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Evaluation of Groundwater Sodium and Sodium Uptake in Taxodium and its Hybrids on Galveston Island, Texas

Daniel Morgan
Stephen F Austin State University, dtmorgan2393@gmail.com

EVALUATION OF GROUNDWATER SODIUM AND SODIUM UPTAKE IN *TAXODIUM* AND ITS HYBRIDS ON GALVESTON ISLAND, TEXAS

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Daniel Taylor Morgan
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Daniel Taylor Morgan

APPROVED:

Dr. Kenneth Farrish, Thesis Director

Dr. David Creech, Committee Member

Dr. Kevin Stafford, Committee Member

Dr. Yanli Zhang, Graduate School Representative

Pauline M. Sampson, Ph. D.
Dean of Research and Graduate Studies

Abstract

In September 2008, Hurricane Ike swept through the Gulf of Mexico striking the Gulf Coast, claiming hundreds of lives and causing billions of dollars in damage. The hurricane left behind elevated sea salt concentrations in the soil and groundwater, preventing the unaided return of live oaks and other species to the island. To determine effective ways to ameliorate the elevated Na^+ concentrations in the soil, eight treatments were applied to the soil and combinations of three species of plants, live oak (*Quercus virginiana*), hybrid bald cypress (*Taxodium* '*T406'*), and yellow hibiscus (*Hibiscus hamabo*) were planted in the plots. These plants were measured for growth in height and diameter over three growing seasons to evaluate the effectiveness of the applied treatments. The *Taxodium 'T406'* specimens were then sampled in order to determine elemental concentrations in the foliage across applied treatments. In addition, foliage samples were taken from a series of *Taxodium* genotypes in order to compare Na^+ tolerance among the genotypes. In order to evaluate the groundwater characteristics of the study area a three by three grid of piezometers, spaced 25 m apart north by south and 60 m apart east by west, was established and groundwater samples were collected from September 2018 to September 2019. Three Solinst Leveloggers were used in the easternmost piezometers in order to provide a continuous stream of data for each piezometer.

Groundwater Na^+ concentrations were compared with precipitation data to determine if precipitation has a significant impact on elemental concentrations.

Plant diameter growth was not significant for diameter among species or treatments, and height growth was also not significant among treatments. *Taxodium distichum* displayed significantly greater height growth than the other species, possibly due to damage to the other species early in the study. Na^+ concentrations did not differ significantly among treatments, although among the genotypes there was a significantly higher concentration of Na^+ in the *Taxodium 'T406'* compared to *Taxodium distichum*. A significant relationship could not be determined between groundwater Na^+ concentrations and precipitation.

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$$K = \frac{r^2 \ln(L_e/R)}{2L_e t_{37}}$$

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1. Introduction

In September 2008, Hurricane Ike swept through the Gulf of Mexico and into the Gulf Coast, claiming nearly 200 lives and causing billions of dollars in damage. In addition to the direct impacts on humans, the 15 foot storm surge rose over Galveston Island and salt water inundated much of the island. This resulted in the devastation of much of the vegetation, including many of the Southern live oaks (*Quercus virginiana)*, one of the historic staples of Galveston's flora. The deposition of salt into the soil and the duration of the storm surge led to the death of trees that had grown for over 100 years. During the recovery period following the hurricane, the Texas Forest Service conducted a study on the mortality rates among planted trees along Galveston roads, revealing that 61.7 percent of live oak trees, roughly 55,000 trees, were killed as a result of the storm, with over 24 million dollars in damages to live oaks alone (Texas Forest Service, 2009). The hurricane left behind elevated concentrations of sea salt, including Na^+, in the soil and groundwater, preventing the unaided return of live oaks and other species to the island. In 2017, Hurricane Harvey struck the Gulf Coast of Texas with much less wind and more precipitation compared to Ike, resulting in dangerous flooding in many areas. Although Hurricane Harvey did not cause the storm surge of Hurricane Ike, it served as a reminder that the changing climate may lead to more frequent and disastrous weather events.

Galveston Island is an approximate 1400 km^2 island located 70 km from central Houston, Texas. The island is 48 km long and is 27 km wide at its widest point. Based on data from the Scholes Field weather station, Galveston Island receives approximately 114 cm of precipitation a year near the project site. Although it was previously noted that southern live oak trees were historically significant trees on Galveston Island, the island was actually considered treeless until the introduction of several species of woody vegetation by Native Americans. One of these species to survive and flourish was the southern live oak.

Following the environmental damages caused by Hurricane Ike, steps were taken in order to develop an understanding of how local vegetation tolerates the sea salt affected soils and groundwater, and how salt moves through the system. Projects funded by the Moody Foundation were put into place that aimed to develop methods to treat the salt affected soils, and to evaluate the soil microbiology. One goal of the projects was to determine the fate of sea salt that was introduced in the environment. Does the salt infiltrate into the groundwater and accumulate, and do the roots of plants encounter those salts as their roots grow downward? The answers to these questions may prove useful in future attempts of site assessment and remediation not only on Galveston Island, but in other coastal and island locations that may be exposed to substantial increases in sea level. The information obtained from this study may be useful for additional areas as they are exposed to more coastal inundations.

Understanding where the deposited sea salts (dominantly Na^+) moves and where it ultimately accumulates is important for evaluating the environmental risks of future weather events and changes in the climate and sea level. Excess Na^+ can be devastating to many plant species, and over time there are few species that could withstand the conditions that Galveston Island faced in 2008. The Moody Foundation provided funding for this project in order to evaluate the factors that affect sodium concentrations, so as to possibly develop methods and treatments to prevent environmental damage and to develop an understanding of the problem that might be useful for more rapid remediation of Na^+ contaminated soils and groundwater.

2. Objectives

The purpose of this study was to develop an understanding of where sodium salts accumulate in the Galveston coastal system of groundwater, soil, and plants, what factors affect the rate of accumulation of salts, and to observe how a series of native and nonnative plants tolerate the salt intake through ground and aerial deposition. To help complete these goals, the following objectives were established.

1. Observe the growth and health of the 296 trees of three species (*Taxodium X 'T406', Quercus virginiana,* and *Hibiscus hamabo*) planted in the study area, and collect data on the elemental concentrations present in the foliage of each species.
2. Characterize the depth and quality of the groundwater by testing for sodium, chloride, pH, electrical conductivity, and temperature over a one-year period.
3. Relate the groundwater conditions with weather data and aerosol deposition data to help characterize the movement of sea salt in the environment.

In addition to meeting the goals of this study, completing these objectives will expand on the results of previous studies conducted at the site, which evaluated soil salinity, soil amelioration, plant survivorship, and aerial sodium deposition.

3. Literature Review

3.1 Salinity in Galveston, Texas

3.1.1 Accumulation of Salts

In coastal areas, the deposition and accumulation of salts is unavoidable. Plants that dominate these areas should ideally be more salt-tolerant than those further inland. However, even these species will struggle with prolonged or excessive exposure to elevated salt, as they did following Hurricane Ike. Southern Live Oak (*Quercus virginiana*), a historically significant plant to Galveston Island, is known to be moderately tolerant of salinity and flooding, but during the course of Hurricane Ike the species lost nearly 62 percent of the population due to the storm surge (Natural Resources Conservation Service, 2017; Texas Forest Service, 2009).

In a study where clean, offsite bank sand was used to build planting beds and ameliorate soil sodium concentrations in Galveston, Texas, soil in these bedded plots was initially shown to have significantly reduced Na^+ concentration. However, after a period of seven months, soil samples collected from the study plots had Na^+ concentrations equal to concentrations of those that did not receive clean sand (Harris, 2019). The increase in soil sodium may be attributable to aerial sodium deposition, capillary action of high sodium groundwater, or a combination of the two. This indicates that over time in coastal areas, soil sodium concentrations in areas where outside soil has been brought in will not likely serve as a long term solution to soil sodium amelioration.

3.1.2 Groundwater Saltwater Intrusion

Saltwater intrusion occurs when outside forces, such as the pumping of groundwater for use, allow for the encroachment of saltwater into freshwater aquifers. In the Atlantic and Pacific coastal regions of the United States in 2000, groundwater was pumped at a rate of 618 m^3/s for agriculture, industry, and public use, with groundwater serving as the primary or sole source of drinking water for coastal communities (Barlow & Reichard, 2010). Galveston Island, Texas has a history of issues with saltwater intrusion, stemming from the heavy pumping occurring on the island and in Texas City. To combat this, groundwater pumping operations were moved further inland to remove the strain on the aquifer below Galveston. This did not eliminate saltwater intrusion entirely (Kerr, 1977). Galveston, as well as many of the nearby cities in Galveston and Harris counties, are affected by the withdrawal of groundwater from the Gulf Coast aquifer system. In addition to the infiltration of saltwater further inland, the potentiometric surface of the groundwater continues to drop, while land-surface subsidence is occurring in the Houston area due to depressurization and compaction of soil layers found in the aquifer sediments (Kasmarek, 2012).

The rate of saltwater intrusion depends on several factors, including the rate of groundwater extraction versus freshwater recharge, the distance between a site of groundwater withdrawal and saltwater, the geologic structure of the aquifer, and the presence of barriers that may prevent saltwater from moving into the aquifer (Barlow & Reichard, 2010). It has been observed that increases in precipitation will increase the groundwater level while lowering the salinity in the groundwater, and that seasonal temperature and precipitation changes are likely to be a large factor in groundwater salinity (Yan, et al., 2014).

3.1.3 Soil Salinity

High salinity in soils is detrimental for plant growth, as salts can impact plants through the plant roots, disrupting normal cellular function as well as causing the wilting of leaves, which reduces a plant's ability to photosynthesize. With the exception of halophytes, plants that receive excess sodium over time will die. The accumulation of salts in soils can occur when minerals in the soil are broken down due to weathering, and there is insufficient precipitation to leach the salt ions from soil profiles (Shrivastava, 2014). The increase of soil salinity can be caused both naturally and anthropogenically. Natural increases in salinity of soils are generally attributed to changes in groundwater. In a saturated flow system, the groundwater rises until lateral groundwater flow occurs, which causes soluble salts to dissolve and ultimately arrive in a discharge area, where they accumulate over time due to the evaporation of the water (Wannakomol, 2005). In the Galveston study area, the water table lies between 1.5 and 0.3 m below the ground surface under normal conditions, with surface ponding occurring following periods of rain. Given these conditions, it is possible that during periods of heavy rainfall when the groundwater level rises above the ground surface salt ions can be brought to the surface, where they may remain after evaporation of the accumulated surface water.

3.1.4 Hurricanes and Flooding Events in Coastal Areas

While normal rates of depositions of salt can be tolerated for many species, even hardy species are put at risk by extended inundation of soils by seawater. Hurricanes, although destructive, serve an important environmental role for coastal wetlands, as the episodic disturbance and regeneration events can potentially increase the diversity of herbaceous species in an area (Middleton, 2016). During Hurricane Ike, Galveston was covered by the storm surge in many areas for 15 days, which was a sufficient amount of time to harm and kill many species on the island. Following Hurricane Hugo in September 1989, low lying coastal forests in South Carolina were inundated with 3 to 4 m of storm surge saltwater. Analyses of groundwater two weeks following the hurricane revealed sodium levels ranging from 100 $mg*L^{-1}$ to over 1000 $mg*L^{-1}$ in some areas. This can be compared to a pre-hurricane range of 4 to 30 $mg*L^{-1}$, which were reached in the eastern well points by January 1990 (Gardner, et al., 1989). In addition to the increase in sodium levels in groundwater, sodium levels in soils were also elevated following the storm surge as the water above the surface moved into soils. In the study, soil salinity was 58 to 142 times higher than pre-storm levels as long as two months after the hurricane (Gardner, et al., 1989).

Following the hurricanes and other events that introduce high amounts of salinity into ecosystems, various plant species compete for reestablishment of an area (Middleton, 2016). Revegetation of a site depends on existing plant species as well as their propagation methods, as in one study it was observed that flooding reduced regeneration potential in baldcypress (*Taxodium distichum)* swamps, while not in freshwater or saltwater marshes (Middleton, 2016).

In addition to damages caused by flooding and sodium deposition, hurricanes can cause damage to plants via high wind speeds, even altering the species variation in areas where trees are not adapted to wind stress. Middleton (2009) observed that the sustained 69 to 94 mph wind speeds affecting Gulf Coast swamps destroyed a larger number of non-dominant species as compared to the dominant species, which were better acclimated for the sites and were more resistant to mechanical stress.

In a study evaluating seedling salt tolerance among species that experienced varying rates of storm surges, it was determined that storm surge water can vary in salt concentration from 3.5 to 19.3 $g*L^{-1}$, and that rainfall can lower these concentrations if the precipitation occurs during or before the event, due to dilution of the saltwater (Williams, Meads, & Sauerbrey, 1998).

3.1.5 Aerial Sodium Deposition

Aerial deposition of salts, also known as salt spray, is a constant source of sodium, chloride, and other ions into coastal plants and soils. As droplets of water from the sea are mobilized by wind, these droplets travel inland, where they are eventually deposited onto the surface of plants and the soil surface, eventually infiltrating and percolating into the soil and groundwater during precipitation events. The quantity of salt that is deposited is affected by several factors, including wind speed, precipitation, and weather. Harris (2019) observed that in Galveston, there was significantly greater deposition of salt into the environment during periods of high precipitation, specifically for Na^+, Cl^-, and Mg^{+2} ions. In the same study, it was observed that the most heavily concentrated ion in aerial deposition was Cl^- followed by Na^+, likely due to the common occurrence of Cl^- as a constituent for sea salts. While there is increased deposition of aerial salinity during periods of increased precipitation, precipitation rinses off salts accumulated on foliage. This sodium that is rinsed off of the foliage is then transferred to soils and groundwater, and may be cycled back into plants through root uptake.

In order to reduce the effects of salt spray on coastal plants, there are several approaches that can be taken. Some of these approaches include using halophytic or salt tolerant plants as wind breaks or barriers, frequent rinsing of the plants and soils with freshwater, and avoiding salt sensitive plants altogether (Appleton, et al., 2015).

3.2 Tree Species

3.2.1 *Taxodium 'T406'*

In order to evaluate the effectiveness of baldcypress reestablishment on salt affected soils, the *T406* hybrid of baldcypress (*Taxodium distichum)* and Montezuma cypress (*Taxodium mucronatum)* was used for a previous study at this site. *Taxodium* X 'T406' is a superior clone from the *Taxodium* Improvement Program of the Nanjing Botanical Garden (Creech, 2017). It is a selection made by Professor Yin Yunlong of the Nanjing Botanical Garden from a crop of seedlings that were the result of a controlled cross of bald cypress and Montezuma cypress. In cooperation with Nanjing Botanical Garden and Stephen F. Austin State University, this clone was named 'LaNana' and is commercially available through a limited number of nurseries across the Gulf South. Key attributes include no knees, strong salt and alkalinity tolerance, good form, tendency to being evergreen and excellent resistance to needle blight. Cercospora needle blight, caused by the fungus *Passalora sequoia* (formerly *Cercospora sequoia*) is a problem on *Taxodium*, Arizona cypress, arborvitae and other other members of the Cupressaceae.

Taxodium distichum, commonly known as baldcypress, is a deciduous conifer that primarily grows in soils that remain wet or with access to moisture year round. Fully grown *T. distichum* specimens range from 30 to 37 m in height, with a 900 cm to 1.5 m diameter, and have double rows of needles ranging from 10 to 19 mm in length (Little, 1984). *T. distichum* is distributed along streams and lakes throughout the Gulf Coastal plain and southeastern United States, and can be found along rivers as far north as Illinois (United States Department of Agriculture, 2010). *T. distichum* have a known tolerance to flooding due to their acclimation to wetland habitats, but perform poorly in highly alkaline soils (Creech, et al., 2011). However, central Texas and more western *T. distichum* specimens are often alkaline tolerant. *Taxodium mucronatum*, commonly known as Montezuma cypress, is native to Mexico, Guatemala, and southern Texas, and grows along rivers, creeks, and lakes. *T. mucronatum* is known to have a higher salt tolerance than *T. distichum* as well as a higher tolerance for high alkalinity in soils, but struggles with prolonged inundation (Creech, et al., 2011).

The hybrid combination of *T. distichum* and *T. mucronatum* provides a plant that has been shown to display an increased tolerance to both increased salt and prolonged inundation (Zhou L. , 2007). The hybrid selected for this site is a hybrid of these plants, and has the designation *Taxodium T406*, also known as *Taxodium* X 'LaNana'. *Taxodium T406* displays increased salt and alkalinity tolerance, fast growth rate, no knees, and grows at a rate of five to six feet per year (Creech, 2015). *Taxodium T302*, the first introduced hybrid of *T. distichum* and *T. mucronatum*, was evaluated for salt tolerance, and was treated with salt rates ranging from 0 ppt to 12 ppt. With no salt treatment, the Na^+ concentration in the foliage was 0.13 percent, while the greatest salt treatment led to a Na^+ concentration of 0.35 percent (Zhou, 2007). These values may be useful in evaluating salt concentrations in the similar hybrid *Taxodium T406* located at the Moody Gardens site.

There is some debate regarding the nomenclature of *Taxodium* species. Previous literature often refers to three separate species of *Taxodium*: *Taxodium distichum* (baldcypress); *T. ascendens* (pond cypress); and, *T. mucronatum* (Montezuma cypress). While the taxonomic relationships among these three species, or varieties, of *Taxodium* remain a source of debate (Tsumura et al., 1999), the ranges of baldcypress and pond cypress overlap and these two have been recognized as possibly being two varieties of *T. distichum* (Integrated Taxonomic Information System, 2009). At least one source combines all *Taxodium* associates into one species with three, in lieu of just two, botanical varieties (Arnold and Denny, 2007), as follows:

Taxodium distichum var. *distichum* (L.) Rich (Baldcypress - BC)

Taxodium distichum var. *imbricarium* (Nutt.) Croom (Pondcypress - PC)

Taxodium distichum var. *mexicanum* Gordon (Montezuma cypress - MC)

3.2.2 *Quercus virginiana*

Southern Live Oak (*Quercus virginiana)* is a popular ornamental tree found in the southeastern coastal plains of the United States, and was well known as a historically significant but non-native tree on Galveston Island. *Q. virginiana* is moderately salt-tolerant, and specimens that are found in coastal areas frequently display increased leaf succulence as a result of exposure to salt spray (NCRS, 2017). A study analyzing the salt tolerances of various ornamental plants found *Q. virginiana* to be moderately sensitive to salinity, observing that *Q. virginiana* could survive at soil electrical conductivity levels of 4.4 $dS*L^{-1}$, while not being able to survive at an electrical conductivity levels of 9.4 $dS*L^{-1}$ (Miyamoto, 2008).

Q. virginiana is tolerant of both significant drought and short periods of flooding, and has a wide range of tolerance for soil conditions such as pH, soil moisture, and compaction. (NCRS, 2017). Structurally, *Q. virginiana* displays a resistance to hurricane conditions, possibly due to the strength of the wood (NCRS, 2017). Given these traits of *Q. virginiana*, it is likely that the storm surge of Hurricane Ike caused the mortality of the *Q. virginiana* in Galveston, due to the combination of prolonged flooding and high salinity water in areas.

In a seedling saltwater tolerance study, it was determined that *Q. virginiana* experienced shoot mortality after exposure to elevated sodium concentrations, but that after being flushed with freshwater resprouted (Williams, et al., 1998).

3.2.3 *Hibiscus hamabo*

Hibiscus hamabo is a deciduous halophyte with a known salt tolerance that is often found naturally on islands and in coastal sands near sea level in

China, Japan, and the Koreas, and is cultivated in India and the Pacific Islands (Li, et. al, 2012).

Due to their halophytic properties, *H.* hamabo can tolerate elevated salt concentrations, and may even thrive under low-saline conditions. Li and others found the ideal concentration for *H. hamabo* germination to be 25 mM NaCl, while the optimal survival concentration ranged from 5 to 10 mM NaCl. *H. hamabo* began to display adverse effects on germination at NaCl concentrations of 100 mM and a complete cease of germination at 500 mM of NaCl, while at a concentration of 100 mM NaCl plant survival was completely inhibited (Li, et al., 2012).

3.3 Coastal Factors Inhibiting Plant Growth

3.3.1 Salinity Stress

Damage to plants through exposure to salt in a coastal system is often the result of growing in salt affected soils and the impact of salt spray from the nearby bodies of salt water. Salt tolerance levels are typically described as soil salinity levels that cause a 25 to 50 percent reduction in plant growth (Miyamoto, 2008). For saline soils, damage can occur when the membrane of plant root cells, which allows the passing of water but not salts, struggles to bring sufficient water into the roots when overwhelmed by salt ions. In addition, the abundance of salt in soils with expanding clays can cause severe compaction as the salt ions bind with the clay (Appleton, et al., 2015). Plant development in most plants is heavily altered by the infiltration of salt ions into soils, with processes such as plant germination, growth, and reproduction being reduced. High salinity can cause ion toxicity as well as nutrient deficiency of ions that can no longer be taken into the plant due to the excess accumulation of Na^+ on the cell walls of the plant roots (Shrivastava, 2014).

Salts that reach plants through aerial transport can have detrimental effects on the establishment and growth of plant species on the coast. In coastal areas, salt is transported through the air as a spray on the wind, where this salt spray serves as a natural abiotic selector. The salt spray deposits the salts on the leaves and bodies of plants, immediately damaging species with a very low tolerance for salt, while damaging the growth of other species over time as the salts accumulate (Griffiths, 2003).

Studies have revealed that short term pulses of high salinity are not enough to cause significant changes in growth or health of some species, such as *Taxodium distichum* (Zhou & Creech, 2010). Some studies have shown *T. distichum* seedlings to be moderately salt tolerant, with no reduction in plant growth with an addition of 3 $g*L^{-1}$ saltwater solution over a period of 60 days, while showing a decrease in height of 17 percent in plants receiving 10 $g*L^{-1}$ saltwater solution over the same period (Pezeshki, 1990). Some plants exposed to elevated sodium concentrations over a short period of time may experience some necrosis, but will reflush following a precipitation event that flushes the plants with freshwater (Williams, at al., 1998). Over time, the effects of chronic exposure to high salinity become more pronounced. In a study performed on one year-old *T. distichum* saplings, it was observed that during the first three months of plant growth, plants that were not being exposed to elevated salinity were growing at twice the rate of those exposed to 100 mM of sodium solution, with the growth rate of the salt-affected plants dropping to 20 percent of control plant growth rates after six months of exposure (Stiller, 2009). The impacts of soil salinity on plant growth were notably more severe than the impact of drought.

Plants have varying degrees of salt tolerance based on several factors, but the ranges for plants are sometimes divided into categories based on tolerance for soil electrical conductivity: sensitive (0 to 3 dS/m), moderately sensitive (3 to 6 dS/m), moderately tolerant (6 to 8 dS/m), tolerant (8 to 10 dS/m), and highly tolerant (more than 10 dS/m) (Miyamoto, 2008). Halophytes, which are plants which grow in elevated salinity conditions and are regularly exposed to saltwater intrusion via roots and aerial sodium deposition, are stimulated at low salinity concentrations, but display completely inhibited growth at high concentrations (Li, et al., 2012). Salt-tolerant plants exhibit one or several of the characteristics that enable them to withstand elevated salt concentrations in the soil, air, and groundwater. Some of these salt-tolerant traits include greater root growth, higher efficiency in water uptake, lower Na^+ permeability, better root osmotic adjustment, and higher root pressure (An, et al., 2003). Root growth in halophytic plants exposed to salt will vary depending on the species, with either stimulation, inhibition, or no change in growth (An, et al., 2003).

3.3.2 Flooding Stress

As climate change leads to global shifts in temperature and sea level, low lying islands and coastal wetlands will be at risk of more frequent and destructive storm surges (Nicholls, 2004). Coastal vegetation that is unique to these ecosystems is particularly at risk. While many coastal plants are resistant to damage caused by flooding, they are still susceptible to sustained and more frequent floods. *T. distichum* is a plant that is highly tolerant of flooding and waterlogging, but increases in flood depth and duration threaten the existence of the plant in some areas, in addition to the risk posed by salinity (Allen, et al., 1995). *T. distichum* seeds do not germinate underwater, and as such cannot regenerate in permanent flooded conditions. In addition, *T. distichum* growth is hindered in water deeper than 1 m, as swamps where permanent flooding is present cannot maintain *T. distichum* populations as compared to swamps where intermittent flooding occurs. *T. distichum* seedlings that do grow in shallow flooding conditions exhibit an initial period of stress as compared to seedlings not subject to flooding, with 30 percent reduction in height, 56 percent reduction in leaf area, and 51 percent reduction in dry weight (Allen, et al., 1995).

3.3.3 Wind Stress

In coastal areas, the continuous impact of wind on plants can cause detrimental effects on plant growth, as well as the physical appearance of plants. In these areas where wind impacts plants, saplings will often grow with a distinct bend and branch orientation away from the source of wind, which is known as flagging. This is due to the branches forming an increased surface area for wind to catch. Over time, the trees will bend, as can be seen in the planted trees at the Moody Gardens project site. A strategy for remediating this on *Taxodium sp.*, as noted by David Creech at the Texas Forestry Association 104th Annual Meeting in 2018, is the removal of all branches on each tree during late winter, only leaving a small amount of leaf material on the top of the tree (Creech, 2018). A common strategy in China, the surface area that catches wind and allows the trees to bend is removed, and the trees can grow vertically with much less resistance.

In response to high wind speeds, some trees will undergo adaptations for certain conditions. A study on *Picea sithchensis* revealed that in a case where specimens had rooting depth restricted by a water table the trees developed structurally altered roots in order to prevent mechanical uprooting. Some of these adaptations included roots developing I-beam shaped cross sections on the windward side of the plant, and roots becoming ovoid in shape as distance from the tree increased (Nicoll & Ray, 1996). These adaptations allowed the trees to prevent uprooting by increasing the surface area below the ground, securing their position. It has yet to be determined if changes in root structure due to wind stress lead to any changes in sodium uptake through plant roots, although an increase in root surface area will increase the potential uptake of water and nutrient into the root system.

4. Justification

The impacts of hurricanes outlast the initial landfall of the storm, with frequent lasting damage due to flooding, high wind speeds, and the deposition of salt via these vectors. Although hurricanes contribute the most acute inputs of salt in environments, chronic salt also accumulates in coastal environments due to aerial deposition. The infiltration of salt into the soil and groundwater in the coastal environments of Galveston Island is not something that is avoidable, but a greater understanding of the long-term effects and accumulation of salinity can allow for the development of strategies to protect plants from future weather events. The results of this study serve as the base for future projects in the Galveston area that aim to protect and maintain native Galveston species. In addition, planted trees that grow successfully during the course of this project can be replanted in areas of Galveston where trees were lost during Hurricane Ike.

5. Methods and Materials

5.1 Project Site

The project site was located at the northwest corner of the Moody Gardens parking lots, directly south of Offat’s Bayou. The property is owned by Moody Gardens, while funding for the project was provided by the Moody Foundation. The center of the site is located at 29°16'31.8" North, 94°51'32.4" West (WGS84). Immediately south of the study area is Scholes International Airport. Moody Gardens owns the property. Before the inception of Stephen F Austin State University’s joint research projects with Moody Gardens, the site was a grassy field, with sparse woody growth. The soils at the site consist of Mustang fine sand covering the southern third of the study area and Madre fine sand covering the northern section of the study area (Web Soil Survey, 2018). Mustang fine sand (Siliceous, hyperthermic Typic Psammaquents) are poorly drained sandy soils with an A horizon (a mineral horizon with an accumulation of humified organic material; has a soil absorption ratio (SAR) of approximately 6) from 0 to 10 cm and a Cg horizon (a horizon with little to no alteration by pedogenic processes and with the presence of strong gleying; has a SAR of approximately 6) past 10 cm. Madre fine sand (Siliceous, hyperthermic Sodic Psammaquents) are poorly drained sandy soils with an An horizon (an A horizon with an accumulation of exchangeable sodium; has a SAR of approximately 40) to 20 cm and a Cng horizon (a C horizon with strong gleying and an accumulation of exchangeable sodium; has a SAR of approximately 16) past 20 cm (Buol, 2011). Given the proximity of the site to the Scholes International Airport, it is likely that some of the soils in the study area may have been graded or filled in order to create a level surface for the nearby airport.

5.2 Project Species and Planting Method

The species used for this study were *Taxodium T406* (*Taxodium distichum-Taxodium mucronatum* hybrid), *Quercus virginiana* (Southern Live Oak), and *Hibiscus hamabo* (Yellow Hibiscus). For the purpose of a previous research study, the trees were planted with different bedding, incorporated mulch, and gypsum treatments in order to determine if there were significant differences in survival and growth using these treatments. There were eight treatment types, with six replications of each treatment. The treatments were the following: Control Flat, Control Bedded, Mulch Flat, Mulch Bedded, Gypsum Flat, Gypsum Bedded, Mulched Gypsum Flat, and Mulched Gypsum Bedded. The plots were placed in random order in two rows roughly 100 m from Offat's Bayou. Each plot contained two trees of each species, placed in a random order. Soil samples were collected during the study to monitor changes in soil chemical properties, including soil electrical conductivity and sodium absorption ratio (SAR).

5.3 Piezometer Construction and Placement

Piezometers were placed in a three by three grid covering the study area, spaced 25 m apart north by south and 60 m apart east by west. The southernmost row of piezometers was located in-between the plots for this study and irrigated plots used for other research. These irrigated plots utilize raised beds, which likely alter the natural flow of surface water runoff. The WGS84 coordinates and lengths for each piezometer are displayed in **Table 1.**

Table 1. World Geodetic System 1984 (WGS84) coordinates and total length for each piezometer within the project area on Galveston Island, Texas.

Piezometer ID	Latitude	Longitude	Piezometer Depth (m)
1	29.275741	-94.859689	1.03
2	29.275556	-94.859685	1.25
3	29.275300	-94.859608	1.36
4	29.275883	-94.858992	1.30
5	29.275663	-94.858959	1.40
6	29.275454	-94.858848	1.51
7	29.276013	-94.858322	1.47
8	29.275766	-94.858265	1.22
9	29.275584	-94.858245	1.40

Piezometers were constructed offsite and transported to the Moody Gardens study area for installation. Preliminary data on the depth to the water table in the proposed piezometer locations, collected by Elaine Harris in May 2015, were used to construct the piezometers to the appropriate depth. In order to ensure the collection of sufficient water samples, the piezometers were constructed to be 50 cm longer than the known depth to the water table. Three of the piezometers were equipped with Solinst Leveloggers, water level dataloggers that can also detect electrical conductivity and water temperature at a predetermined interval. The layout of the piezometers, site topography, and a general overview of the project site can be seen in **Figures 1 through 4.**

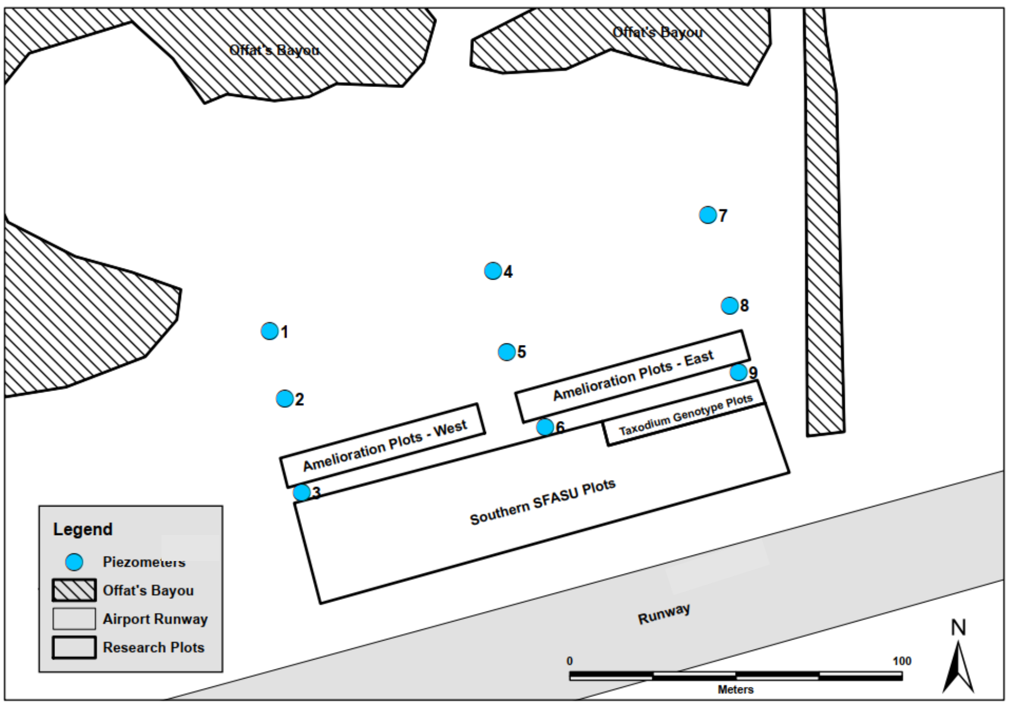


Figure 1. Locations of piezometers at the project site. The taxiway of Scholes Field can be seen to the south, while Offat's Bayou can be seen to the north. A channel is visible on the eastern boundary of the site.

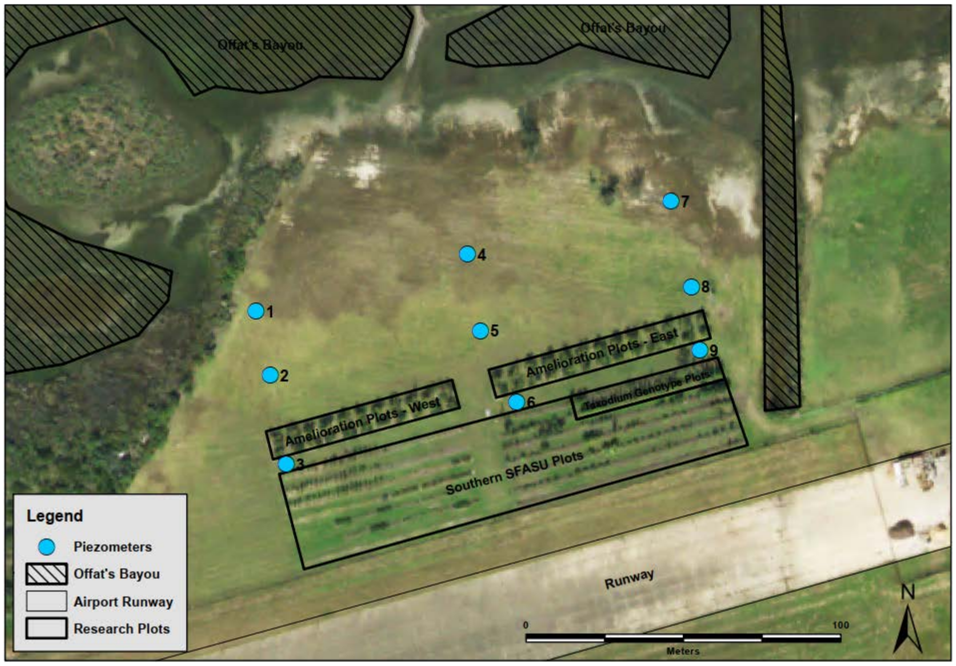


Figure 2. Locations of piezometers at the project site. 2018 Aerial photography was provided by the National Agriculture Imagery Program (NAIP).

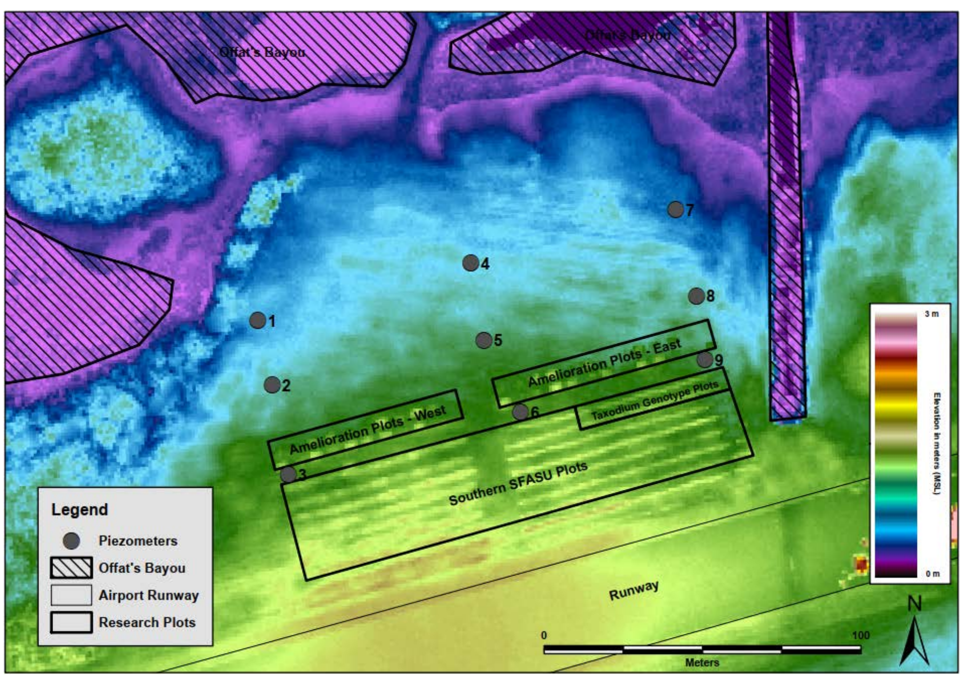
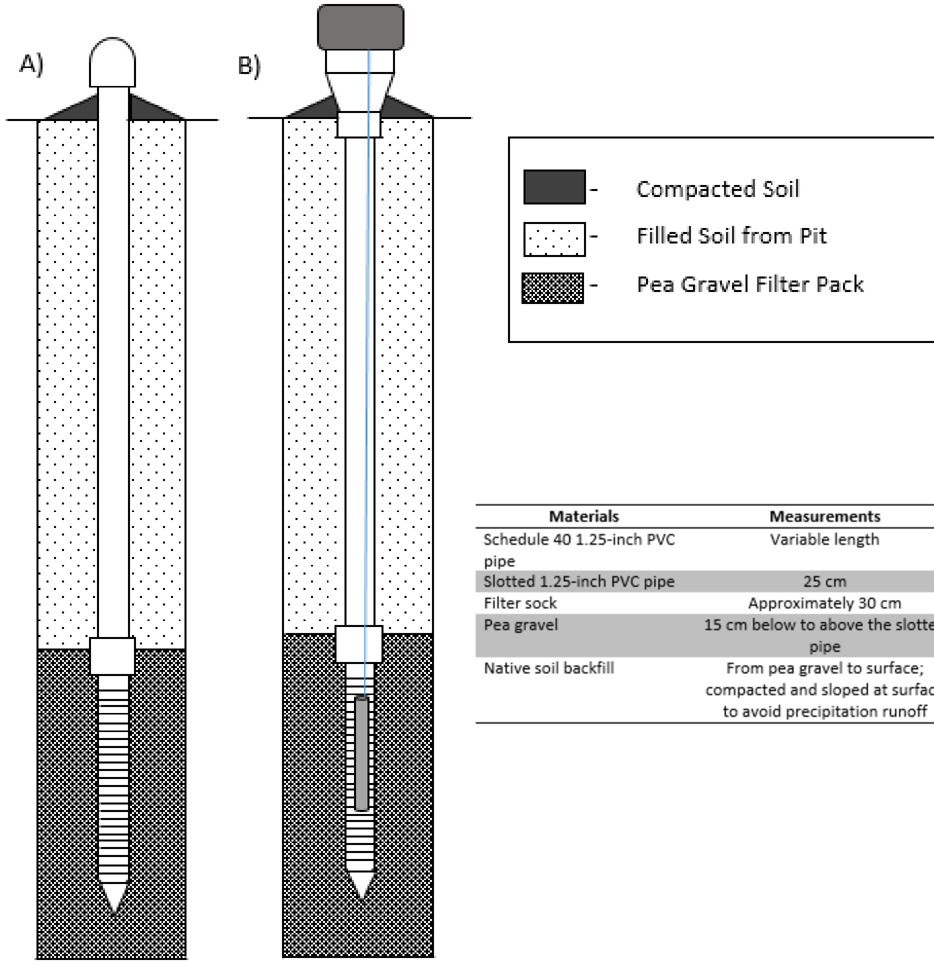


Figure 3. Locations of piezometers at the project site. The site map is overlaid on 2017 Houston-Galveston Area Council Light Detection and Ranging (LiDAR) data, accessed through the Texas Natural Resources Information System (TNRIS).

Figure 4. General vicinity map showing the project site in relation to Galveston Island, the Galveston Bay, the Gulf of Mexico, and other geographic features.

Each piezometer was constructed out of 3.175 cm Schedule 40 PVC pipe. At the bottom of each piezometer, a 25 cm section of 0.25 mm-slotted PVC pipe was attached to the main body of the piezometer. The piezometers that did not contain Leveloggers were capped at the top with PVC pipe caps. The piezometers equipped with Leveloggers used a 3.175 cm to 5.08 cm coupling attached to a 15 cm 5.08 cm diameter PVC pipe, to allow the installation of the Levelogger well cap. The Leveloggers were attached to the well cap using a nylon cord.

The borehole for each piezometer was dug with a 7.62 cm soil bucket auger, until the desired depth was reached. Pre-washed pea gravel was placed into the borehole until a height of 15 cm was filled. The constructed piezometer was placed into the borehole, and the pea gravel was placed into the hole until the slotted section of PVC was covered. The displaced soil was placed back into the borehole, and at the surface excess soil was used to form a compacted soil layer to prevent the rundown of precipitation from the perimeter of the piezometer. Normally for piezometer installation, a layer of sodium bentonite is placed just below the surface in order to serve as a swelling clay barrier to precipitation, but due to the importance of accurate sodium measurements of the groundwater, the method using tightly compacted native soil was implemented instead. Surface soil was compacted after each data collection in order to prevent the intrusion of precipitation via gaps around the piezometer. The design for the piezometers and the pits are shown in **Figure 5.**



Materials	Measurements
Schedule 40 1.25-inch PVC pipe	Variable length
Slotted 1.25-inch PVC pipe	25 cm
Filter sock	Approximately 30 cm
Pea gravel	15 cm below to above the slotted pipe
Native soil backfill	From pea gravel to surface; compacted and sloped at surface to avoid precipitation runoff

Figure 5. Diagram displaying the design of the piezometers used for collection of groundwater data, as well as the design for the piezometer pits. The dimensions of the piezometers and the pits vary based on the location of each point. **Part A** displays the design of a standard piezometer at the site, used for groundwater sampling and measurements. **Part B** displays the design for a piezometer to be used in conjunction with a Solinst Levelogger.

5.4 Leveloggers

The Solinst Leveloggers are dataloggers that collect data on water level, electrical conductivity and water temperature. They can be left onsite to collect continuous data readings to supplement periodic measurements from the water samples. The Leveloggers were set to collect data at an interval of 30 minutes, and ran continuously for the duration of the study. Data was collected from the loggers during the biweekly sample collections in order to ensure the integrity of the data, as well as to check for abnormalities. The three Leveloggers were placed in the easternmost piezometers in order to provide continuous groundwater data at varying distances from Offat's Bayou.

In order to ensure the collection of accurate conductivity readings, the Leveloggers were calibrated using known conductivity solutions before being installed. In order to allow for the greatest detectable range of electrical conductivity, the data loggers were calibrated to the 1,413 $\mu S*cm^{-1}$ and the 12,880 $\mu S*cm^{-1}$ solutions. After each data collection, the Leveloggers were removed from the piezometers and cleaned with deionized water to prevent the accumulation of biological material on the sensors.

5.5 Groundwater Sampling

Groundwater was collected from each of the piezometers every two weeks for a period of one year. Each piezometer was purged before each sample was collected in order to obtain a representative sample, and avoid the collection of stagnant groundwater. Purged groundwater was collected in pails and disposed of properly off-site. Following the purging of each piezometer, a volume of 300 mL was pumped from the piezometer into sample bottles and brought to the Soil, Plant, and Water Analysis Laboratory at Stephen F Austin State University. The groundwater underwent the Standard Water Analysis testing schedule, which measures pH, electrical conductivity, carbonate, bicarbonate, sodium, calcium, magnesium, potassium, iron, sulfate, chloride, phosphate, and nitrate. This data was used in order to evaluate water chemistry over the entire study.

The depth to the water table at each piezometer was determined before the sample extraction in order to avoid altering the depth to water table. The depth to the water table was determined to the nearest cm using a Solinst water level meter.

5.6 Weather Data

Weather data was collected from the weather station located at Scholes Field (KGLS) to determine the occurrence of precipitation events, as well as high, low, and average temperatures. On days with precipitation events, hourly data was accessed in order to compare to readings found with the water level meter and with the Leveloggers.

5.7 Measurement of Plant Growth

Prior to this project, measurements were taken of the height of each tree, as well as the diameter at ground level. These measurements were collected three times during the course of this study; once during the growing season, in July 2017 and 2018, once following the end of the growing season, in November 2017 and 2018, and final measurements taken in March 2019. The diameter at ground level was collected using two perpendicular measurements determined with digital calipers, and averaging these values. Due to the young age of the trees and growing conditions of the project site, the tree height was such that using measuring tape was sufficient. The values found in each season were compared to data collected by Elaine Harris during the 2016 to 2017 season. With this data, the potential relationships between groundwater conductivity levels or amelioration techniques with tree growth were quantified.

5.8 Analysis of Foliage

To determine the presence of salts in the *Taxodium* hybrid, foliage samples were collected from the *Taxodium T406* close to the end of the growing season to determine Na^+ accumulation in the leaves.

In order to collect adequate samples, one paper soil sample bag was filled with live leaves from a *Taxodium* specimen. Leaves were collected from the top third of the crown, on the southern facing direction of the tree. No woody matter was collected.

Upon collection of the samples, the filled bags were opened and placed in a drying oven set to 60˚C to dry. A sample of four bags was removed every three days to be weighed until the bags reached a constant weight. Upon reaching a constant weight, the samples were ground into a fine powder using a Lab Wiley Mill and sent to the Soil, Plant, and Water Analysis Laboratory at Stephen F Austin State University and tested for plant nutrient and Na^+ concentrations. Data was evaluated for sodium concentrations by sodium amelioration technique.

5.9 Hydraulic Conductivity of Soil

Upon completion of groundwater collection, the piezometers were used to determine soil hydraulic conductivity in the study area. The Leveloggers were removed and recalibrated for the slug tests, with the sample interval being changed from 30 minutes to 2 seconds, the fastest possible sample interval. This allowed for a constant stream of data, in order to produce the most accurate hydraulic conductivity data. The Leveloggers were placed into the piezometer, and a 0.5 liter slug of deionized water was quickly poured into the piezometer. The water table was given time to equilibrate, and the Leveloggers were removed for data collection. This test was conducted on each piezometer and gave a complete overview of the hydraulic conductivity of the soil surrounding each piezometer. These tests provided the time that it took for the water level to return to 37 percent of the change in water level, which could be used in combination with piezometer dimensions to calculate hydraulic conductivity.

5.10 Laboratory Analyses

All samples were processed by the Soil, Plant, and Water Analysis Laboratory at Stephen F Austin State University. Groundwater samples were tested with the laboratory's regular analysis testing process, which tests for pH, conductivity, Na, Ca, Mg, B, K, Fe, carbonate, bicarbonate, sulfate, chloride, flouride, phosphate, nitrite, and nitrate. The lab performed these tests through use of an Inductively Coupled Plasma Analyzer and an Ion Chromatograph. Foliage samples collected from the *Taxodium T406* underwent the plant tissue mineral analysis testing schedule, which tests for N, P, K, Ca, Mg, Na, S, Fe, Mn, Zn, Cu, B, and C/N analysis. The analysis of the foliage samples was conducted using the Inductively Coupled Plasma Analyzer. The primary target elements for these analyses were sodium for both foliage and groundwater, and pH, electrical conductivity, and chloride for groundwater samples.

5.11 Statistical Analysis

Scatterplots were employed to identify potential associations between the variables involved in this study. Following the evaluation of scatterplots, linear regression analysis was used to identify correlations and analyze relationships between precipitation, groundwater level, and Na^+ concentrations. To evaluate the relationships between plant growth and the applied treatments, a Two Way ANOVA with Replication was utilized with a significance level, or alpha, of 0.05.

6. Results

6.1 Plant Growth

A summary of plant growth by species and planting method is shown in **Table 2 and Figures 6-7.** Measurements for height and mean diameter at groundline growth can be found in **Appendix B**.

Table 2. Summary of mean diameter at groundline growth for the species of concern (*Q. virginiana, H. hamabo, and T. T406)* over a period of three years, from initial planting in April, 2016 to final measurement in March, 2019. It should be noted that comparisons among species may not be notable, due to differences in plant habit.

Treatment	***Quercus virginiana*** **(mm)**	***Taxodium 'T406'*** **(mm)**	***Hibiscus hamabo*** **(mm)**
Control Bedded (CB)	39.8	92.9	101.1
Control Flat (CF)	44.9	82.6	104.8
Gypsum Bedded (GB)	42.7	89.7	98.3
Gypsum Flat (GF)	52.7	82.4	102.1
Mulch Bedded (MB)	45.4	90.5	102.8
Mulch Flat (MF)	53.6	92.2	101.9
Mulch + Gypsum Bedded (MGB)	44.0	83.9	108.9
Mulch + Gypsum Flat (MGF)	45.8	83.7	97.2

Table 3. Summary of mean height (or crown diameter for *H. hamabo*) growth for the species of concern (*Q. virginiana, H. hamabo, and T. T406)* over a period of three years, from initial planting in April, 2016 to final measurement in March, 2019.

Treatment	***Quercus virginiana* (cm)**	***Taxodium 'T406'* (cm)**	***Hibiscus hamabo* (cm)**
Control Bedded (CB)	114.6	217.4	174.5
Control Flat (CF)	158.3	209.9	167.5
Gypsum Bedded (GB)	160.2	237.9	174.5
Gypsum Flat (GF)	160.3	202.6	177.5
Mulch Bedded (MB)	129.0	207.8	177.6
Mulch Flat (MF)	153.8	227.1	172.4
Mulch + Gypsum Bedded (MGB)	157.9	224.1	177.2
Mulch + Gypsum Flat (MGF)	171.9	219.5	183.2

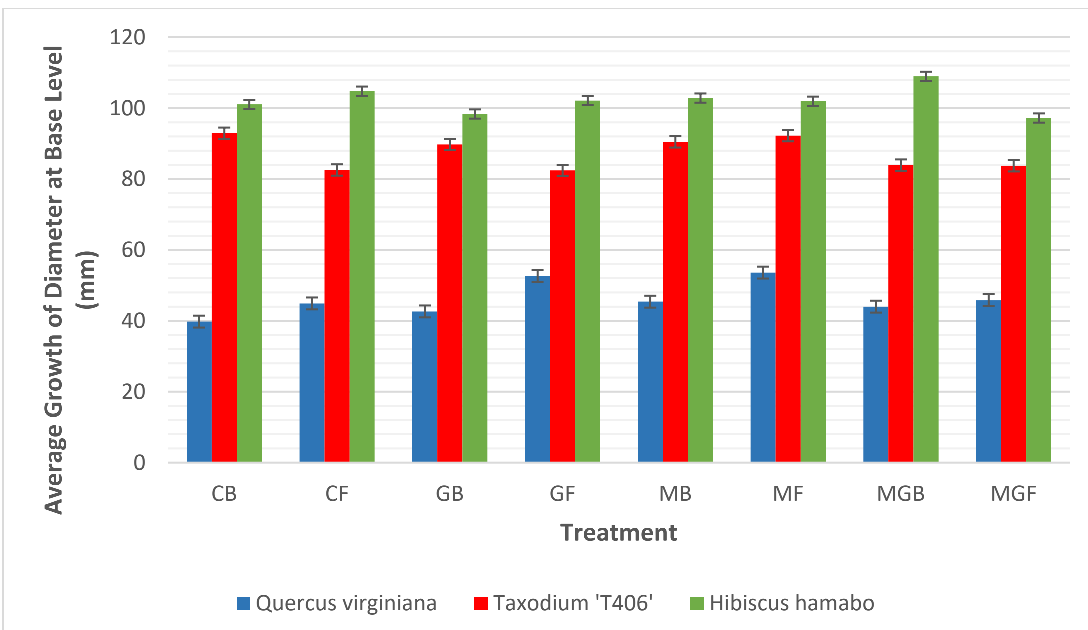


Figure 6. Mean growth of diameter at groundline for each species over the three year duration of the study. Trees were planted in April of 2016, and final measurements were taken in March of 2019. It should be noted that comparisons among species may not be notable, due to differences in plant habit.

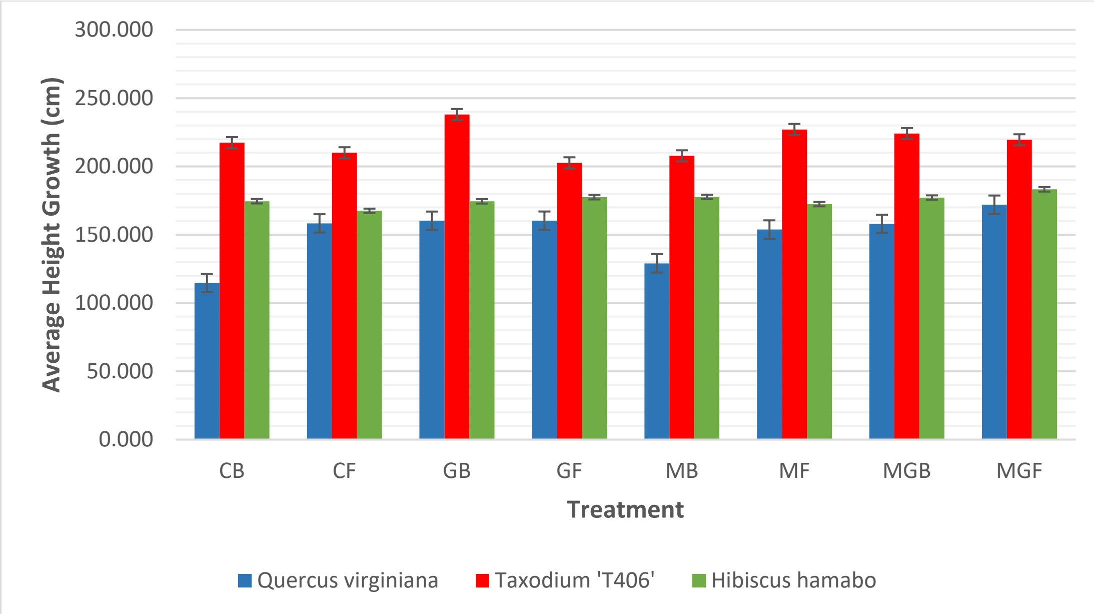


Figure 7. Average height growth for each species for the three year duration of the study. Trees were planted in April of 2016, and final measurements were taken in March of 2019.

Differences in average height growth or average diameter at groundline growth were negligible between treatment methods. *T. T406* displayed the greatest average height growth among all treatment methods, with average growth by treatment ranging from 202.63 cm to 237.98 cm. *H. hamabo* displayed the greatest mean groundline diameter growth among all treatment methods, with average growth by treatment ranging from 97.21 mm to 108.98 mm. The lack of significant differences in growth among the treatments for the 2017 to 2018 growing season is consistent with results from the previous two growing seasons as reported by Harris, 2018. In addition, 291 of the original 296 trees survived until the final measurement date of March 4, 2019, leading to a mortality of only 1.69 percent. Plant species in the study area did not have any apparent mortality or growth problems, although many of the plants had a chlorotic coloration.

To evaluate the relationships between plant growth, species, and the applied treatments, a Two Way ANOVA with Replication was utilized with a significance level, or alpha, of 0.05. The results of this analysis for plant growth in height and diameter are shown in **Table 4 and 5.**

Table 4. Analysis of Variance for total plant diameter growth for the three year duration of the study with a significance level of 0.05.

	DF	SS	MS	F	P-Value	F-Crit
Species	2	783.3	391.7	0.99	**0.37**	3.03
Treatment	7	2462.0	351.7	0.89	**0.51**	2.04
Residuals	278	108434.5	722.1			

Table 5. Analysis of Variance for total plant height growth for the three year duration of the study with a significance level of 0.05.

	DF	SS	MS	F	P-Value	F-Crit
Species	2	235715.4	117857.7	5.45	**1.09E-17**	3.03
Treatment	7	19537.6	2791.1	1.08	**0.38**	2.04
Residuals	278	706670.1	4175.6			

There were no significant differences in plant diameter growth among species or treatment. However, a P-value of 1.09E-17 was found for variance for height growth for each species. Therefore, Tukey’s Test was performed to determine if the difference in mean plant height growth among each species was significant. The results of the Tukey Test is in **Table 6.**

Table 6. Tukey's Test analysis for total plant height growth among species for the 3 year duration of the study.

	Difference	**Lower**	**Upper**	**P-Adjusted**
H. hamabo – T. T406	-44.29	-69.43	-27.14	<0.0001
Q. virginiana – T. T406	-69.18	-86.32	-52.03	<0.0001
Q. virginiana – H. hamabo	-24.89	-42.04	-7.74	0.0021

Based on the data in **Table 6,** it was confirmed that total plant height growth was significantly different among the species tested. However, there were no significant differences in plant height or plant diameter growth among treatments, and plant diameter growth was not significant different among species. Possible causes for the low mortality and similar growth among treatments may be due to freshwater irrigation from nearby research plots, which allowed for the plants in this study to receive more water than anticipated.

6.2 Sodium Concentration in *Taxodium T406*

Foliage samples were collected from *Taxodium T406* specimens in the study plots, as well as from a variety of *Taxodium* hybrids south of the soil amelioration plots. Elemental concentrations for the *T. T406* specimens located on the soil amelioration plots are shown in **Table 7.** The other genotypes, as well as their nutrient concentrations, are shown in **Table 8**. The primary element of concern for this study was Na^+. Na^+ concentrations among the amelioration plots and genotypes are also shown in **Figures 8-9.**

Table 7. Mean foliage elemental concentrations, displayed in mg kg^{-1}, for the *Taxodium T406* specimens separated by soil amelioration treatment. Foliage samples were collected in July, 2018. Samples were analyzed by the Soil, Plant, and Water Analysis Laboratory at Stephen F Austin State University.

Genotype	**Na^+ (mg kg^{-1})**	**K (mg kg^{-1})**	**Ca (mg kg^{-1})**	**Mg (mg kg^{-1})**	**S (mg kg^{-1})**
Control Bedded (CB)	8386	10757	11398	3280	1382
Control Flat (CF)	8690	10653	11065	3383	1305
Gypsum Bedded (GB)	8530	9778	10118	3235	1259
Gypsum Flat (GF)	8251	10843	10094	3280	1265
Mulch Bedded (MB)	9152	11073	10305	3466	1355
Mulch Flat (MF)	8597	11107	11151	3418	1373
Mulch + Gypsum Bedded (MGB)	8894	11454	10691	3436	1420
Mulch + Gypsum Flat (MGF)	8803	11854	10275	3561	1528

Table 8. Mean foliage elemental concentrations, displayed in mg kg^{-1}, for the *Taxodium* genotypes within the study area. Foliage samples were collected in July, 2018. Samples were analyzed by the Soil, Plant, and Water Analysis Laboratory at Stephen F Austin State University.

Genotype	**Na (mg kg^{-1})**	**K (mg kg^{-1})**	**Ca (mg kg^{-1})**	**Mg (mg kg^{-1})**	**S (mg kg^{-1})**
T. distichum	6413	9270	12295	2958	1882
T. 'Oaxaca child'	7237	16744	7703	3023	1814
T407	9374	9860	12256	3691	1821
T406	11060	12279	8791	3401	1990
T405	10579	10852	9454	3210	1853
T27	8701	11665	9092	3058	1949

Genotype	Na (mg kg^{-1})	K (mg kg^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})
T502	9063	9570	8766	3170	1753
T406-North Plots	8662	10940	10637	3382	1361

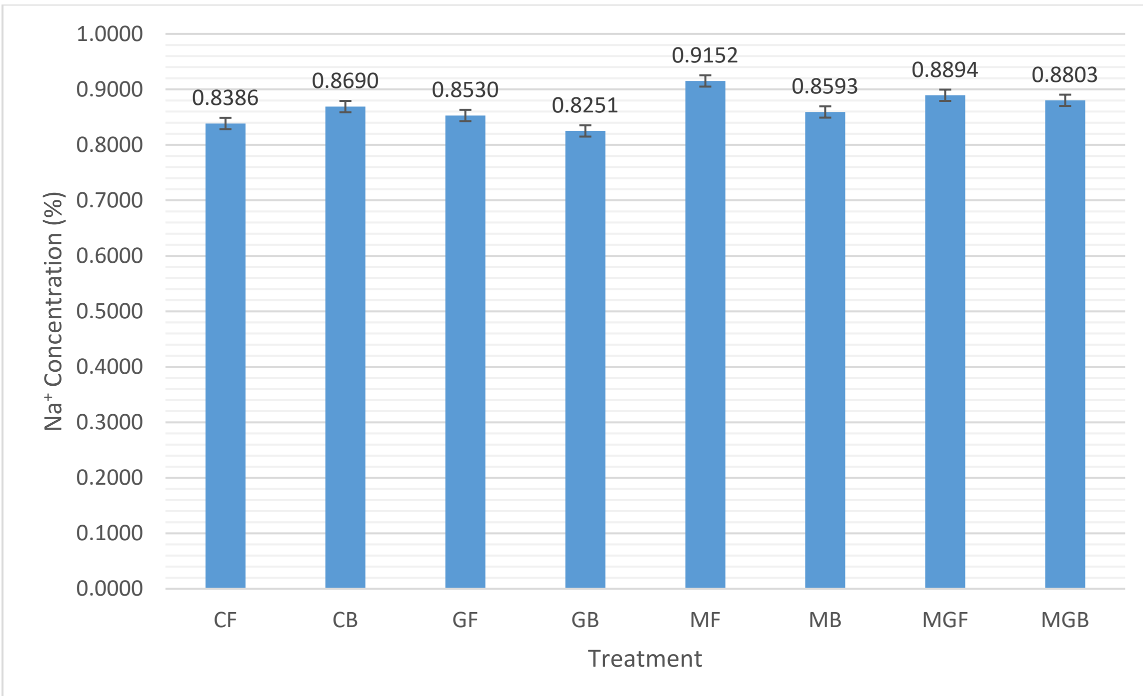


Figure 8. Foliage Na^+ concentrations among soil amelioration treatments, collected from *Taxodium T406* foliage samples at the end of the 2018 growing season.

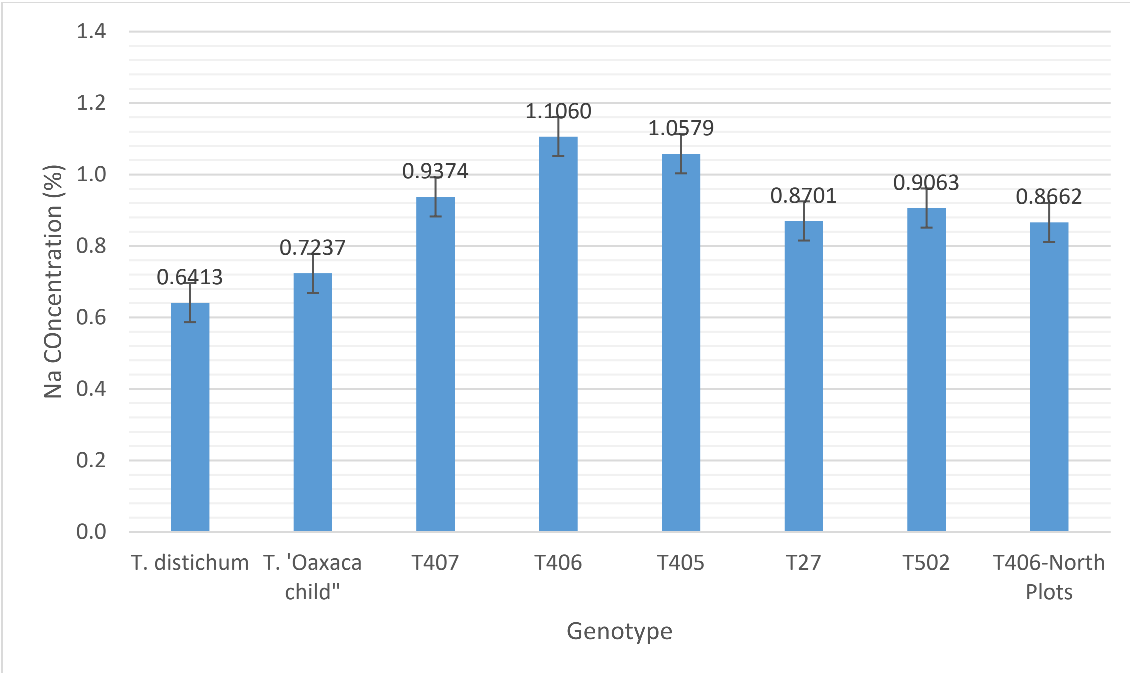


Figure 9. Na^+ concentrations among genotypes found at the Moody Gardens research plots, collected from foliage samples at the end of the 2018 growing season.

Among the amelioration treatments, the Mulch Flat plots contained *T. T406* specimens with the highest Na^+ concentrations, while the Gypsum Bedded plots contained specimens with the lowest Na^+ concentrations. Among the *Taxodium* genotypes, the highest Na^+ concentrations were found in the *T406* specimens located in the southern research plots, while the lowest Na^+ concentrations were found in the *T. distichum* specimens. Due to sample size, these data could not be analyzed statistically.

To evaluate the relationships between foliage Na^+ concentrations and the applied soil amelioration treatments, a One Way ANOVA was utilized with a significance level, or alpha, of 0.05. The results of this analysis are shown in **Table 9**.

Table 9. Analysis of Variance for foliage Na^+ concentrations in the *T. T406* by treatment for the three year duration of the study, with a significance level of 0.05.

	DF	SS	MS	F	P-Value	F-Crit
Among Groups	7	6982650.6	997521.5	0.31	**0.95**	2.11
Within Groups	88	279003724.2	3170497			

There was no significant difference in Na+ concentrations among applied treatments. This is consistent with growth data, which also revealed no significant differences between the applied treatments.

To evaluate the relationships between foliage Na^+ concentrations among genotypes of *Taxodium* located in the southern research plots of the study area, a One Way ANOVA was utilized with a significance level, or alpha, of 0.05. Due to the overwhelming number of *T. T406* samples that were available and collected from the site, this ANOVA was only performed using the samples collected from the genotypes growing south of the applied treatment plots. These genotypes were grown in more uniform conditions, and results are likely to be more representative in order to compare Na^+ concentrations. The results of this analysis are shown in **Table 10.**

Table 10. Analysis of Variance for foliage Na^+ concentrations in the *Taxodium* genotypes within the study area, with a significance level of 0.05.

	DF	SS	MS	F	P-Value	F-Crit
Among Groups	6	83636096.4	13939349	5.89	**0.00045**	2.45
Within Groups	28	66300324.2	2367869			

As seen in **Table 10**, there was a statistically significant difference in Na^+ concentrations of among the genotypes located in the southern research plots. Therefore, Tukey's Test was performed in order to determine which genotypes were significantly different. The results of the Tukey's Test is shown in **Table 11.**

Table 11. Tukey's Test analysis for foliage Na+ concentrations among genotypes of *Taxodium* in the study area.

	Difference	**Lower**	**Upper**	**P-Adjusted**
T. distichum – T. 'Oaxaca child'	823.99	-2263.17	3911.16	0.977
T. distichum – T27	2287.89	-799.27	5375.06	0.256
T. distichum – T405	4166.74	1079.58	7253.91	**0.003**
T. distichum – T406	4647.21	1560.04	7734.37	**0.009**
T. distichum – T407	2960.89	-126.27	6048.06	0.067
T. distichum – T502	2649.92	-437.24	5737.09	0.129
T. 'Oaxaca child' – T27	1463.89	-1623.27	4551.06	0.740
T. 'Oaxaca child' – T405	3342.75	255.59	6429.92	**0.027**
T. 'Oaxaca child' – T406	3823.21	736.05	6910.38	**0.008**
1T. 'Oaxaca child' – T407	2136.89	-950.27	5224.06	0.329
T. 'Oaxaca child' – T502	1825.93	-1261.24	4913.09	0.511
T27 – T405	1878.85	-1208.31	4966.02	0.478
T27 – T406	2359.31	-727.85	5446.48	0.226
T27 – T407	673.00	-2414.16	3760.17	0.992
T27 – T502	362.03	-2725.13	3449.19	0.999
T405 – T406	480.46	-2606.70	3567.63	0.999
T405- T407	-1205.85	-4293.02	1881.31	0.873
T405 – T502	-1516.82	- 4603.99	1570.34	0.708
T406 – T407	-1686.31	-4773.48	1400.85	0.601
T406 – T502	-1997.28	-5084.45	1089.88	0.407
T407 – T502	-310.97	-3398.13	2776.19	0.999

Data from **Table 11** reveals that samples collected from both *T. distichum* and *T. “Oaxaca child”* contained significantly lower Na^+ concentrations than samples collected from *T405* and *T406*. The *T406* genotype located in the southern research plots was the genotype that was utilized in the northern plots that received the applied soil amelioration treatments. As noted earlier, the *T406* was expected to have increased flooding and salt tolerance due to its hybridization between *T. distichum* and *T. mucronatum*. Therefore, it was anticipated that foliage samples from *T406* would contain lower concentrations of Na^+, which was not the case in these results. Nutrient analysis data for the foliage samples can be found in **Appendix C.**

6.3 Groundwater and Soil

6.3.1 Hydraulic Conductivity of Soils

The hydraulic conductivity of the soil at each piezometer was calculated through the use of a 0.5 L slug of water and a Solinst Levelogger. Data capture for the Levelogger was set to the fastest possible interval of two seconds. Three runs were performed for each piezometer, and the Hvorslev Slug-Test Method was employed to determine the hydraulic conductivity at each piezometer location. The formula for the Hvorslev Slug-Test Method can be seen below in **Equation 1.**

Equation 1. The Hvorslev Slug-Test Method.

$$K = \frac{r^2 \ln(L_e/R)}{2L_e t_{37}}$$

Where: K = hydraulic conductivity
r = radius of well casing
R = radius of filter pack
L_e = length of well screen
t_{37} = time for the water level to return to 37 percent of the initial change

The results of the slug tests are shown in **Table 12.** The hydraulic conductivity of the soil ranged from 0.000169 cm/s to 0.003647 cm/s. Hydraulic conductivity varied throughout the study area, although it was less variable as the distance to Offat's Bayou increased. The hydraulic conductivity of the soil at each piezometer may also have been affected by the piezometer construction method, which included a filter sleeve to prevent sediment buildup on the slots of the piezometer. In addition, the pea gravel aggregate that was used to fill the auger hole may have allowed water to filter more quickly from the piezometer.

Table 12. Hydraulic conductivity of the soil at each piezometer. Data was collected through use of 0.5 L slugs of deionized water and a Solinst Levelogger set to record water level at a two-second interval. Slug tests were performed in January 2019. The data was analyzed using the Hvorslev Slug-Test Method.

Piezometer	Average Change in Depth to Water Table (cm)	Average Time for 37 Percent Change to Water Table, t_{37} (s)	Hydraulic Conductivity (cm/s)
1	44.34	35.3	0.003046
2	43.77	96.7	0.002386
3	44.72	129.3	0.001061
4	34.67	35.0	0.003647

Table 12 continued.

Piezometer	Average Change in Depth to Water Table (cm)	Average Time for 37 Percent Change to Water Table, t_{37} (s)	Hydraulic Conductivity (cm/s)
5	31.95	294.7	0.000551
6	50.17	443.3	0.000215
7	32.93	954.0	0.000189
8	27.87	1356.0	0.000169
9	38.11	27.3	0.003136

6.3.2 Water Quality

Groundwater sampling means for the duration of the study are shown in **Table 13.** A groundwater contour map for the study area is shown in **Figure 10.** The data for individual piezometers are shown in **Appendix D.**

Table 13. Means of groundwater sampling data for the Moody Gardens study area, for the duration of the study. Water quality parameters are pH, electrical conductivity (EC), Na^+, Cl^-, and depth to water table (DTWT).

Piezometer	pH	EC (mS/cm)	Na^+ (mg/L)	Cl^- (mg/L)	DTWT (cm)
1	7.94	2.54	360.55	728.47	68.8
2	8.02	2.04	264.92	465.75	72.03
3	7.89	0.91	114.73	86.43	98.17
4	7.87	6.33	845.46	2035.14	63.07
5	8.12	3.02	395.31	775.22	78.39
6	7.99	1.18	299.93	170.11	95.81
7	7.78	4.52	688.18	1460.79	60.46
8	7.78	7.24	962.44	2268.02	84.53
9	8.10	1.45	324.47	167.47	86.43

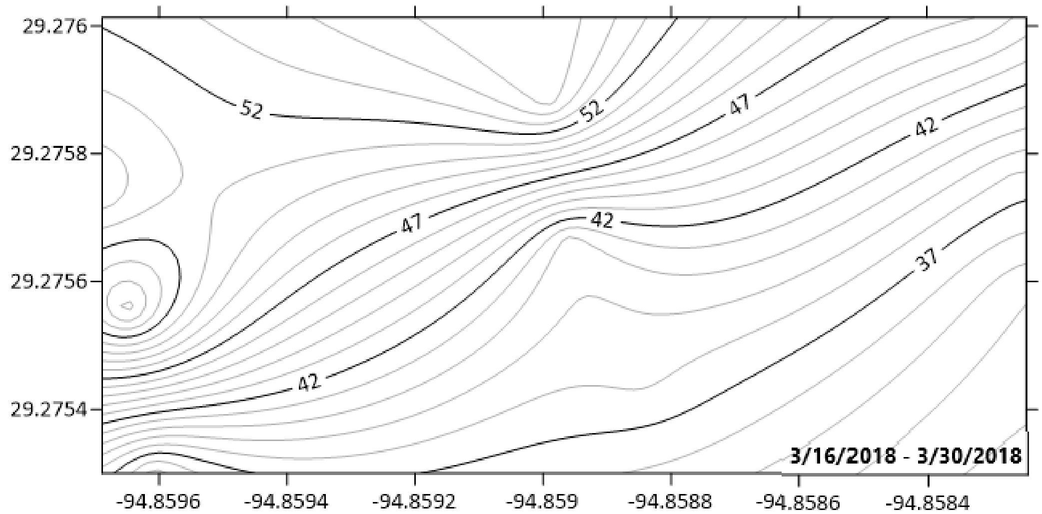


Figure 10. Groundwater contour map for the March 16, 2018 to March 30, 2018 sampling period displaying the groundwater elevation throughout the site in centimeters. Note that groundwater elevation is higher towards Offat's Bayou, indicating that high salinity water may be infiltrating into the groundwater in the study area.

Initial statistical analysis of groundwater samples involved determining the strength of correlations between tested parameters. The strongest positive correlations were generally observed between Cl^- concentrations and electrical conductivity, followed by Na^+ concentration and electrical conductivity. The correlation between groundwater Na^+ concentrations and depth to water table ranged from relatively strong (0.63) and a negligible (0.04). **Table 14** shows the mean correlations between each parameter for all piezometers. Individual correlation tables for each piezometer are shown in **Appendix D.**

Table 14. Correlation statistics summary for the combined nine piezometers.

	pH	EC (mS/cm)	Na^+ (mg/L)	Cl^- (mg/L)	DTWT (cm)	Precipitation (cm)
pH	1.00					
EC	-0.19	1.00				
Na^+	0.08	0.61	1.00			
Cl^-	-0.28	0.81	0.49	1.00		
DTWT	0.48	0.17	0.37	-0.01	1.00	
Precipitation	-0.54	-0.03	-0.09	0.03	-0.49	1.00

Figure 11 shows the average Na^+ concentration over the year of study in each piezometer through the use of an Inverse Distance Weighted (IDW) model to produce Na^+ heat maps. Na^+ heat maps with groundwater contours for the piezometers during each sampling period can be found in **Appendix A**.

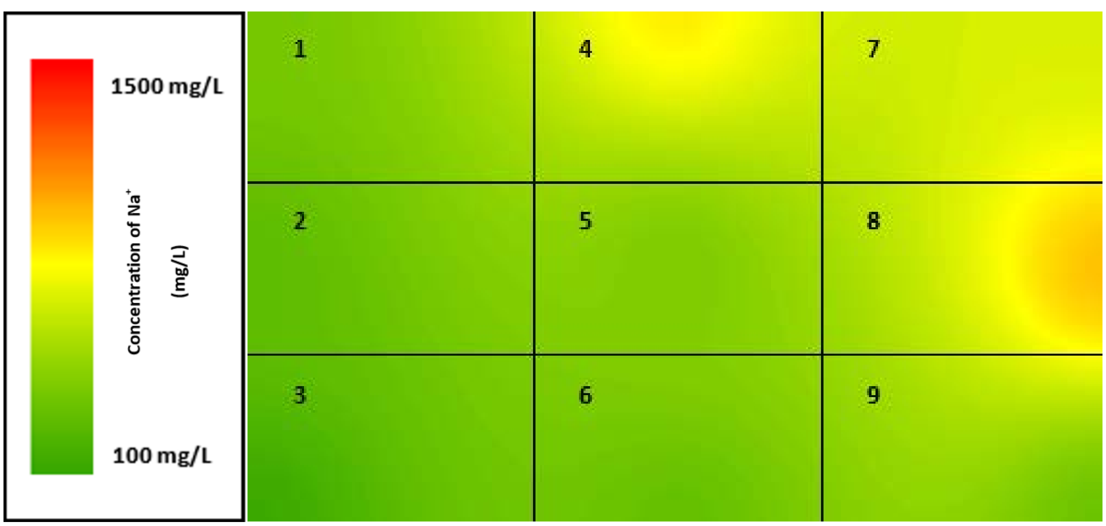


Figure 11. Heat map displaying average concentrations of Na^+ in groundwater in mg/L for the duration of the study. Piezometer 1 was located in the northernmost portion of the grid, while Piezometer 9 was located in the southernmost portion of the grid.

6.3.3 Solinst Levelogger Data

Three Solinst Leveloggers were installed in the eastern piezometers in the study area. The Leveloggers recorded data continuously at a 30 minute interval, and produced data for water level, temperature, and electrical conductivity. Water level data from each piezometer was adjusted using manual measurements, due to limitations of the Levelogger system in a shallow system without barometric correction. **Tables 15-17** display summary statistics for the temperature, water level, and electrical conductivity data collected from the Leveloggers for the duration of the study. The Levelogger data for water levels and electrical conductivity are shown in **Appendix E.**

Table 15. Summary statistics for Levelogger temperature measurements collected for the duration of the study.

Piezometer	Mean Temperature (˚C)	Maximum High Temperature (˚C)	Minimum Low Temperature (˚C)
7	22.03	27.98	13.48
8	23.01	28.90	14.90
9	22.64	29.29	15.41

Table 16. Summary statistics for Levelogger water level measurements collected for the duration of the study.

Piezometer	Mean Water Level (m)	Maximum Water Level (m)	Minimum Water Level (m)
7	11.23	11.81	10.51
8	10.87	11.67	10.31
9	10.68	11.52	10.25

Table 17. Summary statistics for Levelogger electrical conductivity measurements collected for the duration of the study.

Piezometer	Mean Electrical Conductivity (μS/cm)	Maximum Electrical Conductivity (μS/cm)	Minimum Electrical Conductivity (μS/cm)
7	5013.3	20581.0	1267.5
8	8072.9	10006.0	3387.8
9	1559.5	2115.2	39.6

There were discrepancies between Levelogger water level calculations and manual water level measurements, likely due to the lack of barometric correction in the shallow piezometers. This was determined by calculating the difference between the Levelogger reading and the manual measurement, and comparing these differences at each sample point. The difference in depth to water level and the Levelogger water level varied between each collection date, therefore the Levelogger water level readings were unable to be adjusted for accurate data values following the study. However, the Levelogger water level measurements appear to represent changes in tide and major precipitation events, and may be useful to indicate trends in associated with these events. Levelogger readings for electrical conductivity were closer to laboratory determinations, with minor deviations observed throughout the course of the study. These variations are likely due to groundwater fluctuation during sampling. A comparison of tested groundwater electrical conductivity and Levelogger measurements for the three piezometers are shown **Tables 18-20**, and graphs displaying these relationships can be seen in **Figures 12-14.** Raw data from the Leveloggers, which displays the fluctuations in electrical conductivity, can be found in **Appendix E.**

Table 18. Comparison of the mean values of laboratory-tested groundwater electrical conductivity and Levelogger measurements of electrical conductivity at the study area for Piezometer 7.

Sampling Period	Electrical Conductivity from Levelogger (µS/cm)	Electrical Conductivity from Groundwater Samples (µS/cm)	Difference
9/29/2017 - 10/13/2017	15527	15950	-423
10/14/2017 - 10/27/2017	13053	9480	3573
10/28/2017 -11/10/2017	8727	7140	1587
11/11/2019 -11/24/2017	6675	5300	1375
11/25/2017 - 12/8/2017	4624	3640	984
12/9/2017 - 12/22/2017	3593	3740	-147
12/23/2017 -1/5/2018	3305	3270	35
1/6/2018 -1/19/2018	2851	2760	91
1/20/2018 -2/2/2018	4808	6620	-1812
2/3/2018 -2/17/2018	4976	5540	-564
2/18/2018 - 3/2/2018	4322	4030	292
3/3/2018 - 3/16/2018	3998	3490	508
3/17/2019 - 3/30/2018	3577	3130	447
3/31/2018 - 4/13/2018	3502	3010	492
4/14/2018 - 4/27/2018	3100	2740	360
4/28/2018 - 5/11/2018	2888	2650	238
5/12/2018 - 5/25/2018	2890	2510	380
5/26/2018 - 6/8/2018	2880	2450	430
6/9/2018 -6/22/2018	3001	2820	181
6/23/2018 - 7/6/2018	3479	3120	359
7/7/2018 - 7/20/2018	6701	4190	2511
7/21/2018 - 8/3/2018	4039	3540	499
8/4/2018 - 8/17/2018	3466	2940	526
Averages	5043	4524	518

Table 19. Comparison of the mean values of laboratory-tested groundwater electrical conductivity and Levelogger measurements of electrical conductivity at the study area for Piezometer 8.

Sampling Period	Electrical Conductivity from Levelogger (µS/cm)	Electrical Conductivity from Groundwater Samples (µS/cm)	Difference
9/29/2017 - 10/13/2017	15527	7700	7827
10/14/2017 - 10/27/2017	13053	7180	5873
10/28/2017 -11/10/2017	8727	7220	1507
11/11/2019 -11/24/2017	6675	6820	-145
11/25/2017 - 12/8/2017	4624	5920	-1296
12/9/2017 - 12/22/2017	3593	6750	-3157
12/23/2017 -1/5/2018	3305	7050	-3745
1/6/2018 -1/19/2018	2851	6820	-3969
1/20/2018 -2/2/2018	4808	6340	-1532
2/3/2018 -2/17/2018	4976	7150	-2174
2/18/2018 - 3/2/2018	4322	7140	-2818
3/3/2018 - 3/16/2018	3998	7580	-3582
3/17/2019 - 3/30/2018	3577	7400	-3823
3/31/2018 - 4/13/2018	3502	7330	-3828
4/14/2018 - 4/27/2018	3100	7080	-3980
4/28/2018 - 5/11/2018	2888	7320	-4432
5/12/2018 - 5/25/2018	2890	7390	-4500
5/26/2018 - 6/8/2018	2880	7400	-4520
6/9/2018 -6/22/2018	3001	6830	-3829
6/23/2018 - 7/6/2018	3479	7120	-3641
7/7/2018 - 7/20/2018	6701	8410	-1709
7/21/2018 - 8/3/2018	4039	8310	-4271
8/4/2018 - 8/17/2018	3466	8290	-4824
Averages	5043	7241	-2199

Table 20. Comparison of the mean values of laboratory-tested groundwater electrical conductivity and Levelogger measurements of electrical conductivity at the study area for Piezometer 9.

Sampling Period	Electrical Conductivity from Levelogger (µS/cm)	Electrical Conductivity from Groundwater Samples (µS/cm)	Difference
9/29/2017 - 10/13/2017	1759	1640	119
10/14/2017 - 10/27/2017	1896	1699	197
10/28/2017 -11/10/2017	2070	1771	299
11/11/2019 -11/24/2017	2044	1796	248
11/25/2017 - 12/8/2017	1954	1705	249
12/9/2017 - 12/22/2017	1672	1513	159
12/23/2017 -1/5/2018	1495	1458	37
1/6/2018 -1/19/2018	1424	1426	-2
1/20/2018 -2/2/2018	1402	1448	-46
2/3/2018 -2/17/2018	1413	1369	44
2/18/2018 - 3/2/2018	1360	1323	37
3/3/2018 - 3/16/2018	1336	1332	4
3/17/2019 - 3/30/2018	1335	1344	-9
3/31/2018 - 4/13/2018	1389	1349	40
4/14/2018 - 4/27/2018	1420	1375	45
4/28/2018 - 5/11/2018	1432	1492	-60
5/12/2018 - 5/25/2018	362	1342	-980
5/26/2018 - 6/8/2018	6	1293	-1287
6/9/2018 -6/22/2018	381	1252	-871
6/23/2018 - 7/6/2018	1446	1225	221
7/7/2018 - 7/20/2018	1467	1396	71
7/21/2018 - 8/3/2018	653	1408	-755
8/4/2018 - 8/17/2018	962	1430	-468
Averages	1334	1452	-118

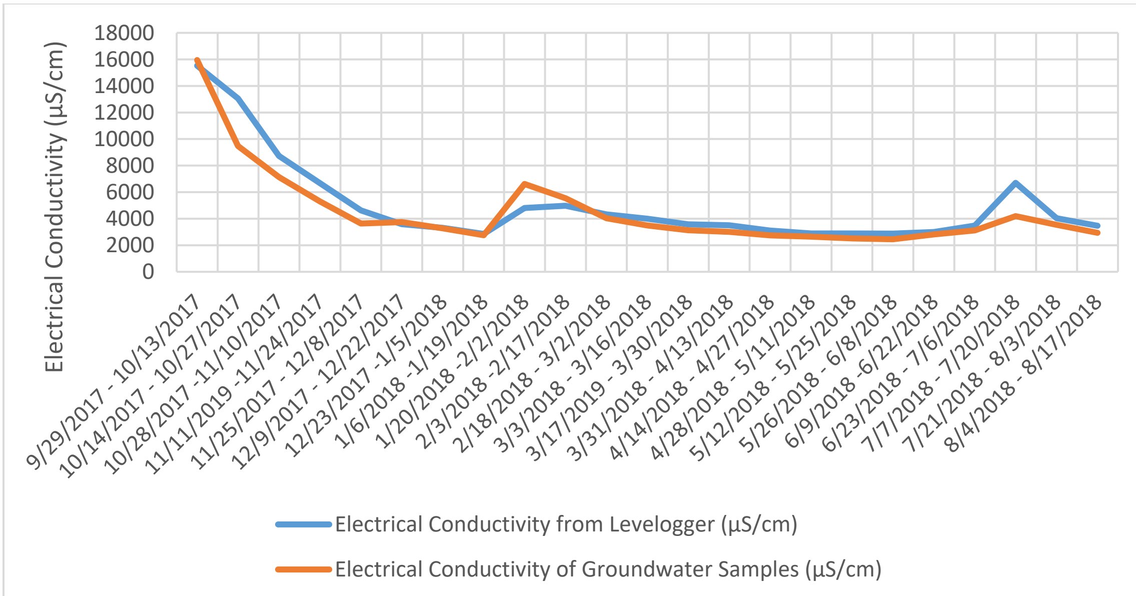


Figure 12. Graph displaying the relationship between mean values of laboratory-tested groundwater electrical conductivity and Levelogger measurements for electrical conductivity for the duration of the study at Piezometer 7.

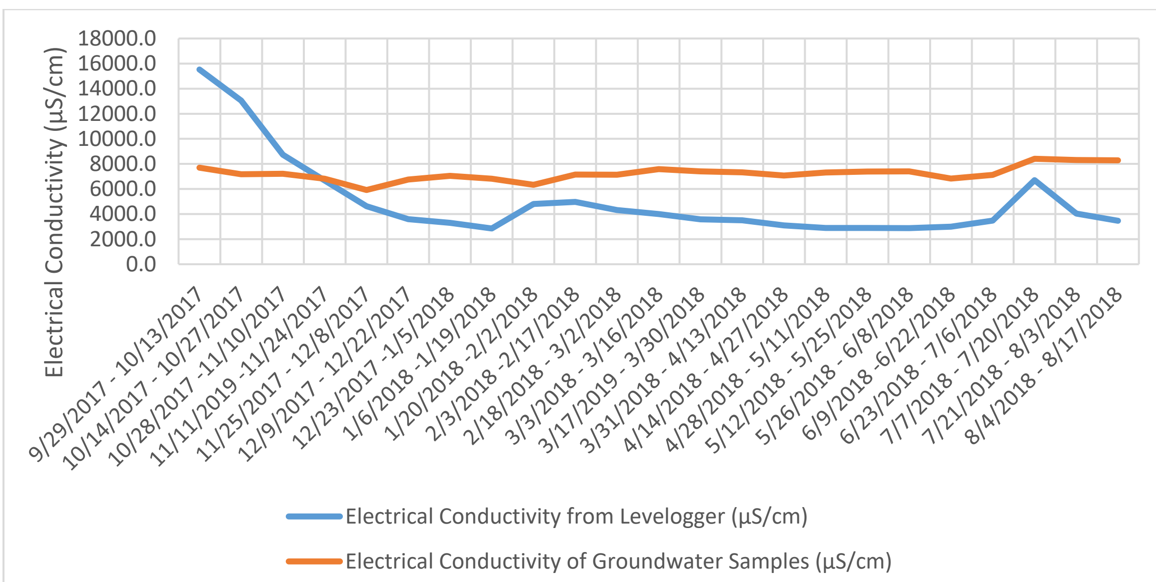


Figure 13. Graph displaying the relationship between mean values of laboratory-tested groundwater electrical conductivity and Levelogger measurements for electrical conductivity for the duration of the study at Piezometer 8.

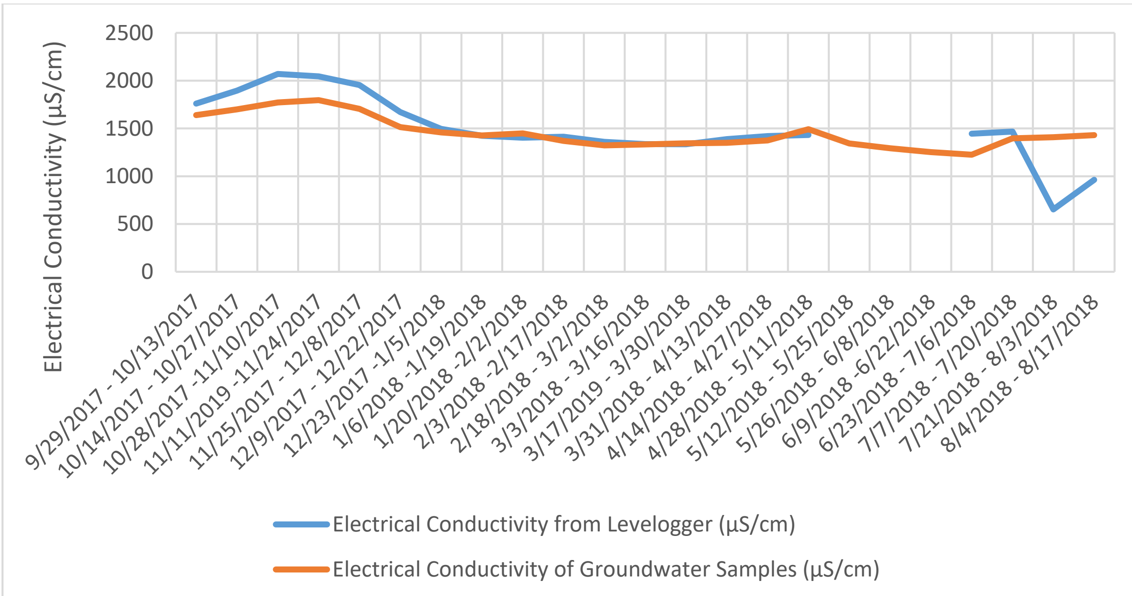


Figure 14. Graph displaying the relationship between mean values of laboratory-tested groundwater electrical conductivity and Levelogger measurements for electrical conductivity for the duration of the study at Piezometer 9. During the 5/26/2018 to 6/8/2018 sampling period, water levels in Piezometer 9 dropped below the sensor of the Levelogger, and therefore were unable to be determined.

As seen in **Tables 18-20** and **Figures 12-14,** electrical conductivity measurements appear to be relatively consistent between the laboratory-tested groundwater samples and the Levelogger readings in Piezometers 7 and 9. Electrical conductivity measurements were not as similar across methods in Piezometer 8, where laboratory-tested groundwater samples had consistently higher electrical conductivity after the initial measurements.

6.3.4 Weather Data

Data was collected from the Scholes Field Weather Station for the duration of the study, and summary statistics of the data collected are shown in **Table 21.** Historical weather data was accessed through AgACIS (Agricultural Applied Climate Information System) in order to compare site conditions during the study to historical weather data for the site, from 1971 to 2019. Analysis of historical weather data determined that site conditions were generally typical during the course of the study. Average high and low temperatures were within 1˚ C of average high and low values. Total precipitation for the year was 134.54 cm, which is above the average yearly precipitation of 114.48 cm. However, although there was a higher than average amount of precipitation for the duration of the study, there were only 41 days in which there was greater than 0.25 cm of precipitation, compared to the average 57 days. This may be due to precipitation occurring primarily in fewer, but larger precipitation events. The comparison of weather data for the study duration and historical data can be seen in **Tables 22-23.**

Table 21. Comparison of temperature data determined during the duration of the study to historical weather data. Data was collected from the weather station located at Scholes Field (KGLS) in Galveston Texas. Historical data referenced includes data from 1971 to 2019.

Month	Average High Temperature (˚C)	Average High Temperatures During Study (˚C)	Difference	Average Low Temperature (˚C)	Average Low Temperatures During Study (˚C)	Difference
January	16.61	14.53	2.08	7.49	9.39	-1.90
February	18.28	21.71	-3.43	15.42	11.33	4.08
March	21.50	24.16	-2.66	17.56	14.83	2.73
April	24.89	24.35	0.54	16.87	18.39	-1.52
May	28.28	29.80	-1.53	23.96	22.50	1.46
June	31.28	31.81	-0.54	26.78	25.67	1.11
July	32.11	31.79	0.32	26.40	26.56	-0.16
August	32.67	32.80	-0.13	27.01	26.72	0.28
September	30.83	30.04	0.80	25.17	24.67	0.50
October	27.06	28.48	-1.42	21.43	20.39	1.04
November	22.11	23.50	-1.39	17.74	15.00	2.74
December	17.83	17.47	0.36	10.32	10.61	-0.29
Totals	**25.29**	**25.87**	**-0.58**	**19.68**	**18.84**	**0.84**

Table 22. Comparison of precipitation data determined during the duration of the study to historical weather data. Data was collected from the weather station located at Scholes Field (KGLS) in Galveston Texas. Historical data referenced includes data from 1971 to 2019.

Month	Total Monthly Precipitation During Study (cm)	Average Monthly Precipitation (cm)	30% Chance Precipitation Less Than This Value (cm)	30% Chance Precipitation More Than This Value (cm)
January	8.43	9.45	5.21	11.51
February	1.65	5.08	2.31	6.22
March	3.40	8.28	4.50	10.11
April	2.43	5.66	2.36	6.91
May	1.78	7.24	2.26	8.61
June	12.70	11.43	5.41	13.97
July	13.36	8.28	3.40	10.06
August	3.28	11.71	3.74	13.97
September	62.56	16.56	9.09	20.19
October	5.79	11.86	5.69	14.48
November	1.09	9.12	4.72	11.15
December	18.06	9.80	6.25	11.81
Totals	**134.54**	**114.48**	**54.94**	**138.99**

Table 23. Weather data for the project area for the 12-month duration of the study, separated into the 2-week sampling periods. Data was collected from the weather station located at Scholes Field (KGLS) in Galveston Texas.

Sampling Period	Precipitation Events (≥0.25 cm)	Total Precipitation (cm)	Average High Temperature (˚C)	Average Low Temperature (˚C)
9/29/2017 - 10/13/2017	3	2.42	31.22	25.07
10/14/2017 - 10/27/2017	2	2.39	27.95	20.38
10/28/2017 -11/10/2017	1	2.62	25.12	18.85
11/11/2019 -11/24/2017	0	0.25	22.34	16.43
11/25/2017 - 12/8/2017	4	13.18	20.83	14.09
12/9/2017 - 12/22/2017	2	2.39	17.66	10.63
12/23/2017 -1/5/2018	1	2.49	12.98	5.99
1/6/2018 -1/19/2018	1	1.75	13.77	6.39
1/20/2018 -2/2/2018	1	6.68	18.41	11.23
2/3/2018 -2/17/2018	0	1.09	19.15	12.56
2/18/2018 - 3/2/2018	0	0.56	24.87	19.10
3/3/2018 - 3/16/2018	0	0.66	22.50	15.91
3/17/2019 - 3/30/2018	1	2.74	25.36	19.05
3/31/2018 - 4/13/2018	0	0.69	23.93	16.55
4/14/2018 - 4/27/2018	2	1.74	24.48	16.98
4/28/2018 - 5/11/2018	0	0.61	27.18	20.95
5/12/2018 - 5/25/2018	0	1.04	29.92	24.25
5/26/2018 - 6/8/2018	0	0.13	31.59	26.23
6/9/2018 -6/22/2018	2	12.67	31.87	26.51
6/23/2018 - 7/6/2018	2	8.99	31.31	26.63
7/7/2018 - 7/20/2018	1	0.86	31.39	26.63
7/21/2018 - 8/3/2018	1	3.53	32.66	26.35
8/4/2018 - 8/17/2018	1	1.45	32.54	26.98
8/18/2018 -8/31/2018	1	1.83	33.17	27.38
9/1/2018 - 9/14/2018	9	41.83	30.00	25.16
9/15/2018 - 9/30/2018	6	19.94	30.39	25.26
Total	41	134.54		

Precipitation data was compared to groundwater Na+ concentrations determined during the study revealed no statistically significant correlations between groundwater Na^+ concentrations and precipitation during the sampling period. A summary of the statistical analysis of the relationship between groundwater Na^+ concentrations and precipitation data can be seen in **Table 24,** and the line fit plots displaying the relationship between groundwater Na+ concentrations and precipitation can be seen in **Figures 15-23.** The compiled linear regression statistics can be found in **Appendix F.**

Table 24. Linear regression statistical analysis of the relationship between groundwater Na^+ concentrations and sampling period sum of precipitation.

Piezometer	Multiple R	R^2	Standard Error
1	0.106	0.011	353.17
2	0.173	0.030	119.59
3	0.161	0.026	90.34
4	0.267	0.071	348.71
5	0.078	0.006	165.34
6	0.201	0.041	366.06
7	0.058	0.003	485.99
8	0.012	0.0001	432.70
9	0.157	0.025	189.30

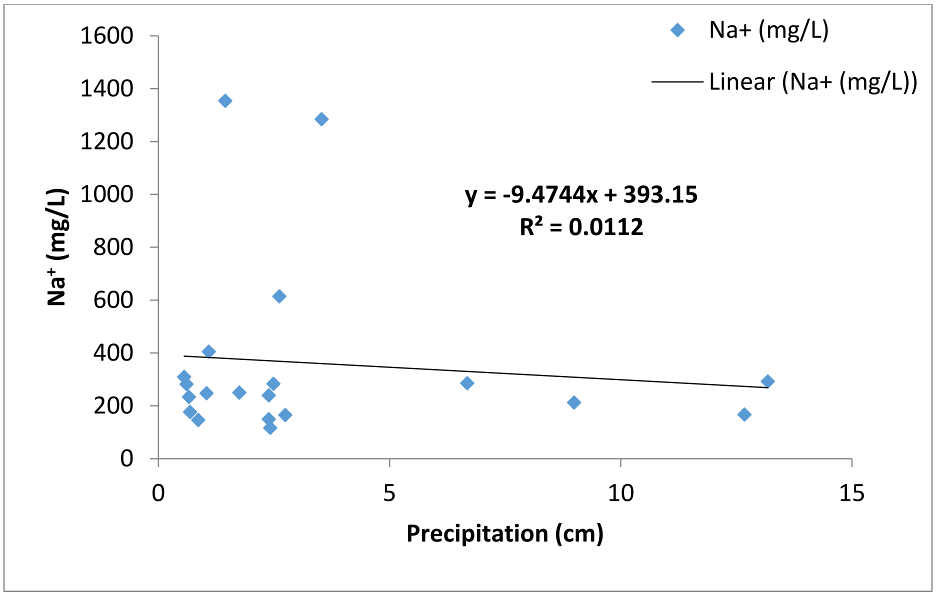


Figure 15. Line fit plot created from linear regression analysis of the relationship between groundwater Na^+ concentrations and sampling period sum of precipitation at Piezometer 1 for the 12-month duration of the study.

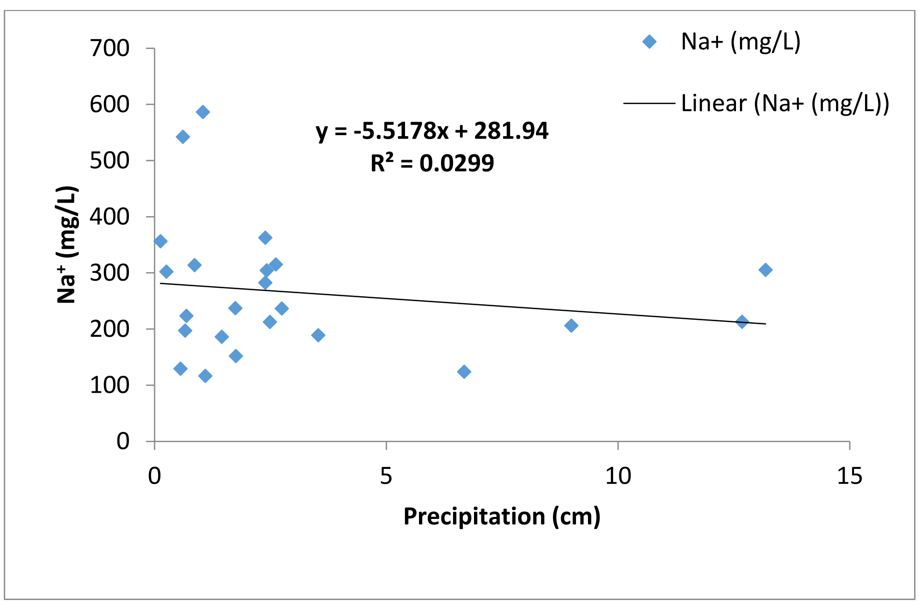


Figure 16. Line fit plot created from linear regression analysis of the relationship between groundwater Na^+ concentrations and sampling period sum of precipitation at Piezometer 2 for the 12-month duration of the study.

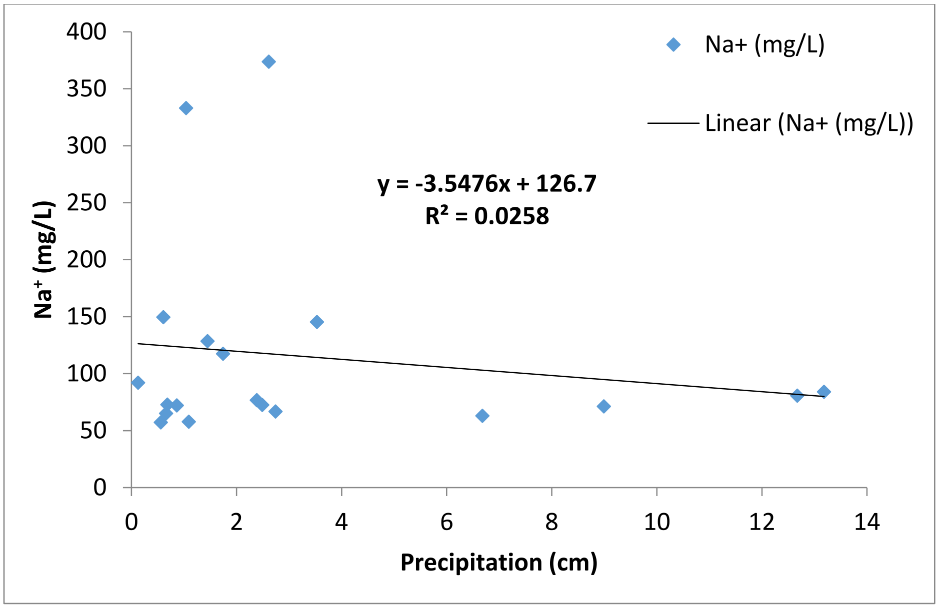


Figure 17. Line fit plot created from linear regression analysis of the relationship between groundwater Na^+ concentrations and sampling period sum of precipitation at Piezometer 3 for the 12-month duration of the study.

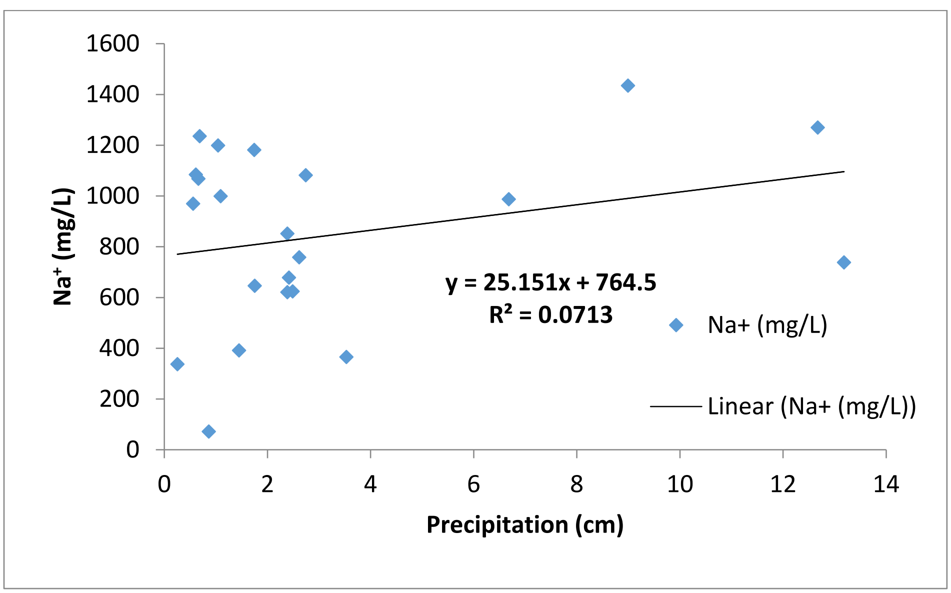


Figure 18. Line fit plot created from linear regression analysis of the relationship between groundwater Na^+ concentrations and sampling period sum of precipitation at Piezometer 4 for the 12-month duration of the study.

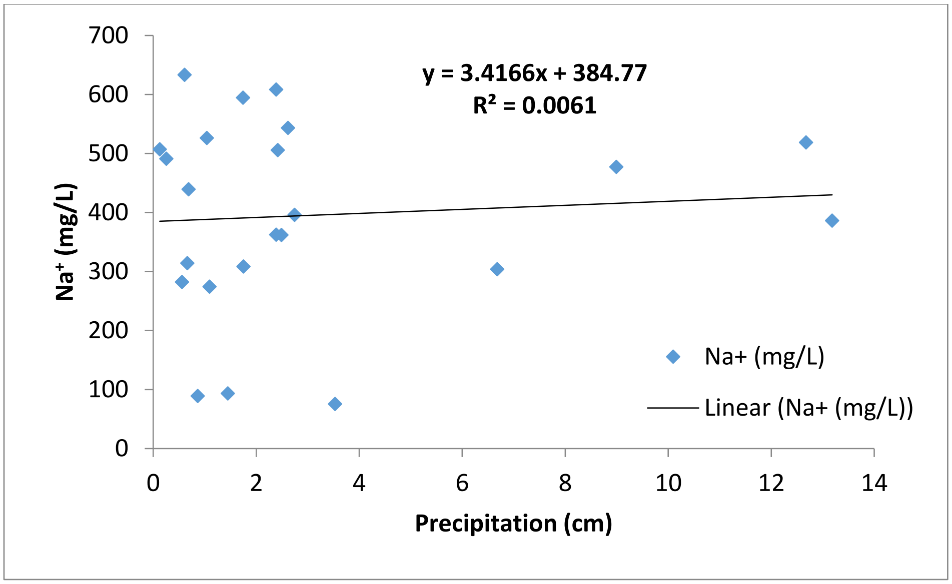


Figure 19. Line fit plot created from linear regression analysis of the relationship between groundwater Na^+ concentrations and sampling period sum of precipitation at Piezometer 5 for the 12-month duration of the study.

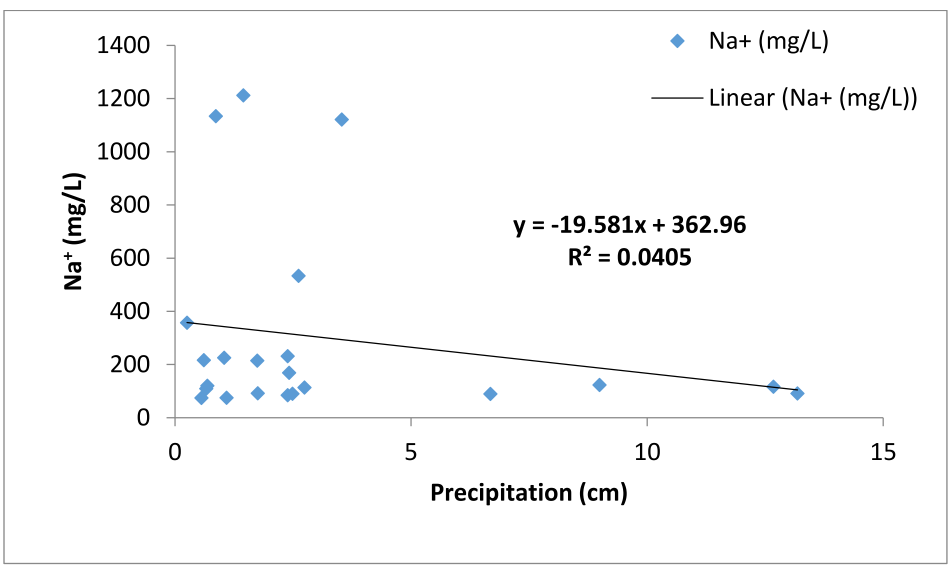


Figure 20. Line fit plot created from linear regression analysis of the relationship between groundwater Na^+ concentrations and sampling period sum of precipitation at Piezometer 6 for the 12-month duration of the study.

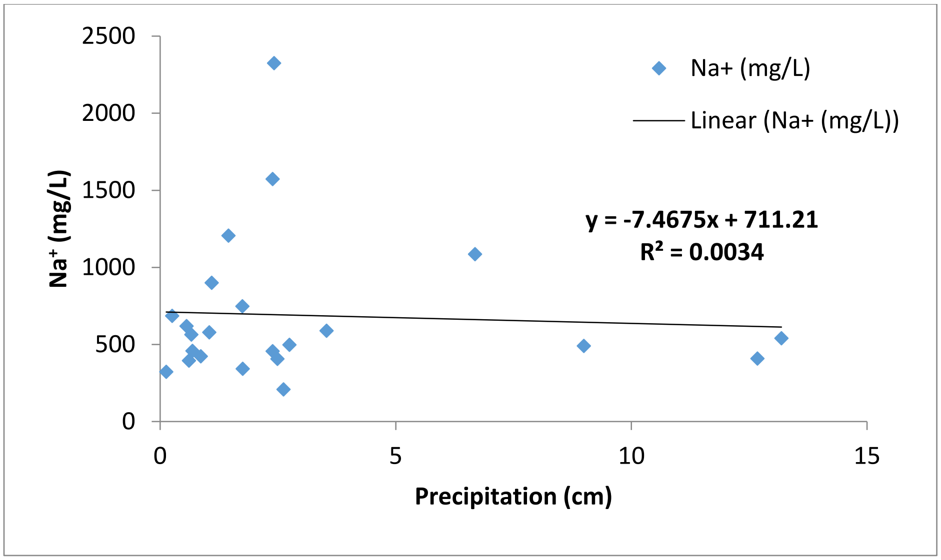


Figure 21. Line fit plot created from linear regression analysis of the relationship between groundwater Na^+ concentrations and sampling period sum of precipitation at Piezometer 7 for the 12-month duration of the study.

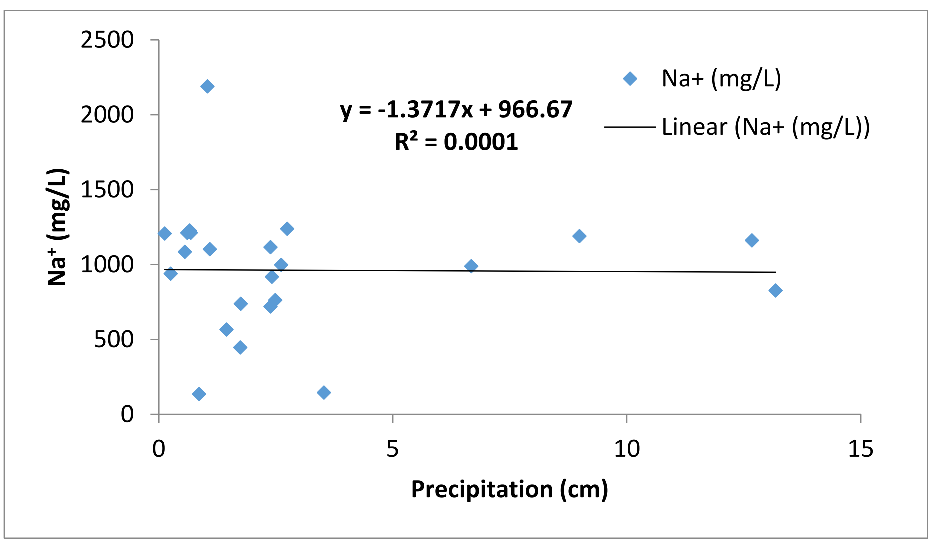


Figure 22. Line fit plot created from linear regression analysis of the relationship between groundwater Na^+ concentrations and sampling period sum of precipitation at Piezometer 8 for the 12-month duration of the study.

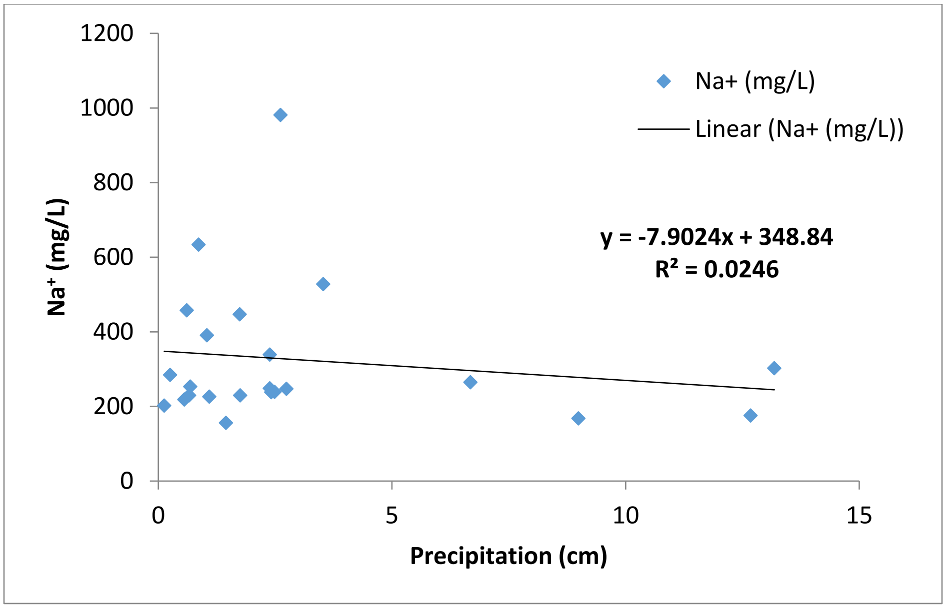


Figure 23. Line fit plot created from linear regression analysis of the relationship between groundwater Na^+ concentrations and sampling period sum of precipitation at Piezometer 9 for the 12-month duration of the study.

7. Discussion

7.1 Survival and Growth of *Taxodium T406* and the Impacts of Sodium

Although the previous study for the project was focused on mortality and growth of the plant species due to an elevated intake of Na^+, there has been minimal mortality over the three years among the species planted at the site. A total of five trees, including four *Q. virginiana* and one *H. hamabo*, had died during the course of the study, despite a lack of freshwater irrigation since the beginning of the second growing season. The species analyzed for Na^+ concentrations in this study, *T. T406*, had the largest height growth among the species, and had no mortality over the course of observation. All three species observed displayed minor responses to coastal stressors such as salt intake and wind stress, which included noticeable chlorosis and the loss of foliage, and a northern sweep away from the Gulf of Mexico. Comparatively, *Taxodium* genotypes immediately south of the project area, which received regular irrigation and fertilizer treatments, displayed more typical green coloration, fuller foliage, and an apparent increase in resistance to wind stress.

ANOVA analysis was performed to evaluate the effects of the applied treatments on plant growth among species after the third growing season, where it was determined that there were no significant differences in plant height (crown diameter for *H. hamabo*) or diameter growth among soil amelioration treatments, and no significant difference in plant diameter growth among species. It was determined that there had been significant differences in plant height (crown diameter for *H. hamabo*) growth among species. The *T. T406* had significantly more height growth over the course of the study than either *Q. virginiana* or *H. hamabo*. Possible reasons for *T. T406* growing more successfully may be due to the robust characteristics of the hybrid allowing it to tolerate the accumulation of Na^+. Other possible reasons for the difference in height growth are likely due to human error throughout the course of study, which includes separate instances of unrequested pruning of the *Q. virginiana* and *H. hamabo* by Moody Gardens personnel.

Comparison of foliage elemental concentrations, groundwater ionic concentrations, and previously recorded aerial deposition data allowed for evaluation of the uptake of Na^+ in *T. T406.* The *T406* foliage samples revealed Na^+ percentages ranging from 8251 mg kg^{-1} to 9151 mg kg^{-1}. However, the highest average concentration of Na^+ in groundwater throughout the study area was approximately 962 mg/L, in Piezometer 8, with average concentrations in the piezometers bordering the *T. T406* plots ranging from 114 mg/L to 324 mg/L. In a study of the effects of salinity on *Taxodium* genotype growth, Zhou utilized salt rates up to 1200 mg/L over the course of her study, and maximum Na^+ concentrations in the *Taxodium* specimens were found to be 3500 mg kg^{-1} (Zhou, 2007). It should also be noted that a previous study determined aerial Na^+ deposition near the *Taxodium* plots, with accumulated Na^+ deposition over a 12-

month period amounting to 0.35 kg km^{-1} (Harris, 2019). Assuming that the conditions in this study were representative of natural conditions, this may indicate that a major vector of Na^+ into the *T. T406* is aerial deposition, with minimal influence by groundwater. Alternatively, the *T.T406* specimens may have higher Na^+ concentrations due to accumulation of salts over a longer period of time. The study performed by Zhou was conducted over a period of only 10 months, while the foliage samples for this study were collected after a period of approximately 30 months. Over this extended period, it is possible that the transpiration of water resulted in some Na^+ being left in plant tissues, which could have resulted in the elevated Na^+ concentrations observed in this study.

In addition, the Na^+ concentrations determined in the foliage samples of *Taxodium* genotypes in the southern research plots revealed varying concentrations of Na^+. The northern amelioration plots received pop-up sprinkler irrigation for the first year of growth, and the *Taxodium* were not pruned over the course of study. The southern plots employed several different techniques as compared to the northern amelioration plots, including the use of drip irrigation and heavy annual pruning. Foliage elemental concentrations for these specimens are shown in **Table 8**, where *Taxodium* hybrids and species in these southern research plots were sampled and compared to the *T. T406* in the northern amelioration plots. One of the specimens sampled was *Taxodium distichum*, which was used to produce the *T. T406*. The Na^+ concentration averages in the *T. distichum* samples were approximately 6413 mg kg^{-1}, which was less than the Na^+ concentration averages in the *T. T406* samples from either the research plots or amelioration plots (11,060 mg kg^{-1} and 8662 mg kg^{-1}, respectively). It was anticipated that the *T. distichum* samples would contain higher Na^+ concentrations, due to *T. distichum* possessing a lower salt tolerance. In this case only the *T. T406* samples from the soil amelioration plots had higher Na^+ concentrations. One possible explanation for the elevated Na^+ concentrations in the *T. T406* samples is possible adaptation to the saline conditions of the site. The *T. T406* specimens are hybrids of *T. distichum* and *T. mucronatum*, which was intended to produce a hybrid with increased tolerances for flooding and saline conditions. As these hybrids are more resistant to saline conditions, it is possible they possess a higher tolerance of Na^+. This will be discussed again in further detail below.

7.2 Precipitation and Groundwater Characteristics

Prior to the installation of piezometers and the collection of groundwater data, Galveston Island and the surrounding areas received approximately 58 cm of precipitation during the landfall of Hurricane Harvey. This may have altered initial groundwater Na^+ concentrations due to the irregular conditions. It was expected that with increases in precipitation, a decrease in groundwater Na^+ would follow, due to the influx of fresh water into the groundwater system. However, linear regression analysis comparing groundwater concentrations of Na^+ and precipitation during the study revealed no direct correlation between the two variables. A possible factor affecting groundwater Na^+ concentrations is the intrusion of lateral saltwater into the groundwater. As seen in **Table 24** and **Figures 15-23**, there was not a strong correlation between groundwater Na^+ concentrations and precipitation. The maximum R^2 value was 0.041, indicating that only 4 percent of the variation in Na^+ is due to variation in precipitation. Therefore, it does not appear that there is a direct relationship between groundwater Na^+ concentrations and precipitation. In **Table 13**, it can be seen that the piezometers that were closer in proximity to Offat's Bayou and the West Bay (Piezometers 1, 4, and 7) generally contained higher concentrations of Na^+, while the piezometers further inland contained lower concentrations of Na^+. It is highly likely that these concentrations are due to saltwater infiltrating the groundwater from the bay and Gulf of Mexico.

In a previous study at the site, it was determined that in Galveston, aerial deposition of salts is a significant contributor to Na^+ accumulation, with a significantly larger volume of salts being deposited during precipitation events (Harris, 2019). However, the total amount of Na^+ deposited by annual aerial input was relatively small, compared to that already in the soils. As this groundwater evaluation study was performed in close proximity to the aerial deposition study, it can be assumed that aerial deposition during precipitation events may be introducing at least small amounts of Na^+ into the groundwater that may partially offset the dilution of Na^+ from the introduction of freshwater to the groundwater. Due to the variability of the Levelogger water levels, the amount of precipitation that reached groundwater following each precipitation event was not able to be determined. Therefore, the dilution effect caused by the introduction of freshwater precipitation to the groundwater could not be quantified.

The groundwater samples collected were generally slightly stained with a slight brown hue, with the exception of Piezometer 8. Throughout the course of the study, groundwater from Piezometer 8 displayed unique characteristics, including nearly opaque black water and a slow recharge rate. In addition, the groundwater collected from Piezometer 8 produced a strong odor throughout most of the year. Most of the piezometers became habitat for fire ants at some point over the course of the study, with Piezometer 8 having the most consistent presence throughout the year. The soil surrounding Piezometer 9 became home to a large colony of ants, which may have been responsible for altering the quality of the groundwater in the area immediately surrounding the piezometer. It is possible that their tunnels altered the groundwater flow and hydraulic conductivity, and that their waste may have resulted in the unusual color of the groundwater. Chemical analyses of the groundwater samples of this piezometer revealed higher electrical conductivity, Na^+ and Cl^+ concentrations, and lower pH when compared to the other piezometers.

The hydraulic conductivity of the soil at each piezometer was determined through the use of a slug test, which involved the rapid placement of a 0.5 L volume of water into each piezometer, and the measurement of the duration for the water level to equilibrate. Using the Hvorslev Slug-Test Method, the hydraulic conductivities for the piezometers were determined to range from 0.000169 cm/s to 0.003647 cm/s, which is typical for sandy clay and sandy clay loam soils. The hydraulic conductivity of the soil is such that water can move quickly through the soil, notably more so in piezometers 1, 4, and 9. Piezometers 1 and 4 were on the northern border of the piezometer grid, and were closest to Offat's Bayou. Both Piezometers 1 and 4 were ponded due to heavy precipitation on multiple occasions throughout the course of the study. Piezometer 9, which had the highest hydraulic conductivity rating, was located in the southeast corner of the piezometer grid, close to the irrigated research plots and the channel bordering the project area. Piezometer 8 had a hydraulic conductivity of 0.000169 cm/s, which was the lowest of all determined values.

The use of the three Solinst Leveloggers provided reliable and accurate data for the electrical conductivity and temperature parameters during the course of this study. However, while electrical conductivity measurements were within 1000 µS/cm for each piezometer, groundwater depth measurements from the Levellogger appeared to differ from the manual measurements taken throughout the study, with inconsistent differences between manual recorded depth to the water table and Levelogger measurements. This is likely due to the shallowness of the study piezometers, which were less than 2 m in depth, as well as the absence of barometric correction. It is possible that the use of deeper piezometers would have alleviated the irregularities in water level measurements, due to the mechanism of determining water level depth being better suited for piezometers greater than 2 m in depth. In addition, the Leveloggers would have been able to provide more accurate water level measurements through use of a Barologger. The Barologger would have been able to correct any error in water level calculation that was observed in the shallow piezometers. Although the data provided by the Leveloggers may not have been providing accurate depth, daily fluctuations due to various factors such as precipitation and tidal forces were apparent.

7.3 Variation in Sodium Tolerance among *Taxodium* Genotypes

As a part of this study, foliage samples were collected from each of the *T. T406* specimens in the soil amelioration treatment plots and tested for concentrations of Na^+ and other elements. As with plant growth, there were no significant differences in Na^+ concentrations among the applied treatments. This may be due to the irrigation of the plots for an extended period of time during the initial stages of the study, which may have leached out some of the accumulated salts. In addition to comparing the Na^+ concentrations among the soil treatments, samples were also taken from seven *Taxodium* species and hybrids, including another series of *T. T406* specimens, which were tested for concentrations of Na^+ and other elements. The *Taxodium* hybrids were not originally within the scope of this study, and received regular irrigation and maintenance. The individuals from these groups displayed notably healthier characteristics, including more typical green coloration and fuller foliage. Each tree on the site was sampled, resulting in five samples from each group total. The *Taxodium* species and hybrids, as well as their elemental concentrations, are shown in **Table 8.**

Given that the *T. T406* is a hybrid that was selected due to its expected higher tolerance to Na^+ and flooding, it was expected that *T. T406* samples would have lower Na^+ concentrations compared to the other groups on the southern plots. Shown in **Table 8** and **Figure 9**, the *T. T406* was determined to contain the highest concentrations of Na^+ among the groups. Most notably, the *T. T406* contained higher Na^+ concentrations than the *T. distichum*, which is a species known to struggle in saline conditions and was expected to have higher Na^+ concentrations (Creech, et al., 2011). In addition, the *T. T406* on the northern plots contained lower Na^+ concentrations, by more than 0.24 percent, than the *T. T406* on the southern plots. The *T. T406* on the southern plots, despite containing significantly higher concentrations of Na^+, did not appear to exhibit any characteristics indicating saline stress. A possible explanation for the comparatively elevated Na^+ concentrations is that the increased Na^+ tolerance of the *T. T406* allows for the plant to accumulate and store higher concentrations of Na^+, as opposed to removing Na^+ at a higher rate or preventing Na^+ from entering plant tissue. This increased Na^+ tolerance may explain why the *T. T406* specimens on the northern plots did not possess the same visual health as the *T. T406* on the southern plots, but did not seem to display inhibited growth.

It is possible that these results may be unrepresentative due to small sample size. There were only five specimens of each of the *Taxodium* in the southern plots, therefore any outliers may have skewed the mean concentrations. A follow up study on the mechanism of Na^+ tolerance in *Taxodium* hybrids may be able to provide a more detailed explanation of how these hybrids tolerate the accumulation of Na^+.

8. Conclusions

Among the three species studied for mortality in saline conditions, survivorship was high, and these plant species have continued to grow through their third growing season while displaying faint signs of salt stress. Soil amelioration treatments with combinations of gypsum, mulching, or bedding did not create a significant change in growth, but there was a significant difference in plant height growth among species. This variation may be due in part to inadvertent trimming of the specimens early in the establishment stage.

Na^+ concentrations among the *T. T406* specimens was not significantly different among the applied soil amelioration treatments. A direct correlation between groundwater Na^+ concentrations and precipitation could not be established. It was expected that increased precipitation would bring an influx of freshwater into the system and dilute the Na^+ concentration of the groundwater. However, the amount of precipitation that actually reached groundwater was unable to be determined, and past research of the study area has revealed that precipitation events deposit a small amount of Na^+ into the soil and groundwater, with annual Na^+ deposition occurring during a typical year being equivalent to 0.39 percent of the total Na^+ quantified in the 10 cm of soil immediately above the groundwater (Harris, 2019). Therefore, it is unlikely that Na^+ concentrations in the groundwater are affected by precipitation.

A series of genotypes of *Taxodium* were compared to evaluate the difference in Na^+ concentrations among species. It was expected that *T. T406* would contain comparatively low Na^+ concentrations due to being a hybrid designed to tolerate saline conditions. It was determined that the *T. distichum* group contained lower Na^+ concentrations than the *T. T406* group, which suggests that the Na^+ tolerance of the *T. T406* may have mechanisms other than removing Na^+ efficiently or blocking Na^+ entry into plant tissue. Due to the scale of this portion of the study, a follow up study on the mechanism of Na^+ tolerance in *Taxodium* hybrids may provide a more complete understanding of Na^+ tolerance in the species.

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10. Appendices

Appendix A – Groundwater Contour and Heat Maps

Figure A-1. Heat map displaying concentrations of Na^+ in groundwater in mg/L compared to groundwater contour map for the sampling period of September 30, 2017 through October 13, 2017.

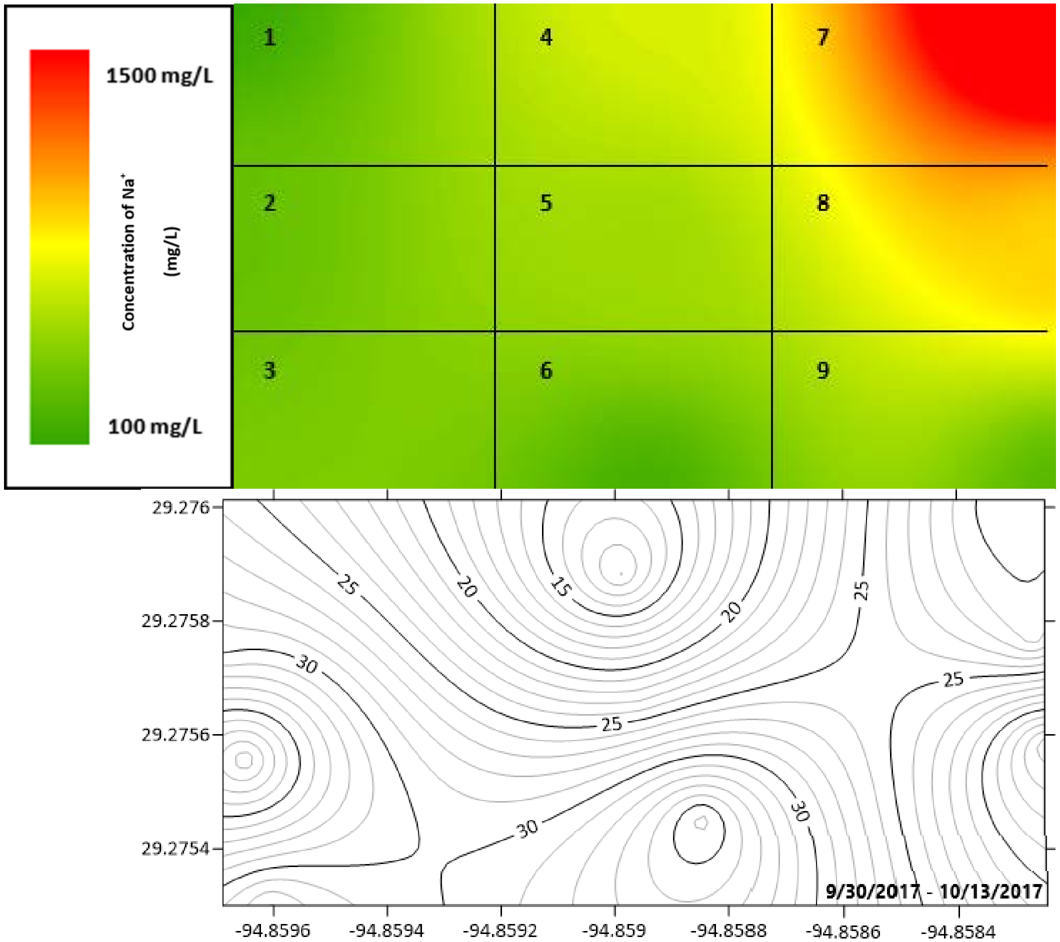


Figure A-2. Heat map displaying concentrations of Na+ in groundwater in mg/L compared to groundwater contour map for the sampling period of October 13, 2017 through October 27, 2017.

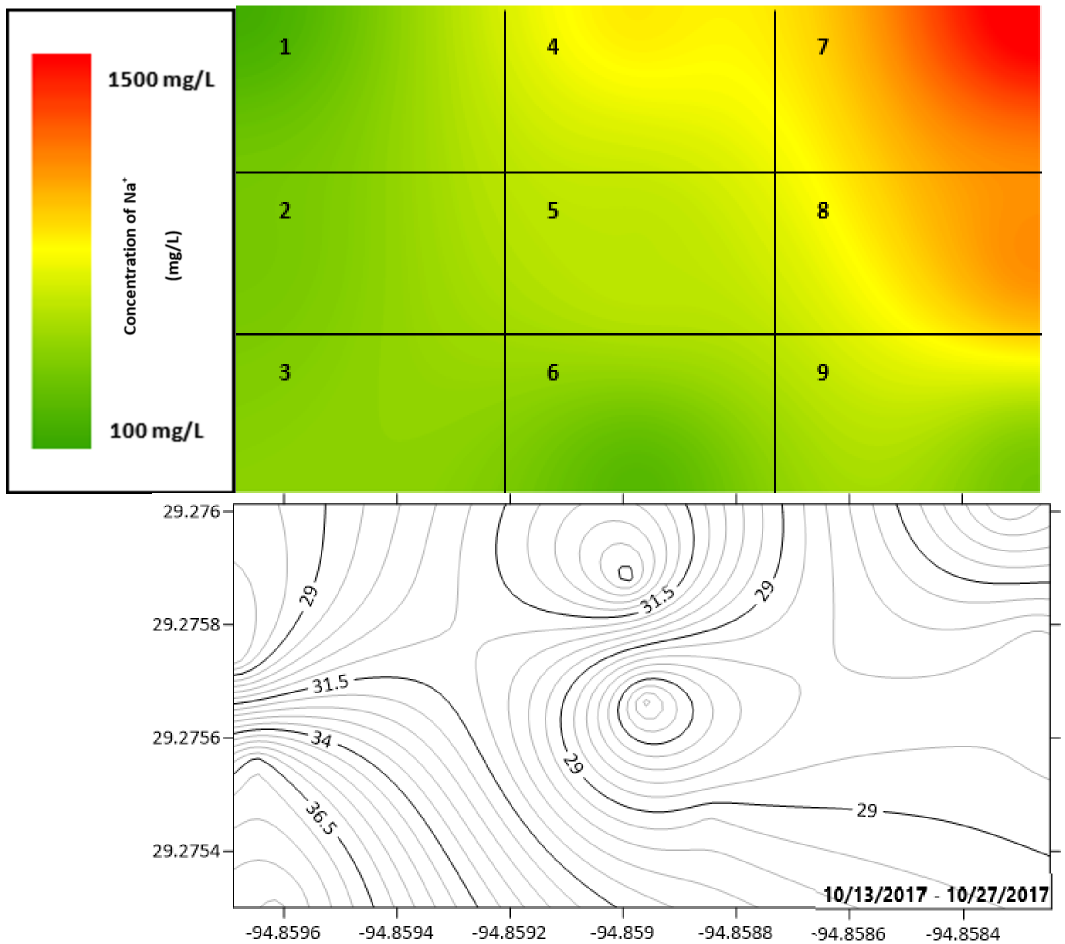


Figure A-3. Heat map displaying concentrations of Na+ in groundwater in mg/L compared to groundwater contour map for the sampling period of October 27, 2017 through November 10, 2017.

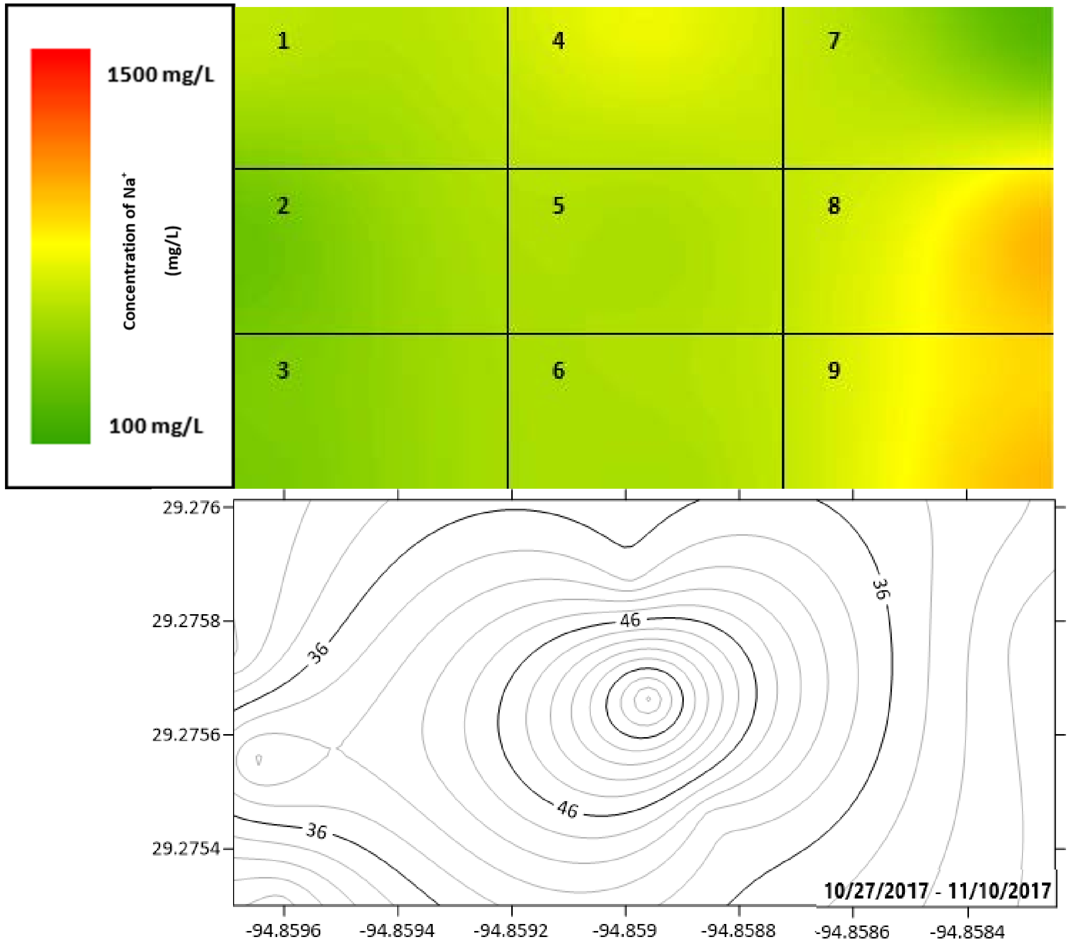


Figure A-4. Heat map displaying concentrations of Na+ in groundwater in mg/L compared to groundwater contour map for the sampling period of November 10, 2017 through November 24, 2017.

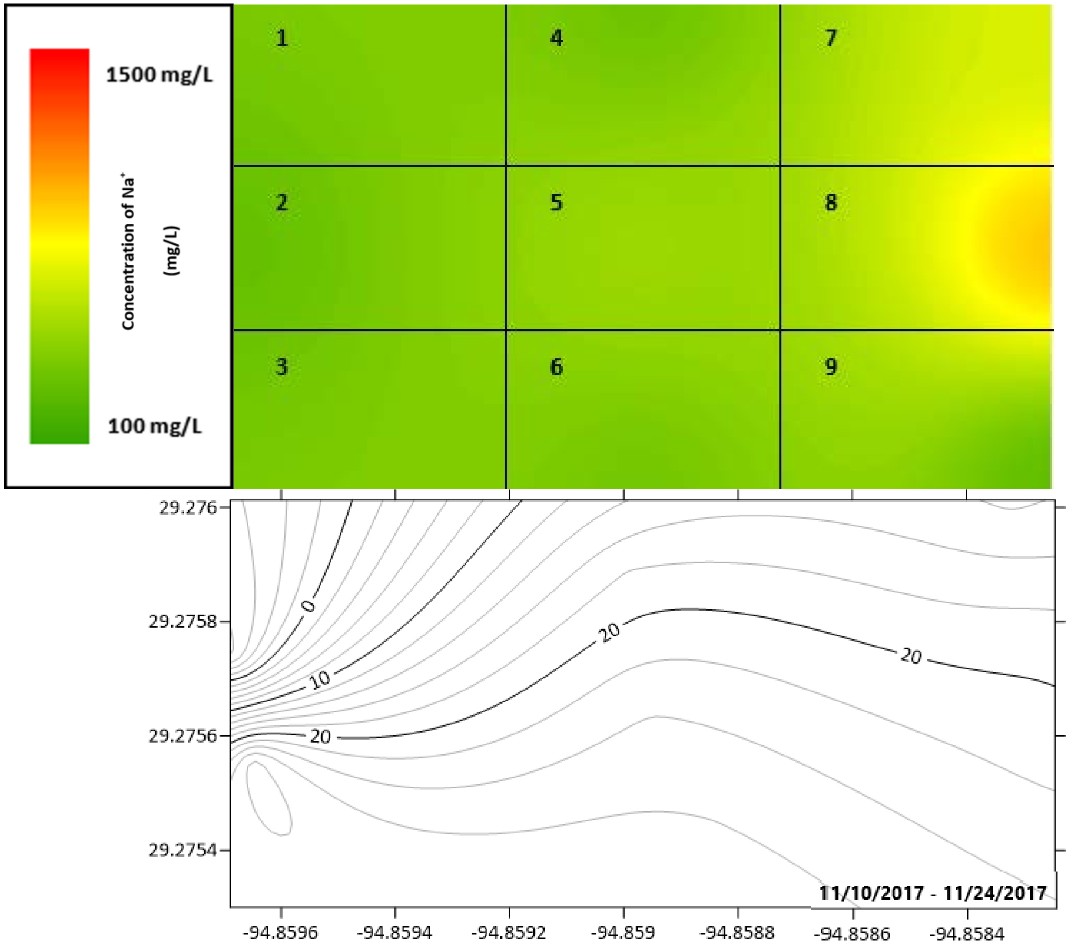


Figure A-5. Heat map displaying concentrations of Na+ in groundwater in mg/L compared to groundwater contour map for the sampling period of November 24, 2017 through December 8, 2017.

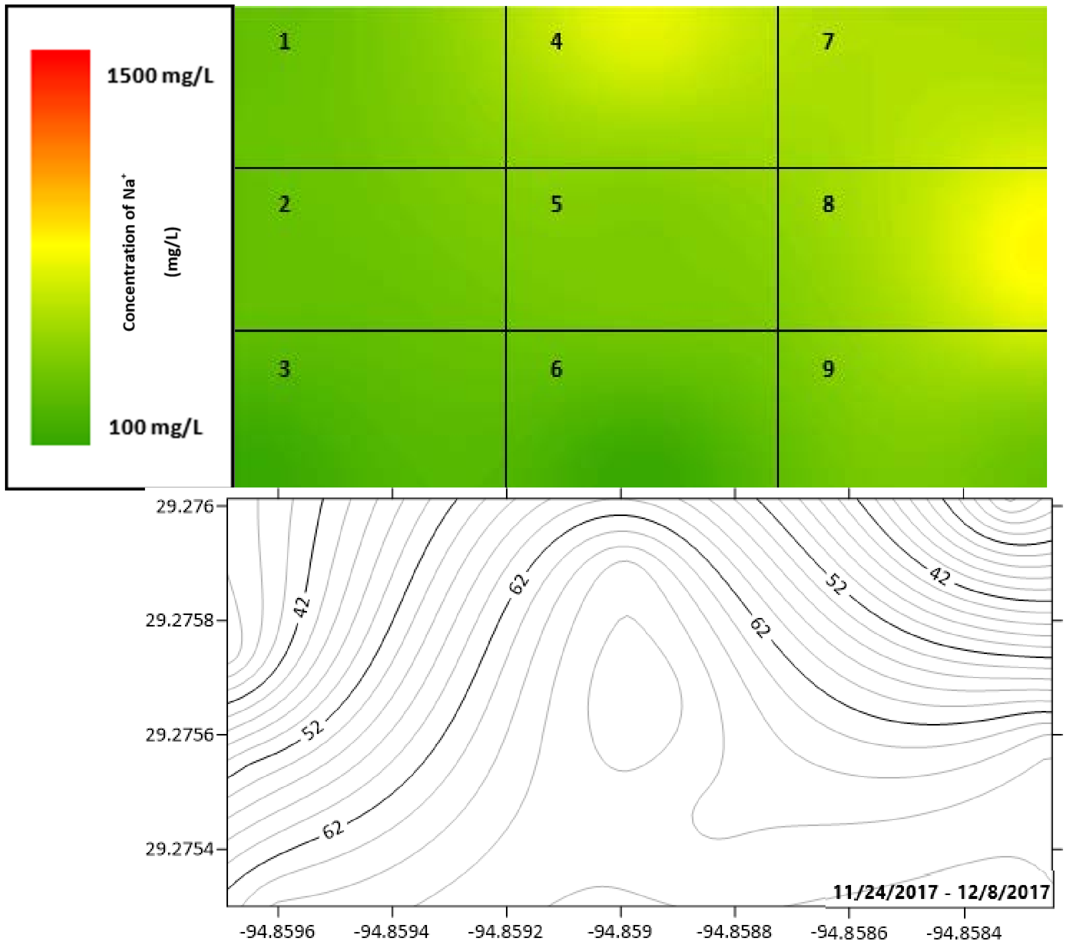


Figure A-6. Heat map displaying concentrations of Na+ in groundwater in mg/L compared to groundwater contour map for the sampling period of December 8, 2017 through December 22, 2017.

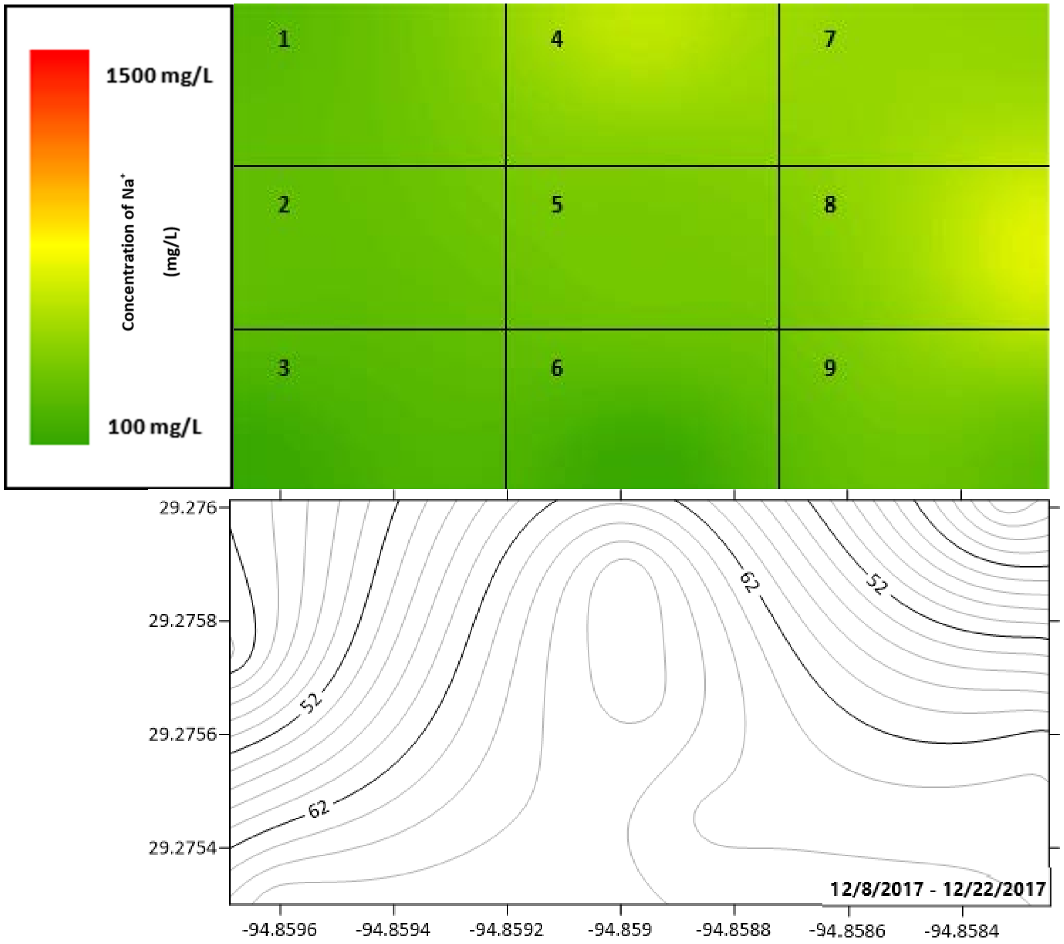


Figure A-7. Heat map displaying concentrations of Na+ in groundwater in mg/L compared to groundwater contour map for the sampling period of December 22, 2017 through January 5, 2018.

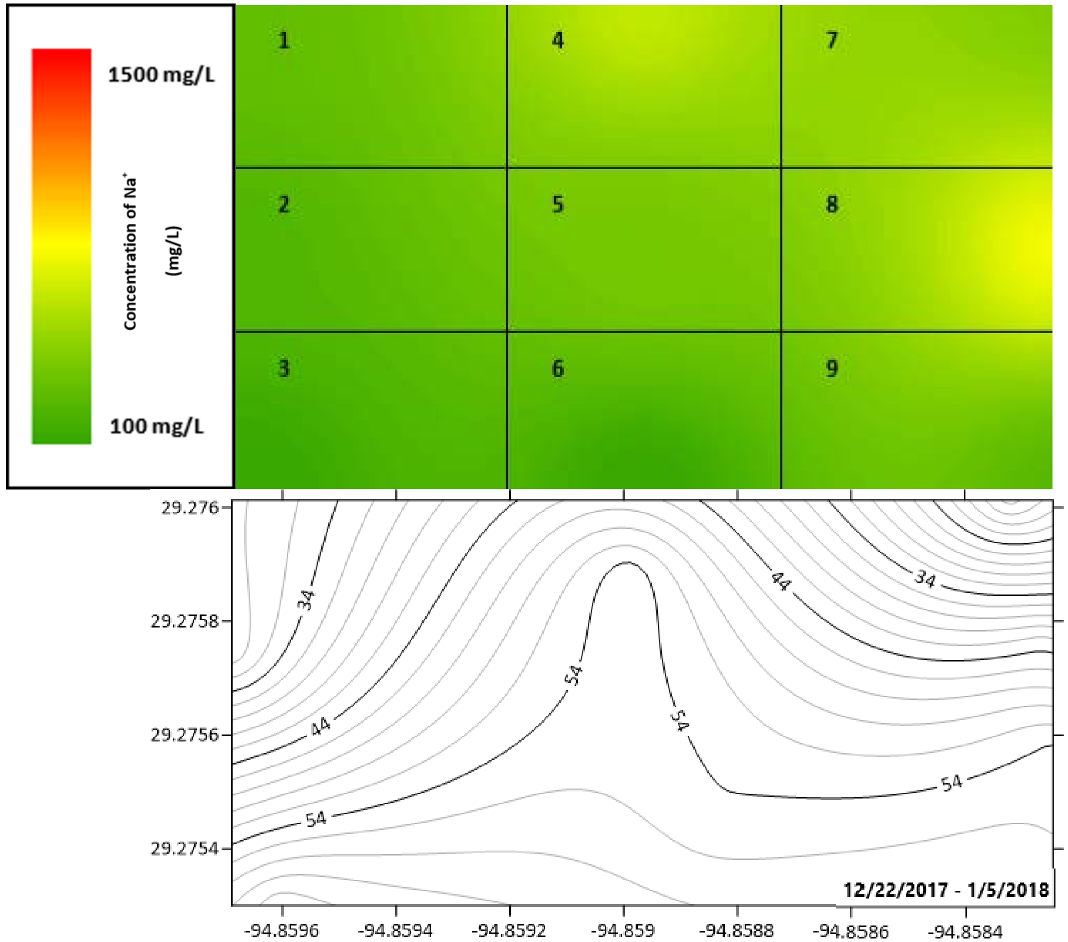


Figure A-8. Heat map displaying concentrations of Na+ in groundwater in mg/L compared to groundwater contour map for the sampling period of January 5, 2018 through January 19, 2018.

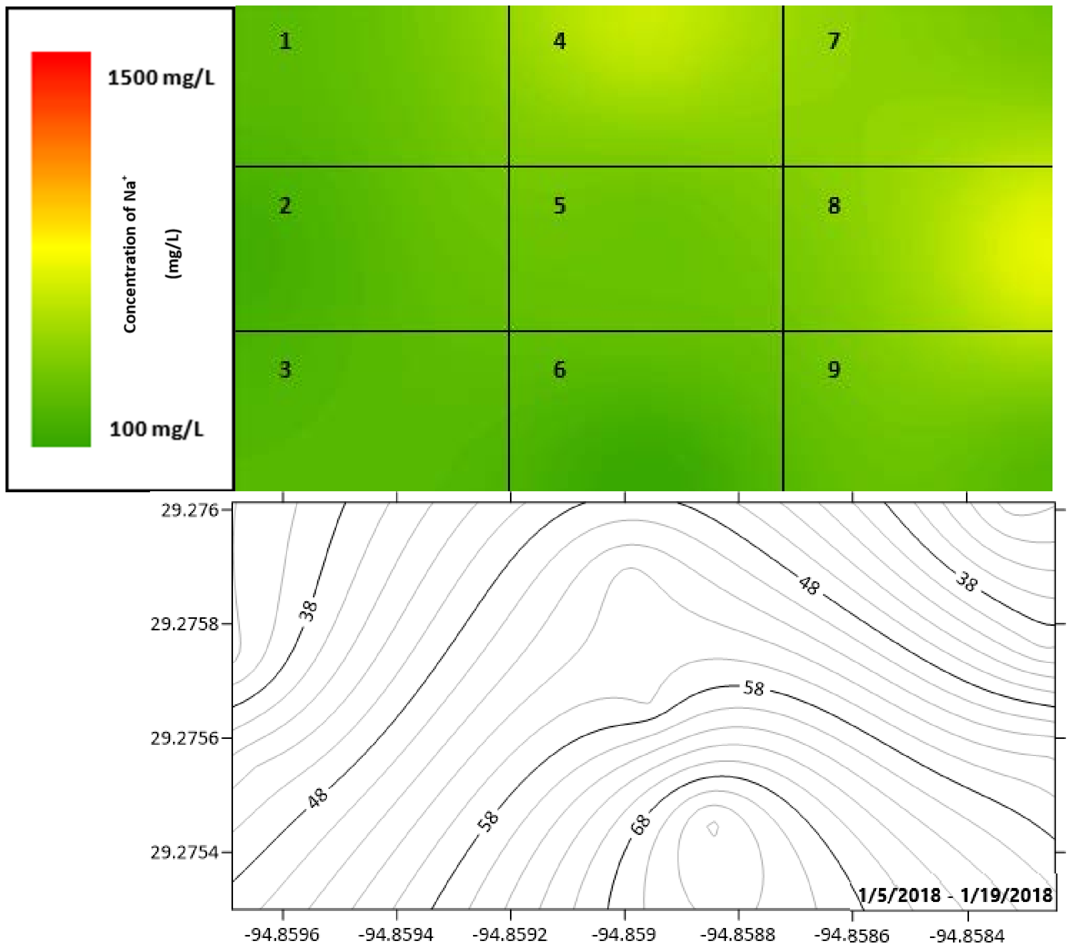


Figure A-9. Heat map displaying concentrations of Na+ in groundwater in mg/L compared to groundwater contour map for the sampling period of January 19, 2018 through February 2, 2018.

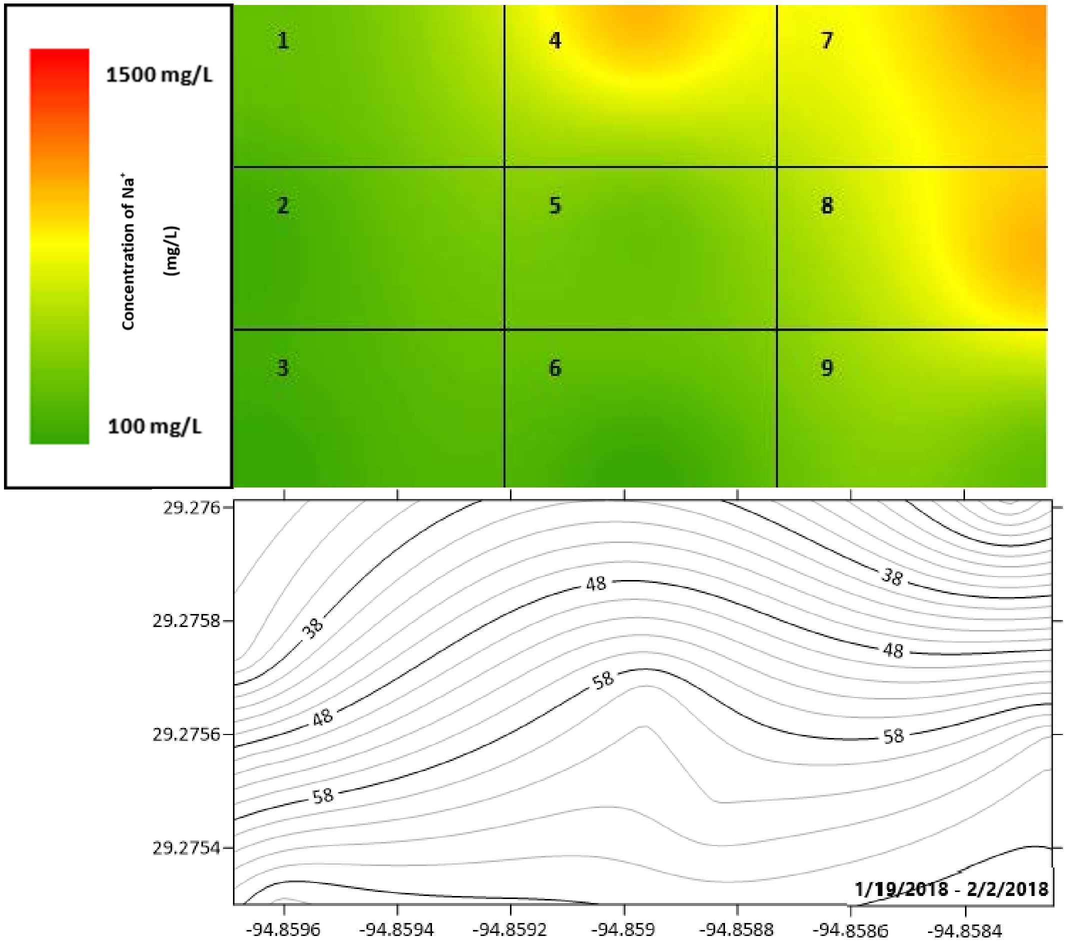
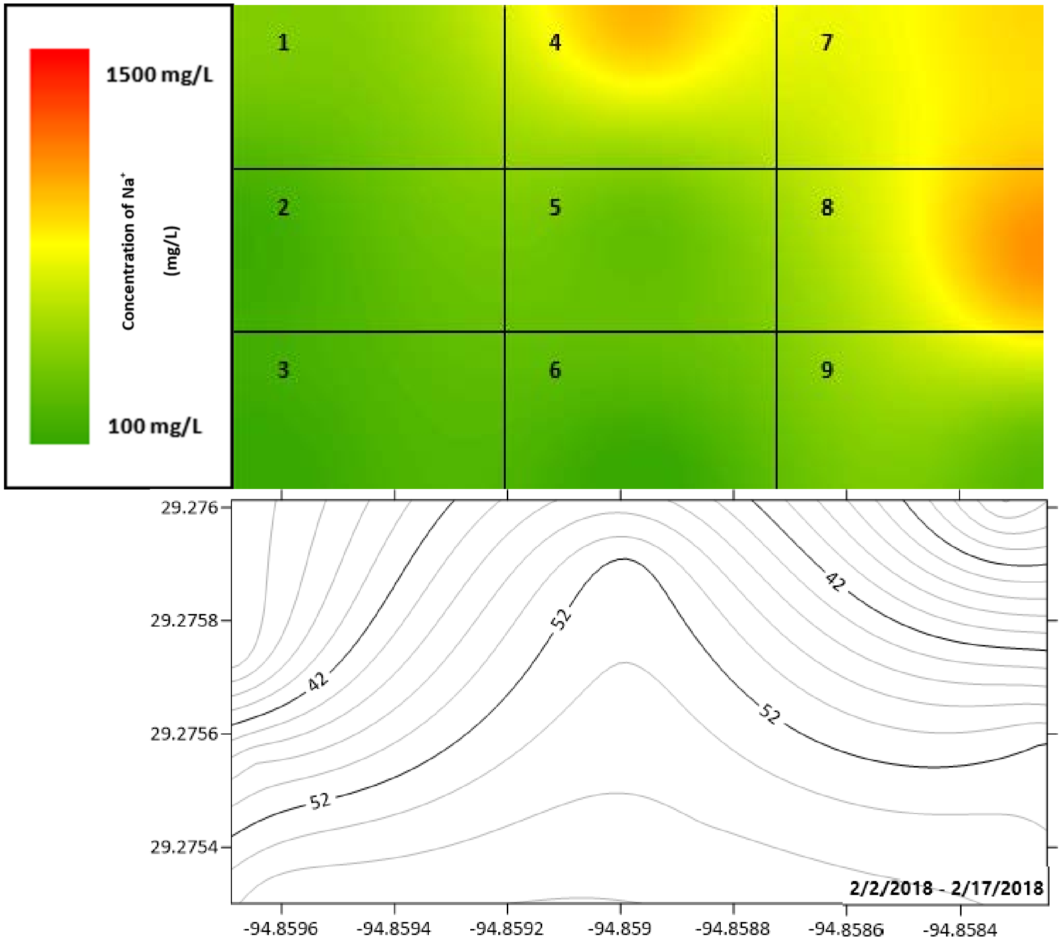


Figure A-10. Heat map displaying concentrations of Na+ in groundwater in mg/L compared to groundwater contour map for the sampling period of February 2, 2018 through February 17, 2018.



<u>Figure A-11.</u> Heat map displaying concentrations of Na+ in groundwater in mg/L compared to groundwater contour map for the sampling period of February 17, 2018 through March 2, 2018.

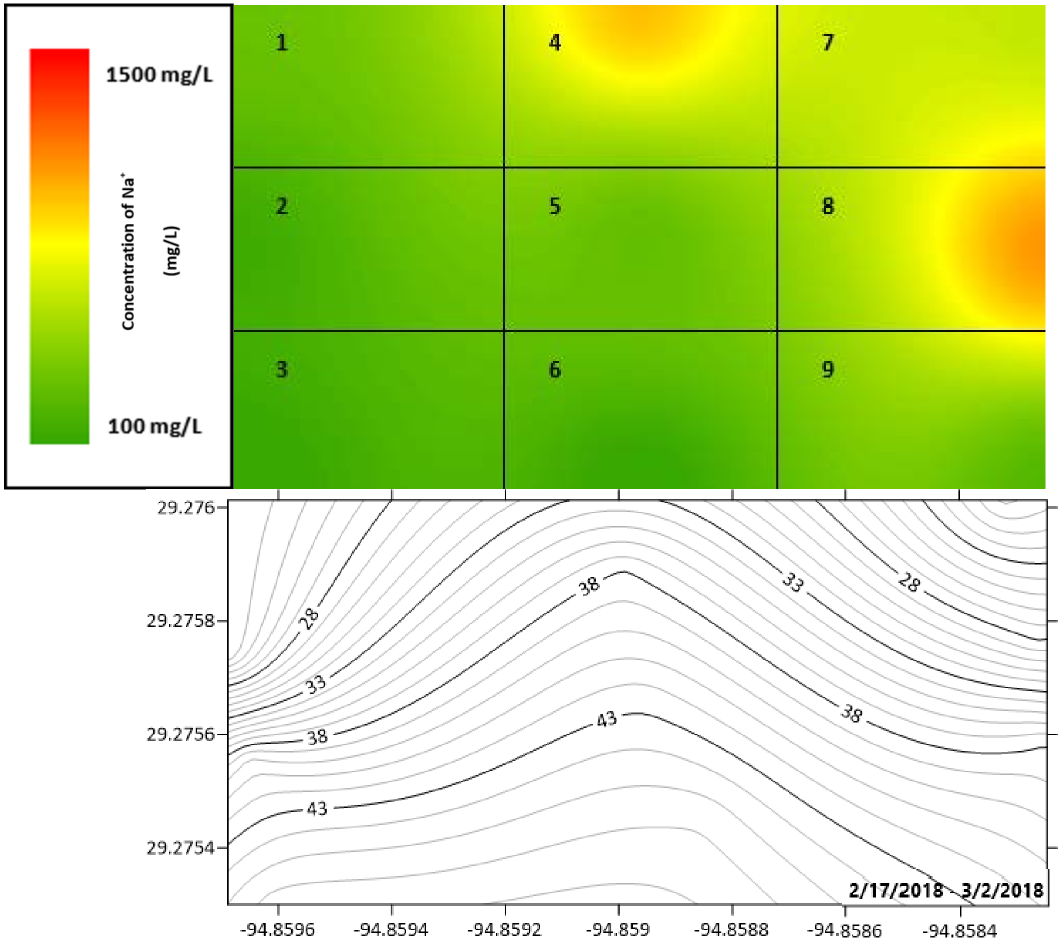


Figure A-12. Heat map displaying concentrations of Na+ in groundwater in mg/L compared to groundwater contour map for the sampling period of March 2, 2018 through March 16, 2018.

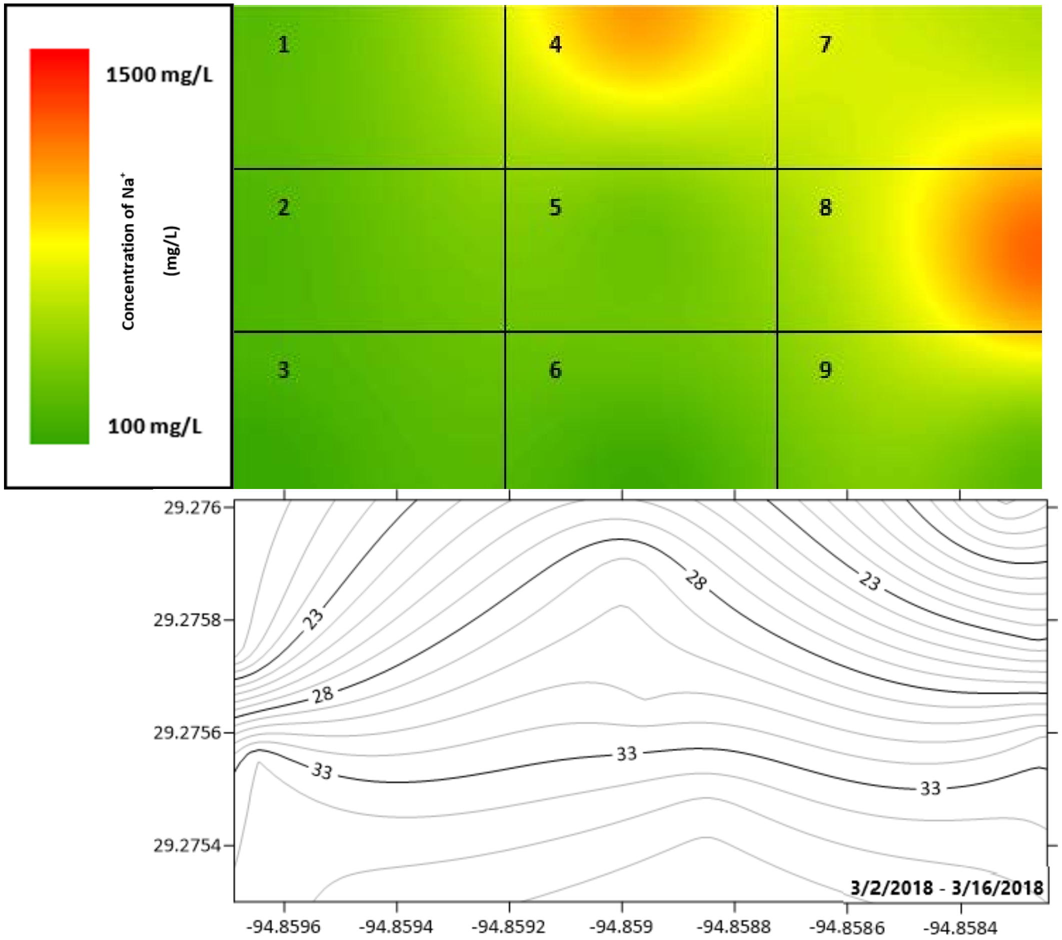


Figure A-13. Heat map displaying concentrations of Na+ in groundwater in mg/L compared to groundwater contour map for the sampling period of March 16, 2018 through March 30, 2018.

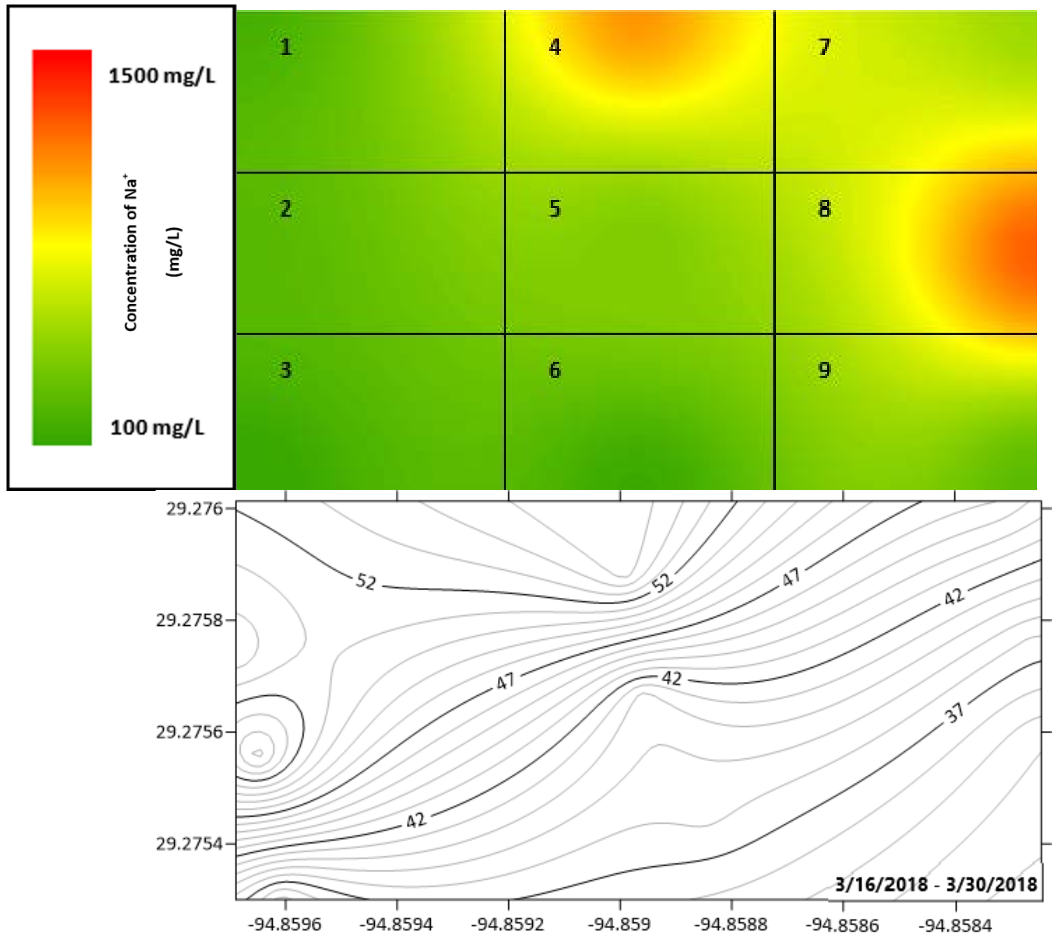


Figure A-14. Heat map displaying concentrations of Na+ in groundwater in mg/L compared to groundwater contour map for the sampling period of March 30, 2018 through April 13. 2018.

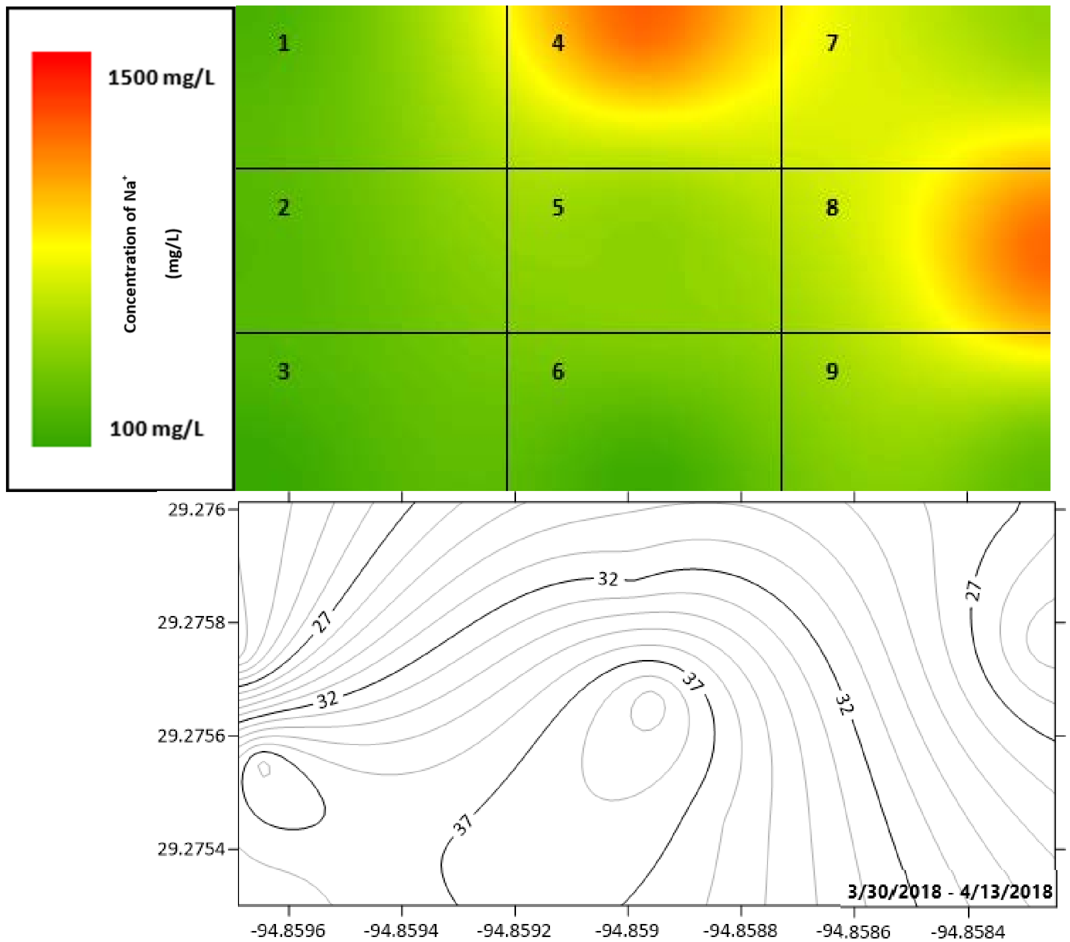


Figure A-15. Heat map displaying concentrations of Na+ in groundwater in mg/L compared to groundwater contour map for the sampling period of April 13, 2017 through April 27, 2018.

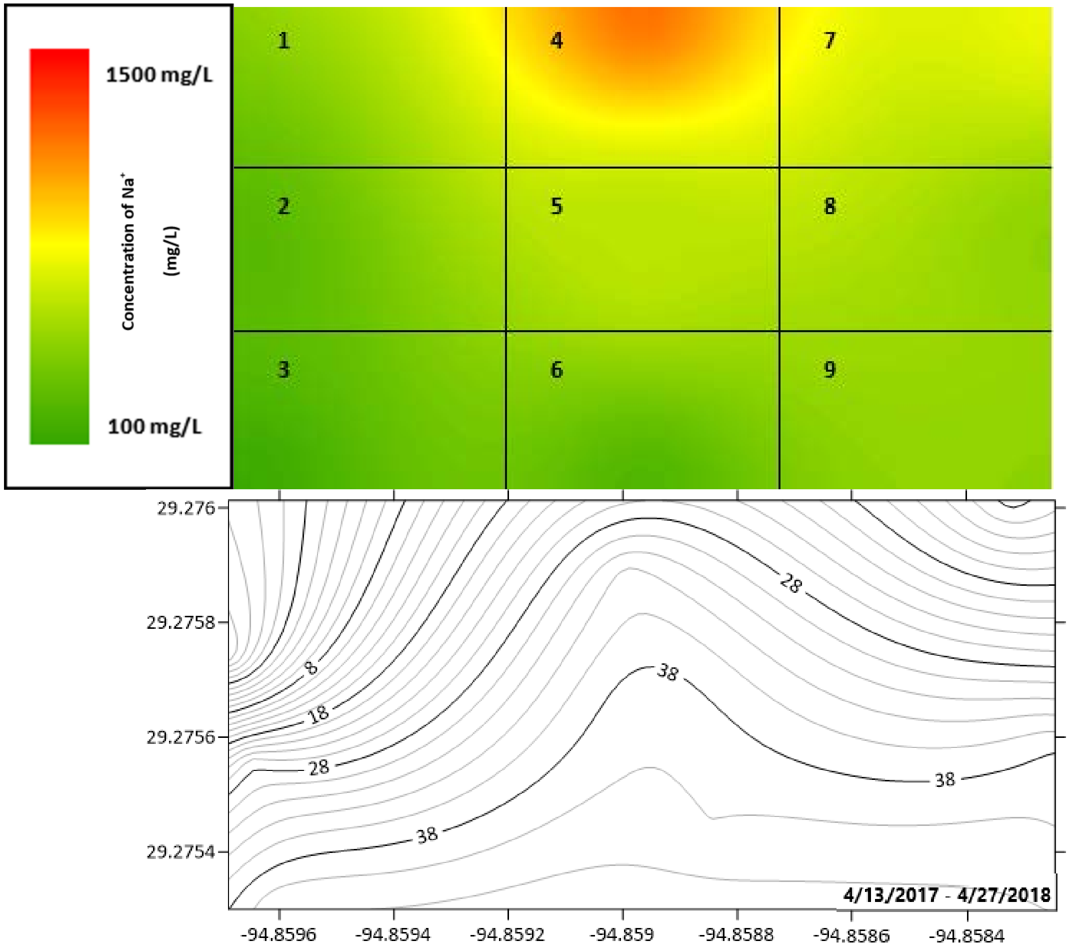


Figure A-16. Heat map displaying concentrations of Na+ in groundwater in mg/L compared to groundwater contour map for the sampling period of April 27, 2018 through May 11, 2018.

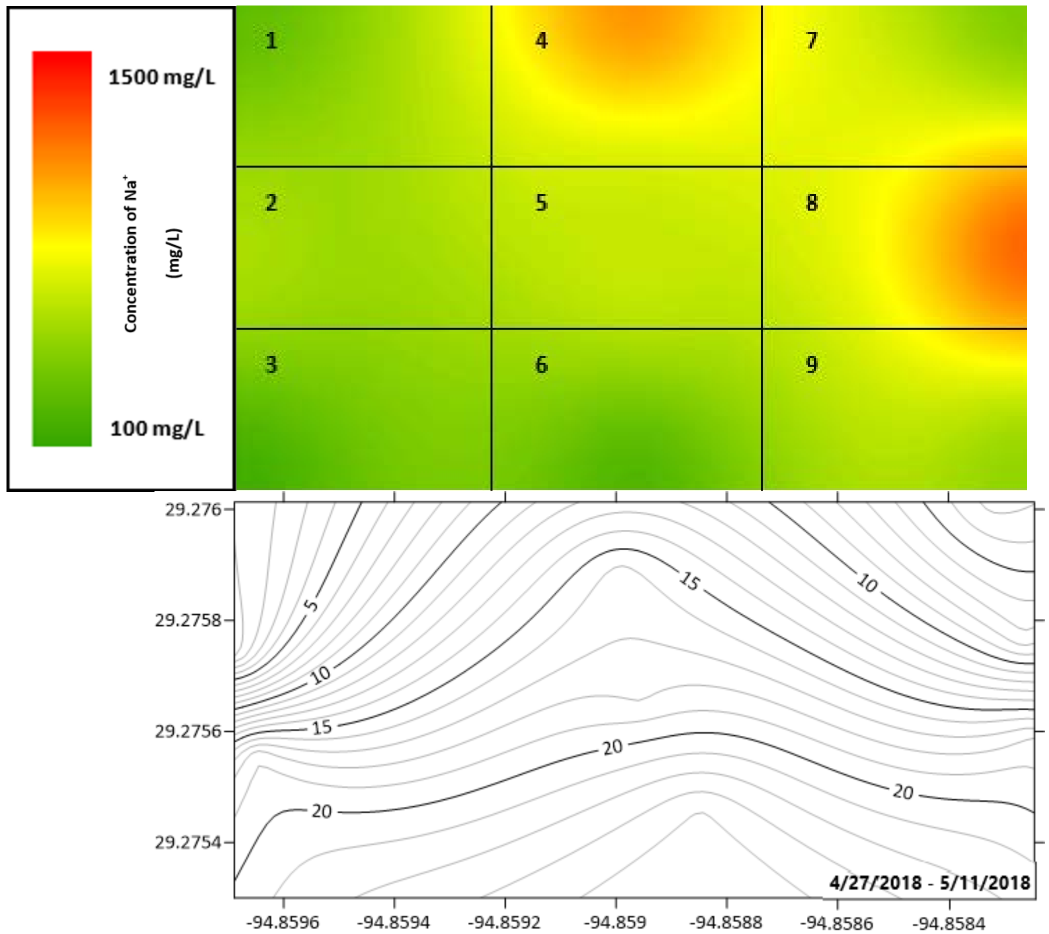


Figure A-17. Heat map displaying concentrations of Na+ in groundwater in mg/L compared to groundwater contour map for the sampling period of May 11, 2018 through May 25, 2018.

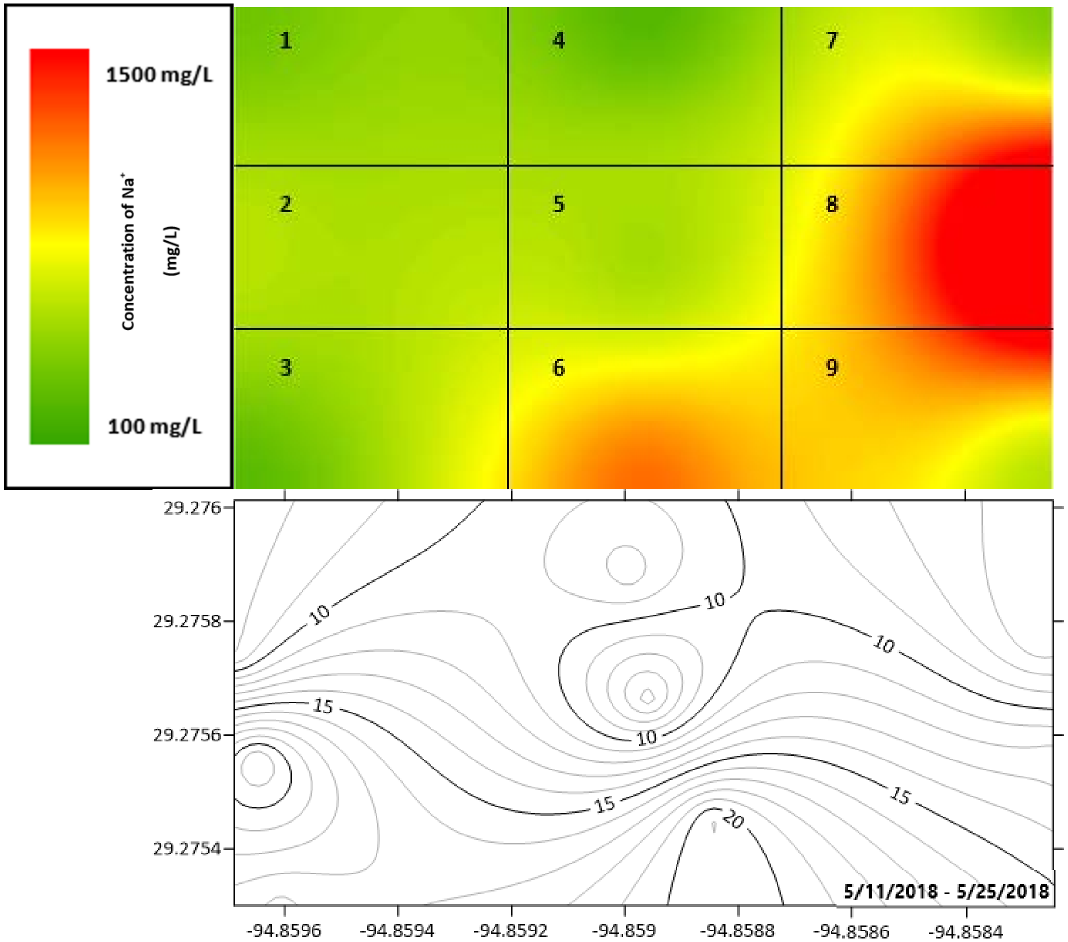


Figure A-18. Heat map displaying concentrations of Na+ in groundwater in mg/L compared to groundwater contour map for the sampling period of May 28, 2018 through June 8, 2018.

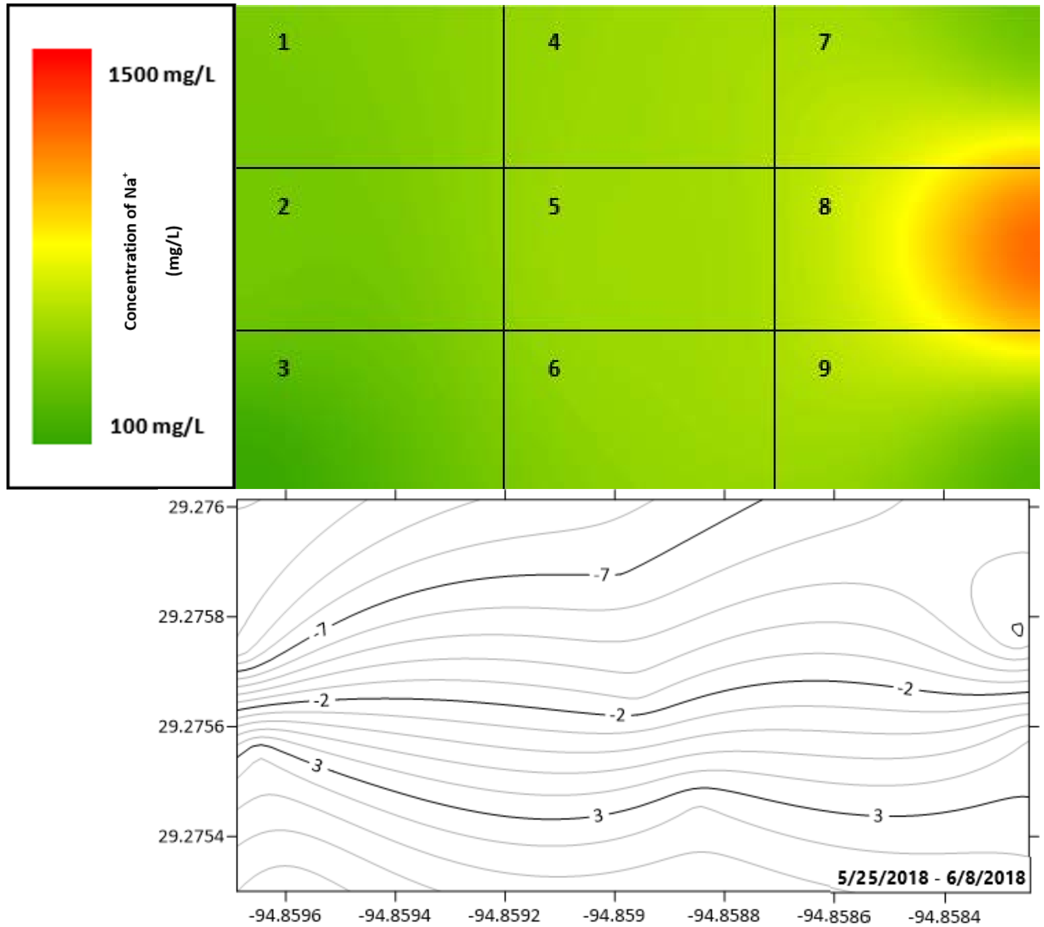


Figure A-19. Heat map displaying concentrations of Na+ in groundwater in mg/L compared to groundwater contour map for the sampling period of June 8, 2018 through June 22, 2018.

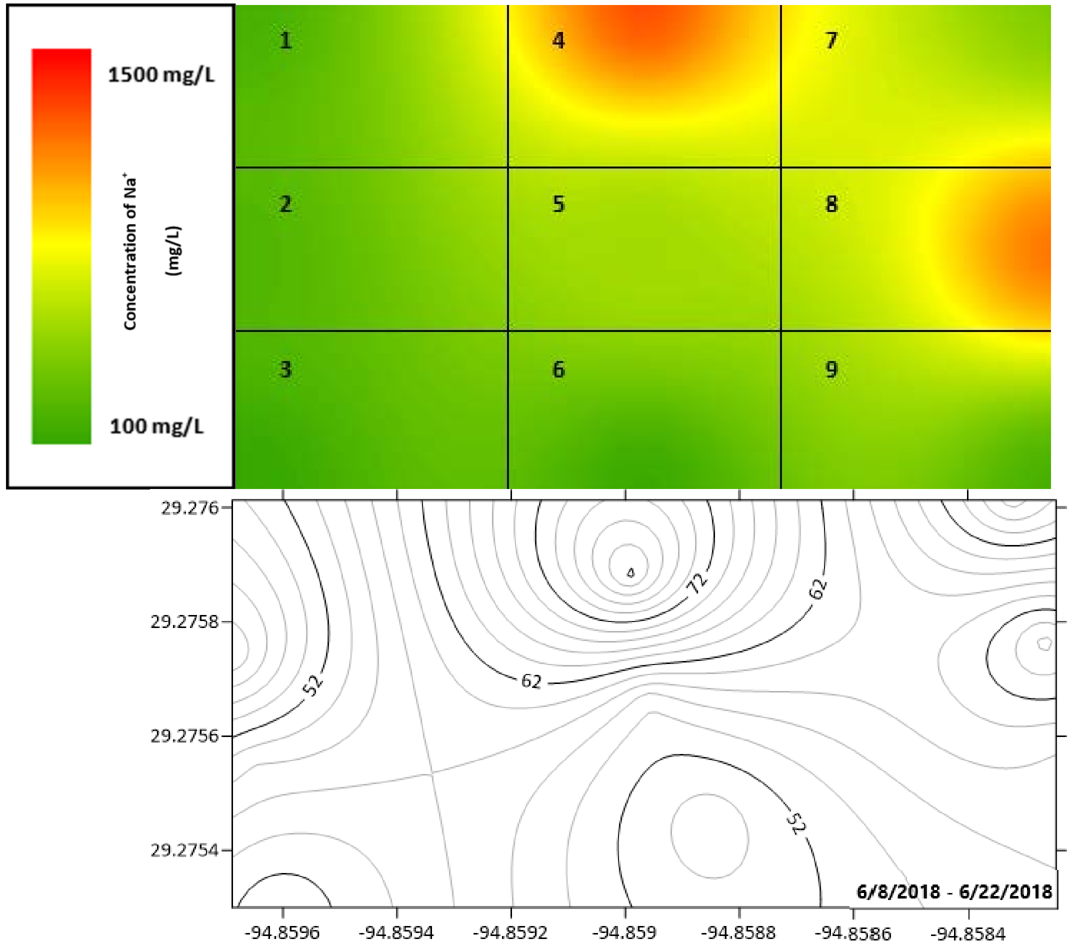


Figure A-20. Heat map displaying concentrations of Na+ in groundwater in mg/L compared to groundwater contour map for the sampling period of June 22, 2018 through July 6, 2018.

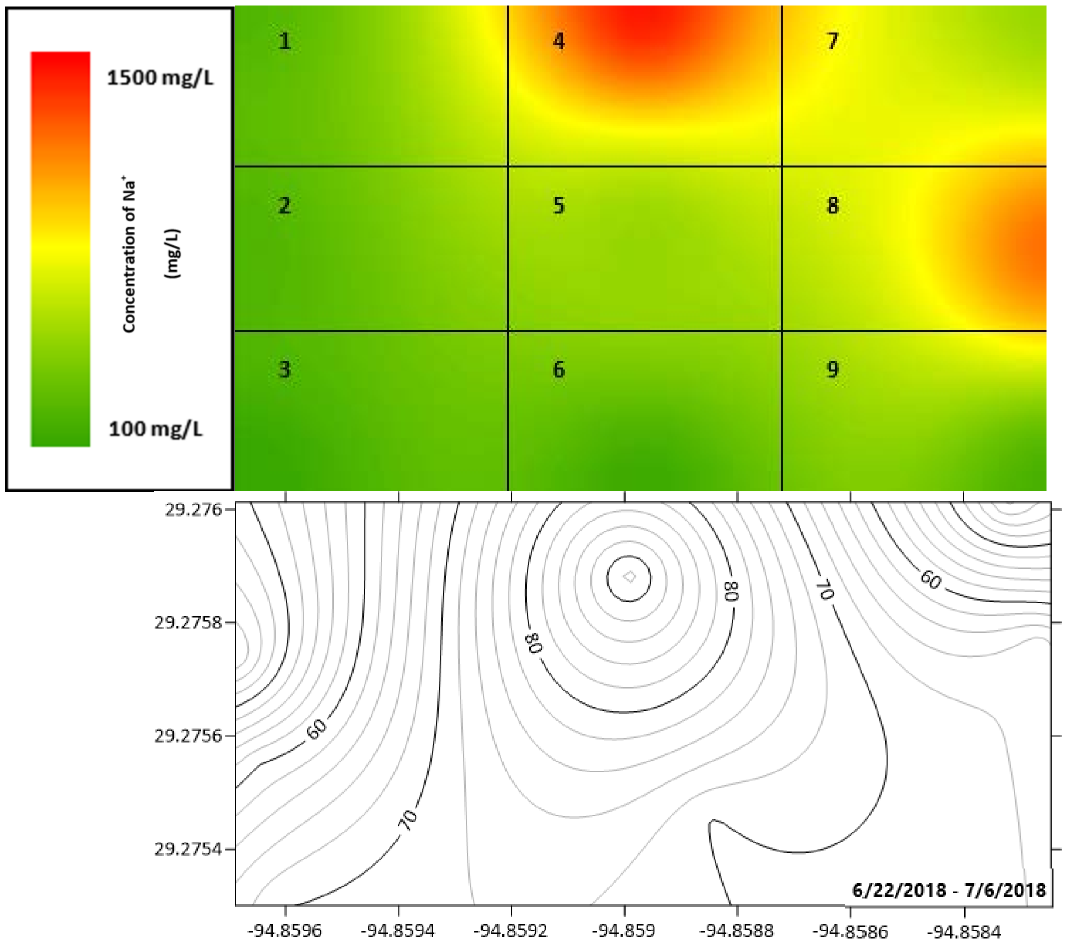


Figure A-21. Heat map displaying concentrations of Na+ in groundwater in mg/L compared to groundwater contour map for the sampling period of July 6, 2018 through July 20, 2018.

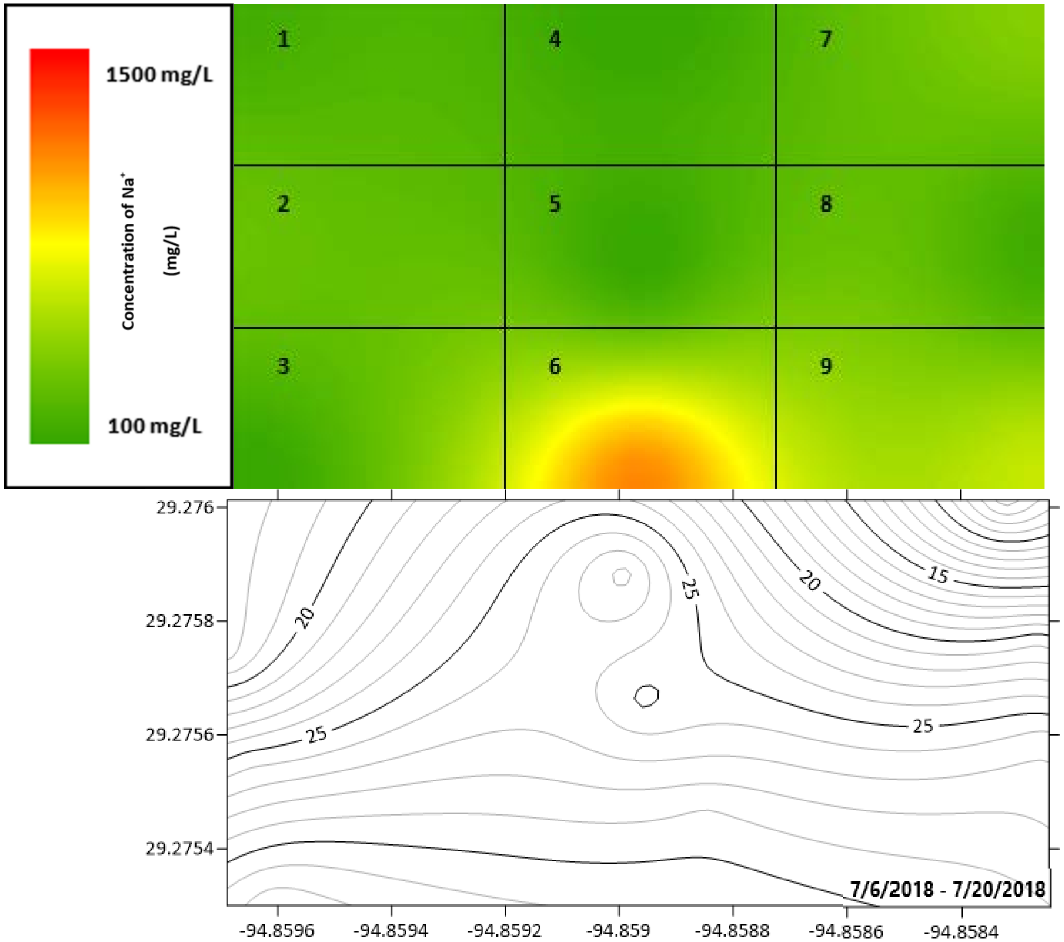


Figure A-22. Heat map displaying concentrations of Na+ in groundwater in mg/L compared to groundwater contour map for the sampling period of July 20, 2018 through August 3, 2018.

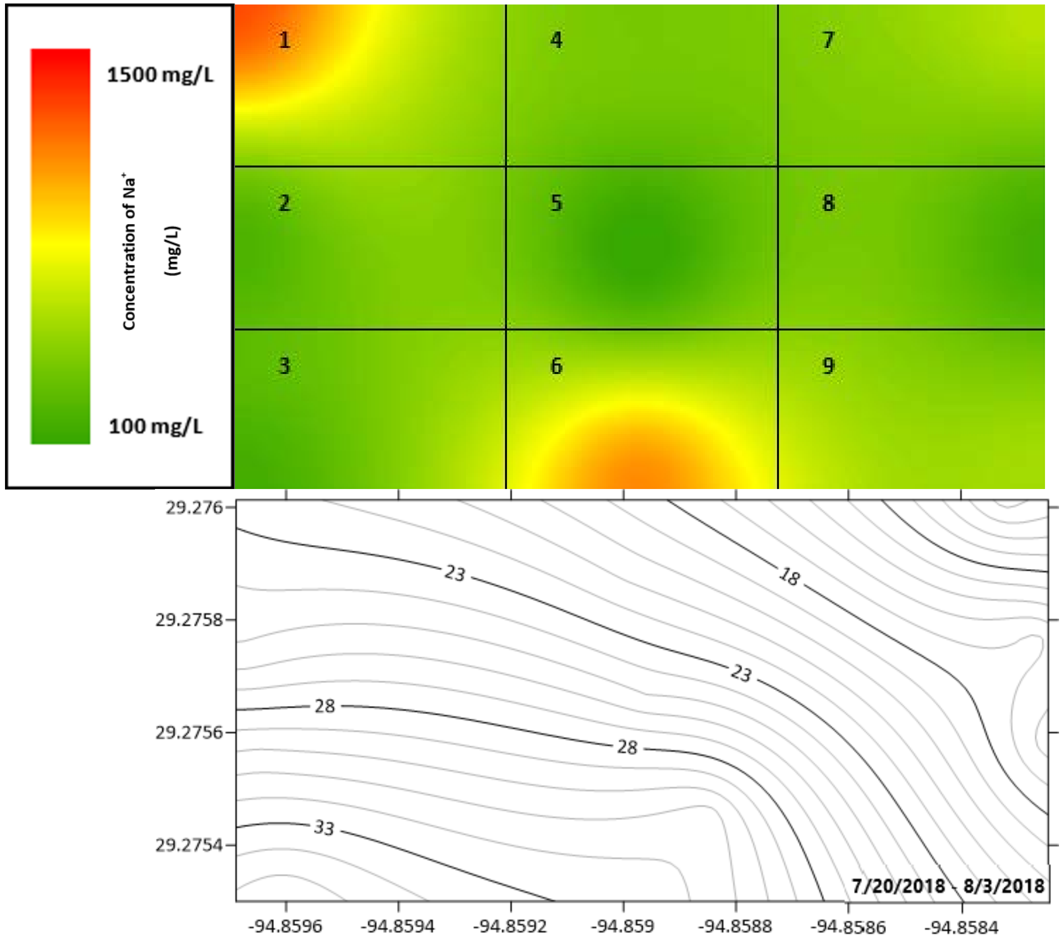
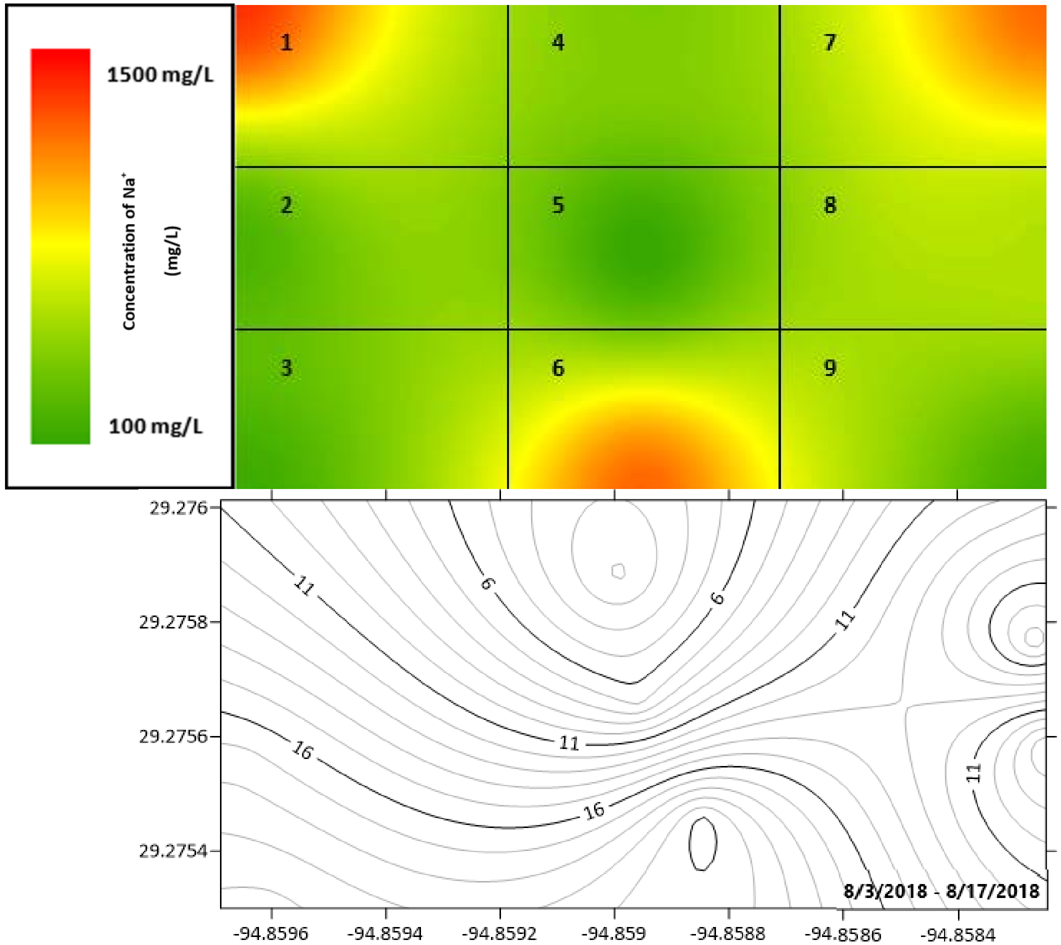


Figure A-23. Heat map displaying concentrations of Na+ in groundwater in mg/L compared to groundwater contour map for the sampling period of August 3, 2018 through August 17, 2018.



Appendix B – Additional Plant Growth Data

Table B-1. Initial and final groundline diameter measurements for each plant at the project site, in addition to total growth for each plant. Initial measurements were taken March 15, 2016, and final measurements were taken March 4, 2019. Data is organized by applied treatment.

Treatment	Species	Initial Groundline Diameter Measurement (mm)	Final Groundline Diameter Measurement (mm)	Total Growth (cm)
CF	BC	54.24	83.95	29.71
CF	LO	18.75	36.6	17.85
CF	HH	52.29	129.5	77.21
CF	BC	44.78	64.55	19.77
CF	LO	19.43	34.2	14.77
CF	HH	41.34	91.85	50.51
CF	HH	47.46	109.55	62.09
CF	HH	40.91	140.55	99.64
CF	LO	27.68	56.8	29.12
CF	BC	66.23	123.15	56.92
CF	BC	45.81	66	20.19
CF	LO	25.61	49.6	23.99
CF	LO	22.07	49.9	27.83
CF	HH	57.49	101	43.51
CF	HH	63.28	111.6	48.32
CF	BC	54.9	72.8	17.9
CF	BC	49.97	95.05	45.08
CF	LO	22.7	70.1	47.4
CF	LO	21.99	44.25	22.26
CF	HH	56.43	112.055	55.625
CF	BC	47.74	106.985	59.245
CF	LO	16.83	63.145	46.315

Table B-1 continued.

Treatment	Species	Initial Groundline Diameter Measurement (mm)	Final Groundline Diameter Measurement (mm)	Total Growth (cm)
CF	BC	52.02	121.785	69.765
CF	HH	48.26	86.62	38.36
CF	LO	32.9	78.755	45.855
CF	BC	61.35	113.495	52.145
CF	HH	48.48	117.515	69.035
CF	LO	19.55	0	-19.55
CF	BC	46.39	96.015	49.625
CF	HH	56.85	107.005	50.155
CF	LO	21.14	50.23	29.09
CF	BC	52.55	108.25	55.7
CF	LO	26.54	109.745	83.205
CF	HH	47.84	85.76	37.92
CF	HH	52.74	117.25	64.51
CF	BC	42.42	85.76	43.34
CB	BC	47.98	84.95	36.97
CB	HH	54.72	116.75	62.03
CB	BC	42.88	81.4	38.52
CB	HH	48.29	108.8	60.51
CB	LO	16.26	0	-16.26
CB	LO	19.87	37.5	17.63
CB	LO	24.03	43	18.97
CB	BC	50.95	81.4	30.45
CB	BC	47.92	105.6	57.68
CB	HH	51.72	104.8	53.08
CB	LO	22.52	45.5	22.98
CB	HH	56.85	107.95	51.1

Table B-1 continued.

Treatment	Species	Initial Groundline Diameter Measurement (mm)	Final Groundline Diameter Measurement (mm)	Total Growth (cm)
CB	LO	17.22	0	-17.22
CB	HH	42.16	105	62.84
CB	BC	63	103.35	40.35
CB	LO	25.28	55.6	30.32
CB	BC	62.51	144.5	81.99
CB	HH	67.1	88.5	21.4
CB	LO	24.79	58.165	33.375
CB	BC	52.21	115.585	63.375
CB	HH	46.52	109.59	63.07
CB	LO	31.57	99.545	67.975
CB	BC	59.9	106.52	46.62
CB	HH	52.1	98.635	46.535
CB	HH	62.72	120.175	57.455
CB	LO	22.14	36.23	14.09
CB	HH	50.21	113.505	63.295
CB	LO	24.91	53.585	28.675
CB	BC	50.38	105.745	55.365
CB	BC	62.92	110.255	47.335
CB	BC	53.47	127.785	74.315
CB	LO	25.81	77.485	51.675
CB	HH	55.78	94.27	38.49
CB	LO	60.42	83.255	22.835
CB	BC	50.75	108.23	57.48
CB	HH	56.98	109.495	52.515
GF	HH	48.95	110.25	61.3
GF	LO	21.83	52.1	30.27

Table B-1 continued.

Treatment	Species	Initial Groundline Diameter Measurement (mm)	Final Groundline Diameter Measurement (mm)	Total Growth (cm)
GF	HH	44.49	125.45	80.96
GF	LO	23.33	69.1	45.77
GF	BC	48.98	102.5	53.52
GF	BC	36.04	99.4	63.36
GF	LO	23.08	49.45	26.37
GF	HH	58.03	120.5	62.47
GF	BC	45.09	75.5	30.41
GF	BC	59.42	96.85	37.43
GF	LO	27.98	63.5	35.52
GF	HH	37.11	79.95	42.84
GF	LO	22.43	74.3	51.87
GF	HH	51.6	114	62.4
GF	HH	58	93.5	35.5
GF	BC	56.94	90	33.06
GF	LO	26.33	81.605	55.275
GF	BC	51.6	72.065	20.465
GF	HH	66.17	105.575	39.405
GF	LO	20.51	64.495	43.985
GF	HH	54.5	101.37	46.87
GF	BC	58.69	106.51	47.82
GF	LO	22.02	64.995	42.975
GF	BC	49.57	79.37	29.8
GF	HH	54.54	113.495	58.955
GF	LO	15.76	32.875	17.115
GF	BC	55.15	114.895	59.745
GF	LO	19.6	57.02	37.42

Table B-1 continued.

Treatment	Species	Initial Groundline Diameter Measurement (mm)	Final Groundline Diameter Measurement (mm)	Total Growth (cm)
GF	BC	50.55	110.525	59.975
GF	HH	50.16	135.01	84.85
GF	LO	29.72	74.9	45.18
GF	HH	52.53	97.505	44.975
GF	BC	44.81	83.16	38.35
GF	LO	23.58	56.075	32.495
GF	BC	69.66	115.865	46.205
GF	HH	30.89	85.555	54.665
GB	HH	43.94	121.9	77.96
GB	BC	58.62	107.5	48.88
GB	BC	57.13	99.9	42.77
GB	HH	57.09	118	60.91
GB	LO	19.27	68.75	49.48
GB	LO	19.87	65.25	45.38
GB	LO	13.99	74.75	60.76
GB	LO	23.43	44.75	21.32
GB	HH	45.81	134.5	88.69
GB	BC	50.42	81.7	31.28
GB	HH	60.13	100.05	39.92
GB	BC	41.95	63.5	21.55
GB	HH	48.02	111.05	63.03
GB	BC	63.17	104	40.83
GB	LO	24.3	37.5	13.2
GB	HH	34.8	96	61.2
GB	LO	18.95	58.75	39.8
GB	BC	66.41	107.3	40.89

Table B-1 continued.

Treatment	Species	Initial Groundline Diameter Measurement (mm)	Final Groundline Diameter Measurement (mm)	Total Growth (cm)
GB	LO	26.25	39.24	12.99
GB	HH	43.29	89.515	46.225
GB	HH	50.27	87.47	37.2
GB	LO	21.91	29.42	7.51
GB	BC	39.86	124.665	84.805
GB	BC	61.2	100.445	39.245
GB	LO	21.88	40.755	18.875
GB	LO	21.14	47.8	26.66
GB	HH	45.47	108.115	62.645
GB	HH	53.38	94.79	41.41
GB	BC	48.15	95.64	47.49
GB	BC	54.3	101.29	46.99
GB	LO	22.3	53.755	31.455
GB	LO	28.96	56.05	27.09
GB	HH	43.94	97.9	53.96
GB	BC	62	132.17	70.17
GB	HH	46.48	90.05	43.57
GB	BC	49	106	57
MF	LO	19.08	62.65	43.57
MF	HH	56.09	139.485	83.395
MF	LO	21.7	58.35	36.65
MF	BC	51.11	111.515	60.405
MF	HH	55.14	130.055	74.915
MF	BC	45.89	93.575	47.685
MF	HH	48.67	110.8	62.13
MF	HH	38.46	97.35	58.89

Table B-1 continued.

Treatment	Species	Initial Groundline Diameter Measurement (mm)	Final Groundline Diameter Measurement (mm)	Total Growth (cm)
MF	LO	11.26	46.5	35.24
MF	BC	45.3	105.6	60.3
MF	BC	44.18	99.5	55.32
MF	LO	20.76	78	57.24
MF	HH	48.7	95.115	46.415
MF	BC	47.91	95.405	47.495
MF	BC	48.43	96.35	47.92
MF	LO	17.23	64.545	47.315
MF	LO	22.74	52.145	29.405
MF	HH	57.9	105.34	47.44
MF	HH	48.75	95.905	47.155
MF	BC	39.09	101.51	62.42
MF	HH	45.21	100.19	54.98
MF	LO	15.1	95.155	80.055
MF	LO	21.17	108.565	87.395
MF	BC	39.64	118.48	78.84
MF	LO	22.01	39.29	17.28
MF	HH	47.33	89.505	42.175
MF	BC	47.28	98.74	51.46
MF	BC	51.27	116.435	65.165
MF	LO	20.72	36.15	15.43
MF	HH	46.51	100.44	53.93
MF	BC	41.35	97.265	55.915
MF	BC	43.66	119.99	76.33
MF	HH	44.45	115.455	71.005
MF	HH	52.96	107.465	54.505

Table B-1 continued.

Treatment	Species	Initial Groundline Diameter Measurement (mm)	Final Groundline Diameter Measurement (mm)	Total Growth (cm)
MF	LO	7.97	0	-7.97
MF	LO	31.69	90.255	58.565
MB	LO	16.53	28.95	12.42
MB	BC	57.83	81.9	24.07
MB	HH	56.43	102	45.57
MB	HH	72.07	111.5	39.43
MB	BC	50.26	78.95	28.69
MB	LO	24.67	42.7	18.03
MB	LO	24.37	61	36.63
MB	HH	60.68	114.5	53.82
MB	BC	51.71	109.5	57.79
MB	HH	64.15	142	77.85
MB	BC	35.46	109.05	73.59
MB	LO	18.94	49.6	30.66
MB	LO	22.57	43.92	21.35
MB	LO	22.45	71.065	48.615
MB	HH	67.48	128.56	61.08
MB	BC	59.24	79.095	19.855
MB	BC	53.34	92.605	39.265
MB	HH	51.93	83.88	31.95
MB	LO	28.95	86.3	57.35
MB	BC	54.27	97.455	43.185
MB	LO	21.87	52.28	30.41
MB	HH	51.41	92.705	41.295
MB	HH	40.25	85.975	45.725
MB	BC	65.98	140.87	74.89

Table B-1 continued.

Treatment	Species	Initial Groundline Diameter Measurement (mm)	Final Groundline Diameter Measurement (mm)	Total Growth (cm)
MB	BC	53.03	111.255	58.225
MB	LO	23.97	57.525	33.555
MB	LO	15.76	24.6	8.84
MB	BC	52.19	117.765	65.575
MB	HH	40.65	102.535	61.885
MB	HH	43.74	118.495	74.755
MB	HH	44.3	103.94	59.64
MB	BC	55.84	109.97	54.13
MB	HH	42.74	110.05	67.31
MB	LO	25.69	61.55	35.86
MB	LO	29.1	74.545	45.445
MB	BC	58.62	114.75	56.13
MGF	LO	23.94	47.3	23.36
MGF	HH	48.88	100	51.12
MGF	BC	49.23	86.95	37.72
MGF	HH	47.5	96.55	49.05
MGF	BC	29.29	91.5	62.21
MGF	LO	23.54	64.25	40.71
MGF	HH	45.49	99.9	54.41
MGF	BC	35.84	72.55	36.71
MGF	LO	21.18	42	20.82
MGF	HH	52.9	103.45	50.55
MGF	BC	50.52	130	79.48
MGF	LO	29.79	72.05	42.26
MGF	HH	60.16	114.135	53.975
MGF	LO	18.7	31.045	12.345

Table B-1 continued.

Treatment	Species	Initial Groundline Diameter Measurement (mm)	Final Groundline Diameter Measurement (mm)	Total Growth (cm)
MGF	LO	19.97	37.05	17.08
MGF	BC	50.01	85.785	35.775
MGF	BC	54.68	100.75	46.07
MGF	HH	59.88	119.405	59.525
MGF	HH	64.43	97.01	32.58
MGF	LO	21.17	36.56	15.39
MGF	BC	52.75	82.605	29.855
MGF	LO	23.83	62.785	38.955
MGF	BC	49.71	90.7	40.99
MGF	HH	48.23	84.55	36.32
MGF	BC	51	110.05	59.05
MGF	HH	71.8	128.455	56.655
MGF	BC	30.75	109.445	78.695
MGF	HH	0	82.31	82.31
MGF	LO	24.16	55.25	31.09
MGF	LO	19.31	67.805	48.495
MGF	LO	22.52	66.895	44.375
MGF	HH	55.24	94.255	39.015
MGF	HH	50.49	108.01	57.52
MGF	BC	51.66	93.55	41.89
MGF	BC	52.42	97.005	44.585
MGF	LO	27.55	66.515	38.965
MGB	LO	15.39	18.85	3.46
MGB	HH	71.82	139.15	67.33
MGB	LO	22.31	57.205	34.895
MGB	BC	47.43	54.615	7.185

Table B-1 continued.

Treatment	Species	Initial Groundline Diameter Measurement (mm)	Final Groundline Diameter Measurement (mm)	Total Growth (cm)
MGB	HH	42.58	98.75	56.17
MGB	BC	58.03	83	24.97
MGB	LO	25.99	80.45	54.46
MGB	BC	34.7	102.75	68.05
MGB	HH	59.64	94.7	35.06
MGB	LO	24.93	54.25	29.32
MGB	HH	53.27	138.5	85.23
MGB	BC	57.31	85.5	28.19
MGB	LO	21.5	70	48.5
MGB	BC	53.97	88.15	34.18
MGB	LO	22.41	49.5	27.09
MGB	HH	46.14	118.5	72.36
MGB	HH	31.12	92.2	61.08
MGB	BC	44.76	95.05	50.29
MGB	LO	25.28	62.4	37.12
MGB	HH	43.9	115.1	71.2
MGB	BC	59.6	108.005	48.405
MGB	HH	52.65	100.25	47.6
MGB	LO	23.39	30.99	7.6
MGB	BC	58.21	130.82	72.61
MGB	LO	26.15	54.025	27.875
MGB	HH	57.49	137.675	80.185
MGB	BC	39.65	100.515	60.865
MGB	BC	54.21	118.055	63.845
MGB	HH	39.65	113.75	74.1
MGB	LO	15.91	30.74	14.83

Table B-1 continued.

Treatment	Species	Initial Groundline Diameter Measurement (mm)	Final Groundline Diameter Measurement (mm)	Total Growth (cm)
MGB	LO	24.83	52.745	27.915
MGB	HH	45.04	118.95	73.91
MGB	HH	53.4	96.485	43.085
MGB	LO	26.07	73.04	46.97
MGB	BC	62.21	103.05	40.84
MGB	BC	72.64	99.275	26.635

Table B-2. Initial and final height (and crown diameter for *H. hamabo*) measurements for each plant at the project site, in addition to total growth for each plant. Initial measurements were taken March 15, 2016, and final measurements were taken March 4, 2019. Data is organized by applied treatment.

Treatment	Species	Initial Height Measurement (cm)	Final Height Measurement (cm)	Total Growth (cm)
CF	BC	204	236	32
CF	LO	103	214	111
CF	HH	110	194	84
CF	BC	173	284	111
CF	LO	85	248	163
CF	HH	94	160.5	66.5
CF	HH	88	171	83
CF	HH	82	174.5	92.5
CF	LO	148	216	68
CF	BC	219	324	105
CF	BC	161	248	87
CF	LO	149	234	85

Table B-2 continued.

Treatment	Species	Initial Height Measurement (cm)	Final Height Measurement (cm)	Total Growth (cm)
CF	LO	125	260	135
CF	HH	113	239	126
CF	HH	155	207	52
CF	BC	225	312	87
CF	BC	154	272	118
CF	LO	121	264	143
CF	LO	85	220	135
CF	HH	128	190.5	62.5
CF	BC	190	323	133
CF	LO	79	219	140
CF	BC	210	216	6
CF	HH	116	0	-116
CF	LO	158	324	166
CF	BC	210	320	110
CF	HH	126	246	120
CF	LO	102	0	-102
CF	BC	166	336	170
CF	HH	110	147.5	37.5
CF	LO	123	270	147
CF	BC	140	300	160
CF	LO	129	260	131
CF	HH	85	177	92
CF	HH	113	243.5	130.5
CF	BC	188	298	110
CB	BC	185	300	115
CB	HH	127	171	44

Table B-2 continued.

Treatment	Species	Initial Height Measurement (cm)	Final Height Measurement (cm)	Total Growth (cm)
CB	BC	180	260	80
CB	HH	87	180	93
CB	LO	66	0	-66
CB	LO	144	230	86
CB	LO	127	228	101
CB	BC	188	280	92
CB	BC	182	294	112
CB	HH	104	185.5	81.5
CB	LO	118	200	82
CB	HH	121	165	44
CB	LO	83	0	-83
CB	HH	114	235	121
CB	BC	204	270	66
CB	LO	153	256	103
CB	BC	206	372	166
CB	HH	132	158.5	26.5
CB	LO	178	232	54
CB	BC	178	232	54
CB	HH	120	207.5	87.5
CB	LO	170	250	80
CB	BC	190	270	80
CB	HH	124	184.5	60.5
CB	HH	100	235	135
CB	LO	96	225	129
CB	HH	78	190.5	112.5
CB	LO	114	212	98

Table B-2 continued.

Treatment	Species	Initial Height Measurement (cm)	Final Height Measurement (cm)	Total Growth (cm)
CB	BC	178	314	136
CB	BC	156	295	139
CB	BC	205	340	135
CB	LO	90	168	78
CB	HH	131	173	42
CB	LO	156	258	102
CB	BC	199	300	101
CB	HH	127	148	21
GF	HH	0	172.5	172.5
GF	LO	172	220	48
GF	HH	125	202.5	77.5
GF	LO	132	260	128
GF	BC	195	340	145
GF	BC	160	260	100
GF	LO	156	208	52
GF	HH	116	202	86
GF	BC	210	248	38
GF	BC	217	310	93
GF	LO	139	288	149
GF	HH	90	187	97
GF	LO	134	254	120
GF	HH	129	200.5	71.5
GF	HH	126	198	72
GF	BC	191	284	93
GF	LO	170	290	120
GF	BC	181	212	31

Table B-2 continued.

Treatment	Species	Initial Height Measurement (cm)	Final Height Measurement (cm)	Total Growth (cm)
GF	HH	123	227	104
GF	LO	96	306	210
GF	HH	135	183	48
GF	BC	200	312	112
GF	LO	120	180	60
GF	BC	198	256	58
GF	HH	140	179.5	39.5
GF	LO	102	208	106
GF	BC	195	330	135
GF	LO	76	181	105
GF	BC	191	336	145
GF	HH	140	170	30
GF	LO	164	290	126
GF	HH	155	166.5	11.5
GF	BC	170	260	90
GF	LO	145	304	159
GF	BC	205	302	97
GF	HH	100	190	90
GB	HH	103	199	96
GB	BC	180	384	204
GB	BC	210	302	92
GB	HH	124	217.5	93.5
GB	LO	98	258	160
GB	LO	105	210	105
GB	LO	65	242	177
GB	LO	120	240	120

Table B-2 continued.

Treatment	Species	Initial Height Measurement (cm)	Final Height Measurement (cm)	Total Growth (cm)
GB	HH	108	151	43
GB	BC	177	306	129
GB	HH	128	157.5	29.5
GB	BC	163	242	79
GB	HH	131	212.5	81.5
GB	BC	223	384	161
GB	LO	154	226	72
GB	HH	110	167	57
GB	LO	103	272	169
GB	BC	196	362	166
GB	LO	107	248	141
GB	HH	80	196.5	116.5
GB	HH	80	164	84
GB	LO	150	132	-18
GB	BC	145	248	103
GB	BC	174	322	148
GB	LO	83	230	147
GB	LO	113	240	127
GB	HH	68	213	145
GB	HH	97	214	117
GB	BC	160	268	108
GB	BC	167	310	143
GB	LO	132	208	76
GB	LO	153	238	85
GB	HH	117	189.5	72.5
GB	BC	196	310	114

Table B-2 continued.

Treatment	Species	Initial Height Measurement (cm)	Final Height Measurement (cm)	Total Growth (cm)
GB	HH	75	175	100
GB	BC	196	290	94
MF	LO	105	275	170
MF	HH	115	139.5	24.5
MF	LO	128	240	112
MF	BC	205	360	155
MF	HH	117	130	13
MF	BC	227	310	83
MF	HH	130	205.5	75.5
MF	HH	100	145	45
MF	LO	66	216	150
MF	BC	181	324	143
MF	BC	170	304	134
MF	LO	120	260	140
MF	HH	130	202.5	72.5
MF	BC	226	318	92
MF	BC	180	298	118
MF	LO	109	200	91
MF	LO	97	220	123
MF	HH	118	169.5	51.5
MF	HH	114	194	80
MF	BC	148	310	162
MF	HH	115	187.5	72.5
MF	LO	112	153	41
MF	LO	186	228	42
MF	BC	167	180	13

Table B-2 continued.

Treatment	Species	Initial Height Measurement (cm)	Final Height Measurement (cm)	Total Growth (cm)
MF	LO	63	172	109
MF	HH	107	253.5	146.5
MF	BC	183	350	167
MF	BC	193	295	102
MF	LO	97	160	63
MF	HH	80	168.5	88.5
MF	BC	143	318	175
MF	BC	210	328	118
MF	HH	96	215	119
MF	HH	127	197.5	70.5
MF	LO	68	0	-68
MF	LO	160	300	140
MB	LO	69	172	103
MB	BC	180	252	72
MB	HH	116	169	53
MB	HH	136	197.5	61.5
MB	BC	176	276	100
MB	LO	102	154	52
MB	LO	106	280	174
MB	HH	94	186.5	92.5
MB	BC	198	279	81
MB	HH	148	198.5	50.5
MB	BC	142	314	172
MB	LO	90	139	49
MB	LO	147	152	5
MB	LO	115	168	53

Table B-2 continued.

Treatment	Species	Initial Height Measurement (cm)	Final Height Measurement (cm)	Total Growth (cm)
MB	HH	125	211	86
MB	BC	231	228	-3
MB	BC	282	284	2
MB	HH	114	171	57
MB	LO	106	262	156
MB	BC	188	248	60
MB	LO	95	248	153
MB	HH	120	182	62
MB	HH	67	164.5	97.5
MB	BC	216	342	126
MB	BC	214	340	126
MB	LO	80	226	146
MB	LO	83	140	57
MB	BC	208	330	122
MB	HH	90	175	85
MB	HH	90	167.5	77.5
MB	HH	88	230	142
MB	BC	183	298	115
MB	HH	72	226	154
MB	LO	143	250	107
MB	LO	148	240	92
MB	BC	200	310	110
MGF	LO	115	208	93
MGF	HH	105	195	90
MGF	BC	190	278	88
MGF	HH	112	189.5	77.5

Table B-2 continued.

Treatment	Species	Initial Height Measurement (cm)	Final Height Measurement (cm)	Total Growth (cm)
MGF	BC	125	298	173
MGF	LO	121	274	153
MGF	HH	105	155	50
MGF	BC	192	260	68
MGF	LO	193	222	29
MGF	HH	140	230	90
MGF	BC	203	312	109
MGF	LO	141	274	133
MGF	HH	110	222	112
MGF	LO	114	228	114
MGF	LO	153	200	47
MGF	BC	202	290	88
MGF	BC	176	318	142
MGF	HH	150	184	34
MGF	HH	122	241.5	119.5
MGF	LO	136	248	112
MGF	BC	156	288	132
MGF	LO	109	286	177
MGF	BC	147	272	125
MGF	HH	120	171	51
MGF	BC	187	340	153
MGF	HH	112	246.5	134.5
MGF	BC	160	270	110
MGF	HH	0	155.5	155.5
MGF	LO	130	252	122
MGF	LO	108	298	190

Table B-2 continued.

Treatment	Species	Initial Height Measurement (cm)	Final Height Measurement (cm)	Total Growth (cm)
MGF	LO	157	262	105
MGF	HH	100	175	75
MGF	HH	113	169.5	56.5
MGF	BC	203	300	97
MGF	BC	180	300	120
MGF	LO	123	252	129
MGB	LO	82	83	1
MGB	HH	137	215.5	78.5
MGB	LO	131	260	129
MGB	BC	170	242	72
MGB	HH	125	199	74
MGB	BC	197	306	109
MGB	LO	129	270	141
MGB	BC	182	230	48
MGB	HH	140	154	14
MGB	LO	126	280	154
MGB	HH	122	201	79
MGB	BC	198	306	108
MGB	LO	128	248	120
MGB	BC	200	300	100
MGB	LO	101	284	183
MGB	HH	117	209	92
MGB	HH	82	172.5	90.5
MGB	BC	232	376	144
MGB	LO	128	242	114
MGB	HH	118	167	49

Table B-2 continued.

Treatment	Species	Initial Height Measurement (cm)	Final Height Measurement (cm)	Total Growth (cm)
MGB	BC	244	332	88
MGB	HH	125	185.5	60.5
MGB	LO	140	172	32
MGB	BC	208	364	156
MGB	LO	155	280	125
MGB	HH	126	237.5	111.5
MGB	BC	169	300	131
MGB	BC	204	304	100
MGB	HH	100	183.5	83.5
MGB	LO	99	140	41
MGB	LO	137	294	157
MGB	HH	103	176	73
MGB	HH	89	171.5	82.5
MGB	LO	141	210	69
MGB	BC	215	356	141
MGB	BC	219	356	137

Appendix C – Additional Foliage Testing Data

Table C-1. Table displaying results of foliage elemental testing, displayed in mg kg^{-1}, for the *Taxodium* genotypes. Foliage samples were collected in July, 2018. Samples were analyzed by the Soil, Plant, and Water Analysis Laboratory at Stephen F Austin State University.

	Test Parameter (mg kg^{-1})					
Sample	**P**	**K**	**Ca**	**Mg**	**S**	**Na**
TAX DC-1	1969	8403	10614	3166	1904	6289
TAX DC-2	1996	8743	13020	3207	1803	5801
TAX DC-3	2117	8376	12893	2837	1899	4793
TAX DC-4	2051	10896	11429	2168	1648	6121
TAX DC-5	2994	9931	13521	3409	2155	9059
TAX OC-1	3612	16923	7968	3408	1992	10043
TAX OC-2	2589	15907	8456	2602	1679	4720
TAX OC-3	2655	16048	7376	3033	1815	6988
TAX OC-4	2847	17649	6287	3310	1886	9711
TAX OC-5	2880	17192	8428	2762	1697	4721
TAX 407-1	2403	9716	11161	3778	1770	10912
TAX 407-2	2314	9506	12252	3594	1721	8977
TAX 407-3	2419	9613	12576	3545	1854	7875
TAX 407-4	2913	10124	14430	3889	1882	9275
TAX 407-5	2758	10343	10862	3648	1878	9829
TAX 406-1	3202	12212	7651	3124	2051	10983
TAX 406-2	3209	10530	10252	3907	2029	10390
TAX 406-3	3032	13462	9133	3186	1833	10282
TAX 406-4	2936	13614	7472	3344	2030	12267
TAX 406-5	3245	11575	9447	3446	2008	11376
TAX 405-1	2321	10226	8990	3208	1958	11253
TAX 405-2	2366	11587	8806	2982	1963	11431
TAX 405-3	2012	9618	10562	3484	1833	10985
TAX 405-4	3038	12306	8417	3056	1703	10294
TAX 405-5	2387	10524	10493	3317	1809	8934
TAX 27-1	2605	12972	7634	2726	2037	9805

Table C-1 continued.

	Test Parameter ($mg\ kg^{-1}$)					
Sample	**P**	**K**	**Ca**	**Mg**	**S**	**Na**
TAX 27-2	2064	12356	9481	3147	1982	7809
TAX 27-3	2418	9355	10121	3445	1792	10864
TAX 27-4	2172	10950	9347	3003	2009	7458
TAX 27-5	2286	12690	8878	2969	1923	7567
TAX 502-1	2712	10508	8698	3114	1973	7812
TAX 502-2	2569	10280	7992	3188	1820	10804
TAX 502-3	2878	9561	8863	3163	1806	7391
TAX 502-4	2389	9012	9379	3373	1653	9402
TAX 502-5	2159	8487	8897	3011	1516	9904

Appendix D – Additional Groundwater Data and Correlation Tables

Table D-1. Groundwater sampling data for piezometer 1. Water quality parameters highlighted include pH, electrical conductivity (EC), Na^+, Cl^-, and depth to water table (DTWT).

Date	pH	EC (mS/cm)	Na^+ (mg/L)	Cl^- (mg/L)	DTWT (cm)
10/13/2017	7.96	1.74	149.51	520.19	61.5
10/27/2017	7.86	1.86	614.06	2122.19	64.0
11/10/2017	7.60	6.11	292.06	1008.33	61.8
11/24/2017	-	-	-	-	100.0
12/8/2017	7.62	3.14	239.65	784.09	57.1
12/22/2017	7.81	2.73	282.81	961.95	52.0
1/5/2018	7.92	3.05	249.49	790.44	62.8
1/19/2018	7.95	2.56	285.25	831.92	58.0
2/2/2018	8.02	2.82	405.02	1200.82	58.6
2/17/2018	7.96	3.60	309.31	913.09	59.5
3/2/2018	7.88	2.91	233.64	677.24	68.4
3/16/2018	8.18	2.30	164.78	556.22	72.0
3/30/2018	8.06	1.99	176.43	541.03	42.4
4/13/2018	8.10	1.93	281.63	460.98	68.9
4/27/2018	-	-	-	-	103.0
5/11/2018	8.45	2.18	247.51	402.08	91.0
5/25/2018	8.48	1.67	149.51	520.19	83.6
6/8/2018	-	-	-	-	101.4
6/22/2018	7.58	2.01	166.77	487.22	49.4
7/6/2018	7.69	2.26	211.95	589.72	49.6
7/20/2018	7.83	1.93	145.97	399.19	73.9
8/3/2018	7.84	2.13	1284.65	529.71	66.3
8/17/2018	7.95	1.87	1354.09	370.86	77.2

Table D-2. Groundwater sampling data for piezometer 2. Water quality parameters highlighted include pH, electrical conductivity (EC), Na^+, Cl^-, and depth to water table (DTWT).

Date	pH*	EC (mS/cm)	Na^+* (mg/L)	Cl^-* (mg/L)	DTWT (cm)
10/13/2017	7.78	2.95	304.35	724.89	70.0
10/27/2017	7.72	3.04	362.55	912.46	72.9
11/10/2017	7.80	3.08	314.95	922.20	67.3
11/24/2017	7.91	3.15	302.09	970.15	81.1
12/8/2017	7.74	2.93	305.32	818.14	58.2
12/22/2017	7.93	2.28	282.34	559.09	56.0
1/5/2018	8.14	1.43	212.56	219.92	65.4
1/19/2018	8.01	0.89	151.95	108.93	66.0
2/2/2018	8.18	0.88	124.06	107.57	58.9
2/17/2018	8.07	1.01	116.55	146.24	62.2
3/2/2018	8.08	1.21	129.35	163.22	69.6
3/16/2018	8.37	1.18	197.25	161.74	75.8
3/30/2018	8.28	1.35	236.55	236.85	54.3
4/13/2018	8.26	1.34	223.53	147.84	71.5
4/27/2018	8.03	1.24	237.13	220.96	82.7
5/11/2018	8.45	2.18	542.25	506.68	91.0
5/25/2018	8.21	2.35	586.29	575.52	87.6
6/8/2018	7.83	2.75	356.42	674.94	106.0
6/22/2018	7.86	1.54	212.77	324.21	54.0
7/6/2018	7.82	1.52	205.99	268.18	50.2
7/20/2018	8.03	2.27	313.90	437.77	84.2
8/3/2018	8.01	3.00	188.94	743.14	79.4
8/17/2018	8.00	3.38	186.04	761.51	92.3

Table D-3. Groundwater sampling data for piezometer 3. Water quality parameters highlighted include pH, electrical conductivity (EC), Na^+, Cl^-, and depth to water table (DTWT).

Date	pH*	EC (mS/cm)	Na^+* (mg/L)	Cl^-* (mg/L)	DTWT (cm)
10/13/2017	-	-	-	-	113.0
10/27/2017	-	-	-	-	101.2
11/10/2017	7.85	2.38	373.82	536.51	113.0
11/24/2017	-	-	-	-	113.0
12/8/2017	7.57	0.85	84.03	49.98	73.5
12/22/2017	7.85	0.75	76.69	34.74	70.0
1/5/2018	7.75	0.78	72.53	60.52	76.3
1/19/2018	-	-	-	-	89.1
2/2/2018	7.77	0.82	62.99	116.33	69.0
2/17/2018	7.75	0.77	57.87	82.57	82.0
3/2/2018	7.72	0.78	57.19	75.45	93.3
3/16/2018	8.17	0.82	65.04	64.96	105.2
3/30/2018	8.10	0.79	66.83	70.54	105.3
4/13/2018	7.99	0.83	72.79	80.47	104.7
4/27/2018	7.87	0.90	117.47	56.08	98.1
5/11/2018	8.20	0.71	149.57	55.48	118.7
5/25/2018	7.64	0.59	333.01	61.13	124.2
6/8/2018	7.91	0.92	91.99	58.56	132.1
6/22/2018	7.83	0.88	80.65	52.45	76.0
7/6/2018	7.88	0.88	71.33	39.07	69.9
7/20/2018	7.86	0.91	72.14	42.21	107.0
8/3/2018	7.91	0.91	145.39	48.08	103.8
8/17/2018	8.20	1.04	128.49	57.09	119.4

Table D-4. Groundwater sampling data for piezometer 4. Water quality parameters highlighted include pH, electrical conductivity (EC), Na^+, Cl^-, and depth to water table (DTWT).

Date	pH	EC (mS/cm)	Na^+ (mg/L)	Cl^- (mg/L)	DTWT (cm)
10/13/2017	7.71	5.38	678.31	1519.27	91.0
10/27/2017	7.64	5.43	851.77	1700.84	67.5
11/10/2017	7.83	5.86	758.65	1898.32	65.2
11/24/2017	7.94	5.84	337.42	2027.05	83.6
12/8/2017	7.44	5.60	738.32	1859.91	32.1
12/22/2017	7.81	5.59	621.46	1773.69	30.0
1/5/2018	7.85	5.73	624.57	1889.16	46.4
1/19/2018	7.93	1.43	646.53	2072.59	47.0
2/2/2018	7.88	6.74	987.68	2074.45	54.5
2/17/2018	7.90	6.64	999.29	2202.42	48.4
3/2/2018	7.89	6.38	970.16	2295.09	63.6
3/16/2018	8.14	6.28	1068.07	2072.74	72.0
3/30/2018	8.03	6.43	1082.06	2194.17	46.3
4/13/2018	7.96	7.50	1235.84	2571.91	70.1
4/27/2018	7.86	7.65	1181.95	2314.26	66.9
5/11/2018	8.15	6.45	1084.57	1914.75	85.3
5/25/2018	8.12	6.83	1199.07	2081.28	89.2
6/8/2018	-	-	-	-	108.9
6/22/2018	7.55	7.59	1269.61	2094.81	19.1
7/6/2018	7.68	8.11	1435.32	2353.46	9.0
7/20/2018	7.92	7.33	71.93	1868.85	73.4
8/3/2018	7.93	7.02	365.98	1972.75	81.1
8/17/2018	7.96	7.56	391.46	2021.26	100.0

Table D-5. Groundwater sampling data for piezometer 5. Water quality parameters highlighted include pH, electrical conductivity (EC), Na^+, Cl^-, and depth to water table (DTWT).

Date	pH	EC (mS/cm)	Na^+ (mg/L)	Cl^- (mg/L)	DTWT (cm)
10/13/2017	8.09	4.51	505.69	1258.46	95.0
10/27/2017	7.85	4.38	608.22	1278.17	93.0
11/10/2017	8.02	4.44	543.43	1372.59	55.3
11/24/2017	8.15	4.27	491.01	1337.12	94.2
12/8/2017	7.59	2.96	386.31	792.54	45.9
12/22/2017	8.02	2.92	362.48	767.18	47.0
1/5/2018	7.98	2.86	361.78	766.54	63.3
1/19/2018	8.17	2.25	308.57	526.03	62.0
2/2/2018	8.10	1.89	303.93	379.02	56.2
2/17/2018	8.15	1.76	274.45	357.69	63.3
3/2/2018	8.22	1.83	282.06	388.24	75.2
3/16/2018	8.41	1.91	314.07	406.15	86.9
3/30/2018	8.33	2.28	395.87	567.03	78.3
4/13/2018	8.29	2.60	439.29	670.66	78.2
4/27/2018	8.21	2.54	594.40	579.94	78.3
5/11/2018	8.74	2.15	633.22	502.57	100.0
5/25/2018	8.60	3.19	526.23	857.37	112.4
6/8/2018	7.80	3.31	507.02	864.25	121.2
6/22/2018	7.90	3.68	518.66	1019.49	63.3
7/6/2018	7.86	3.06	477.29	773.24	37.0
7/20/2018	8.03	2.71	89.13	562.69	93.1
8/3/2018	8.08	3.96	75.55	915.29	92.7
8/17/2018	8.09	4.06	93.51	887.75	111.2

Table D-6. Groundwater sampling data for piezometer 6. Water quality parameters highlighted include pH, electrical conductivity (EC), Na^+, Cl^-, and depth to water table (DTWT).

Date	pH	EC (mS/cm)	Na^+ (mg/L)	Cl^- (mg/L)	DTWT (cm)
10/13/2017	8.21	0.99	169.00	65.93	101.0
10/27/2017	8.18	1.01	231.61	-	107.8
11/10/2017	8.34	1.05	533.48	69.87	98.6
11/24/2017	7.74	2.46	357.28	622.47	111.4
12/8/2017	7.56	1.12	91.65	176.33	70.0
12/22/2017	7.98	0.99	84.93	153.07	72.0
1/5/2018	7.98	1.05	89.94	165.16	83.0
1/19/2018	7.78	0.94	92.15	159.84	63.0
2/2/2018	7.79	0.93	89.67	125.91	75.1
2/17/2018	7.63	1.00	75.13	136.66	81.6
3/2/2018	8.18	1.07	74.23	127.39	91.7
3/16/2018	8.14	1.10	109.56	137.39	101.7
3/30/2018	8.11	1.14	113.88	143.65	99.0
4/13/2018	8.25	1.15	120.46	152.35	101.2
4/27/2018	8.01	1.21	214.94	120.77	97.4
5/11/2018	8.36	1.24	216.76	175.86	113.3
5/25/2018	8.21	1.18	225.77	173.47	116.3
6/8/2018	-	-	-	-	133.3
6/22/2018	7.76	0.99	116.73	79.19	88.7
7/6/2018	7.71	1.16	123.31	169.24	67.5
7/20/2018	7.99	1.32	1133.94	187.18	108.1
8/3/2018	7.99	1.42	1121.65	221.39	105.9
8/17/2018	8.02	1.43	1212.45	209.08	116.0

Table D-7. Groundwater sampling data for piezometer 7. Water quality parameters highlighted include pH, electrical conductivity (EC), Na^+, Cl^-, and depth to water table (DTWT).

Date	pH	EC (mS/cm)	Na^+ (mg/L)	Cl^- (mg/L)	DTWT (cm)
10/13/2017	7.70	15.95	2324.59	5820.96	50.0
10/27/2017	7.45	9.48	1572.77	3488.19	57.0
11/10/2017	7.46	7.14	208.69	2538.03	48.4
11/24/2017	7.67	5.30	685.29	1765.20	67.4
12/8/2017	7.11	3.64	540.48	1300.73	57.6
12/22/2017	7.66	3.74	456.61	1227.25	49.0
1/5/2018	7.93	3.27	406.98	1067.41	66.0
1/19/2018	7.94	2.76	342.41	943.18	52.0
2/2/2018	8.00	6.62	1086.19	2169.42	61.9
2/17/2018	7.77	5.54	900.28	1830.60	57.3
3/2/2018	7.98	4.03	619.18	1299.30	62.3
3/16/2018	8.10	3.49	564.78	1063.05	67.3
3/30/2018	8.10	3.13	498.37	955.70	35.0
4/13/2018	8.07	3.01	458.17	912.05	53.8
4/27/2018	7.70	2.74	747.71	767.76	74.0
5/11/2018	8.48	2.65	395.35	736.09	78.4
5/25/2018	7.84	2.51	579.25	660.42	74.2
6/8/2018	7.74	2.45	322.25	610.12	86.1
6/22/2018	7.41	2.82	409.12	780.95	36.2
7/6/2018	7.38	3.12	491.06	924.79	39.5
7/20/2018	7.86	4.19	423.12	1057.99	75.7
8/3/2018	7.71	3.54	589.30	923.07	72.5
8/17/2018	7.90	2.94	1206.24	755.86	69.0

Table D-8. Groundwater sampling data for piezometer 8. Water quality parameters highlighted include pH, electrical conductivity (EC), Na^+, Cl^-, and depth to water table (DTWT).

Date	pH	EC (mS/cm)	Na^+ (mg/L)	Cl^- (mg/L)	DTWT (cm)
10/13/2017	8.01	7.70	918.96	2388.74	86.0
10/27/2017	7.56	7.18	1116.90	2422.83	87.0
11/10/2017	7.58	7.22	998.18	2577.17	87.1
11/24/2017	7.60	6.82	938.93	2510.89	96.2
12/8/2017	7.42	5.92	827.39	2148.17	66.7
12/22/2017	7.68	6.75	720.63	2349.68	63.0
1/5/2018	7.57	7.05	763.18	2481.73	72.6
1/19/2018	7.57	6.82	738.99	2476.95	76.0
2/2/2018	7.77	6.34	989.29	2137.27	69.3
2/17/2018	7.67	7.15	1102.49	2508.07	74.5
3/2/2018	7.74	7.14	1085.32	2715.23	87.4
3/16/2018	8.01	7.58	1227.57	2489.88	92.5
3/30/2018	8.05	7.40	1239.44	2460.73	77.5
4/13/2018	8.06	7.33	1212.30	2447.38	91.1
4/27/2018	7.86	7.08	447.05	1995.78	90.5
5/11/2018	8.30	7.32	1212.17	2138.89	108.1
5/25/2018	7.82	7.39	2189.90	1240.15	109.4
6/8/2018	7.78	7.40	1207.30	1942.59	122.6
6/22/2018	7.59	6.83	1161.57	1782.76	48.6
7/6/2018	7.65	7.12	1190.72	1946.59	48.5
7/20/2018	7.87	8.41	135.79	2276.94	94.7
8/3/2018	7.91	8.31	145.89	2428.27	98.1
8/17/2018	7.87	8.29	566.04	2297.81	96.7

Table D-9. Groundwater sampling data for piezometer 9. Water quality parameters highlighted include pH, electrical conductivity (EC), Na^+, Cl^-, and depth to water table (DTWT).

Date	pH	EC (mS/cm)	Na^+ (mg/L)	Cl^- (mg/L)	DTWT (cm)
10/13/2017	7.88	1.64	238.43	191.92	107.0
10/27/2017	7.90	1.69	338.97	245.42	94.0
11/10/2017	8.11	1.77	981.21	260.61	93.5
11/24/2017	8.18	1.79	284.79	259.58	101.3
12/8/2017	7.72	1.71	302.57	237.71	54.6
12/22/2017	8.12	1.51	248.42	192.83	59.0
1/5/2018	8.07	1.46	239.09	186.98	68.2
1/19/2018	8.07	1.43	229.76	183.43	69.0
2/2/2018	8.11	1.45	264.88	172.76	57.0
2/17/2018	8.06	1.37	226.45	153.63	70.2
3/2/2018	8.06	1.32	218.74	144.76	84.4
3/16/2018	8.36	1.33	229.67	138.36	89.8
3/30/2018	8.25	1.34	247.26	142.49	88.2
4/13/2018	8.35	1.35	253.16	148.03	95.2
4/27/2018	8.15	1.38	447.05	127.76	84.5
5/11/2018	8.69	1.49	457.79	176.79	104.0
5/25/2018	8.14	1.34	390.77	138.54	110.3
6/8/2018	7.98	1.29	202.51	126.59	120.4
6/22/2018	7.98	1.25	175.74	126.35	64.1
7/6/2018	7.79	1.23	167.92	125.63	55.4
7/20/2018	8.12	1.39	633.81	124.94	95.6
8/3/2018	8.09	1.41	527.86	109.91	106.9
8/17/2018	8.14	1.43	155.99	136.67	115.3

Table D-10. Correlation statistics for piezometer 1.

	pH	EC (mS/cm)	Na^+ (mg/L)	Cl^- (mg/L)	DTWT (cm)	Precipitation (cm)
pH	1.00					
EC	-0.62	1.00				
Na^+	-0.37	0.95	1.00			
Cl^-	-0.66	0.99	0.93	1.00		
DTWT	0.68	-0.20	0.04	-0.26	1.00	
Precipitation	-0.50	0.17	0.06	0.18	-0.38	1.00

Table D-11. Correlation statistics for piezometer 2.

	pH	EC (mS/cm)	Na^+ (mg/L)	Cl^- (mg/L)	DTWT (cm)	Precipitation (cm)
pH	1.00					
EC	-0.64	1.00				
Na^+	0.05	0.62	1.00			
Cl^-	-0.67	0.99	0.58	1.00		
DTWT	0.29	0.20	0.63	0.18	1.00	
Precipitation	-0.39	0.20	-0.07	0.21	-0.50	1.00

Table D-12. Correlation statistics for piezometer 3.

	pH	EC (mS/cm)	Na^+ (mg/L)	Cl^- (mg/L)	DTWT (cm)	Precipitation (cm)
pH	1.00					
EC	0.00	1.00				
Na^+	-0.15	0.61	1.00			
Cl^-	-0.03	0.98	0.68	1.00		
DTWT	0.46	0.21	0.62	0.27	1.00	
Precipitation	-0.49	0.04	-0.13	-0.01	-0.54	1.00

Table D-13. Correlation statistics for piezometer 4.

	pH	EC (mS/cm)	Na^+ (mg/L)	Cl^- (mg/L)	DTWT (cm)	Precipitation (cm)
pH	1.00					
EC	0.20	1.00				
Na^+	0.45	0.59	1.00			
Cl^-	0.45	0.39	0.59	1.00		
DTWT	0.43	0.27	0.21	-0.03	1.00	
Precipitation	-0.70	-0.08	-0.16	-0.27	-0.53	1.00

Table D-14. Correlation statistics for piezometer 5.

	pH	EC (mS/cm)	Na^+ (mg/L)	Cl^- (mg/L)	DTWT (cm)	Precipitation (cm)
pH	1.00					
EC	-0.37	1.00				
Na^+	0.20	0.60	1.00			
Cl^-	-0.37	0.99	0.59	1.00		
DTWT	0.65	0.23	0.56	0.21	1.00	
Precipitation	-0.66	0.02	-0.17	0.01	-0.55	1.00

Table D-15. Correlation statistics for piezometer 6.

	pH	EC (mS/cm)	Na^+ (mg/L)	Cl^- (mg/L)	DTWT (cm)	Precipitation (cm)
pH	1.00					
EC	-0.18	1.00				
Na^+	0.37	0.43	1.00			
Cl^-	-0.36	0.95	0.27	1.00		
DTWT	0.67	0.44	0.53	0.26	1.00	
Precipitation	-0.52	-0.22	-0.19	-0.15	-0.52	1.00

Table D-16. Correlation statistics for piezometer 7.

	pH	EC (mS/cm)	Na^+ (mg/L)	Cl^- (mg/L)	DTWT (cm)	Precipitation (cm)
pH	1.00					
EC	-0.33	1.00				
Na^+	-0.22	0.89	1.00			
Cl^-	-0.36	1.00	0.88	1.00		
DTWT	0.24	-0.30	-0.11	-0.32	1.00	
Precipitation	-0.56	0.05	0.04	0.07	-0.18	1.00

Table D-17. Correlation statistics for piezometer 8.

	pH	EC (mS/cm)	Na^+ (mg/L)	Cl^- (mg/L)	DTWT (cm)	Precipitation (cm)
pH	1.00					
EC	0.63	1.00				
Na^+	0.31	0.40	1.00			
Cl^-	-0.15	0.06	-0.54	1.00		
DTWT	0.53	0.60	0.58	-0.38	1.00	
Precipitation	-0.43	-0.78	-0.24	-0.15	-0.56	1.00

Table D-18. Correlation statistics for piezometer 9.

	pH	EC (mS/cm)	Na^+ (mg/L)	Cl^- (mg/L)	DTWT (cm)	Precipitation (cm)
pH	1.00					
EC	-0.40	1.00				
Na^+	0.11	0.43	1.00			
Cl^-	-0.40	0.96	0.40	1.00		
DTWT	0.39	0.08	0.28	-0.04	1.00	
Precipitation	-0.57	0.34	-0.01	0.33	-0.60	1.00

Appendix E – Additional Levelogger Data

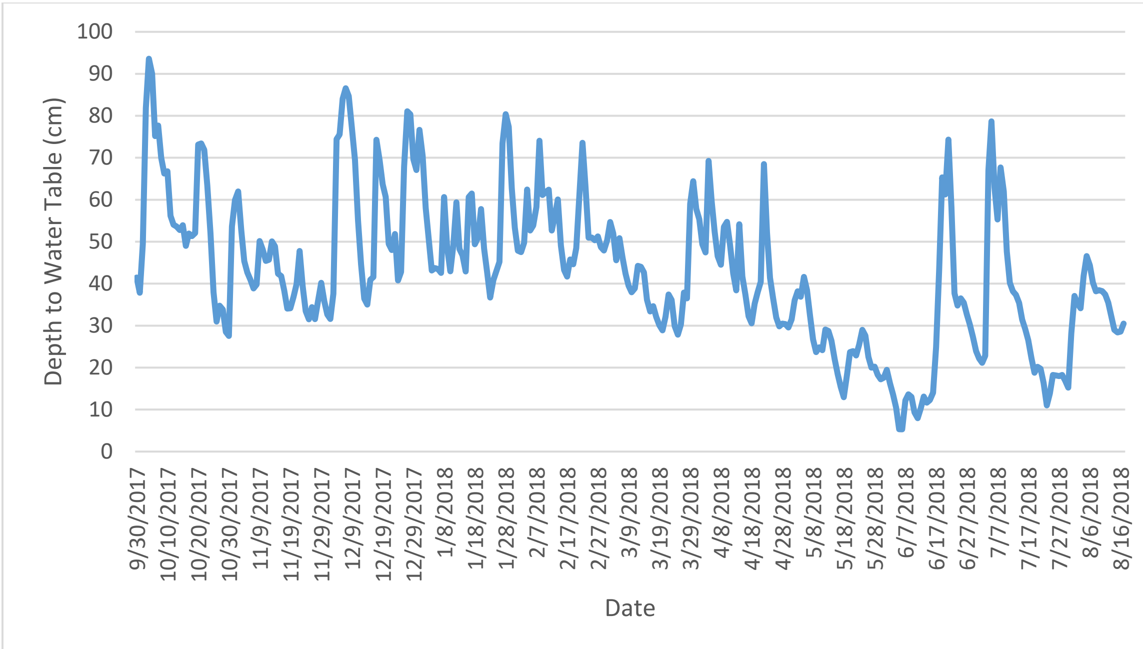


Figure E-1. Water level data for Piezometer 7, collected using Solinst Levelogger.

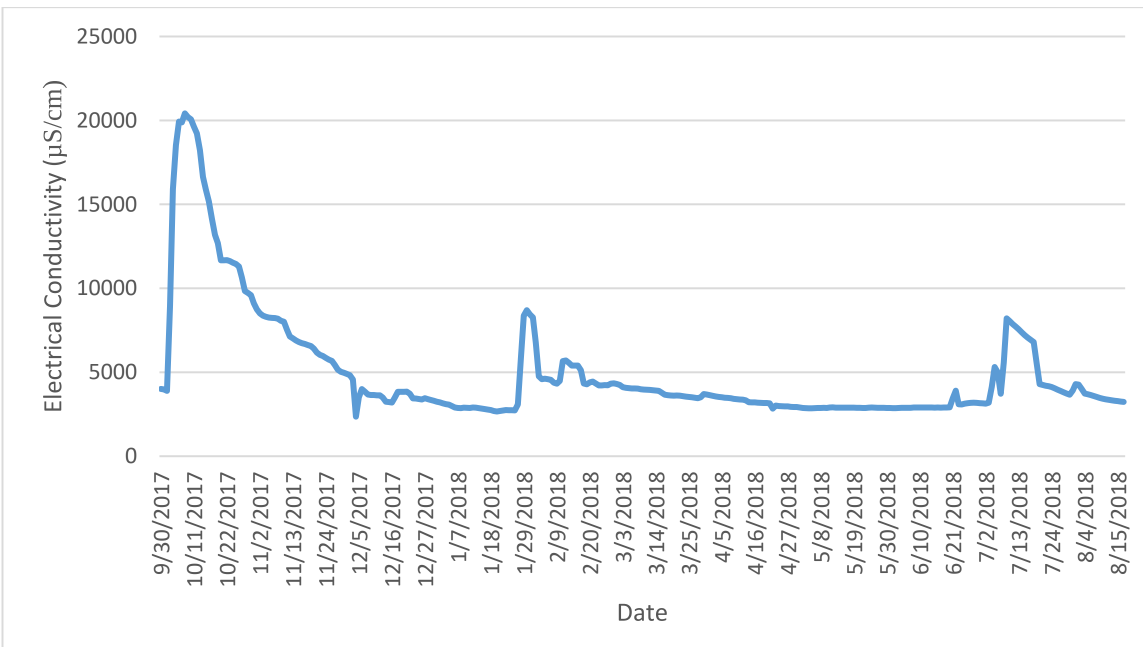


Figure E-2. Electrical conductivity data for Piezometer 7, collected using Solinst Levelogger.

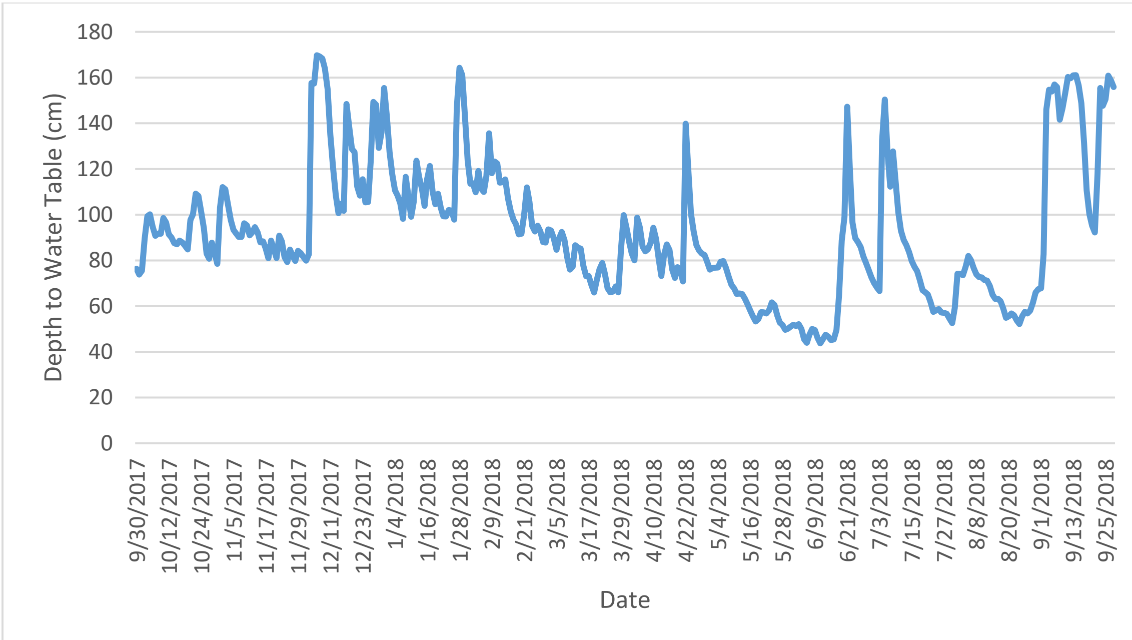


Figure E-3. Water level data for Piezometer 8, collected using Solinst Levelogger.

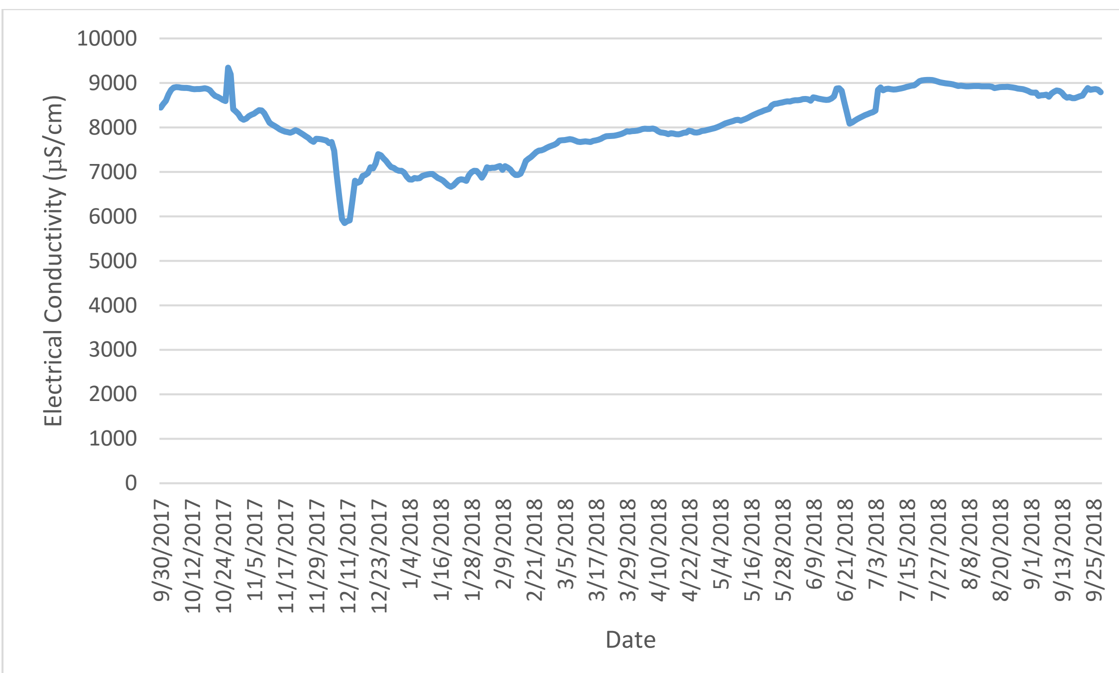


Figure E-4. Electrical conductivity data for Piezometer 8, collected using Solinst Levelogger.

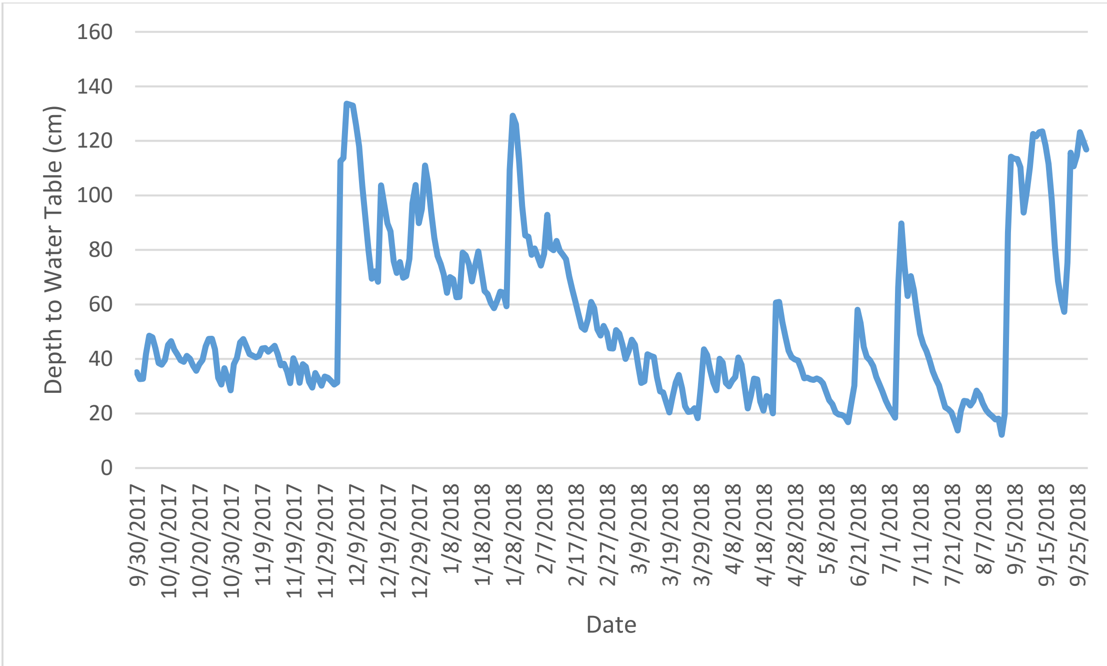


Figure E-4. Water level data for Piezometer 9, collected using Solinst Levelogger.

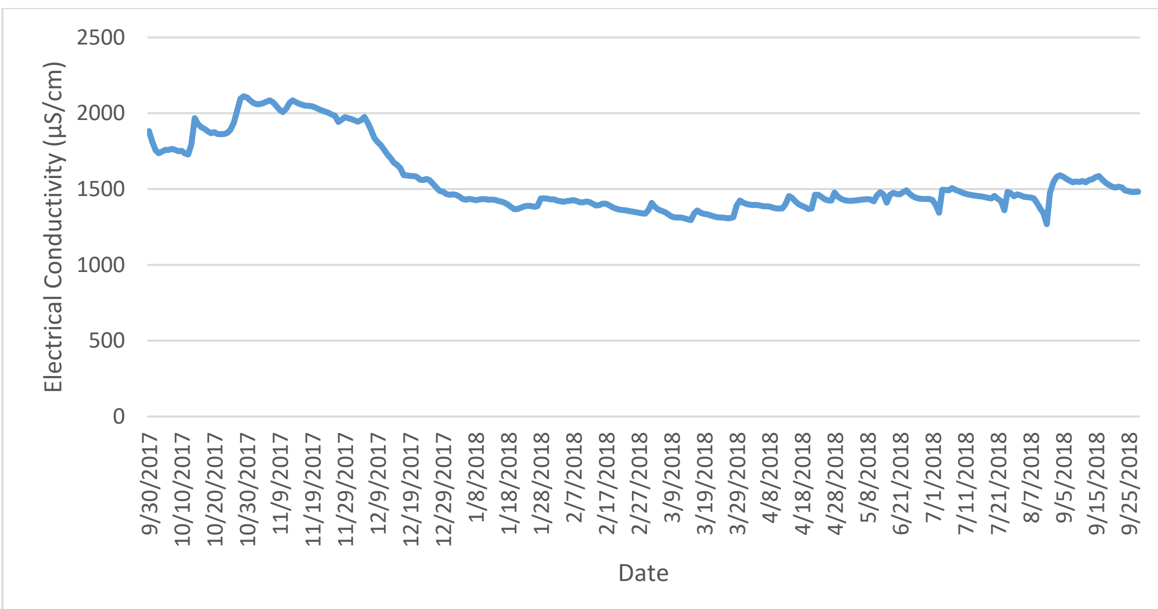


Figure E-5. Electrical conductivity data for Piezometer 9, collected using Solinst Levelogger.

Appendix F – Linear Regression Analysis Statistics

Table F-1. Summary statistic table for linear regression analysis of the relationship of groundwater Na^+ concentrations and precipitation at Piezometer 1.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.105811474
R Square	0.011196068
Adjusted R Square	-0.043737484
Standard Error	353.1658165
Observations	20

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	25420.56	25420.56	0.203811	0.657054
Residual	18	2245070	124726.1		
Total	19	2270490			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	393.1470022	107.0056	3.67408	0.001736	168.3366	617.9574	168.3366	617.9574
Precipitation (cm)	-9.474361522	20.98631	-0.45145	0.657054	-53.565	34.61623	-53.565	34.61623

Table F-2. Summary statistic table for linear regression analysis of the relationship of groundwater Na^+ concentrations and precipitation at Piezometer 2.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.172972
R Square	0.029919
Adjusted R Square	-0.01627
Standard Error	119.5999
Observations	23

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	9264.608	9264.608	0.647687	0.429959
Residual	21	300387.1	14304.15		
Total	22	309651.7			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	281.9356	32.69697	8.622683	2.43E-08	213.9386	349.9327	213.9386	349.9327
Precipitation (cm)	-5.51785	6.85626	-0.80479	0.429959	-19.7762	8.740524	-19.7762	8.740524

Table F-3. Summary statistic table for linear regression analysis of the relationship of groundwater Na^+ concentrations and precipitation at Piezometer 3.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.16063
R Square	0.025802
Adjusted R Square	-0.0315
Standard Error	90.33909
Observations	19

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3674.546	3674.546	0.450248	0.511232
Residual	17	138739.6	8161.151		
Total	18	142414.1			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	126.7008	27.34832	4.632855	0.000238	69.00089	184.4007	69.00089	184.4007
Precipitation (cm)	-3.54758	5.286962	-0.67101	0.511232	-14.7021	7.606934	-14.7021	7.606934

Table F-4. Summary statistic table for linear regression analysis of the relationship of groundwater Na^+ concentrations and precipitation at Piezometer 4.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.26701
R Square	0.071294
Adjusted R Square	0.024859
Standard Error	348.7099
Observations	22

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	186695.5	186695.5	1.535343	0.229657
Residual	20	2431972	121598.6		
Total	21	2618667			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	764.5038	98.97177	7.724463	1.99E-07	558.0523	970.9553	558.0523	970.9553
Precipitation (cm)	25.15057	20.29762	1.23909	0.229657	-17.1895	67.49067	-17.1895	67.49067

Table F-5. Summary statistic table for linear regression analysis of the relationship of groundwater Na^+ concentrations and precipitation at Piezometer 5.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.078419
R Square	0.00615
Adjusted R Square	-0.04118
Standard Error	165.3376
Observations	23

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3552.072	3552.072	0.129939	0.722096
Residual	21	574067	27336.52		
Total	22	577619.1			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	384.7745	45.20102	8.512517	3E-08	290.7738	478.7751	290.7738	478.7751
Precipitation (cm)	3.416624	9.478246	0.36047	0.722096	-16.2945	23.12772	-16.2945	23.12772

Table F-6. Summary statistic table for linear regression analysis of the relationship of groundwater Na^+ concentrations and precipitation at Piezometer 6.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.201279
R Square	0.040513
Adjusted R Square	-0.00746
Standard Error	366.0605
Observations	22

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	113160.4	113160.4	0.844479	0.36907
Residual	20	2680006	134000.3		
Total	21	2793166			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	362.9566	103.8963	3.493453	0.00229	146.2328	579.6804	146.2328	579.6804
Precipitation (cm)	-19.5807	21.30756	-0.91896	0.36907	-64.0275	24.8661	-64.0275	24.8661

Table F-7. Summary statistic table for linear regression analysis of the relationship of groundwater Na^+ concentrations and precipitation at Piezometer 7.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.058391
R Square	0.003409
Adjusted R Square	-0.04405
Standard Error	485.9899
Observations	23

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	16968.51	16968.51	0.071844	0.791286
Residual	21	4959910	236186.2		
Total	22	4976878			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	711.2144	132.8629	5.352993	2.62E-05	434.9108	987.518	434.9108	987.518
Precipitation (cm)	-7.46755	27.86016	-0.26804	0.791286	-65.4059	50.47082	-65.4059	50.47082

Table F-8. Summary statistic table for linear regression analysis of the relationship of groundwater Na^+ concentrations and precipitation at Piezometer 8.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.012066
R Square	0.000146
Adjusted R Square	-0.04747
Standard Error	432.7015
Observations	23

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	572.5224	572.5224	0.003058	0.956424
Residual	21	3931843	187230.6		
Total	22	3932415			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	966.6659	118.2946	8.17168	5.85E-08	720.6587	1212.673	720.6587	1212.673
Precipitation (cm)	-1.37168	24.80532	-0.0553	0.956424	-52.9572	50.2138	-52.9572	50.2138

Table F-9. Summary statistic table for linear regression analysis of the relationship of groundwater Na^+ concentrations and precipitation at Piezometer 9.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.156938
R Square	0.02463
Adjusted R Square	-0.02182
Standard Error	189.2992
Observations	23

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	19002.3	19002.3	0.530284	0.47453
Residual	21	752517.8	35834.18		
Total	22	771520.1			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	348.8446	51.75179	6.740726	1.14E-06	241.2209	456.4683	241.2209	456.4683
Precipitation (cm)	-7.90241	10.85188	-0.72821	0.47453	-30.4701	14.66532	-30.4701	14.66532

VITA

Daniel Morgan graduated from Nacogdoches High School in Nacogdoches, Texas in June 2012. He graduated with the degree of Bachelor of Science in Biology from Henderson State University in May 2016, where he was a 4-year New South Intercollegiate Swim Conference Scholar-Athlete for the Red Wave Swim Team. In August 2016 he entered the Graduate School of Stephen F. Austin State University to pursue a Master of Science degree in Environmental Science under the direction of Dr. Kenneth Farrish. In April 2019, he started work at Hydrex Environmental while finishing his thesis research. Daniel received his Master of Science Degree in August 2020 and continues to work at Hydrex Environmental as an Environmental Scientist.

Permanent Address: 1435 Shelton Drive,
Nacogdoches, Texas 75965

This thesis follows the style of Phytochemistry Journal.

This thesis was typed by Daniel Morgan.