2020-01-01

Remediation And Prevention Of Harmful Algae Blooms (HABS) In Ascarate Lake At El Paso, Texas

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Master's Program in Civil Engineering

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REMEDIATION AND PREVENTION OF HARMFUL ALGAE BLOOMS (HABS) IN ASCARATE LAKE AT EL PASO, TEXAS

by

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THESIS

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

Department of Civil Engineering

THE UNIVERSITY OF TEXAS AT EL PASO

May 2020

ACKNOWLEDGMENTS

I WOULD LIKE TO EXTEND MY DEEPEST APPRECIATION TO ERIKA CAMPOS FOR HER LOVE AND SUPPORT. SINCERE GRATITUDE TO MY MENTOR AND COMMITTEE CHAIR DR. IVONNE SANTIAGO FOR ALL THE SUPPORT AND VERY CONSTRUCTIVE COMMENTS ON MY WORK. SINCERE THANKS TO THE COMMITTEE MEMBERS DR. SHANE WALKER AND DR. ADEEBA RAHEEM. A THANK YOU TO MY FELLOW LABORATORY MATES DAVID MACIAS AND DANIELA DUARTE FOR ALL THEIR HELP COLLECTING AND ANALYZING SAMPLES. EXTREMELY GRATEFUL TO KARLA LOPEZ FOR ALL HER SUPPORT DURING THIS JOURNEY. LAST BUT NOT LEAST, THANKS TO THE PUBLIC WORKS DEPARTMENT AT THE COUNTY OF EL PASO FOR OPENING ASCARATE PARK FOR THIS RESEARCH AND FUNDING PART OF IT. WITHOUT YOU NONE OF THIS WOULD HAVE BEEN POSSIBLE, THANK YOU.

ABSTRACT

ASCARATE PARK IN EL PASO, TEXAS IS AN EXAMPLE OF AN URBAN ECOSYSTEM IN THE MIDDLE OF A GROWING CITY. IT IS THE LARGEST PUBLIC-USE RECREATIONAL PARK IN EL PASO COUNTY AND IT INCLUDES A 48-ACRE ASCARATE LAKE. THE PURPOSE OF THIS STUDY WAS TO PREVENT HARMFUL ALGAE GROWTH IN ASCARATE LAKE USING PHYTOREMEDIATION BY ANALYZING DIFFERENT WATER QUALITY PARAMETERS. WE INSTALLED ARTIFICIAL ISLANDS ON WEST COVE OF THE LAKE WITH AFRICAN IRIS PLANTS TO DETERMINE THE FEASIBILITY OF REMEDIATION TO PREVENT ALGAE BLOOMS IN ASCARATE LAKE. WATER SAMPLES WERE COLLECTED AT DIFFERENT POINTS CLOSE AND AWAY FROM THE ISLANDS AND TESTED FOR DISSOLVED OXYGEN, PH, TEMPERATURE, CHLOROPHYLL-*A*, NUTRIENTS AND OTHER PARAMETERS. AERIAL PHOTOGRAPHS WERE CAPTURED FROM THE LAKE TO EVALUATE ITS USE FOR OBSERVING HARMFUL ALGAE BLOOMS. RESULTS SHOW THAT TEMPERATURE PLAYS A KEY ROLE WHEN ANALYZING WATER CONDITIONS FOR ALGAE GROWTH. THE USE OF ARTIFICIAL ISLANDS SHOWED THAT OVERALL NITRATE LEVELS WERE SLIGHTLY REDUCED CLOSEST TO THE ISLANDS REGARDLESS OF THE SEASON. THEREFORE, PHYTOREMEDIATION CAN BE A VIABLE WAY TO PREVENT ALGAL BLOOM IN ASCARATE LAKE, BUT MORE ARTIFICIAL ISLANDS ARE NEEDED TO REDUCE THE OVERALL LEVELS OF NUTRIENTS AND PREVENT ALGAE GROWTH THAT COULD AFFECT AQUATIC LIFE.

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CHAPTER 1 - INTRODUCTION

Conservation of water resources has become a necessity all around the world and the development of new techniques for obtaining fresh water is now a desideratum. Improving the ways of restoring water quality for consumption or irrigation are priority on solving daily life problems in our area. El Paso is a city in the west Texas with a population estimate of 682,000 in 2018. It is a border city that stands to the south next to Mexico being divided by the Rio Grande. El Paso has a desert climate featuring hot summers, with little humidity and cold to mild dry winters. Rainfall averages 9.7 in (250 mm) per year and the sun shines 302 days per year on average. Average annual snowfall and rainfall are 6.1 inches (15cm) with a median of 0 (meaning most years see no snow at all) and only about 9.7 in (250 mm) respectively.

Urban lakes provide significant ecological services to cities and thus must be restored and protected using integrated approaches that involve water quality and water resources management. In order to restore and preserve urban lakes, key technologies, including innovative water treatment devices, sensing technology, GIS technology, and hydrological models, offer valuable tools to address sustainability challenges within urban systems. Currently efforts to manage nutrient pollution in lakes containing aquatic life has been limited to mechanical cleansing avoiding the use of chemical-based algaecides. However, these efforts are not sufficient because they require more time and capital investment that the use of a non-toxic algaecide or phytoremediation. Nutrient pollution is a problem that lakes are facing due to the increase of nutrients entering the lakes. The main nutrients are phosphorus and nitrogen and the excessive inflow of these cause algae to grow faster. Even tough phosphorus provides a greater risk for algae blooms than nitrogen, both nutrients must be limited to reduce occurrence of harmful algae blooms. The excessive algae growth can promote water pollution, particularly in lakes. Fish and other aquatic life can suffocate when bacteria use up dissolved oxygen while consuming dead algae.

Natural urban ecosystems, like Ascarate Park and its lake contribute to public health and increase the quality-of-life of urban citizens, moreover, air quality is improved. Cities significantly contribute to global climate change, they produce 78% of greenhouse gases (Grim et al, 2000). There is no doubt that natural ecosystems in the middle of the city are essential, they are contributors to the urban sustainable communities.

1.1 ASCARATE PARK AND LAKE

Ascarate Park, built in 1937, is the largest public-use recreational park in El Paso County and is dedicated to sports, picnicking, fishing and other recreational activities. Spanning over 400 acres, Ascarate Park features an 18-hole 72 par golf course and a 9-hole executive course called the Delta 9, a 48-acre surface lake, lakeside boardwalk, fully equipped aquatic center, playgrounds and picnic facilities. (Figure 1) The Ascarate Golf Course which sits on 280 acres and is adjacent to the 48-acre surface lake within the park, was opened in December 1940 after more than 200 Civilian Conservation Corps (CCC) removed more than 1 million cubic yards of sand from what was originally part of a banco, or river loop, or the Rio Grande. Ascarate Lake is home to trout (winter), catfish (summer), largemouth bass, black bass, sun perch, blue gill, carp, shad, crappie hybrid sunfish and minnows. Ascarate Lake is part of the southern plains ecoregion that covers approximately 405,000 square miles and includes central and northern Texas. The terrain is a mix of smooth and irregular plains interspersed with tablelands and low hills.

Figure 1 - Aerial Photograph of Ascarate Park obtained from Google Earth Maps, 2020.

The lake has suffered from nutrient pollution effects on different seasons of the year. As far back as 1950, there have been reports of game fish density as low at 11% that has been attributed to the use of rotenone in the Lake watershed. (Hobbs, 1963). Rotenone is a naturally occurring chemical with insecticidal properties that is also considered a piscicide (fish-killer). Recent major fish kills related to Golden Algae have taken place in late December early January in 2011, 2012, 2013, 2015, and 2016. The addition of 18 electric aerators in November 2015 did not seem to alleviate the problem. Other natural events that are enhanced by anthropogenic activities include dust that can increase sediment accumulation in the lake. Being that the park is located in the Chihuahuan Desert and in a major metropolitan area, there have been dust plumes that were classified as "hazardous" on the US Environmental Protection Agency (EPA) Air Quality

Index (AQI) that can be partly attributed to un-vegetated land cover from large distances from the City (Rivera et al, 2010).

1.2 GOAL AND OBJECTIVES

The overarching goal of this project was to evaluate an alternative to reduce and control algae growth in Ascarate Lake. Specific objectives included:

1. Study the viability of using phytoremediation to reduce the concentration of Nitrogen and Phosphorus (primary nutrients for algae growth).
2. Control algae growth in Ascarate Lake by installing artificial floating islands with wetland flora in a cove of the lake.

CHAPTER 2 - LITERATURE REVIEW

2.1 NUTRIENT POLLUTION AND ALGAE GROWTH

From all the nutrients that plants require to growth, inorganic nitrogen and phosphorus are the two major nutrients required. Algae growth and vascular plants growth is strongly affected by the available nitrogen and phosphorus. These nutrients are natural parts of aquatic systems; however, in large amounts they become pollutants and affect the aquatic life. Nitrogen and phosphorus support the growth of algae; excessive algae growth is called algae bloom and can lead to a decrease of oxygen needed by aquatic animals to survive. Additionally, some algal blooms are harmful to humans because they produce elevated toxins and bacterial growth that can make people sick if they come into contact with polluted water, consume tainted fish or shellfish, or drink contaminated water.

Eutrophication is the process by which water bodies are made more eutrophic through an increase in their nutrient supply. Even tough, it is a natural part of lake aging, it has been accelerated by human influences and the increased amount of nutrients entering the lakes. Water in lakes can be classified as oligotrophic, mesotrophic, eutrophic and hypertrophic state depending on the available quantity of nutrients supplies. The trophic state can be classified depending on its chlorophyll-*a* concentration or their primary production. Lakes with high nutrient levels, high plant production rates, and an abundance of plant life are termed eutrophic, whereas lakes that have low concentrations of nutrients, low rates of productivity and low biomass are termed oligotrophic. Lakes that fall in between are mesotrophic and those on the extreme ends of the scale are termed hypereutrophic or ultra-oligotrophic. Nutrient limitations refer to the primary limiting factor (key nutrient) for plant growth and the rate of supply of this nutrient and if it is proportional to the growth of plants. It is important to restrict the load of nutrients to avoid effects such as algae blooms, odor, and fish kills among others. There is no ideal trophic state for lakes, it all depends on the use of the lake. Based on Chlorophyll-*a* concentration, 13% of US lakes are oligotrophic, 37% are mesotrophic, 30% are eutrophic, and 20% are hypereutrophic according to Texas Parks and Wildlife Department (TPWD, 2020). The results also show that natural lakes tend towards mesotrophic conditions and man-made lakes towards eutrophic conditions. (Table 1)

Table 1- Percent of U.S. Lakes (natural and man-made) by trophic state, based on four alternative trophic state indicators (Source National Lakes Assessment: A collaborative Survey of the Nation's Lakes 2020 p.45)

Indicator	Oligotrophic	Mesotrophic	Eutrophic	Hypereutrophic
Chlorophyll-*a*	12.8	36.6	30.1	20
Secchi transparency	10.5	22.5	39.8	18.4
Total Nitrogen	22.1	37.5	22.0	18.4
Total Phosphorus	25.0	28.8	24.7	21.4

There are different sources that work as external supplies or loads of nitrogen and phosphorus to aquatic ecosystems such as groundwater, alluvial, and atmospheric inputs. These external supplies can be divided into point sources or non-point sources. Point sources are localized and can be monitored and controlled while non-point sources are more difficult to control and monitor since they are not localized.

EPA has delineated nine ecoregions for the continental U.S.: Northern Appalachians (NAP), Southern Appalachians (SAP), Coastal Plains (CPL), Upper Midwest (UMW), Temperate Plains (TPL), Southern Plains (SPL), Northern Plains (NPL), Western Mountains (WMT) and Xeric (XER) Figure 2. It is important to assess waterbodies in their own geographical setting, for Ascarate lake the SPL region is going to be used.

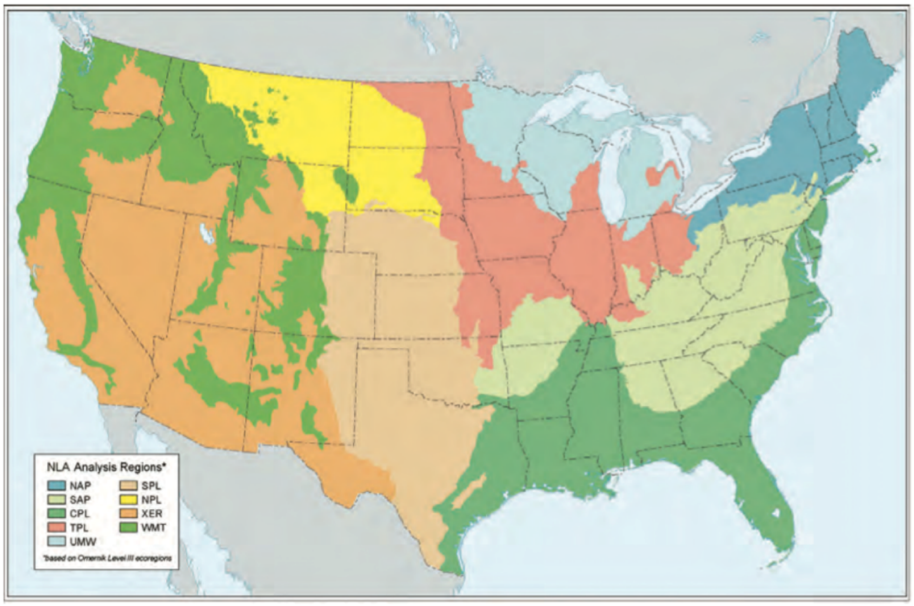

Figure 2 - Ecoregions divisions used by Texas Parks and Wildlife Department (TPWD) in previous Lakes Assessments (Source National Lake Assessment: A Collaborative Survey of the Nation's Lakes, 2020)

2.2 WATER QUALITY PARAMETERS

Water quality parameters such as phosphorus and nitrogen levels, temperature, pH, dissolved oxygen, conductivity, chlorophyll-*a* and *b*, rainfall or drought patterns, and human disturbance can affect the rate of growth of harmful algae blooms (HABs) and consequently affect aquatic life.

Phosphorus and Nitrogen. Phosphorus and Nitrogen are critical nutrients necessary to support flora and algae.

Temperature. Toxic blue-green algae prefers warmer water whereas golden algae prefers colder temperatures. Warmer temperatures prevent water from mixing, allowing algae to grow thicker and faster. Warmer water is easier for small organisms to move through and allows algae to float to the surface faster. Algae blooms absorb sunlight, making water even warmer and promoting more blooms.

pH and Conductivity. Some organisms that are more pH- sensitive than others. Depending on the type of organism, the pH conditions can facilitate algae blooms in acidic or basic conditions. Conductivity acts in the same way for algae blooms; depending on the type of organism, it can facilitate cultivation.

Dissolved Oxygen (DO). It is a direct indicator of the ability of the water body to support life. Depending on the organism, the levels of required dissolved oxygen for growth or reproduction can vary. Dissolved oxygen is consumed by aquatic plants, animals and bacteria decreasing the levels sometimes to critical ranges. Generally, levels below 3 mg/L are of concern for maintaining aquatic life and below 1 mg/L are known as hypoxic and aquatic life is not supported.

Chlorophyll-a. It is a type of plant pigment that is present in all algae types sometimes in direct proportion to the biomass of algae. It is an indicator of the algae toxins and can be used to asses trophic conditions. The levels of cyanobacteria and cyanotoxins concentrations can change chlorophyll-*a* rapidly depending on the weather conditions.

Precipitation and Drought Patterns. As mentioned before, climate change can cause droughts and also intense storms. Droughts can increase salinity in water and intense storms can cause more nutrients runoff into waterbodies feeding more algae blooms.

Human disturbance. Any human activity related to the water nature is a physical stressor for any water body. Depending on the extent and intensity of human activity, the changes can be minors or major alterations. Some examples of human disturbance are the removal of trees, construction, and invading natural areas among others. Human activity can harm different species and in the lake aesthetics.

2.3 IMPACTS OF HARMFUL ALGAE BLOOMS (HABS)

Being in contact directly with toxic algae can lead to health problems; they can go from simple rashes to stomach or liver illness, respiratory problems, and neurological effects. The direct contact could be by accidentally swallowing, swimming or drinking contaminated water. The contamination of water could be by the storm water runoff that carries nutrients to lakes or reservoirs or through the use of fertilizers that contain nitrate in high amounts. Even though the water treatments plants use disinfectants to treat toxic algae, this treatment could create harmful chemicals called dioxins that later on can cause many other health problems. Once again, the best way to avoid health problems is to reduce the amount of toxic algae in drinking water to avoid byproducts in the treatment process.

Nutrient pollution affects not only human health, it also has negative consequences on aquatic ecosystems. Dead zones, hypoxia, acid rain, and air pollution are some of the environmental consequences of nutrient pollution. Dead zones are areas in water bodies with little or no oxygen, as little that aquatic life cannot survive; these areas are known are hypoxia and it is caused by algae blooms that use the oxygen as they die and decompose. Acid rain is caused also by nutrient pollution in the air and can damage lakes, streams, etc. Oxygen depletion is an effect of HABs and can cause suffocation of fish, which has happened a couple of times in Ascarate Lake being the most recent event on 2019.

Golden Algae (*Prymnesium parvum)* is defined by the Texas Parks and Wildlife Department (TPWD) as a single-celled organism that lives in water. It is found mainly in coastal waters but also in rivers and lakes. When it enters a phase of rapid growing (blooms) can cause problems because it produces toxins that kill fish. The toxins affect organisms that have gills: all types of fish, freshwater mussels and clams, and the gill-breathing juvenile stage of frogs and other amphibians. The toxins attack cells and waterborne chemicals gets into the circulatory system of fish and they behave as if there is lack of oxygen in water. Fish will travel to the top of the water surface or rest on the bottom in edges and shallow areas. Golden algae can produce enough toxin to cause a fish kill when cell concentrations are as low as 10,000 cells/milliliter, but losses typically do not occur until counts reach at least 20,000 cells/milliliter. (TPWD, 2020). Bloom causes fish kill when golden alga accounts for 50% or more of the total population. Blooms increases as water temperatures rises, the optimal temperatures are between 18° Celsius and 29° Celsius, however, the probability for golden algae blooms increase as water rises 10° Celsius. Blooms can occur on specific areas of the water body and change location from one day to another. Some indications of alga blooms can be water agitated or water changing to a yellowish-copper color. In Texas, golden alga-related fish kills have occurred in inland waters with high salt or mineral content, usually west of I-35. The first confirmed case was in 1985 on the Pecos River in the Rio Grande Basin. Since then, golden algae has been responsible for multiple fish kills in five river basins. After a major fish kill, the water body recovers depending on the type of fish and its reproduction time. There is no evidence that golden algae toxins pose a direct threat to humans, other mammals, or birds. Still, people should avoid picking up dead or dying fish for consumption.

Blue-green algae is a single cell organism with large colonies and filaments very similar to bacteria, it is also called cyanobacteria and it is part of all freshwater ecosystems. The main characteristic is that it can form very thick blooms that seem to paint blue-green color the surface of water. It can grow in a variety of conditions and it is commonly found in water bodies, however, the growth is encouraged during the warmer season of the year. The optimal temperature for blue-green algae growing is above 25° Celsius. There are two forms found in Texas called *Anabaena* and *Microcystis*. They produce toxins that can kill fish and can cause taste and odor problems in water supplies. Wildlife drinking water contaminated with blue-green toxins can die and if not completely removed from water treatment plants can harm humans too. Eutrophication in lakes facilitates conditions to the rapidly growth of cyanobacteria, the blooms can be seen as a floating layer of odiferous scum.

Human health effects related to the exposure to cyanobacteria can be possible, however, the documented cases have been not severe health effects. Among the common allergic reactions, skin irritation, rashes, eye irritation, and respiratory symptoms are the most common. Severe effects can include gastroenteritis and liver or kidney problems. The most likely exposure for humans would be by accident while doing recreational activities or accidental ingestion. While EPA does not presently have water quality criteria for microcystin, cyanotoxin, or any other algae toxins, the World Health Organization (WHO) has established recreational exposure guidelines for Chlorophyll-*a*, cyanobacterial cell counts, and microcystin (Table 2).

Table 2 - World Health Organization threshold of risk associated with potential exposure to cyanotoxins.(Source Human Health Recreational Ambient Water Quality Criteria, 2020 p.7)

Relative Probability of Acute Health Effects	Cyanobacteria (cells/mL)	Chlorophyll *a* (µg/L)	Estimated Microcystin Levels (µg/L)[a]
Low	< 20,000	< 10	< 10
Moderate	20,000–100,000	10–50	10–20
High	>100,000–10,000,000	50–5,000	20–2,000
Very High	> 10,000,000	> 5,000	> 2,000

[a] WHO (2003b) derived the microcystin concentrations from the cyanobacterial cell density levels.

2.4 REMEDIATION AND PREVENTION OF ALGAE GROWTH

There is a natural advantage on plants to take up, accumulate, and/or degrade constituents that are present in soils and water environments such as nutrients and heavy metals (GWRTAC, 1996). Phytoremediation is the process where these plants are used to clean up contaminated soils and groundwater. If the plants can store large amounts of nutrients are called hyper-accumulators.

According to Barter (1999), there are five basic phytoremediation techniques: rhizofiltration, phytoextraction, phytotransformation, phytostimulation, and phytostabilization.

Rhizofiltration. Remediation technique where plant's roots take up the contaminants.

Phytoextraction. Soil is the one that uptake the contaminants.

Phytotransformation. Using plant metabolism, contaminants are degraded. It can involve soil and water.

Phytostimulation or plant-assisted bioremediation. All the work is done in the root zone where microbial degradation is stimulated.

Phytostabilization. Migration or movement of contaminants through the soil is reduced using plants.

Phytoremediation can clean up several different contaminants; heavy metals, chlorinated solvents, PCBs, insecticides, explosives, among others, have been tested in laboratories in small-scale. (Nedunuri et al., 2000). Advantages and disadvantages of phytoremediation are shown in Table 3.

Table 3 - Advantages and Disadvantages of Phyto-remediation

Advantages	Disadvantages
Remediation is accomplished with minimal environmental disturbance.	Remediation usually requires more than one growing season.
It is an aesthetically pleasing and passive, solar energy-driven technology.	Treatment is limited to soils less than one meter from the surface and groundwater less than 3 m from the surface.
It can be used on a large range of contaminants.	Climate and hydrologic conditions such as flooding, and drought may restrict plant growth and the type of plants that can be utilized.
The generation of secondary wastes is minimal.	Contaminants may enter the food chain through animals which eat the plants used in these projects.
Organic pollutants may be converted to CO2 and H2O instead of transferring toxicity.	Require special disposal of the used plants.
It is cost-effective for large contaminated sites (with a low concentration of contaminants).	
The topsoil is left in a usable condition and may be used in agriculture.	
The soil can remain at a site after the removal of the contaminant rather than being disposed of or isolated.	
The uptake of contaminated groundwater can prevent the migration of contaminants.	

Constructed wetlands are engineered systems that have been designed and constructed to utilize the natural processes involving wetland vegetation, soils, and their associated microbial assemblages to assist in treating wastewater. They are designed to take advantage of many of the processes that occur in natural wetlands within a more controlled environment. (Hammer and Bastian, 1989).

2.5 OTHER POTENTIAL METHOD TO CONTROL ALGAE IN RESERVOIRS

Modified Zeolite as an algaecide. Zeolites are naturally occurring volcanic minerals; they are from hydrated aluminosilicate minerals family and alkali and alkaline-earth metals such as calcium and potassium. The zeolites are noted for their lability toward ion-exchange and reversible dehydration. They have a framework structure that encloses interconnected cavities occupied by large metal cations and water molecules, in other words, they are negatively charged and have a cation adsorption capacity; because of their honeycomb structure, they can absorb other materials much as a sponge absorbs water**.** Because of the properties of zeolite, it is a perfect material to be used in filters to prevent and treat algae problems in a less toxic way for the environment. The salinity absorbance potential of zeolite can be maximized if surface-tailored with copper and used as a natural algaecide. The essential structural feature of a zeolite is a three-dimensional tetrahedral framework in which. Some natural zeolites such as Clinoptilolite, has proven to be one of the best natural exchange resins and it is inexpensive compared to synthetic media.

CHAPTER 3 –MATERIALS AND METHODS

Figure 3 shows an overview of the methodology followed chronologically and the type of analysis performed with the data obtained.

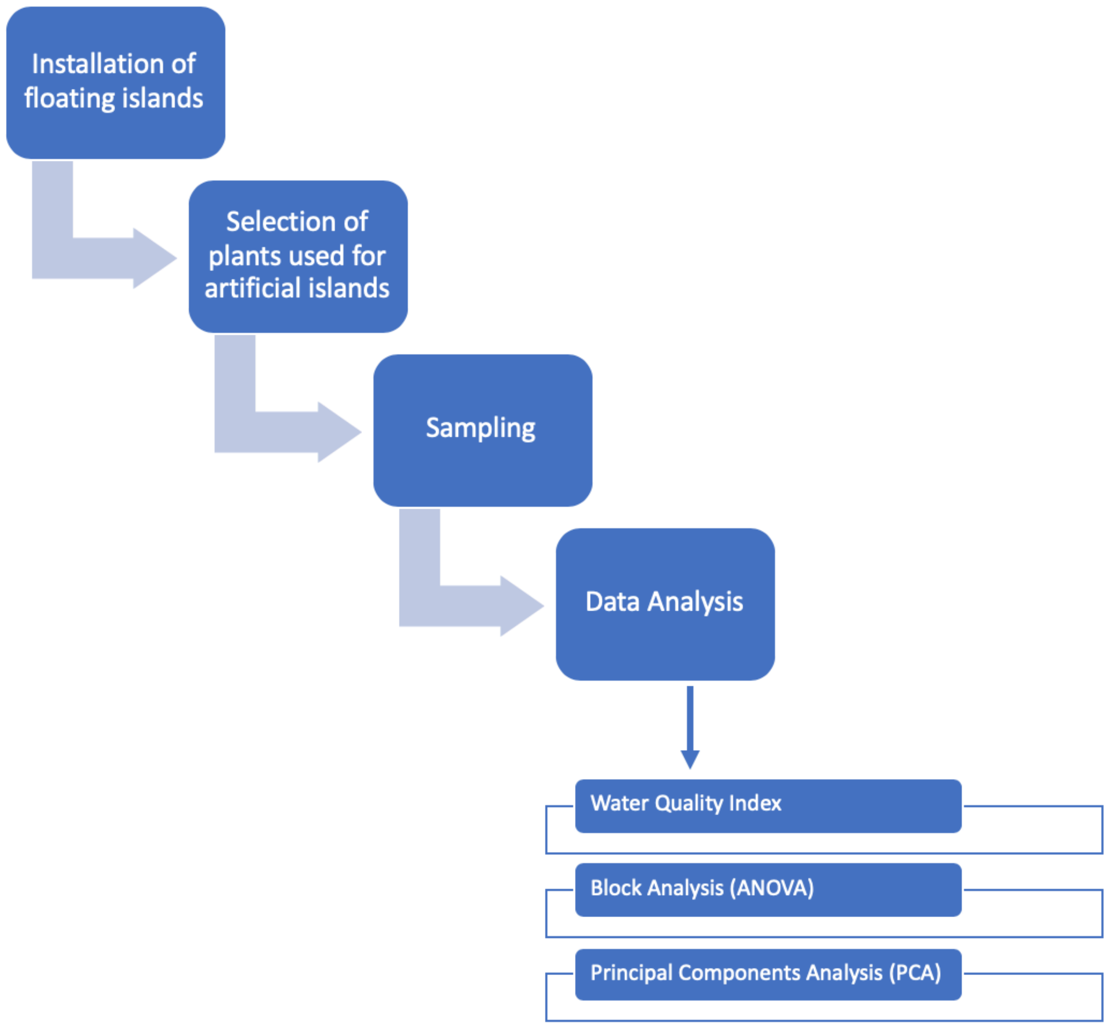

Figure 3 - Overview of the methodology chronologically followed.

3.1 INSTALLATION OF FLOATING ISLANDS

In September 2018, two 35 square feet kidney shaped BioHaven ® Floating islands (BFI) from Martin Ecosystems were installed in a west cove of the lake (Figure 4).

Figure 4. Aerial photo showing location of floating islands in Ascarate Lake obtained from Google Earth Maps, 2020.

The floating islands have polyurea armoring and were installed with a single anchor point with a swivel shackle with stainless wires to cinder blocks. The floating islands have openings for "planting" the flora designed to remove nutrients from the water such as NO_3^-, PO_4^{3-}. Illustration of the floating islands is in Figure 5.

Figure 5 - Installed floating Islands

3.2 SELECTION OF PLANTS USED FOR THE ARTIFICIAL ISLANDS

Four plants were tested, Rain Lily, African Iris, Regal mist and Horse tail; all four plants are perennials and low maintenance. Undergraduate research assistants used a modified methodology by McFarlane and Yanai (2006) to test NO_3^- and PO_4^{3-} uptake. The results showed that African Iris, Horse tail and Regal Mist have greater absorption rates. However, African Iris was selected because is readily available in plant nurseries in El Paso.

3.3 SAMPLING

Even though water quality monitoring was performed immediately after the floating islands were installed, a rigorous sampling protocol for this research project started in January 2019. Georeferenced samples were collected from a boat at different distances from the islands (Figure 6). We used a Garmin eTrex Summit HC GPS to georeferenced location of samples as follows: site A is located right next to the artificial island; site B is located between the islands;, site C is located to the south bridge between the islands and the aerator; site D is located next to the aerator; and site E outside of the cove. .

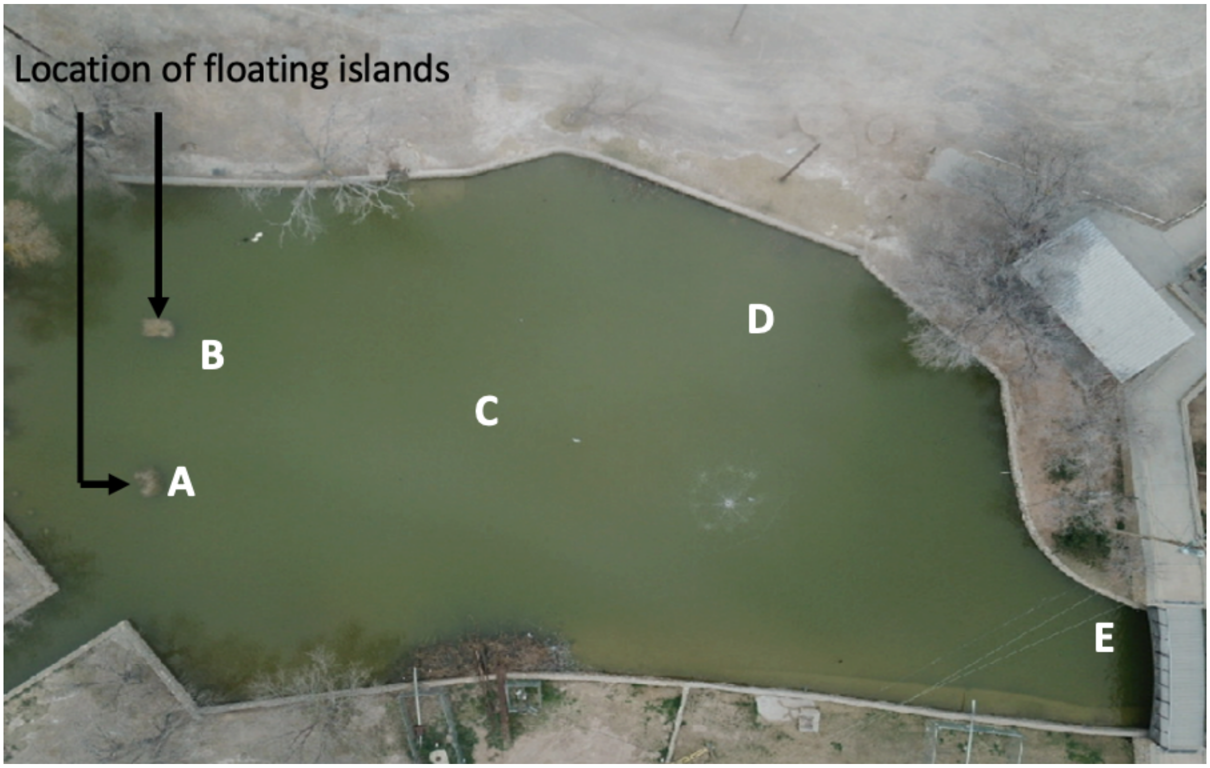

Figure 6 - General location of sampling points

Figure 7 shows a photo of the team collecting samples. Our team visited the lake more than 30 times to collect samples. However, weather conditions were not always favorable for sample collection. For this research, only 20 weeks' samples were used. Table 4 shows a summary of the data collected.

Figure 7 - Sampling and testing in Ascarate Lake

As can be seen in Table 4, 10 different water quality parameters: dissolved oxygen, pH, temperature, chlorophyll-*a* & *b* and nutrients were measured in different locations throughout the lake. Electrical conductivity, temperature, dissolved oxygen, pH were measured at the time of sampling using a Vernier pH and conductivity probe along with a portable Vernier LabQuest 2 device model LQ2-LE. Probes and portable devices were calibrated following manual manufacturer instructions. Probes were rinsed with deionized water and dried using kimtech kimwipes in the site after every sample measuring. Nitrate, total nitrogen and phosphorus (reactive and total) levels were measured at the Civil Engineering Laboratories in the University following the HACH Method 10206, 10208 and 10209/10210 respectively. Chlorophyll-*a* and *b* were tested using Turner Design AquaFluor portable design model 8000-010 using the manufacturer's instructions.

Table 4 - Summary of data considered for the analysis.

No. of Visits	Date	No. of Sites	No. of Parameters
1	6/5/19	10	pH, Conductivity, Temp, Chlorophyll-*a* & *b*, NO_3^-, PO_4^{3-} , and DO
2	6/12/19	10	
3	6/19/19	10	
4	6/25/19	10	pH, Conductivity, Temperature, Chlorophyll-*a* & *b*, NO_3^-, PO_4^{3-}, and Dissolved Oxygen
5	7/3/19	10	
6	7/10/19	10	
7	7/15/19	10	
8	7/24/19	10	
9	7/29/19	10	
10	9/11/19	10	pH, Conductivity, Temperature, Chlorophyll-*a* & *b*, NO_3^-, PAR, and DO
11	9/20/19	10	
12	9/27/19	10	
13	10/11/19	5	pH, Conductivity, Temperature, Chlorophyll-*a* & *b*, NO_3^-, TKN, PO_4^{3-}, and Dissolved Oxygen
14	10/18/19	5	
15	10/25/19	5	
16	11/1/19	5	
17	11/8/19	5	
18	11/15/19	5	
19	11/22/19	5	
20	12/06/19	5	

3.4 AERIAL PHOTOGRAPHS

Aerial photographs were taken using the DJI Mavic 2 Pro drone with Hasselblad Camera 1” CMOS sensor. The captured georeferenced images from the lake and surrounding infrastructure were processed using ENVI software to observe changes in vegetation and algae in the lake.

3.5 DATA ANALYSIS

Water Quality Analysis

To evaluate the changes in water quality of Ascarate Lake, the calculation and formulation of the Water Quality Index (WQI) were done. A water quality index is a weighted average of selected ambient concentrations of pollutants usually linked to water quality classes. (Glossary of Environment Statistics, Studies in Methods, New York, 1997). The index is a mathematical means of calculating a single value from multiple test results. The index result represents the level of water quality in the lake and can be used to monitor water quality over a period of time in order to detect changes in the water's ecosystem as well as compare with other lakes. We used two different methods to calculate the water quality index; the first method used was a modified procedure by Alboidy et al. (2010) as follows:

1. Five parameters were selected (pH, chlorophyll-*a*, temperature, dissolved oxygen and NO_3^-.). These parameters were selected because they are regulated by Texas Commission on Environmental Quality (TCEQ). Each of the selected parameters was assigned a weight (AWi) ranging from 1 to 4 being 1 the least significant and 4 the most significant as follows: AW_{DO}=2, AW_{pH}=3, $AW_{Chl\text{-}a}$=3, AW_{Temp}=4, AW_{NO3-}=4.
2. The relative weight (RW) was calculated using the following Equation 1:

Equation 1- Relative weight (RW)

$$RW = \frac{AWi_i i}{\sum I}$$

Where RW is the relative weight and AW_i the assigned weight for each parameter, and ΣI is the sum of the Assigned Weights, in this case 16.

3. A Quality rating scale (Q_i) was calculated by dividing its concentration in each water sample (C_i) by its respective standard according to the EPA standards for surface water (S_i). The result was then multiplied by 100 as shown in the following Equation 2:

Equation 2 – Quality rating scale (Qi)

$$Qi = \frac{Ci}{Si} * (100)$$

The Standards Values (Si) used to get our WQI were: NO_3^- = 10 mg/L temperature = 95°F, dissolved oxygen = 5 mg/L, pH= 9 SU, chlorophyll-*a*= 75 mg/L. Where *Qi* is the quality rating scale, *Ci* is the concentration found and *Si* is the standard value according to EPA standards.

4. The sub-indices SI_i were calculated using the following Equation 3:

Equation 3 - Standards Values (Si)

$$SIi = RW * Qi$$

5. Finally, the WQI was calculated using the following Equation 4:

Equation 4 - Water Quality Index (WQI)

$$WQI = \sum_{i=1}^{n} SIi$$

The used of a second method to calculate the water quality index (WQI) was required to have standard values not based on assigned values and obtain data that can be compared to other lakes. The second method used was a procedure by Srivastava, Kumar (2014). For this procedure there are two parts of the water quality index, the Q-value and weighting factor. The Q-value is an indication of how good (or bad) the water quality is relative to one parameter and it ranges from 0 to 100 as shown in Table 5.

Table 5 - Water quality ranges

Index Ranges	Water Quality
0-25	Very bad
25-50	Bad
50-70	Medium
79-90	Good
90-100	Excellent

The weighting factor sets the relative importance of the parameter to overall water quality. (Srivastava, 2014). The weighting factors of water quality parameters are shown in Table 6 under the column named weight factors (x). The values that we used to calculate our water quality index (WQI) and their corresponding weighting factors are under columns named Y-factors and Weight factors (y).

Table 6 - Weighting factors of water quality parameters

Parameters	Weight Factors (x)	Y- Factors	Weight Factors (y)
DO	0.17	DO	0.17
Fecal Coliform	0.16	pH	0.11
BOD	0.11	Nitrate	0.10
pH	0.11	Temperature	0.10
Nitrate	0.10	-	-
Phosphate	0.10	-	-
Temperature	0.10	-	-
Turbidity	0.08	-	-
TDS	0.07	-	-
Total Wx	**1.00**	**Total Wy**	**0.48**

The standard formula used to calculate water quality index with all the parameters is Equation 5:

Equation 5 – Standard water quality index (WQI)

$$WQI = \sum WxQx$$

The formula used when concentrations of some parameters are not available is Equation 6:

Equation 6 – Water quality index for missing parameters (WQI_{MP})

$$WQI_{MP} = \sum WyQy \,/ \sum Wy$$

Where y= available parameters, Qy =q-values of available parameters and Wy= weighting factors of available parameters.

Block Analysis

Once a water quality index was calculated we looked at arranging the data in groups (blocks) with comparable properties as shown in Table 7.

For the block analysis, there are seven data groups or blocks as follows:

1. Time (20 visits)
2. Location (georeferenced sampling sites: Five sampling sites) (Figure 6)
3. Water Quality Parameters (5 parameters: NO_3^-, pH, Conductivity, Chlorophyll-*a* and Dissolved Oxygen DO)

The results were analyzed for differences in space from sampling in site A right next to the artificial island, site B between the islands, site C to the south bridge between the islands and the aerator, site D next to the aerator, or site E outside of the cove to compare the results of sampling. Results were analyzed for differences in time as well, visit 1 in comparison to the rest of the visits. Using Minitab software, an analysis of Variance (ANOVA) was performed for each parameter to determine if there were significant differences between the variances found in areas close to the islands compared to areas outside the influence of the islands for each of the parameters and blocks. ANOVA is used to analyze the differences among group means in a sample. (Jackson, 1994-2012).

Additionally, a Principal Component Analysis (PCA) was used to identify which are the principal components of the data and understand how influential they were for the variance. Following is a definition of the terms used understand ANOVA results.

F-value –The F-value is the test statistic used to determine whether the term is associated with the response. F-value is used to calculate the p-value, which is used to make a decision about the statistical significance of the terms and model.

F- Critical – F- Critical value is the value to compare with the obtained f-value to find out if the means between two populations are significantly different. It is also called F statistics.

P-value –The p-value is a probability that measures the evidence against the null hypothesis. Lower probabilities provide stronger evidence against the null hypothesis. To determine whether each main effect and the interaction effect is statistically significant, compare the p-value for each term to your significance level to assess the null hypothesis. Usually, a significance level (denoted as α or alpha) of 0.05 works well. A significance level of 0.05 indicates a 5% risk of concluding that an effect exists when there is no actual effect.

- If the p-value is less than or equal to the significance level, then the effect for the term is statistically significant. In other words, the null hypothesis of no change is rejected.
- If the p-value is greater than the significance level, the effect is not statistically significant. In other words, the null hypothesis of no change cannot be rejected.

CHAPTER 4 – RESULTS AND DISCUSSION

4.1 WATER QUALITY INDEX

Figure 8 shows the mean values of the water quality index (WQI) obtained for each parameter. The average values were obtained from the 20 weeks per site, being site A right next to the artificial island, site B between the islands, site C to the south bridge between the islands and the aerator, site D next to the aerator and site E outside of the cove.

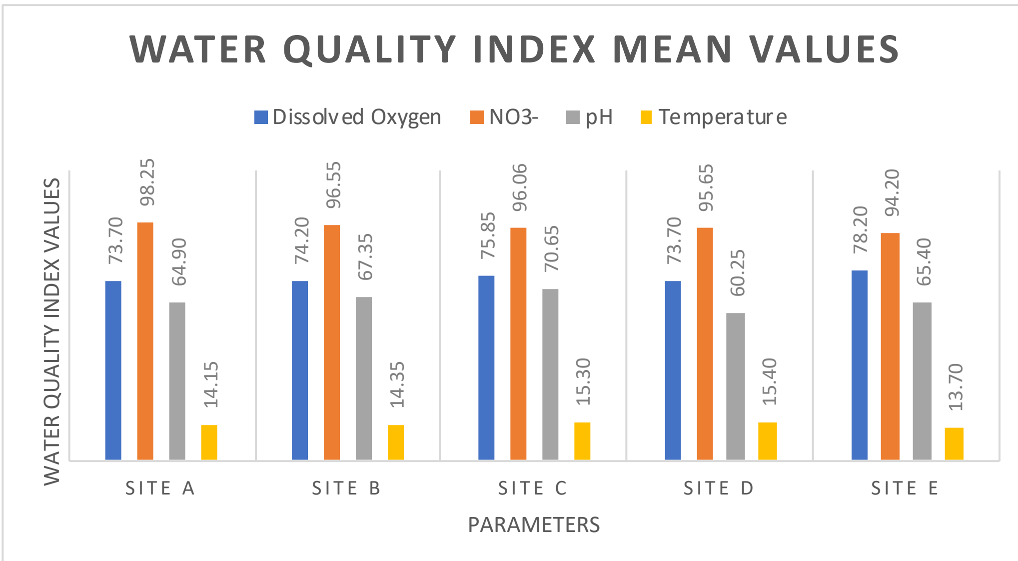

Figure 8 - Parameters Mean Values

4.2 BLOCK ANALYSIS

Based on water quality index performed, we decided to perform a block analysis on the data to compare the data obtained among visits and in between sites. In Table 7, the blocks used for the analysis and its corresponding description is presented.

Table 7 - Groups or blocks used for the Block Analysis

Block 1	Visit dates (Visit)
Block 2	Sampling Site location (Site)
Block 3	NO_3^-
Block 4	pH
Block 5	Temperature
Block 6	Chlorophyll-a
Block 7	DO

4.3 ANOVA

An analysis of variance was performed for each of the parameters considered for the analysis: NO_3^-, pH, chlorophyll-*a*, temperature and dissolved oxygen. Based on the histograms obtained from each analysis, data is close enough to a normal distribution, thus ANOVA could be used. We performed a non-parametric test to corroborate that F- and P-values were consistent. P-values indicate if there are significant differences within the groups. The F-value indicates the ratio of two variances, the ratio of the variances between the groups to the variances within the groups, the larger the value, the greatest dispersion. For both P-and F-Values the null hypothesis is that there are no significant differences whereas the alternate hypotheses is that there are significant differences. Specifically, the larger the F-value, the greater the differences between the groups. After comparing P-value to the Significance Level α of 0.05, we can determine if the null hypothesis is rejected or not. If the P-value is less than or equal to the significance level (α), the null hypothesis is rejected. As stated earlier, for this analysis, the blocks used were Visit/date, Site/location and Water Quality Parameters. Results for the ANOVA General linear modeling are shown in Table 8 for NO_3^-, Ph, Chlorophyll a, Temperature and Dissolved oxygen, respectively.

Table 8 shows that P-values for visits were less than 0.05 which infers that differences in visits were significant for NO_3^-, pH, Chlorophyll, Temperature, and Dissolved Oxygen.

If $P<0.05$, null hypothesis stands, meaning that there is not a significant change. If $P>0.05$, the null hypothesis is rejected so there is evidence to support that there are significant changes.

Table 8 - ANOVA P & F-values

Blocks	Parameter	F-Value	F-Critical	P-Value	Alpha (α)
Visit	NO_3^-	3.50	1.73	0.00	0.05
Site	NO_3^-	1.08	2.49	0.37	0.05
Visit	pH	1.99	1.73	0.02	0.05
Site	pH	0.64	2.49	0.63	0.05
Visit	Chlorophyll-*a*	50.42	1.73	0.00	0.05
Site	Chlorophyll-*a*	1.34	2.49	0.26	0.05
Visit	Temperature	216.95	1.73	0.00	0.05
Site	Temperature	2.20	2.49	0.08	0.05
Visit	DO	67.18	1.73	0.00	0.05
Site	DO	1.73	2.49	0.15	0.05

In Figure 9, we can see how the F-value is being compared to F-Critical value for visits; if F- value is less than the F-critical value, there is no evidence to reject the null hypothesis but in this case F-value is greater so we can reject the null hypothesis and say that differences in variances amount visits are significant for our analysis. P-value is the area from the calculated F-value towards the right in our sample, so if F-value is greater than F-Critical, P-value will be less than alpha (0.05).

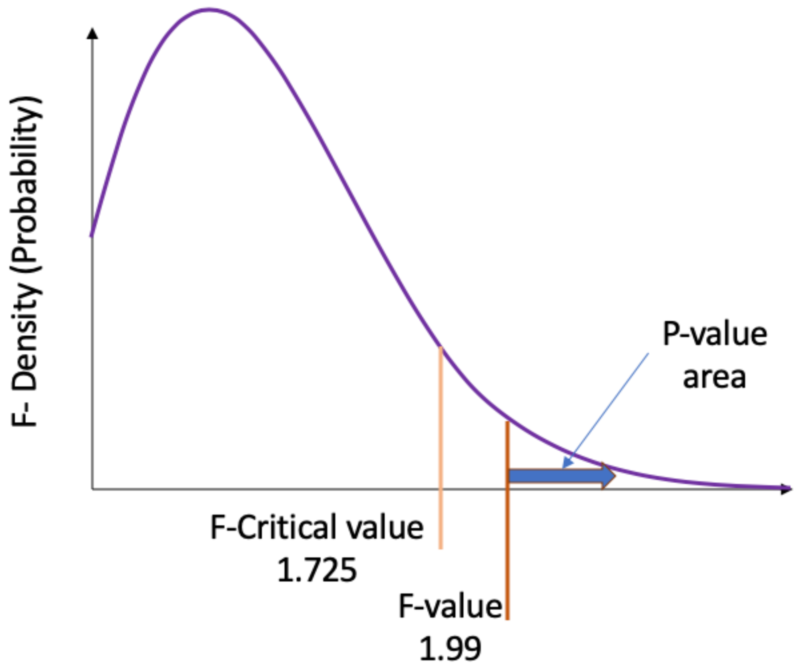

Figure 9 - F-critical comparison to F-value for visit 1, site 1.

4.4 PRINCIPAL COMPONENT ANALYSIS (PCA)

Since we found that Visits were significant when analyzing data, we wanted to look at what are the most influential water quality parameters. Therefore, we performed a Principal Component Analysis. PCA is a multivariate analysis used to explore big data sets. PCA helps to identify relationships and significance in and between the data. PCA was used in Minitab to identify the principal components from our observed data. PC1 defines the first principal component, PC2 stands for the second principal component and so on. Using Table 9, we decided to use the size of eigenvalue to determine the principal component. The largest Eigenvalue >1 will determine the principal components, in this case there are two principal components. To verify that our principal components are included in the acceptable level of variance, we use the cumulative values to identify the principal component. The first three components explain the 86% variation of the data which is above the acceptable level of variance 80%. Analyzing the proportion values, we can see that the first principal component accounts for 56.4% of the total variance, and using Table 10 we can identify the variables that correlate the most with the first principal component (PC1) as Temperature and NO_3^- as the second principal component (PC2).

Table 9 – Eigenanalysis of the Correlation Matrix

Eigenanalysis	PC1	PC2	PC3
Eigenvalue	**2.47**	**1.02**	**0.81**
Proportion	0.49	0.20	0.16
Cumulative	0.49	0.70	0.86

Table 10 – Eigenvectors

Variable	PC1	PC2	PC3
NO_3^-	0.420	0.032	0.690
pH	0.009	0.981	0.081
Chlorophyll-*a*	-0.468	0.146	-0.379
Temperature	**0.564**	-0.032	-0.366
DO	-0.535	-0.119	0.489

The number of principal components can be visualized in Figure 10. The scree plot orders the eigenvalues from largest to smallest. We use the components in the steep curve of the graph to determine the number of principal components in this case there is one principal component that accounts for more than 50% of the total variance.

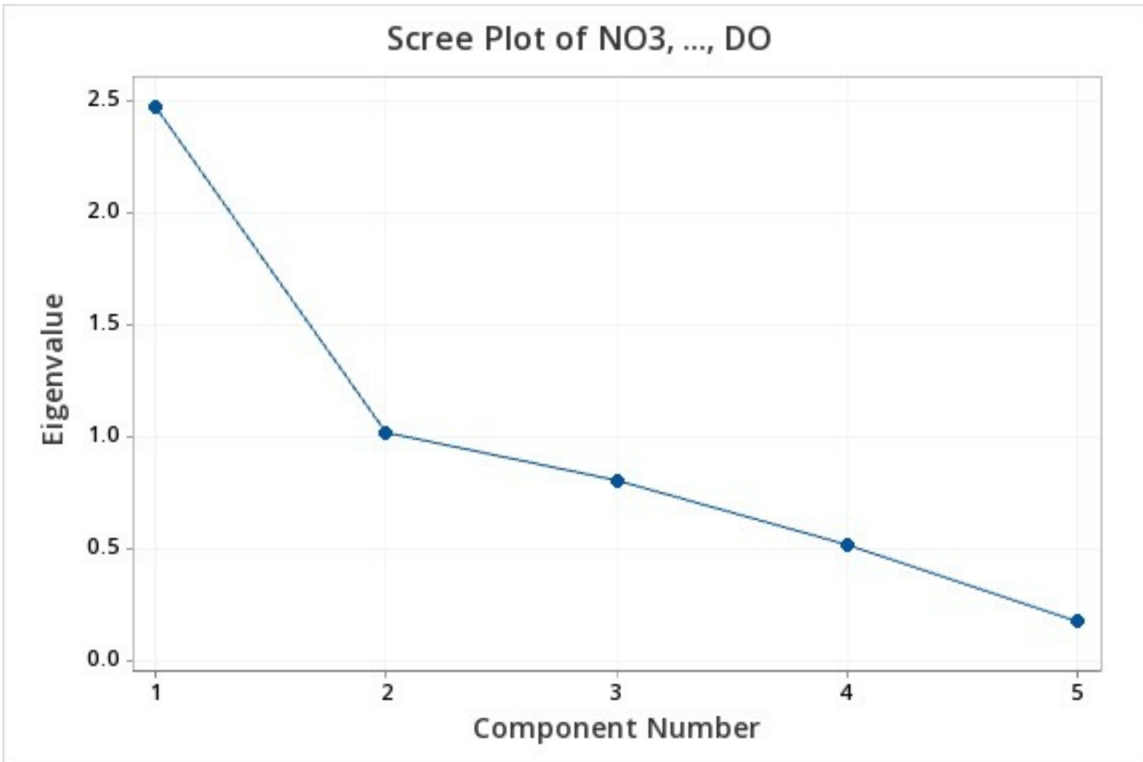

Figure 10 – Scree Plot for the Principal Component Analysis (PC 1=temperature, PC2=NO_3^-)

On Figure 11, loading scree and clusters graphs can be seen, was used to visually interpret the first two principal components; Temperature and NO_3^- parameters have large positive loadings on component 1 while pH has large positive loading on component 2. The clusters can tell us that data can be grouped.

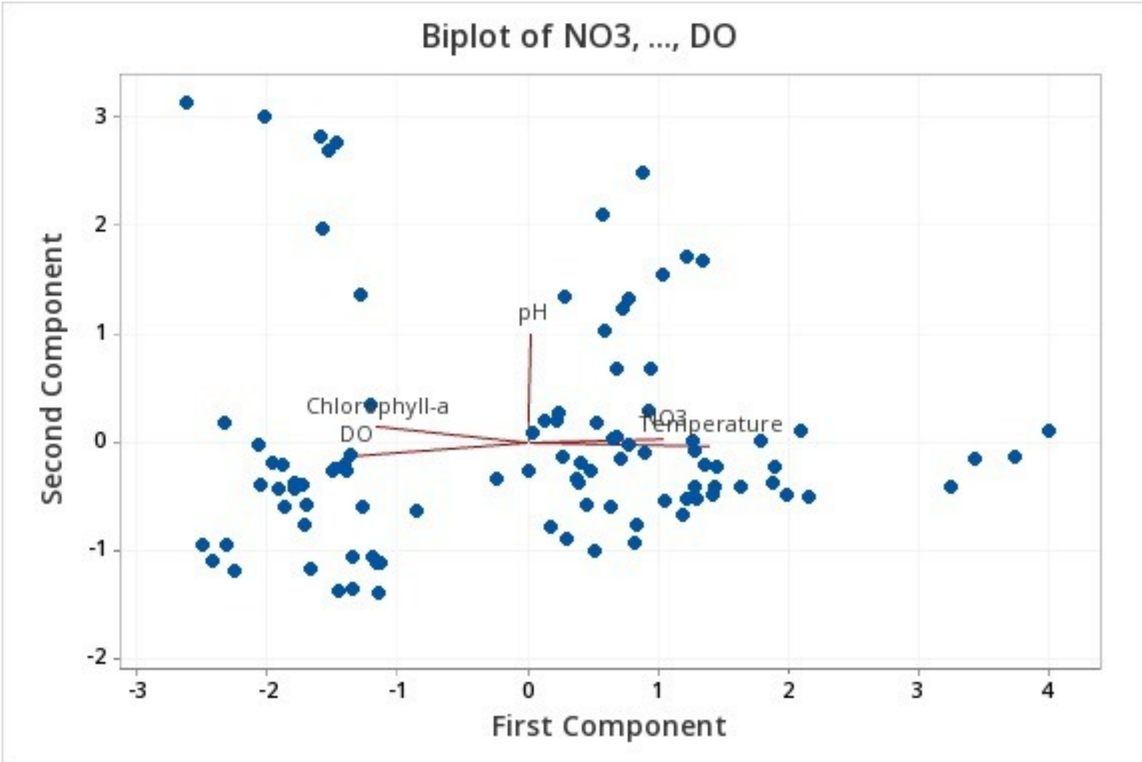

Figure 11 - Biplot of Principal Component Analysis

In summary, temperature was the component that accounted for greater variance and we can see also how NO_3^- values are incrementing towards sample 5 (Site E) which is the farthest from the artificial Islands and pH is decreasing in average towards the sample 5 (Site E). Visits were significant for all the parameters measured. In other words, the date when the sample was taken is important and it can be seen in the analysis. This could be because the samples were taken in different seasons with different temperatures for each. Weather conditions during summer were not the same as weather conditions during the fall or winter when temperatures decrease, and less solar light is available during the day. As corroborated by PCA, Temperature and NO_3^- were the two principal components of our analysis. They are correlated and explain why the presence of NO_3^- changes overall assisting the algae growth. There was a slightly decrease in the nitrate levels surrounding the artificial islands compared with the samples taken away from the islands. In order to make this gap greater and easier to perceive, more artificial islands might be needed to reduce the overall levels of nutrients and prevent algae growth that could affect aquatic life.

4.5 AERIAL PHOTOGRAPHS

Aerial georeferenced images were processed using the NDVI Normalized Difference Vegetation Index (NDVI) in ENVI software. NDVI normalizes green leaf scattering in the near-infrared wavelength and chlorophyll absorption in the red wavelength. (Figure 12)

- Values range from -1 to 1
- Healthy veg. 0.2 to 0.8

In the processed image, the change in color can be easily observed and can account for an easy determination of presence of algae blooms. This is a promising method to analyze data in the future. (**Error! Reference source not found.**)

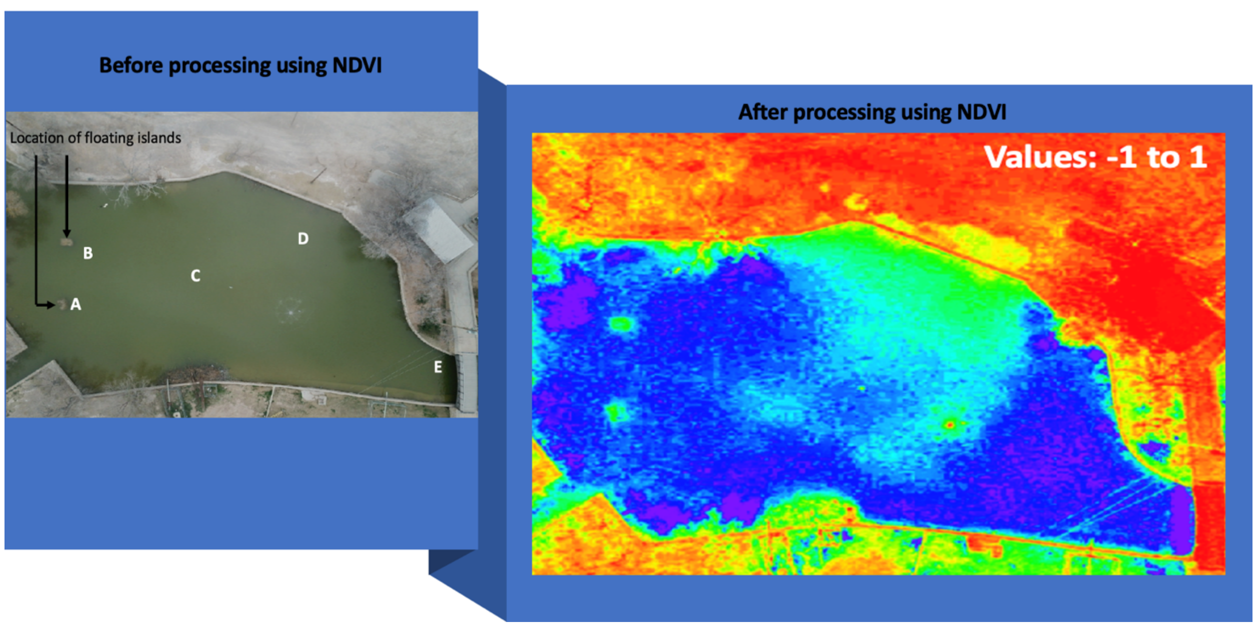

Figure 12- Aerial photograph of the lake's cove where the islands were installed before and after processing it using NDVI

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

As results showed, there was an apparently decrease in the nitrate levels surrounding the artificial islands compared with the samples taken further away from the islands. Therefore, the use of floating islands showed potential as a phytoremediation technique to prevent HABs in Ascarate Lake. However, ANOVA says the difference is not statistically significant so more artificial islands are needed to reduce the overall levels of nutrients and make that gap significant for the analysis of variance. The principal component analysis showed us that there was a difference and special attention must be placed on temperature when trying to understand levels of nitrate. During summer or winter, different conditions will be present in the lake, increasing or decreasing NO_3^- levels, however, placing artificial islands with African iris plants can help reducing the levels of nitrate overall. The presence of artificial islands will resist to create optimum conditions for algae growth. It is a way to help Ascarate Lake to reduce levels of nitrate all year around and protect the aquatic life of the lake. Additional advantages to the eco-friendly alternative of using phytoremediation are that it is cost-effective and provide a pleasant view for the visitants.

5.1 RECOMMENDATIONS FOR FUTURE WORK

This study will provide a platform for an integrated approach to the short- and long-term study of the restoration and preservation of the water quality of a lake as an urban ecological system within an urban watershed, using process-based watershed modeling, GIS technology, and hyperspectral remotely sensed information. This preliminary work will provide the basis for studying and implementing phytoremediation to prevent algae growth in lakes.

Market prioritization for use of Zeolite as algaecide. As part of a National Science Foundation Regional I-Corps course which teaches professionals how to commercialize their technologies and identify if there is a potential market for that specific product or not. The customer discovery phase is an iterative process of physically getting out of the building to interview potential customers and stakeholders to understand their problems and pain points. My team tested the zeolite algaecide for use on pools instead of high phosphorus concentrations common algaecides. We tested algae problems in pools, interest in new environmentally friendly alternatives, and cost-effective products. We talked to pool maintenance workers, apartment managers, pool owners, pool users, park maintenance manager and pool supplier's companies to see if there were some possible customers are interested in our offer. The results of our customer discovery process changed our focus market to lakes and reservoirs managers who are facing algae problems and want to use natural products. After conducting more than 30 interviews we deducted that the zeolite based algaecide has a potential for commercialization among lakes and natural water deposits. Managers that are struggling with high levels of algae would be interested in our product because it is natural.

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APPENDIX

06/05/2019

Samples	Lat N°	Lat '	Lat "	Long W°	Long '	Long "	Ph	EC	Chl. A	Chl B.	NO3- (mg/L) -N	PO43- (mg/L) -PO43-	Temp	DO
1	31	45	14.4	106	24	18.5	8.0	298.3	28.35	0.052	4.5	0.04	28.45	5.06
2	31	45	15.0	106	24	18.7	7.9	300	27.56	0.05	3.4	0.11	28.72	**5.13**
3	31	45	15.2	106	24	18.4	8.0	299.8	24.1	0.041	0.1	0.02	29.31	5.36
4	31	45	14.5	106	24	18.0	8.3	301.1	23.38	0.044	0.1	0.25	28.98	5.4
5	31	45	14.7	106	24	17.8	9.0	299.4	28.93	0.051	4.6	0.2	29.21	5.44
6	31	45	14.8	106	24	17.3	13.5	298.1	25.92	0.039	3.1	0.19	28.7	5.21
7	31	45	15.5	106	24	17.7	8.4	298.6	29.01	0.048	1.3	2.46	28.39	5.5
8	31	45	14.9	W106	24	15.7	8.5	294.2	37.75	0.085	2.8	0.2	28.58	5
9	31	45	15.4	106	24	15.9	8.5	290.1	35.23	0.071	0.7	0.4	29.24	5.15
10	31	45	15.0	106	24	14.9	8.4	286.6	38.48	0.076	0.9	0.73	29.01	5.32

06/12/2019

Samples	Lat N°	Lat '	Lat "	Long W°	Long '	Long "	Ph	EC	Chl. A	Chl B.	NO3- (mg/L) -N	PO43- (mg/L) -PO43-	Temp	DO
1	31	45	14	106	24	18.11	7.63	285.8	4.428	0.005	1.1	0.16	29.57	5.63
2	31	45	14.55	106	24	18.4	7.76	287.4	4.667	0.001	2.1	0.3	29.46	5.03
3	31	45	14.9	106	24	18.88	7.86	287.9	3.771	0.001	2.7	0.32	29.51	5.05
4	31	45	12.76	106	24	17.9	7.85	288.5	4.102	0.001	0.6	0.12	29.4	5.13
5	31	45	14.8	106	24	17.49	7.94	288.6	4.078	0.002	1.7	0.18	29.79	5.32
6	31	45	14.66	106	24	17.54	7.50	290.5	5.958	0.001	1	0.07	29.66	5.08
7	31	45	14.95	106	23	17	7.80	290.1	4.425	0.004	1.4	0.17	29.5	5.02
8	31	45	15	106	24	16.6	7.85	292.1	3.773	0.002	3.2	0.1	29.81	5.07
9	31	45	15.21	106	24	16.32	8.05	290.7	5.766	0.001	5.2	0.1	29.9	5.22
10	31	45	14.74	106	24	15.88	8.14	291.1	7.300	0.003	2.1	1.5	29.79	5.18

06/19/2019

Samples	Lat N°	Lat '	Lat "	Long W°	Long '	Long "	Ph	EC	Chl. A	Chl B.	NO3- (mg/L) -N	PO43- (mg/L) -PO43-	Temp	DO
1	31	45	14.46	106	24	18.39	7.35	276.6	12.45	0.023	N/A	0.28	29.59	5.05
2	31	45	14.96	106	24	18.6	7.67	273.6	11.82	0.014	0.4	1.39	29.68	5.08
3	31	45	15.6	106	24	18.13	7.92	275.2	11.07	0.012	N/A	0.27	29.8	5.14
4	31	45	14.97	106	24	18.39	7.99	276.1	11.39	0.014	0.9	0.28	30.13	5.07
5	31	45	14.43	106	24	17.49	8.04	277.4	11.00	0.016	0.1	0.29	29.31	5.18
6	31	45	14.08	106	24	18.51	7.95	277.3	11.50	0.010	1.2	0.14	29.48	5.36
7	31	45	7.25	106	23	57.07	7.95	278.5	9.70	0.007	0.4	0.34	29.52	5.7

8	31	45	15.01	106	24	15.67	8.17	278.7	16.99	0.029	2.9	0.22	29.31	5.19
9	N31	45	15.46	W106	24	14.81	8.22	284.5	16.17	0.024	3.7	0.62	29.42	5.39
10	N31	45	14.9	W106	24	15.05	8.32	283.3	20.85	0.036	2.6	N/A	29.62	5.46

06/25/2019

Samples	Lat N°	Lat '	Lat "	Long W°	Long '	Long "	Ph	EC	Chl. A	Chl B.	NO3- (mg/L) -N	Temp	DO
1	31	45	14.33	106	24	18.11	7.3	289.8	16.58	0.024	3.5	29.57	5.43
2	31	45	14.81	106	24	18.26	7.59	293.2	17.44	0.013	1.2	29.38	5.61
3	31	45	15.4	106	24	18.11	7.79	292.2	16.93	0.01	0.2	29.61	5.9
4	31	45	15.03	106	24	17.81	7.88	291.9	18.69	0.017	0.4	29.42	5.29
5	31	45	14.58	106	24	17.31	8.07	292.7	18.19	0.021	1.5	28.79	5.73
6	31	45	14.76	106	24	17.2	8.02	293.1	15.76	0.011	0.5	28.2	5.89
7	31	45	15.25	106	24	16.66	8.04	292.7	17.94	0.016	N/A	29.37	5.31
8	31	45	14.7	106	24	15.56	8.41	293.4	30.62	0.043	3.6	29.33	5.28
9	31	45	15.22	106	24	15.26	8.62	292.8	29.43	0.038	1.2	29.51	5.38
10	31	45	11.22	106	24	5.72	8.69	292.2	29.50	0.036	0.2	29.59	5.67

07/03/2019

Samples	Lat N°	Lat '	Lat "	Long W°	Long '	Long "	Ph	EC	Chl. A	Chl B.	NO3- (mg/L) -N	Temp	DO
1	31	45	14.6	106	24	18.44	6.65	288.5	9.38	0.208	0.8	28.76	5.31
2	31	45	14.87	106	24	18.6	6.99	289.4	17.26	0.012	0.7	29.13	5.06
3	31	45	15.1	106	24	18.49	8.19	288.6	16.79	0.017	2.1	29.34	5.56
4	31	45	15.33	106	24	17.24	8.36	284.5	17.35	0.025	N/A	28.68	5.68
5	31	45	14.8	106	24	17.5	9.7	287.5	16.26	0.012	1.2	28.5	5.8
6	31	45	14.65	106	24	17.71	7.45	289.1	17.42	0.012	N/A	29.45	5.32
7	31	45	14.89	106	24	17.3	8.92	288.9	15.02	0.016	0.2	29.19	6.08
8	31	45	15.3	106	24	16.33	9.02	288.5	19.37	0.02	3.9	29.51	5.1
9	31	45	15	106	24	16.01	8.15	289.4	18.54	0.018	0.9	29.41	6.17
10	31	45	14.78	106	24	15.92	8.61	288.4	19.10	0.021	11.1	29.3	5.9

07/10/2019

Samples	Lat N°	Lat '	Lat "	Long W°	Long '	Long "	Ph	EC	Chl. A	Chl B.	NO3- (mg/L) -N	PO43- (mg/L) -PO43-	Temp	DO
1	31	45	15.1	106	24	15.16	7.19	289	5.406	0.001	0.7	N/A	30.29	5.09
2	31	45	15.04	106	24	15.24	7.59	290.3	7.647	0.003	N/A	N/A	31.58	5.12

3	31	45	14.84	106	24	15.46	7.45	290.7	5.816	0	N/A	N/A	31.15	5.13
4	31	45	15.29	106	24	16.66	7.86	290.9	7.53	0.002	0.82	N/A	30.38	5.02
5	31	45	14.84	106	24	16.84	7.98	290.5	5.861	0.002	9.6	N/A	31.61	6.65
6	31	45	14.54	106	24	17.5	7.50	289.4	5.288	0.002	0.5	N/A	30.12	5.58
7	31	45	14.57	106	24	17.69	7.80	289.6	7.728	0.004	3.1	N/A	29.83	5.3
8	31	45	15.3	106	24	18.17	8.20	289.4	9.875	0.008	0.8	N/A	29.91	5.04
9	31	45	14.82	106	24	18.46	8.50	289.2	10.41	0.004	2	N/A	30.72	5.37
10	31	45	14.69	106	24	18.34	8.75	289.4	12.260	0.015	0.2	N/A	30.69	6.56

07/15/2019

Samples	Lat N°	Lat '	Lat "	Long W°	Long '	Long "	Ph	EC	Chl. A	Chl B.	NO3- (mg/L) -N	PO43- (mg/L) -PO43-	Temp	DO
1	31	45	14.52	106	24	18.23	6.95	289	13.86	0.002	2.4	N/A	30.92	5.69
2	31	45	14.97	106	24	18.51	7.45	289.9	16.08	0.002	1	N/A	30.57	6.23
3	31	45	15.18	106	24	18.18	7.64	289.8	4.472	0.001	5.4	N/A	30.4	6.31
4	31	45	10.01	106	24	17.62	7.78	290.5	4.945	N/A	5.8	N/A	30.39	5.78
5	31	45	14.68	106	24	17.49	7.88	293.9	2.035	N/A	1.2	N/A	29.79	6.34
6	31	45	14.85	106	24	17.15	7.94	291.2	4.242	0.001	5.7	N/A	30.51	6.56
7	31	45	15.48	106	24	16.57	7.97	290.2	4.58	0.001	4.2	N/A	30.68	5.61
8	31	45	14.63	106	24	15.6	8.45	290.3	9.704	0.001	0.6	N/A	30.99	5.48
9	31	45	15.13	106	24	15.38	8.79	290.1	7.605	0.006	0.3	N/A	30.42	6.21
10	31	45	15.05	106	24	14.85	8.93	290	7.520	0.002	1.5	N/A	30.77	6.5

07/24/2019

Samples	Lat N°	Lat '	Lat "	Long W°	Long '	Long "	Ph	EC	Chl. A	Chl B.	NO3- (mg/L) -N	PO43- (mg/L) -PO43-	DO	Temp
1	31	45	14.4	106	24	18.2	7.21	292.9	6.232	0.002	1.2	N/A	6.86	29.58
2	31	45	14.9	106	24	18.5	7.26	292.5	13.82	0.007	0.5	N/A	6.82	30.1
3	31	45	15.2	106	24	18.5	7.47	292.6	5.388	0.001	N/A	N/A	7.57	29.78
4	31	45	15	106	24	17.6	7.66	288.7	6.779	0.001	0.6	N/A	6.88	29.85
5	31	45	14.6	106	24	17.5	7.76	289.7	8.749	0.002	1.2	N/A	6.95	30.41
6	31	45	14.7	106	24	17.1	7.97	289.5	5.532	0.001	N/A	N/A	6.9	29.45
7	31	45	15.5	106	24	16.7	8.10	289.3	7.018	0.001	0.95	N/A	6.89	29.55
8	31	45	15.1	106	24	15.9	8.44	288.9	9.421	0.007	N/A	N/A	6.89	30.3
9	31	45	15	106	24	15.3	8.76	288.2	5.625	0.001	11	N/A	6.79	30.28
10	31	45	14.5	106	24	15.1	8.80	288.9	14.290	0.013	3.6	N/A	6.91	29.51

07/29/2019

Samples	Lat N°	Lat '	Lat "	Long W°	Long '	Long "	Ph	EC	Chl. A	Chl B.	NO3- (mg/L) -N	PO43- (mg/L) -PO43-	DO	Temp
1	31	45	14.6	106	24	18.5	6.71	270.4	10.14	0.005	N/A	N/A	6.84	29.71
2	31	45	15	106	24	18.5	7.28	262.7	9.975	0.014	1.6	N/A	6.73	29.54
3	31	45	15.2	106	24	18.1	7.58	269.2	8.172	0.167	2.2	N/A	6.55	30.31
4	31	45	14.7	106	24	17.8	7.81	267.9	9.645	0.006	0.7	N/A	6.55	29.6
5	31	45	14.6	106	24	17.3	7.84	266.8	15.73	0.014	4.2	N/A	6.59	29.54
6	31	45	14.9	106	24	16.9	7.85	264.2	9.561	0.05	N/A	N/A	6.42	29.61
7	31	45	15.1	106	24	16.9	7.88	267.8	8.803	0.003	9.4	N/A	6.44	30.38
8	31	45	15	106	24	15.5	7.93	266.6	8.511	0.018	2.1	N/A	6.46	29.51
9	31	45	15.1	106	24	15.4	8.29	262.9	13.42	0.011	1.6	N/A	6.69	29.8
10	31	45	14.9	106	24	15.3	8.57	262.2	10.650	0.009	N/A	N/A	7.12	29.35

09/11/2019

Samples	Lat °	Lat '	Lat "	Long °	Long '	Long "	Ph	EC	Chl. A	Chl B.	NO3- (mg/L) -N	PO43- (mg/L) -PO43-	DO	Temp
1	N31	45	13.7	W106	24	17.28	13.43	3921	19.16	0.029	1.15	N/A	4.44	29
2	N31	45	14.8	W106	24	18	9.15	3997	17.21	0.026	2.67	N/A	4.61	30.2
3	N31	45	15.1	W106	24	18	10.12	4007	19.87	0.024	1.85	N/A	4.65	27.4
4	N31	45	14.8	W106	24	17.42	9.13	4014	18.25	0.034	1.47	N/A	6.32	27.7
5	N31	45	15	W106	24	17.32	12.20	4010	17.68	0.029	1.33	N/A	4.8	27.7
6	N31	45	14.9	W106	24	16.71	12.36	4050	16.9	0.034	1.28	N/A	6.62	27.9
7	N31	45	15.6	W106	24	16.84	13.10	4010	17.69	0.034	1.99	N/A	4.77	27.4
8	N31	45	15.1	W106	24	15.72	9.10	3893	19.95	0.039	2.24	N/A	5.37	28.5
9	N31	45	15.5	W106	24	15.17	9.88	3886	22.34	0.04	1.16	N/A	4.94	33.6
10	N31	45	15.1	W106	24	14.86	9.25	3972	21.980	0.044	1.05	N/A	5.3	30.9

09/20/2019

Samples	Lat °	Lat '	Lat "	Long °	Long '	Long "	Ph	EC	Chl. A	Chl B.	NO3- (mg/L) -N	PO43- (mg/L) -PO43-	DO	Temp
1	N31	45	14.1	W106	24	17.69	7.81	3997	18.08	0.027	1.18	N/A	5.05	27.6
2	N31	45	14.9	W106	24	18.25	8.32	3998	18.11	0.028	0.93	N/A	5.04	28.8
3	N31	45	15.2	W106	24	18.1	12.24	4006	18.46	0.03	1.53	N/A	5.09	28.2
4	N31	45	14.8	W106	24	17.6	13.40	4028	18.34	0.028	1.86	N/A	5.11	26.7
5	N31	45	14.8	W106	24	17.3	12.10	N/A	19.22	0.033	1.99	N/A	4.9	26.3
6	N31	45	14.9	W106	24	16.8	9.34	4004	17.5	0.027	1.55	N/A	5.33	25.5
7	N31	45	15.6	W106	24	16.8	9.98	N/A	19.41	0.036	1.42	N/A	5.03	26.4
8	N31	45	15	W106	24	15.7	11.12	3885	20.43	0.03	1.46	N/A	5.18	27.9
9	N31	45	15.4	W106	24	15.34	10.77	3872	23.68	0.04	1.82	N/A	5.57	28.9
10	N31	45	15	W106	24	14.8	9.67	3874	22.850	0.038	1.07	N/A	5.48	29.1

09/27/2019

Samples	Lat °	Lat '	Lat "	Long °	Long '	Long "	Ph	EC	Chl. A	Chl B.	NO3- (mg/L) -N	PO43- (mg/L) -PO43-	DO	Temp
1	N31	45	14.5	W106	24	18.1	11.64	4159	38.53	0.073	1.6	N/A	5.03	30
2	N31	45	14.9	W106	24	18.5	9.24	4170	38.23	0.078	1	N/A	5.06	27.2
3	N31	45	15.2	W106	24	18.2	9.02	4177	30.82	0.073	0	N/A	5.54	27.1
4	N31	45	14.8	W106	24	17.8	8.25	4172	35.05	0.069	3.5	N/A	5.33	25.9
5	N31	45	14.5	W106	24	17.3	7.66	4174	37.71	0.078	0	N/A	5.07	25.9
6	N31	45	14.9	W106	24	16.9	7.48	4182	35.47	0.07	0.98	N/A	5.14	25.9
7	N31	45	15.6	W106	24	16.8	8.08	4177	40.7	0.076	3.4	N/A	5.2	25.7
8	N31	45	14.9	W106	24	15.7	8.05	4056	50.3	0.104	1.4	N/A	5.62	27.2
9	N31	45	15.2	W106	24	15.5	7.66	4049	47.84	0.108	2.7	N/A	5.92	27.2
10	N31	45	14.8	W106	24	14.7	7.03	4045	46.490	0.11	3.1	N/A	6.22	27.3

10/11/2019

Samples	Lat °	Lat '	Lat "	Long °	Long '	Long "	Ph	EC	Chl. A	Chl B.	NO3- (mg/L) -N	PO43- (mg/L) -PO43-	DO	Temp
1	31	45	14.1	106	24	17.1	8.15	4329	77.58	0.206	0.121	N/A	7.48	27.8
2	31	45	14.5	106	24	16.8	8.05	4355	62.44	0.136	0.133	N/A	7.63	26.1
3	31	45	15.5	106	24	16.5	7.99	4326	49.52	0.116	0.107	N/A	7.84	23.7
4	31	45	15.7	106	24	17.7	8.07	4325	44.42	0.089	0.125	N/A	8.01	23.6
5	31	45	15.3	106	24	18.5	7.98	4333	43.16	0.089	0.13	N/A	7.56	26

10/18/2019

Samples	Lat °	Lat '	Lat "	Long °	Long '	Long "	Ph	EC	Chl. A	Chl B.	NO3- (mg/L) -N	PO43- (mg/L) -PO43-	DO	Temp
1	31	45		106	24		8.23	4268	38.59	0.085	0.097	0.017	7.28	24.3
2	31	45	14.9	106	24	16.3	7.95	4298	42.63	0.095	0.114	0.01	7.16	24.5
3	31	45	14.9	106	24	16.2	7.94	4299	38.6	0.097	0.107	0.166	7.26	23.6
4	31	45	15.5	106	24	16.4	6.42	4203	38.97	0.092	0.113	3.46	6.9	24
5	31	45	15.2	106	24	18.5	6.00	4205	38.51	0.084	0.112	0.072	7.3	24.6

10/25/2019

Samples	Lat °	Lat '	Lat "	Long °	Long '	Long "	Ph	EC	Chl. A	Chl B.	NO3- (mg/L) - N	PO43- (mg/L) - PO43-	DO	Temp
1	31	45	21.4	106	24	30.5	7.95	4711	23.91	0.057	0.149	0.014	7.65	15.3
2	31	45	27.4	106	24	28.7	8.05	4692	22.07	0.052	0.135	0.015	7.89	15.2
3	31	45	25.4	106	24	27.2	8.11	4682	23.18	0.063	0.116	0.313	8.43	15.3
4	31	45	25.4	106	24	29.7	8.02	4700	21.18	0.053	0.101	0.01	8.23	15.2
5	31	45		106	24		8.03	4695	19.75	0.075	0.124	0.324	8.07	15.3

11/01/2019

Samples	Lat °	Lat '	Lat "	Long °	Long '	Long "	Ph	EC	Chl. A	Chl B.	NO3- (mg/L) - N	PO43- (mg/L) - PO43-	DO	Temp
1	31	45	13	106	24	18	6.81	94.7	38.25	0.08	0.124	0.022	8.2	16.6
2	31	45	13	106	24	13	7.7	316	38.74	0.07	0.129	0.028	6.3	16.6
3	31	45	13	106	24	15	7.2	316	39.59	0.078	0.132	0.035	6.62	16.2
4	31	45	14	106	24	16	6.81	315.8	41.34	0.08	0.127	0.03	6.45	16.8
5	31	45	14	106	24	17	7.27	317.1	40.2	0.08	0.125	0.03	7.21	17.5

11/08/2019

Samples	Lat °	Lat '	Lat "	Long °	Long '	Long "	Ph	EC	Chl. A	Chl B.	NO3- (mg/L) -N	PO43- (mg/L) -PO43-	DO	Temp
1	31	45	14.6	106	24	18	13.46	316.6	39.27	0.103	0.101	0.08	7.22	20.7
2	31	45	15.1	106	24	18.4	6.25	316.6	41.76	0.09	0.095	0.067	6.25	21.9
3	31	45	15.1	106	24	17.4	6.21	319.2	36.75	0.08	0.096	0.056	6.21	20.2
4	31	45	15.5	106	24	16.8	6.2	319.1	38.85	0.08	0.094	0.063	6.2	21.4
5	31	45	15.1	106	24	16	6.28	319.2	39.44	0.088	0.095	0.087	6.28	19

11/15/2019

Samples	Lat °	Lat '	Lat "	Long °	Long '	Long "	Ph	EC	Chl. A	Chl B.	NO3- (mg/L) - N	PO43- (mg/L) - PO43-	DO	Temp
1	31	45	13	106	24	18	13.46	310.1	28.62	0.057	0.104	0.039	6.94	16.3
2	31	45	13	106	24	13	13.46	310.2	24.63	0.058	0.12	0.098	7.35	16.2
3	31	45	13	106	24	15	7.39	313.8	21.55	0.037	0.152	0.081	7.96	16.5
4	31	45	14	106	24	16	12.11	313.3	26.63	0.052	0.127	0.093	7.27	16
5	31	45	14	106	24	17	6.17	313.7	23.05	0.05	0.137	0.092	7.33	17

11/22/2019

Samples	Lat °	Lat '	Lat "	Long °	Long '	Long "	Ph	EC	Chl. A	Chl B.	NO3- (mg/L) -N	PO43- (mg/L) -PO43-	DO	Temp
1	31	45	13.9	106	24	17.7	7.25	310.9	32.7	0.079	0.092	0.091	6.6	21.8
2	31	45	14.9	106	24	18.2	5.92	318.8	28.35	0.065	0.088	0.087	6.57	19
3	31	45	15.5	106	24	17.6	7.35	310.6	30.3	0.077	0.107	0.094	6.69	18.8
4	31	45	15.5	106	24	16.5	10.82	310.5	33.97	0.085	0.096	0.087	6.74	20.1
5	31	45	14.7	106	24	16.5	9.02	312	29.79	0.075	0.102	0.063	6.53	18.4

12/06/2019

Samples	Lat °	Lat '	Lat "	Long °	Long '	Long "	Ph	EC	Chl. A	Chl B.	NO3- (mg/L) -N	PO43- (mg/L) -PO43-	DO	Temp
1	31	45	14.4	106	24	18.8	13.46	311.8	68.9	0.162	0.118	0.071	6.97	17.1
2	31	45	14.1	106	24	17.9	13.46	311.9	58.36	0.141	0.137	0.08	7.13	21.8
3	31	45	14.6	106	24	16.3	6.23	314.4	58.62	0.138	0.128	0.184	6.95	14.9
4	31	45	15.2	106	24	16.3	6.26	314.7	49.76	0.131	0.137	0.075	7.59	16.1
5	31	45	15.4	106	24	18.1	6.27	313.8	42.27	0.119	0.128	0.066	7.92	17.5

CURRICULUM VITA

Elizabeth Herrera obtained her Bachelors of Science in Civil Engineering at the University of Texas at El Paso in December 2018. The unfortunately events happened in Ascarate Lake in the last years grabbed her attention and guided by Dr. Ivonne Santiago, she did her master thesis looking for solutions to these events. She completed the Master of Science in Civil Engineering and obtained a Graduate Certificate in Construction Management in May 2020. While pursuing her Master's degree, she worked as a teaching assistant for the Department of Civil Engineering.

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