2 Sample Labeling

Field samples will be labeled in a clear, organized format to allow for proper identification of each individual sample. Each sample label shall contain collection location, collection date and time (in military time), team name, sampler initials, parameters to be measured, sampling identification number, type of sample (field sample, blank or replicate) and preservation method. Samples labels will be written legibly in black permanent marker.

2.0 Data Generation and Acquisition

2.1 Sampling Design

The field samples will be obtained from sites 1, 2, 4, 5, 6 (if time permits) located on Lake Thunderbird as depicted on **Figure 5**. These sites are located in areas of varying depths and include the inflow and outflow areas where the main tributaries are entering or leaving the body of water. Field samples will be collected at these different sites in order to represent a more accurate distribution of data across the entire lake. The standard water quality parameters that will be measured will include the pH, temperature, dissolved oxygen, specific conductance (SC), conductivity, turbidity, salinity, total dissolved solids (TDS), resistivity, oxidation-reduction potential (ORP), alkalinity, hardness, nutrient concentrations such as phosphorus, nitrogen, and chlorophyll-a.

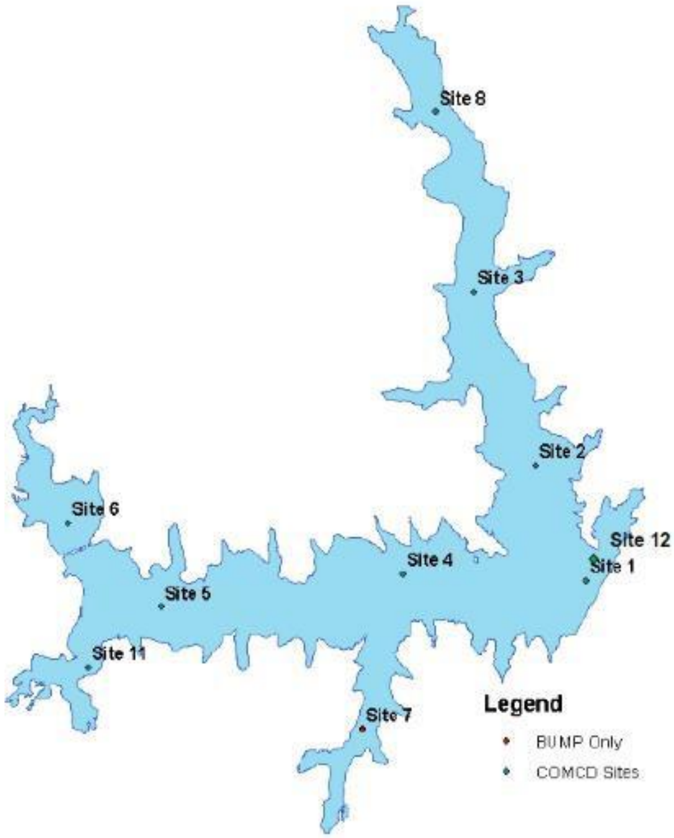

Figure 5: Lake Thunderbird Sampling Sites (OWRB 2019)

2.2 Sampling Methods

Five samples will be taken for sites 1, 2, 4, 5, and 6 at the surface level while three samples will be taken at varying depths of 4, 8, and 12 meters for site 1, as this is the site where the water level is deepest. The field blank and duplicate will be collected to meet the QA/QC measures stated in the QA/QC objectives above. EPA (1996) recommends that at least 10% of the samples collected are QC samples. To account for the 10%, there will be one field blank and one duplicate that will be taken for the whole trip. The specific site for the blank and duplicate samples will be chosen at random upon sampling. For all other sampling procedures, reference the SAP.

To collect a field blank, clean, deionized water will be brought to the sampling site. The deionized water will be poured into a clean bottle in the field and will be treated the same as any other sample collected on site. The field blank will be used to check for contamination and field variability between the field blank and the original sample. One field duplicate will be collected at a random site. The field duplicate will be collected at the same time and place as the field sample is collected. This will ensure the samples are representative of each other and allow for the detection of sampling errors.

When using the field equipment during sampling, the appropriate detection limit must be met for each type of instrument. The detection limit will be verified from the associated equipment manuals. The measurement must not fall below the specified detection limit as any measurement taken below this limit will be unreliable to record. Calibration of the field equipment will be done prior to the sampling process and will follow calibration instructions from each instrument's equipment manuals (see instrument calibration section). Decontamination procedures will be followed (see sampling handling section) and an additional equipment blank will be taken before using all field equipment. The equipment blank will be taken as another measure to check for contamination that may have occurred from reusing the field equipment at each sampling site.

2.3 Sample Handling and Custody

When sampling, nitrile gloves will be worn and replaced with new gloves each time a sample is collected to protect the sample from outside contamination. All sampling equipment will be decontaminated before each sample is collected by following decontamination procedures stated by the EPA (2015). In-situ YSI probe, Secchi Disk, and sample collection bottles will be rinsed with decontamination (deionized) water and sealed before being transported to the site for use. On site, the YSI probe, Secchi Disk, and sample collection bottles will be rinsed three times with lake water to ensure no contamination.

After sampling, chain-of-custody forms must be completed to record the following information: sample ID, location, date, time, the signatures of who released and received the samples. Proper documentation of the storage and transport of the samples is vital to ensure preservation until the time for sample analysis.

2.4 Analytical Methods

Water Quality Parameter	Analytical Method/ Instrumentation
Total Nitrogen (TN)	HACH Method 10208
Total phosphorous (TP)	HACH Method 10209/10210

Turbidity	HACH 2100P Turbidimeter
Transparency	Secchi Disk
Alkalinity	HACH Method 8203
Hardness	EDTA Titration
Anions (SO_4^{2-}, Cl^-, PO_4^{3-} (ortho), NO_2^-, NO_3^-)	Seal Analytical AQ 300 Automated Discrete Analyzer
Physical Parameters: Temperature Specific Conductance Conductivity Resistivity Total Dissolved Solids Salinity Dissolved Oxygen Concentration pH Oxidation Reduction Potential Chlorophyll-a	YSI 6920 V2 Multiparameter Datasonde

Table 3: Water Quality Parameters Determined by Analytical Methods/Instrumentation

After the sample episode, statistical analysis methods including the standard deviation, relative standard deviation, and relative percent difference will be used to determine the degree of uncertainty across the range of measurements. Data from all the samples will be presented as an average and standard deviation when analyzing the data (EPA 2014). The coefficient of correlation and student t-test will also be performed to assess variations of the observed water quality parameters. The statistics of the relative percent difference (RPD) are calculated to describe the precision of each laboratory parameter based on the comparison of the spiked and replicated samples (OWRB 2019). The RPD equation is represented as $c = \frac{x_2 - x_1}{x_1}$, where x_2 is the final value and x_1 is the initial value. There must be a very small RPD between the samples in order to be considered a precise measurement (EPA 1996).

2.5 Instrument Calibration

Prior to use, equipment manuals will be used to calibrate all field and laboratory equipment. Calibration checks will be performed at the beginning of each analytical sequence, after every 10 samples, and at the end of the analysis sequence. All analytes should be within ±10% of expected value and relative standard deviation (RSD) of replicate integrations <5%. The equation for RSD is $CV = \frac{\sigma}{\mu}$, where σ is the standard deviation and μ is the mean. Calibrations will be checked with a calibration blank after every calibration, and the level of analytes detected should be greater than the limit of detection (EPA, 1996).

3.0 Assessment and Oversight

3.1 Assessments/Oversight and Response Actions

EPA standards and procedures will be followed to ensure all sampling and analysis activities are conducted correctly (EPA 2001). More detailed information about sampling, labeling and transportation is in the Sampling and Analysis Plan. Data collected that does not comply with SAP procedures will be rejected. All field and laboratory testing will follow the proper handling methods to prevent contamination or inaccurate data.

This project is divided into these general phases:

1. Input model and monitoring data collected by OWRB on behalf of COMCD. During this event, outliers can be identified and documented by taking the average and standard deviation of the data set.
2. From the data given, proper remediation processes will be identified by teammates. A general timeline and cost estimations will be determined for the remediation of the water body. The team leader's judgment will make the final decision on how to assess the project.
3. The data trends will be analyzed along with the methods of improvement in order to create an accurate remediation method that will be presented to the COMCD.

To ensure the project is completed on schedule, the project will follow the Gantt chart timeline presented in **Figures 2 and 3**. QAPP, HSP, PWP, and SAP draft documents will be submitted on November 9th, 2020. After feedback is provided, documents will be edited by all members of the team to be finalized and resubmitted on December 2nd, 2020. In May of 2021, the final project and site remediation designs will be presented to COMCD.

3.2 Reports to Management

With the supervision of the project advisors, Dr. Robert Knox and Robert Nairn, H_2OU Engineering members will work in groups of two on all project documentation and sampling. Weekly Zoom team meetings will be conducted to provide progress status and updates to ensure all teammates are meeting deliverable milestones. When field sampling, all team members will attend unless COVID-19 interferes. COVID-19 regulations are described in the HSP. The dates of field sampling will be determined in January 2020.

4.0 Data Review and Usability

4.1 Data Review, Verification, and Validation Requirements

To ensure that the data are accessible, readable, and accurate, data collected in the field will be recorded by multiple team members. All data will be compiled, assessed for outliers, and put into an Excel sheet that will be available to all members. If there are multiple outliers, proper statistical techniques will be performed to ensure accuracy of the data set. The team leader and data analysist lead will coordinate the data review portion of the project. In addition to their calculations, appropriate statistical measures will be applied to assess precision and accuracy. Samples will be taken for quality control purposes, and all samples will be labeled in the lab and Excel sheet accordingly.

5.0 **References**

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Health and Safety Plan

for

Evaluation of Watershed-Level and In-Lake Options to Address Lake Thunderbird Water Quality

Prepared by

H_2OU Engineering

Rachel Bandy, Monica Ha, Paige Hardman,

Sarah Hobson, and Kaleb Schwab

Prepared for

Central Oklahoma Master Conservancy District

(COMCD)

November 9th, 2020

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1.0 Introduction

The Health and Safety Plan (HSP) is used to establish health and safety regulations and procedures to ensure that each member of H_2OU Engineering is protected. To establish these safety guidelines, all information and emergency contact information are in this document.

2.0 Project and Site Information

2.1 Site History and Current Status

"The Norman Project," today known as Lake Thunderbird, was initiated with the intent of flood control management along the Little River. The design plans for the Norman Reservoir included current and future water demands for the surrounding communities including Midwest City, Norman, Del City, Moore, and Tinker Air Force Base, and a provision was added to allow for the allocation of any surplus water to Oklahoma City. This plan was determined to be economically feasible and "The Norman Project" was authorized under Public Law 86-529 and signed into law by President Eisenhower in 1960 with subsequent planning and construction funding provided by President Kennedy's Works Appropriation Bills by 1962 (Simonds, 1999).

Construction of the dam began in 1962 by Cosmo Construction. Spillway and outlet works were constructed by the L&A Construction Company, the reservoir and relift pumping plant were constructed by the Lee-Emmert Corporation, clearing operations for the reservoir were managed by Schutt Construction Company, and recreation infrastructure was managed by the Pool Construction Company (Simonds, 1999). Construction of the 2456-hectare (6070 acre) reservoir was completed in mid-1965. The Norman reservoir was renamed as Lake Thunderbird and water use began in 1966.

Operation and maintenance of Lake Thunderbird was transferred from the US Bureau of Reclamation (BOR) to the Central Oklahoma Master Conservancy District (COMCD) in 1966 just after water deliveries began. Maintenance has included resolving pipe vibration (1969), relocation of a Del City pipeline segment (1974), and several small breaks (Simonds, 1999). The reservoir continues to supplement water for surrounding communities and prevent flooding today.

Today, Lake Thunderbird is ranked as Priority 1 and in Category 5a of Oklahoma's 303(d) list. This classification indicates impaired water quality and failure to meet designated uses (DEQ

2013). The Department of Environmental Quality (DEQ) has further designated the lake as a Sensitive Water Supply (SWS) that fails to meet requirements for Fish & Wildlife Propagation (FWP) for a Warm Water Aquatic Community and Public Water Supply uses (OCC, 2008). Reasons for impairment include low sub-thermocline dissolved oxygen levels, high turbidity, and high chlorophyll-a concentrations (OWRB, 2019). These parameters also cause the water to have aesthetic concerns and raise water treatment costs (OWRB, 2011).

2.2 Scope of Work

Lake Thunderbird is an important body of water to many in Oklahoma. Because it is used for drinking water, recreation, and animal habitats, it is imperative to preserve the health of the lake and its surroundings. Accordingly, proposed technologies should not interfere with the overall function or appearance of the lake. Within these parameters, H_2OU will examine treatment methods for both the lake and the watershed as a whole. Exploring options at both the lake- and watershed-level will allow H_2OU to develop a holistic plan.

3.0 Team Member Contact and Emergency Contact

Table 1 will be used to inform the respective member's emergency contact in the event of an emergency.

Table 1: Individual Emergency Contact Information

Name	Address	Phone Number	Emergency Contact Name	Emergency Contact Number
Paige Hardman	1208 W Havenwood Drive, Midwest City, OK 73110	918-712-0070	Jaclyn Gaulding	918-807-2138
Monica Ha	2200 Classen Blvd, Norman, OK 73071	405-568-9258	Joseph Ha	405-520-3638
Sarah Hobson	1325 Commerce Drive, Norman, OK 73071	405-802-2333	Liz Bergey	405-609-7854
Kaleb Schwab	1300 Steamboat Way, Norman OK 73071	918-720-8219	Sherri Schwab	918-200-2399
Rachel Bandy	510 S University Blvd, Apt. 2, Norman, OK 73069	701-204-1491	Anthony Wilkinson	405-637-4449
Robert Nairn	1629 Wilderness Drive, Norman, OK 73071	405-388-8819	Kathryn Amanda Nairn	405-664-0989
Robert Knox	824 S. Flood Avenue, Norman OK 73071	405-505-2355	Linda Goeringer	405-349-8893

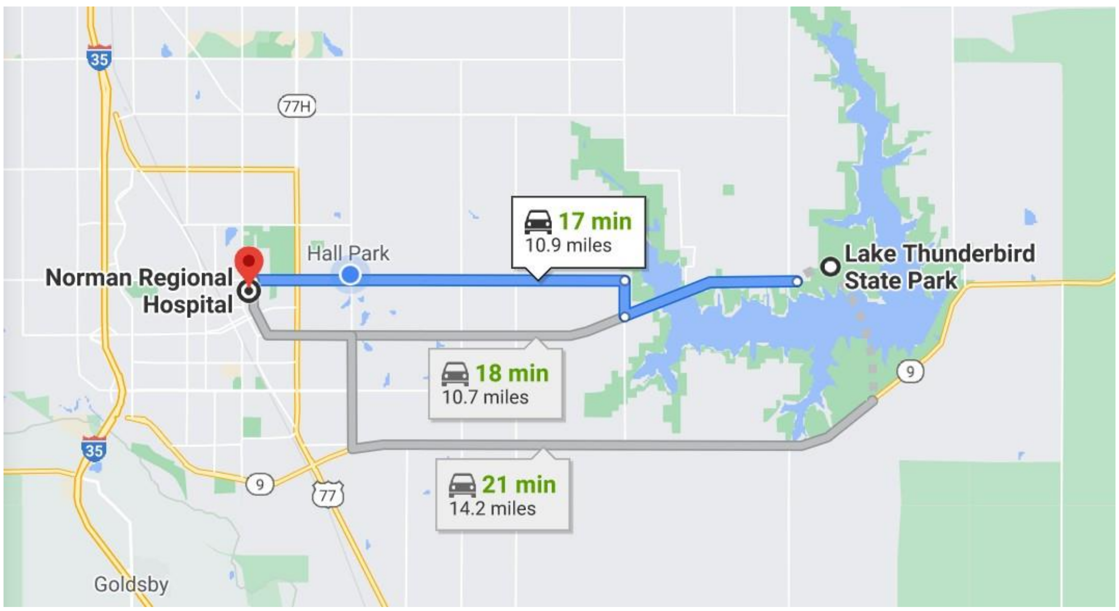
3.1 Emergency Contact and Directions

Table 2 shows the closest hospital and emergency first responder's contact information to Lake Thunderbird. **Figure 1** indicates directions to the nearest hospital in case of an emergency.

Table 2: Closest Emergency Contact Departments

Name	Address	Phone Number
Norman Regional Hospital	901 N Porter Ave, Norman, OK 73071	405-307-1000
Norman Fire Department	415 E Main St, Norman, OK 73070	405-292-9780

Figure 1: Directions to Norman Regional Hospital from Lake Thunderbird State Park (Google Maps 2020)



4.0 Field Hazards

4.1 General Hazards

Driving to Lake Thunderbird can be hazardous during inclement weather conditions. Team members will use proper driving skills such as going the speed limit and not going off the road. Cellphone usage when driving is not allowed.

Before any site evaluation occurs, the team will conduct a tailgate safety brief to ensure all members know what tasks need to be accomplished and the hazards associated with each task. While on site, members will communicate with each other using walkie-talkies.

Since the site evaluation will be conducted on rough terrain, lifting debris and hauling equipment may be necessary. Team members are encouraged to use proper lifting techniques that include lifting from the legs rather than the back, and to only lift what the team member can withstand. If a member needs help with lifting an item, they must ask for help from the other team members.

In general, team members will only visit the site in the daylight and are responsible for cleaning up anything taken to the testing site. A good rule of thumb is to leave the site better than when arrived. Not disturbing the surrounding environment, when applicable, will be encouraged.

4.2 Weather Hazards

Since the site is in Oklahoma, the daily weather conditions are unpredictable. Because of the uncertainty, team members will check the weather forecast before leaving for the site. If extreme heat occurs, team members are responsible for hydrating, taking breaks when needed, and wearing sunscreen. If an extreme cold occurs, team members are responsible for wearing warm and waterproof clothing. In the case of high winds or pollution, team members are responsible for wearing proper eye personal protective equipment (PPE) and taking allergy medicine when necessary. All team members are responsible for telling the HSP leader any medication that is necessary when on site or in the laboratory.

4.3 Physical Hazards

Lake Thunderbird is in a rural area, making physical obstacles such as large rocks and uneven ground potential dangers for falling-related injuries. Poisonous plants, such as poison ivy, and animals, namely copperheads, may be a potential threat to team members as well. ~~Bugs~~Insects, such as mosquitoes, may be present in the area as well. To combat these hazards, team members must wear long pants, long sleeved shirts, insect repellant, and non-slip close toed shoes. Team members must be aware of their surroundings and avoid any wildlife and unknown plants when applicable.

4.4 Water and Boat Hazards

If a water sample is needed, only team members that are competent swimmers are allowed in the water. Each team member in the water must wear a floatation device. When team members are by the water, a buddy system will be used in case one member falls into the water.

When sampling from a boat, only competent swimmers wearing floatation devices will be allowed on the boat. When boarding the boat, members are advised to be aware of their surroundings in case of a slippery dock. Members need to verify that the boat is tied to a dock, anchored, or secured to shore prior to attempting to board or disembark. Two team members are required to assist when loading or unloading equipment from the boat. While on the boat, standing is not allowed by any team member, and all hands and feet must be inside the vessel. Members are required to be mindful of oncoming boat traffic and other obstacles in the water when driving the boat. In the case of a member going overboard, a life preserver will be in an easy-to-access location. When the boat is not moving, the anchor will be dropped. When sampling, the sampling equipment will be located at the center of the boat. Each member will keep a low center of gravity while maneuvering to sample. Coordination with the other team members is essential during sampling. Motions such as twisting or turning should be avoided during placement and retrieval of tools and/or sampling equipment.

4.5 COVID-19 Hazards

If COVID-19 is still a threat when sampling activities are done at Lake Thunderbird, social distancing will be required in compliance with CDC and University of Oklahoma COVID-19 guidelines to reduce the chance of infection. Masking will be required by all members while sampling at Lake Thunderbird. Team members will be provided with masks and face shields.

5.0 **Laboratory Hazards**

Laboratory hazards include handling chemicals and glassware. The methods used for analysis may involve the use of harmful chemicals. Team members performing laboratory analyses are required to wear long pants, non-slip close toed shoes, laboratory coats, gloves, and goggles. Team members must understand the side effects and hazards of all chemicals used before the laboratory begins. If a chemical is spilled, the laboratory leader will be informed, and the spill will be cleaned up and disposed of according to the proper laboratory guidelines.

Glassware will be inspected for any chips or cracks before the laboratory begins. If the glassware used in the laboratory is chipped or broken, team members will tell the laboratory leader and dispose of it. Gloves will be worn while picking up the pieces and disposed of afterwards.

Team members will clean the laboratory stations before and after laboratory analysis. All glassware and other laboratory tools will be cleaned with DI water and left to dry after the laboratory is conducted. All chemical substances will be disposed of into the proper containers, and the chemical jars will be closed tightly. All borrowed laboratory equipment and PPE will be returned to the proper areas.

If COVID-19 is still a threat, laboratory analyses will be conducted following CDC and University of Oklahoma COVID-19 regulations. Masking and social distancing in the laboratory will be required. If social distancing cannot be performed, the team members will wear a face shield along with their mask.

6.0 **Personal Protective Equipment**

Personal protective equipment (PPE) is essential for team members to reduce injury. For field and laboratory work, team members must wear long pants, and non-slip close toed shoes. On site, team members must wear appropriate clothing depending on the weather. Heavy-duty gloves available when moving debris, and latex or nitrile gloves should be worn while sampling to avoid contamination. If in the water, flotation devices should be worn. In the laboratory, proper PPE will be worn such as laboratory coats, gloves, and goggles.

7.0 Safety Documents

7.1 Personnel Contact Information

Table 3 shows the phone number and email address for all H_2OU Engineering members and supervisors who will be working at the study site.

Table 3: Contact Information for All H2OU Engineering Personnel

Name	Position	Contact Information
Robert Knox	Project Advisor	rknox@ou.edu 405-550-2355
Robert Nairn	Project Advisor	nairn@ou.edu 405-888-3812
Paige Hardman	Community and Regulations Specialist	paigehardman@ou.edu 918-712-0070
Sarah Hobson	Team Leader	shobson@ou.edu 405-802-2333
Monica Ha	Watershed Specialist	monica.ha@ou.edu 405-568-9258
Rachel Bandy	Data Analysis Lead Project Documents Editor	rachel.j.bandy-1@ou.edu 701-204-1491
Kaleb Schwab	In Lake Specialist	Kaleb.j.schwab-1@ou.edu 918-720-8219

7.2 Emergency Department Information

Table 4 shows the pertinent emergency response contact information that might be needed in case of an emergency.

Table 4: Emergency Response Contact Information

Name	Address	Phone Number
Norman Regional Hospital	901 N Porter Ave, Norman, OK 73071	405-307-1000
Norman Fire Department	415 E Main St, Norman, OK 73070	405-292-9780

8.0 **References**

Google Maps. 2020. https://www.google.com/maps/dir/Lake+Thunderbird+State+Park,+Alameda+Drive,+Norman,+OK/Norman+Regional+Hospital,+North+Porter+Avenue,+Norman,+OK/@35.2191894,-97.4270333,11.31z/data=!4m15!4m14!1m5!1m1!1s0x87b24fbc1f385c0b:0x1529344a925f65e8!2m2!1d-97.2518004!2d35.2364075!1m5!1m1!1s0x87b269e04d76c4b9:0x2f751d1499968351!2m2!1d-97.4391496!2d35.2301496!3e0!5i1. [Accessed 10/6/2020]

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OWRB. 2011. *American Recovery and Reinvestment Act of 2009 (ARRA) 2009 Developing In-Lake BMPs to Enhance Raw Water Quality of Oklahoma's Sensitive Water Supply*. OWRB the water agency. Norman, OK. 2P-96690801.

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Appendix B: Initial Methods

List of methods considered:

Rain Gardens

Permeable Pavement

Erosion Control Logs

Wetlands

Decrease Fertilizers

Community Initiative to Decrease Trash in Storm Sewers

Catch Basin Filters

Contour Farming

Stormwater Regulation Ordinances/Regulations

In-line Stormwater Treatment Device

Green Roofs

Bioretention Areas

Dry Detention Ponds: quantity over quality

Biomanipulation

Shoreline Revegetation

Breakwater Systems

Phosphorous Inactivation

Sediment Oxidation

Coagulation-Magnetic Separation

Algicides/Herbicides

Hydrogen Peroxide Addition

Hypolimnetic Aeration/Oxygenation System

Down Flow Bubble Contact System

Sediment Dredging

Ultrasound Irradiation

Appendix C: Initial Methods Considered Table

Table 26: H_2OU's In-Lake Methods Initial Considerations

Method	Cost	Effectiveness	Lifetime
Biomanipulation	\$55/100 fish; \$90/fish (Dunn Fish Farms, 2021)	Lowers nutrient concentrations, Chl-a, and turbidity (Klinge et al. 1995; Mäler 2004; Tang et al. 2015)	High
Treatment wetlands	\$30,000 to \$65,000 per acre (USEPA Wetlands Fact Sheet, 1999)	Effectiveness depends on the type of wetland (Zhang et al., 2020)	Medium
Shoreline revegetation	\$35,000 per converted acre including breakwater systems (SAWPA, 2020)	Mitigate erosion and aquatic biomass attenuates waves to reduce physical sediment resuspension (Moss, 1990) Uptake phosphorous and nitrogen and release oxygen to improve water quality (Slembrouck et al., 2018)	High
Breakwater systems	\$35,000 per converted acre including shoreline revegetation (SAWPA, 2020)	Degrading the COD, Mn, N, and P contents. Reducing ammonia, nitrate, and nitrite nitrogen concentrations. Increasing DO and redox potential (Zhang et al. 2020)	High
P inactivation	\$500-\$1,500/acre (ENSR, 2016)	Control P inputs in excess and algal growth (ENSR, 2016)	Low
Sediment oxidation	1.2-hectare lake and cost approximately \$232,500 (Lewtas et al. 2015)	70 to 85% reduction in phosphorous loadings (Lewtas et al. 2015)	Low
Coagulation magnetic separation	Inexpensive since using waste product (Liu, 2013)	Removal efficiencies of COD, TN, and TP were 93%, 91%, and 94%, respectively (Liu, 2013)	Low
Down Flow Bubble Contact System	\$3,349,000 capital cost for Camanche reservoir project (Horn et al., 2019)	Chl-a decreased by 73% and soluble phosphate from the sediment pool declined by 84% (Horn et al., 2019)	Low
Sediment dredging	\$1,820,000 Capital Cost for Great Lake project (FRTR, 2020)	Effectively limiting the Chl-a concentrations in the water (Yu et al., 2017)	Low

Table 27: H_2OU's In-Lake Methods Initial Considerations Continued

Method	Maintenance	Scale	Public Acceptance
Biomanipulation	Restock lake with fish; maintain fishing; water quality testing (Gulati & Donk 2002)	High	High
Treatment Wetlands	Cleaning/redesigning after 20 years (USEPA Wetlands Fact Sheet, 1999)	Medium	Medium
Shoreline Revegetation	Minimal maintenance (Spears et al., 2011)	Medium	High
Breakwater Systems	Medium maintenance (Sample et al. 2020)	Medium	High
P Inactivation	High maintenance due to lifetime (Welch & Cooke, 1999)	Medium	Medium
Sediment Oxidation	High maintenance due to lifetime (Lewtas et al. 2015)	Low	Medium
Coagulation Magnetic Separation	High maintenance due to lifetime (Liu, 2013)	Low	Medium
Down Flow Bubble Contact System	Low (Horn et al., 2019)	Medium	High
Sediment Dredging	High maintenance due to lifetime (FRTR, 2020)	Medium	Low

Table 28: H_2OU's Watershed Methods Initial Considerations

Method	Cost	Effectiveness	Lifetime
Erosion Control Logs	$10-$60 per meter (Allen, 1999)	72-92% effective (Wilson, 2019)	Low
Rain Gardens	$10-$40 per square foot (Coffman, L.S., R. Goo and R. Frederick, 1999)	25 to 50 percent, and nitrogen removal is between 40 to 60 percent (CWP, 2008)	High
Permeable Pavement	$1-10 per square foot (CTC & Associates LLC, 2012)	TP removal 65 percent to 85 percent TN removal 80 percent to 85 percent (CTC & Associates LLC, 2012)	Medium
Green Roofs	$10.30 to $19.70 per square foot (GSA, 2008)	Filter suspended solids and remove pollutants associated with those solids (Minnesota Storm Water Manual, 2020)	High
Catch Basin Filters	$200 to $4000 per catch basin (Narayanan & Pitt, 2006)	Filter suspended solids (Narayanan & Pitt, 2006)	Low

Table 29: H_2OU's Watershed Methods Initial Considerations Continued

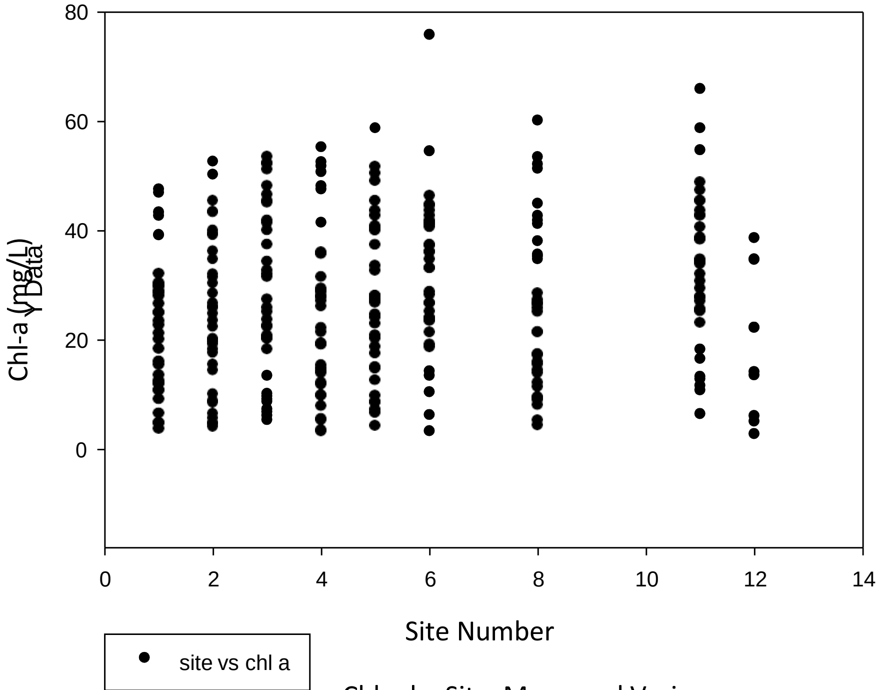
Method	Maintenance	Scale	Public Acceptance
Erosion Control Logs	Minimal (Allen, 1999)	Low	Medium
Rain Gardens	Minimal (Maria Cahill, Derek C. Godwin, and Jenna H. Tilt, 2018)	High	High
Permeable Pavement	Minimal (CTC & Associates LLC, 2012)	Medium	Medium
Green Roofs	Low (GSA, 2008)	Low	High
Catch Basin Filters	High (Narayanan & Pitt, 2006)	Medium	Medium

Appendix D: Chlorophyll-a

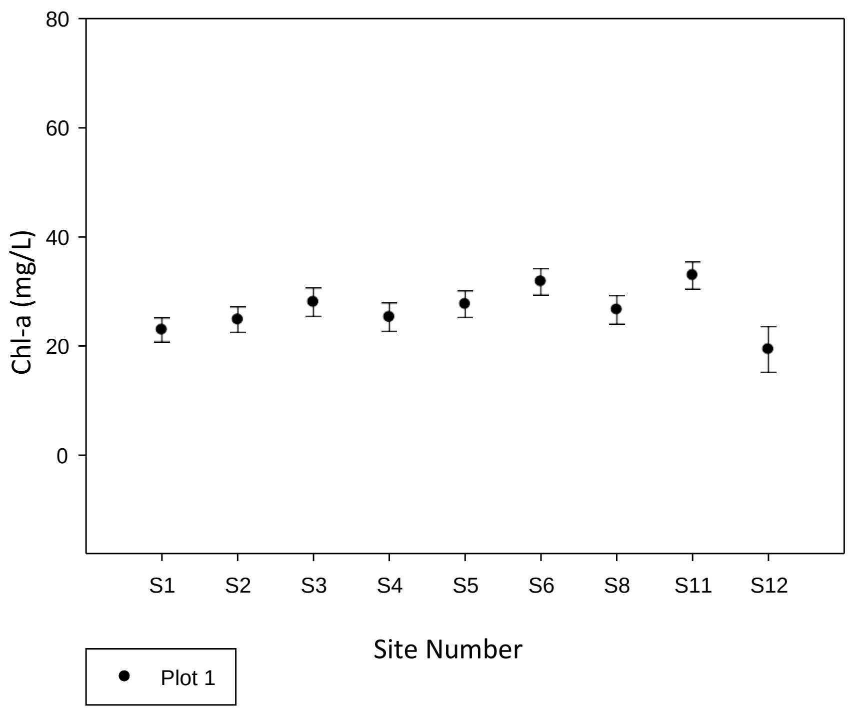
Appendix D.1: Chl-a by Site

Chl-a by site (note: sites 7, 9 and 10 have no data)
Graph 4 is all data; graph 5 is means and SE bars)

Chl-a by Site



Chl-a by Site, Mean and Variance



Normality Test (Shapiro-Wilk) Failed ($P < 0.050$)

Test execution ended by user request; ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: Data 1 in LkT-bird analysis

Group	N	Missing	Median	25%	75%
S1	34	0	23.000	11.975	29.925
S2	36	0	24.150	14.675	35.825
S3	36	0	25.500	14.625	41.675
S4	36	0	24.150	12.625	35.775
S5	36	0	27.300	15.625	40.300
S6	36	0	33.100	23.500	41.400
S8	35	0	25.800	13.900	38.000
S11	35	0	33.800	25.200	42.700
S12	10	0	18.150	5.805	34.625

H = 15.768 with 8 degrees of freedom. ($P = 0.046$)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference ($P = 0.046$)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunn's Method):

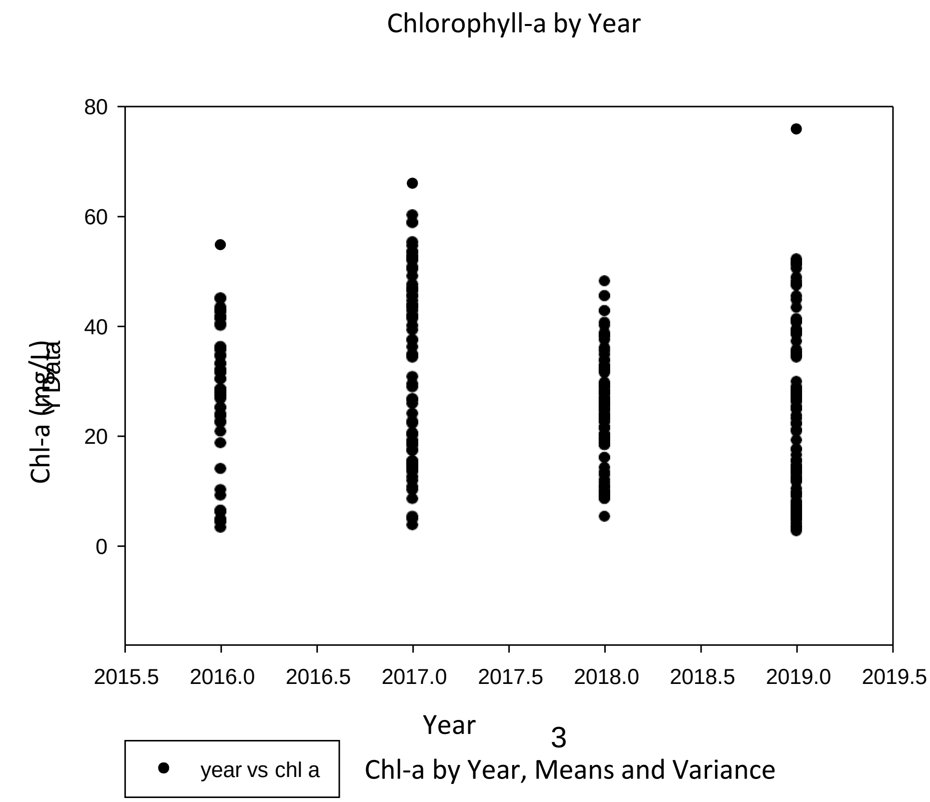
Comparison	Diff of Ranks	Q	P<0.05
s11 vs S12	78.993	2.591	No
s11 vs S1	56.140	2.742	Do Not Test
s11 vs S2	46.243	2.291	Do Not Test
s11 vs S4	43.854	2.173	Do Not Test
s11 vs S8	37.471	1.844	Do Not Test
s11 vs S5	30.201	1.497	Do Not Test
s11 vs S3	28.687	1.422	Do Not Test
s11 vs S6	7.021	0.348	Do Not Test
S6 vs S12	71.972	2.368	Do Not Test
S6 vs S1	49.119	2.416	Do Not Test
S6 vs S2	39.222	1.957	Do Not Test
S6 vs S4	36.833	1.838	Do Not Test
S6 vs S8	30.451	1.509	Do Not Test
S6 vs S5	23.181	1.157	Do Not Test
S6 vs S3	21.667	1.081	Do Not Test
S3 vs S12	50.306	1.655	Do Not Test
S3 vs S1	27.453	1.350	Do Not Test
S3 vs S2	17.556	0.876	Do Not Test
S3 vs S4	15.167	0.757	Do Not Test
S3 vs S8	8.784	0.435	Do Not Test
S3 vs S5	1.514	0.0756	Do Not Test
S5 vs S12	48.792	1.606	Do Not Test
S5 vs S1	25.939	1.276	Do Not Test
S5 vs S2	16.042	0.801	Do Not Test
S5 vs S4	13.653	0.681	Do Not Test

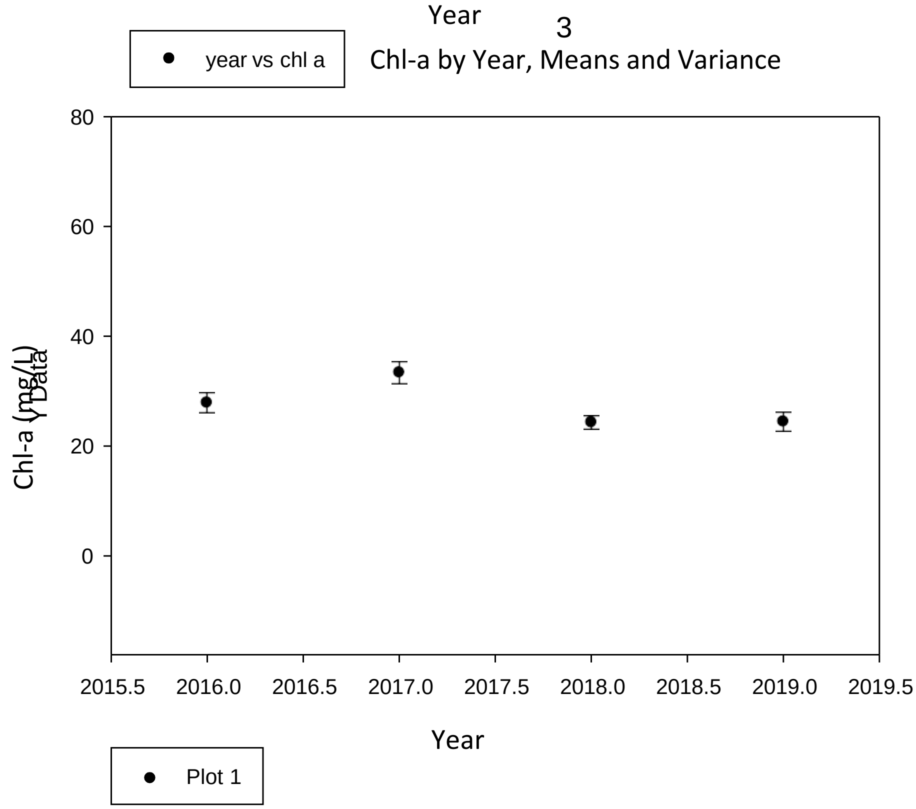
S5 vs S8	7.270	0.360	Do Not Test
S8 vs S12	41.521	1.362	Do Not Test
S8 vs S1	18.668	0.912	Do Not Test
S8 vs S2	8.771	0.435	Do Not Test
S8 vs S4	6.383	0.316	Do Not Test
S4 vs S12	35.139	1.156	Do Not Test
S4 vs S1	12.286	0.604	Do Not Test
S4 vs S2	2.389	0.119	Do Not Test
S2 vs S12	32.750	1.078	Do Not Test
S2 vs S1	9.897	0.487	Do Not Test
S1 vs S12	22.853	0.747	Do Not Test

Column	**Size**	**Missing**	**Mean**	**Std Dev**	**Std. Error**
S1	34	0	22.912	12.576	2.157
S2	36	0	24.830	13.752	2.292
S3	36	0	28.012	15.372	2.562
S4	36	0	25.311	15.270	2.545
S5	36	0	27.644	14.426	2.404
S6	36	0	31.757	14.337	2.389
S8	35	0	26.655	15.310	2.588
s11	35	0	32.906	14.106	2.384
S12	10	0	19.373	13.226	4.182

Column	**Range**	**Max**	**Min**	**Median**
S1	43.800	47.500	3.700	23.000
S2	48.500	52.600	4.100	24.150
S3	48.100	53.400	5.300	25.500
S4	51.900	55.200	3.300	24.150
S5	54.400	58.700	4.300	27.300
S6	72.540	75.800	3.260	33.100
S8	55.700	60.100	4.400	25.800
s11	59.500	65.900	6.400	33.800
S12	35.870	38.600	2.730	18.150

Appendix D.2: Chl-a by Year





Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: Data 1 in LkT-bird analysis

Group	N	Missing	Median	25%	75%
2016	55	0	28.500	22.400	36.200
2017	72	0	35.400	17.600	46.800
2018	79	0	24.000	18.300	32.000
2019	88	0	23.400	10.700	38.100

H = 17.215 with 3 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunn's Method):

Comparison	Diff of Ranks	Q	P<0.05
2017 vs 2019	49.930	3.696	Yes
2017 vs 2018	47.568	3.434	Yes
2017 vs 2016	24.289	1.595	No
2016 vs 2019	25.641	1.755	No
2016 vs 2018	23.279	1.559	Do Not Test
2018 vs 2019	2.362	0.179	Do Not Test

Descriptive Statistics:

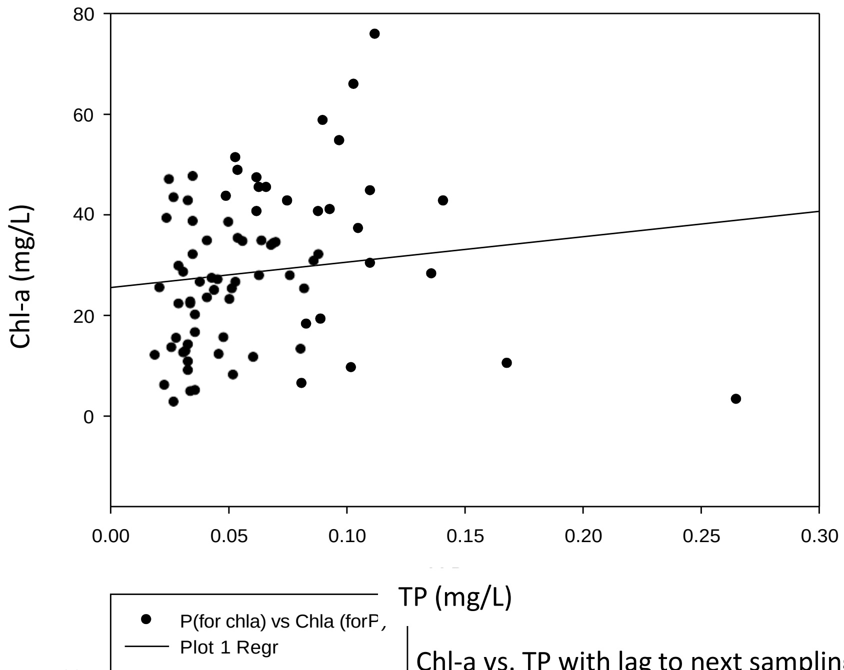
Data source: Data 1 in LkT-bird analysis

Column	Size	Missing	Mean	Std Dev	Std. Error
2016	55	0	27.891	12.922	1.742
2017	72	0	33.353	16.544	1.950
2018	79	0	24.320	10.348	1.164
2019	88	0	24.462	15.788	1.683

Column	Range	Max	Min	Median
2016	51.400	54.700	3.300	28.500
2017	62.200	65.900	3.700	35.400
2018	42.800	48.100	5.300	24.000
2019	73.070	75.800	2.730	23.400

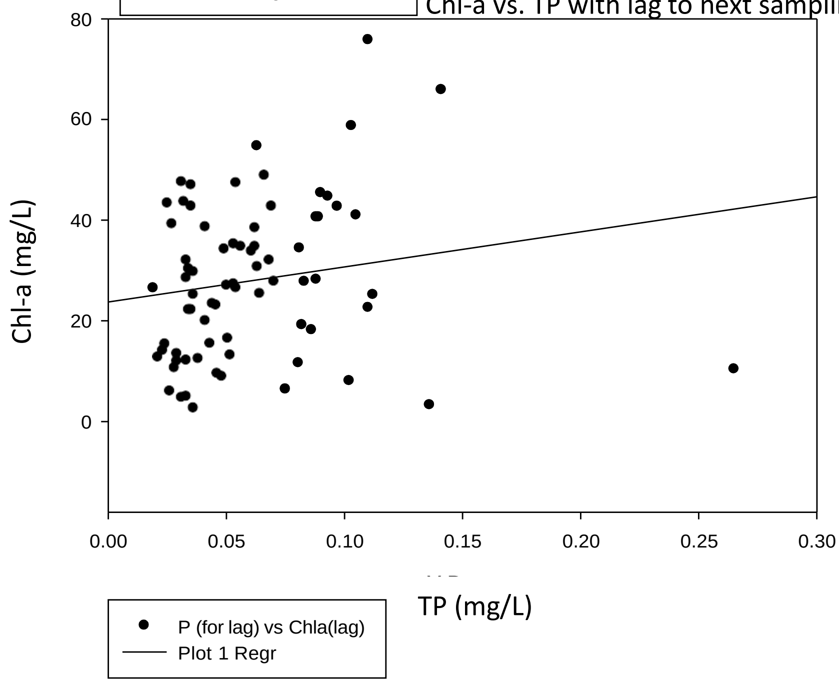
Appendix D.3: Chl-a Comparison to Total Phosphorus and Lag

Chl-a vs. TP



Values for the same sites at 0.5 m. (occurrences with 2-3 replicate P samples – use median for 3 values and mean for 2 values)

Chl-a vs. TP with lag to next sampling period



Same as graph above, but Chl-a lag until the next sampling period

Multiple Linear Regression (Chl-a & Total P)

Chl-a for (P) = 25.557 + (50.521 * P (for Chl-a))

N = 78

R = 0.127 Rsqr = 0.0160 Adj Rsqr = 0.00309

Standard Error of Estimate = 15.437

	Coefficient	Std. Error	t	P	VIF
Constant	25.557	3.294	7.760	<0.001	
P (for Chl-a)	50.521	45.396	1.113	0.269	1.000

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	295.143	295.143	1.239	0.269
Residual	76	18110.682	238.298		
Total	77	18405.826	239.037		

The dependent variable Ch-la (for P) can be predicted from a linear combination of the independent variables:

	P
P (for Chl-a)	0.269

Multiple Linear Regression (with lag between P & Chl-a)

Chl-a(lag) = 23.740 + (69.687 * P (for lag))

N = 73 Missing Observations = 5

R = 0.168 Rsqr = 0.0284 Adj Rsqr = 0.0147

Standard Error of Estimate = 15.456

	Coefficient	Std. Error	t	P	VIF
Constant	23.740	3.455	6.872	<0.001	
P (for lag)	69.687	48.392	1.440	0.154	1.000

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	495.391	495.391	2.074	0.154
Residual	71	16961.341	238.892		
Total	72	17456.731	242.455		

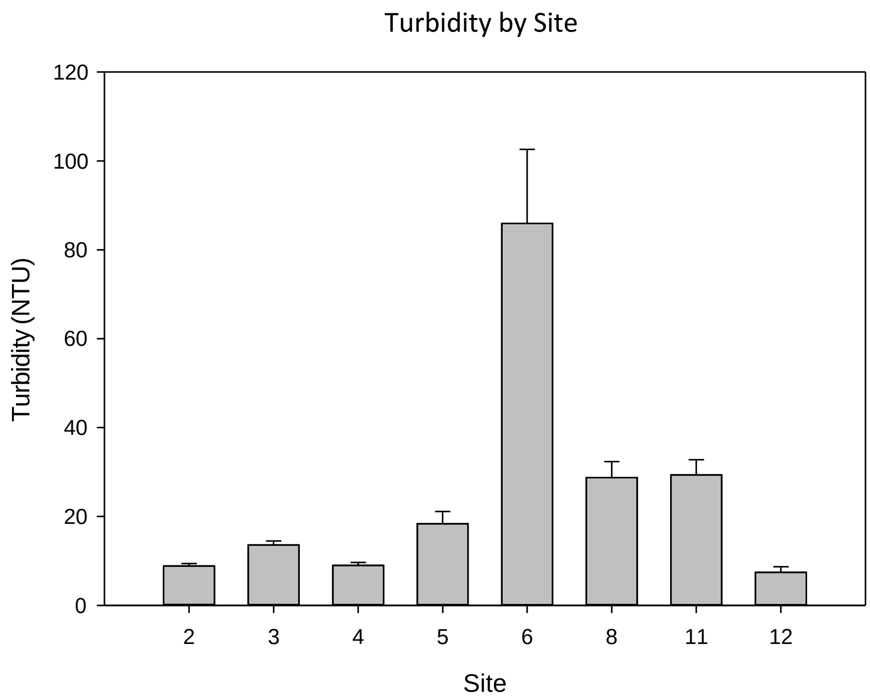
The dependent variable Chl-a (lag) can be predicted from a linear combination of the independent variables:

	P
P (for lag)	0.154

Not all of the independent variables appear necessary (or the multiple linear model may be underspecified)

Appendix E: Turbidity

Appendix E.1: Turbidity by Site



One Way Analysis of Variance

Normality Test (Shapiro-Wilk) Failed ($P < 0.050$)
Test execution ended by user request; ANOVA on Ranks begun
Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: Data 1 in LkT-bird analysis

Group	N	Missing	Median	25%	75%
Tur2	39	0	8.000	7.000	9.000
Tur3	39	0	12.000	9.000	17.000
Tur4	39	0	8.000	6.000	10.000
Tur5	39	0	14.000	10.000	23.000
Tur6	39	0	58.000	39.000	78.000
Tur8	38	0	25.000	18.000	33.250
Tur11	77	0	21.000	7.000	39.000
Tur12	9	0	6.000	5.000	9.510

H = 142.550 with 7 degrees of freedom. ($P = <0.001$)

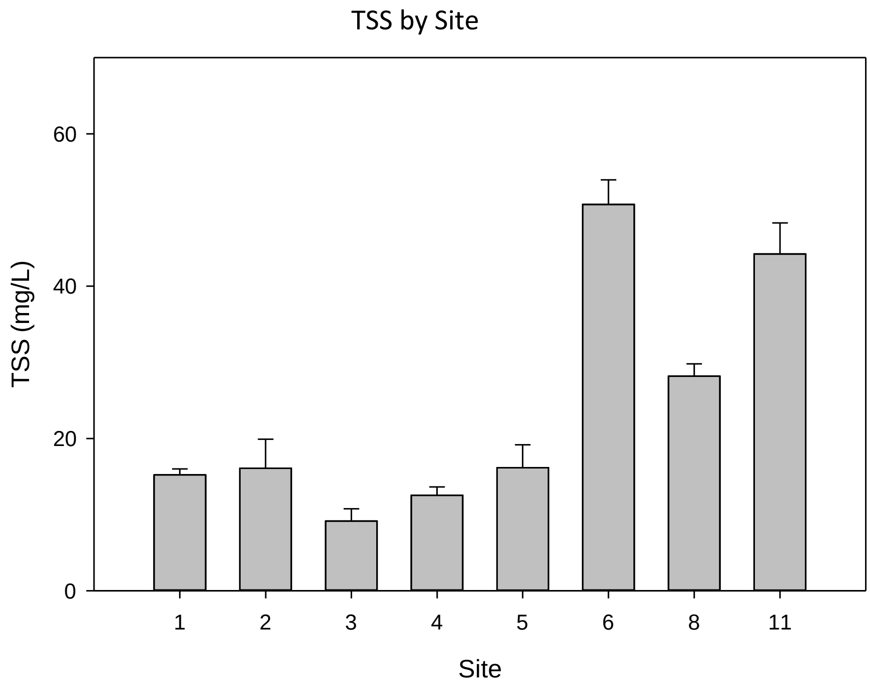
The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference ($P = <0.001$)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunn's Method):

Comparison	**Diff of Ranks**	**Q**	**P<0.05**
Tur6 vs Tur12	223.197	6.544	Yes
Tur6 vs Tur4	192.192	9.202	Yes
Tur6 vs Tur2	190.923	9.141	Yes
Tur6 vs Tur3	135.923	6.508	Yes
Tur6 vs Tur5	112.346	5.379	Yes
Tur6 vs Tur11	108.106	5.964	Yes
Tur6 vs Tur8	60.650	2.885	No
Tur8 vs Tur12	162.547	4.754	Yes
Tur8 vs Tur4	131.543	6.257	Yes
Tur8 vs Tur2	130.273	6.197	Yes
Tur8 vs Tur3	75.273	3.580	Yes
Tur8 vs Tur5	51.696	2.459	No
Tur8 vs Tur11	47.457	2.595	Do Not Test
Tur11 vs Tur12	115.090	3.542	Yes
Tur11 vs Tur4	84.086	4.639	Yes
Tur11 vs Tur2	82.817	4.569	Yes
Tur11 vs Tur3	27.817	1.535	No
Tur11 vs Tur5	4.240	0.234	Do Not Test
Tur5 vs Tur12	110.850	3.250	Yes
Tur5 vs Tur4	79.846	3.823	Yes
Tur5 vs Tur2	78.577	3.762	Yes
Tur5 vs Tur3	23.577	1.129	Do Not Test
Tur3 vs Tur12	87.274	2.559	No
Tur3 vs Tur4	56.269	2.694	Do Not Test
Tur3 vs Tur2	55.000	2.633	Do Not Test
Tur2 vs Tur12	32.274	0.946	Do Not Test
Tur2 vs Tur4	1.269	0.0608	Do Not Test
Tur4 vs Tur12	31.004	0.909	Do Not Test

Appendix E.2: TSS by Site



Descriptive Statistics:

Data source: Data 1 in LkT-bird analysis

Column	Size	Missing	Mean	Std Dev	Std. Error
TSS1	289	0	15.207	13.323	0.784
TSS2	58	0	16.064	29.202	3.834
TSS3	8	0	9.125	4.643	1.641
TSS4	70	0	12.514	9.380	1.121
TSS5	13	0	16.154	10.885	3.019
TSS6	65	0	50.740	26.087	3.236
TSS8	57	0	28.163	12.219	1.618
TSS11	44	0	44.236	27.079	4.082

Column	Range	Max	Min	Median
TSS1	111.000	112.000	1.000	12.000
TSS2	214.000	215.000	1.000	10.000
TSS3	13.000	18.000	5.000	8.500
TSS4	51.000	52.000	1.000	10.500
TSS5	32.000	35.000	3.000	14.000
TSS6	123.000	133.000	10.000	48.600
TSS8	58.300	68.300	10.000	25.000
TSS11	160.500	163.000	2.500	40.500

One Way Analysis of Variance

Data source: Data 1 in LkT-bird analysis

Normality Test (Shapiro-Wilk) Failed (P < 0.050)

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: Data 1 in LkT-bird analysis

Group	N	Missing	Median	25%	75%
TSS1	289	0	12.000	10.000	16.700
TSS2	58	0	10.000	7.000	16.000
TSS3	8	0	8.500	5.000	12.250
TSS4	70	0	10.500	6.000	17.000
TSS5	13	0	14.000	6.000	25.500
TSS6	65	0	48.600	32.500	68.100
TSS8	57	0	25.000	20.000	35.000
TSS11	44	0	40.500	29.000	57.900

H = 248.628 with 7 degrees of freedom. (P = <0.001)

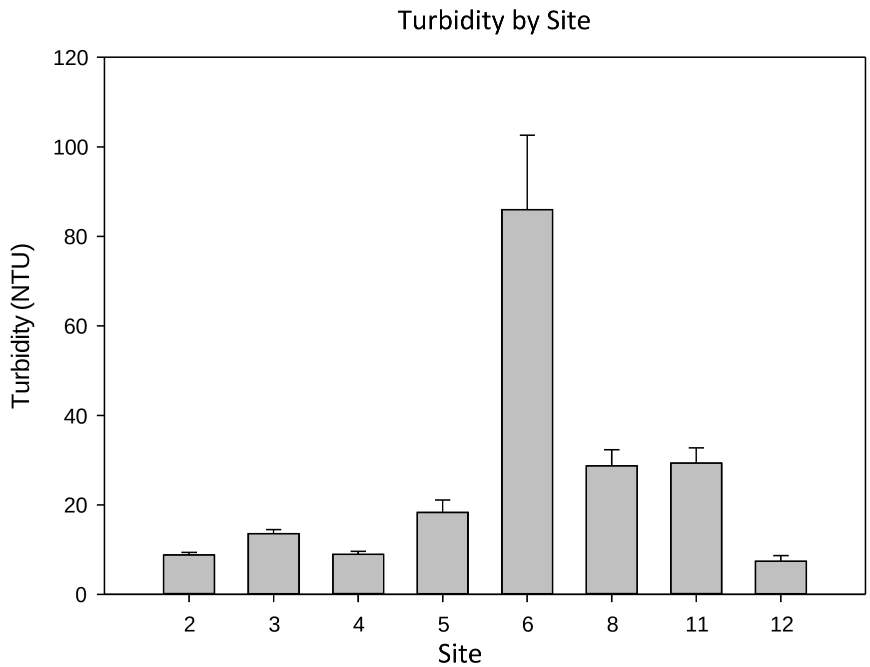
The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

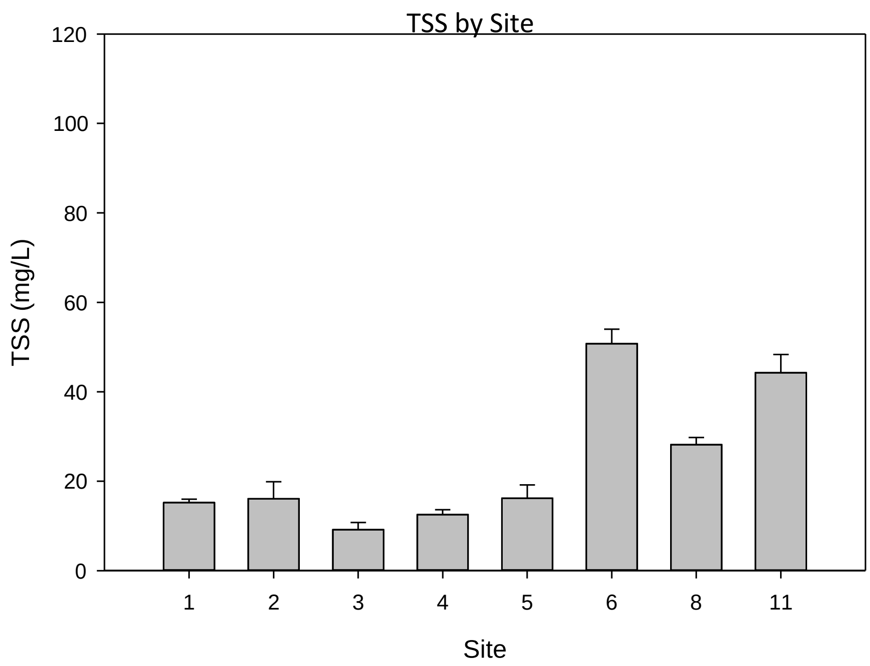
To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunn's Method):

Comparison	Diff of Ranks	Q	P<0.05
TSS6 vs TSS3	369.859	5.657	Yes
TSS6 vs TSS4	308.539	10.265	Yes
TSS6 vs TSS2	303.244	9.621	Yes
TSS6 vs TSS1	266.108	11.109	Yes
TSS6 vs TSS5	243.700	4.597	Yes
TSS6 vs TSS8	76.739	2.423	No
TSS6 vs TSS11	33.717	0.990	Do Not Test
TSS11 vs TSS3	336.142	5.012	Yes
TSS11 vs TSS4	274.822	8.186	Yes
TSS11 vs TSS2	269.528	7.726	Yes
TSS11 vs TSS1	232.392	8.229	Yes
TSS11 vs TSS5	209.983	3.812	Yes
TSS11 vs TSS8	43.023	1.229	Do Not Test
TSS8 vs TSS3	293.120	4.449	Yes
TSS8 vs TSS4	231.800	7.445	Yes
TSS8 vs TSS2	226.505	6.959	Yes
TSS8 vs TSS1	189.369	7.488	Yes
TSS8 vs TSS5	166.961	3.113	No
TSS5 vs TSS3	126.159	1.609	No
TSS5 vs TSS4	64.839	1.230	Do Not Test
TSS5 vs TSS2	59.544	1.112	Do Not Test
TSS5 vs TSS1	22.408	0.453	Do Not Test

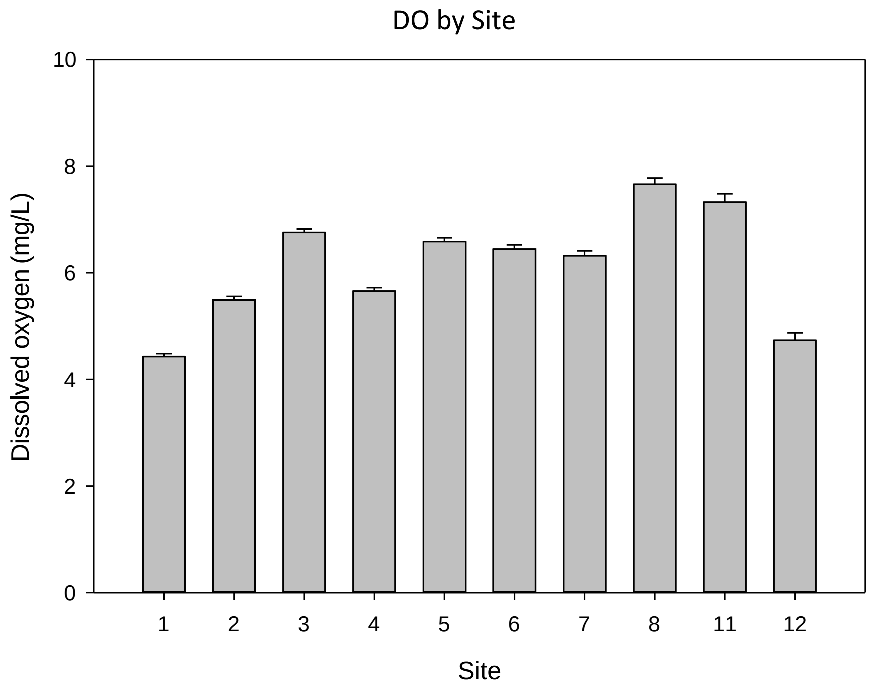
Appendix E.3: Comparison of Turbidity and TSS





Appendix F: Dissolved Oxygen

Appendix F.1: DO by Site



One Way Analysis of Variance

Data source: Data 1 in LkT-bird analysis

Normality Test (Kolmogorov-Smirnov) Failed ($P < 0.050$)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: Data 1 in LkT-bird analysis

Group	N	Missing	Median	25%	75%
DO S1	3436	0	4.825	0.430	7.167
DO S2	2394	0	6.190	3.038	7.820
DO S3	1421	0	7.060	5.770	8.310
DO S4	2340	0	6.330	3.580	7.940
DO S5	1337	0	6.870	5.395	8.295
DO S6	711	0	6.440	5.060	7.880
DO S7	706	0	6.355	4.908	8.080
DO S8	344	0	7.825	6.622	8.960
DO S11	230	0	7.525	6.128	8.625
DO S12	546	0	6.215	0.690	7.550

$H = 1074.780$ with 9 degrees of freedom. ($P = <0.001$)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunn's Method):

Comparison	**Diff of Ranks**	**Q**	**P<0.05**
DO S8 vs DO S1	4128.277	18.780	Yes
DO S8 vs DO S12	3447.349	12.884	Yes
DO S8 vs DO S2	2820.123	12.582	Yes
DO S8 vs DO S4	2622.873	11.685	Yes
DO S8 vs DO S7	2027.583	7.933	Yes
DO S8 vs DO S6	1987.089	7.783	Yes
DO S8 vs DO S5	1540.560	6.556	Yes
DO S8 vs DO S3	1281.194	5.485	Yes
DO S8 vs DO S11	560.320	1.692	No
DO S11 vs DO S1	3567.957	13.477	Yes
DO S11 vs DO S12	2887.029	9.448	Yes
DO S11 vs DO S2	2259.803	8.421	Yes
DO S11 vs DO S4	2062.553	7.679	Yes
DO S11 vs DO S7	1467.263	4.972	Yes
DO S11 vs DO S6	1426.769	4.839	Yes
DO S11 vs DO S5	980.240	3.533	Yes
DO S11 vs DO S3	720.874	2.609	No
DO S3 vs DO S1	2847.082	23.222	Yes
DO S3 vs DO S12	2166.155	11.067	Yes
DO S3 vs DO S2	1538.929	11.822	Yes
DO S3 vs DO S4	1341.679	10.263	Yes
DO S3 vs DO S7	746.388	4.170	Yes
DO S3 vs DO S6	705.894	3.953	Yes
DO S3 vs DO S5	259.366	1.751	No
DO S5 vs DO S1	2587.716	20.653	Yes
DO S5 vs DO S12	1906.789	9.658	Yes
DO S5 vs DO S2	1279.563	9.642	Yes
DO S5 vs DO S4	1082.313	8.122	Yes
DO S5 vs DO S7	487.022	2.693	No
DO S5 vs DO S6	446.528	2.475	Do Not Test
DO S6 vs DO S1	2141.188	13.370	Yes
DO S6 vs DO S12	1460.261	6.602	Yes
DO S6 vs DO S2	833.035	5.018	Yes
DO S6 vs DO S4	635.784	3.819	Yes
DO S6 vs DO S7	40.494	0.196	Do Not Test
DO S7 vs DO S1	2100.694	13.078	Yes
DO S7 vs DO S12	1419.767	6.409	Yes
DO S7 vs DO S2	792.541	4.761	Yes
DO S7 vs DO S4	595.290	3.567	Yes
DO S4 vs DO S1	1505.404	14.449	Yes
DO S4 vs DO S12	824.476	4.463	Yes
DO S4 vs DO S2	197.250	1.746	No
DO S2 vs DO S1	1308.153	12.641	Yes
DO S2 vs DO S12	627.226	3.402	Yes
DO S12 vs DO S1	680.927	3.802	Yes

Note: The multiple comparisons on ranks do not include an adjustment for ties.

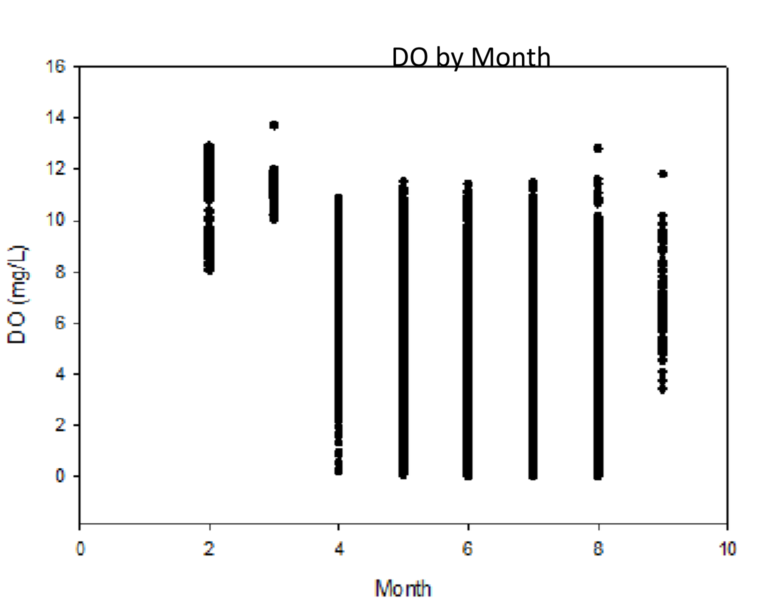
Descriptive Statistics:
Data source: Data 1 in LkT-bird analysis

Column	Size	Missing	Mean	Std Dev	Std. Error
DO S1	3436	0	4.428	3.398	0.0580
DO S2	2394	0	5.491	3.239	0.0662
DO S3	1421	0	6.755	2.500	0.0663
DO S4	2340	0	5.656	3.210	0.0664
DO S5	1337	0	6.587	2.590	0.0708
DO S6	711	0	6.443	2.155	0.0808
DO S7	706	0	6.322	2.434	0.0916
DO S8	344	0	7.659	2.197	0.118
DO S11	230	0	7.326	2.348	0.155
DO S12	546	0	4.732	3.281	0.140

Column	Range	Max	Min	Median
DO S1	12.900	12.900	0.000	4.825
DO S2	12.900	12.900	0.000	6.190
DO S3	12.860	12.960	0.1000	7.060
DO S4	13.860	13.860	0.000	6.330
DO S5	13.520	13.620	0.1000	6.870
DO S6	13.350	13.440	0.0900	6.440
DO S7	13.580	13.700	0.120	6.355
DO S8	13.260	13.360	0.1000	7.825
DO S11	13.500	13.630	0.130	7.525
DO S12	11.000	11.100	0.1000	6.215

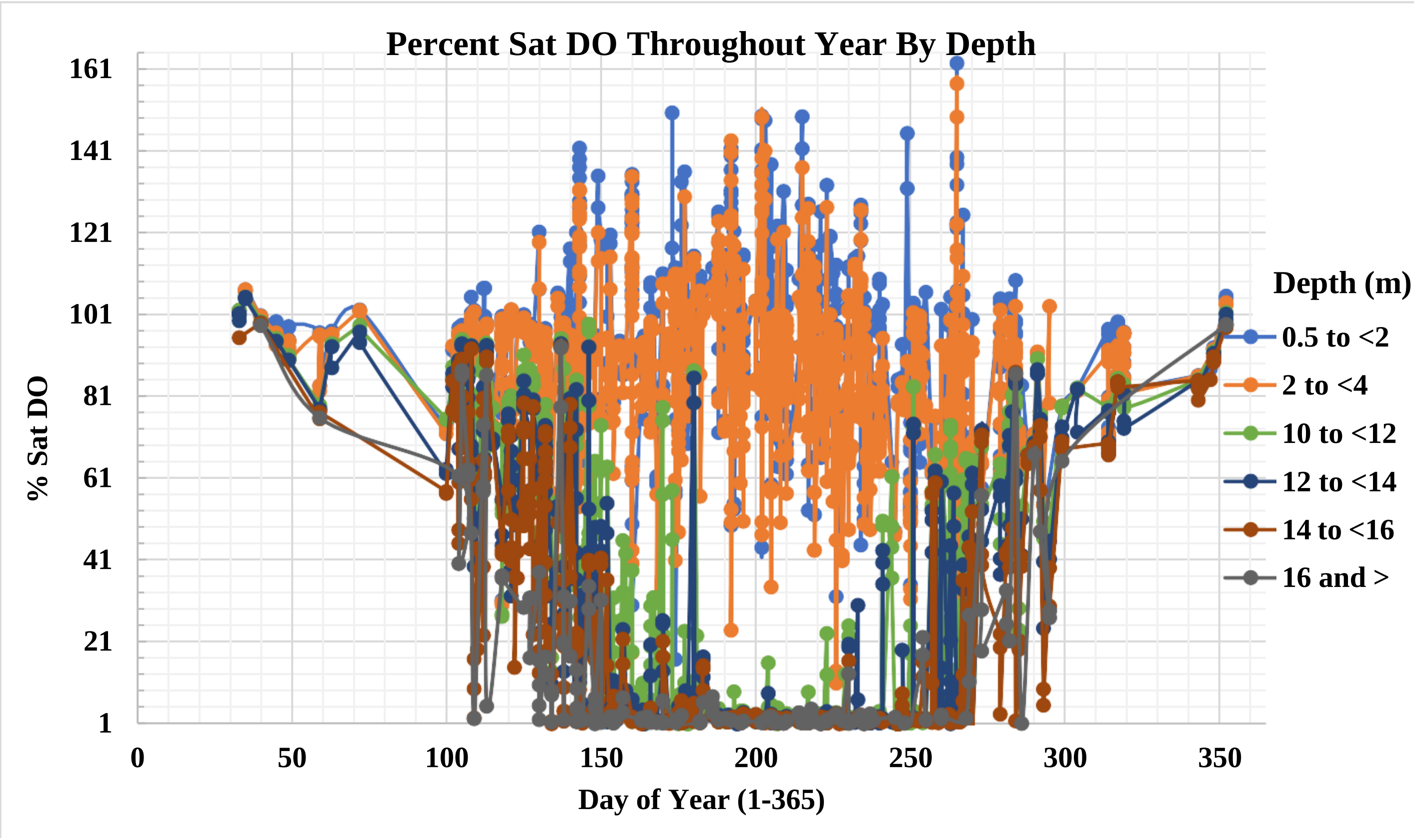
Appendix F.2: DO by month

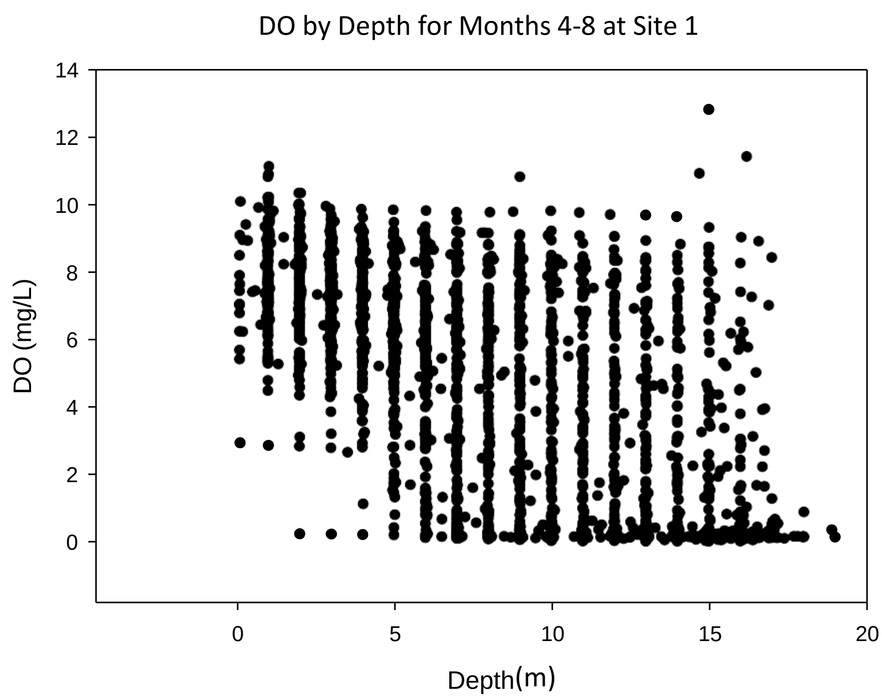
DO versus month (all depths, all data)



Note: Month 2= February, Month 10= October

Appendix F.3: DO by Depth





Linear Regression
Data source: Data 1 in LkT-bird analysis

Site1 DO = 8.023 - (0.458 * Site1 depth)

N = 2524

R = 0.637 Rsqr = 0.405 Adj Rsqr = 0.405

Standard Error of Estimate = 2.555

	Coefficient	**Std. Error**	**t**	**P**
Constant	8.023	0.107	74.802	<0.001
Site1 depth	-0.458	0.0111	-41.455	<0.001

Analysis of Variance:

	DF	**SS**	**MS**	**F**	**P**
Regression	1	11220.958	11220.958	1718.546	<0.001
Residual	2522	16466.979	6.529		
Total	2523	27687.937	10.974		

Normality Test (Shapiro-Wilk) Failed (P = <0.001)

Constant Variance Test: Failed (P = <0.001)

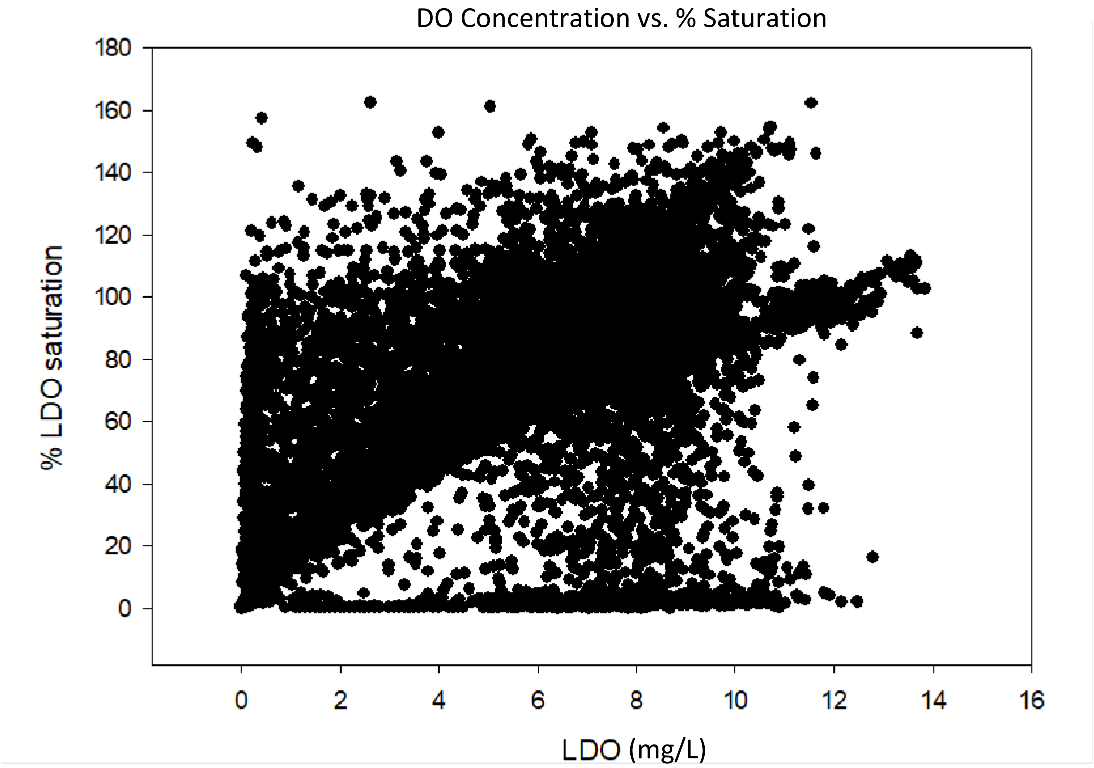
Power of performed test with alpha = 0.050: 1.000

Descriptive Statistics:
Data source: Data 1 in LkT-bird analysis

Column	**Size**	**Missing**	**Mean**	**Std Dev**	**Std. Error**
Site1 DO	2524	0	4.108	3.313	0.0659

Column	**Range**	**Max**	**Min**	**Median**
Site1 DO	12.800	12.800	0.000	4.595

Appendix F.4: DO Concentration vs. % Saturation



Linear Regression

LDO%Sat = 26.509 + (7.125 * LDO)

N = 17505

R = 0.625 Rsqr = 0.391 Adj Rsqr = 0.391

Standard Error of Estimate = 28.628

	Coefficient	Std. Error	t	P
Constant	26.509	0.437	60.697	<0.001
LDO	7.125	0.0672	106.002	<0.001

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	9208609.339	9208609.339	11236.352	<0.001
Residual	17503	14344361.416	819.537		
Total	17504	23552970.755	1345.576		

Normality Test (Kolmogorov-Smirnov) Failed (P = <0.001)

Constant Variance Test: Failed (P = <0.001)

Power of performed test with alpha = 0.050: 1.000

Appendix G: Descriptive Statistics

Appendix G.1: Oxygen, P, and N descriptive stats inclusive of all sites

Data source: Data 1 in LkT-bird analysis

Column	Size	Missing	Mean	Std Dev	Std. Error
LDO	17505	0	5.644	3.219	0.0243
LDO%Sat	17505	0	66.723	36.682	0.277
orthoP	1093	0	0.0502	0.104	0.00316
total P	1093	0	0.0874	0.124	0.00376
TKN	633	0	0.865	0.571	0.0227
NH3	633	0	0.504	0.741	0.0294
NO2	633	0	0.0289	0.0707	0.00281
NO3	633	0	0.0553	0.0907	0.00360

Column	Range	Max	Min	Median
LDO	13.860	13.860	0.000	6.390
LDO%Sat	162.300	162.300	0.000	78.100
orthoP	0.815	0.816	0.001000	0.0150
total P	1.259	1.260	0.001000	0.0460
TKN	5.493	5.550	0.0570	0.720
NH3	5.547	5.550	0.00300	0.0200
NO2	0.876	0.880	0.00400	0.01000
NO3	0.529	0.530	0.00100	0.01000

Appendix G.2: Descriptive Statistics for Nitrogen by Site

Data source: Data 1 in LkT-bird analysis

Column	Size	Missing	Mean	Std Dev	Std. Error
TKNS1	326	0	0.927	0.664	0.0368
TKNS2	90	0	0.763	0.449	0.0474
TKNS3	10	0	0.743	0.186	0.0588
TKNS4	92	0	0.771	0.513	0.0535
TKNS5	19	0	0.847	0.869	0.199
TKNS6	39	0	0.889	0.208	0.0334
TKNS8	34	0	0.803	0.192	0.0330
TKNS11	22	0	0.888	0.141	0.0300
NH3S1	326	0	0.630	0.828	0.0458
NH3S2	90	0	0.327	0.613	0.0646
NH3S3	10	0	0.415	0.437	0.138
NH3S4	92	0	0.339	0.656	0.0684
NH3S5	19	0	0.444	1.008	0.231
NH3S6	39	0	0.508	0.481	0.0769
NH3S8	34	0	0.318	0.431	0.0739
NH3S11	22	0	0.411	0.464	0.0989
NO2S1	326	0	0.0331	0.0847	0.00469
NO2S2	90	0	0.0193	0.0424	0.00447
NO2S3	10	0	0.0243	0.0452	0.0143

NO2S4	92	0	0.0197	0.0422	0.00440
NO2S5	19	0	0.0522	0.0707	0.0162
NO2S6	39	0	0.0314	0.0662	0.0106
NO2S8	34	0	0.0183	0.0372	0.00638
NO2S11	22	0	0.0337	0.0812	0.0173
NO3S1	326	0	0.0623	0.0966	0.00535
NO3S2	90	0	0.0627	0.102	0.0107
NO3S3	10	0	0.0551	0.0976	0.0309
NO3S4	92	0	0.0612	0.0907	0.00945
NO3S5	19	0	0.0361	0.0611	0.0140
NO3S6	39	0	0.0298	0.0613	0.00982
NO3S8	34	0	0.0218	0.0392	0.00672
NO3S11	22	0	0.0124	0.0213	0.00454

Column	**Range**	**Max**	**Min**	**Median**
TKNS1	5.485	5.550	0.0650	0.710
TKNS2	3.760	3.817	0.0570	0.680
TKNS3	0.520	0.970	0.450	0.765
TKNS4	3.937	4.327	0.390	0.685
TKNS5	4.047	4.377	0.330	0.640
TKNS6	1.227	1.300	0.0730	0.900
TKNS8	0.820	1.230	0.410	0.770
TKNS11	0.560	1.250	0.690	0.890
NH3S1	5.547	5.550	0.00300	0.560
NH3S2	3.807	3.817	0.01000	0.0150
NH3S3	0.960	0.970	0.01000	0.340
NH3S4	4.317	4.327	0.01000	0.0200
NH3S5	4.367	4.377	0.01000	0.01000
NH3S6	1.297	1.300	0.00300	0.660
NH3S8	1.167	1.170	0.00300	0.0200
NH3S11	1.092	1.095	0.00300	0.00300
NO2S1	0.876	0.880	0.00400	0.01000
NO2S2	0.240	0.250	0.01000	0.01000
NO2S3	0.143	0.153	0.01000	0.01000
NO2S4	0.290	0.300	0.01000	0.01000
NO2S5	0.210	0.220	0.01000	0.01000
NO2S6	0.326	0.330	0.00400	0.01000
NO2S8	0.156	0.160	0.00400	0.00400
NO2S11	0.336	0.340	0.00400	0.00400
NO3S1	0.459	0.460	0.001000	0.01000
NO3S2	0.529	0.530	0.001000	0.01000
NO3S3	0.249	0.250	0.001000	0.01000
NO3S4	0.309	0.310	0.001000	0.01000
NO3S5	0.209	0.210	0.001000	0.01000
NO3S6	0.249	0.250	0.001000	0.00400
NO3S8	0.136	0.140	0.00400	0.00400
NO3S11	0.0760	0.0800	0.00400	0.00400

Appendix G.3: Descriptive Statistics: Turbidity

Data source: Data 1 in LkT-bird analysis

Column	Size	Missing	Mean	Std Dev	Std. Error
Tur2	39	0	8.827	3.633	0.582
Tur3	39	0	13.559	5.740	0.919
Tur4	39	0	8.983	4.105	0.657
Tur5	39	0	18.318	17.310	2.772
Tur6	39	0	85.949	104.069	16.664
Tur8	38	0	28.708	22.408	3.635
Tur11	77	0	29.335	30.153	3.436
Tur12	9	0	7.433	3.788	1.263

Column	Range	Max	Min	Median
Tur2	16.000	20.000	4.000	8.000
Tur3	23.000	29.000	6.000	12.000
Tur4	17.000	21.000	4.000	8.000
Tur5	109.000	116.000	7.000	14.000
Tur6	512.000	525.000	13.000	58.000
Tur8	142.000	149.000	7.000	25.000
Tur11	131.000	135.000	4.000	21.000
Tur12	10.120	15.000	4.880	6.000

Descriptive Statistics: Secchi depth

Column	Size	Missing	Mean	Std Dev	Std. Error	C.I. of Mean
S2 Secchi	74	0	58.973	18.154	2.110	4.206
S4 Secchi	39	0	66.487	18.642	2.985	6.043
S5-Secchi	39	0	45.718	13.115	2.100	4.251
S6 Secchi	38	0	16.684	7.245	1.175	2.381
S8 Secchi	38	0	34.684	11.447	1.857	3.763
S11 Secchi	39	0	22.718	7.807	1.250	2.531
S12 Secchi	35	0	70.457	18.302	3.094	6.287

Column	Range	Max	Min	Median
S2 Secchi	95.000	120.000	25.000	56.000
S4 Secchi	79.000	113.000	34.000	62.000
S5-Secchi	66.000	78.000	12.000	46.000
S6 Secchi	27.000	29.000	2.000	18.000
S8 Secchi	58.000	66.000	8.000	32.000
S11 Secchi	33.000	38.000	5.000	23.000
S12 Secchi	93.000	122.000	29.000	68.000

Descriptive Statistics: phosphorus by site

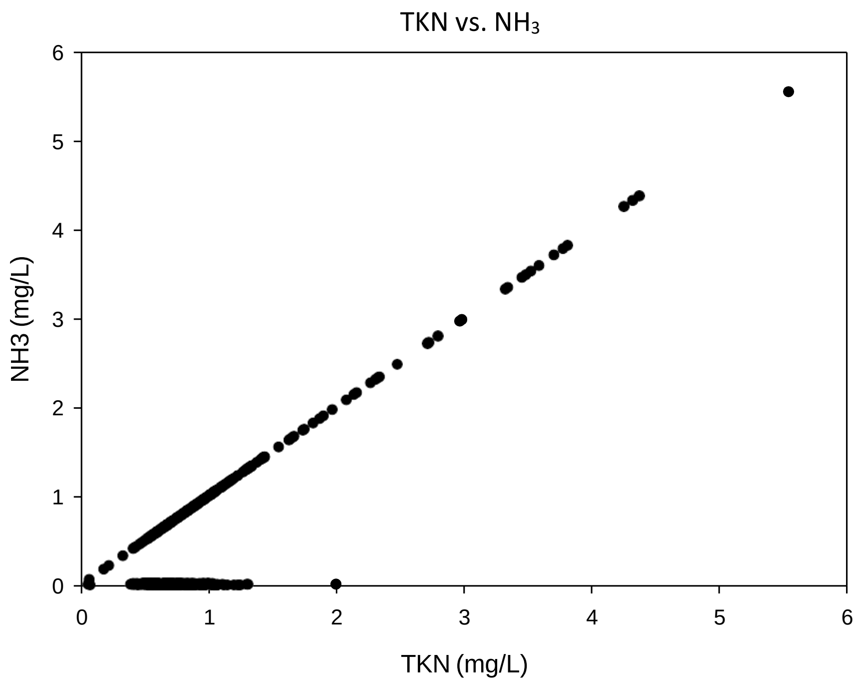
Column	Size	Missing	Mean	Std Dev	Std. Error	C.I. of Mean
S1	694	11	0.106	0.145	0.00556	0.0109
S2	99	0	0.0500	0.0495	0.00498	0.00987
S3	9	0	0.0454	0.0223	0.00743	0.0171
S4	102	0	0.0572	0.0816	0.00808	0.0160
S5	16	0	0.0620	0.0293	0.00733	0.0156
S6	102	0	0.115	0.127	0.0125	0.0249
S8	95	0	0.0512	0.0242	0.00248	0.00492
S11	186	5	0.0986	0.127	0.00942	0.0186
S12	20	0	0.158	0.195	0.0436	0.0912

Column	Range	Max	Min	Median

S1	1.255	1.260	0.00500	0.0450
S2	0.366	0.371	0.00500	0.0350
S3	0.0750	0.1000	0.0250	0.0390
S4	0.649	0.660	0.0110	0.0380
S5	0.0960	0.118	0.0220	0.0600
S6	1.079	1.090	0.0110	0.0925
S8	0.140	0.151	0.0110	0.0480
S11	0.959	0.978	0.0190	0.0660
S12	0.557	0.580	0.0230	0.0385

Appendix H: Other Parameters

Appendix H.1: Nitrogen Comparisons (NH3, TKN, NO3, NO2)



Linear Regression

NH3 = -0.479 + (1.136 * TKN)

N = 633

R = 0.876 Rsqr = 0.767 Adj Rsqr = 0.767

Standard Error of Estimate = 0.358

	Coefficient	Std. Error	t	P
Constant	-0.479	0.0258	-18.552	<0.001
TKN	1.136	0.0249	45.597	<0.001

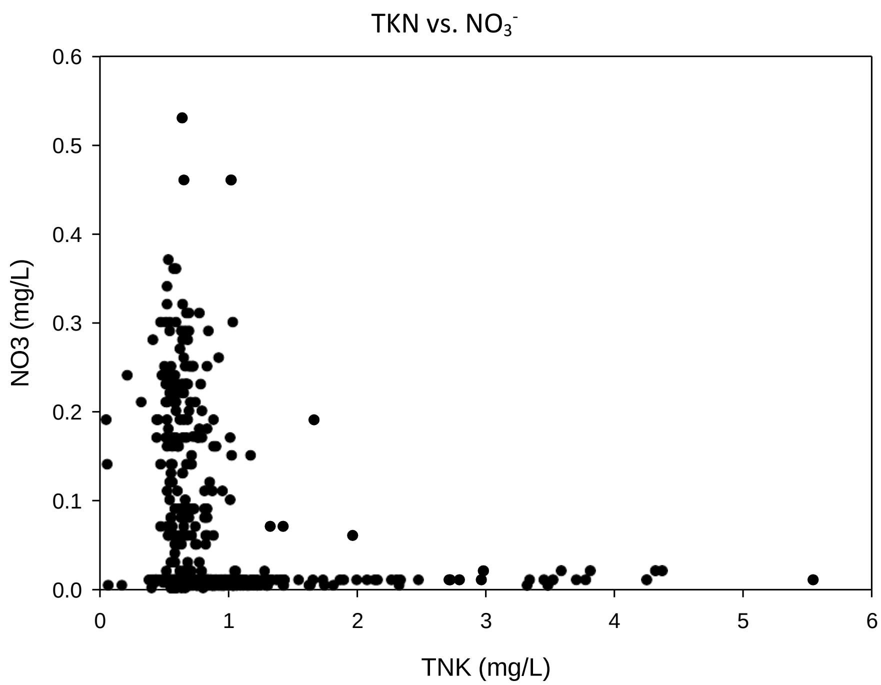
Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	265.953	265.953	2079.052	<0.001
Residual	631	80.718	0.128		
Total	632	346.671	0.549		

Normality Test (Shapiro-Wilk)   Failed   (P = <0.001)

Constant Variance Test: Failed   (P = <0.001)

Power of performed test with alpha = 0.050: 1.000



Linear Regression

NO3 = 0.0797 - (0.0282 * TKN)

N = 633

R = 0.177   Rsqr = 0.0314   Adj Rsqr = 0.0299

Standard Error of Estimate = 0.089

	Coefficient	Std. Error	t	P
Constant	0.0797	0.00645	12.352	<0.001
TKN	-0.0282	0.00622	-4.524	<0.001

Analysis of Variance:

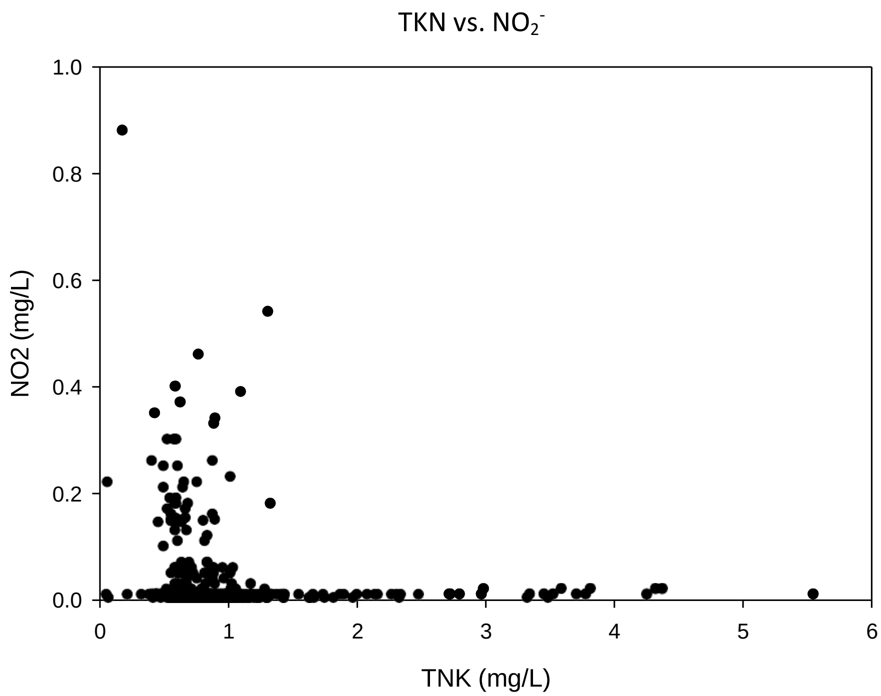
	DF	SS	MS	F	P
Regression	1	0.163	0.163	20.463	<0.001

Residual	631	5.034	0.00798
Total	632	5.197	0.00822

Normality Test (Shapiro-Wilk) Failed (P = <0.001)

Constant Variance Test: Failed (P = <0.001)

Power of performed test with alpha = 0.050: 0.994



Linear Regression

NO2 = 0.0386 - (0.0111 * TKN)

N = 633

R = 0.0898 Rsqr = 0.00807 Adj Rsqr = 0.00650

Standard Error of Estimate = 0.071

	Coefficient	**Std. Error**	**t**	**P**
Constant	0.0386	0.00509	7.574	<0.001
TKN	-0.0111	0.00491	-2.266	0.024

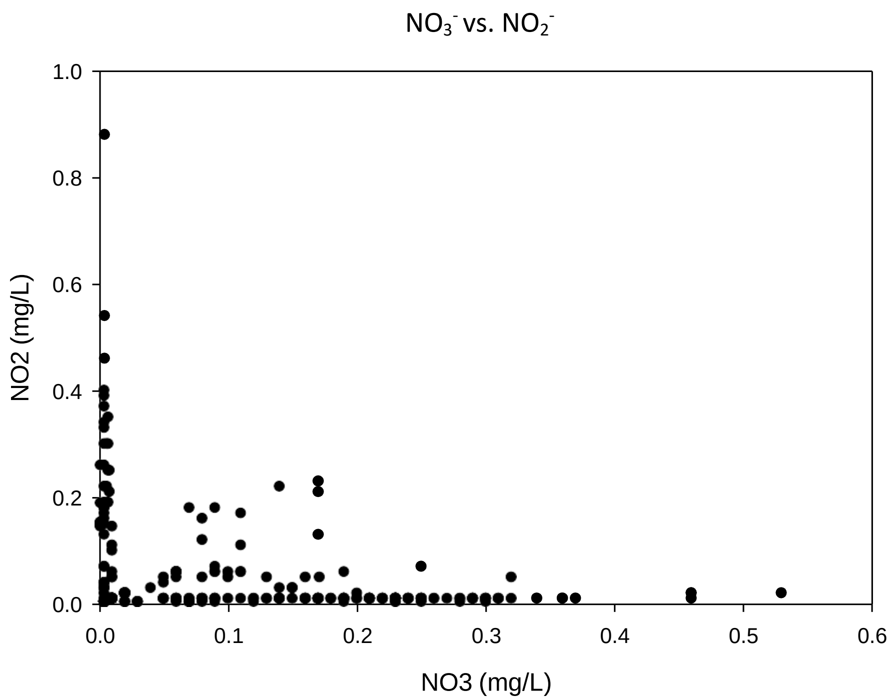
Analysis of Variance:

	DF	**SS**	**MS**	**F**	**P**
Regression	1	0.0255	0.0255	5.134	0.024
Residual	631	3.137	0.00497		
Total	632	3.162	0.00500		

Normality Test (Shapiro-Wilk) Failed (P = <0.001)

Constant Variance Test: Failed (P = <0.001)

Power of performed test with alpha = 0.050: 0.618



Linear Regression

NO2 = 0.0321 - (0.0568 * NO3)

N = 633

R = 0.0728 Rsqr = 0.00529 Adj Rsqr = 0.00372

Standard Error of Estimate = 0.071

	Coefficient	**Std. Error**	**t**	**P**
Constant	0.0321	0.00329	9.753	<0.001
NO3	-0.0568	0.0310	-1.833	0.067

Analysis of Variance:

	DF	**SS**	**MS**	**F**	**P**
Regression	1	0.0167	0.0167	3.358	0.067
Residual	631	3.146	0.00498		
Total	632	3.162	0.00500		

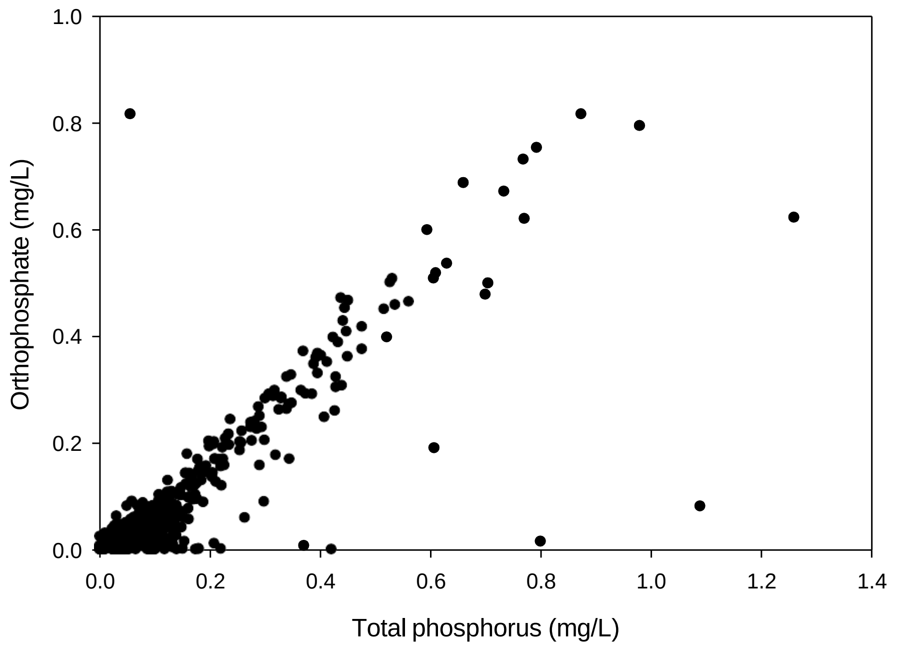
Normality Test (Shapiro-Wilk) Failed (P = <0.001)

Constant Variance Test: Failed (P = <0.001)

Power of performed test with alpha = 0.050: 0.448

The power of the performed test (0.448) is below the desired power of 0.800.
Less than desired power indicates you are less likely to detect a difference when one actually exists. Negative results should be interpreted cautiously.

Appendix H.2: Comparison of Orthophosphate and Phosphorus



Linear Regression

orthoP = -0.0141 + (0.735 * total P)

N = 1093

R = 0.875 Rsqr = 0.766 Adj Rsqr = 0.766

Standard Error of Estimate = 0.051

	Coefficient	**Std. Error**	**t**	**P**
Constant	-0.0141	0.00187	-7.520	<0.001
total P	0.735	0.0123	59.747	<0.001

Analysis of Variance:

	DF	**SS**	**MS**	**F**	**P**
Regression	1	9.115	9.115	3569.696	<0.001
Residual	1091	2.786	0.00255		
Total	1092	11.901	0.0109		

Normality Test (Shapiro-Wilk) Failed (P = <0.001)

Constant Variance Test: Failed ($P = <0.001$)

Power of performed test with alpha = 0.050: 1.000