THE IMPACT OF PROJECTED CLIMATE CHANGE
ON BIOSWALES IN NORTH TEXAS

By

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ABSTRACT

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This research addresses how bioswales are affected by the projections for climate change in the North Texas region. Bioswales are a type of green infrastructure that conveys stormwater before directing it to a storm sewer system or other flood control structure (McLaughlin, 2016). They minimize the volume of stormwater runoff from the ground level and allow for the infiltration and remediation of pollutants while reducing the amount of water that is directed towards storm sewers. The research seeks to provide an understanding of how the efficacy of bioswales is related to the projected climatic conditions in North Texas and their resiliency related to these shifts.

The affects of climate change are manifesting themselves in diverse ways across the globe in the form of droughts, rainfall, and more intense storm events (Adger, et al., 2011). This research studies the resiliency of bioswales and their ability to absorb the disturbance of projected climatic conditions while retaining their functionality within the built environment of North Texas. The use of bioswales by landscape architects is slowly becoming a component of normative practice. However, it is unclear what degree of knowledge the average landscape architect and related professionals in North Texas currently possess on the topic. In part, this study seeks to determine whether the use of bioswales is a common practice or primarily relegated to common knowledge that is not implemented. A greater understanding of the relationship between climate change and bioswales will facilitate implementation by better preparing landscape architects and related professionals to design for the impending effects climate change has on bioswales.

This research makes use of qualitative methods of data collection and ethnographic interviews with professionals to gain an understanding of the topic. Data for the literature review was collected form scholarly journals, professional papers, and academic texts, as well as government web sources. Qualitative data collection assisted the researcher in identifying themes within the interviews that linked to comprehensive findings from the data collection. The Diffusion of Innovation theory was instrumental in this research to assist the researcher in understanding how information is spread throughout the field of landscape architecture and related professions.

The research focuses on understanding the Diffusion of Innovation, or spread of ideas, related to bioswales across the fields of landscape architecture and related professions in North Texas. The data collected indicates that the current technologies and methods of bioswale planning and construction may not be equipped to withstand the shifting climate in North Texas. More information needs to be available in the fields of stormwater management and green infrastructure to help educate professionals and the public on the benefits of these systems throughout the North Texas region and to improve their efficacy.

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CHAPTER 1

INTRODUCTION

1.1 Research Objectives

This research is an exploration of the potential impact of projected climate change on bioswales in North Texas. The research provides an understanding of how a bioswale's capacity to alleviate urban surface water can be affected by climate shifts within a region (Hogan, 2011). North Texas is one of many areas across the country that are becoming greater contributors to weather and climate change through their rapid increases in population, land cover, water and air pollution, and development (NOAA, 2007).

A major part of the hydrologic planning component of the landscape architecture profession is the ability to manage water in the area where it falls (ASLA, 2003). Ground water and surface water, which account for only 1% of the world's water, are the most important water resources for human beings (USGS, 2016). Even though the concept of bioswales has been utilized since the mid 1970's, landscape architects did not utilize them in their current configuration within an urban environment until the 1990's (Hogan, 2011).

Understanding the Diffusion of Innovation, the rate at which ideas spread, in regard to bioswales is essential to how the practice of landscape architecture adapts to the changing urban climate. When the projected changes of climate and increased demand for water in North Texas are taken into consideration, these looming realities can cause profound impacts on ground and surface water supplies. The competition between environmental and human water needs ought to be modified based on climate variability and change.

The construction and biologic makeup of bioswales are limited or determined by the climactic conditions in a region and whether or not the bioswales have the potential to mitigate issues caused by projected climate change. The ability of a bioswale to withstand the projected shift in temperature and precipitation in North Texas is directly correlated to its structural, vegetative, and construction/materials components. "If established with appropriate native vegetation, the bioswale may become a riparian corridor or wetland restoration element of the natural landscape" (Hogan, 2011, p. 2). Although bioswales can thrive if established with appropriate plants and materials, success and failure of bioswales is primarily attributed to a lack of accurate information or professional input into the design, materials, construction, and maintenance of bioswales (Jurries, 2003).

Analyzing how landscape architects and related professionals gather information on bioswales and utilize it for design decisions within the changing landscape of North Texas is critical to the growth of environmentally sensitive development practices. The environmental concerns are the effect of the ways in which humans degrade the environment (Floyd & Matthew, 2013). While development is generally considered a sign of growth and an improvement of human living conditions, industrialization and over-development leads to increased pollution, runoff, and deforestation. The correlation between development practices and the impacts they have on the environment calls for a rethinking of sustainable practices. This research is intended to inform and facilitate that process.

1.2 Research Questions

The questions under review include:

1. Do landscape architects and related professionals in North Texas consider water management primarily on an on-site basis or do they also prioritize the greater watershed impacts?
2. How do landscape architects and related professionals in North Texas gain knowledge about bioswales and incorporate it into their practice?
3. How does the avenue from which landscape architects and related professionals gain information affect the Diffusion of Innovation?
4. How are landscape architects and related professionals responding to projected climate changes in North Texas, and how do they expect it to affect the resiliency of bioswales in the region?

1.3 Definition of Terms

The following terms are utilized within this document and are derived from research fitting the context of this research:

Adaptation: A transformation, taking place over time, in order to build resilience (Melillo, et al., 2014).

Best Management Practices (BMP): Environmentally responsive applications for successful, site-specific management, created to provide real world, practical solutions to waste and stormwater within built landscapes (Cahill, 2008).

Bioretention: Stormwater collection and retention designed to remove contaminants and sedimentation from runoff through biotic media or infiltration/filtration practices (Li, et al., 2010).

Bioswale: A vegetated source control channel constructed to capture storm water from impermeable surfaces allowing greater infiltration, reduced runoff, water treatment, and an alternative to conventional storm sewers (Hogan, 2011) (McLaughlin, 2012) (United States Department of Agriculture, 2007) (University of Florida, 2008).

Clean Water Act of 1972 (CWA): Legislation passed by Congress to protect the waters of the United States (Wright, Tomlinson, Schueler, Cappiella, Kitchell, & Hirschman, 2006).

Climate Change: Any shift in climate data, taking place over an extended period of time, that can be linked to human emissions outputs (Freas, et al., 2008) (Pielke & Sarewitz, 2005).

Climate Change Mitigation: The reduction of major contributors of greenhouse gas emissions ("Planning for Climate Change Mitigation and Adaptation in North Central Texas," 2009).

Conservation: Anything that reduces the utilization, loss, or waste of water in order to better the effectiveness or reuse of water and to establish a water source accessible to future or alternative uses (Freese and Nichols, 2014).

Develop: To alter an area of land in order to serve a specific program (Stevenson & Lindberg, 2010).

Diffusion of Innovation: A theory established in 1962 interpreting the distribution of new ideas among cultures and evaluating technology's affect on the rate of disbursement (Rogers, 2003).

Domain Analysis: The establishment of main ideas or "domains", from interview responses in qualitative data, to create categories and sub-categories to construct a concept of inter-relationships between data (Atkinson & Abu Haj, 1996).

Ecological Detention: Man-made structures that capture and detain water runoff from a site to manage stormwater flow and mitigate erosion, sedimentation, and reduced water quality (Jurries, 2003).

Green Infrastructure: Types of low-impact structures designed to decrease the velocity and quantity of stormwater being directed to storm sewers (Tornes, 2012).

Habitat: The home or environment, providing cover, food, and water for an animal, plant, or other organism that enables the organism to maintain itself in a given area (Stevenson & Lindberg, 2010).

Low Impact Development (LID): An approach to development that aims to model hydrologic activity on a site according to predevelopment or natural site features (Kalt, 2015).

National Pollutant Discharge Elimination System (NPDES): A part of the Clean Water Act that inhibits or removes pollutants from the waters of the United States (Schueller & Holland, 2000).

North Central Texas Council of Governments (NCTCOG): An assembled legislative body of civic authorities on behalf of municipalities from a sixteen county area in North Central Texas (Wright, 2006).

Ordinance: A public decision or directive (Stevenson & Lindberg, 2010).

Potable: Deemed satisfactory for drinking standards (Stevenson & Lindberg, 2010).

Resilience: The stability of a system and its capacity to assimilate to change, recover from, and persist through a failure in or the disruption of relationships within a system (Holling, 1973).

Runoff: Storm water that flows from impermeable and permeable surfaces such as parking lots, buildings, roadways, etc. (Hogan, 2011).

Source Controls: A framework in which stormwater is held at the source of a pipe rather than at the outlet (McLaughlin, 2012).

Storm Water: An irregular influx of water brought on by any rain event or a snowstorm (Cahill, 2008).

Texas Commission on Environmental Quality (TCEQ): An administrative group that oversees the actions of governments and organizations within the state of Texas to create guidelines and requirements for the establishment of water conservation plans (Freese and Nichols, 2014).

Urbanization: A population increase leading to the spread of a city center into non-urban or rural territory (Stevenson & Lindberg, 2010).

Visual Aesthetic: A feature attributed to a picturesque or scenic view of a landscape (Stevenson & Lindberg, 2010).

Wastewater: Water that has had prior use for cleaning, manufacturing, flushing, etc. (Stevenson & Lindberg, 2010).

Zoning: The designation of land-uses for a site, such as the number and uses for buildings (Stevenson & Lindberg, 2010).

1.4 Research Methods

This research utilizes qualitative data analysis to study the resiliency of bioswales to the projected climate change in North Texas. Interviews were conducted with landscape architects, planners, water resource professionals, climatologists, and related professionals throughout the region. The interview participants were selected using professional databases, peer recommendations, and personal association with the researcher. Interviews were recorded via a smart phone device and transcribed by the researcher. The interviews were then reviewed using the Domain Analysis research method to establish themes and key words identifiable within the responses (Atkinson & Abu El Haj, 1996).

1.5 Delimitations & Limitations

The extent of this research is delimited to climate change and bioswale structures in North Texas. Research from both within the region and elsewhere was called upon to assess how landscape architects and other related professionals address the use and construction of bioswales in light of the challenges presented by climate change projections. The research was also delimited by the exemption of biologists, chemists, and other scientific professionals.

The timeline of the research as well as the lack of physical testing of bioswale structures within North Texas were limitations of this study. Opinions and experiences presented in this research may differ from those of interview participants. These opinions may influence the outcomes presented by the results of this research.

1.6 Conclusion

The use of bioswales has the potential to be an important component of alternative water management practices that are ecologically based while mitigating the volume of runoff within the urban stormwater system. This chapter summarized the purpose of the research and provided background information for the topics that were addressed. It also gave a brief overview of key terms that are significant to the research. Chapter two explores the literature relating to bioswales, resilience, and the current and projected climate conditions in North Texas. The research introduces how these issues relate to landscape architects and related professionals and how these fields can contribute to the design and use of bioswales within the region. Chapter three provides the methodology used in this research. The fourth chapter contains the responses of interview participants and the analysis of themes observed in these discussions. The final chapter, five, summarizes conclusions derived from the research and provides observations for future research on the topic of bioswale resiliency to the projected climate changes in North Texas.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

This literature review explores the use of bioswales and their anticipated resilience to projected climate changes in North Texas. For the purpose of this research, as defined by the North Central Texas Council of Governments, the North Texas region is made up of the sixteen counties of Collin, Dallas, Denton, Ellis, Erath, Hood, Hunt, Johnson, Kaufman, Navarro, Palo Pinto, Parker, Rockwall, Somervell, Tarrant, and Wise (NCTCOG, 2016). Figure 1 is a graphic representation of this region.

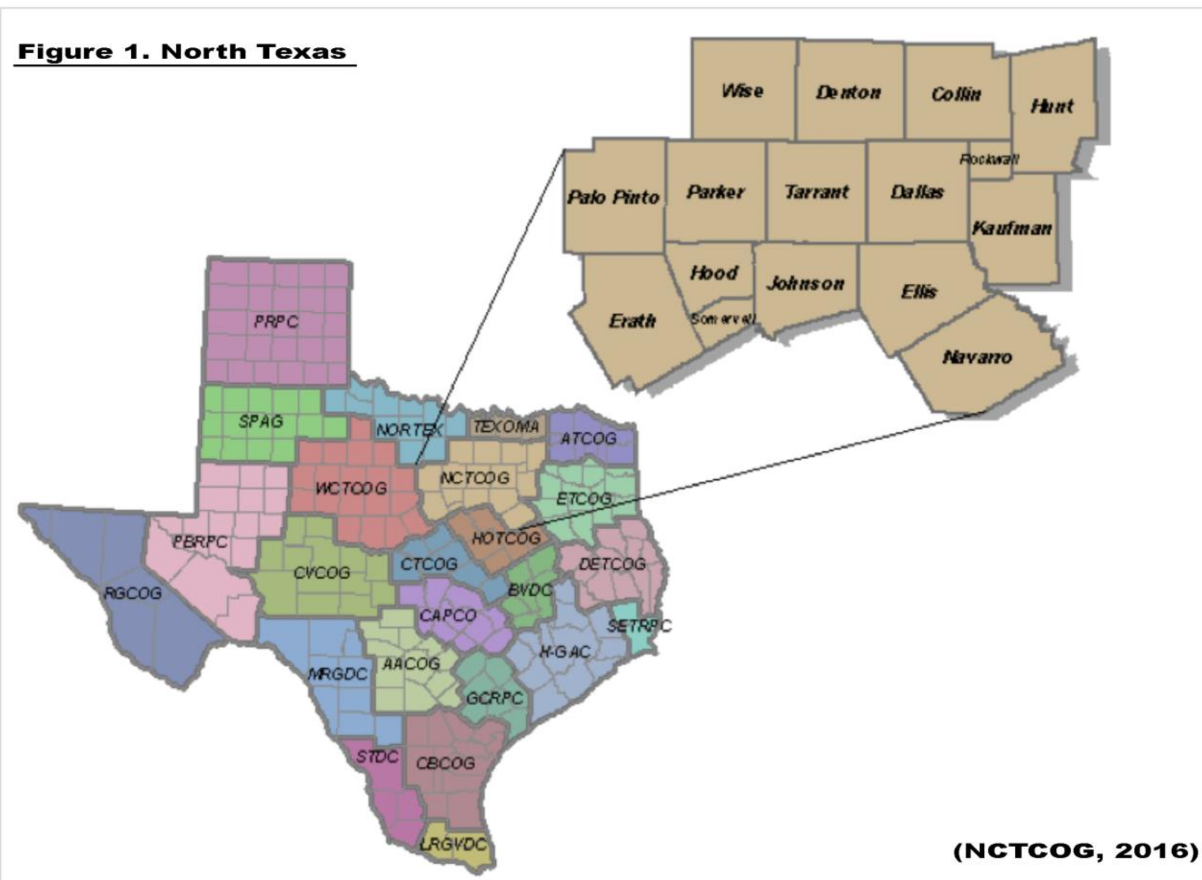


Figure 1. North Texas

(NCTCOG, 2016)

The review assesses current and predicted climatic shifts of the region and explores the potential for bioswales to compensate for some of the effects of regional climate change. The review then focuses on the methods used by landscape architects and related professionals to collect data on bioswales. The data demonstrates how these features can perform to mitigate certain effects of climate change. The amount of knowledge these professionals possess regarding how climate affects the use of bioswales can be determined by their educational and professional backgrounds and work with green infrastructure methods. The professionals' knowledge about bioswales and green infrastructure devices was determined by their previous work with these systems in and around North Texas.

2.1 Changing Climatic Conditions in the North Texas Region

North Texas is classified as a humid subtropical climatic region made up of dry winters and a minimum of eight months with average temperatures greater than 68°F (Winguth, et al., 2015). The region is facing changes in its climatic state. Across the country "temperatures have warmed 1.3-1.9 degrees Fahrenheit since 1895, with most of the increase since 1970" (Samenow, 2014, p. 3). The North Texas region is facing changes in its climatic states with predicted increases in surface air temperatures reaching as high as +8.1°F. "Historical trends suggest that droughts associated with prolonged heat waves have been more frequent in the last two decades" (Winguth, et al., 2015, p. 4). Figure 2 demonstrates the monthly mean temperatures and precipitation rates for Dallas-Fort Worth from 1980 to 2010 and

Figure 3 represents the annual consecutive days over 100°F from 1978-2011 recorded at DFW airport.

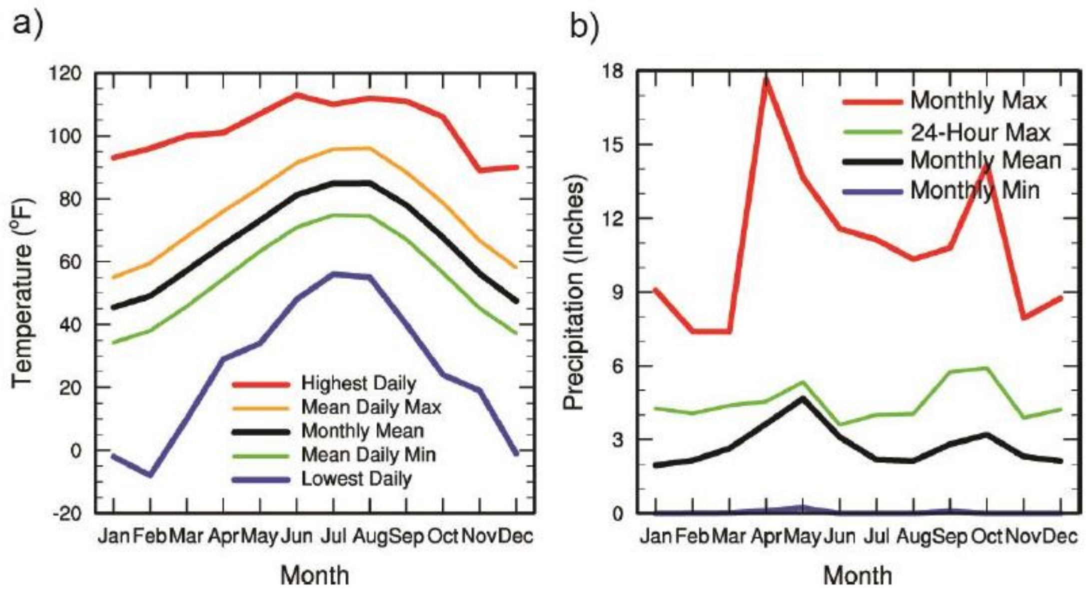


Figure 2. Monthly mean temperature (a) and precipitation (b) for Dallas-Fort Worth averaged from 1980 to 2010 (Source: National Weather Service, Fort Worth, 2012). Annual mean temperature is 65.4 °F (18.8°C) and annual precipitation is 33.1 in (839.91 mm) year-1 averaged over the period 1900 to 2010.

(Winguth, et al., 2015)

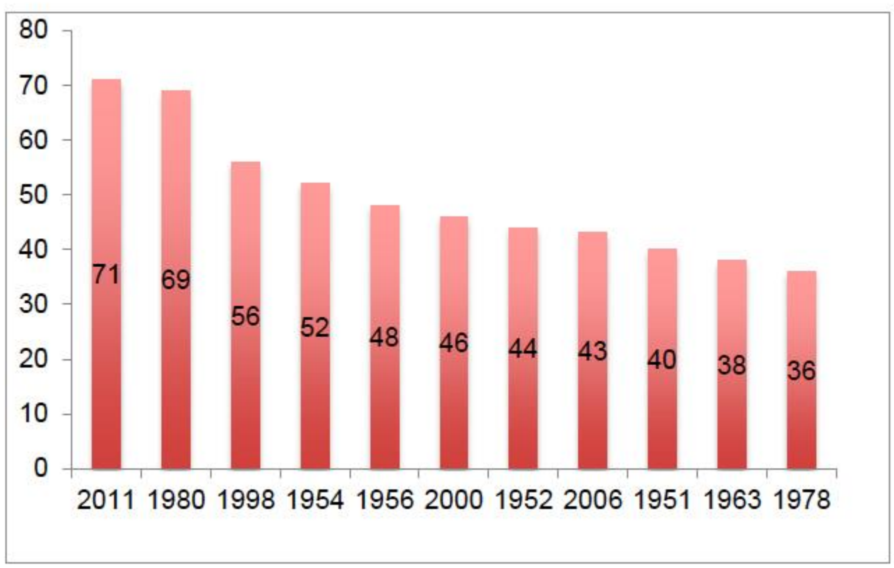


Figure 3. Dallas-Fort Worth annual consecutive 100° F days (NWS Dallas-Fort Worth).

(Winguth, et al., 2015)

Since the mid 1980's North Texas has been experiencing climate change in the form of hazardous weather, drought, and flooding. Spring thunderstorms contribute the greatest percentage of yearly rainfall, with large amounts of precipitation occurring over brief periods (Winguth, et al., 2015). Figures 4 and 5 demonstrate the growing trend in temperature anomalies. "Climate scientists have now established that climate change is moving climate conditions outside of what we have experienced in the recent past" (Brawley-Chesworth, et al., 2014, p. 4). Figure 4 graphically demonstrates the temperature and precipitation anomalies in the Dallas/Fort Worth area between 1900 and 2010. As seen in the Annual Temperature Anomalies graph, occurrences of high temperatures have increased since the year 2000. Figure 5 demonstrates the shift seasonal temperature anomalies based on the bell curve distribution (Hansen, et al., 2012). The normal distribution has moved to increased positive temporal shifts in the United States and a 1.5% change across the globe. The subset of extreme heat outliers has

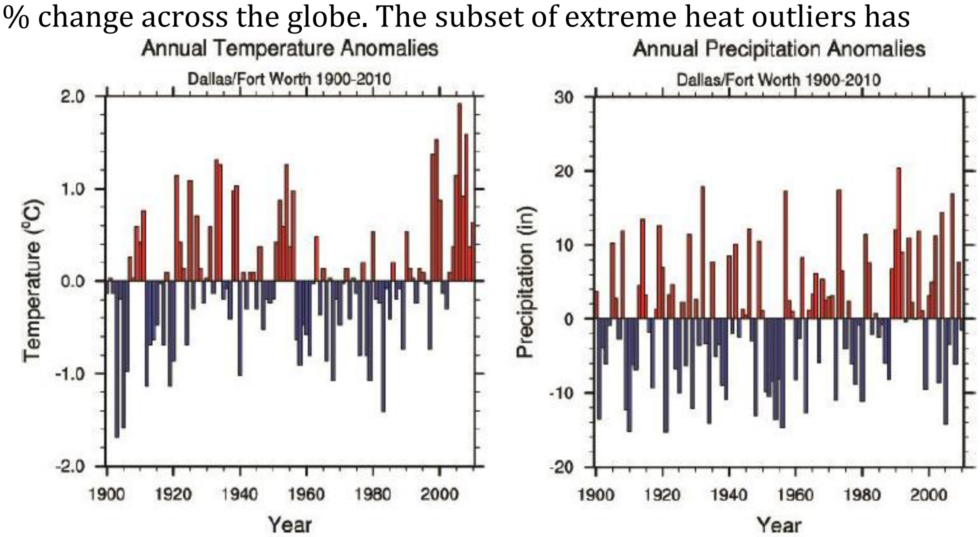


Figure 4. Annual average surface temperature (a) and rainfall (b) anomalies as compared to the average between 1900 and 2010, in °C from NWS COOP station 412242 (Dallas-Fort Worth International Airport).

(Winguth, et al., 2015)

contributed to the most change on the bell curve.

Severe storm events such as tornadoes, hurricanes, and winter storms are also becoming more frequent (Melillo, et al., 2014). These weather hazards are becoming increasingly common rather than the occasional anomaly.

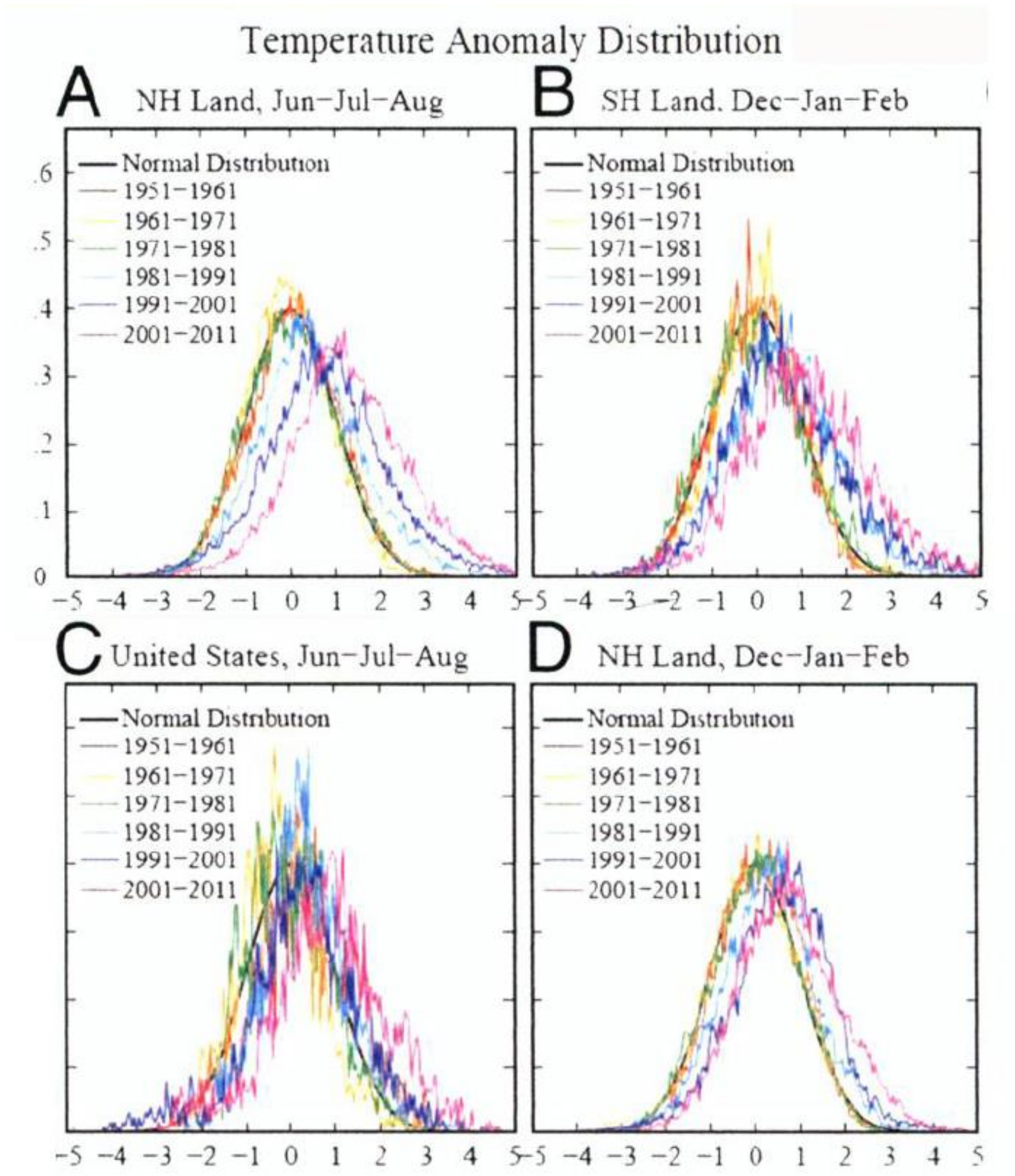


Figure 5.

Frequency of occurrence of local temperature anomalies (relative to 1951-1980 mean) divided by local standard deviation obtained by counting gridboxes with anomalies in each 0.05 interval of the standard deviation (x axis). Area under each curve is unity.

(Hansen, et al., 2012)

Annual precipitation within the region has been increasing over the past fifty years. Figure 6 exhibits the historical precipitation data for the Great Plains region, including North Texas, and how annual precipitation is projected to change over time (Melillo, et al., 2014). Graphics B1 and A2 indicate the areas where precipitation is projected to change based on higher emissions levels and lower emissions levels within the region. While the amount of precipitation overall has not been forecasted to increase substantially, the areas where the precipitation falls are shifting. Historically the areas of

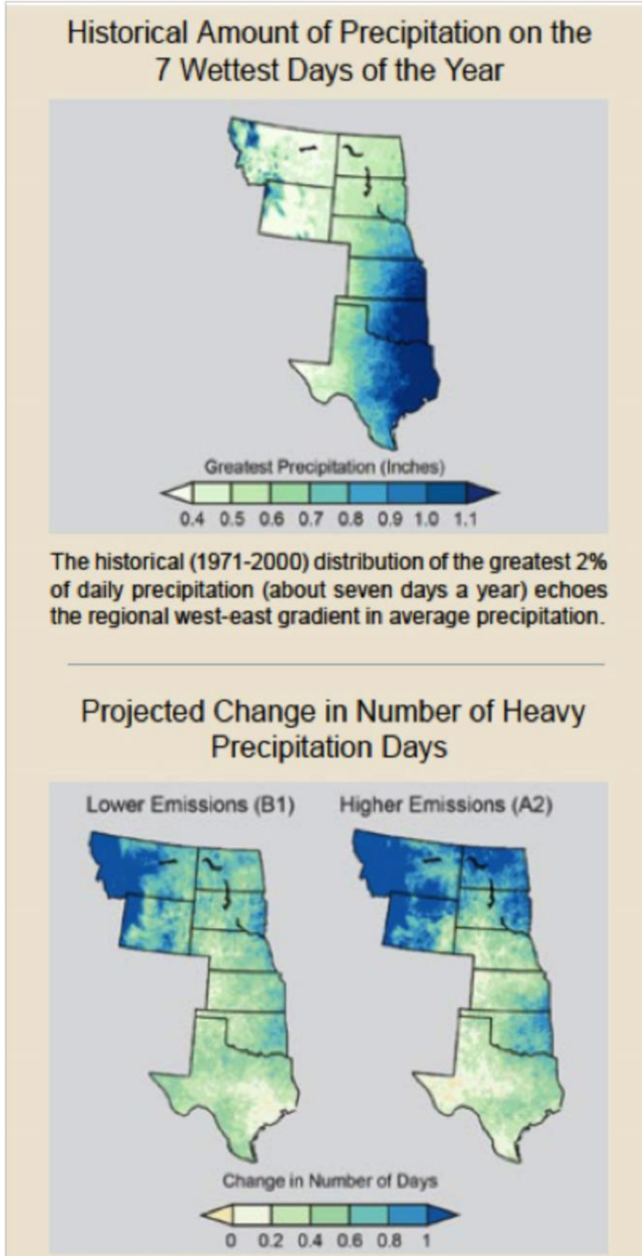


Figure 6. The number of days with the heaviest precipitation is not projected to change dramatically. By mid-century (2041-2070), the projected change in days exceeding those precipitation amounts remains greatest in the northern area for both the lower emissions scenario (B1) and for the higher emissions scenario (A2). (Figure source: NOAA NCDC / CICS-NC).

(Melillo, et al., 2014)

greater precipitation levels were found in the southeastern areas of the region. Inversely, Figure 7 demonstrates the projected change in number of consecutive dry days shifting significantly to a broader range across the state (Melillo, et al., 2014). Consecutive dry days tended to be more prevalent in the southwestern part of the region but have been projected to spread eastward across the Great Plains as rates of CO2 levels climb. This shift is apparent in scenarios with both low and high emission levels

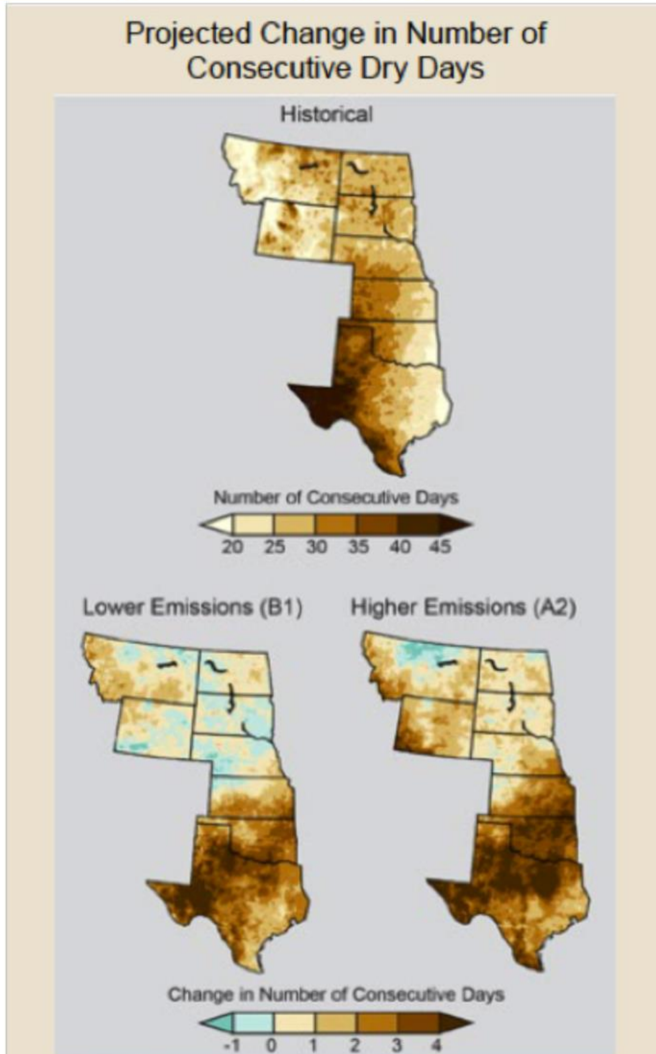


Figure 7. Current regional trends of a drier south and a wetter north are projected to become more pronounced by mid-century (2041-2070 as compared to 1971-2000 averages). Maps show the maximum annual number of consecutive days in which limited (less than 0.01 inches) precipitation was recorded on average from 1971 to 2000 (top), projected changes in the number of consecutive dry days assuming substantial reductions in emissions (B1), and projected changes if emissions continue to rise (A2). The southeastern Great Plains, which is the wettest portion of the region, is projected to experience large increases in the number of consecutive dry days. (Figure source: NOAA NCDC / CICS-NC).

(Melillo, et al., 2014)

The trend towards longer dry periods and more intense climatic events is visible across the region. The study in figure seven suggests that the methods currently in effect to handle climate risks addresses only short term solutions and do not consider complex systems that seek to increase resiliency (Adger, et al., 2011). Figure 6 also illustrates how CO2 emissions levels are directly linked to the number of consecutive dry days. When dry weather increases, temperature swings and emissions also increase. The urban heat island effect contributes to CO2 emissions levels through the density of paved surfaces in the urban environment and the amount of vehicular pollution, as well as heating and air conditioning electrical usage (Eubanks, et al., 2014). Texas has the highest levels of carbon dioxide emissions in the United States, according to a survey conducted by the Pew Center on Global Climate Change (Powledge, 2012).

Human activity is generally accepted as the greatest contributor in recent history to changes in the climate. Energy use, urbanization, burning of fossil fuels, deforestation, and human agriculture practices and production are all contributors to environmental consequences across the globe. In North Texas, the largest contributor to climate change is the CO2 emissions produced by large population growth and development. Across the region, this contributes to the urban heat island effect. Development activities increase the CO2 emission levels in urbanized areas, thus resulting in these areas experiencing greater disposition toward projected climate change scenarios (NOAA, 2013).

North Texas' rapid population growth and increased water consumption are emerging as pivotal concerns within the region (Meillo, et al., 2014). The growing urbanization of the area is geared toward vehicular-reliant expansion. The fossil fuel economy that drives this growth is a direct contributor to increased carbon emissions, which have been demonstrated to impact climatic change (Howard & Hurst, 2009). The resilience of the environmental resources to the expanding climate impacts is a growing concern in the region.

Intense precipitation events and the length of the frost-free season are both increasing in North Texas. Increased temperatures during winter months create the potential for greater rain events. The displacement of wildlife communities, increased invasive species of flora and fauna, lower agricultural yields, rising sea levels, reduced soil moisture, and negative effects on human health are all accompanying impacts of climate change. The North Texas region is just beginning to prepare for the projected climate change, by implementing green infrastructure practices and monitoring industrial output of greenhouse gasses, but is not yet adequately equipped to manage the resulting impacts of climate change (Samenow, 2014).

2.1.1 Existing Challenges Affecting Bioswales in North Texas

Rainfall in North Texas averages approximately 37 inches each per year, accompanied by long stretches lacking rain altogether during summer and winter months (Schueler, 2000). The urban heat island effect can intensify vegetation loss due to decreased functioning of natural cooling cycles (Eubanks, et al., 2014). When air and soil temperatures are not able to cool at night, plants are not able to recover from the stresses caused by high heat during daylight hours. This increases the possibility and frequency of plant loss during summer months in urban areas. Due to the climatic conditions in the region, supplemental water from other states and regions is occasionally necessary to maintain the hydrologic needs of North Texas. This is especially prevalent in urbanized areas due to manicured lawn areas needing irrigation and mass areas of man-made/paved surfaces causing urban heat island effects. This phenomenon is illustrated graphically in Figure 8. It demonstrates the clustered area of where urban heat island is located in the North Texas region.

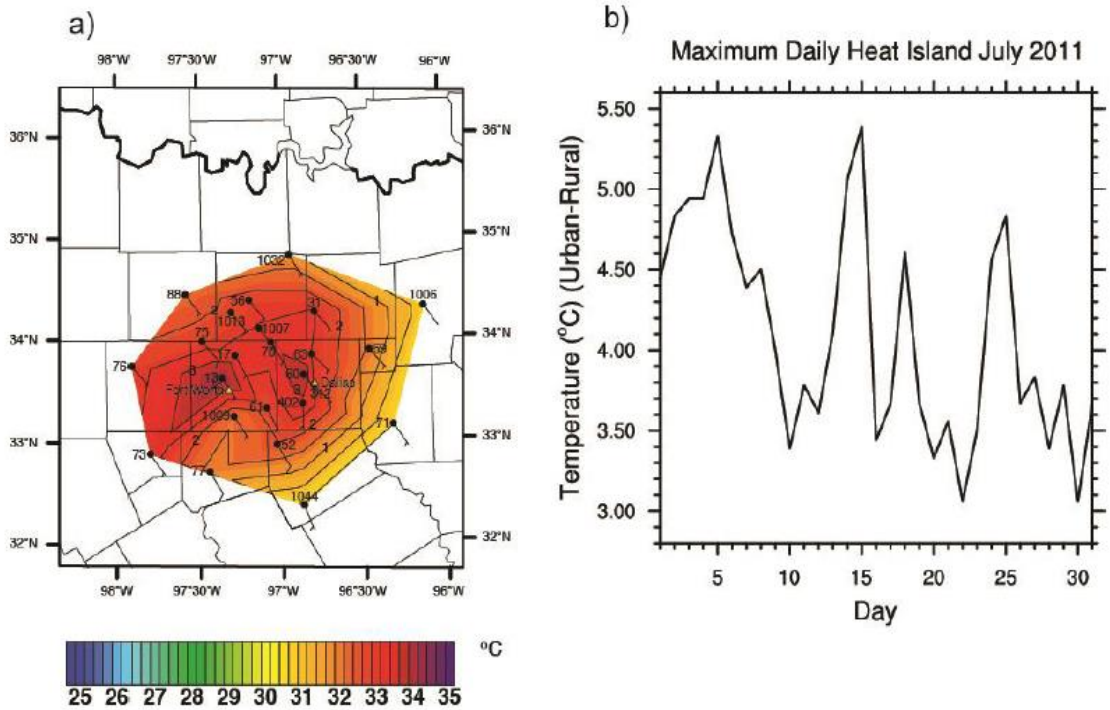


Figure 8.

Maps of the average air temperatures (°C) at screen level at (a) 21:00, reported by TCEQ stations. Wind barbs are in knots. Each short barb represents 5 knots and each long barb 10 knots. Contour lines show the magnitude of the urban heat island relative to the Kaufman station (CAMS 71). Contour line interval is 0.5°C, b) Daily maximum urban heat island in July 2011.

(Winguth, et a;., 2015)

Plants and animals also face challenges due to temperatures rising at increasing rates (Melillo, et al., 2014). Plants that function to mitigate air and water contaminants, can be affected by temperature changes and lose their ability to function properly. Depending on temperatures and the degree of drought conditions, vegetation health declines and deaths can occur. Figure 9 provides a schematic of the change in flora and fauna due to climatic warming. Alteration of these natural systems impacts human, wildlife, aquatic, and environmental patterns. The ability of bioswales to mimic wetlands and other natural systems allows them to serve as a habitat restoration device.

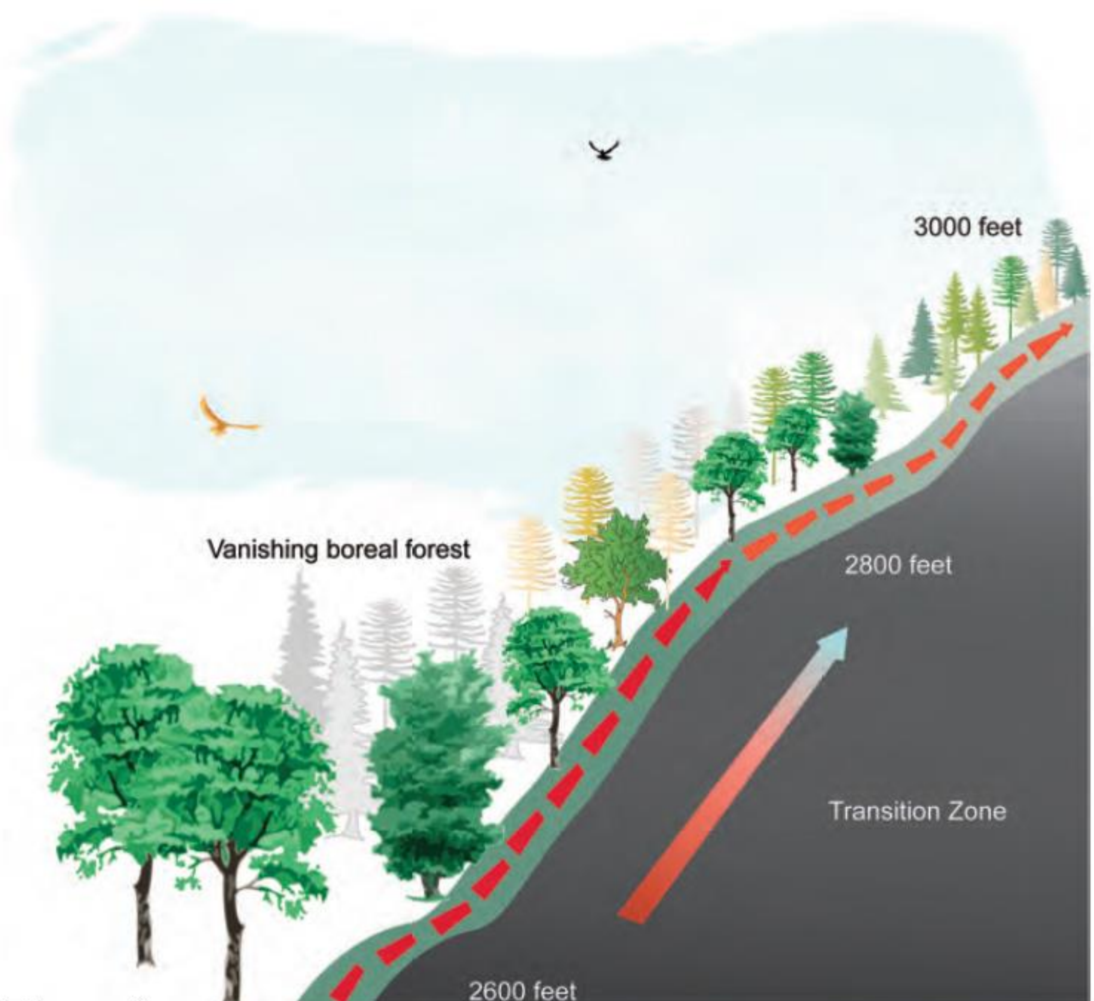


Figure 9.

As the climate warms, hardwood trees out-compete evergreen trees that are adapted to colder conditions. Source: US Global Change Research Program (www.globalchange.gov).

The processes by which bioswales facilitate stormwater management, have the ability to alleviate some of the gaps in water quality and hydrologic changes during storm events in North Texas. One such process is filtration, or the removal of pollutants from stormwater runoff. Bioswales make use of the ability of plants to filter water through bioremediation. The longer the water is retained in the channel, the greater the pollutant removal effects of the plants (Jurries, 2003). These contaminants include phosphorus, nitrogen, oils and grease, as well as suspended solids that can lead to increased erosion (Tornes, 2012). Figure 10 shows the obtainable percentages of pollutant removal in urban bioswales. Incorporating bioswales into new and existing development projects in an urban setting can contribute to increasing the overall health and safety of residents of North Texas.

Obtainable Efficiencies:

Obtainable reductions of pollutants in bioswales are:

Total Suspended Solids –	83 to 92%
Turbidity (with 9 minutes of residence) –	65%
Lead –	67%
Copper –	46%
Total Phosphorus –	29 to 80%
Aluminum –	63%
Total Zinc -	63%
Dissolved Zinc –	30%
Oil/Grease –	75%
Nitrate-N –	39 to 89%

Figure 10. **(Jurries, 2003)**

2.1.2 Projected Climate Change

Not only is the temperature within the region projected to change, but longer drought periods and stronger rain events are also anticipated in the region. The projected shift in the climate of North Texas will include temperature changes and a greater variability in storm events, i.e. reduced precipitation during winter months and greater levels in the summer (Jeong, et al., 2014). The change in amount of precipitation has an equal impact on the natural systems of the region as the change in timing of the precipitation. This is indicated by the heavy rain and flood events occurring in 2015. Throughout Texas, the number of days over 100º F and nights over 80º F are expected to nearly double by the end of the 21st century (Melillo, et al., 2014). Figures 11 and 12 demonstrate the changes of these climatic conditions throughout the region. These results are influenced by the increases in greenhouse gas emissions (Samenow, 2014). The growth in summer temperature irregularities has increased by approximately 10% in recent years (Hansen, et al., 2012). The 2011 drought throughout Texas, Oklahoma, and much of Mexico is an example of how the temperature increase can impact affected areas.

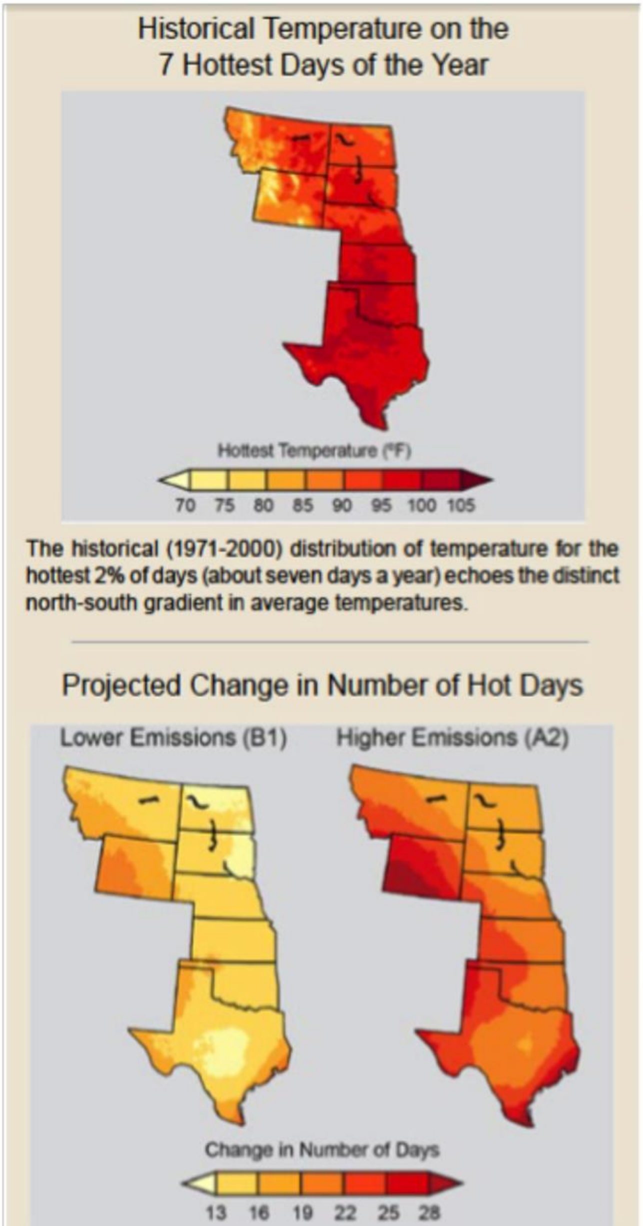


Figure 11. The number of days with the hottest temperatures is projected to increase dramatically. By mid-century (2041-2070), the projected change in the number of days exceeding those hottest temperatures is greatest in the western areas and Gulf Coast for both the lower emissions scenario (B1) and for the higher emissions scenario (A2). (Figure source: NOAA NCDC / CICS-NC).

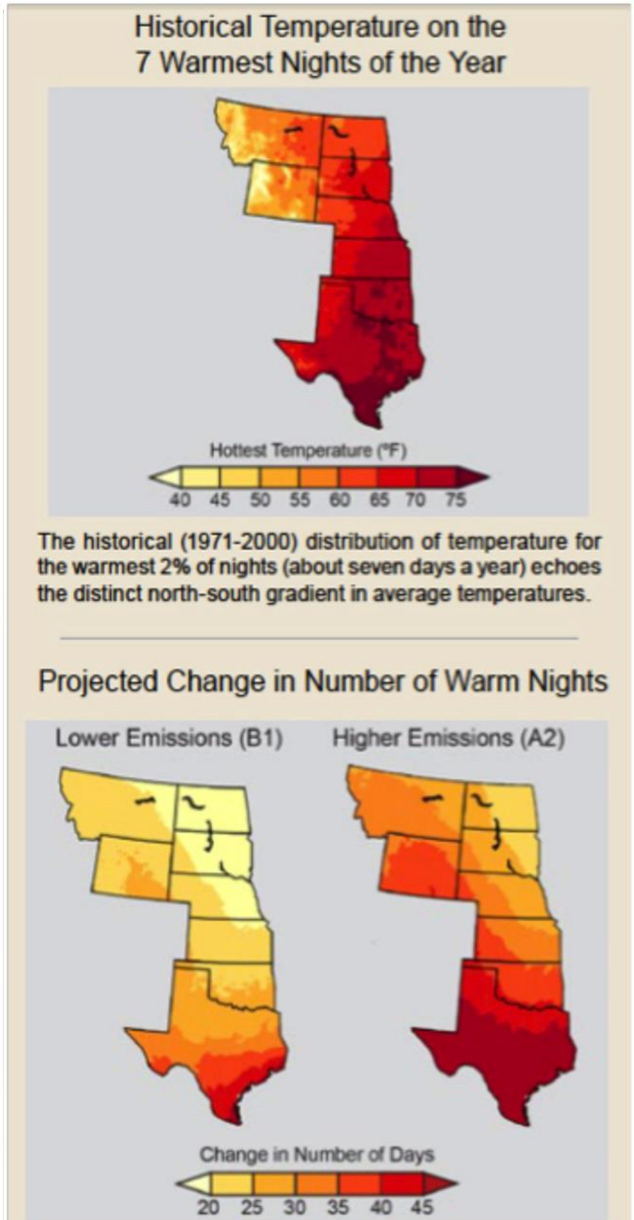


Figure 12. The number of nights with the warmest temperatures is projected to increase dramatically. By mid-century (2041-2070), the projected change in number of nights exceeding those warmest temperatures is greatest in the south for both the lower emissions scenario (B1) and for the higher emissions scenario (A2). (Figure source: NOAA NCDC / CICS-NC).

(Melillo, et al., 2014)

Temperatures and precipitation rates are affecting many aspects of life within the region, including the usage and quality of water, as well as supply and demand (Elliott, 2013). Availability of water supply is a growing concern in North Texas. "Climate change significantly increases the risk of water supply stress by mid-century" (Samenow, 2014, p. 15). Partnered with the greater evaporation rates Texas experiences during the hotter summer months, more intense rain events during these months are not enough to result in infiltration into groundwater. Soil moisture is projected to decrease by 10–15 percent, contingent upon the level of greenhouse gas emissions (Samenow, 2014). Taking into account the amount of potable water in Texas that comes from groundwater reservoirs, reduced infiltration has a large impact on the drinking water supply in large areas of the state, although not in North Texas where only surface water is collected in man-made lakes used for potable water.

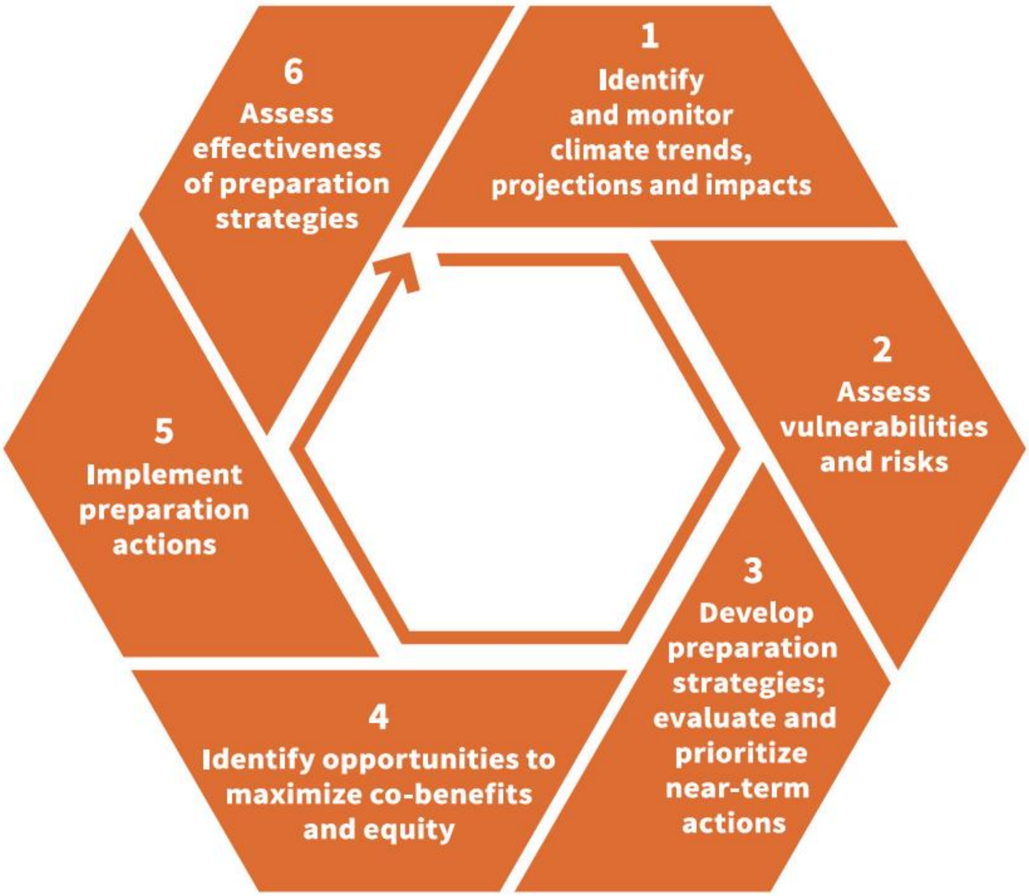
With the precipitation continuing as part of the surface water level, and not progressing into the groundwater table, water remains 100% the property of the State of Texas (Russell Laughlin, 2015). Ownership of the water limits its uses by both state and private organizations. Groundwater, on the other hand, is in the possession of the landowner (Kaiser, 1987). They are free to capture and pump groundwater within the bounds of their property. This creates a complex situation for city and state organizations that try to impose water regulations on private property.

"Water supply is projected to decrease over the next 50 years" (Elliott, 2013, p. 21). A longer stretch of dry weather increases the risk of a stream being classified as ephemeral (Jeong, et al., 2014). A stream experiencing a high-flow rate after this condition is more likely to undergo bank failure, environmental flow issues such as pollution and reduced water quality, as well as habitat and property destruction along creek paths. Due to the growing population density in North Texas, there is an increased likelihood of pollution in regional waterways further exasperating the problems caused by water reduction.

The processes by which climate change continues to have significant influence over both social and ecological systems and response issues require serious consideration (Adger, et al., 2011). Figure 13 demonstrates a possible plan that cities can implement to prepare for climate change. This study incorporates the first two steps in the climate preparation planning process. Steps three through five have been implemented by some landscape architects and related professionals in North Texas, as is documented in chapter four. Bioswales can be utilized as appropriate strategies for mitigating risks and vulnerabilities of stormwater systems in North Texas.

The climatic projections indicate increasingly severe weather events, droughts, and heat waves (Melillo, et al., 2014). Utilizing green infrastructure, public policy, and municipal resources can help alleviate some of the repercussions climate change has on the environment of North Texas. “The purpose of a bioswale is to increase the function of these conveyance systems by integrating features that improve water quality, reduce runoff volume and enhance landscape aesthetics” (Hogan, 2011, p. 5). Bioswales and green infrastructure programs have the ability to mitigate erosion, slow water, and reduce pollution while providing aesthetic benefits to surrounding areas.

Figure 13. Climate change preparation planning and implementation process



Adapted from **(Eubanks, et al., 2014)**

2.1.3 Resilience

Figure 14 illustrates a basic framework for resilient communities. Not only does "[r]esilience determine the persistence of relationships within a system…" (Holling, 1973, p. 17), but it also defines "[t]he speed of recovery from an unsatisfactory condition…" (Birgani, et al., 2013, p. 43). Figure 14 illustrates the structuring of communities through the knowledge of climatic conditions and disaster risk, to create resilient livelihoods and influences on environmental policy. Researching how climate change affects agriculture, food security, water and waterways, environmental resources, and human populations in this region highlights how vulnerable some communities are to these experiences and how they are projected to be weakened or resilient in the future. Other parts of the world have resilience through community-based adaptation has been practiced, for example, in the drylands of East and Southeast Africa (Bowa, 2014).

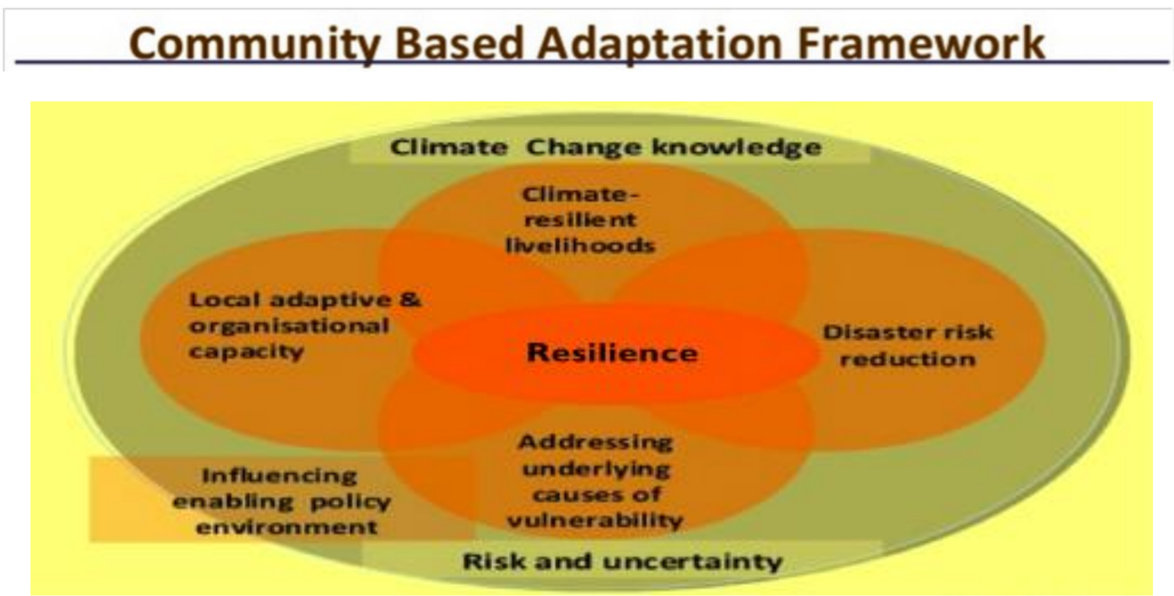


Figure 14. **(Bowa, 2014)**

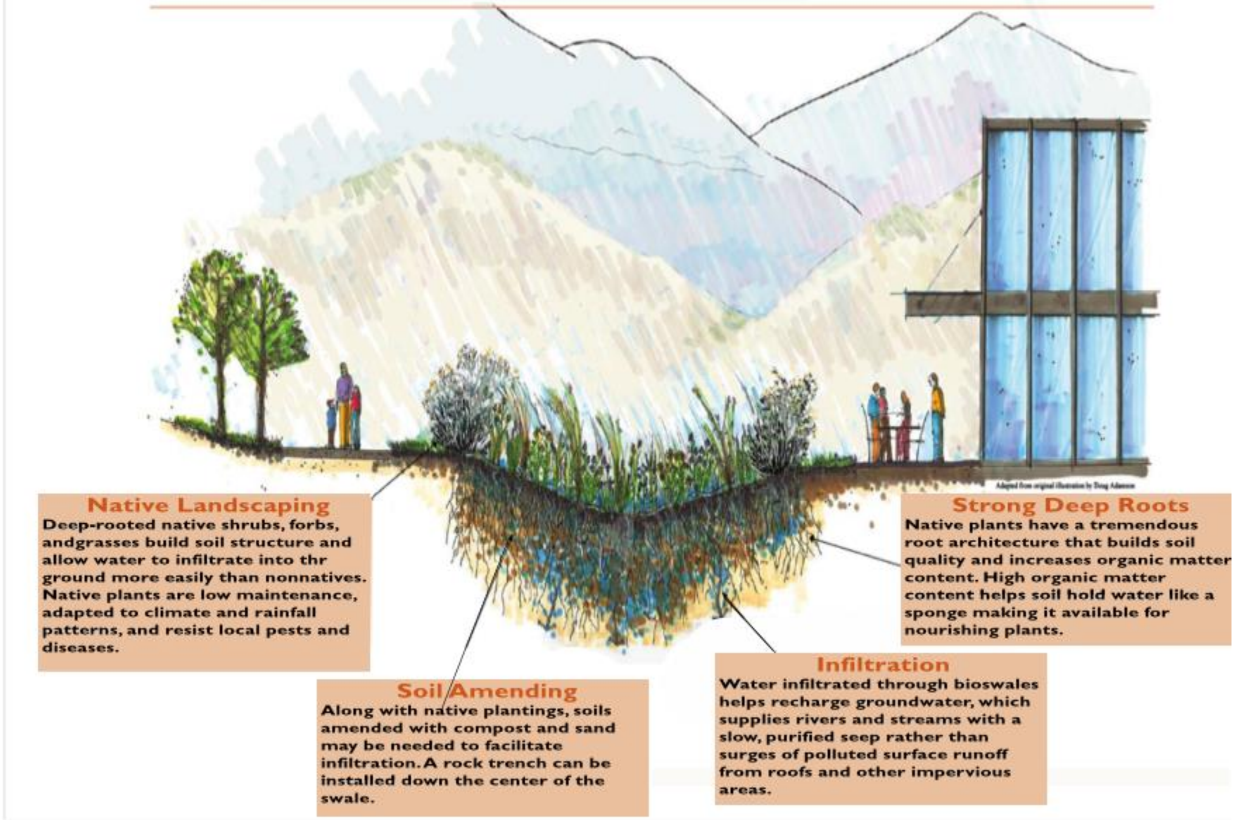
According to Houdeshel, et al., (2012), North Texas is not prepared to assimilate to the coming climatic and hydraulic changes. The resilience of or the ability for North Texas to assimilate to, recover from, and persist through, these projected climate changes can have drastic implications for the region's future. North Texas is currently not capable of absorbing disturbances to the daily function of landscape planning due to the stress on the region's recourses (Adger, et al., 2011). The limited water resources, drastic climate shifts, densely paved urban environment and growing population in the region all contribute to inhibiting stormwater infiltration and climate mitigation potential.

The resiliency of bioswales in North Texas is linked to projected climate change. The way in which bioswales function both during storm events and in dry periods is of equal importance for their functionality. Designing these structures in a creative manner that can be resilient to both of these conditions, affects their future viability in North Texas. The impact of resilience on the design and function of bioswales is addressed in section 2.2.

2.2 Bioswales

Bioswales are green infrastructure elements, within water management capacities, are either engineered or natural resource facilities that manage stormwater, public health and safety, and water quality to imitate or preserve natural systems (Brawley-Chesworth, et al., 2014). Figure 15 is an example of a bioswale in a corporate campus setting. Green infrastructure can be in the form of wetlands, natural greenspace and waterways, added landscaping and trees, ecoroofs, bioswales and more.

Figure 15. Bioswale in a Corporate Setting



(United States Department of Agriculture, 2007)

Low Impact Development (LID) is an approach to planning that aims to generate the least practical impact on a site by recreating the predevelopment hydrology and stormwater flows through collection and filtration features (Kalt, 2015). Both of these approaches can promote on-site infiltration in site planning and design. Bioswales are LID and green infrastructure tools that are often used in conjunction with other water quality systems to capture and filter stormwater. Figure 16 demonstrates a bioswale alongside a parking lot in a commercial area.

Figure 16.

(Tornes, 2012)

As in other areas of the United States, North Texas faces diverse stormwater events during various seasons. Bioswales were chosen for the parameters of this study due to their potential for designed resilience and ability to function effectively within the changing climatic conditions of the region. Choosing the correct type of infrastructure to manage runoff and stormwater contaminants is critical to site planning and low impact development.

Hydrology driven structures are created as retention and detention elements "…designed to capture and convey water, while allowing it to infiltrate the ground slowly over 24 to 48 hours…" (Hickman, 2014, p. 1). "The natural hydrology of each site must be evaluated…" (Houdeshel, et al., 2012, p. 1186), so every strategy may not be viable for every site. Slope, soil type, and volume of water during heavy storms are all contributing factors to site hydrology that must be taken into consideration when designing bioswales. Assessment of the viability of bioswales to the intended site determines the possibility for long-term success.

2.2.1 Environmental Factors

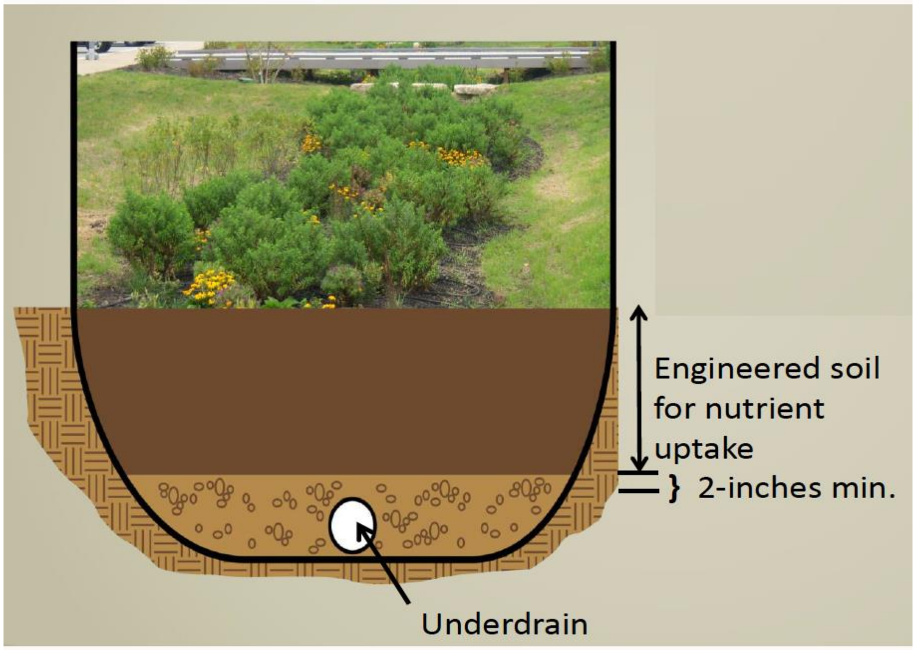
Bioswales provide various opportunities for environmental benefits. They help to create resilient and sustainable communities while managing stormwater (Brawley-Chesworth, et al., 2014). Bioswales are most commonly constructed in the form of intermittent streams. This element provides flood control benefits by mitigating periodic flooding in urban areas (Hogan, 2011). The pollution prevention benefits also protect aquatic organisms and fish in streams and lakes while lessening the impacts of nutrient loading and algal blooms in urban lakes and waterways. Pollution in runoff from intense storm events enters waterways in the form of heavy metals, fertilizers, pesticides, herbicides, and other chemicals. These chemicals came from previous agricultural uses, landscape and lawn care products, and urban sites. Residual chemicals seep into urban waters and contribute to elevated pathogen and bacteria levels (Jurries, 2003).

2.2.2 Design Elements

The design of bioswales is just as important as making sure that they are located and maintained appropriately. “When designing a swale to handle a certain storm event, occasionally a storm event of greater volume than the design event will occur and result in the runoff overflowing the swale” (Jurries, 2003, p. 23). While bioswales do possess flood control benefits, temporary flooding is likely to happen during intense storm events. The standard design of bioswales is to handle a ten-year flood event with retention times ranging from 24 to 48 hours. When excess water is present, bioswales are designed in such a way as to allow the water to flow into nearby storm drains using a technique called Integrated Stormwater Management I.S.W.M. (McLaughlin, 2012).

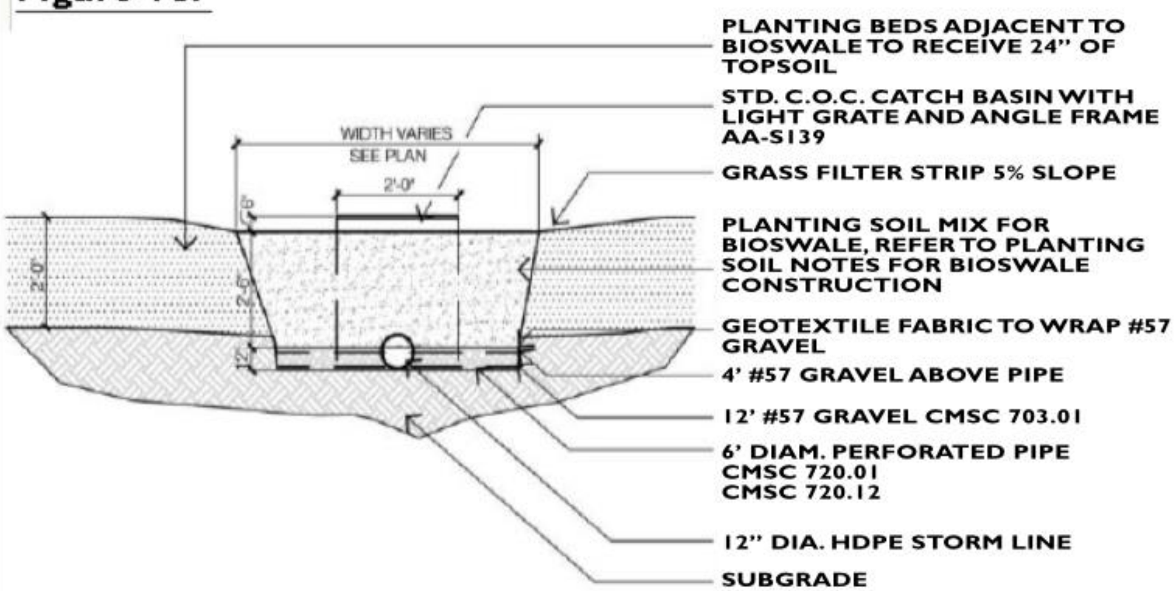
The path of a bioswale can be linear, curved, or a meandering channel. The more time that water is allowed to infiltrate, the more effective a bioswale can be in filtering and trapping pollutants (Hogan, 2011). The recommended slope of the channel gradient is no more than six percent in order to generate moderate stream velocity. When a bioswale's location is such that the length is not enough for adequate retention time, they are used in conjunction with other green infrastructure systems, green roofs, retention ponds, rain gardens, etc., to filter pollution (Jurries, 2003). In areas where the slope exceeds six percent, bioswales can be built to follow the grade of a hill to limit the slope of the swale. Check dams can also be utilized to reduce the velocity of the water and increase pollutant removal rates. Figures 17 and 18 demonstrate the soil and structural components of bioswales. The base layer is composed of gravel or large aggregate around a perforated pipe drain line. Above this is often a filter-fabric to create a space between the layers and ensure the gravel will not be filled with sediment. Bioswales can go without filter fabric if the gravel layer is carefully graded. The largest layer in the bioswale is the engineered soil, made from highly porous material that allows for quick drainage and works as a planting medium. The plants or mulch are the top layer on the surface.

Figure 17.



(Tornes, 2012)

Figure 18.



(Tornes, 2012)

Bioswales are often thought of as intermittent streams. A well-designed bioswale requires subsurface drainage, gravel and appropriate soil for drainage, planting medium, and plant material. Use of native vegetation in a bioswale creates the possibility of creating a wetland restoration or riparian corridor (Hogan, 2011). Ornamental grasses and other native plants are the most appropriate choices for bioswale vegetation due to their hardiness and ability to withstand natural climate shifts in the region. The more coverage of plant material in the swale, the better contaminant filtration occurs (United States Department of Agriculture, 2007). There are several requirements for bioswale vegetation. Plants must stand upright during designated maximum flow events and tolerate occasional flooding, and they must also have a dense root structure to prevent erosion in the swale and provide cover of the bioswale area. Plants must be able to grow well in the prepared soil and tolerate drought conditions due to the soil's propensity to dry out quickly. Plants can be added to existing earthen swales, but it is not necessary if subsoil is prepared appropriately. Sand, gravel, rock, and soil are layered in an uncompacted formation to allow permeability and water movement through the substrate (Jurries, 2003). The use of a bioswale can include visual aesthetics as much as functionality in some areas. Plant selections must uphold municipality visibility and setback requirements but can include turf and ornamental grasses, perennials, trees, cobblestones, and a variety of other plant and material options depending on the desired visual effect.

2.2.3 Applications

In many applications, bioswales are incorporated into existing infrastructure. They can be used in conjunction with other forms of green infrastructure to capture more runoff and reduce the stormwater load to sewers.

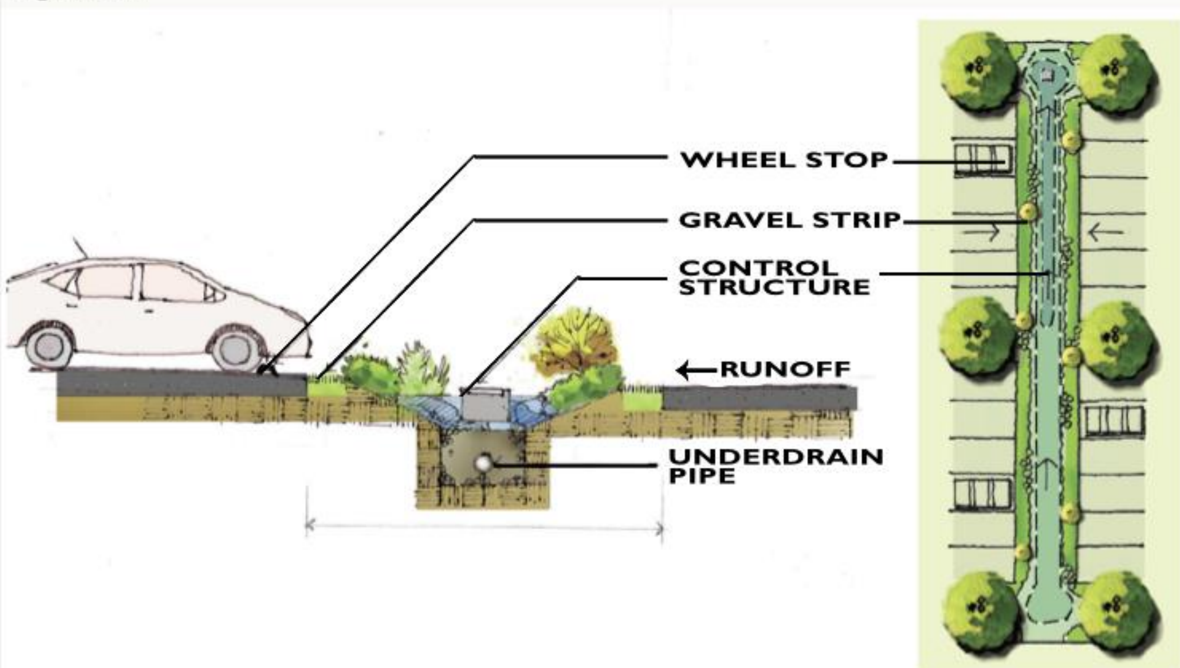
Figure 19.

A road ditch can serve as a bioswale. The rock trench and wetland vegetation are notable features along with the natural drainageway in the background that serves as a bioswale for residential runoff.

(United States Department of Agriculture, 2007)

When added to existing development, bioswales provide a cost-effective alternative to upgrading traditional underground stormwater systems. Figure 19 is an example of a bioswale alongside a roadway; Figure 20 demonstrates the design features of a parking lot bioswale. "Costs vary greatly depending on size, plant material, and site considerations. Bioswales are generally less expensive when used in place of underground piping" (United States Department of Agriculture, 2007, p. 2). Bioswale maintenance costs also lessen as plants become established, requiring less water, fertilizer, and weeding over time.

Figure 20.



(University of Florida, 2008)

2.3 Projected Climate Change Implications on Bioswales in North Texas

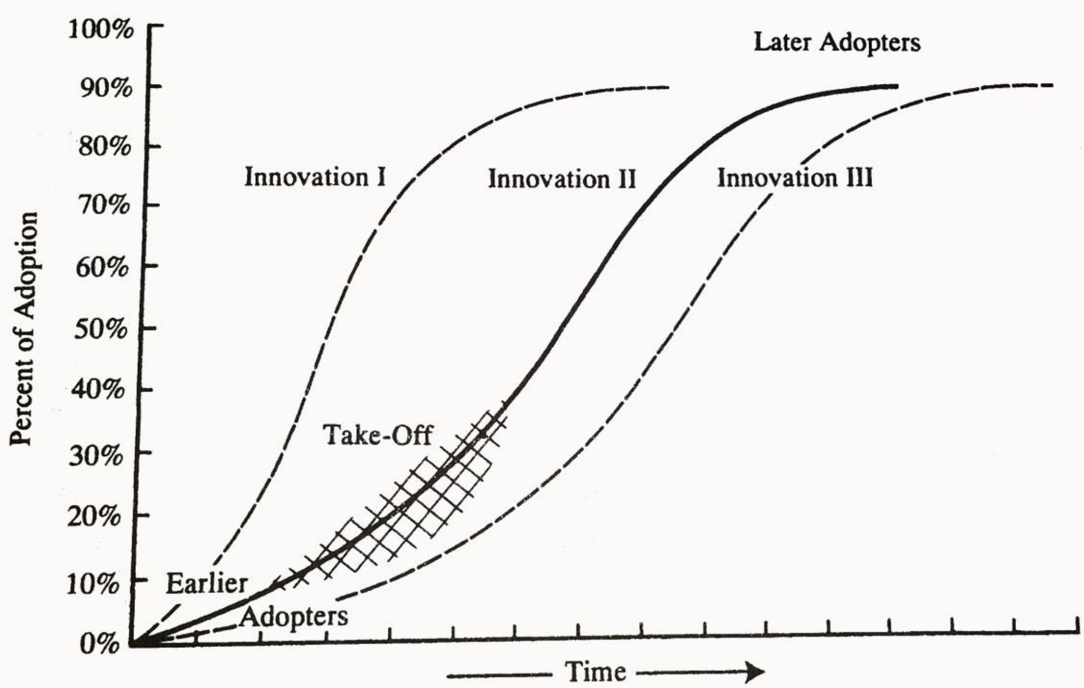
The projected climate of higher temperatures and dryer atmospheric conditions intensifies the rate of evaporation of water supplies across North Texas (Melillo, et al., 2014). "The two major climatic changes that will affect the region's natural systems are increased temperatures and shifts in the timing and amounts of precipitation" (Brawley-Chesworth, et al., 2014, p. 43). The limitation of water resources adds stress to the region in the form of greater use of water for irrigation, interior household uses, and energy generation needs. Climate change also compounds the challenges of streamflows when accompanied by sensitive climates changed greenhouse and emission gases (Houdeshel, et al., 2012). "Hotter summers will lead to reduced air quality, especially ground level ozone, which can become particularly problematic during high-heat days" (Brawley-Chesworth, et al., 2014, p. 37). The planning of efficient landscape elements can mitigate these negative effects and can influence the availability, and quality of the water supply, through water preservation and groundwater recharge (Elliott, 2013).

The rate of increase for climate change has nearly doubled over the past 50 years, and the water supply is not projected to be able to meet the demand required for the region over the next 50 years with present rates of consumption (Hall, et al., 2008). Managing storm flows and affecting the water quality are the main considerations in the design of ecological detention structures such as bioswales (Li, et al., 2010). Both wet and dry bioswales supply water quantity and quality applications (University of Florida, 2008). The ability to capture and reuse stormwater is critical to addressing the water supply needs of North Texas. "Landscape architecture involves the planning of water and land resources, so landscape architects delve into hydrology as part of their job description (and as part of the reason for professional licensure)" (Elliott, 2013, p. 2).

2.3.1 Diffusion of Innovation

The way in which ideas and methods disseminate throughout landscape architecture and related fields is of great importance to the growth and maturation of said field (Rogers, 2003). This diffusion of innovation evaluates not only the ideas, but also the technological advances throughout the field. Ideas are spread through human interactions and, over time, channel through the social system to become identifiable knowledge (Rogers, 2003). Figure 21 demonstrates the process that information takes as it is dispersed throughout society. This process is called Trialability and evaluates the capacity for new ideas to be experimented on, or "tried", in order to re-invent the initial experiment. "If an innovation can be designed so as to be tried more easily, it will have a more rapid rate of adoption" (Rogers, 2003, p. 258). Trialability is as less important to late adopters of ideas as it is to new adopters.

Figure 21. The Diffusion Process



(Rogers, 2003)

The way in which ideas spread has shifted over time. While the collegiate setting is still the major source of information for young professionals, offices and conference settings, word-of-mouth, professional papers, and the Internet are all substantial methods in which information is shared throughout the practice of landscape architecture (ASLA, 2015). The American Society of Landscape Architect (ASLA) conferences are also a notable source for information on bioswales and other new technologies. The conference establishes a setting in which professionals and students can come together and further their knowledge of the planning and design of bioswales and other green infrastructure. It allows them to build relationships with vendors and other professionals and to share ideas about materials and sources of information that can be beneficial to project success.

2.4 Conclusion

This review has focused on how bioswales are affected by projected climate change in North Texas. The ability of these bioswales to withstand the climatic swings associated with the region will influence the future resilience of the landscape of North Texas. The ability of landscape architects to work alongside other professions to adopt new ideas and practices and to discover avenues for which bioswales and other forms of green infrastructure can be utilized in North Texas places landscape architects and related professionals in a powerful position.

The literature review was conducted to establish an informational foundation for the interviews conveyed in Chapter Four. It provides context for the professional opinions throughout the duration of this paper and brings together information from different domains that establish context. The broad scope of data collected in this study contributes to the multi-disciplinary diffusion of bioswale information in North Texas.

CHAPTER 3

3.0 Introduction

This chapter addresses the methodology employed in this research. Qualitative research collection was used to establish trends and professional knowledge presented by interview participants. Qualitative research analysis establishes themes within the research findings and links them to a comprehensive model of findings within the data that is collected (Bazeley, 2009). The data was then analyzed through a domain analysis to link a variety of terms and similar characteristics to the subjects addressed. Utilizing a domain analysis, "interviews can be analyzed singly, emphasizing individual continuity and coherence, or together representing an identifiable social group with a common overview on the research question concerned" (Atkinson & Aby El Haj, 1996, p. 438).

3.1 Preliminary Questions Preceding Data Analysis

Before data collection began, several questions were formulated about the knowledge landscape architects and related professionals have about bioswales and climate change in North Texas. These questions were based on the literature review and the researcher's experience with professionals in the field. The first speculation was that landscape architects and related professionals may not have adequately considered the impact the projected climate change will have on the region. This is visible in the human impacts that severe weather events of 2013-2016 have had on the North Texas region.

The second question was that area professionals are inclined to use research from areas with different climates when planning for bioswales in North Texas. While these can be useful resources, will the functionality of bioswales in this region, based on this information, be adversely affected by the North Texas climate which is different than that where the research originated? The last speculation was that landscape architects and related professionals have not adequately considered whether or not bioswales will be resilient to climate changes in the North Texas region. These questions were utilized to design the interview questions used in this study.

3.2 Interview Procedure

One-on-one interviews were utilized to gather data on the subject's knowledge and experience with bioswales and their utilization in North Texas. After initial contact and interview consent was made, interviewees were asked to choose a location and time for the interview. They were also provided with a brief overview of climate data for North Texas, shown in Appendix A, and the informed consent document, Appendix B, that thoroughly explained the participant's rights throughout the interview process. The interviews were recorded via a smart-phone device and transcribed by http://www.samedaytranscription.com and the researcher in a Clean Verbatim transcription style. This left out incidental utterances such as "uh's", etc. The files will be stored with the transcriptions in room

421 of the Architecture Building at The University of Texas at Arlington, in accordance with university policy.

3.2.1 Study Population

Interview candidates were chosen by the researcher based on their involvement with selected built bioswales in North Texas, professional recommendations, and notable personal reputation within the field of landscape architecture, hydrology, site development, and related fields. These typically utilize bioswales or other physical means to manage effects of climate on the built environment. Each interviewee was asked for the names of other potential contacts to provide snowballing interview methods. Non-landscape architect candidates were chosen because of their work with bioswales and knowledge of climate change in North Texas. These interview candidates have varying amounts of knowledge on climate mitigation and water retention practices within the region, creating a diverse group from which to gather information. The range of work experience of the participants ranged from one and a half years to over forty years. The participant with only one and a half years of experience held a master's degree in ecology and worked closely with bioswale maintenance and research. Participants also had a range of work experience in architecture, landscape architecture, engineering, hydrology, and academia in Dallas, Fort Worth, Irving, and McKinney, Texas. The nine selected interviewees provided a sample of North Texas professionals with knowledge of bioswales and their resiliency to climate change and how this information spreads.

3.2.2 Interview Questions

1. *How is the functionality of bioswales in North Texas affected by the more intense stormwater events of recent years?*

The first question was designed to gain an understanding of the interviewee's general grasp of bioswales and the climate events of recent years in North Texas. The knowledge of how bioswales handle more intense stormwater events directly affects how they are planned and constructed. The interview participant's knowledge of this subject was also helpful in gauging the Diffusion of Innovation of bioswales throughout the field of landscape architecture and related professions.

2. *Are bioswales a way to mitigate the runoff from recent storm events such that existing stormwater infrastructure will not need to be improved as much?*

The second question linked the knowledge gained in the first question to one of the specific uses for bioswales in North Texas. Without the ability to handle the projected larger storm events, the effectiveness of bioswales could be compromised.

3. *How does the North Texas climate affect how bioswales should be or are used and how they are designed?*

This question was designed to gauge the professional's knowledge of bioswale design and usages. The question sought to develop a list of recommended designs or practices for implementation of bioswales in the region.

4. *Where do you get information about bioswales and other stormwater management tools?*

Question four delved into the avenue from which landscape architects and related professionals gain their knowledge of the products and practices they employ. The source of knowledge has the ability to skew the data and cause the designers/operators to become biased or less informed.

5. *What do you think are the most appropriate types of development areas for bioswales?*

The fifth question presented a direct inquiry to how and where the professionals have used bioswales in practice or their theoretical knowledge of their effectiveness. It allowed the researcher to gain a better understanding of how bioswales are being used in the field. The way in which bioswales are used, treatment trains, development type, slope, etc., contributes to better evolution of green development in North Texas.

6. *How is plant loss during seasons of drought a factor when considering the use of bioswales in North Texas?*

This question created an avenue for understanding the interviewee's knowledge of the link between plant life and climate. Gaining an understanding of how bioswales react to climate swings can establish better construction and implementation methods for both professionals and researchers. This understanding can be helpful to look into plant losses during climate shifts to determine if vegetated bioswales are a viable option for managing runoff or if there are alternative mediums for bioswales that are more functional.

7. *What has been the trajectory of bioswale adoption in stormwater management design over the course of your career?*

The seventh question explored the participant's individual work experience within the North Texas region. Altering how bioswales are designed and implemented is approached differently based on changing climatic conditions and civic pressures. Does the way in which bioswale design has changed have implications for how the profession uses them? The scale of these changes can help future professionals gauge the extent, if any, to which climate change should be considered in project design and planning.

8. *Based on the previous question, has the pace of change in stormwater management been sufficient, insufficient, or expeditious?*

Question eight analyzed the interviewee's understanding of the changing environment of green infrastructure. This helps to establish a frame of reference for how landscape architects and related professionals are working with new technologies and changes in the needs of the human and natural environment.

9. *How are bioswales and/or the projected climate change in North Texas relevant to your work?*

This question sought to comprehend the relevance of this research to the average landscape architect or related professional in North Texas. Understanding the way in which an interviewee considers climate change in their work grants the researcher a insight into the practical knowledge for bioswales in the region.

10. In your opinion, has the current or predicted climate change in North Texas affected how you approach your profession?

The way in which landscape architects and related professionals design and plan a project can be of equal importance to the way in which it is constructed and the aesthetics of the project. Understanding the interviewee's approach and how this may have changed throughout their career, in light of climate and physical needs, can establish a framework for how climate change is dealt with in North Texas' green infrastructure projects.

11. With regard to the predicted climate change in North Texas, are there stormwater mitigation advantages that can be achieved through the implementation of bioswales?

The final question seeks to understand the mindset of practicing landscape architects and related professionals. With the projections for climate change in North Texas, it is likely that the use of bioswales may have to be altered. The willingness for professionals to adjust their thinking in regards to coming changes has the ability to forecast if bioswales will flourish in the new environment.

3.3. Data Analysis

Interview transcriptions were examined using domain analysis to gain a better understanding of landscape architects' and related professionals' grasp on resilience of bioswales to climate change in North Texas. The domain analysis method allows the researcher to interpret interview responses to help supplement the data collected in the literature review (Atkinson & Aby El Haj, 1996). It analyzes verbal cues and nuances of language to find either coherence or individuality among the participants' responses. The domain analysis assisted the researcher in determining if there was a collective understanding of bioswale resiliency in North Texas or if the interviewees held opposing views on the subject.

Domain analysis was chosen as a data analysis tool due to its ability to link characteristics of the participants' responses, even if those responses are not identical. It enables interviewees to establish topical importance within their own work experience and knowledge, while also allowing the interviewer the ability to analyze patterns identifiable through common themes. Grouping thematic topics allows the author to connect inter-relational ideas to their research-based counterpoints, thus establishing a research outcome.

3.4 Limitations and Delimitations

A heterogeneous group of interview participants was sought to diversify responses for data collection. Research was confined to the utilization of bioswales within North Texas in order to narrow the focus of the research and create a meaningful result. The value of qualitative research is that it can encompass opinions and examine research outcomes beyond numerical or quantitative data.

3.5 Conclusion

This study is a snapshot assessment of professional knowledge of bioswales' resiliency to climate change in North Texas. The Diffusion of Innovation of these technologies and climate data through landscape architecture and related fields has the ability to affect the outcome of this study. Due to the nature of climate implications on bioswales, the data is expected to change over time. Through interviewing professionals and analyzing the data obtained using Domain Analysis, the researcher gained an understanding of the extent of knowledge and use of bioswales within North Texas at the present time. It also shed light on how professionals gain information about such structures, and the resiliency of bioswales to projected climate change in the region.

CHAPTER 4

DATA ANALYSIS AND FINDINGS

4.0 Introduction

The data collected from interviews with landscape architects and related professionals was analyzed based on the Domain Analysis method. Domain Analysis is a technique for analyzing qualitative research that "…is based on the identification within the content of the data of key topics, referred to as domains, and the relationships between them" (Atkinson & Abu El Haj, 1996, p. 438). Thematic patterns found within participant responses helped the researcher gain insight into how bioswales are designed and deployed in North Texas landscapes. Keywords and phrases were found within the interviews, these were used to create linkages between responses and insights from the other participants. Domain Analysis provided insight about the ways in which landscape architects and related professionals expect bioswales to function in the projected climate changes in North Texas, and how these practicioners believe the field should adapt to these changes. A Domain Analysis was conducted separately for each interview question, and a meta-domain analysis was constructed to summarize findings across all interviewees.

4.1 Summary of Findings

The professionals who took part in the interviews all reported that they had a basic working knowledge of bioswales and the projected climate change in North Texas. They were chosen as interview participants based on their prior experience working with bioswales and their knowledge of climate events in the region. Some of the institutions and projects associated with interview participants include Texas A&M AgriLife Research and Extension Center, the Botanical Research Institute of Texas (BRIT), The University of Texas at Arlington, Deep Ellum, Streetscape projects in Dallas, Sundance Square redesign project in Fort Worth, and many other landscape architecture and municipal projects. The Domain Analysis uncovered several themes within the interview responses. The primary domains discovered were stormwater management, environmental impacts, diffusion of innovation, design, climate, social and economic impacts, and bioswales in a treatment train. The topics of bioswales in a treatment train and diffusion of innovation were of particular interest to the researcher due to their potential to lend insight into how information about bioswales has spread.

4.2 Interview Analysis

1. *How is the functionality of bioswales in North Texas affected by the more intense stormwater events of recent years?*

Figure 22

	Domains Addressed in Interview Responses: Question 1					
Interview Participants	**Design**	**Stormwater Management**	**Climate**	**Social & Economic Impacts**	**Bioswales in a Treatment Train**	**Environmental Impacts**
1	rainfall exceeds capacity	runoff	increased precipitation			
2	design to reduce runoff	storage capacity		maintenance	overflows to a pond	
3		erosion				urban heat island
4	reduced design efficiency	excess water	intense droughts and storms			
5	designed for certain rainfall	drainage				
6	better design decisions	soil infiltration problems	large rain events			
7	finite capacity	increased stormwater				
8	drainage infrastructure	water quality control	insufficient climate data		treatment combination	resource protection
9	pipe sizing	runoff	stronger storms			

Interviewee's responses to Question 1 predominantly focused on design and stormwater management. All participants agreed that a bioswale's functionality will be stressed by more intense stormwater events. This was mostly due to the "higher flows and more velocity" associated with these climatic events. When these high intensity storm events occur, bioswales are strained to handle high volumes of runoff that often exceed designed capacity. "They're designed based on a certain amount of rainfall … and with the increase in precipitation, that's really skewing the design." One of the participants commented that stormwater management is "…one of the reasons why we have watershed departments…" within our cities. They help manage not only storm water quantity but also water quality. Bioswales are one of many approaches that North Texas cities are using to manage storm water.

Altering bioswale design to accommodate anticipated changes in storage capacity was addressed by all but one of the interviewees in response to this question. A standard bioswale is designed to have a flow rate of "…around 50-60 inches per hour…" but because it is filling too quickly, it often overflows the inlet. According to three of the interviewees, this is where using bioswales within a treatment train can assist in establishing additional storage capacity. Utilizing a rain garden or retention pond in conjunction with a bioswale can retain the water that overflows the structure on site so that it doesn't "… run off into our storm system". Throughout this research, it was stated by most of the interview participants that utilizing bioswales in a treatment train was a better system than isolated projects because it allows the bioswales to be a part of the greater green infrastructure equation of the region.

The only social impact an interviewee commented on was the maintenance associated with bioswales, especially during overflow events. When a bioswale overflows, bark mulch can be washed out of the system and clog the inlet. If this issue is not addressed through regular maintenance, it can affect the bioswales ability to function properly.

Climatic impacts on a bioswale's functionality are directly linked to the need for altered bioswale design. One interviewee stated, " …we are looking at 100 year storms that are based on 30 years of precipitation data". This was an interesting statement, because it shows how new even the science of climate mapping is within North Texas. "The upcoming 30 to 50 years may be substantially different than the preceding 30 to 50 years due to some of the changes we are seeing in the climate." As a result, professionals may be designing bioswale capacity based on statistics that may be unreflective of present conditions even before they are constructed. Potential negative environmental impacts for wildlife and plants that are associated with bioswales in North Texas.

2. Are bioswales a way to mitigate the runoff from recent storm events such that existing stormwater infrastructure will not need to be improved as much?

Figure 23

	Domains Addressed in Interview Responses: Question 2						
Interview Participants	**Design**	**Stormwater Management**	**Climate**	**Social & Economic Impacts**	**Bioswales in a Treatment Train**	**Environmental Impacts**	**Diffusion of Innovation**
1		watershed planning			compliment stormwater system		
2		runoff					education
3		stormwater absorption			extent of bioswales	erosion	
4	aesthetics				functionality		education
5	aesthetics	supplement storm system					
6		retrofitting bioswales to infrastructure					
7	additional capacity needed	drainage and flooding	more flooding	maintenance			
8	change design standards			makes economic sense			
9	increase storage capacity	runoff	increased precipitation	cannot get funding			

The responses to Question 2 collected information regarding a bioswales's ability to mitigate runoff to stormwater infrastructure varied across all seven domains. According to one of the participants, bioswales "…could definitely help with our stormwater infrastructure". They are "…a good supplement to existing stormwater systems…" due to their ability to "…reduce the use of conventional infrastructure". An interviewee discussed the age of the underground infrastructure in North Texas. Much of drainage in the region was designed and installed during the 19th century based on a 25-year storm. "In the early 1980's… somebody went and studied all that again and they found that [the rainfall data] is not valid." Bioswales create opportunities to redirect runoff so that it "…is captured to some degree and mitigated before it goes into our stormwater system".

Bioswales serve multiple purposes. Altering the way impervious surfaces are designed in North Texas allows for functional green infrastructure to remove some of the storm flows from conventional subsurface storm drains throughout the region. Incorporating bioswales into existing development areas allows them to relieve pressure on existing systems that are often overburdened. Using bioswales in new development creates an opportunity for stormwater filtration and diverting stormwater for groundwater recharge and/or irrigation purposes.

3. *How does the North Texas climate affect how bioswales should be or are used and how they are designed?*

Figure 24

	Domains Addressed in Interview Responses: Question 3					
Interview Participants	**Design**	**Stormwater Management**	**Climate**	**Social & Economic Impacts**	**Bioswales in a Treatment Train**	**Diffusion of Innovation**
1	plant selection		climate irregularities			
2	design standards	reduce runoff		maintenance		education
3	planning	mitigate climate effects	flashfloods and droughts			
4	design standards					testing new technologies
5			rainfall distribution		bioswale promotion	
6			extreme temperatures			
7	should not be design focused	flooding				
8	functionality; plant selection		more frequent intense storms	maintenance		
9	design standards	runoff	rainfall events			

The responses to Question 3 address all of the themes. Several participants commented on how the shifting climatic state of the region will alter the palette of plants that can thrive in bioswales. One interviewee stated "…the North Texas climate affects the way you have these bioswales…on the one hand, you have these severe flashfloods… and the other effect is the droughts". They made the point that these extremes are bound to cause plant loss. However, according to one interviewee, the rainfall distribution in North Texas provides "…a very good environment to promote bioswale technology." So while the interview participants mostly agreed that climate shifts do affect how bioswales are applied, there were varying opinions about the extent of the effects.

Two participants questioned the diffusion of innovation in bioswale technology and made the point that "most of the research on bioswales is either on the northwest coast or the east coast with entirely different climates, land, and soils." Given these differences "… it is hard to apply the data from other places in the world to here." One interviewee stressed, "…it is more education and the fact that we need to make the right ones [bioswales] for our applications." The topic of educating both the public and professionals across all associated fields recurred throughout this research. By increasing education about bioswales and other methods of green infrastructure, the learning curve between new methods of stormwater management and classic methods can be lessened.

4. *Where do you get information about bioswales and other stormwater management tools?*

Figure 25

Interview Participant	Domains Addressed in Interview Responses: Question 4
	Diffusion of Innovation
1	Online, Government Sources, EPA, Universities
2	A&M Agrilife Extension, North Carolina State University, EPA, Online, David Hopman
3	Trinity River Authority, USGA, NOAA, NCTCOG
4	Online databases, technology, Water & Climate Research Foundation, Water Environment Federation, NACWA, AWA, NCTCOG, 319 Grant, EPA, TCEQ, ASCE
5	NCTCOG, LID Authority, Online
6	Online databases, BRIT, David Hopman, Texas A&M University, LARC journals
7	Online, Professional Seminars
8	A&M Agrilife Extension, Watershed Protection Group, Partnerships
9	Grants, Expiramentation, Conferences, Other Professionals, Developers/Suppliers

Question 4 was in a different format than the other questions. Instead of being a question about the interviewee's knowledge of bioswale and climate change information, it sought to find their source of information. All of these answers fell into the domain of Diffusion of Information, because all of the contacts and resources are ways in which information about bioswales and other forms of green infrastructure are spread. The most popular source of information about bioswales was online internet databases, such as university, governmental or other institutional databases. The ease and availability of this resource make it the most popular way of gaining information. It is also a good way to gain the most up-to-date information on changing green infrastructure practices. Government and university resources were the next most stated sources of information. The Environmental Protection Agency (EPA), North Central Texas Council of Governments (NCTCOG), The Trinity River Authority, Water and Climate Research Foundation, Water Environment Federation, National Oceanic and Atmospheric Administration, American Waterworks Association, North American Clean Water Administration, and various government grants were some of the regional and national government sources. The Texas A&M AgriLife Research and Extension Service program, North Carolina State University, and the University of Texas at Arlington were the top universities mentioned by interview participants. Partnerships with other professionals, suppliers and developers, landscape architecture and engineering journals, and professional seminars, as well hands-on experimentation were also discussed as sources of information on bioswales and stormwater management.

5. What do you think are the most appropriate types of development areas for bioswales?

Figure 26

	Domains Addressed in Interview Responses: Question 5					
Interview Participants	**Design**	**Stormwater Management**	**Environmental Impacts**	**Social & Economic Impacts**	**Bioswales in a Treatment Train**	**Diffusion of Innovation**
1	residential and commercial			industrial collaboration		education
2	development areas	runoff		growth; costs; maintenance		education
3	development areas			urban centers		
4	area, soil, slope, design configuration	water quality			part of an integrated system	education
5		reduced mitigation efficiency			co-exist with other features	
6	urban impermeable surfaces		lessons learned in nature			
7	residential and commercial		native environmental restoration	maintenance		
8		runoff		property values	engineered systems	education
9	residential areas					public perception

The domains in Question 5 were varied with the most responses regarding design, social and economic impacts, and diffusion of innovation. The most prevalent responses to appropriate types of development were commercial properties, any area with large impermeable surfaces (like roads and parking lots), and residential neighborhoods. Two of the interviewees said that they could and should be constructed anywhere "…as long as you're producing runoff, there's an opportunity for the use of a bioswale."

The diffusion of innovation, and social and economic impacts domains come into context with Question 5 in consideration of educating the public on the benefits of a bioswale. One of the greatest inhibitors of bioswale construction is the public perception of them as pest magnets or maintenance headaches. "Education is really an important component. Educating the municipalities, but also the residents and commercial establishments." One of the interviewees had created a report on maintenance costs for bioswales over classically landscaped parking lot islands and found that "…there was not really any cost difference in adding a LID [Low Impact Development] or GI [Green Infrastructure] feature and standard." She went on to state that "maintenance costs were not even the problem, it is just education and learning how to maintain it… They just don't understand it can cost less if they're looking at the entire cost with maintenance and everything else." It is more important to look at the "…life cycle costs." Another participant discussed that the public does desire to have green space and that "…with a little signage and a little bit of promotion…", they will be able to learn the benefits of bioswales and experience the added property value.

6. *How is plant loss during seasons of drought a factor when considering the use of bioswales in North Texas?*

Figure 27

Interview Participant	Domains Addressed in Interview Responses: Question 6				
	Design	**Stormwater Management**	**Climate**	**Social & Economic Impacts**	**Environmental Impacts**
1	plants			maintenance	
2	plants				
3		erosion	high temperatures; weather extremes	maintenance	ecosystem hazards
4	native plant establishment			maintenance	
5	aesthetics a result of soil				
6	plants for functionality and aesthetics				
7	aesthetics; native plants; sustainable	water demands		maintenance	
8	right types of vegetation; functionality				
9				maintenance	

The majority of responses to Question 6 were focused on the domains of design and social and economic impacts. One of the most important aspects of bioswale design is choosing the "…right type of vegetation." According to one of the interviewees, North Texas is currently going through a "horticultural revolution" because of the drastic change in popularity of native plant varieties. Utilizing hardy

“…indigenous plants, which already fit the local environment…” is the easier solution than choosing plants that would struggle to survive. Utilizing properly chosen native plants, which seven out of the nine interview participants discussed, is the best way to avoid excess plant loss. Choosing plants that can tolerate a variety of moisture conditions are the key to bioswale design. “Bioswales…have a significant infiltration component, so they tend to be fairly resistant to drought.” One of the participants suggested “…staggering plants…so they may go dormant during dry times, but will come back when there’s rain”. She stated, “…the thing is to provide a diversity of plants, so that the appearance of the system during drought will still have some green… but then you have the contrast of the other plants which may go dry.” Creating the year-round aesthetics, which will appeal to public perception, is the key to public bioswale adoption. “The problem comes when people don’t have a good understanding…from a plant specialist, landscape architecture type person, who understands the plant community that needs to be in the place that they’re designing.”

The social and economic impacts of the bioswales come from the maintenance. “A lot of green infrastructure requires more maintenance, and it’s labor intensive maintenance because you’re not just mowing something. It takes manual labor to go out there and pull the weeds and care for the plants.” The simple solution to avoid plant loss during seasons of intense drought is to irrigate the beds, “…at least in July and August when we’re so incredibly hot… You need to maintain them or they become degraded.”

7. *What has been the trajectory of bioswale adoption in stormwater management design over the course of your career?*

Figure 28

	Domains Addressed in Interview Responses: Question 7						
Interview Participant	**Design**	**Stormwater Management**	**Climate**	**Social & Economic Impacts**	**Bioswales in a Treatment Train**	**Diffusion of Innovation**	**Environmental Impacts**
1						education	
2		storage capacity; flow			integration	education	
3			paved surfaces increase temperatures				urban heat island
4	soil planning	water quality			integration		
5	sustainability trending	runoff carrying chemicals				popular demand	chemical absorption
6					incorporation into cities		
7	aesthetic features	water planning		maintenance		education	
8	riparian areas; meandering channels	water planning					environmentally sensitive areas; water protection
9	functionality			integration		education	

The answers to Questions 7 varied across all seven domains. The most prevalent themes were design, stormwater management, and diffusion of innovation. “The design approach for many, many years was to put that storm water in something that’s concrete and get it out of the city as fast as you can”. When the drainage solution was vegetated, the only available solution was a “bar ditch.”

Recently, industry professionals are helping cities "…integrate them [bioswales] into the larger context of stormwater models". One interviewee said, "… there's a lot more people these days who like sustainability and they like everything green. It's so they will evaluate the life quality and also what they're going to pay for." So many forms of green infrastructure are gaining popularity not only within the industry but also with the public because of their trendy and healthy reputation.

8. Based on the previous question, has the pace of change in stormwater management been sufficient, insufficient, or expeditious?

Figure 29

	Domains Addressed in Interview Responses: Question 8					
Interview Participant	**Design**	**Stormwater Management**	**Climate**	**Social & Economic Impacts**	**Bioswales in a Treatment Train**	**Diffusion of Innovation**
1		wetland restoration				education
2				maintenance		education
3		flooding				education
4	soil types		different storm conditions	stormwater legislation	integrated systems	
5	design experience			financial constraint		education
6			vast climate change	population growth		
7		stormwater capacity		increasing population		
8		manage flooding		economic components		
9	improve designs	behind in stormwater improvement			decentralized systems	

None of the interview participants responded to Question 8 with descriptions “expedious”, six responded “insufficient”, and three responded with “sufficient.” Overall, these industry professionals interviewed did not consider the speed in which stormwater management reform has taken place to be adequate. One interviewee response was “insufficient” stating, “I know the vastness of the climate changes happening and how much these things needed to be done yesterday…" Another participant referenced "increasing population" and "new storm waters" as additional reasons for industry professionals to push for further stormwater reform. He stressed that "…changing attitudes regarding water use is a greater concern."

Respondents, from both "sufficient" and "insufficient" mindsets, referenced the monetary concerns as causing delay in the adoption of alternative stormwater management methods. One "sufficient" responder stated, "I expected it to happen even faster, but in reality it still has a lot of financial constraints associated with it". One of the interviewees, who works for one of the large North Texas municipalities, stated "Texas is a unique entity with the way they feel about property rights and private control and keeping the government out. So I would say that for Texas, in relation to the rest of the country, we were probably behind the curve significantly." Another participant said "…working at a municipality, you can't work without considering the political and economic components of the decision-making process." This is a "hot button" issue for most bioswale projects, because they are often found on public property and constructed with public dollars. "We have to work through the political and economic component of it every bit as much as the science and engineering components of it."

For these reasons, several of the interviewees discussed the need for further research on bioswales in North Texas. By educating not only the public, but industry professionals, and city employees, they can make better informed decisions when it comes to green infrastructure and alternative stormwater management techniques.

“The more research that we can get, the more opportunities to show success for this different way of thinking of stormwater management.” One interviewee, who is a landscape architect, stated that in her eight years working with various green infrastructure projects, “…it is starting to gather more momentum as people understand and more people are getting educated.”

9. *How are bioswales and/or the projected climate change in North Texas relevant to your work?*

Figure 30

	Domains Addressed in Interview Responses: Question 9						
Interview Participant	**Design**	**Stormwater Management**	**Climate**	**Social & Economic Impacts**	**Bioswales in a Treatment Train**	**Diffusion of Innovation**	**Environmental Impacts**
1			drought conditions				
2	aesthetics	runoff		maintenance; costs		education	
3		short range decision making	climate is evolving				urban heat island
4		problem with stormwater management			part of a treatment process		
5		hydrology study	changing rainfall patterns	education			
6					incorporate into infrastructure	education	natural systems
7		water restrictions	droughts	saves money		education	water availability
8		sediment loading	longer drought cycles				protecting natural waters
9			change in rainfall and temperature patterns		rainwater harvesting systems		

The main responses to Question 9 were climate and stormwater management, regardless of the interviewee's professional background. Landscape architects, climate specialists, municipal employees, researchers, and hydrologists all agreed that the influx of water, runoff, and droughts are going to affect their professional life in some way. “The stormwater regulations are still somewhat in their infancy…for the state of Texas.” New positions have been created within some cities and offices such as “drought coordinator” and “Green Infrastructure Program coordinator” to help with the transitioning technology. “Dealing with stormwater issues is a daily concern…”

Understanding how the climate is projected to change and knowing how to handle these shifts is important to the growth of new stormwater management techniques. One participant explained a project he is working on to “…understand how regional climate change is evolving in the future here in Dallas/Fort Worth area.” So far, the results have shown that monthly averages are expected to increase 3 to 4 degrees Fahrenheit (F) on a monthly basis but as much as 5 to 6 F degrees higher on a daily basis. Another interviewee is “…looking at the impact of climate change in rainfall and temperature patterns on the use of rainwater harvesting…and the effectiveness of bioretention areas…” So the research on this subject for North Texas has begun, but the industry is still waiting on the diffusion of innovation.

Education also played a part in the responses to Question 9. A landscape architect explained, “…more people are getting educated on stormwater capture. The City of Dallas does rain capture workshops.” This demonstrated that cities and the general public are making small strides toward change.

10. Has the current or predicted climate change in North Texas affected how you approach your profession?

Figure 31

	Domains Addressed in Interview Responses: Question 10					
Interview Participant	**Design**	**Stormwater Management**	**Climate**	**Social & Economic Impacts**	**Diffusion of Innovation**	**Environmental Impacts**
1			shifting climate			
2	plant selection	runoff	more dry and wet cycles			
3			global climate phenomenon		education	regional effects of climate change
4			climate is changing	need more planning		
5		runoff	higher rainfall intensity and droughts	maintenance		
6	mitigation and adaptation		critical climate situation		push for responsibility	
7		water restrictions		economics		
8	designs are not adequate	resource planning				
9	design for climate change	stormwater research	changing storm patterns	funding		reduce carbon emissions

Seven of the nine interview participants responded that climate change would affect how they approach their profession. One practical approach mentioned, "…climate change is not something that we should plan to change. We do day to day, but we should plan with the potential and the possible risk of what could happen in the future." The recent years of 2011-2016 have contained some of the most obvious examples of climate change in recorded history. One participant was "…not sure if the change is in this last few years…" This was a question raised by multiple participants. One participant stated, "…I'm very concerned that what we're doing from a design standpoint may not be adequate for the future… we're basing all of those decisions off the past patterns…historical patterns and historical knowledge that may prove to be inaccurate…" He went on to explain "…if we design a concrete channel that's supposed to last at least 50 years and we size it based off the last 30 years of data…what's our assurance 50 years from now that the design storm is going to be anywhere close to accurate."

The research shows that the rainfall intensity is going to increase with these storm events. "That rainfall intensity is driving the floods…because the climate changes constantly, and they're really going to change the rainfall patterns." One interviewee has focused his research on how climate change is "…a global phenomenon, and Texas is only one of the areas that is affected…" This study is only addressing the regional effects of a global problem.

11. With regard to the predicted climate change in North Texas, are there stormwater mitigation advantages that can be achieved through the implementation of bioswales?

Figure 32

	Domains Addressed in Interview Responses: Ouestion 11					
Interview Participant	**Design**	**Stormwater Management**	**Climate**	**Social & Economic Impacts**	**Bioswales in a Treatment Train**	**Environmental Impacts**
1		water quality; groundwater				protection environment & human health
2	plant selection	runoff		maintenance; budget cuts		deforestation
3		large stormwater management: runoff				
4		intense storm management			part of an entire program	
5		runoff	shifting rain events	maintenance		
6		erosion	greater storm events			
7	location and implementation	water filtration		costs & maintenance		
8		water challenges	precipitation and temperature changes			protecting habitat and water
9	drought tolerant plant selection	mitigation	climate change increase stormwater			

Responses to Question 11 predominantly surrounded the domain of stormwater management. Some of the stated advantages that were expected for bioswale implementation included mitigating erosion, reducing runoff, and stormwater, protecting human health through water filtration, and protecting habitat and the region's water resources. One of the interview participants held the opinion that every small project helps the greater good. She suggested, "if every parking lot over a certain square footage had a bioswale associated with it that was five percent of the total square footage, I think the mitigation would be outrageous." Incorporating bioswales into a treatment train allows them to be utilized "…as part of your entire program…with the ability to handle intense storms, maybe even to handle long term drought and recover." Bioswales are "…the mitigation for the impact of climate change on the stormwater system."

4.3 Interview Analysis Summary

The seven primary domains established within the interview responses were design, stormwater management, climate, social and economic impacts, bioswales in a treatment train, environmental impacts, and diffusion of innovation. Through analyzing the seven primary domains, many secondary domains were discovered and a framework for categorizing the data was established. The seven hierarchical flow charts below demonstrate the diffusion of these concepts.

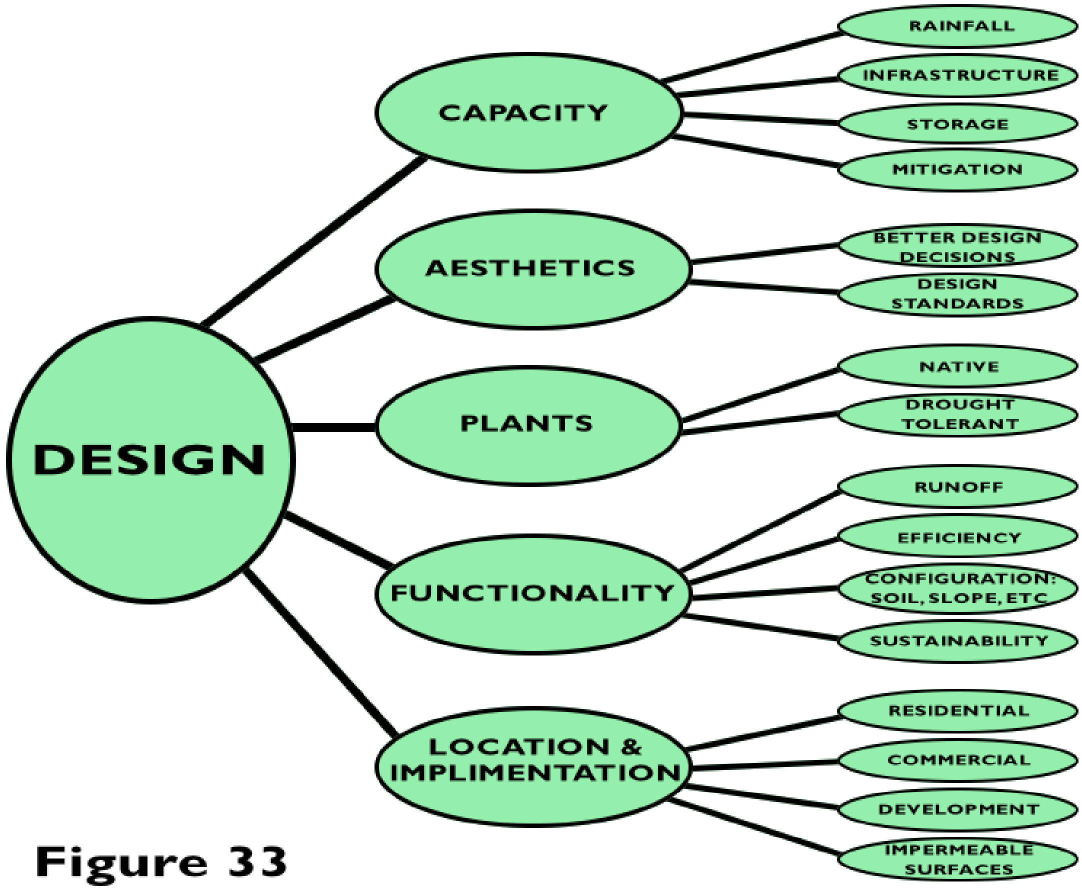


Figure 33

The domain of design lent insight into the thought process behind bioswales implementation in North Texas. The capacity of water that bioswales handle during storm events is more than their design is intended to handle. Apparent from the interview responses, this is becoming more of a concern during the design process. The storage and mitigation properties of bioswales and other green infrastructure systems can be reduced if the underground infrastructure in the region is exceeded during storm events. The functionality of bioswales to handle the runoff in an efficient manner must be also considered during the design phase of bioswale implementation.

The location in which bioswales are developed, whether it be residential, commercial, or other, contributes to their efficiency. Making better design decisions and creating new design standards to consider the changing climate of North Texas are the first steps to improving aesthetic properties of bioswales. The plants utilized within bioswales also contribute to the aesthetic properties of the systems. Incorporating native and drought tolerant plants ensure less plant loss and therefore better aesthetics.

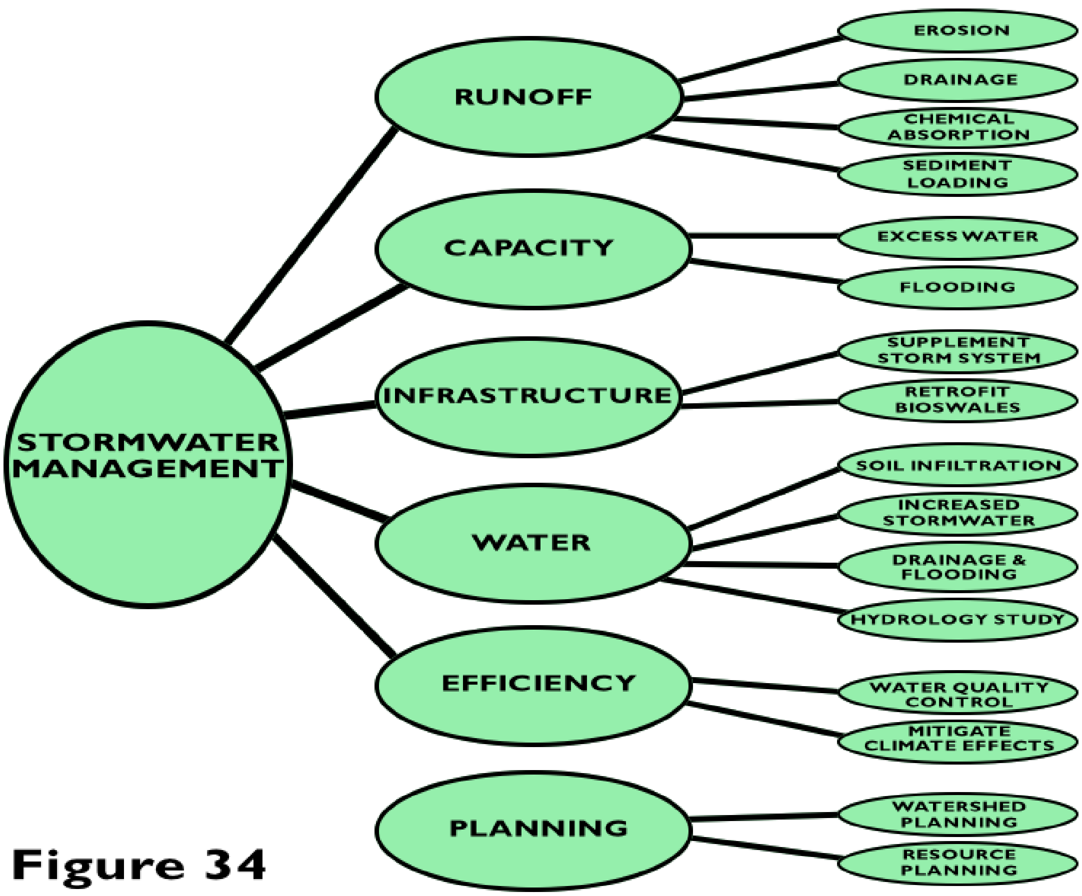


Figure 34

Stormwater management incorporates many aspects of bioswale function and success. As discussed in the design domain, excess water and flooding from greater storm events are beyond the designed capacity of bioswales in North Texas.

Runoff, especially from nearby development areas, can create further problems for bioswales in the form of greater erosion and sediment loading, reduced drainage within bioswales, and reduced chemical absorption capabilities. Bioswales can be incorporated into the existing stormwater infrastructure of North Texas to suppliment the existing underground stormwater system.

The efficiency of bioswales is directly correlated to the ability for the systems to mitigate the shifting climate within the region and control water quantity and quality. Further study into how increased water impacts bioswales in North Texas can help landscape architects and related professionals better plan for future green development within the region.

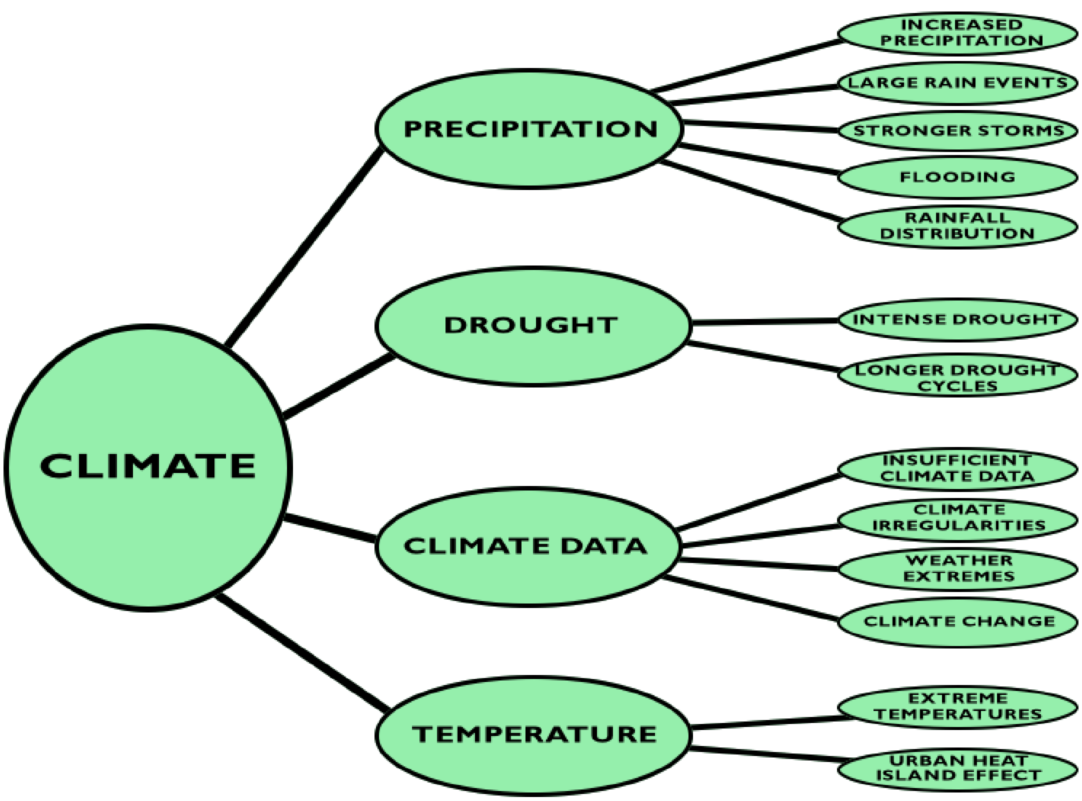


Figure 35

The domain of climate created a helpful graphic regarding the ways in which climate change affects the North Texas region. Not only does climate change create drought and increased rain, but the temperatures within the region are changing. The data on climate, specifically for the North Texas region, demonstrates that there are further irregularities. The interview participants voiced that the data on weather extremes and the climate data for this region are insufficient.

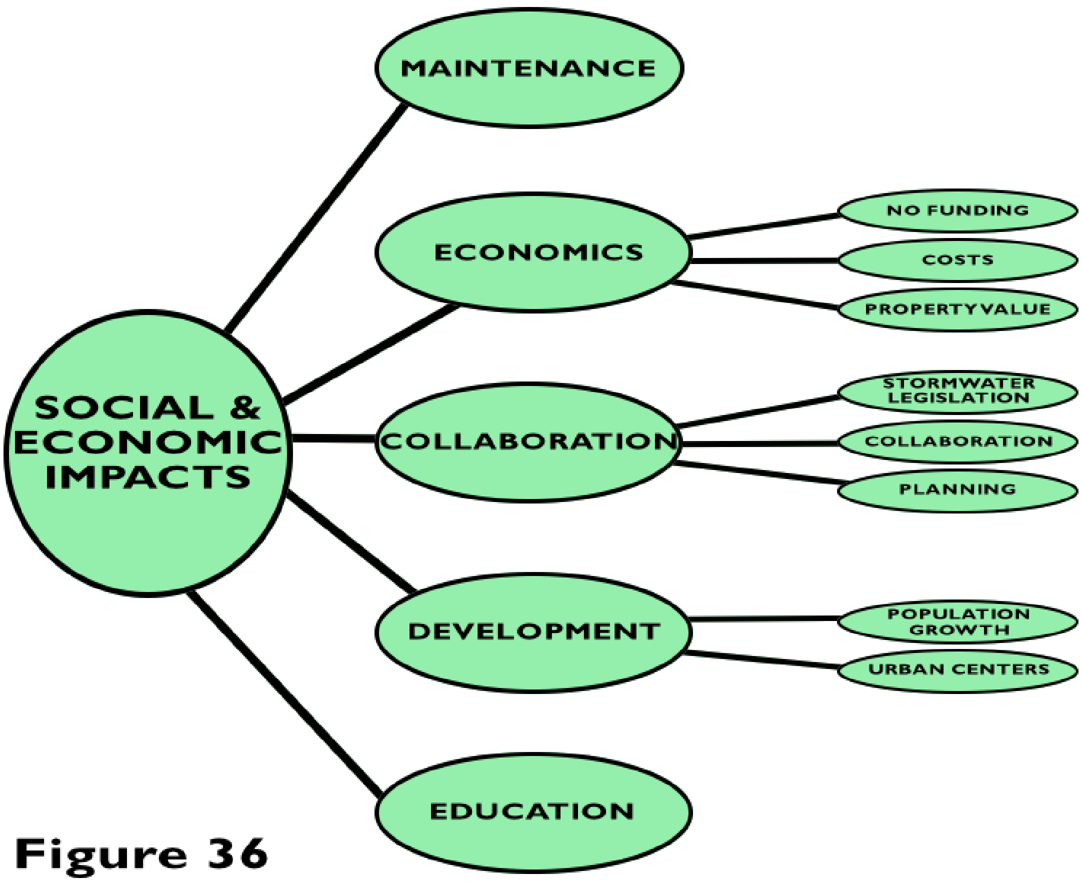


Figure 36

Social and economic impacts contribute to the majority of the decisions associated with bioswale implementation in North Texas. Funding for bioswale and green infrastructure research is limited, making the knowledge about bioswales with both the public and professional limited. Creating collaborative groups between related professionals within the region can open doors for planning future development. Bioswale implementation can contribute to increased property values in urban centers. The most discussed sub-domain within social and economic impacts was that of education. Without the spread of ideas and getting the word out about bioswales and green infrastructure, there will be no growth.

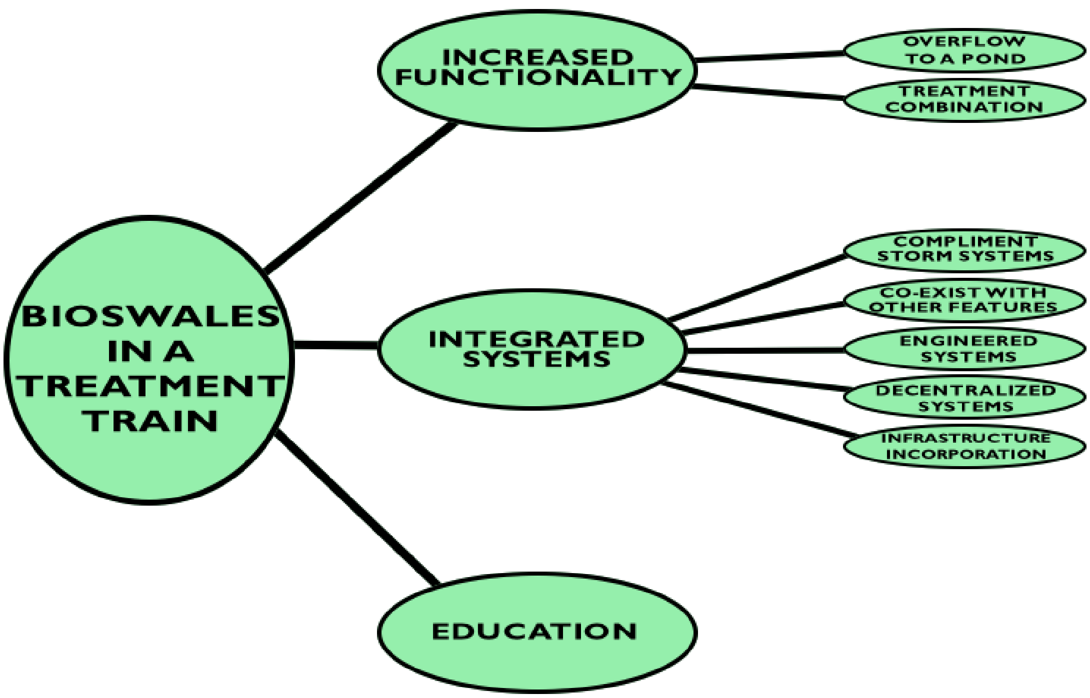


Figure 37

Incorporating bioswales into treatment trains increased functionality through the use of integrated systems. Constructing a bioswale in an area where it can overflow to a retention or detention pond when its capacity is exceeded, allows it to be more functional within the urban environment. Integrating bioswales with other types of green infrastructure contributes to the better incorporation with existing stormwater infrastructure and the creation of complementary systems.

More education is needed to further bioswale and treatment train implementation within North Texas.

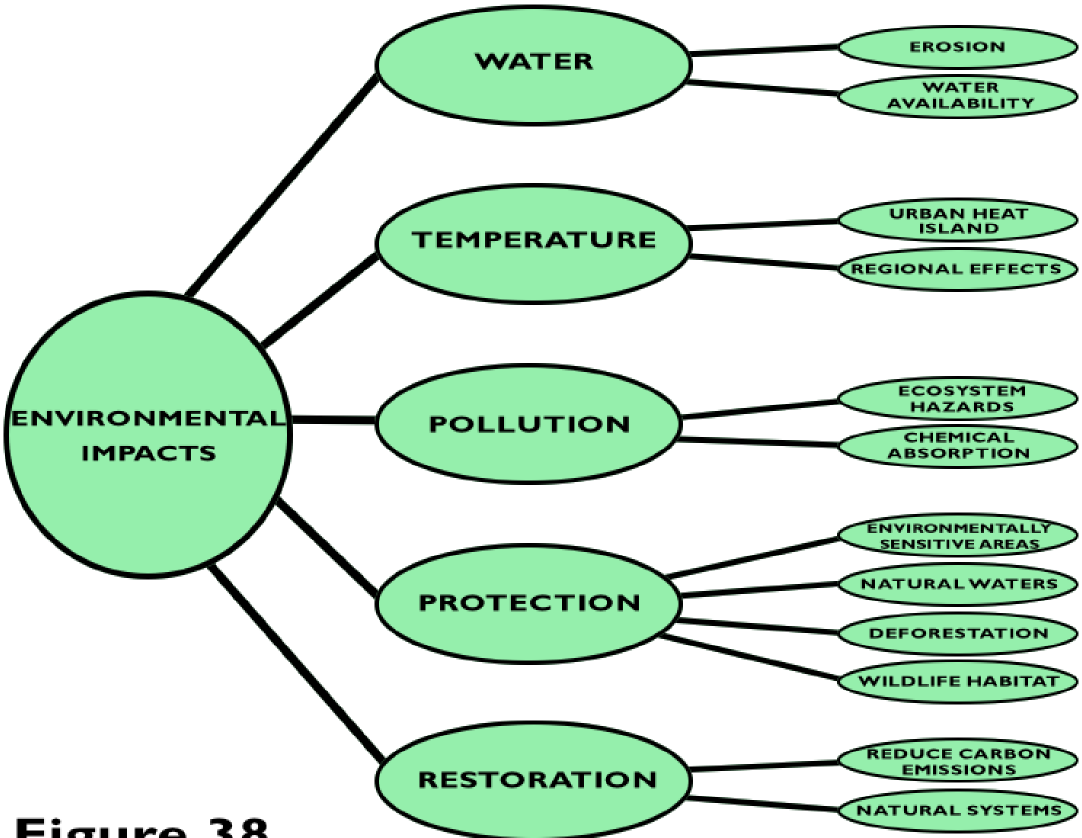


Figure 38

Water, temperature, pollution, environmental protection and restoration all contribute to the domain of environmental impacts. The extent to which bioswales contribute to the reduction of pollution, erosion, water usage, and urban heat island effect within North Texas is not fully known. Protection of environmentally sensitive areas, natural waterways, local forests, and wildlife habitats can all be positively affected by bioswales within North Texas. They can also help restore natural systems and reduce carbon emissions and other pollutants within the region.

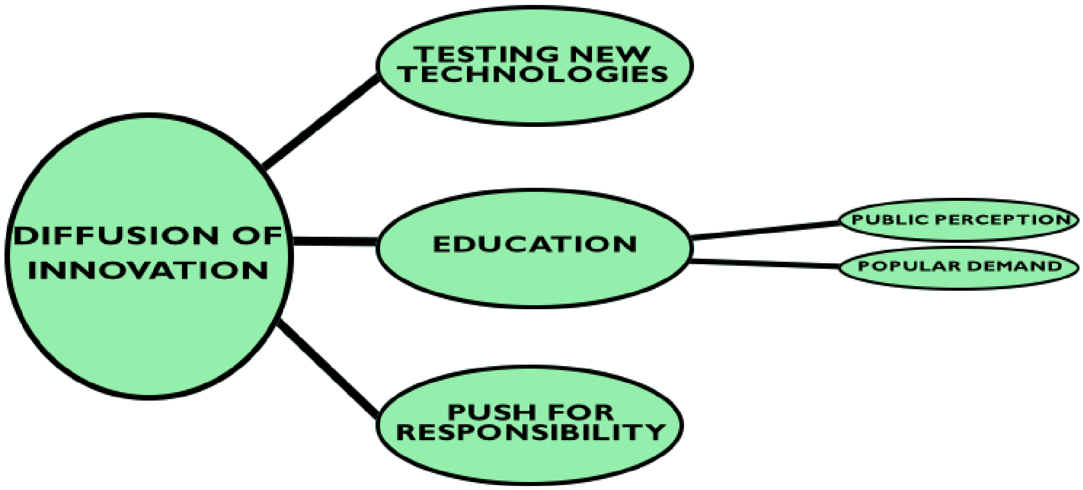


Figure 39

The diffusion of innovation is the driving force for furthering bioswale implementation in North Texas. New technologies, incorporating the regional climate change data, contribute to creating more functional/sustainable bioswales in the region. Pushing the public and officials within North Texas to be responsible for water management will have a drastic impact on the growth of green infrastructure. Creating better avenues in which to educate the public and industry professionals will create more demand for bioswale technology.

4.4 Conclusion

Chapter Four has assessed the findings from interviews with practicing landscape architects and related professionals from the North Texas region. The interview findings were analyzed using the domain analysis method to find similar themes and terminology within the responses. Although the answers were not always identical, the responses across questions and participants fell into similar themes. The three most prominent recurring themes were those of stormwater management, design, and climate.

The respondents had a basic knowledge of the climate conditions of the region and how this will affect the practice of landscape architecture over time. The affects of bioswales within the built environment were perceived overall as positive. Design, placement, and education are components that will need further consideration for bioswales and other forms of green infrastructure to gain more popularity within North Texas.

CHAPTER 5

CONCLUSION

5.0 Introduction

The intent of this research was to study how bioswales could be affected by the impact of climate change in North Texas. The research revealed the extent of knowledge landscape architect and related professionals within the region possess regarding the implications of climate shifts and events on bioswales. Chapter 5 provides a synopsis of the findings from the research and professional interviews, and proposes suggestions for further research.

5.1 Research Summary

Analysis of the ways in which landscape architects and related professionals approach the utilization of bioswales in North Texas has the ability to influence the way these systems are designed and deployed to manage stormwater in the future. The climate change in North Texas is projected to become more extreme, with increasing frequency and intensity of severe storm events (Melillo, et al., 2014). If these climate shifts only slightly affect bioswales, simple solutions such as changing plant material can reduce these impacts. Larger affects, such as the inability for bioswales to manage greater stormwater intensity, make the case for a more in-depth engineering insight into the hydrologic capacity of these systems. With temperatures, precipitation rates, storm events, and the number of consecutive dry days all increasing, the method in which bioswales are designed and utilized needs to adapt to these changes.

Since bioswales are designed with the intent of receiving stormwater, larger storm events can typically overload these structures, affecting their ability to function properly. When large storm events occur, bioswales rarely have the capacity to handle increasing volumes of runoff and stormwater. They become more susceptible to complications such as unprocessed storm flows, debris impending the efficiency of the systems, plant and soil material eroding, and other maintenance issues, as was stated by some of the interview participants. Extended droughts are also a matter of importance. The soil used in bioswales, be it native or engineered, can have a dramatic impact on the structure's success, or lack thereof, during times of drought. Plant material is the component that needs to be the most adaptable to both conditions. All of these aspects must be considered during the design and installation of bioswales in North Texas.

5.2 Responses to Research Questions

1. *Do landscape architects and related professionals in North Texas consider water management primarily on an on-site basis or do they also consider the greater watershed impacts?*

According to this research, landscape architects and related professionals consider water management primarily on a site-specific basis. All of the participants interviewed made comments that watershed implications are important, but due to budgetary constraints, project timelines, client interest or general lack of information about bioswales and other green infrastructure practices, watershed scale impacts are not highly considered in most projects. Three of the participants interviewed referenced their resources and research on watershed level impacts of climate change, but without the funding to continue research or construct more green stormwater management projects throughout the watershed, there will be no significant change. While this avenue is considered in the broad planning phase of some projects, managing water on-site is all that is required by development practices policies, and it is the most important goal during the watershed-planning phase of projects.

2. *How do landscape architects and related professionals in North Texas gain knowledge about bioswales?*

The sources of information gathering for landscape architects and related professional varies. Attending conferences and presentations such as the ASLA Conference or continuing education classes offered by North Carolina University were one way that interview participants received information. Another was reading about successful bioswale and green infrastructure projects in Landscape Architecture Magazine and various other journals and online databases. The negatives associated with these sources is that they rarely publish information about unsuccessful projects, so the data provided is likely to be skewed. This was also mentioned about gathering information from vendors. Even when considering these two sources, the researcher could not find a rigorous resource for obtaining information about bioswales specific to North Texas. One of the participants does hands-on scientific field research through a state university to establish firsthand research in this region. He was also cited as a good resource by several of the other interview participants.

3. *How does the avenue from which landscape architects and related professionals gain information affect the Diffusion of Innovation?*

The avenues by which landscape architects and related professionals gain information has a considerable impact on the Diffusion of Innovation for the resiliency of bioswales to the projected climate change in North Texas. As noted by several of the interviewees, there is no consensus about the best source or sources of information about bioswales specific to North Texas. The need for landscape architects and related professionals to compile information from alternative sources outside of the region often discourages them from sharing the data that has been gathered. All of the interview participants expressed the need for further educating both the general public and industry professionals about the uses, benefits, drawbacks, and design considerations of bioswales in North Texas. There also seemed to be a bifurcation of information between disciplines involved in the implementation of bioswales and other methods of green infrastructure. Engineers, hydrologists, landscape architects, city officials, and others all seemed to have different information about the process of implementing bioswales. Bringing these professions together to create interdisciplinary groups for various green infrastructure projects could be the best solution for idea and knowledge sharing.

The lack of a reputable source of information and lack of collaboration affects the Diffusion of Innovation on bioswales to the public and industry professionals.

4. *How are landscape architects and related professionals responding to projected climate changes in North Texas, and how do they expect it to affect the resiliency of bioswales in the region?*

Landscape architects and related professionals are responding to the projected climate change in North Texas by considering the resiliency of materials used and structural capacity of bioswales. The plant materials and soil composition used in bioswale development are important to the overall success of these projects. Incorrect plant selection leads to plant loss and reduced water filtration abilities of bioswales. Incorporating bioswales into treatment train systems allows for greater stormwater capacity and a greater ability to mitigate runoff and flooding during large storm events. The professionals that contributed to this research have considered the climate implications on bioswales and are making these design considerations to ensure the continued viability of these structures moving forward. A more in-depth consideration of materials used in bioswales could create better alternatives for resilient green infrastructure projects in North Texas.

5.3 Significance on the Practice of Landscape Architecture

The responsibilities of landscape architects and related professionals are changing in North Texas. The projected climate changes create the necessity for more water-conscious, more resilient methods for approaching landscape initiatives and water management in the region. The ability for landscape architects to work in conjunction with engineers, architects, water management agencies, municipalities, hydrologists, and other disciplines will determine if they can adapt to not only the changing climate, but also the changing application of landscape architecture within North Texas.

5.4 Recommended Research

To further consider the ways in which landscape architects and related professionals evaluate the implications of the projected climate change on bioswales in North Texas, the following can be explored:

1. How can landscape architects affect change in stormwater management through the use of bioswales in North Texas?
2. What role do plants play in contributing to pollutant filtration and removal from stormwater runoff in bioswales?
3. How can interdisciplinary cooperation contribute to the growth of green infrastructure in North Texas?
4. How is the role of landscape architects in North Texas being affected by interdisciplinary relationships?
5. Is there a best combination of green infrastructure devices for treatment trains in the North Texas region?
6. How can bioswales best be utilized as part of a treatment train in North Texas?
7. How can landscape architects improve the Diffusion of Innovation about green infrastructure in North Texas?

8. Are pollutant removal rates in bioswales affected by heavy rains in North Texas?
9. Are the pollutant filtration capacities of bioswales affected by more intense storm events in North Texas?
10. What are the best sources for providing landscape architects and related professionals with data concerning the utilization of bioswales in North Texas?

5.5 Conclusion

When designed using appropriate materials, bioswales have the potential to be more resilient in the face of the projected change in weather events in North Texas. The climate change in the region affects how, where, and with what materials these structures should be designed. Based on this research, landscape architects and related professionals create opportunities for these and other green infrastructure installations to mitigate stronger storm events, and to be resilient during longer projected drought conditions. In order to continue development of these structures and the Diffusion of Innovation regarding their use, interdisciplinary relationships need to be strengthened. Furthermore, creating more education opportunities for both industry professionals and the general public is of great importance to the continued implementation of bioswales and other forms of green infrastructure projects throughout the North Texas region.

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