TWENTY YEARS OF LAND USE AND THE IMPACT OF NITRATE, E. COLI AND CHLOROPHYLL FOR TWO LAKES IN NORTH CENTRAL TEXAS

by

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THESIS

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ABSTRACT

TWENTY YEARS OF LAND USE AND THE IMPACT OF NITRATE, E. COLI AND CHLOROPHYLL FOR TWO LAKES IN NORTH CENTRAL TEXAS.

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Clean and safe drinking water is a human right. Global, federal, and state agencies that monitor the source and quality of drinking water are limited in power and oversight. Historically, human groups have replaced wetland habitat with cropland, disregarding the abundance of resources. To mediate the loss, human constructed artificial wetlands aid in cleaning natural water ways. In chapter one, four floating wetland structures were installed on Lake Arlington and historical water quality data from 2001-2018 was analyzed. Historical data included six variables: Chlorophyll α, Dissolved Oxygen, Temperature, Specific Conductivity and Turbidity. The Mann Kendall Seasonality Trend test found that Specific Conductance, Turbidity, and pH had significant monotonic trends. In chapter two, land use changes over time are reviewed and compared to drinking water quality parameters, Chlorophyll α, Total Coliform and Nitrate at two reservoirs. Lake Arlington and Joe Pool Lake water quality data was provided by Trinity River Authority and land use data was downloaded from the NCTCOG Regional Data Center. Lake Arlington chlorophyll α was highly correlated with five out of nine land use categories, these included commercial, dedicated, institutional, residential, and undeveloped lands. Joe Pool Lake tests of chlorophyll α, and nitrate returned significant correlations. Chlorophyll α is negatively correlated with land use categories dedicated, infrastructure and institutional. Nitrate was negatively correlated with dedicated, infrastructure and institutional land use categories. Reviewing the results of chapter 2, a closer look at land use categories dedicated, infrastructural and institutional may provide deeper insight to the root of the nitrate and chlorophyll α correlations.

LIST OF FIGURES

LIST OF TABLES

TABLE OF CONTENTS

Chapter 1

Feasibility of Constructed Treatment Wetlands at Lake Arlington, Texas

Water quality monitoring of inland freshwater resources is important for management considerations of current and future use of potable water. Contamination and pollution of natural water systems can lead to unsafe drinking water for much of the world. Currently, two billion humans on the planet do not have access to safely managed drinking water, while half of the global human population lack access to sanitary sewage systems (WHO/UNICEF 2019). The United States (US) is no exception, clean water and proper sewage services are not guaranteed. Regulatory agency Environmental Protection Agency (EPA) provides Americans with peace of mind that available drinking water is safe. Regulations on drinking water began in 1974 with the Safe Drinking Water Act (SDWA) passed by congress. Revisions in 1986 and 1996 set standards for drinking water parameters and authorized the EPA to regulate and enforce safe drinking water supplies in the United States ((Hill, 2017) (United Nations,). However, there are scenarios where communities have fallen through the cracks of the system. After years long complaints of discolored water and illness, the city of Flint, Michigan admitted that the lead concentrations in the faucet water were seven times higher than EPA limit (Hill, 2017). In Sebring, Ohio a similar occurrence happened, the small town discovered high lead contamination levels in multiple homes. Ohio EPA allegedly knew lead and copper concentrations were significantly higher than the legal limit (Kara Driscoll, 2017). The pipes are in the replacement process, but the discovery of contaminated water lines continues (Lauren del Valle, 2016).

The European Union (EU) is the governing agency for drinking water standards in the EU (World Health Organization, 2018). The overlap of the EU and the World Health Organization (WHO), which is responsible for environmental oversight of the United Nations (UN) is vital, but gaps in power leave opportunity for mistakes. The availability of water leaves many global citizens without reliable and clean drinking water. Natural resources in general are stretched thin as human populations increase 1% each year (*World Population Prospects 2019: Highlights*2019). Increasing human populations continue to put pressure on environmental services and resources.

Water is required for all needs in daily life, including the life of plants and animals of which coexist with the natural environment and maintain specialized interconnected systems. The connection of these systems is dependent on land that is used for farming, livestock, habitats, homes, and communities. The greatest impact on land conversion is agriculture and ranchland; to prepare for crops and cattle wetlands in the U.S. were drained and cleared. For over three hundred years from the 1600's through to the 20th century wetlands were destroyed in one way or another, such as the overharvesting of wildlife, fertilizer over-application, and clearing out of entire habitats (Mattei, 2019). Human culture of containing or altering wetland areas goes far back into human history (Chen et al., 2007) (Beach et al., 2015). The negative perspective of wetlands was prevalent in Britain where disease was thought to originate from standing water. Colonialists originating from marshy areas associated wetlands with illness and disease, especially as the plasmodium parasite spread Malaria throughout Europe. Standard practice was to drain the wetlands and prepare the land for crops and agriculture, often using forced slave labor (Mattei, 2019). While wetlands were cleared for crops, first indigenous peoples of the Northeast region used the native wetland plants for sustenance and could cultivate, sustain, and process the plant foods (Wickman, 2021) demonstrating the potential of natural resources available in wetland habitats.

In the 1970's the concept of preserving wetlands for wildlife and migratory birds became popular. Earlier interest in the twentieth century focused on habitat conservation and management solely for hunting and fishing purposes (Lewis, 2001). The interdependence of living organisms and biochemical reactions is crucial for the ecosystem to survive. Wetlands are highly productive ecosystems and provide important services, such as protecting coasts and banks from erosion, acting as a natural water filter for pollutants and sediment, and habitat for many species, which may be threatened, endangered, ecosystem engineers and/or economically important species. Wetlands are responsible for nitrification, the reaction changing ammonium into the ready to use molecule nitrate by aquatic plants, forming the foundation of swamps and marshlands. Wetlands are areas where soil is deeply saturated with water seasonally or annually, this hydroperiod plays a key role in overall productivity ((Mitsch & Gosselink, 2015a).

The world is covered in water but only a small fraction is available for human use, and while water is considered a renewable resource, the status depends on resource management and conservation (Lewis, 2001). Distribution of drinking water sources are not even, while some areas may never feel a water scarcity, others are constantly under threat of drought. Water availability shifts over time, a review of satellite data from 2001-2016 indicates that groundwater use is at a unsustainable rate (Rodell et al., 2018). Particularly in the world's most irrigated agriculture regions, freshwater resources are disappearing. In Texas, groundwater use has exceeded aquifer recharge quantities for decades in irrigated cropland to the point where parts of the aquifer have dried up completely (Rodell et al., 2018). Additionally, pollution and contamination issues must be addressed. In north central Texas scientists found pollutants and contaminants collect in underground wells and nitrate concentrations increase with well depth (Hudak & Blanchard, 1997).

To gain interest and support of ecological preservation and conservation, economic impacts must be understood. The monetary value of ecosystems is complex to calculate and often oversimplified with focus on either ecological or socio-economic value (Boerema et al., 2016). The scale of economic loss varies depending on the circumstances, Lake Erie experienced millions of dollars in recreation revenue loss due to poor water quality and months long cyanobacteria blooms in the spring and summer, resulting in a drop of fishing license sales (Wolf et al., 2017). Catastrophic weather events along the coast are exacerbated by wetland loss, flood control averages $2 billion dollars each year in the US. Recreational fishing is worth an estimated $116 billion dollars. Wetlands play a crucial part in recreational fishing accounting for 90% of the fish caught recreationally (Economic Benefits of Wetlands.). A case study in Texas which reviewed water quality data and associated standards from 1970 to 2018 indicates that failure to meet water quality standards for Dissolved Oxygen (DO) and Chlorophyll α has remained consistent from 1990 to 2018. Over the course of 48 years, the share of waterbodies that are not suitable for drinking, swimming, boating, or fishing in Texas has plateaued (Kuwayama et al. 2020).

While the original acreage of wetlands in the United States can only be estimated, less than half of the coverage remains, an estimated 750 million hectares (Mahdianpari et al., 2020). The loss of wetlands has profound environmental impacts (Qadri et al., 2019). Point and non-point source pollution is nonstop with millions of tons of sewage dumped into the world's water daily (Mishra & Dubey, 2015). In areas of wetland loss and degradation, habitat improvement such as the addition of human constructed wetlands to habitats is critical to support local wildlife and ecosystems. The constructed wetland consists of adding plants into a current wetland system by planting them around the banks (Texas Community Watershed Partners, 2019). Floating constructed wetlands (FCW) are placed on the surface of the water and have a unique set of benefits. The roots act as a microhabitat for aquatic animals that can hide, eat, grow, and develop. The anchor attached to the FCW can act as additional fish habitat if constructed thoughtfully (Hense, 1996).

Human constructed treatment wetlands (CTW) are designed to maximize plant functionality of nutrient uptake, sedimentation, and microhabitat surface area. Types of CTWs are categorized into two main categories: Floating Plant Mat System and Matrix-Based System. Floating plant mat systems are less complicated than matrix-based systems which include either rooted or submerged plants and multiple flow options. Floating systems are specifically composed of rooted plants that grow above the water surface (Navarro-Frómeta & Bayona, 2018). Both options can range in cost between $1-$24 per square foot of raft with lower cost options using recycled plastics or PVC (Polyvinyl Chloride). Professionally constructed treatment wetlands are priced much higher (Sample et al., 2013). For example, an 8x8ft square raft can range from $64 - $1,536 depending on material quality.

The species of wetland plants designated for the treatment wetland must be carefully considered. Each wetland is different, in-depth knowledge of the seasonal cycle, water depths, water parameters, plant and animal species and recreational use of the waterbody is necessary to curate a floating wetland. Consider the size of the waterbody and the growth rate of the plants, high plant biomass correlates with high nutrient uptake (Spangler et al., 2019). The reverse is also true with high concentrations of nutrient availability, particularly nitrogen and phosphorous drive the growth of aquatic macrophytes and algae. In an experiment of floating treatment wetlands in Jakarta, Indonesia scientists studied two different wetland plants, one with submerged vegetation and one with above surface vegetation. The two mats were equally successful in removing nutrients and total suspended solids; however, the submerged vegetation grew very dense and required more pruning maintenance (Henny et al., 2019). Awareness of which plants are most suitable for the designated wetland is important in long term benefits of the floating treatment wetlands. The positive impacts of artificial wetlands include increased public awareness and education, a more balanced local ecosystem and microhabitat for small fishes and invertebrates in the water below the raft. In small spaces they can be installed vertically to the water surface (Olguín et al., 2017). To maximize positive ecological impacts, anchor the floating wetland to the lake bottom with more than a concrete block or boat anchor. Georgia fish attractor devices add below water habitat allowing space for fish to hide (Hense, 1996). To attract fish is to attract sports fishers which seek out exceptional areas for recreation use. Wetland utilization measurements such as land use coverage over time (Zorrilla-Miras et al., 2014), mathematical modeling ((Wong et al., 2017), and public recreation use (Venohr et al., 2018) are useful to infer impacts of floating constructed treatment wetlands.

Methods

Study Site

Lake Arlington is in North Central Texas on Village Creek off the Trinity River. The research site is Lake Arlington-Village Creek, located on the West Fork of the Trinity River, seven miles west of Tarrant County in Arlington, Texas. Construction of the dam began on May 15, 1956, and ended on July 19, 1957, surface area is 2,275 acres, volume is 40,188-acre feet and maximum depth is 51 feet. Lake Arlington is a source of drinking water, fishing, and recreation; and is owned and operated by the City of Arlington (Texas Parks and Wildlife, 2021).

Floating Wetland Raft Design and Construction

Design of the floating wetland rafts originated from literature searches on the UTA (University of Texas at Arlington) Libraries database using the main keywords: “floating wetland raft”, “floating artificial wetland”, “wetland mat”, and “treatment wetland”; and reviewing construction videos. The final design of the rafts was tailored to the Lake Arlington study site. The layers of the raft construction can be seen in Appendix 2. Each raft was an 8ft-by-8ft square with constructed with a PVC pipe frame, black mats, hardware netting and coconut fiber (Texas Community Watershed Partners, 2019). Native plant species Water Willow (*Justicia americana)* and Button Bush (*Cephalanthus occidentialis*) were chosen due to their hardiness level and affordability. Texas heat made *J. americana* a proper choice due to its resiliency against desiccation, even in full sun (Touchette et al., 2012). Known for its globe shaped flowers *C. accidentialis* is highly attractive to bees and other pollinators (Krochmal, 2018). Cost of materials was covered by Texas Parks and Wildlife Beautification funds; a cost breakdown of the rafts can be found in Appendix 1.

Placement of floating rafts was based on proximity to shoreline, water depth at day of deployment (minimum 12 ft depth) and distance between floating wetlands. Each floating raft was monitored monthly along with a control location (Control B) between August 2019-August 2020. However, due to equipment malfunctions at the testing laboratory and the COVID-19 pandemic, water sample collection and testing only occurred six times from August 2019-June 2020.

The water quality parameters included on site sample testing using a multiparameter water sonde to measure Temperature, pH, Specific Conductance, Dissolved Oxygen (mg/L), Chlorophyll α, Phycocyanin, and barometric pressure. Turbidity was measured using a 120cm Translucent Secci tube. Air temperature and Lake Depth data was collected from the City of Arlington boat navigation device. The Sonde device was borrowed from Trinity River Authority and calibrated before and after use. Lab tests were conducted at the Pierce-Burch lab for Bromide, Chloride, Fluoride, Nitrite, Nitrate, Orthophosphate, Sulfate using Ion Chromatography.

Control B

The historical water quality report for Lake Arlington Control B was accessed through Texas Commission of Environmental Quality using the Surface Water Quality Monitoring Information System

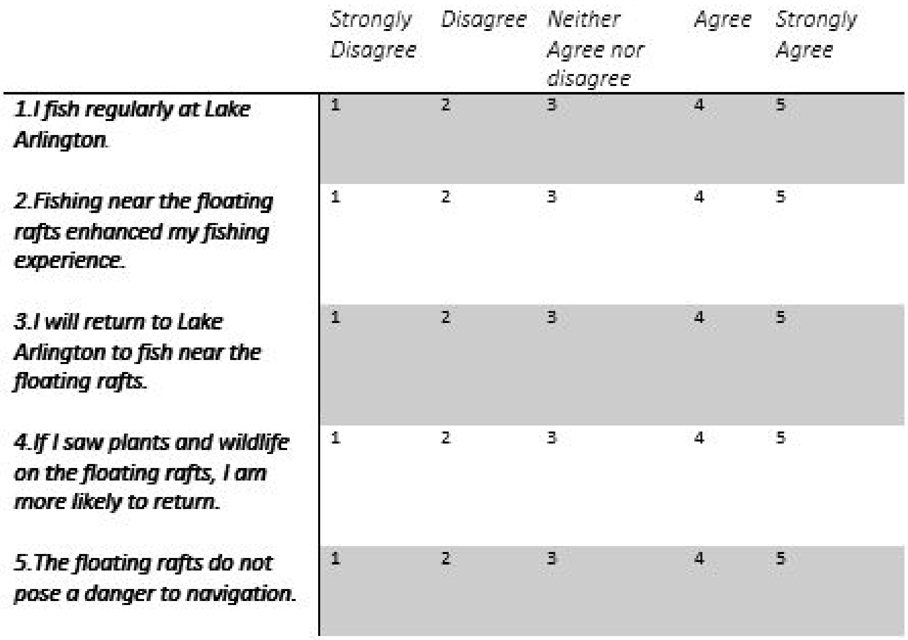
(SWQMIS) provided by the Trinity River Authority (Texas Commission on Environmental Quality). The role of Control B was to compare tested values at floating wetland sites to historical data. Control B water parameters tested are Chlorophyll α, Dissolved Oxygen, Temperature, Specific Conductivity, Turbidity, and pH. The Mann Kendall Seasonality Trend test was performed on each water parameter.

Fisher Surveys

A fisher is defined an individual that is using a boat while returning from Lake Arlington at the Richard Simpson Park access dock. The surveyor approaches a fisher with a prepared script and questionnaire. Participation in the survey is voluntary with no awards to participants and must meet the following requirements: 18 years of age or older and fished off on the floating rafts at the lake the same day as survey administration.

The researcher used Likert style surveys to quantify public perspectives on the floating wetland islands (Edmondson et al., 2012). The responses are rated 1-5 and then tested the hypothesis for a Chi Square test (Norman, 2010). The survey requests answers to one question and four statements. The first question asks the fisher “Not counting the current season, how many fishing licenses have you purchased in the past five years?”. Using this information, the individual is placed into one of four categories: Recruited, Retained, Re-activated or Lifetime or Multi-year (American Sportfishing Association, 2015). The four statements gauge individual’s agreeability, each statement requests a choice between: strongly disagree, disagree, neither agree nor disagree, agree, or strongly agree (See Figure 1).

1. I fish regularly at Lake Arlington; 2. Fishing near the floating rafts enhanced my fishing experience; 3. I will return to Lake Arlington to fish near the floating rafts; 4. If I saw plants and wildlife on the floating rafts, I am more likely to return; and 5. The floating rafts do not pose a danger to navigation.



	Strongly Disagree	Disagree	Neither Agree nor disagree	Agree	Strongly Agree
1.I fish regularly at Lake Arlington.	1	2	3	4	5
2.Fishing near the floating rafts enhanced my fishing experience.	1	2	3	4	5
3.I will return to Lake Arlington to fish near the floating rafts.	1	2	3	4	5
4.If I saw plants and wildlife on the floating rafts, I am more likely to return.	1	2	3	4	5
5.The floating rafts do not pose a danger to navigation.	1	2	3	4	5

Figure 1 Likert survey for fishers input on their use of floating wetlands at Lake Arlington

Statistics

Chi square test: Null Hypothesis states that an independent relationship exists between the category of fisher license renewal and agreeability towards the floating wetlands rafts.

Mann-Kendall Seasonal Trend test: Hypothesis states that temporal variation of water parameters is expected to change with each season. Data is Control B site historical data from 2001-2018. This test was generated through R Studio using the SeasonalMannKendall(x) command.

Results

Very few fisher surveys were completed and therefore data could not be used for any statistical or inferential analyses. This portion is discarded. Water quality collected at floating wetland sites was too few for the chi-square tests. This portion is discarded.

Control B water quality data tested six parameters total. Three test parameters – Specific Conductance, Turbidity and pH reject the null hypothesis as there is a statistically significant seasonal trend present in the dataset (see Table 2). The remaining three test parameters - Chlorophyll α, Dissolved Oxygen and Temperature fail to reject the null hypothesis.

Table 1 Correlation coefficient (τ) and associated p-values for test parameters at Control site B for six water quality variables.

Mann-Kendall Seasonality trend tests on Control B at Lake Arlington		
Test Parameter	Reject Null Hypothesis	Significance
Chlorophyll α	does not reject the null hypothesis	τ = 0.12 p-value = 0.06
Dissolved Oxygen	does not reject the null hypothesis	τ = -0.0982 p-value = 0.13
Temperature	does not reject the null hypothesis	τ = 0.0546 p-value =0.40
Specific Conductivity	Rejects the null hypothesis Upwards Trend	τ = 0.719 p-value = <0.001
Turbidity	Rejects the null hypothesis Downwards Trend	τ = -0.34 p-value = <0.001
pH	Rejects the null hypothesis Downwards Trend	τ = -0.19 p-value = 0.002

Descriptive statistics for Chlorophyll-α

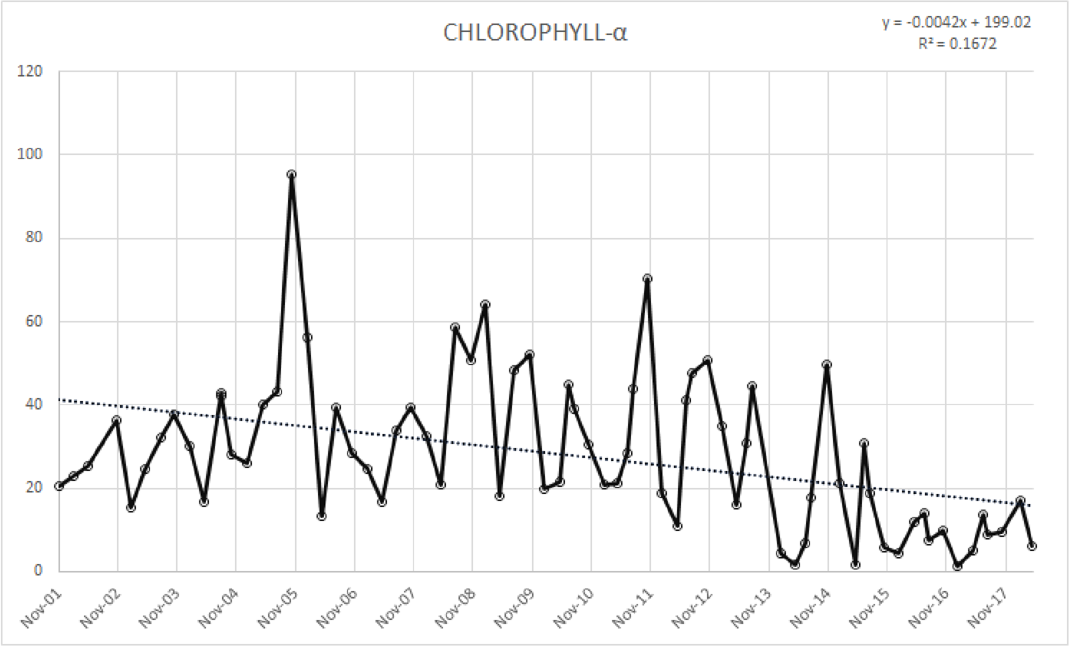


Figure 2 Time series of chlorophyll a at Control B site on Lake Arlington

Table 2 Chlorophyll a descriptive statistic

Chlorophyll-α	
Mean	28.15
Standard Error	2.11
Median	25.025
Mode	16.7
Standard Deviation	18.11
Sample Variance	328.05
Kurtosis	1.39
Skewness	0.91
Range	94.1
Minimum	1.3
Maximum	95.4
Sum	2082.74
Count	74

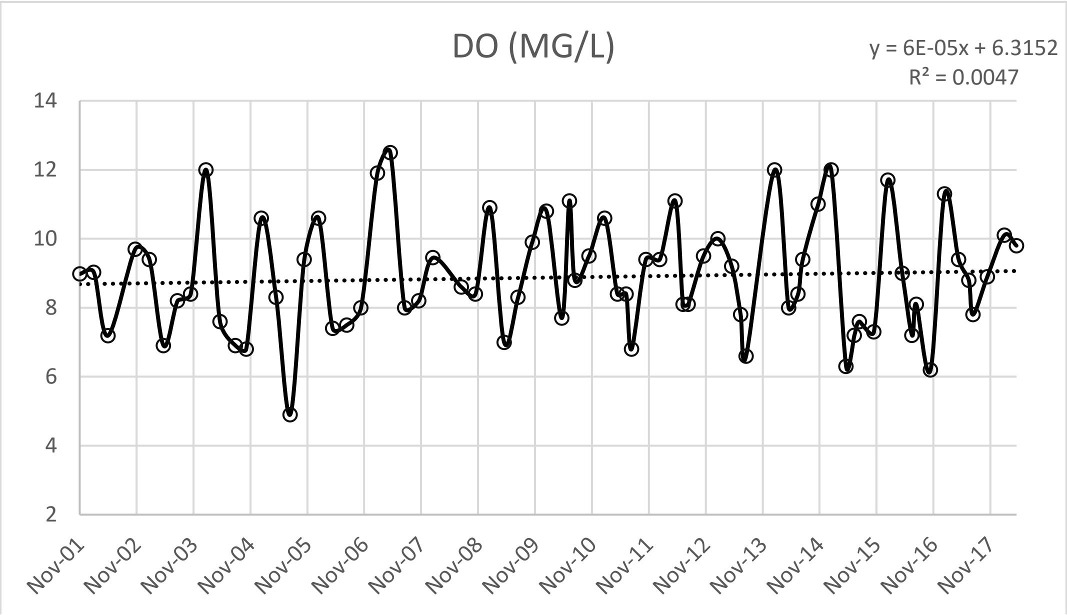


Figure 3 Time series of dissolved oxygen concentrations at Control B site on Lake Arlington

Table 3 Dissolved oxygen descriptive statistics

Dissolved Oxygen 2001-2018	
Mean	*8.885416667*
Standard Error	*0.191967302*
Median	*8.7*
Mode	*9.4*
Standard Deviation	*1.628896574*
Sample Variance	*2.653304049*
Kurtosis	*-0.356932897*
Skewness	*0.267329956*
Range	*7.6*
Minimum	*4.9*
Maximum	*12.5*
Sum	*639.75*
Count	*72*

Descriptive statistics for temperature.

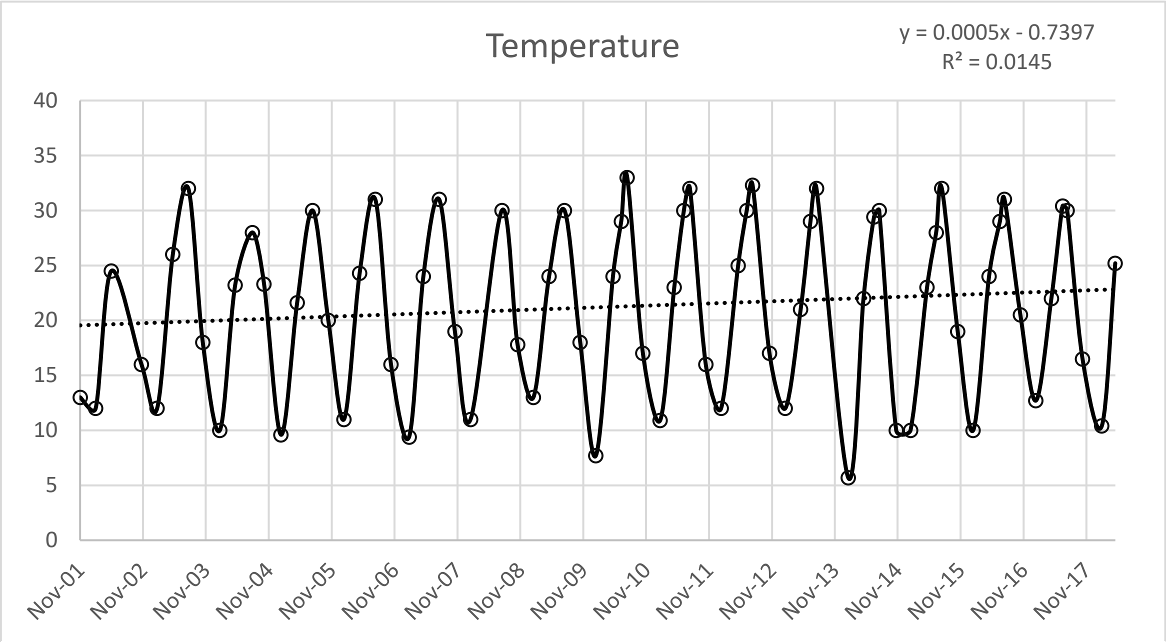


Figure 4 Time series of temperature of Control B site on Lake Arlington

Table 4
Temperature descriptive statistics

Temperature 2001-2018	
Mean	21.28
Standard Error	0.93
Median	22.5
Mode	30
Standard Deviation	7.93
Sample Variance	62.87
Kurtosis	-1.29
Skewness	-0.20
Range	27.3
Minimum	5.7
Maximum	33
Sum	1532.4
Count	72

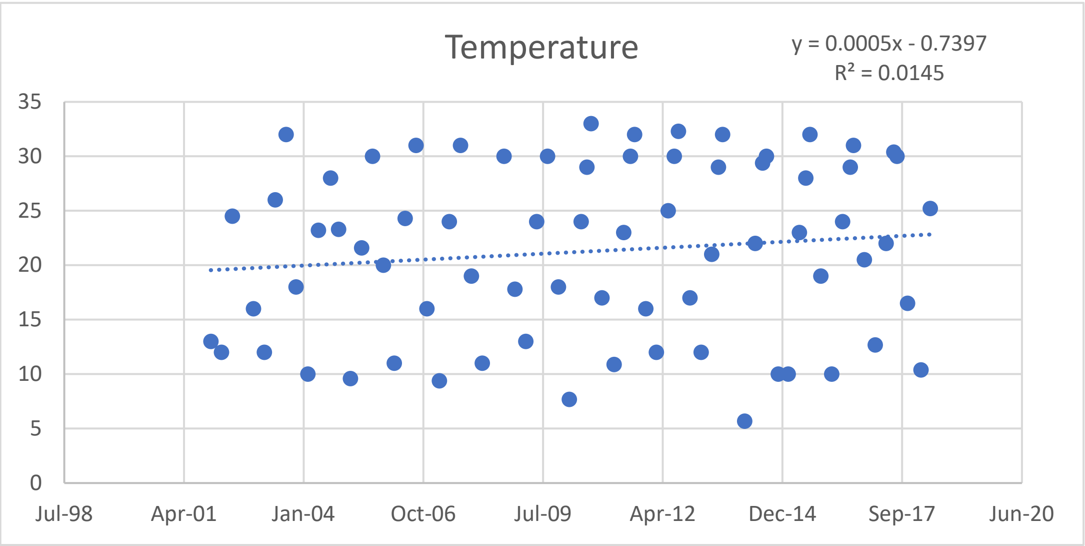


Figure 5 Scatterplot of temperature at Control B site at Lake Arlington

Descriptive statistics for specific conductivity.

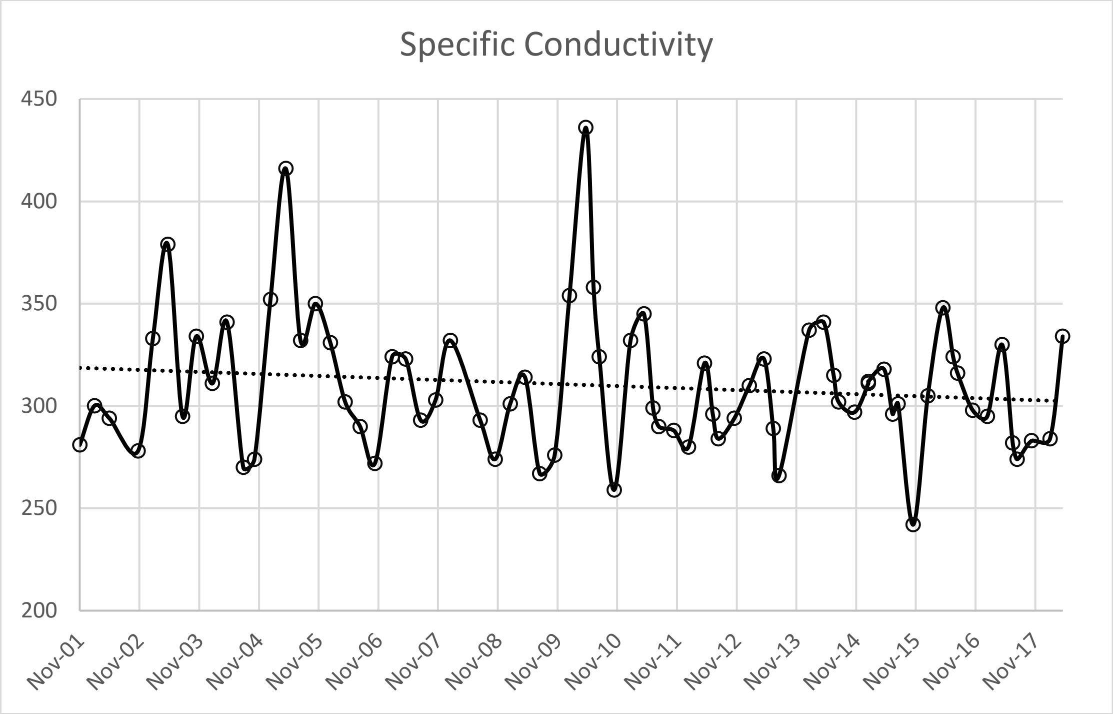


Figure 6 Time series of specific conductivity at Control B site at Lake Arlington

Table 5 Specific conductivity descriptive statistics

Specific Conductivity 2001-2018	
Mean	310.00
Standard Error	3.96
Median	302
Mode	274
Standard Deviation	33.38
Sample Variance	1114.20
Kurtosis	2.83
Skewness	1.18
Range	194
Minimum	242
Maximum	436
Sum	22010.1
Count	71

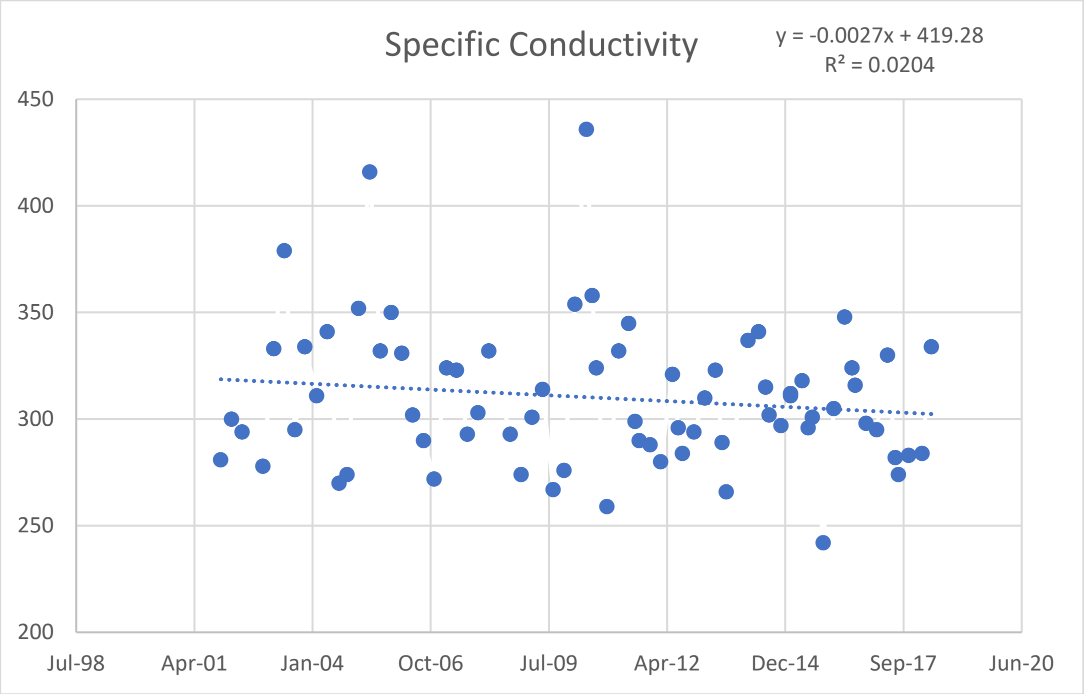


Figure 7 Scatterplot of specific conductivity at Control B site at Lake Arlington

Descriptive statistics for turbidity.

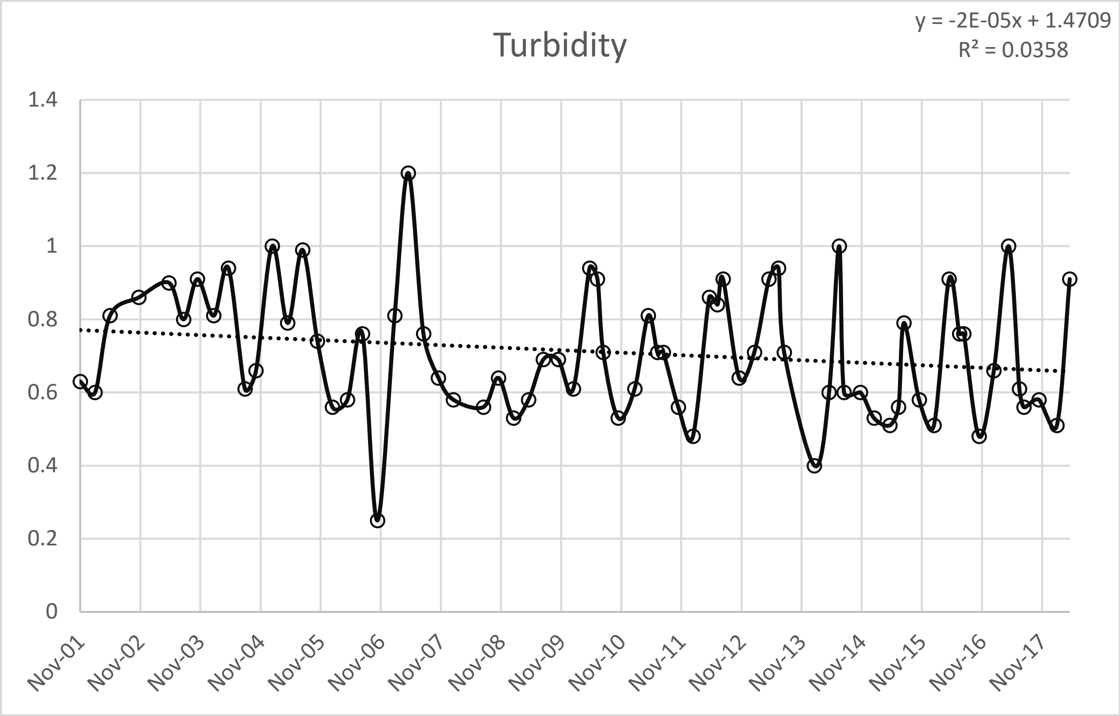


Figure 8 Time series of turbidity at Control B site at Lake Arlington

Table 6 Turbidity descriptive statistics

Turbidity 2001-2018	
Mean	0.71
Standard Error	0.02
Median	0.69
Mode	0.91
Standard Deviation	0.17
Sample Variance	0.03
Kurtosis	0.01
Skewness	0.25
Range	0.95
Minimum	0.25
Maximum	1.2
Sum	50.4
Count	71

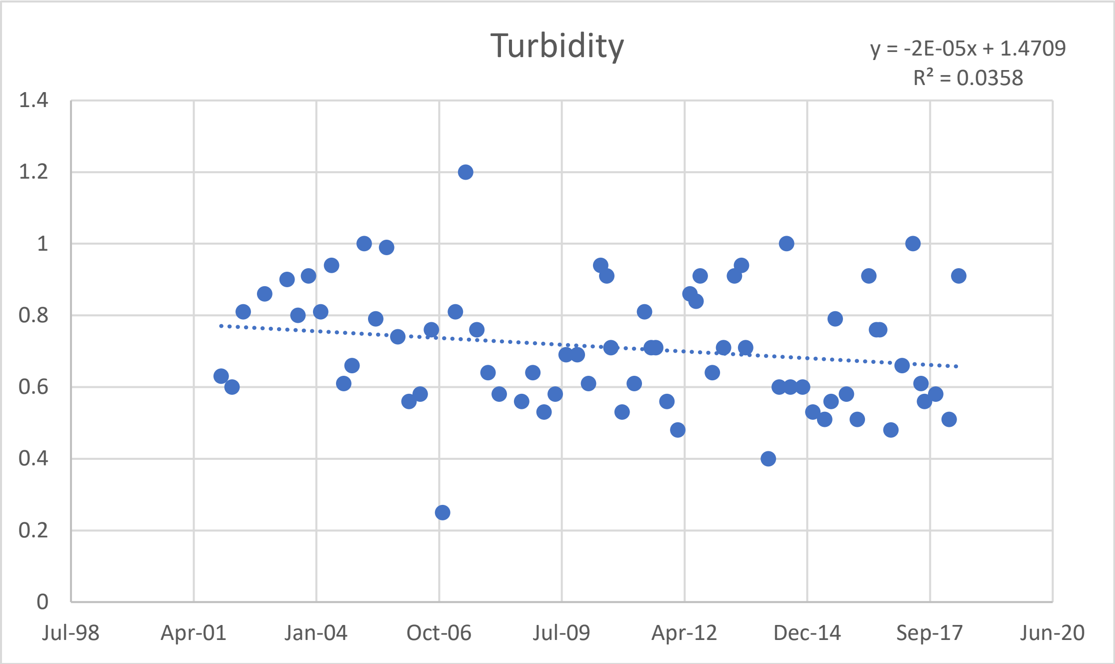


Figure 9 Scatterplot of turbidity at Control B site at Lake Arlington

Descriptive statistics for pH.

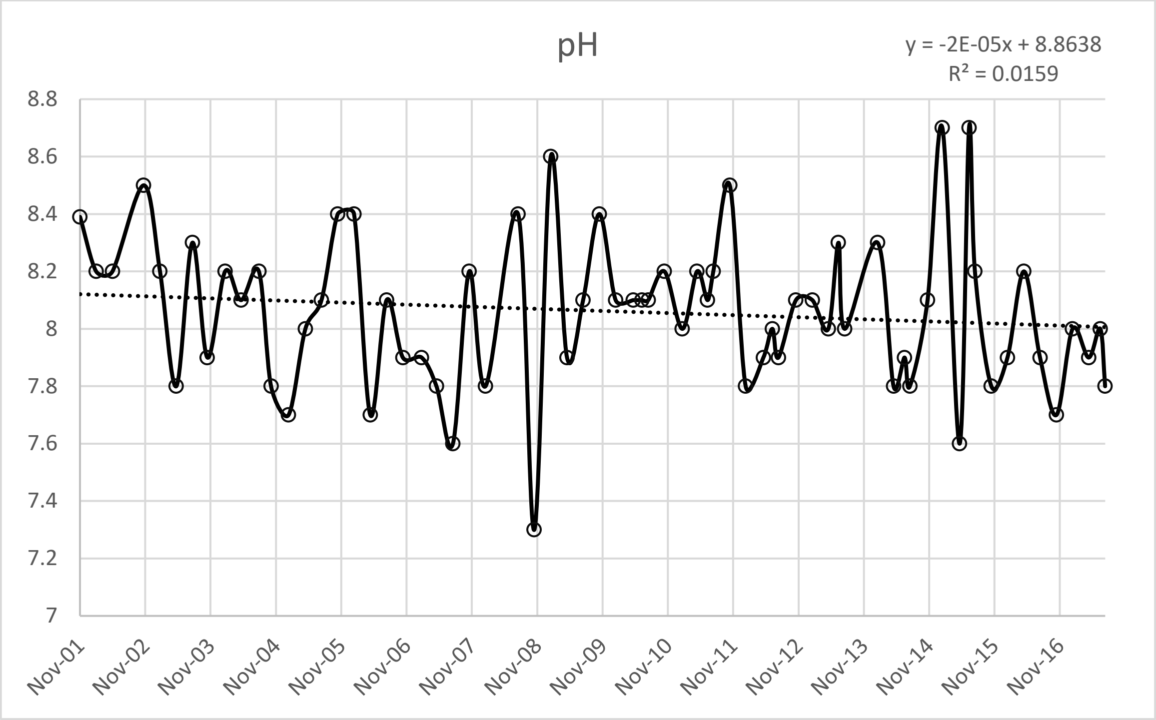


Figure 10 Time series of pH at Control B site at Lake Arlington

Table 7 pH descriptive statistics

pH 2001-2017	
Mean	8.06
Standard Error	0.03
Median	8.1
Mode	8.1
Standard Deviation	0.27
Sample Variance	0.07
Kurtosis	0.41
Skewness	0.11
Range	1.4
Minimum	7.3
Maximum	8.7
Sum	548.09
Count	68

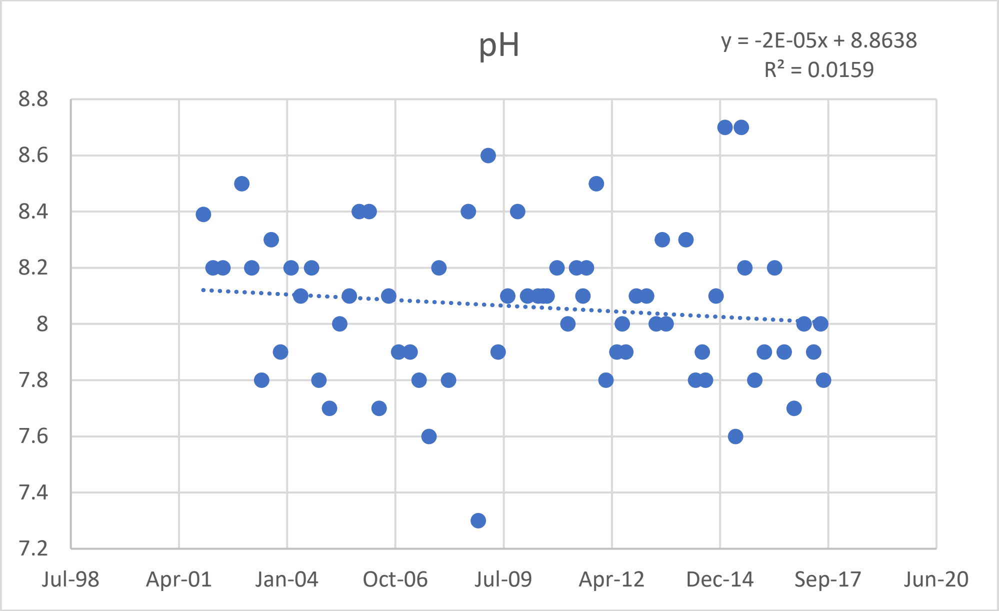


Figure 11 Scatterplot of pH at Control B site at Lake Arlington

Discussion

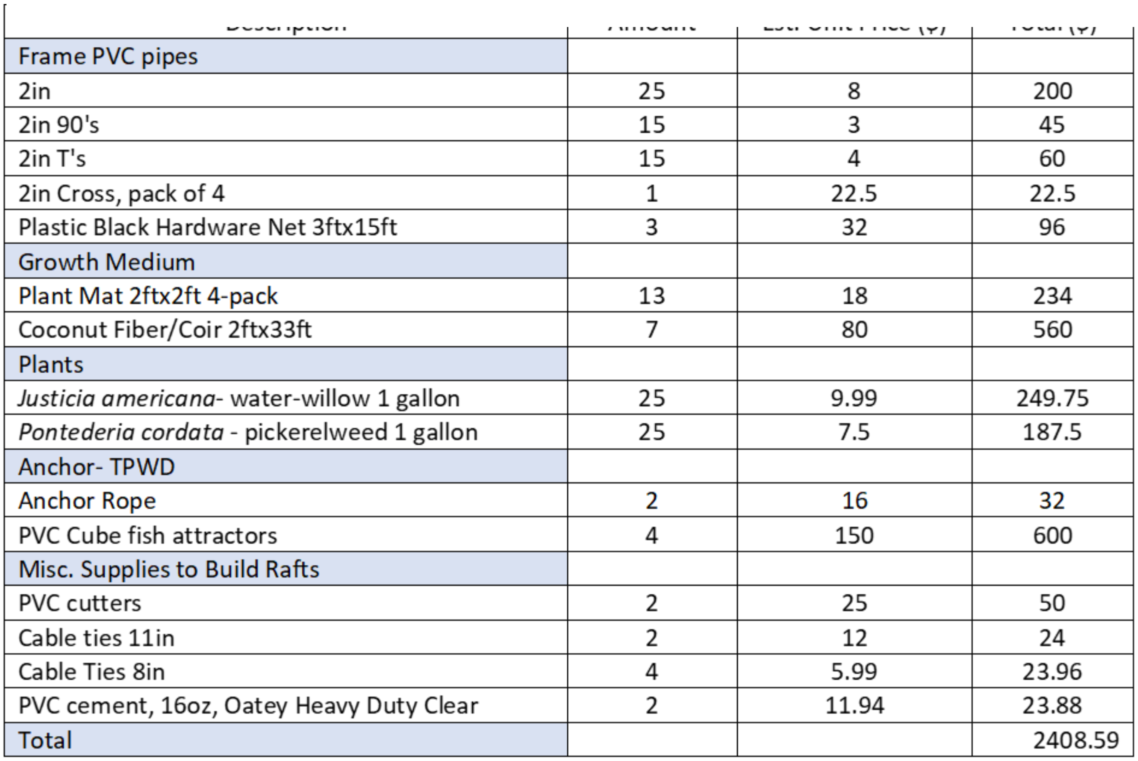
Floating wetland data and fishers survey data are inconclusive, the data collected do not provide insight to the research question. Laboratory equipment and pandemic issues led to this portion of the data set to be dismissed.

Traditionally, floating wetland construction is designed around the water body. In many designs, water is forcibly channeled through the wetland rafts at a passive speed (Eslamian et al., 2020). The construction of the Lake Arlington experimental rafts did not follow the traditional design due to the shape of the waterbody. Instead, the design allows water to move around the wetland raft passively and not actively channeled through. In the future, installing the wetland rafts near stormwater drain outlets or narrow tributaries may lead to improved root uptake of excess nutrients. Any area which allows water to flow slowly through the raft should improve nutrient uptake and allow for suspended solids to settle in the roots.

Consider wave activity of the water body and the establishment of plants root systems prior to placement, the motion of the lake tore apart the Lake Arlington rafts in a few months. Unless you have easy access to maintaining and caring for the raft plants, spend one season growing the plants to proper root size before planting into a treatment wetland (Navarro-Frómeta & Bayona, 2018). It is important to review native wetland plants in the area you wish to treat, this will protect against invasive or competitive plants. Time permitting, consider an experiment with prospective plants to determine which species is most hardy and efficient for nutrient removal (Liu et al., 2016)(Ge et al., 2016). Specific Conductivity displayed a strong monotonic upward trend ($\tau = 0.719$) indicating an increase in total dissolved inorganic solids seasonally (Evans et al., 2014). A look at Figure 6 will show that increases in conductivity occurs in the warmer months when fertilizer application to lawns and croplands are prevalent. Turbidity displayed a strong monotonic downwards trend ($\tau = -0.34$) indicating a significant decline in turbidity due to seasonality (Hestir et al., 2016). Turbidity is a measure of particulate matter in the water column such as silt, algae, plankton, and other microscopic organisms. A decline of turbidity over time due to seasonality indicates that over time there is an overall decline in turbidity, this could be an indicator that potential pollutants are decreasing (United States Geological Survey, 2001).

Appendix 1:

Table 8 Material costs for floating wetlands



Frame PVC pipes			
2in	25	8	200
2in 90's	15	3	45
2in T's	15	4	60
2in Cross, pack of 4	1	22.5	22.5
Plastic Black Hardware Net 3ftx15ft	3	32	96
Growth Medium			
Plant Mat 2ftx2ft 4-pack	13	18	234
Coconut Fiber/Coir 2ftx33ft	7	80	560
Plants			
Justicia americana- water-willow 1 gallon	25	9.99	249.75
Pontederia cordata - pickerelweed 1 gallon	25	7.5	187.5
Anchor- TPWD			
Anchor Rope	2	16	32
PVC Cube fish attractors	4	150	600
Misc. Supplies to Build Rafts			
PVC cutters	2	25	50
Cable ties 11in	2	12	24
Cable Ties 8in	4	5.99	23.96
PVC cement, 16oz, Oatey Heavy Duty Clear	2	11.94	23.88
Total			2408.59

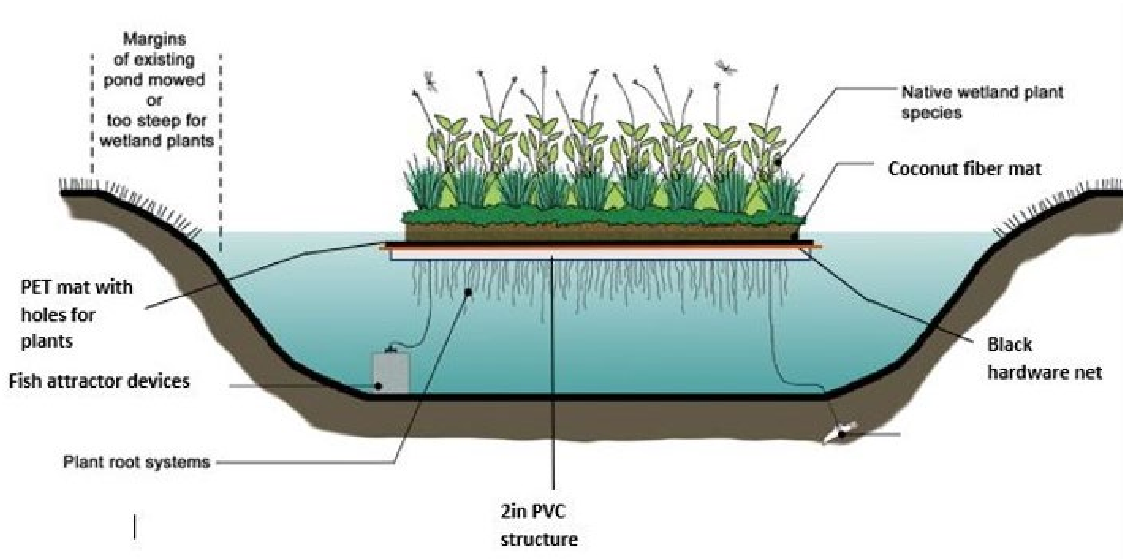


Figure 12 Illustration of the multiple layers and components used to build floating wetlands

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Chapter 2

The Impact of Land Use Changes on Two Drinking Water Reservoirs

The human species evolved within the confines of natural resources availability and as a social and intelligent species became the ultimate ecosystem engineers (Bruce D. Smith, 2007). As humans spread through the continents, lands were modified in search of food, fiber, shelter, and water (Boivin et al., 2016). Today, the ecological impact of human societies is impossible to ignore. Published evidence for land change suggests the average global loss of wetlands is 53.5% with the rate of loss nearly two times faster for inland wetlands than coastal (Davidson, 2014). For example, in the Doñana marshland, one of the largest European wetlands, 70.5% of the land cover has been converted to agriculture since 1918 (Zorrilla-Miras et al., 2014). While restoration is an important task, a study of ecosystem services in the Danube Delta revealed that 50 years of land modification will require significant restoration. Even after 20 years of restoration benefits, two thirds of the ecosystem services remain depleted. To restore productivity to pre-1960 levels, improvements will take much longer than the decades of harvesting and development (Gómez-Baggethun et al. 2019).

Ancient plant remains found at multiple Levant excavation sites suggest that plant and animal domestication began approximately 11,500 - 11,000 years ago (Zeder, 2011) with the settlement of human groups in the Fertile Crescent. The warmer temperatures at the beginning of the New Stone Age known as the Holocene epoch led to an increase of food resources. As the ice melted away the human hunter-gatherer groups began to cultivate the land which led to the major change from nomadism to sedentism (Zeder, 2011)(Chen et al., 2007). Evidence suggests that agriculture began in human groups to supplement the hunter-gatherer lifestyle which allowed humans to settle in an area without running out of resources (Zhang et al., 2018) (Ma et al., 2016). However, phytolith evidence found in the Azraq Basin suggests that human groups settled in the Fertile Crescent dating back 23,000 years, 10,000 years earlier than agriculture practices (Zeder, 2011). Contents of the dig site led to the discovery that sedentary humans settled in the area due to the abundant natural resources of the wetlands and not due to agriculture (Ramsey et al., 2016).

Review of global land change over 35 years (1982-2016) as measured by satellite sensors included three categories of cover: tree canopy (TC), short vegetation (SV), and bare ground (BG) (Song et al. 2018). Data was catalogued using satellite sensors, radiometers, and other various sensors to collect and measure optical observations. Land change percentages were calculated for each category from 1982 – 2016. Bare ground coverage indicated a 3% decrease and short vegetation coverage indicated a 1.4% decrease, however, total area of tree cover increased by 7% since 1982. The large increase in tree canopy cover is unevenly distributed across biomes, tree canopy land percentage increased in subtropical, temperature and boreal climates. Tropical biomes underwent an 8% net loss of tree canopy coverage (Song et al. 2018). The decrease in tree canopy coverage and increase in short vegetation in tropical biomes points toward deforestation for agricultural expansion. In the United States, large areas of grassland and forests were converted to agriculture between 1700 – 1950. Expansion occurred at different rates with significant change occurring in the Northeast and Southwest. Westward movement carried agricultural development and the land cover changes which affected the Midwest and Northern and Southern Great Plains the greatest (Lu et al., 2018). While the increase in human niche construction has left few areas untouched official laws and policies are widespread to manage natural resources.

Texas highly regards private property rights for landowners; while surface water is owned by the state and requires a permit for private use, ground water legislation states that percolating groundwater accessible on private property is available for pump and capture for personal use. Diffuse surface water such as rainfall can be captured and retained for private use, even if this impacts groundwater availability and aquifer recharge (Templer 2019). This has led to groundwater on private property being sold off to other areas of the state for urban use (Ronald C. Griffin, 2011). Unfortunately, availability is not the only issue affecting Texas water sources. A 1999 study found an aquifer in north Texas was susceptible to nitrate contamination levels which exceeded the drinking water limit. The three nearby counties use the land predominantly for cropland and rangeland. In multiple nearby wells, nitrate concentrations decreased as well depth increased; leading to the conclusion that fertilizer the likely source of contamination (Hudak & Blanchard, 1997). Unfortunately tracing the pollution to the source continues to be a challenge, technology used to detect and control non-point source water pollution is lagging behind point source pollution.

Mathematical modeling of water resources is an integral part of understanding the impact of human landscape modification. The technique has been in use for nearly 100 years (Overton 1976), and in use by the EPA for over 40 years (1983). Computer models range from simple to complex with focus on water quality and watershed usage to gain information on pollution sources and/or water scarcity (Liu et al. 2017). The ability to test various conditions and pressures can allow scientists to better predict the outcomes of a set of variables. Various land uses impact water quality in diverse ways, and a mixture of modeling and observed data provides insight to a modeling process that benefits from tangible data.

The European Union (EU) Water Framework Directive (WFD) integrated impact modelling framework (IIMF) measured the impact of soil management, fertilization intensity and crop choice on climate and socio-economic pressures. Utilizing this model on a regional scale provides direct insight for policy makers and stakeholders to best use land without direct or indirect negative impacts. It was discovered that croplands are areas most likely to exceed EU WFD limitations (Zessner et al. 2017). In New Zealand, the CLUES (Catchment Land Use and Environmental Sustainability) models are user friendly enough to run on a typical ArcGIS program. The CLUES model uses different scenarios to forecast annual mean values of Total Nitrogen, Total Phosphorous, *E. coli*, sediments, and nutrient concentration on small areas (Elliott et al. 2016). Using the model in government settings could provide information on projected water quality and drought restrictions in a user accessible software.

Acidification of aquatic ecosystems is due to the deposition of reactive Nitrogen. Freshwaters are affected due to their weak acid neutralizing ability leading to the death of sensitive aquatic invertebrates and fish and amphibian fry species. (Erisman et al., 2013). Eutrophication events caused by agriculture nutrient and pesticide run-off, sewage discharge and erosion of nutrient laden soil provide excess nutrients for cyanobacteria and algal blooms (Erisman et al., 2013). Algal blooms are detrimental to drinking water sources and recreational spaces (Mitsch & Gosselink, 2015b). Chlorophyll α is the standard indicator for algae and is routinely measured.

Methods

Lake Arlington and Joe Pool Lake are urban lakes located in North Central Texas, U.S.A. Each lake was reviewed and measured for water quality drinking water parameters, Coliform, Nitrate, and Chlorophyll α from years 2000-2019 at 44 total sites. Data was accessed through Trinity River Authority (Surface Water Quality Data) and North Central Texas Council of Governments Data Center (Land Use Census data).

Water Quality Data

Historical water quality reports of Joe Pool Lake and Lake Arlington were accessed through Texas Commission of Environmental Quality using the Surface Water Quality Monitoring Information System (SWQMIS) provided by the Trinity River Authority (Texas Commission on Environmental Quality,). Water quality data was provided from 2000-2020. Joe Pool has 27 testing stations, Lake Arlington has 17 testing stations total. According to the date and time columns on the report, site stations were tested routinely for weeks, months and/or years.

The water parameters dataset included Alkalinity, Arsenic, Barium, Bicarbonate, Biological Oxygen Demand, Boron, Bromide, Cadmium, Calcium, Carbon, Carbonate, Chloride, Chlorophyll α, Depth, Dissolve Oxygen, *Escherichia coli*, Fecal Coliform, Flow Stream, Fluoride, Total Hardness, Iron, Magnesium, Manganese, Nickel, Nitrate, Nitrite, Ammonia, Total Nitrogen, Orthophosphate, pH, Phosphorous, Phytoplankton Density, Potassium, Residue, Sodium, Specific Conductance, Sulfate, Temperature, Transparency and Zinc.

Nitrate, Coliform, and Chlorophyll α are the parameters used in this study. Test parameters are represented by:

- Nitrate: Nitrate Nitrogen, Dissolved and Nitrate, Nitrogen, Total (mg/L as N)
- Coliform: *e. coli*, Colilert Indexx Method (MPN / 100 mL)
- Chlorophyll α: Spectrometric acid. Meth. (µg/L)

Other nitrogen tests such as ammonia and nitrite were not considered in this study. Sediment based Coliform tests were also not considered due to the irregularity of the samples. Additionally, some water monitoring sites only included data before year 2000 and/or after 2019 and thusly were discarded.

Cleaning Water Quality Data

Water Quality data was organized by station identifier and date. Many of the parameters were measured in quick succession at a single testing event as evident by the time stamp. These values were averaged together to have a single value per test date. Parameters took place between years 2000-2019. The date, time and water parameters measured vary from site to site. Lastly, water quality values were organized into five-year increments: 2000-2004, 2005-2009, 2010-20014, and 2015-2019.

Table 9 Counties and years of land use data collected

Dallas	2000
	2005
	2010
	2015
Ennis	2000
	2005
	2010
	2015
Johnson	2000
	2005
	2010
	2015
Tarrant	2000
	2005
	2010
	2015

Land Use Data

Land use data was downloaded from North Central Texas Council of Governments (NCTCOG) Regional Data Center Site (Research and Information Services (RIS) department,) and viewed in ArcGIS software. The entirety of the data is in four feature layers of land use 2000, 2005, 2010 and 2015 for 16 counties in North Texas. Four counties were of interest - Dallas, Ellis, Johnson, and Tarrant counties due to their proximity to Lake Arlington (Tarrant and Johnson counties) and/or Joe Pool Lake (Dallas, Ellis, and Tarrant counties). Therefore, the data for the four counties was exported into MS Excel for further data cleaning and organizing by data year and county (Table 9).

Table 10 Land use subcategories

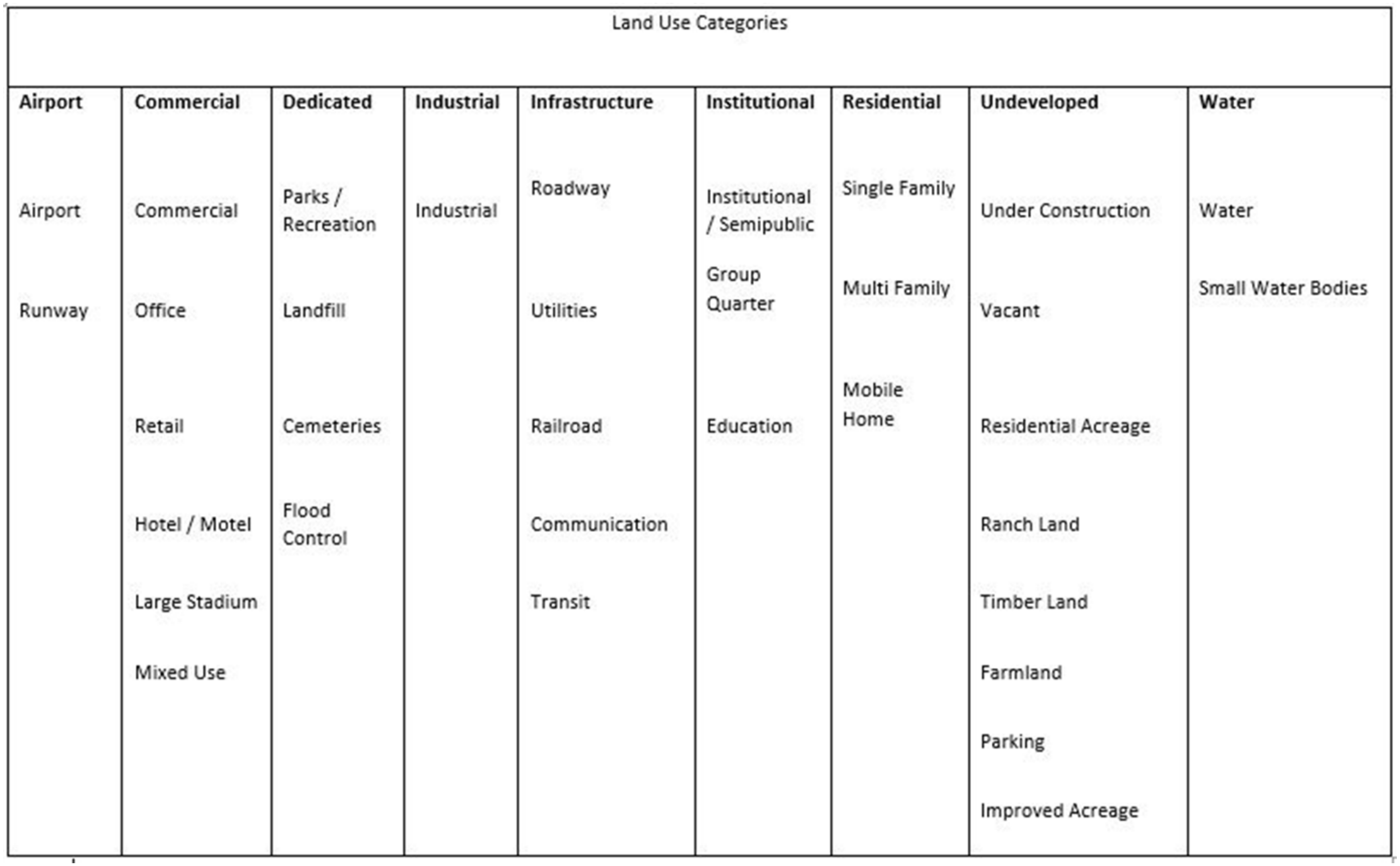
Land Use Subcategories
Commercial
Office
Retail
Hotel / Motel
Large Stadium
Mixed Use
Parks / Recreation
Landfill
Cemeteries
Flood Control
Roadway
Utilities
Railroad
Communication
Transit
Institutional / Semipublic
Group Quarter
Education
Single Family
Multi Family
Mobile Home
Under Construction
Vacant
Residential Acreage
Ranch Land
Timber Land
Farmland
Parking
Improved Acreage

Each county was divided into a spreadsheet, leading to a total of 16 spreadsheets – Four counties with four separate years each as shown in Table 9. Spreadsheets were then changed into CSV files and imported into ArcGIS and formatted into a shapefile. Land use data was organized into one of 34 categories (Table 10). Data was further organized into one of nine larger categories: Airport, Commercial, Dedicated, Industrial, Institutional, Infrastructure, Residential, Undeveloped or Water (Table 11).

Cleaning Land Use Data

Each data collection site is associated with a five-digit identifier (Table 12). Data collection for the three water parameters measured took place between years 2000-2019. The date, time and water parameters measured vary from site to site. To highlight potential correlations between either water bodies: Joe Pool Lake and Lake Arlington, county land use data was summarized in five-year increments: 2000-2004, 2005-2009, 2010-2014, and 2015-2019 (Table 13). This means that each waterbody included only the counties which drain into the associated Lake. Joe Pool Categories included land mileage from Ellis, Dallas, and Tarrant counties. Lake Arlington categories included land mileage from Tarrant and Johnson counties. An example of the pre-analysis correlation chart is shown in Table 12, this is for the total coliform test performed on Joe Pool Lake. All six correlation matrices were organized in the same way for analysis.

Table 11 Land use categories as defined by the North Central Texas Council of Governments



Land Use Categories								
Airport	**Commercial**	**Dedicated**	**Industrial**	**Infrastructure**	**Institutional**	**Residential**	**Undeveloped**	**Water**
Airport	Commercial	Parks / Recreation	Industrial	Roadway	Institutional / Semipublic	Single Family	Under Construction	Water
Runway	Office	Landfill		Utilities	Group Quarter	Multi Family	Vacant	Small Water Bodies
	Retail	Cemeteries		Railroad	Education	Mobile Home	Residential Acreage	
	Hotel / Motel	Flood Control		Communication			Ranch Land	
	Large Stadium			Transit			Timber Land	
	Mixed Use						Farmland	
							Parking	
							Improved Acreage	

Table 12 Correlation matrix table prior to analysis. The table contains the average of total coliform at each site and year in column 1. Columns 3-11 contain the sum of mileage area per category for the years 2000, 2005, 2010 and 2015

Site Identifier – Year of data collection	**Average Total Coliform Value Per Site and Year**	Total area (mi^2) of land use for each category								
Site-Year	**Coliform**	**Airport**	**Commercial**	**Dedicated**	**Industrial**	**Infrastructure**	**Institutional**	**Residential**	**Undeveloped**	**Water**
10780-00	110	19	29.7	45.8	38.6	3.7	24	253	1023	48
10781-00	357	19	29.7	45.8	38.6	3.7	24	253	1023	48
10785-00	150	19	29.7	45.8	38.6	3.7	24	253	1023	48
10786-00	152	19	29.7	45.8	38.6	3.7	24	253	1023	48
10786-05	539	11.7	33.8	53.7	37.4	11.3	30	336	925	50
10793-05	231	11.7	33.8	53.7	37.4	11.3	30	336	925	50
10798-05	274	11.7	33.8	53.7	37.4	11.3	30	336	925	50
10805-05	506	11.7	33.8	53.7	37.4	11.3	30	336	925	50
10809-05	130	11.7	33.8	53.7	37.4	11.3	30	336	925	50
11042-05	11	11.7	33.8	53.7	37.4	11.3	30	336	925	50
11042-10	389	14.4	66.5	45.8	31.5	19.7	36	332	291	43
13671-10	1346	14.4	66.5	45.8	31.5	19.7	36	332	291	43
13897-10	341	14.4	66.5	45.8	31.5	19.7	36	332	291	43
11040-15	0.45	15.1	68.1	85.2	37.3	16.4	36	349	414	46
11042-15	0.98	15.1	68.1	85.2	37.3	16.4	36	349	414	46
11043-15	0.07	15.1	68.1	85.2	37.3	16.4	36	349	414	46
13897-15	2722	15.1	68.1	85.2	37.3	16.4	36	349	414	46
13899-15	1887	15.1	68.1	85.2	37.3	16.4	36	349	414	46
13904-15	11802	15.1	68.1	85.2	37.3	16.4	36	349	414	46
21759-15	94	15.1	68.1	85.2	37.3	16.4	36	349	414	46
21762-15	82	15.1	68.1	85.2	37.3	16.4	36	349	414	46
21763-15	174	15.1	68.1	85.2	37.3	16.4	36	349	414	46
22008-15	275	15.1	68.1	85.2	37.3	16.4	36	349	414	46

Table 13 Square mileage area per county - year and land use categories. Each cell contains the total amount of square mileage per category.

County and Census Year	Residential	Commercial	Industrial	Infrastructure	Institutional	Water	Airport	Dedicated	Undeveloped
Dallas 2000	243	50	45	3	28	45	11	37	321
Dallas 2005	243	42	47	12	36	41	11	56	268
Dallas 2010	251	85	24	17	31	33	12	115	117
Dallas 2015	247	74	32	17	34	33	12	109	132
Tarrant 2000	214	27	35	3	23	43	0.5	44	380
Tarrant 2005	230	31	33	10	27	41	0.6	47	347
Tarrant 2010	258	57	23	18	28	39	0.8	72	163
Tarrant 2015	266	61	16	16	30	42	0.8	77	256
Ennis 2000	73	7	7	< 0.1	3	10	0.5	1	1642
Ennis 2005	57	4	6	1	4	17	0.4	4	825
Ennis 2010	80	16	13	3	5	11	0.5	7	369
Ennis 2015	80	8	13	3	5	11	1	11	146
Johnson 2000	39	3	4	1	1	5	0.5	2	643
Johnson 2005	106	3	5	0.3	3	9	0.6	7	578
Johnson 2010	74	9	8	2	8	5	0.8	6	158
Johnson 2015	83	7	12	2	6	5	1	8	128

Statistics

Six correlation matrices were generated, three for Lake Arlington and three for Joe Pool Lake in R studio ver4.1.0 with rcorr test using package "Hmisc". Correlation charts and p values were generated.

Results

Descriptive statistics for Lake Arlington Land Use (Table 14- Table 22)

Table 14 Lake Arlington commercial land descriptive statistics

Lake Arlington Commercial Land	
Mean	0.01
Standard Error	0
Median	0
Mode	0
Standard Deviation	0.01
Sample Variance	0
Kurtosis	304.98
Skewness	13.24
Range	0.46
Minimum	0
Maximum	0.46
Sum	157.90
Count	30233

Table 15 Lake Arlington infrastructure land descriptive statistics

Lake Arlington Infrastructure Land	
Mean	*0.009*
Standard Error	*0*
Median	*0.002*
Mode	*#N/A*
Standard Deviation	*0.03*
Sample Variance	*0*
Kurtosis	*115.20*
Skewness	*9.33*
Range	*0.46*
Minimum	*0*
Maximum	*0.46*
Sum	*50.82*
Count	*5668*

Table 16 Lake Arlington institutional land descriptive statistics

Lake Arlington Institutional Land	
Mean	0.01
Standard Error	0
Median	0
Mode	#N/A
Standard Deviation	0.03
Sample Variance	0
Kurtosis	373.78
Skewness	14.50
Range	1.06
Minimum	0
Maximum	1.06
Sum	125.98
Count	11648

Table 17 Lake Arlington water land descriptive statistic

Lake Arlington Water Land	
Mean	0.01
Standard Error	0
Median	0
Mode	#N/A
Standard Deviation	0.24
Sample Variance	0.06
Kurtosis	1848.64
Skewness	39.07
Range	13.27
Minimum	0
Maximum	13.27
Sum	187.15
Count	16334

Table 18 Lake Arlington industrial land descriptive statistics

Lake Arlington Industrial Land	
Mean	*0.02*
Standard Error	*0*
Median	*0*
Mode	*0*
Standard Deviation	*0.07*
Sample Variance	*0*
Kurtosis	*2171.571*
Skewness	*40.70*
Range	*3.92*
Minimum	*0*
Maximum	*3.92*
Sum	*136.06*
Count	*8768*

Table 19 Lake Arlington dedicated land descriptive statistics

Lake Arlington Dedicated Land	
Mean	0.036
Standard Error	0.002
Median	0.004
Mode	0
Standard Deviation	0.139
Sample Variance	0.019
Kurtosis	235.162
Skewness	12.827
Range	3.580
Minimum	0
Maximum	3.580
Sum	262.764
Count	7282

Table 20 Lake Arlington airport land descriptive statistics

Lake Arlington Airport Land	
Mean	0.07
Standard Error	0.01
Median	0
Mode	#N/A
Standard Deviation	0.21
Sample Variance	0.05
Kurtosis	39.80
Skewness	5.59
Range	2.45
Minimum	0
Maximum	2.45
Sum	60.30
Count	897

Table 21 Lake Arlington undeveloped land descriptive statistics

Lake Arlington Undeveloped Land	
Mean	0.03
Standard Error	0
Median	0
Mode	0
Standard Deviation	0.26
Sample Variance	0.07
Kurtosis	3757.44
Skewness	46.65
Range	28.68
Minimum	0
Maximum	28.68
Sum	2652.56
Count	101818

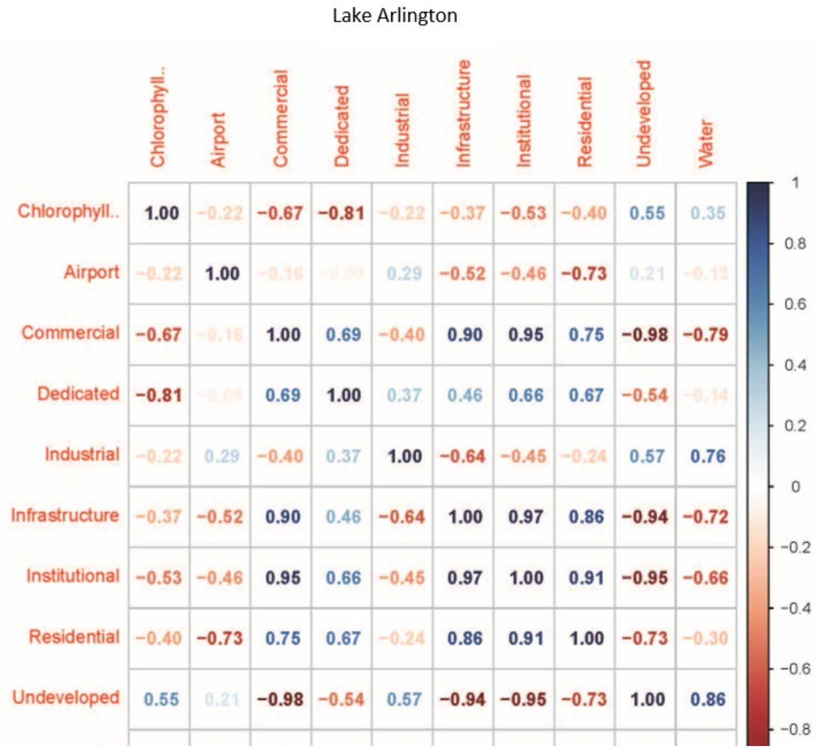
Table 22 Lake Arlington residential land descriptive statistics

Lake Arlington Residential Land	
Mean	0.007
Standard Error	3.91E-05
Median	0.003
Mode	0.002
Standard Deviation	0.016
Sample Variance	0
Kurtosis	268.6
Skewness	11.9
Range	0.83
Minimum	1.49E-12
Maximum	0.83
Sum	1270
Count	173308

Chlorophyll α on Lake Arlington is highly correlated with Commercial, Dedicated, Institutional, Residential and Undeveloped land (Table 23). Total coliform did not return any significantly correlated results (Table 24). The Lake Arlington nitrate data set has incomplete and missing data; therefore, a correlation test was not performed. Commercial, dedicated, institutional and residential land uses are positive correlated (cor= 0.55) with chlorophyll α. Whereas undeveloped land uses are negatively correlated (cor= -0.55) with chlorophyll α.

Table 23 Lake Arlington land use data from 2000-2019 compared to Chlorophyll α. Correlation coefficients and associated p-values.

Lake Arlington	Chlorophyll α	
Land	Cor	p-value
Airport	-0.55	0.28
Commercial	0.55	<0.001
Dedicated	0.55	<0.001
Industrial	-0.55	0.28
Infrastructure	0.55	0.07
Institutional	0.55	0.0059
Residential	0.55	0.046
Undeveloped	-0.55	0.004
Water	0.55	0.09

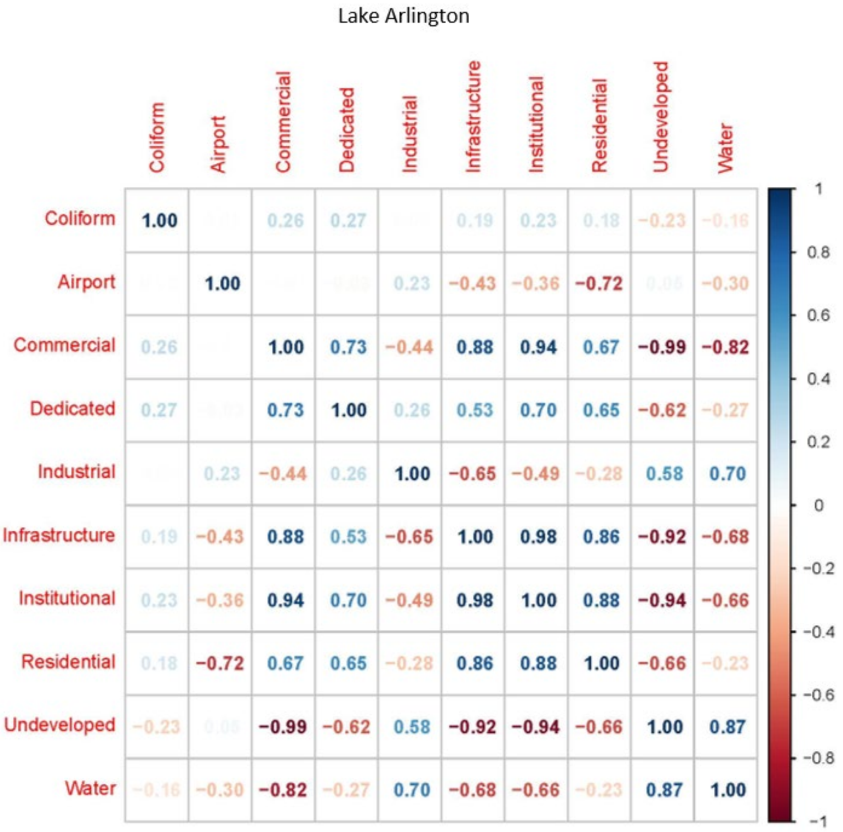

Lake Arlington

	Chlorophyll..	Airport	Commercial	Dedicated	Industrial	Infrastructure	Institutional	Residential	Undeveloped	Water
Chlorophyll..	1.00	−0.22	−0.67	−0.81	−0.22	−0.37	−0.53	−0.40	0.55	0.35
Airport	−0.22	1.00	−0.16	−0.09	0.29	−0.52	−0.46	−0.73	0.21	−0.13
Commercial	−0.67	−0.16	1.00	0.69	−0.40	0.90	0.95	0.75	−0.98	−0.79
Dedicated	−0.81	−0.09	0.69	1.00	0.37	0.46	0.66	0.67	−0.54	−0.14
Industrial	−0.22	0.29	−0.40	0.37	1.00	−0.64	−0.45	−0.24	0.57	0.76
Infrastructure	−0.37	−0.52	0.90	0.46	−0.64	1.00	0.97	0.86	−0.94	−0.72
Institutional	−0.53	−0.46	0.95	0.66	−0.45	0.97	1.00	0.91	−0.95	−0.66
Residential	−0.40	−0.73	0.75	0.67	−0.24	0.86	0.91	1.00	−0.73	−0.30
Undeveloped	0.55	0.21	−0.98	−0.54	0.57	−0.94	−0.95	−0.73	1.00	0.86

Figure 13 Correlation matrix plot for Chlorophyll a at Lake Arlington with numbers representing correlation coefficient

Table 24 Lake Arlington land use data from 2000-2019 compared to Total Coliform. Correlation coefficients and associated p-values.

Lake Arlington	Coliform	
Land	Cor	p-value
Airport	0.02	0.94
Commercial	0.26	0.24
Dedicated	0.27	0.21
Industrial	<0.001	0.99
Infrastructure	0.19	0.37
Institutional	0.23	0.28
Residential	0.18	0.40
Undeveloped	-0.23	0.29
Water	-0.16	0.47



Lake Arlington

	Coliform	Airport	Commercial	Dedicated	Industrial	Infrastructure	Institutional	Residential	Undeveloped	Water
Coliform	1.00	0.02	0.26	0.27	0.00	0.19	0.23	0.18	−0.23	−0.16
Airport	0.02	1.00	[illegible]	−0.03	0.23	−0.43	−0.36	−0.72	0.06	−0.30
Commercial	0.26	[illegible]	1.00	0.73	−0.44	0.88	0.94	0.67	−0.99	−0.82
Dedicated	0.27	−0.03	0.73	1.00	0.26	0.53	0.70	0.65	−0.62	−0.27
Industrial	0.00	0.23	−0.44	0.26	1.00	−0.65	−0.49	−0.28	0.58	0.70
Infrastructure	0.19	−0.43	0.88	0.53	−0.65	1.00	0.98	0.86	−0.92	−0.68
Institutional	0.23	−0.36	0.94	0.70	−0.49	0.98	1.00	0.88	−0.94	−0.66
Residential	0.18	−0.72	0.67	0.65	−0.28	0.86	0.88	1.00	−0.66	−0.23
Undeveloped	−0.23	0.06	−0.99	−0.62	0.58	−0.92	−0.94	−0.66	1.00	0.87
Water	−0.16	−0.30	−0.82	−0.27	0.70	−0.68	−0.66	−0.23	0.87	1.00

Figure 14 Correlation matrix plot for Total Coliform at Lake Arlington with numbers representing correlation coefficient

Descriptive statistics for Lake Arlington Land Use (Table 25- Table 34)

Table 25 Joe Pool Lake commercial land descriptive statistics

Joe Pool Lake Commercial Land	
Mean	0.006
Standard Error	0.0001
Median	0.002
Mode	0.001
Standard Deviation	0.013
Sample Variance	0.0002
Kurtosis	265.462
Skewness	11.269
Range	0.687
Minimum	0
Maximum	0.69
Sum	395.91
Count	70389

Table 26 Joe Pool Lake infrastructure land descriptive statistics

Joe Pool Lake Infrastructure Land	
Mean	810.27
Standard Error	8.22
Median	810
Mode	0
Standard Deviation	468.20
Sample Variance	219208.82
Kurtosis	-1.20
Skewness	0.0003
Range	1629
Minimum	0
Maximum	1629
Sum	2627713
Count	3243

Table 27 Joe Pool Lake residential land descriptive statistics

Joe Pool Lake Residential Land	
Mean	0.01
Standard Error	0.00
Median	0.003
Mode	0.00
Standard Deviation	0.01
Sample Variance	0.00
Kurtosis	563.18
Skewness	16.37
Range	0.96
Minimum	0.00
Maximum	0.96
Sum	1592.68
Count	281697

Table 28 Joe Pool Lake Undeveloped land descriptive statistics

Joe Pool Lake Undeveloped Land	
Mean	0.024
Standard Error	0.001
Median	0.001
Mode	0.000
Standard Deviation	0.216
Sample Variance	0.046
Kurtosis	1794.498
Skewness	32.214
Range	21.905
Minimum	0.000
Maximum	21.905
Sum	4141.649
Count	176201

Table 29 Joe Pool Lake institutional land descriptive statistics

Joe Pool Lake Institutional Land	
Mean	0.01
Standard Error	0
Median	0.003
Mode	0
Standard Deviation	0.03
Sample Variance	0.001
Kurtosis	362.94
Skewness	14.23
Range	1.06
Minimum	0
Maximum	1.06
Sum	253.02
Count	24357

Table 30 Joe Pool water land descriptive statistics

Joe Pool Lake Water Land	
Mean	0.013
Standard Error	0.001
Median	0.001
Mode	0.000
Standard Deviation	0.217
Sample Variance	0.047
Kurtosis	1729.385
Skewness	36.714
Range	13.273
Minimum	0.000
Maximum	13.273
Sum	363.043
Count	28679

Table 31 Joe Pool Lake dedicated land descriptive statistics

Joe Pool Lake Dedicated Land	
Mean	0.038
Standard Error	0.001
Median	0.003
Mode	0.000
Standard Deviation	0.154
Sample Variance	0.024
Kurtosis	479.451
Skewness	16.536
Range	6.726
Minimum	0.000
Maximum	6.726
Sum	579.683
Count	15308

Table 32 Joe Pool Lake airport land descriptive statistics

Joe Pool Lake Airport Land	
Mean	0.071
Standard Error	0.008
Median	0.005
Mode	#N/A
Standard Deviation	0.308
Sample Variance	0.095
Kurtosis	238.851
Skewness	13.118
Range	6.358
Minimum	0.000
Maximum	6.358
Sum	106.026
Count	1483

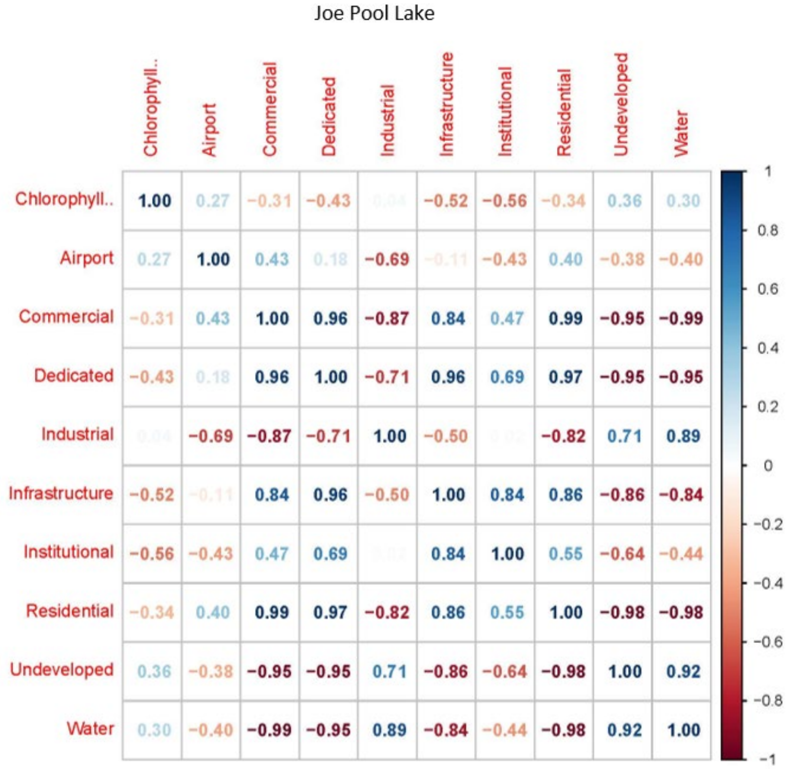
Table 33 Joe Pool Lake industrial land descriptive statistics

Joe Pool Lake Industrial Land	
Mean	0.016
Standard Error	0.0004
Median	0.005
Mode	0
Standard Deviation	0.054
Sample Variance	0.003
Kurtosis	622.764
Skewness	20.011
Range	2.384
Minimum	0
Maximum	2.384
Sum	292.729
Count	18240

Chlorophyll α and Nitrate returned statistically significant correlations at Joe Pool Lake (Table 35 and 36). Chlorophyll α is negatively correlated with dedicated (cor= -0.43), infrastructure (cor= -0.52) and institutional (cor= -0.56) (Table 35). Nitrate on Joe Pool Lake is negatively correlated with Dedicated (cor= -0.40), Infrastructure (cor=-0.48) and Institutional (cor= -0.53 land use categories. Total coliform did not return any significantly correlated results (Table 36).

Table 34 Joe Pool Lake land use data from 2000-2019 compared to Chlorophyll α. Correlation coefficients and associated p-values.

Joe Pool Lake	Chlorophyll α	
Land	Cor	p-value
Airport	0.27	0.18
Commercial	-0.31	0.13
Dedicated	-0.43	0.03
Industrial	0.042	0.84
Infrastructure	-0.52	0.007
Institutional	-0.56	0.003
Residential	-0.34	0.09
Undeveloped	0.36	0.07
Water	0.30	0.14

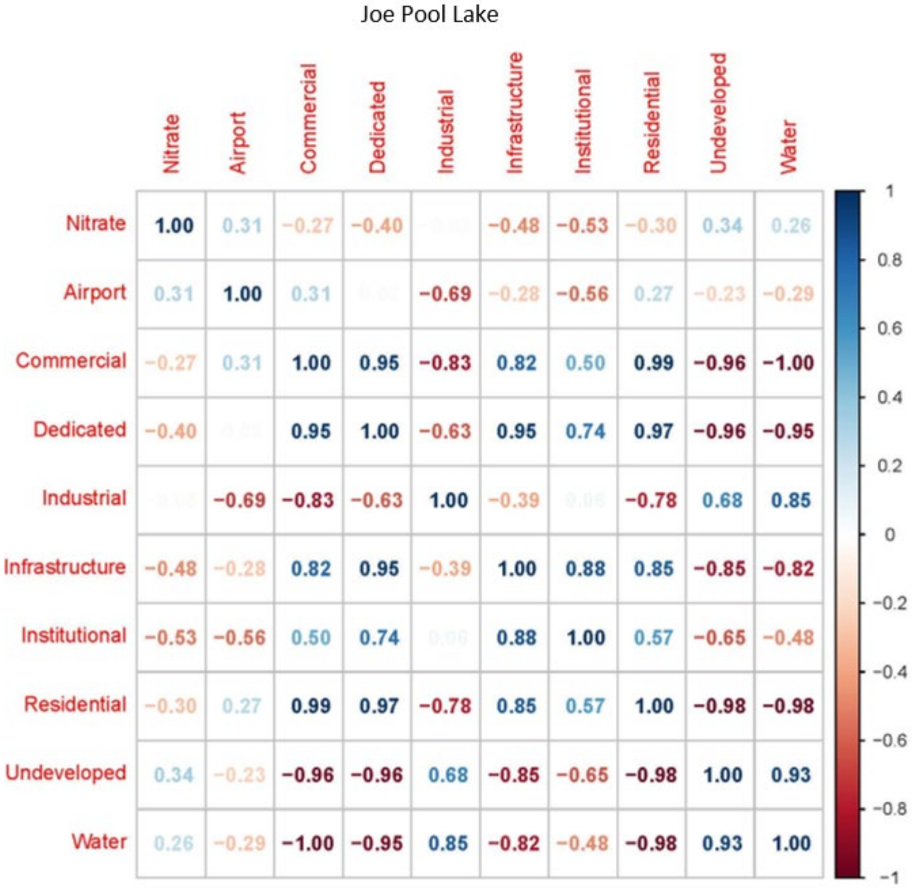


	Chlorophyll..	Airport	Commercial	Dedicated	Industrial	Infrastructure	Institutional	Residential	Undeveloped	Water
Chlorophyll..	1.00	0.27	−0.31	−0.43	0.04	−0.52	−0.56	−0.34	0.36	0.30
Airport	0.27	1.00	0.43	0.18	−0.69	−0.11	−0.43	0.40	−0.38	−0.40
Commercial	−0.31	0.43	1.00	0.96	−0.87	0.84	0.47	0.99	−0.95	−0.99
Dedicated	−0.43	0.18	0.96	1.00	−0.71	0.96	0.69	0.97	−0.95	−0.95
Industrial	0.04	−0.69	−0.87	−0.71	1.00	−0.50	0.02	−0.82	0.71	0.89
Infrastructure	−0.52	−0.11	0.84	0.96	−0.50	1.00	0.84	0.86	−0.86	−0.84
Institutional	−0.56	−0.43	0.47	0.69	0.02	0.84	1.00	0.55	−0.64	−0.44
Residential	−0.34	0.40	0.99	0.97	−0.82	0.86	0.55	1.00	−0.98	−0.98
Undeveloped	0.36	−0.38	−0.95	−0.95	0.71	−0.86	−0.64	−0.98	1.00	0.92
Water	0.30	−0.40	−0.99	−0.95	0.89	−0.84	−0.44	−0.98	0.92	1.00

Figure 15 Correlation matrix plot for Chlorophyll a at Joe Pool Lake with numbers representing correlation coefficient

Table 35 Joe Pool Lake land use data from 2000-2019 compared to Nitrate. Correlation coefficients and associated p-values.

Joe Pool Lake	Nitrate	
Land	Cor	p value
Airport	0.31	0.07
Commercial	-0.27	0.12
Dedicated	-0.40	0.02
Industrial	-0.03	0.88
Infrastructure	-0.48	0.004
Institutional	-0.53	0.001
Residential	-0.31	0.08
Undeveloped	0.34	0.05
Water	0.26	0.14

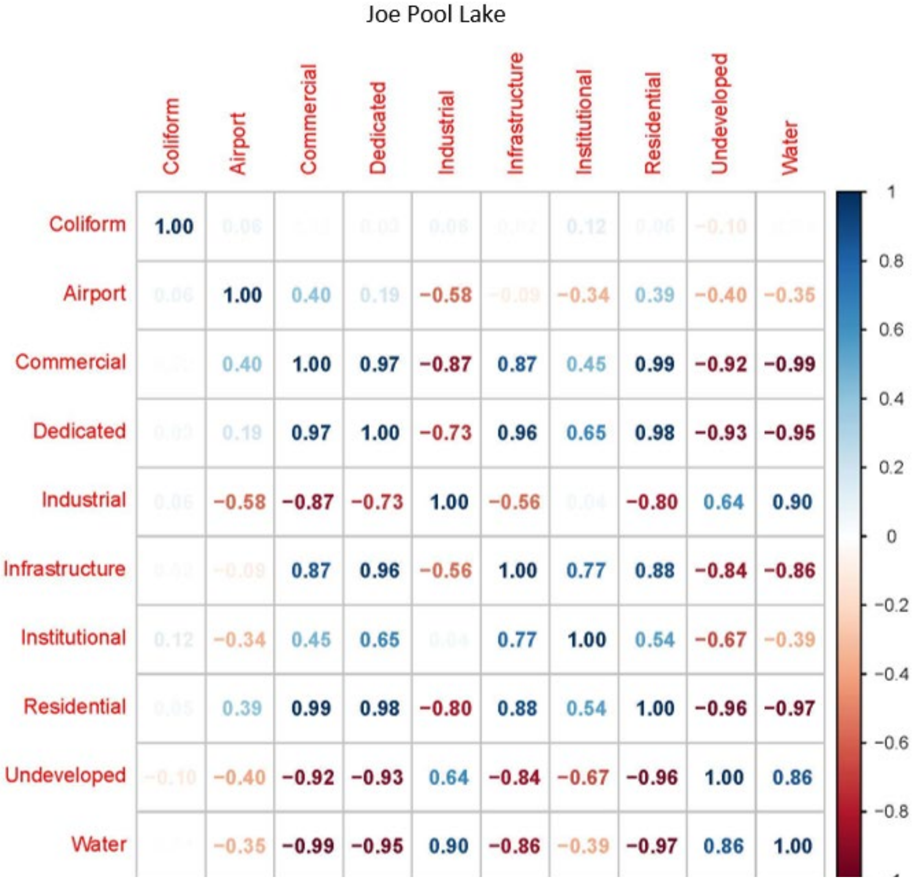


	Nitrate	Airport	Commercial	Dedicated	Industrial	Infrastructure	Institutional	Residential	Undeveloped	Water
Nitrate	1.00	0.31	−0.27	−0.40	−0.03	−0.48	−0.53	−0.30	0.34	0.26
Airport	0.31	1.00	0.31	0.02	−0.69	−0.28	−0.56	0.27	−0.23	−0.29
Commercial	−0.27	0.31	1.00	0.95	−0.83	0.82	0.50	0.99	−0.96	−1.00
Dedicated	−0.40	0.02	0.95	1.00	−0.63	0.95	0.74	0.97	−0.96	−0.95
Industrial	−0.03	−0.69	−0.83	−0.63	1.00	−0.39	0.06	−0.78	0.68	0.85
Infrastructure	−0.48	−0.28	0.82	0.95	−0.39	1.00	0.88	0.85	−0.85	−0.82
Institutional	−0.53	−0.56	0.50	0.74	0.06	0.88	1.00	0.57	−0.65	−0.48
Residential	−0.30	0.27	0.99	0.97	−0.78	0.85	0.57	1.00	−0.98	−0.98
Undeveloped	0.34	−0.23	−0.96	−0.96	0.68	−0.85	−0.65	−0.98	1.00	0.93
Water	0.26	−0.29	−1.00	−0.95	0.85	−0.82	−0.48	−0.98	0.93	1.00

Figure 16 Correlation matrix plot for Nitrate at Joe Pool Lake with numbers representing correlation coefficient

Table 36 Joe Pool Lake land use data from 2000-2019 compared to Total Coliform. Correlation coefficients and associated p-values.

Joe Pool Lake	Coliform	
Land	Cor	p-value
Airport	0.06	0.77
Commercial	0.02	0.93
Dedicated	0.03	0.87
Industrial	0.06	0.77
Infrastructure	0.02	0.91
Institutional	0.12	0.56
Residential	0.05	0.82
Undeveloped	-0.10	0.62
Water	0.01	0.96



Joe Pool Lake

	Coliform	Airport	Commercial	Dedicated	Industrial	Infrastructure	Institutional	Residential	Undeveloped	Water
Coliform	1.00	0.06	0.02	0.03	0.06	0.02	0.12	0.05	−0.10	0.01
Airport	0.06	1.00	0.40	0.19	−0.58	−0.09	−0.34	0.39	−0.40	−0.35
Commercial	0.02	0.40	1.00	0.97	−0.87	0.87	0.45	0.99	−0.92	−0.99
Dedicated	0.03	0.19	0.97	1.00	−0.73	0.96	0.65	0.98	−0.93	−0.95
Industrial	0.06	−0.58	−0.87	−0.73	1.00	−0.56	0.04	−0.80	0.64	0.90
Infrastructure	0.02	−0.09	0.87	0.96	−0.56	1.00	0.77	0.88	−0.84	−0.86
Institutional	0.12	−0.34	0.45	0.65	0.04	0.77	1.00	0.54	−0.67	−0.39
Residential	0.05	0.39	0.99	0.98	−0.80	0.88	0.54	1.00	−0.96	−0.97
Undeveloped	−0.10	−0.40	−0.92	−0.93	0.64	−0.84	−0.67	−0.96	1.00	0.86
Water	0.01	−0.35	−0.99	−0.95	0.90	−0.86	−0.39	−0.97	0.86	1.00

Figure 17 Correlation matrix plot for Total Coliform at Joe Pool Lake with numbers representing correlation coefficient

Discussion

Lake Arlington is a drinking water reservoir for the City of Arlington (Templer, 2019). Tarrant and Johnson counties surface and stormwater run-off drains to the lake (The Village Creek-Lake Arlington Watershed Protection Partnership, 2019). Land use data measured by correlation matrices found positive correlations (0.55) between chlorophyll α and commercial, dedicated, and institutional land uses. The value indicates that when land use acreage for these categories grows, chlorophyll α increases. This makes sense as the categories include areas with high potential for pollutant run off such as landfills, public parks, and impermeable surfaces such as commercial properties (The Village Creek-Lake Arlington Watershed Protection Partnership, 2019). A negative correlation exists between chlorophyll α and undeveloped land. The relationship is expected as undeveloped land includes cropland, ranchland, vacant and areas under construction. As this acreage decreases, so does the value for chlorophyll α, the indicator for algae. Surface run off from undeveloped lands may include animal waste, fertilizer, pesticide use and debris from construction areas if improperly managed.

Joe Pool Lake is a drinking water source for the City of Mansfield. Ellis, Dallas, and Tarrant counties drain into the water body. Water parameters chlorophyll α and nitrate have strong correlations with various land use categories. Chlorophyll α is negatively correlated with institutional, infrastructure and dedicated lands. Nitrate is negatively correlated with institutional and infrastructure land uses. Between both Lake Arlington and Joe Pool Lake, institutional land use is the most correlated land category. Interestingly, chlorophyll α has a negative correlation at Joe Pool Lake, but a positive correlation at Lake Arlington.

Land categories to monitor include institutional, infrastructure and dedicated lands. These three categories had the most correlations regardless of waterbody. This group of categories include large areas of urban development, transportation including roadways, landfills, parks, and flood control management. Data collected and measured locally can help policy makers and stake holders make future decisions on land use (Ronald C. Griffin, 2011). This is particularly helpful when coupled with the appropriate modeling platforms. Increase accessibility and readability of mathematical models that general professionals can run and interpret the findings such as this model that is within a GIS framework, a mapping program that is commonly used (Elliott et al., 2016).

Appendix

Table 37 Lake Arlington station identifiers and site descriptions

Station ID	Lake Arlington Station Identifiers and Descriptions
10780	VILLAGE CREEK ON WEST BANK AT IH 20 WEST FEEDER ROAD IN ARLINGTON
10781	VILLAGE CREEK 200 METERS DOWNSTREAM OF US BUS 287P SW OF ARLINGTON
10785	VILLAGE CREEK 348 METERS UPSTREAM OF OAK GROVE/RENDON ROAD/FM 1187
10786	VILLAGE CREEK IMMEDIATELY DOWNSTREAM OF RENDON ROAD SW OF ARLINGTON
10793	WILDCAT BRANCH AT SOUTH CRAVENS ROAD IN ARLINGTON APPROXIMATELY 200 METERS SOUTH OF DOWDELL ROAD
10798	UNNAMED TRIBUTARY OF LAKE ARLINGTON AT BOWMAN SPRINGS ROAD
10805	DEER CREEK AT OAK GROVE ROAD IN FORT WORTH

11040	LAKE ARLINGTON MID LAKE NEAR DAM 1.35 KM EAST AND 772 METERS SOUTH OF INTERSECTION OF ROSEDALE STREET AND ARKANSAS LANE
11042	LAKE ARLINGTON MID LAKE 177 METERS NORTH AND 865 METERS WEST OF INTERSECTION OF ARBOR VALLEY DRIVE AND PERKINS ROAD
13671	VILLAGE CREEK AT EVERMAN-KENNEDALE ROAD
13897	LAKE ARLINGTON USGS SITE FC 570 METERS EAST OF INTERSECTION OF KAY DRIVE AND KALTENBRUN ROAD
13899	LAKE ARLINGTON USGS SITE EC 254 METERS SOUTH AND 493 METERS EAST OF INTERSECTION OF CRAVENS ROAD AND WILBARGER STREET
13904	LK ARLINGTON USGS SITE AC ID 324304097113601 LOCATION MATCHES SITE MAP 518 M N AND 507 M W INTERSECT OF LK ARLINGTON BLVD AND GREEN OAK
21759	QUIL MILLER CREEK AT COUNTY ROAD 532 IN THE CITY OF BURLESON
21762	VILLAGE CREEK 198 METERS TO THE EAST OF FREEMAN DRIVE AND ESCO DR IN FOREST HILL AREA OF FORT WORTH 312 METERS UPSTREAM OF SE LANDFILL ROAD
21763	VILLAGE CREEK AT FM 3391 IN BURLESON
22008	VILLAGE CREEK AT WEST JOHNSON CR 714/DOBSON STREET IN THE CITY OF BURLESON NEAR THE INTERSECTION OF SH 174/SOUTHWEST WILSHIRE BOULEVARD AND FM731/SOUTHEAST JOHN JONES DRIVE

Table 38 Joe Pool Lake station identifiers and site descriptions

Station ID	Joe Pool Lake Station Identifiers and Descriptions
11071	JOE POOL LAKE MOUNTAIN CREEK ARM AT LAKE RIDGE PKWY/MANSFIELD ROAD 251 M N AND 1.19 KM W OF INTERSECTION OF ANDERSON RD AND LK RIDGE USGS SITE DC 323503097012201
11072	JOE POOL LAKE WALNUT CREEK ARM AT LAKE RIDGE PARKWAY 1.43 KM NORTH AND 503 M WEST OF INTERSECTION OF LAKE RIDGE PKWY AND HANGER LOWE RD
11073	JOE POOL LAKE MID LAKE AT DAM 48 METERS SOUTH AND 2.24 KM WEST OF INTERSECTION OF MANSFIELD ROAD AND FM 1382
13621	WALNUT CREEK AT MATLOCK ROAD 2.6 MI NORTHEAST OF MANSFIELD

13622	MOUNTAIN CREEK AT FM 157 3.9 MI NORTH OF VENUS 3.0 MI UPSTREAM FROM GRASSY CREEK
13891	JOE POOL LK USGS SITE AC LOCATION MATCHES USGS SITE MAP USCE 323819096584801 210 M S AND 685 M W OF INTERSECT OF FM 1382 AND MANSFIELD
13892	JOE POOL LAKE USGS SITE BC 1.03 KM SOUTH AND 1.61 KM EAST OF INTERSECTION OF MANSFIELD ROAD AND LAKE RIDGE PARKWAY
13894	JOE POOL LAKE USGS SITE CC 213 METERS NORTH AND 2.10 KM EAST OF INTERSECTION OF GRAND PENINSULA DRIVE AND LAKE RIDGE PARKWAY
13896	JOE POOL LAKE USGS SITE EC 474 METERS SOUTH AND 2.02 KM EAST OF INTERSECTION OF SPRING LAKE PARKWAY AND HOLLAND ROAD
16433	HOLLINGS BRANCH AT TANGLE RIDGE ROAD 1KM UPSTREAM OF CONFLUENCE OF HOLLINGS BRANCH WITH JOE POOL LAKE
16434	MOUNTAIN CREEK AT US287 1.6KM NORTHWEST OF INTERSECTION OF US 287 AND FM 661
16435	SOAP CREEK IMMEDIATELY DOWNSTREAM OF US 287 173 METERS SOUTHEAST OF INTERSECTION OF US 287 AND FM 661
17198	LYNN CREEK 136 METERS DOWNSTREAM OF WEBB LYNN ROAD 2.6 KM UPSTREAM OF JOE POOL LAKE IN GRAND PRAIRIE
17680	SUGAR CREEK IMMEDIATELY UPSTREAM OF EAST SEETON ROAD NORTH OF SPRING CREEK PARK IN GRAND PRAIRIE
17684	JOE POOL LK MOUNTAIN CK ARM AT BOAT RAMP IN BRITTON PK 92 M S AND 1.08 KM E OF INTERSECTION OF BRITTON RD AND FM 661/LAKEVIEW DR IN MANSFIELD
20790	WALNUT CREEK AT RETTA ROAD IN SOUTHEAST TARRANT COUNTY
22131	WALNUT CREEK AT FM 2738/LILLIAN HIGHWAY IN JOHNSON COUNTY
22132	WALNUT CREEK AT JOHNSON COUNTY ROAD 519 WEST OF LILLIAN IN JOHNSON COUNTY
22133	BOWMAN BRANCH AT SOUTH SH 360 IN THE CITY OF GRANDE PRAIRE IN TARRANT COUNTY
22134	SOAP CREEK 1.1 KILOMETERS UPSTREAM OF THE CONFLUENCE WITH MOUNTAIN CREEK IN ELLIS COUNTY
22135	LOW BRANCH AT SOUTH HOLLAND ROAD EAST OF THE CITY OF MANSFIELD IN TARRANT COUNTY

22136	BAGGETT BRANCH AT MANSFIELD ROAD IN THE CITY OF CEDAR HILL IN DALLAS COUNTY
22137	MOUNTAIN CREEK TRIBUTARY 2 AT FM 1382/BELT LINE ROAD ALONG THE NORTHERN BOUNDARY OF CEDAR HILL STATE PARK IN DALLAS COUNTY
22138	MOUNTAIN CREEK AT FM 2738 IN JOHNSON COUNTY
22139	JOE POOL LAKE AT INTAKE STRUCTURE 423 METERS WEST OF THE BOAT RAMP AT JOE POOL MARINA IN CEDAR HILL STATE PARK
22140	JOE POOL LAKE AT INTAKE STRUCTURE 785 METERS NORTHWEST FROM THE INTERSECTION OF ANDERSON ROAD AND MANSFIELD ROAD IN DALLAS COUNTY

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