Treatments of Contaminants from Hydraulic Fracturing:

A Study of the Attitudes of Professionals Towards the Use of

Phytoremediation Methods in Tarrant County

by

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And a special shout out to the friends, studio mates, and loved ones that have been with me since day one.

You guys rock!

* I fought for what I wanted and reached my goal.

ABSTRACT

Treatments of Contaminants from Hydraulic Fracturing:

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The University of Texas at Arlington, May 2021

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Hydraulic fracturing poses challenges to the environmental stability of the areas surrounding a hydraulic fracturing site due to exposure to the byproducts of the hydraulic fracturing process. (Rahm, 2011; Perry, Sutton, Guo, Yan, & Yang, 2018; Gómez-Sagasti et al., 2012; Richardson et al., 2015). The use of hydraulic fracturing has increased in the United States, notably in North Texas. As the population of the DFW metroplex increases, oil and natural gas companies have begun to construct hydraulic fracturing sites within neighborhoods in the urban setting (Rahm, 2011). As the number of wells created in the urban setting continues to increase, efforts are being made nationwide to discover ecological and minimally invasive methods to treat the toxic byproducts of the fracturing process, such as phytoremediation and phytotechnology. Phytoremediation and phytotechnology methods are currently used to treat polluted soils and water in mining and sites with heavy metal usage and are also subject for research as methods for treating the contaminants left behind by the hydraulic fracturing process (Perry, Sutton, Guo,

Yan, & Yang, 2018). Phytoremediation has shown promise in delivering lower cost remediation for sites that are considered to have low levels of contaminants. The type of methods used for phytotechnology and evidence that supports the use of indigenous and regionally based plant palettes can be customized according to the specific pollutants found in the flowback fluids and other industrial activities (Kennen & Kirkwood, 2017). However, it is a method which has not been extensively studied in the applications of hydraulic fracturing treatment within the state of Texas.

This research assesses the current attitudes of practicing professionals in Tarrant County of this method of remediation. Subjects of the study include implementation of phytotechnology methods to treat pollutants found in flowback fluids such as BTEX (Benzene, Toluene, Ethyl benzene, and Xylene), environmental and ecological benefits, and the feasibility of implementing regionally native plants. The study area will be limited to Tarrant County, and will focus on the overlap of the Barnett Shale with the Tarrant County biome to study the potential of a regionally appropriate plant pallet. By discussing the current policy and regulations which exist in the state of Texas and in Tarrant County for the remediation of flowback fluid contaminants, a case is made for the importance of studying the implementation of phytotechnology treatments as a solution to treat the surrounding soil of hydraulic fracturing pads, the water found in flowback fluids, and the implementation of a regionally appropriate plant pallet.

TABLE OF CONTENTS

List of Tables 9

List of Figures 9

Chapter 1 Introduction 11

1.1 Introduction 11

1.2 Problem Statement 12

1.3 Research Purpose 13

1.4 Research Questions 13

1.5 Methodology 14

1.6 Analysis and Findings 14

1.8 Significance, Limitations, and Delimitations 17

1.9 Conclusion 18

Chapter 2 Literature Review 19

2.1 The Need for Treatment of Fracturing 19

2.2 Phytoremediation and Phytotechnology 26

2.2.1 Phytovolatilization 30

2.2.2 Phytostabilization 31

2.2.3 Phytodegradation 32

2.2.4 Rhizodegradation 33

2.3 Benzene and its Effects on Health 34

2.4 Regional and Local Native Plants 35

2.4.1 Eastern Cross Timbers 37

2.4.2 Western Cross Timbers 37

2.4.3 Grand Prairie 37

2.4.4 Northern Blackland Prairie 38

2.5 Policy and Recommendations 38

2.6 Precedent Studies 39

2.6.1 Phytoremediation Study at Carswell Naval Station Golf Club, Fort Worth, TX 39

2.6.2 U.S. Coast Guard Former Fuel Storage Facility, Elizabeth City, NC 42

2.6.3 Westergasfabriek, Amsterdam, The Netherlands 49

2.9 Conclusion to Literature Review 52

Chapter 3 Methodology 53

3.1 Introduction 53

3.2 Literature Review 54

3.3 Interview 54

3.4 Study Population and Location 55

3.5 Data Collection 55

3.6 Domain Analysis 56

3.7 Research Limitations 56

Chapter 4 Analysis and Findings 58

4.1 Introduction 58

4.2 Domain Analysis of Interview Data 58

4.2.1. Initial Analysis of Collected Interview Data 58

4.2.2 Identifying the Domains 62

4.2.3 Creating a Taxonomy of Subdomains 63

4.3 Findings – Specifying the Primary Domains 65

4.3.1 Current post-use remediation methods 65

4.3.2 Phytoremediation 67

4.3.3 Plant Pallet 69

4.3.4 Future within the Profession 71

4.4 Summary: Findings – Relating the Domains 72

Chapter 5 Conclusion 74

5.1 Introduction 74

5.2 Synthesis of Findings 74

5.3 Conclusions and Discussion 75

5.5 Future Research 79

5.6 Conclusion 82

Appendix: Interview Questions 83

References 93

List of Tables

Table 1 *Local Native Plant Pallet* 35

Table 2 *Ecoregions Found in Tarrant County* 36

Table 3 *2007 Soil Gas TPH Overlaid by Tree Mortality* 46

Table 4 *Average Soil Gas Decrease from 2007 to 2008* 49

Table 5 *Division of Participant [disciplines or professions]* 59

Table 6 *Preliminary List of Themes* 61

Table 7 *Second Cycle of Coding Example* 62

Table 8 *Current Post-Use Remediation Subdomain Mentions* 65

Table 9 *Phytoremediation Subdomain Mentions* 67

Table 10 *Plant Pallet Plant Type Recommendations* 69

Table 11 *Future within the Profession Subdomain Mentions* 71

List of Figures

Figure 1.1: *Natural Gas Shales within the State of Texas* 12

Figure 2.1: *Natural Gas Wells within the State of Texas* 20

Figure 2.2: *Natural Gas Wells within Tarrant County and surrounding Counties* 21

Figure 2.3: *Hydraulic Fracturing Process* 24

Figure 2.4: *Hydraulic Fracturing Site in Pennsylvania* 25

Figure 2.5: *Site Contaminants Chart* 28

Figure 2.6: *Phytomechanisms Diagram* 29

Figure 2.7: *Phytovolatilization Diagram* 30

Figure 2.8: *Phytostabilization Diagram* 31

Figure 2.9: *Phytodegradation Diagram* 32

Figure 2.10: *Site Contaminants Chart* 33

Figure 2.11: *Contamination of Carswell Field and Designation of Phytoremediation Demonstration Site* 40

Figure 2.12: *Fuel Location and Analysis* 43

Figure 2.13: *Overall Planting design of phytoremediation plan* 44

Figure 2.14: *Mapping showing the loss of soil gas mass of BTEX over one and a half growing seasons* . 47

Figure 2.15*: Mapping showing the loss in soil gas mass of petroleum hydrocarbons (TPH). TPH represents BTEX plus larger, volatile petroleum hydrocarbo*ns 48

Figure 2.16: *Westergasfabriek Master Plan* 51

Figure 3.1 *Research Design Diagram*........ 53

Figure 4.3: *Taxonomic Analysis of Primary Domains*........ 64

Chapter 1

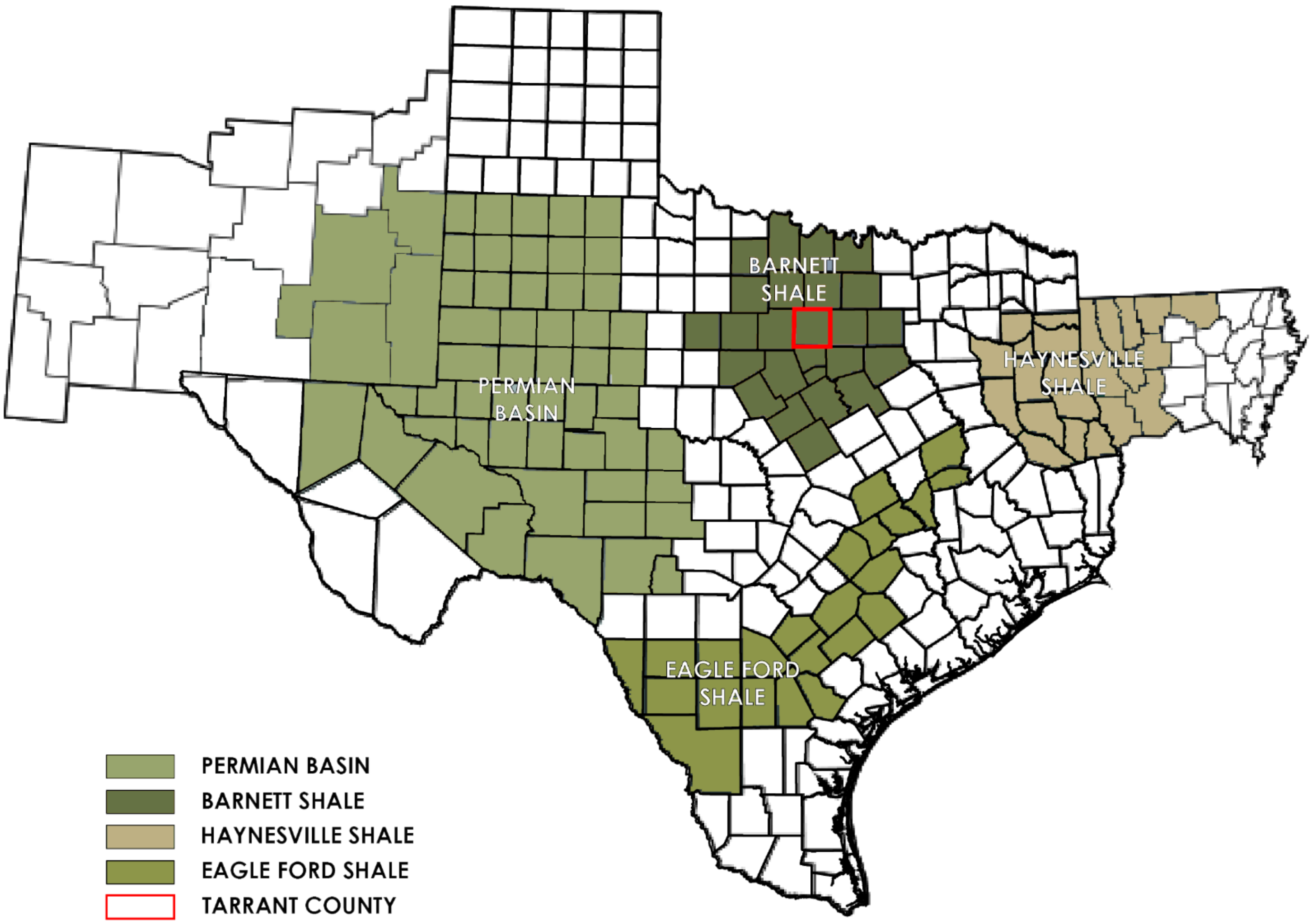
Introduction

1.1 Introduction

The use of hydraulic fracturing in the extraction of oil and natural gas has increased in the United States, with hydraulic fracturing occurring in all four major shales in Texas (see Figure 1.1). With a portion of the Barnett Shale located within the DFW metroplex and the rapid expansion of the urban population, natural gas industries are creating hydraulic fracturing wells within the urban context. The erection of these new pipelines within the Barnett Shale has caused issues for these high-pressure gas lines which are now within the proximity of residential areas (Rahm, 2011). In 2011, it was predicted that at the time of establishment, the Barnett Shale will have nearly 6,000 wells within the City of Fort Worth, thus becoming the first urban gas field in the country (Rahm, 2011).

With the establishment of these wells, the concerns of environmental pollution created by the hydraulic fracturing process have become a topic of interest (Richardson et al., 2015). The process of hydraulic fracturing uses hydraulic fluid, called flowback fluid or produced water, consisting of a combination of water, proppant, and chemical additives. This fluid is pumped at high pressures into the selected rock formation in a well, creating a fracture in which natural gas is extracted. This process requires the fluid to be returned to the surface where it is then stored in concrete tanks until it is treated or disposed of. Although this fluid is extracted into these tanks, not all of the water is captured. This results in contamination of the surrounding soil and water located near the hydraulic fracturing pad (Shores, Hethcock, & Laituri, 2018).

Figure 1.1: *Natural Gas Shales within the State of Texas*



Source: Federal Reserve Bank of Dallas

1.2 Problem Statement

Current methods of remediation for polluted soil include a variety of physicochemical remediation methods. These processes involve using chemicals to modify the state of contaminant particles (chokhavatia.com, 2020), which have proven to be economically unattractive. These methods "result in a considerable deterioration of the soil ecosystem…and do not permit a natural reshaping of the soil ecosystem." (Gómez-Sagasti et al., 2012). Conventional methods involve the excavation and landfilling of soil, washing, and replacement of soil with clean materials, in extreme cases, capping the site with an impenetrable material to create a protective layer. (Gómez-Sagasti et al., 2012)

These practices have brought about that "there is a growing concern, and controversy regarding the practice of hydraulic fracturing" (Rahm. 2011). These concerns become more prevalent when it comes to the presence of contaminants in air emissions, the potential for water contamination, and ecological worries. (Rahm, 2011; Perry, Sutton, Guo, Yan, and Yang, 2018)

1.3 Research Purpose

Currently, hydraulic fracturing sites are treated using one of the previously mentioned methods, but phytoremediation is considered "a widely accepted and less invasive measure to remove toxins from the environment" (Shores, Hethcock, & Laituri, 2018). This research addresses the following:

1. An assessment of phytoremediation as an alternative method of remediation through literature and the opinions of professionals towards the use of phytoremediation.
2. An exploration of the potential for regionally native and locally native plant use for the phytoremediation process in Tarrant County.

1.4 Research Questions

Taking the research objectives into consideration, the following questions are explored in this research.

1. What are the current policies in place for Tarrant County which promote or hinder phytoremediation methods as a treatment if flowback fluid contaminants?

2. What regionally appropriate plants to the Tarrant County biomes could be used to effectively remediate pollutants on hydraulic fracturing sites?
3. What locally indigenous plants to the Tarrant County biomes could be used to effectively remediate pollutants on hydraulic fracturing sites?
4. What are strategies that can be adopted by landscape architects and allied professions to promote phytoremediation in Tarrant County on hydraulic fracturing sites?

1.5 Methodology

The data for this study was collected through the process of in-depth interviews. The goal was to understand the current attitudes of professionals over the current procedures used to treat flowback fluid contaminants and on phytoremediation. Interview questions were created from the information gathered in the literature review over the most relevant topics to create a list that could be answered by different professionals.

1.6 Analysis and Findings

The interview process focused on collecting qualitative data from the participants to allow the researcher to gather opinions of the selected group of individuals. Practices, such as snowball sampling (Sommer and Sommer, 2002) and semistructured interviews (Sommer and Sommer, 2002), allowed for a deeper understanding of the opinions of the participants. The collected data was coded using Saldaña’s (2016) coding of key terms method.

The coded data was then put through another coding process named domain analysis (Atkinson and Haj, 1996). This four-step process allowed a further understanding of the recurring topics which emerged from the data, in order to obtain specific domains to further analyze the data.

1.7 Definitions of Terms

This research focused on the attitudes of landscape architects and the allied professions on phytoremediation as a remediation method to treat contaminants on hydraulic fracturing sites. The following definitions provide information that is not referenced in the body of this document.

Abandonment: As defined by the Railroad Commission of Texas, it is the plugging of a well and restoration of the drill site to as close as possible to its original condition, in conformity with the regulations. (Arlington 2011, Sec. 7.03).

Completion: The method used to prepare a well for production and drilling. This includes installation of equipment for production. (GWPC 2009, p. 81)

Disturbance: An event that significantly alters the pattern of variation in the structure or function of an ecological system (Forman 1995, p. 38).

Gas well pad site: "An area dedicated to all gas well drilling and production activities, including the drill site, all structures, closed-loop drilling systems, dehydrators, parking areas, security cameras, lighting, tanks, tank battery, drilling rigs, separators, compressors, perimeter walls, utilities, and all other features or objects contemplated for use during and after gas well drilling or production, as designated on the gas well development plat or gas well development site plan" (Denton 2010, 22-2).

Horizontal drilling: "A drilling procedure in which the wellbore is drilled vertically to a kick-off depth above the target formation and then angled through a wide 90-degree arc such that the producing portion of the well extends horizontally through the target formation." (GWPC 2009, p. 82).

Hydraulic fracturing or fracking: The injection of a mixture of sand, water, and chemicals into dense rock layers and shale, creating cracks that allow natural gas trapped inside to escape to the surface (Svoboda 2010).

Phytoremediation: The use of plants to remediate contaminants which have seeped into the surrounding soil and water. (Kennen & Kirkwood, 2017)

Phytotechnology: Including the use of plants used for phytoremediation, these are systems which can help treat and prevent future contamination events. (Kennen & Kirkwood, 2017)

Plugging: The process of filling a well hole with concrete and soil and marking it for future notification. This must be done within one year after operations have ceased (Varela 2000, p. 1).

Proppant: "Silica sand or other particles pumped into a formation during a hydraulic fracturing operation to keep fractures open and maintain permeability" (GWPC 2009, p. 83).

Reclamation: Rehabilitation of a disturbed area to make it acceptable for reuse. This involves regrading, replacement of topsoil, re-vegetation, and other work necessary to restore it (GWPC 2009, p. 83).

Rhizosphere: Soil found in the area surrounding the plant roots that is influenced by the root as well. This is an area of high nutrients and has an active microbial population. (Kennen & Kirkwood, 2017)

Stabilization: Using plants which uptake contaminants in a soil, but do not break it down, but absorb it and keep it stabilized. These plants require proper disposal. (Kennen & Kirkwood, 2017)

Watershed: Land which is enclosed by a continuous hydrologic drainage divide and lay upslope from a specified point on a stream (GWPC 2009, p. 84).

1.8 Significance, Limitations, and Delimitations

This research aims to inform landscape architects and environmental consultants on alternative methods to Biochar or other engineered methods for the remediation of hydraulic fracturing sites. It will also study the current perspectives of professionals in landscape architecture and design and allied industry professionals on phytoremediation methods. This study will not include politicians as an allied profession. This information will facilitate active consideration of plant-based approaches for the remediation of hydraulic fracturing contaminants.

However, the study has been limited by variables outside of the researcher's control. These limitations included a limited number of published case studies found by the researcher on the longitudinal effects of hydraulic fracturing, a notable deficiency in the number of completed case studies of phytoremediation used on hydraulic fracturing sites, and a limited number of published public information documents on the subject available from the natural gas industry. Studies of the same nature have collected their data based on the application of phytoremediation on hydraulic fracturing sites but had not been published at the time this research was conducted.

This study will study the treatments which would work best within the Barnett Shale and the Tarrant County biome. Information for this research was gathered through a cross-disciplinary investigation.

1.9 Conclusion

This chapter has provided a brief summary of this research and will serve as an outline for the rest of this document. The research aimed to achieve insight into the relevance of phytoremediation and hydraulic fracturing to practicing professionals in the year 2021. Professionals from allied fields to landscape architecture and hydraulic fracturing were interviewed to create a broader spectrum. However, the researcher is also aware that this research is only a small portion of the actual views within the profession. With this known, this research aims to provide a snapshot of current attitudes and offer potential avenues for the future of this research.

Chapter 2

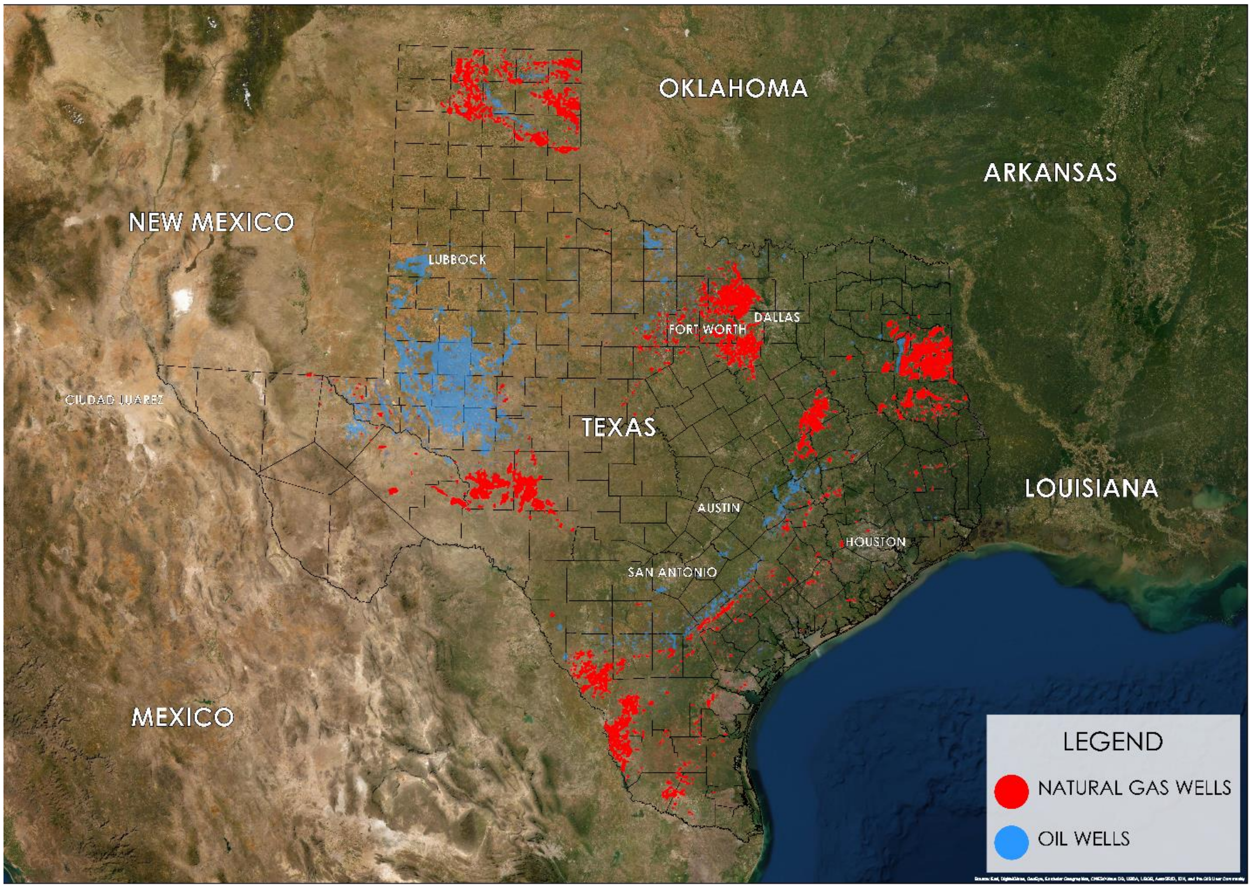
Literature Review

This literature review focuses on the importance of addressing the impacts of fracturing from the perspective of a landscape architect. The review will start with the need for phytoremediation treatments in hydraulic fracturing sites, an overview of phytoremediation and phytotechnologies, the implications of the fracturing process on the contamination of local water, and the health implications which it causes within an urban context. As fracturing sites move from rural sites and are now being constructed within the urban context, the implications of having fracturing occurring close to everyday settings are something that should be considered as cities continue to develop. This chapter will review the current methods of treatment of flowback fluid, the effects of pollutants, such as benzene, on its surroundings, various phytotechnology methods which can be used to treat oil and petroleum sites, and how landscape architects have begun to treat previously functional fracturing sites.

2.1 The Need for Treatment of Fracturing

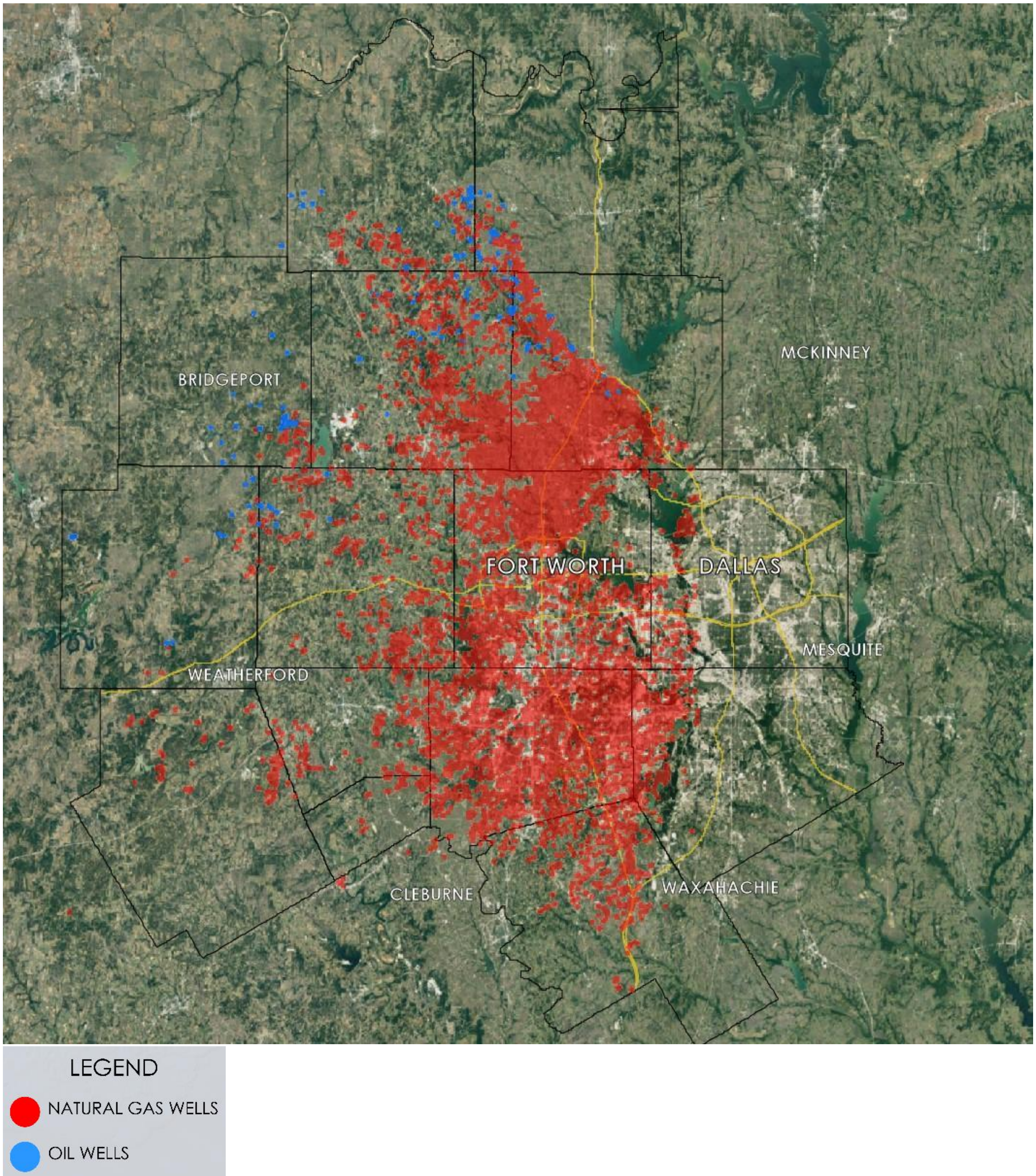
As the use of hydraulic fracturing in the United States has grown as a method of production since the early 2000s, the negative impacts which these productions cause have begun to appear in various towns and cities. This has caused the city government to begin banning new fracturing sites as occurred in Denton, Texas in 2014. (Williams, Havens, Banks, & Wachal, 2007). According to the Fracktracker Alliance, a non-profit organization that focuses on investigating health concerns and data gaps surrounding fracturing, there are a total of 101, 266 functioning wells within the state of Texas, with 12,000 of them located within the Fort Worth Basin which can be seen in Figure 2.2 (FracTracker Alliance, Jackson, & Kelso, 2020). As the usage of fracturing increases, mitigation efforts of contaminants, along with the revegetation of fracturing sites postproduction, aim to achieve a pre-production state.

Figure 2.1: *Natural Gas Wells within the State of Texas*



Source: TCEQ, 2018

Figure 2.2*: Natural Gas Wells within Tarrant County and surrounding Counties*



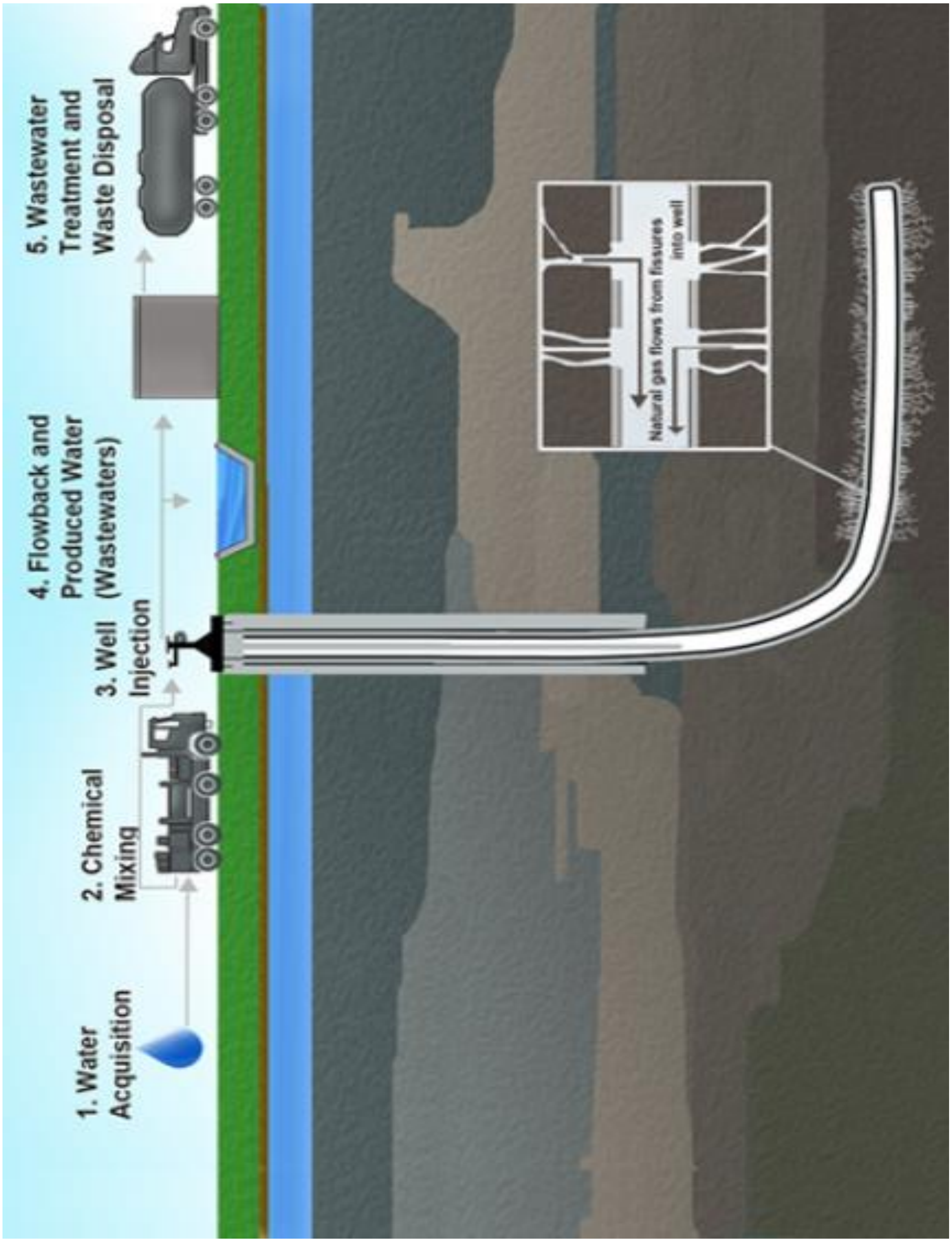
Source: TECQ, 2016

The Barnett shale is estimated to cover close to five thousand square miles and is located within twenty-five counties, twelve of which are located within the North Central Texas Council of Governments (NCTCOG) region. A report on research conducted by the Groundwater Protection Council (GWPC), a national nonprofit association created to promote the protection and conservation of groundwater sources, stated that sites are chosen for horizontal proximity to gas reserves in the shale and other wells in the immediate area. This caused overall concerns over health risks, habitat loss, and the impact on adjacent land values, concerns which are moving to the forefront of discussion in relation to local government policies (GWPC 2009).

It was also determined that the average rock formation of a well in the Barnett Shale typically takes up to thirty days to drill, later followed by production and completion phases. Depending on the regulations of a given municipality, there is typically more than one perforation completed to create a number of wells on a site. Once the well enters the production phase, the well is able to produce natural gas, which has to be processed before it is delivered to market.

This causes an increased amount of traffic to the area in the form of trucks. These trucks are culprits of site contamination from spilled fracturing fluids in transportation (Meng, 2014). A current study done by Fractracker.org (2015), states that on average 44 trucks can come and go off a producing site in an hour, with the potential to up to 116 trucks on sites with more than one well. Once a well is no longer functioning, the well is sealed using concrete, and the property is fenced off. The site can then be revegetated to remediate the land from any contaminants which might have seeped into the surrounding soil. Fracturing sites differ slightly from the traditional oil and natural gas wells which were commonly used prior to the early 1980s. The construction of a natural gas fracturing pad requires a larger pad site area to support the larger rigs and hydraulic fracturing simulation equipment used in the fracturing method. However, the need for land clearing, excavation, grading, pad construction, pipeline and utility installation, sump hole excavation, and the creation of related roads is still required (Meng, 2014).

Figure 2.3: *Hydraulic Fracturing Process*



Source: USGS

Figure 2.4: *Hydraulic Fracturing Site in Pennsylvania*

Source: Penn State

The implementation of screening and revegetation of the surrounding land has been a growing trend for the remediation and reclamation of fracturing sites. When it comes to revegetation, however, there are factors that work against these methods being used, especially when it comes to the use of phytotechnologies. These include the cost of the upkeep, installation costs, the lack of knowledge of native plants to use for phytoremediation, the time it takes for sites to be remediated to standard EPA safety levels, and the lack of actionable research regarding the benefits of phytotechnology treatment.

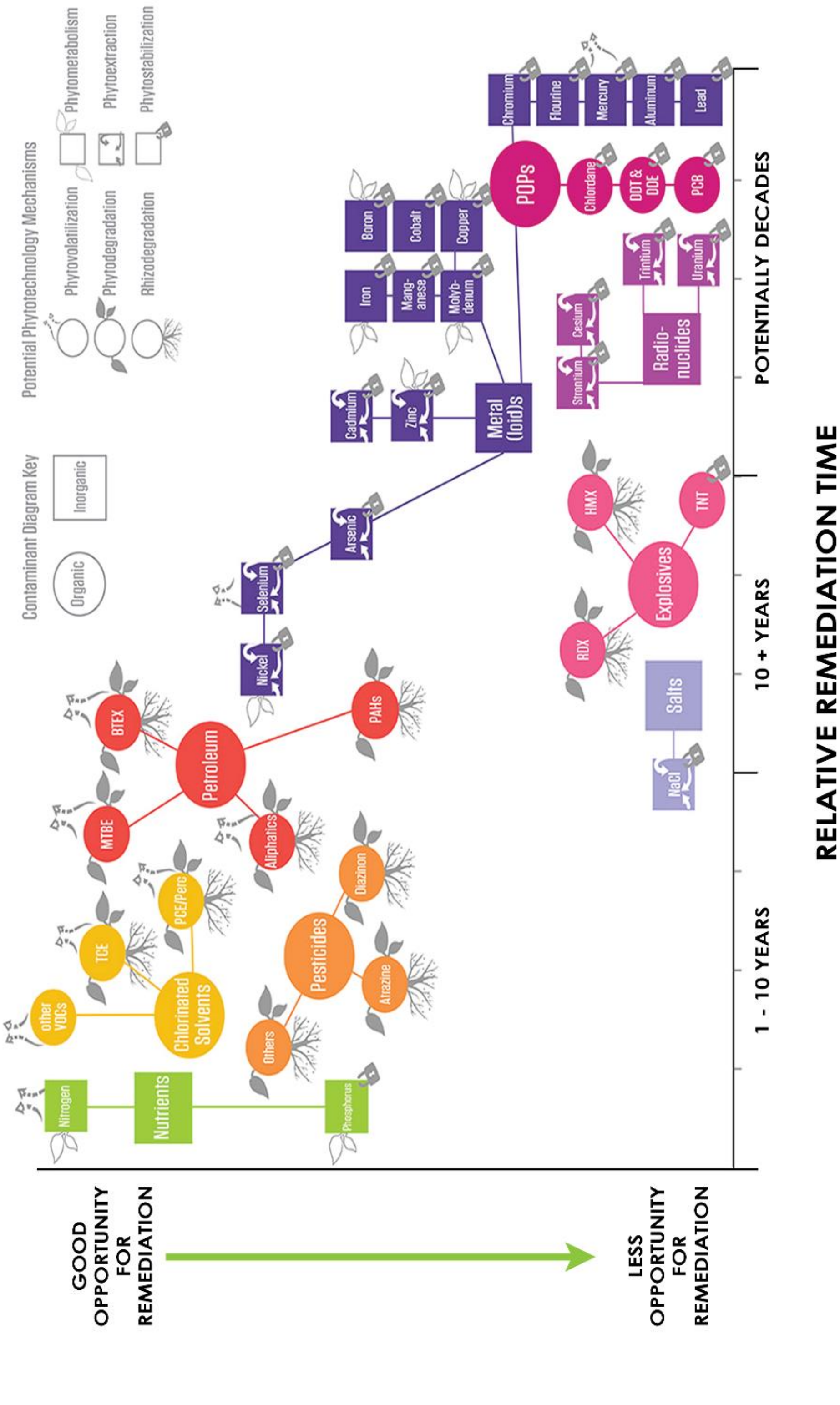
Usage and safety standards are set in place by the Environmental Protection Agency (EPA) for all forms of remediation. However, in the case of phytoremediation and phytotechnology, these are only guidelines, with no actual existing regulations. Regulations that have been created put public safety in the highest possible standard, which could help potential developers and promote the use of this practice for the design of fracturing well sites.

2.2 Phytoremediation and Phytotechnology

Phytoremediation and Phytotechnology are two terms that are often confused and used to refer to as the same process. However, they are two different processes and should be understood and used accordingly. Phytoremediation is the process by which a plant filters, degrades, and/or removes a particular type of pollutant using a specific group of plants (Kennen & Kirkwood, 2017). These plants have the ability to either eliminate the contaminants which are found on the site and/or to capture, filter, or uptake the pollutant amongst other properties. If uptake is the case, proper removal and disposal are needed depending on the contaminant which is absorbed.

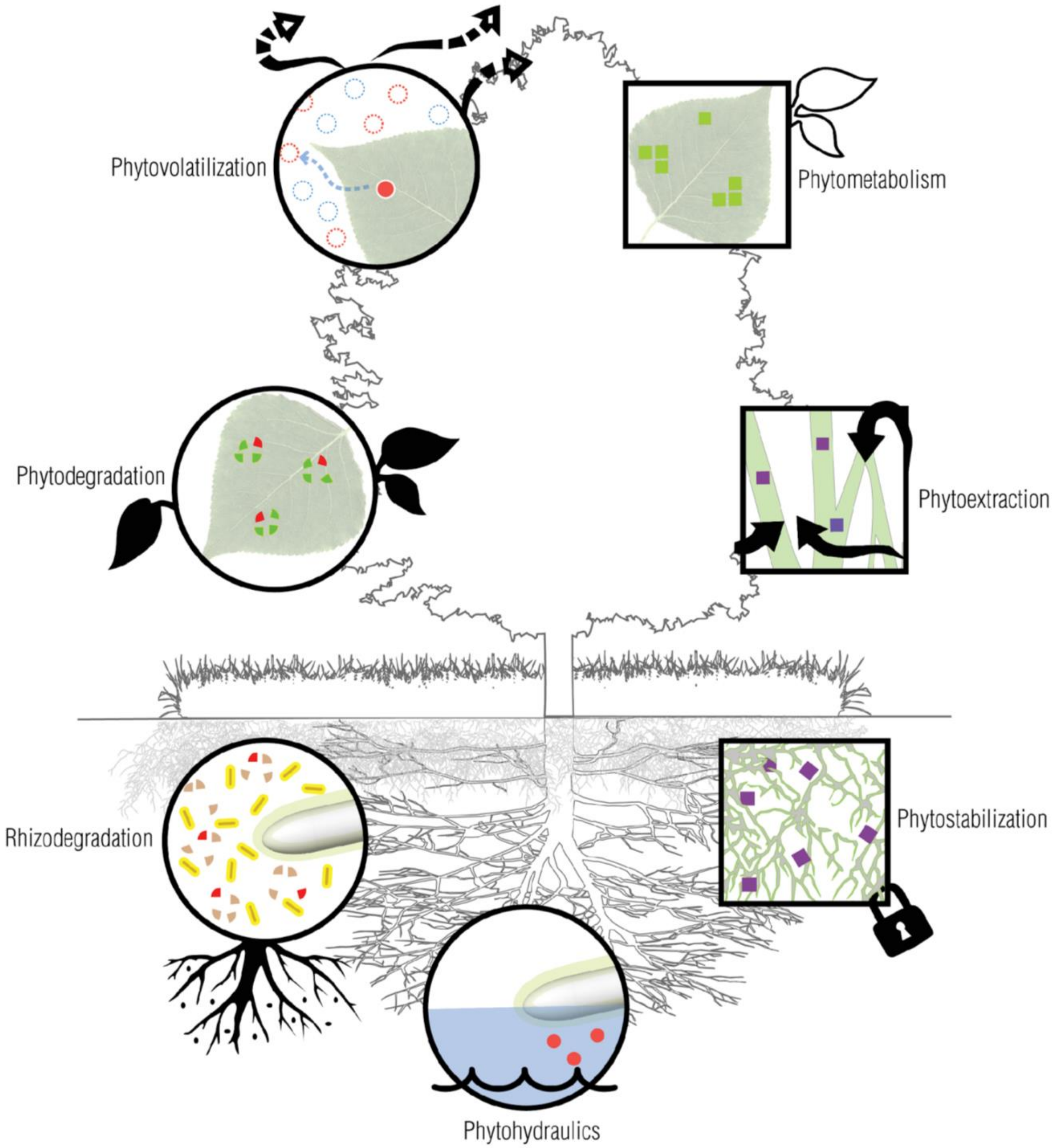
Phytotechnology includes the same qualities as phytoremediation, however, it also includes techniques such as stabilization of pollutants and pre-emptive measures to treat pollutants or mitigate future ecological problems (Kennen & Kirkwood, 2017). With stabilization, remediation is not the principal goal. Pollutants are rather stabilized and kept in place in the soil which they have leached into. Figure 2.6 shows a chart showing the opportunity for these methods, as well as how long the methods would take to be successful. Phytotechnology varies in methods of application for it includes all the plant-based pollution remediations (Figure 2.5), as well as all of the preventative systems. Figure 2.5 demonstrates the relationship between the present contaminant’s opportunity for remediation versus the amount of time in which the contaminant would be remediated. Contaminants that are considered to be hydrocarbons or volatile organic compounds have a higher possibility of successfully being remediated. However, contaminants that are considered metals or salts have a lower opportunity to be remediated and could take decades to be successful. For the purpose of this research, the methods of phytovolatilization, phytodegradation, phytostabilization, and rhizodegradation are the four styles addressed.

Figure 2.5: *Site Contaminants Chart*



Source: Kennen and Kirkwood, 2017

Figure 2.6*: Phytomechanisms Diagram*

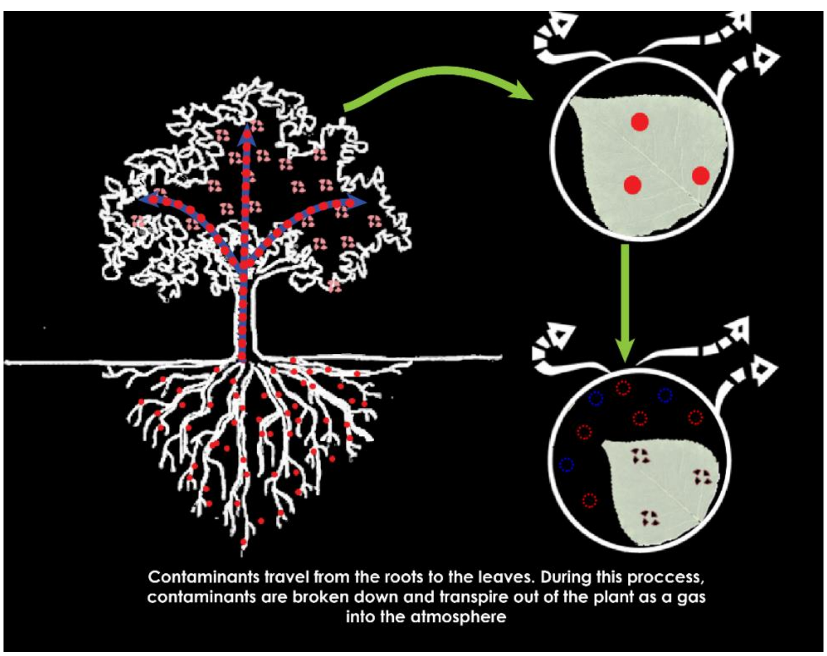


Source: Kennen and Kirkwood, 2017

2.2.1 Phytovolatilization

During phytovolatilization, the selected plants are used to uptake the pollutants which are in either solid, liquid, or gas form (Kennen and Kirkwood, 2017). This method can also be a metabolic process within the plant that could treat contaminants present in the soil and plant root system (Pivetz, 2001). Once the plant takes up the pollutant, the plant transpires the pollutant into the atmosphere as a gas which removes it from the site. While the pollutants are released into the air as a gas, the transpiration occurs slowly enough to where there is no visible and usually minimal impact on the local air quality (Ma and Burken, 2002). This method is commonly used to treat organic contaminants which do not take very long to be treated. In this case, petroleum and the byproducts of fracturing and drilling are contaminants that could be treated using this method.

Figure 2.7: *Phytovolatilization Diagram*

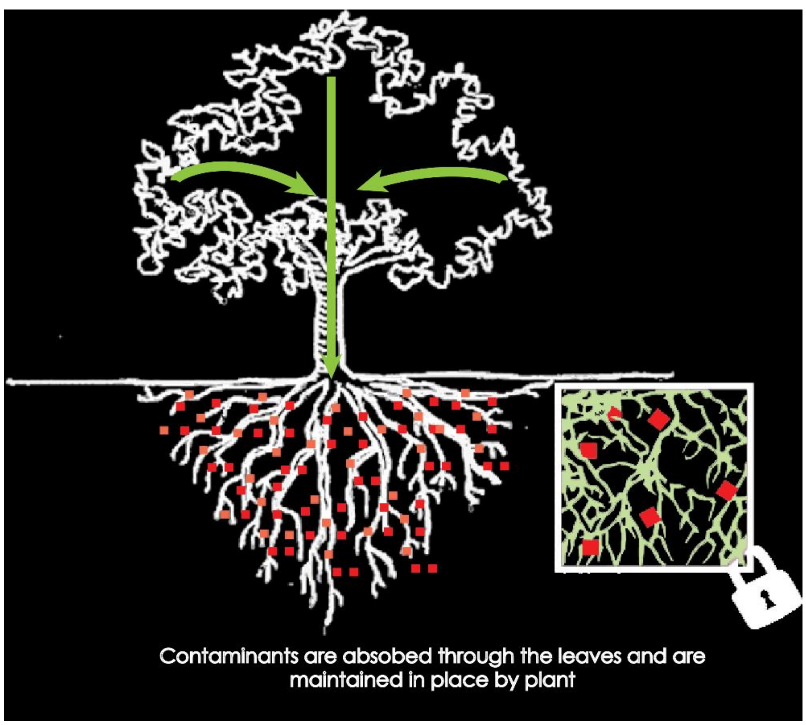


Source: Kennen and Kirkwood, 2017

2.2.2 Phytostabilization

Phytostabilization often goes by other names, such as phytoseqcuestration, rhizofiltration, or *in situ* (Pivetz, 2001). The process of phytostabilization uses plant roots to hold the contaminants in place so they do not leech off of the site. While the plant physically covers the entirety of the contaminated area, it also releases phytochemicals into the soil which bind the contaminants and make them less available for leaching. This process can also include the collection of airborne pollutants, filtering pollutants out of the air (Kennen & Kirkwood, 2017). This process is heavily used on former mining sites, due to its ability to keep contaminants from leaving the site (Pivetz, 2001).

Figure 2.8: *Phytostabilization Diagram*

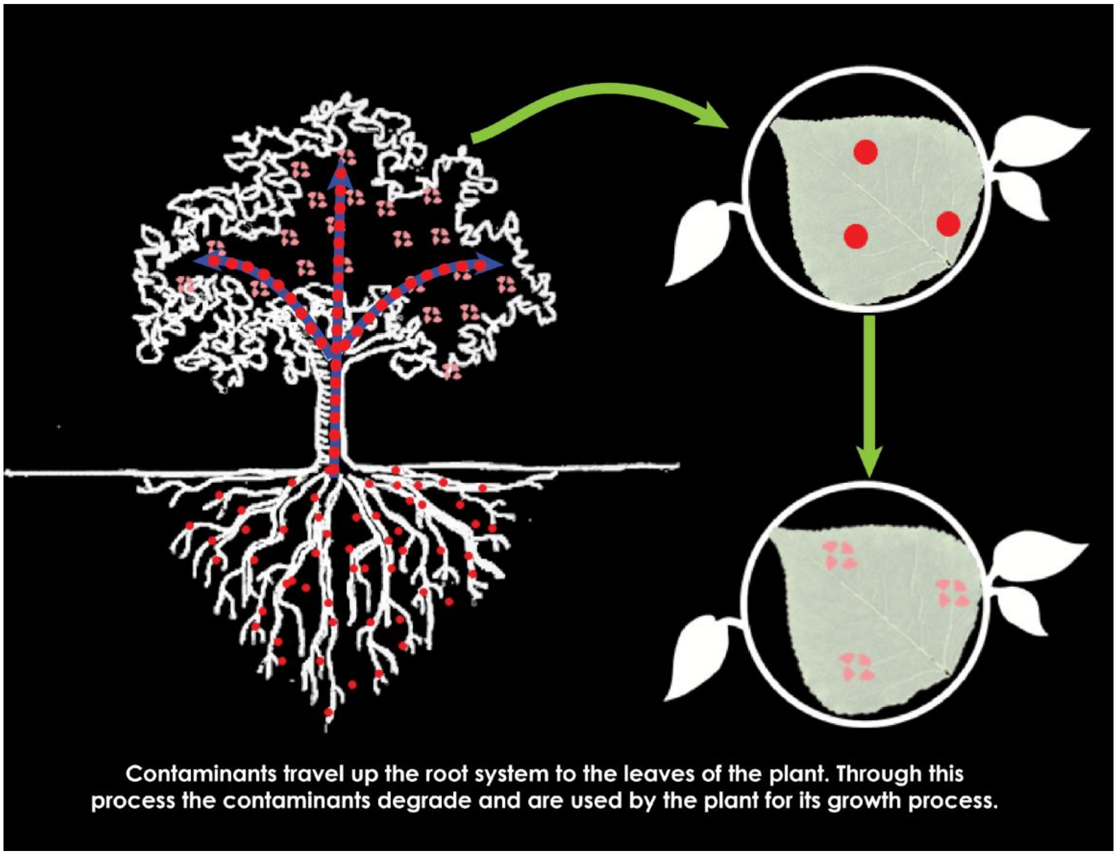


Source: Kennen and Kirkwood, 2017

2.2.3 Phytodegradation

Phytodegradation is the process where the contaminants are taken up by the plant and are broken into smaller parts, or metabolites, which are considered non-toxic (IRTC, 2009). The plant often uses these metabolites to grow whereby they are mostly absorbed. This degradation occurs during photosynthesis or by the microorganisms within the rhizosphere. By the end of this process, very little of the contaminants remain in the plant (Kennen & Kirkwood, 2017). This method has been used in sites that have wastewater or ammunition waste (Pivetz, 2001).

Figure 2.9: *Phytodegradation Diagram*

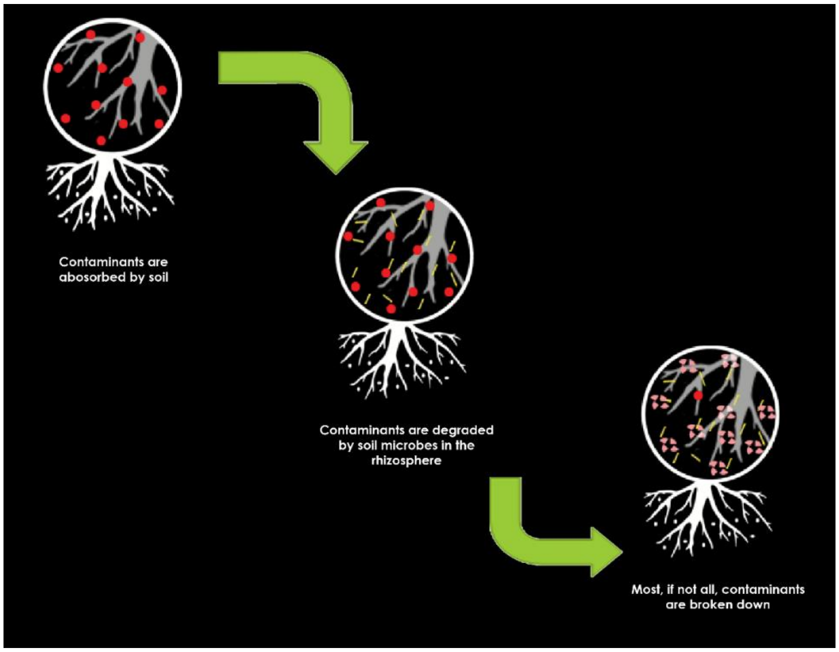


Source: Kennen and Kirkwood, 2017

2.2.4 Rhizodegradation

Rhizodegradation is the process where the root exudates released by the plant or the soil microbiology around the root break down the contaminants (IRTC,2009). While this process occurs, the plant releases phytochemicals and sugars, which allow the microbes to thrive. (Reynolds et al., 1999) While this process relies mostly on the microbes of the soil, the plant is providing the necessary environment to enhance the environment for the microbes to create what is needed for the removal of the contaminants. The usage of phytodegradation and rhizodegradation is considered the best possible scenario since the pollutants are degraded to the simplest form, and harvesting is not necessary. This method is preferred on sites that have petroleum hydrocarbons, pesticides, chlorinated solvents, or large quantities of BTEX (Pivetz, 2001).

Figure 2.10: *Site Contaminants Chart*



Source: Kennen and Kirkwood, 2017

2.3 Benzene and its Effects on Health

One of the most volatile contaminants released into the environment from the process of hydraulic fracturing is benzene. While it is commonly used as a base material for plastic, dyes, detergents, and pesticides, to name a few, it is also naturally found in the emissions from fires. It is also a component of crude oil, gasoline and can be found in large amounts in petroleum refineries or oil pipelines (Smith, 2010). Benzene is a human carcinogen that is known to cause various side effects, such as respiratory problems, dermatologic irritation, and risk of endocrine disruption. (Mcdermott-Levy, Kaktins, & Sattler, 2013) These health issues are common amongst residents near the vicinity of “unconventional” extraction or fracturing. This is a growing concern among health professionals and residents as benzene has been linked to childhood leukemia (Smith, 2010) and other chronic diseases among adults (Mcdermott-Levy, Kaktins, & Sattler, 2013).

When it comes to the process of fracturing, the health risks are believed to start at the beginning of the onset drilling and can linger long past the conclusion of production. Water and air pollution are the main concerns with benzene. With water, the principal source of drinking water collection in Tarrant County is from surface water such as rivers, and reservoirs. The presence of chemicals, such as methane, in the soil surrounding fracturing sites increase from the start date of fracturing. This contamination also occurs from the runoff of water used in the fracturing process or water which has not been correctly treated. Air pollution occurs more intensely at the initial period of the fracturing injection and transportation of the fuel and fracturing fluid. Benzene is one of the high-level carcinogens which are leaked into the air during this production.

2.4 Regional and Local Native Plants

Within Tarrant County, there are four ecoregions classified by the EPA:

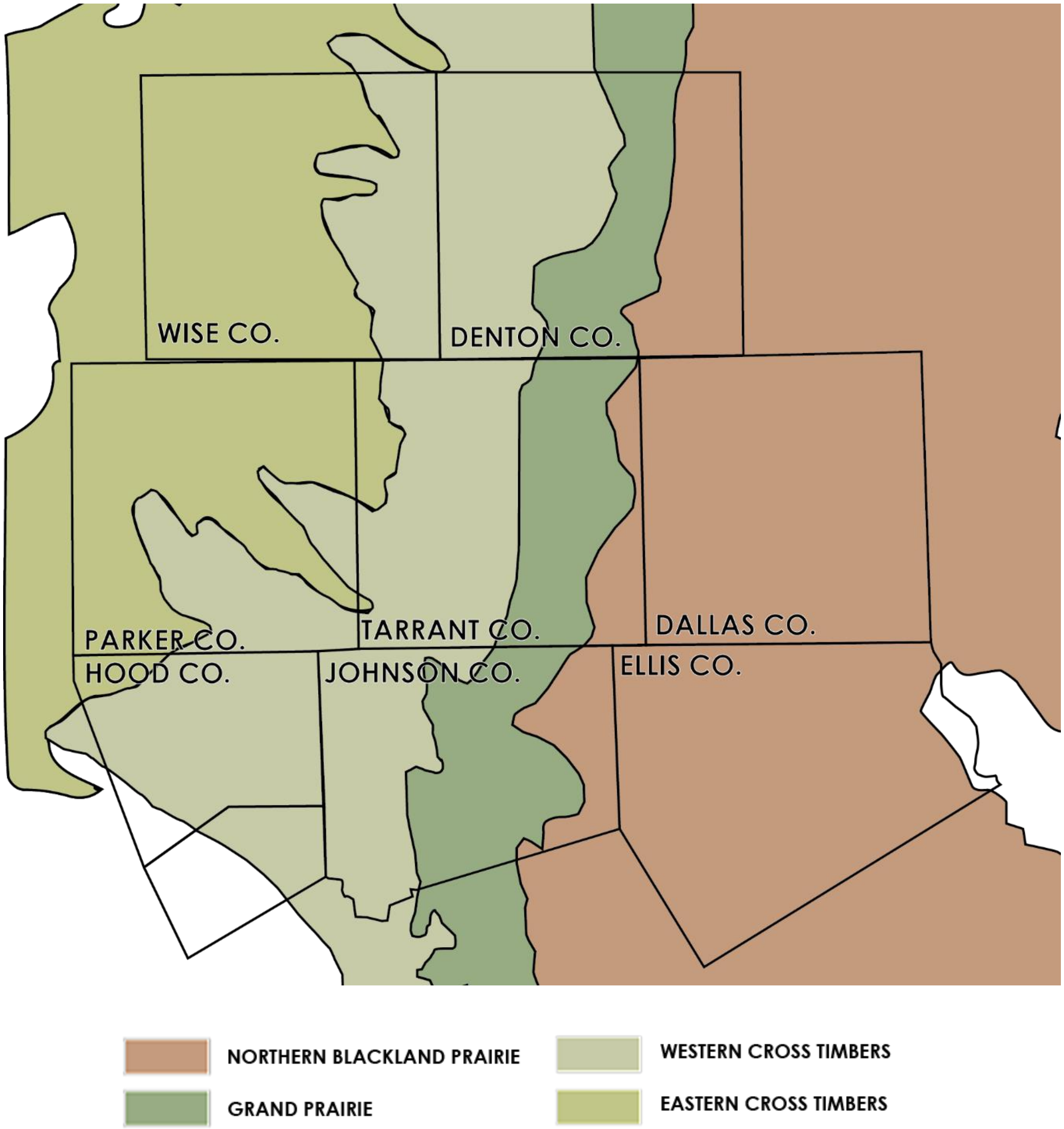
- Eastern Cross Timbers (29b)
- Western Cross Timbers (29c)
- Grand Prairie (29d)
- Northern Blackland Prairie (32a)

As referenced below in Table 2, these four ecoregions stretch across the county with the Western Cross Timbers making up a large percentage of the county. Table 1 contains a listing of plants commonly found in the respective regions. This table also highlights the names of plants that have been used for phytoremediation within the ecoregions.

Table 1:
Local Native Plant Pallet

Western Cross Timbers	Eastern Cross Timbers	Grand Prairie	Northern Blackland Prairie
Post Oak	Post Oak	Post Oak	Oak
Eastern Redcedar	Eastern Redcedar	Eastern Cottonwood	Hackberry
Big Bluestem	Blackjack Oak	Silver Bluestem	Ash
Yellow Indian Grass	Black Hickory	Seep Muhly	Elm
Eastern cottonwood	Prickly Pear	Grama Grass	Eastern Cottonwood
Switchgrass	Honey Mesquite	Bermuda Grass	Little Bluestem
Silver Bluestem	Eastern Cottonwood	Elm	Big Bluestem
Sideoats Gramma	Switchgrass	Pecan	Yellow Indian Grass
Walnut	Big Bluestem	Hackberry	Tall Dropseed
Netleaf Hackberry	Sideoats Gramma	Buffalograss	Switchgrass
		Little Bluestem	Eastern Gamagrass
		Yellow Indian Grass	Coneflower

Table 2:
Ecoregions Found in Tarrant County



Source: Griffith, Bryce, Omernik, and Rogers, 2007

2.4.1 Eastern Cross Timbers

The Eastern Cross Timbers ecoregion occurs on a band of sandstone rock formation, between the Grand Prairie and the Texas Blackland Prairies. This region is influenced by the patterns of vegetation, geology, and soils in the area. It is a limestone formation region that can sustain a prairie plant community that is different from the one found in the neighboring ecoregions. The difference from the Western Cross Timbers is that the Eastern receives a higher yearly precipitation amount, more fertile sandy soil, and taller trees. Plants native to this region include *Quercus stellata* (Post Oak), *Juniperus virginiana* (Eastern Redcedar), *Sorghastrum nutans* (yellow Indiangrass), *and Schizachyrium spp.* (big and little bluestem) (Griffith, Bryce, Omernik, and Rogers, 2007).

2.4.2 Western Cross Timbers

Extending into Oklahoma and Kansas, the Western Cross Timbers covers the wooded areas west of the Grand Prairie. The region is a savannah combination of oak woodland and prairie that transitions between the eastern deciduous forest and the Great Plains. Trees in this ecoregion can be drought-stressed and grow no taller than 20 to 30 feet. Examples of plants native to this region are *Sorghastrum nutans* (yellow Indiangrass), *Andropogon gerardii* (Big Bluestem), *Panicum virgatum* (Switchgrass), *Bouteloua curtipendula* (Sideoats Grama), and *Prosopis glandulosa* (Mesquite) (Griffith, Bryce, Omernik, and Rogers, 2007).

2.4.3 Grand Prairie

In contrast to the Cross Timbers, the Grand Prairie is more open plains. Much of the vegetation in the Grand Prairie is similar to that found in the Northern Blackland Prairie, however, plants in this area a more resistant to weather conditions, thinner soil, and less precipitation. Plants native to this region are *Ulmus spp.* (Elm), *Cary illinoensis* (Pecan), *Celtis* *spp.* (Hackberry), *Sorghastrum nutans* (yellow Indiangrass), and *Schizachyrium scoparium* (Little Bluestem) (Griffith, Bryce, Omernik, and Rogers, 2007).

2.4.4 Northern Blackland Prairie

Stretching over 300 miles, the Northern Blackland Prairie was historically part of the tallgrass prairie vegetation. Frequent grazing and fires shaped the Blackland Prairie landscape. This area is known for its very active and expansive soils. Plants native to this region are *Schizachyrium scoparium* (Little Bluestem), *Andopogon gerardii* (Big Bluestem), *Sorghastrum nutans* (yellow Indiangrass), *Panicum virgatum* (Switchgrass), *Celtis laevigata* (Sugar Hackberry), and *Populus deltoides* (Eastern Cottonwood) (Griffith, Bryce, Omernik, and Rogers, 2007).

2.5 Policy and Recommendations

The largest entity which oversees the natural gas industry in Tarrant County is the Railroad Commission of Texas (RRC). They are a state agency that provides primary regulatory jurisdiction over the oil and natural gas industry, pipeline transporters, natural gas and hazardous liquid pipeline industry, natural gas utilities, and coal and uranium surface mining operations (RRC, direct quote). The RRC does not have any regulations which promote the use of phytoremediation in their lists of best practices. In their Administrative Code with the Texas Commission on Environmental Quality (TCEQ) *"Spill Prevention and Control",* the party responsible for the spill must remediate any potential pollutants to the site but which methods could be used are not specified.

The TCEQ, while responsible for overseeing the environmental quality of projects, does not have any recommendation on phytoremediation either. However, there are documented situations in which *in situ* remediation is not recommended near bodies of water. (TCEQ, 2018)

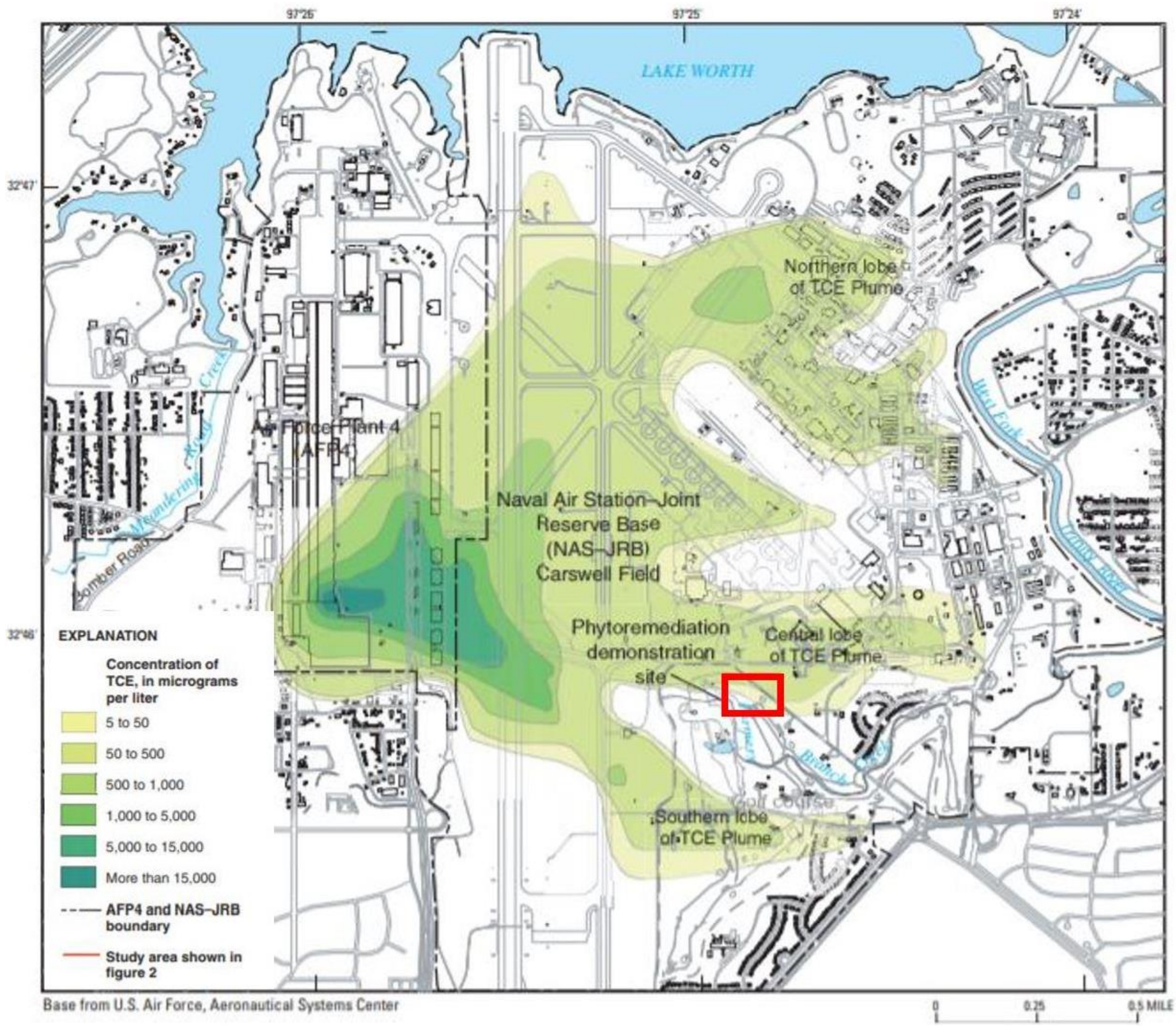
2.6 Precedent Studies

The following three studies were selected due to the demonstration of phytoremediation use. Two of the studies are located within the United States, and the third is from Europe. They were selected according to the type of contaminants which were remediated, the plant selection, and the professionals which were involved in the process.

2.6.1 Phytoremediation Study at Carswell Naval Station Golf Club, Fort Worth, TX

The Carswell Naval Station Golf Club in Fort Worth, Texas is an example of a site which is located over a large unattended plume of chlorinated solvents (see Figure 2.12). This site was chosen by the Superfund Innovate Technology Evaluation (SITE) Program for the treatment of the found solvents using a phytoremediation process called the Short Rotation Woody Crop Groundwater Treatment (SRWCGT) System (Shah and Braun, 2004). The section of the Carswell Golf Course (CGC) that was selected for the study is located a mile from the southern portion of the main assembly building of the Air Force Plant 4. This area was estimated to have produced up to 6,000 tons of waste per year, which included many of the waste solvents, oils, fuels, and other chemicals. (Shah and Braun, 2004) The goal of this treatment was to validate and promote an innovative phytoremediation technology while being cost-efficient.

Figure 2.11: *Contamination of Carswell Field and Designation of Phytoremediation Demonstration Site*



Source: Griffith, Bryce, Omernik, and Rogers, 2007

The study used *Populus deltoides*, or Eastern Cottonwood, as the selected plant species to promote the degradation of the solvents as well as to control the present hydraulic gradient (grade at which the land is eroding toward the river) (see figure 2.12) to reduce adverse contaminant mitigation of the leeching of contaminants towards the water (Shah and Braun, 2004). *Populus deltoides* were selected based on literature review and per the recommendation of the Texas Forest Service, the National Resources Conservation Service, and the US Forest Service Harwood Laboratory (Shah and Braun, 2004). Due to the process of phytoremediation requiring an extended time frame, monitoring systems were designed to measure small incremental changes in the site over time. These monitors collected data that help determine how well the system performed over time and whether or not the *Populus deltoides* had an impactful enough process on the site.

Two objectives were examined during the study; the phytoremediation system's ability to reduce the number of pollutants and the examination of the SRWCGT System's contaminant-reduction mechanism. During the first objective, the data collected showed that the researcher's goal of reaching reductions of 30 and 50 percent of TCE concentrations during two continuous growing seasons was not achieved. The concentrations present gradually decreased from their baseline measurement of contaminants found in the groundwater (Shah and Braun, 2004). However, while these concentrations did not decrease, there was a reduction in the mass of TCE found further away from the site. The implementation of the *Populous deltoides*, therefore, had helped filter the groundwater which was flowing out of the site in comparison to the initial measurements (Shah and Braun, 2004).

The second objective studied the success of *Populous deltoides* during the trial. A future projection was made from the growth of the trees during the course of four growing seasons

(Shah and Braun, 2004). Over time the growth of the canopy, the caliper diameter, the depth of the roots, and their biomass was studied to determine the specific requirements for the survival of the species used. Two sections were planted, one with trees which were considered to be more expensive than their counterparts. By the second year, both tree types had reached the water table concluding that there is little to no difference between a more expensive *Populous deltoides* and their cheaper counterparts.

The study also examined the number of volatile compounds (VOC) which were found in the plants through uptake. Only seven compounds were found in the cottonwoods from the thirty VOCs which were scanned (Shah and Braun, 2004). Of those seven, five of the compounds were chlorinated, of which Toluene was found (Shah and Braun, 2004). Even though the second objective was to measure the growth of the *Populous deltoides*, there was no correlation found with the size of the caliper with respect to the concentration of VOCs (Shah and Braun, 2004).

Overall, the study was successful in reducing the mass of contaminants found in the groundwater as it moved offsite. However, a longer study was recommended to determine the rate of absorption of contaminants over a prolonged time frame, as well as its effect on the concentration of contaminants found in the water table.

2.6.2 U.S. Coast Guard Former Fuel Storage Facility, Elizabeth City, NC

From the years 1942 to 1991, a 5-acre site served as a US Coast Guard Fuel Farm in Elizabeth City, North Carolina. This piece of land leaked large amounts of fuel during its active use. (Kennen & Kirkwood, 2017) The fuel which was leaked would migrate towards the Pasquotank River located 150 meters (490 feet) from the site of the leak. In 2004, groundwater samples from the site indicated areas where petroleum contamination of chemicals, such as Benzene, were greater than the allowed Groundwater Standard measurement. (Nichols et al., 2014)

Figure 2.12: *Fuel Location and Analysis*

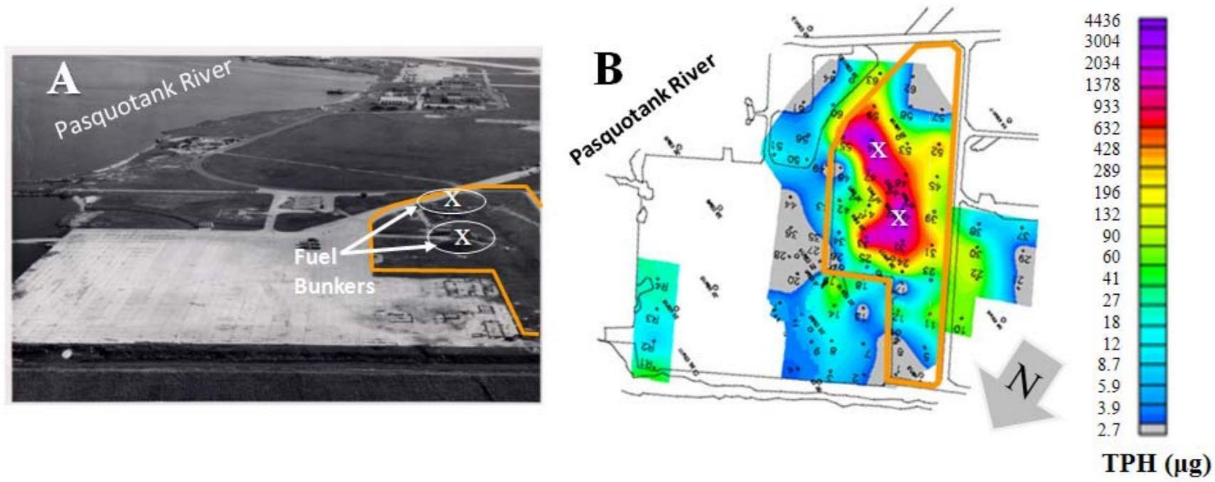


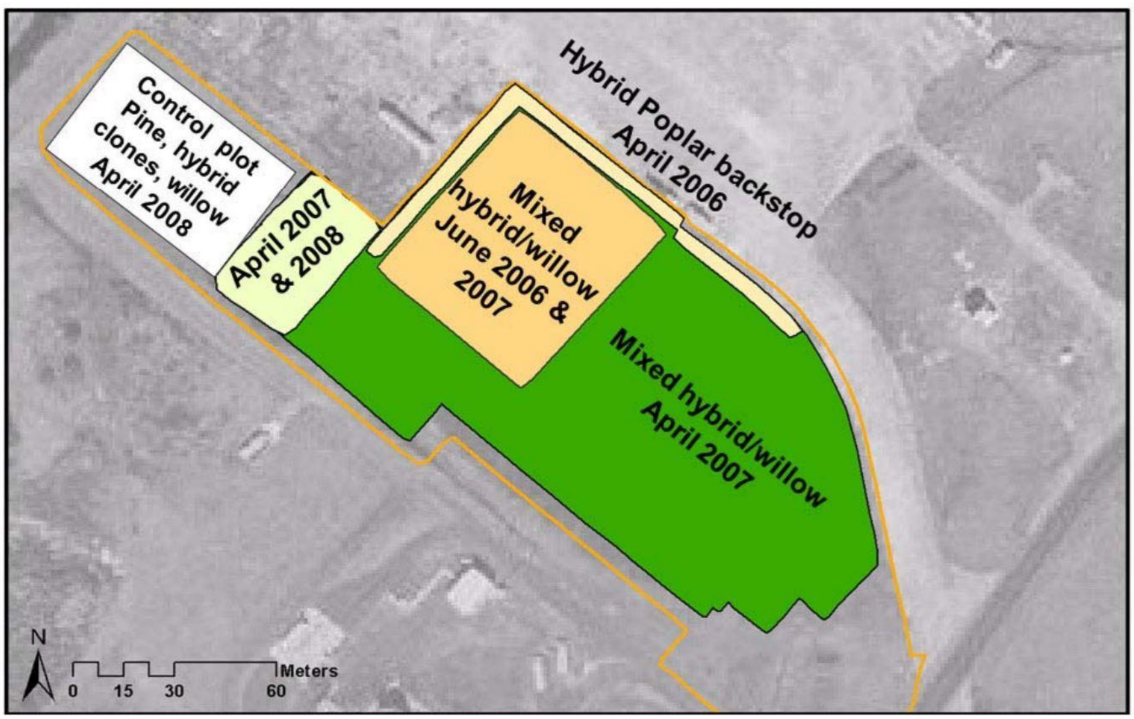
Figure 1 (A) *Location of fuel storage in 1942.* **Figure (B)** *Soil gas analysis shows greater total petroleum hydrocarbons (TPH) mass in areas of former fuel bunkers (GORE, 2007)*

Source: Nichols et al., 2014

In 2007, fuel was detected in the surface soils, which are located in the top 4 feet of the ground. Prior attempts by the US Coast Guard to remove the plume and the contamination had not been successful. “This site provided the opportunity to demonstrate the ability of a vegetative system to contain residual free product and retard the migration of dissolved phased petroleum to the river.” (Nichols et al., 2014) A four-phase process began to treat the contaminants from the fuel leak. Of these four phases, the first two focused on the installation of a phytoremediation system, while phase III focused on the collection of data, and phase IV focused on data synthesis. (Nichols et al., 2014)

In April of 2006, mixed hybrid poplar (*Populus spp.*) and willow (*Salix spp.*) were planted across the site. (Nichols et al., 2014) This process continued until April of 2008. However, during that year, loblolly pine (*Pinus tadea*) was also planted across the site and a particular control plot as shown in the figure below. These tree species were selected for their ability to dissipate fuel contaminants such as BTEX and PAHs in contaminated groundwater and soils, as well as for their ability to establish deep root systems. (Nichols et al., 2014) The Pinus tadea was selected in order to test how evergreen species would grow in these conditions.

Figure 2.13: *Overall Planting design of phytoremediation plan*



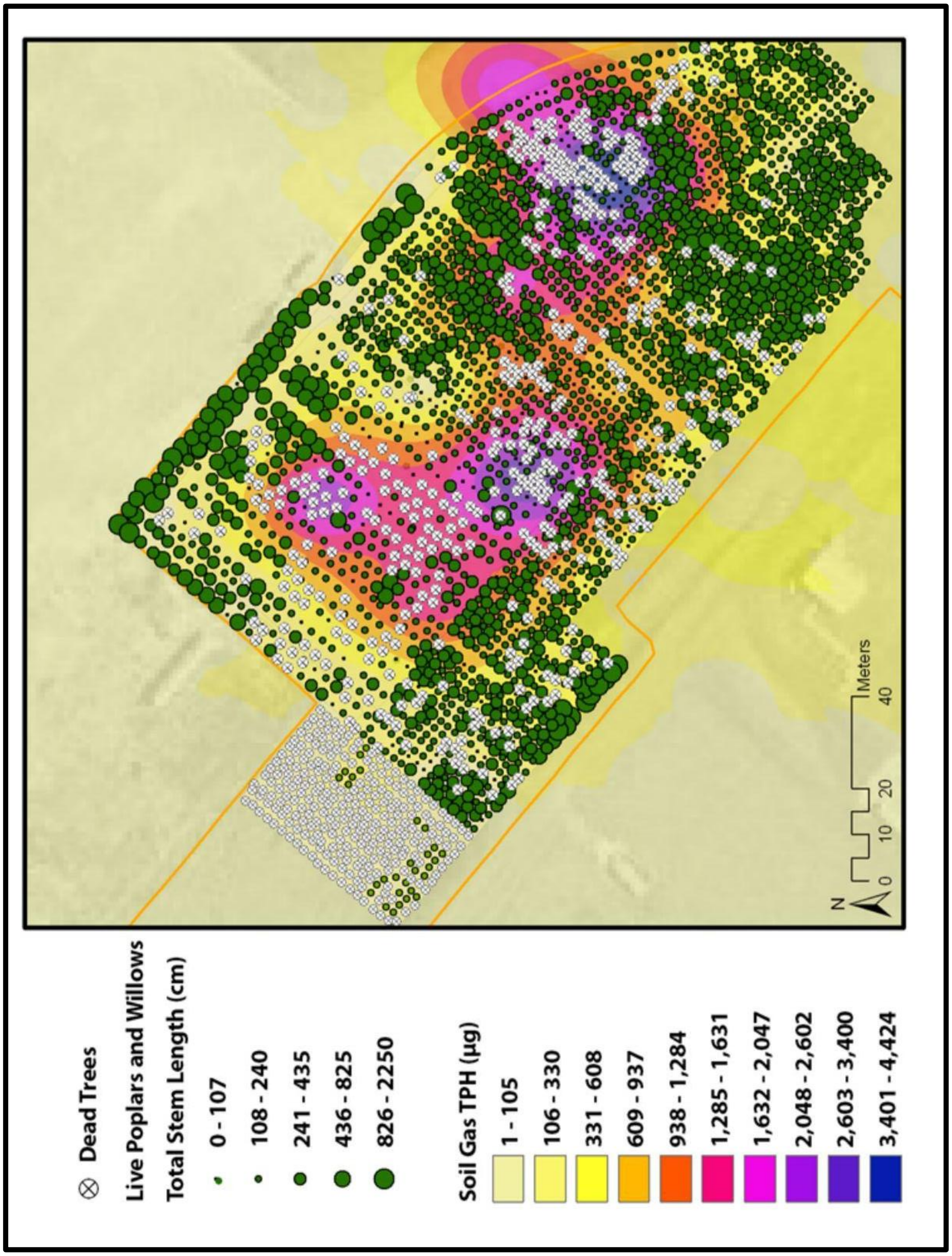
Source: Nichols et al., 2014

During phase I, the researchers did not have an accurate mapping of the contaminant levels which were currently on the site at the time of planting. This caused a mortality rate in trees of

55 to 65 percent, which is higher than the 12 percent which was recorded previously in 2006. However, this loss was credited to the planting formation in which the trees were placed and not the unquantified fuel sources which were not accounted for. (Nichols et al., 2014) During the new soil gas analysis, “hot spots”, or sites with higher concentrations of fuel, were delineated. These new hot spots required a change of planting methods and instead of being planted in the “V” formation the previous trees were planted in, these were planted in 4 foot deep, 9-inch augured holes and were filled with clean topsoil and mulch. After this change in 2007, tree mortality declined to 13 percent. (Nichols et al., 2014)

Table 3

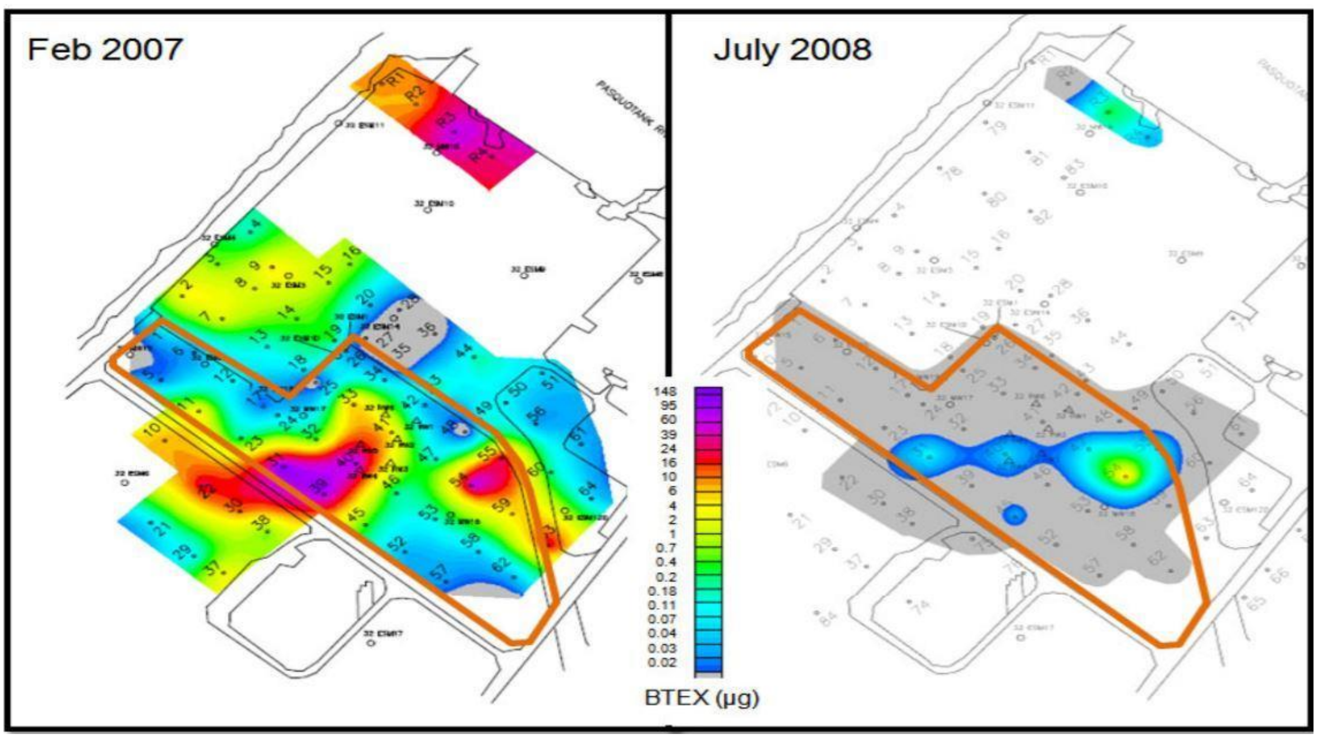
2007 Soil Gas TPH Overlaid by Tree Mortality



Source: Nichols et al., 2014

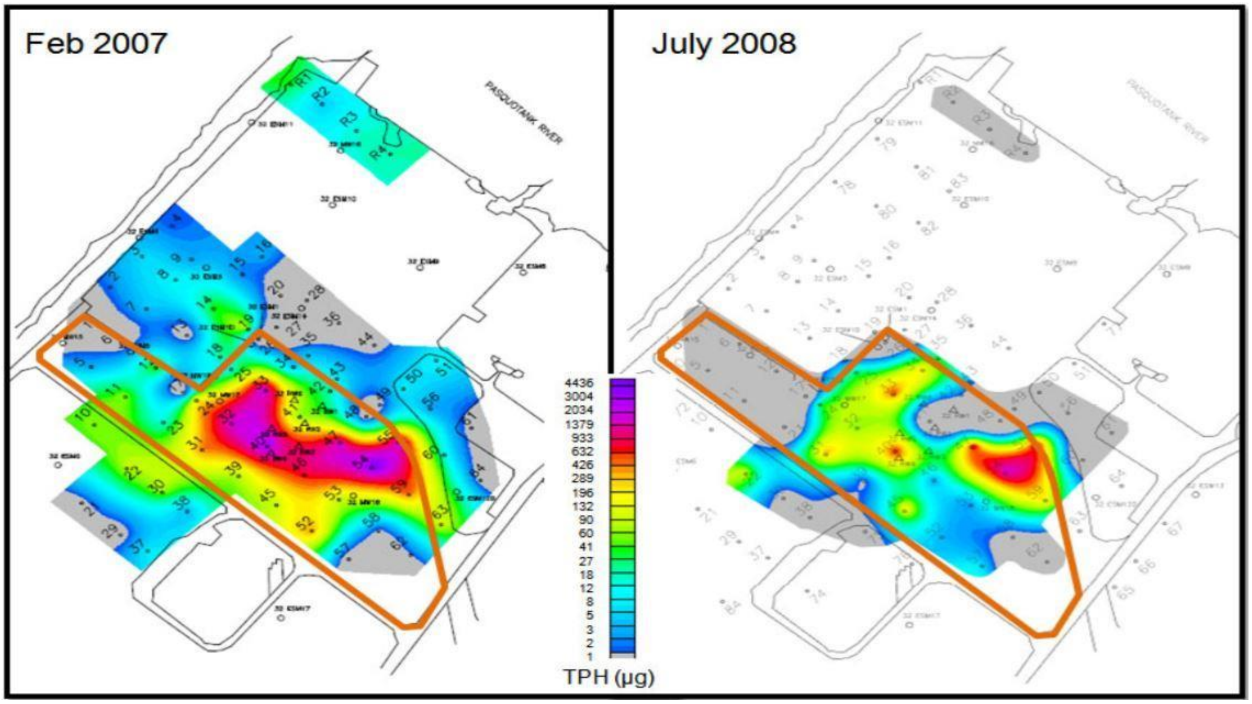
During the study (April 2006 to April 2008), soil gas and groundwater samples were taken to monitor the levels of contamination. As shown in the figures below, there was a substantial soil gas mass loss during the years 2007 and 2008. These figures show the difference in estimated fuel mass in soil vapors or residual buildup from surface contaminants. There was a substantial decline in contaminant masses evident for lighter fuel fractions, BTEX, and volatile fractions of fuel. (Nichols et al., 2014) Figure 2.18 demonstrates the amount of TPH present, which represents BTEX plus larger, volatile petroleum hydrocarbons. Of the 17 percent of trees which died, many were located in the red portions of this map due to the higher concentration of contaminants.

Figure 2.14: *Mapping showing the loss of soil gas mass of BTEX over one and a half growing seasons*



Source: Nichols et al., 2014

Figure 2.15*: Mapping showing the loss in soil gas mass of petroleum hydrocarbons (TPH). TPH represents BTEX plus larger, volatile petroleum hydrocarbo*ns

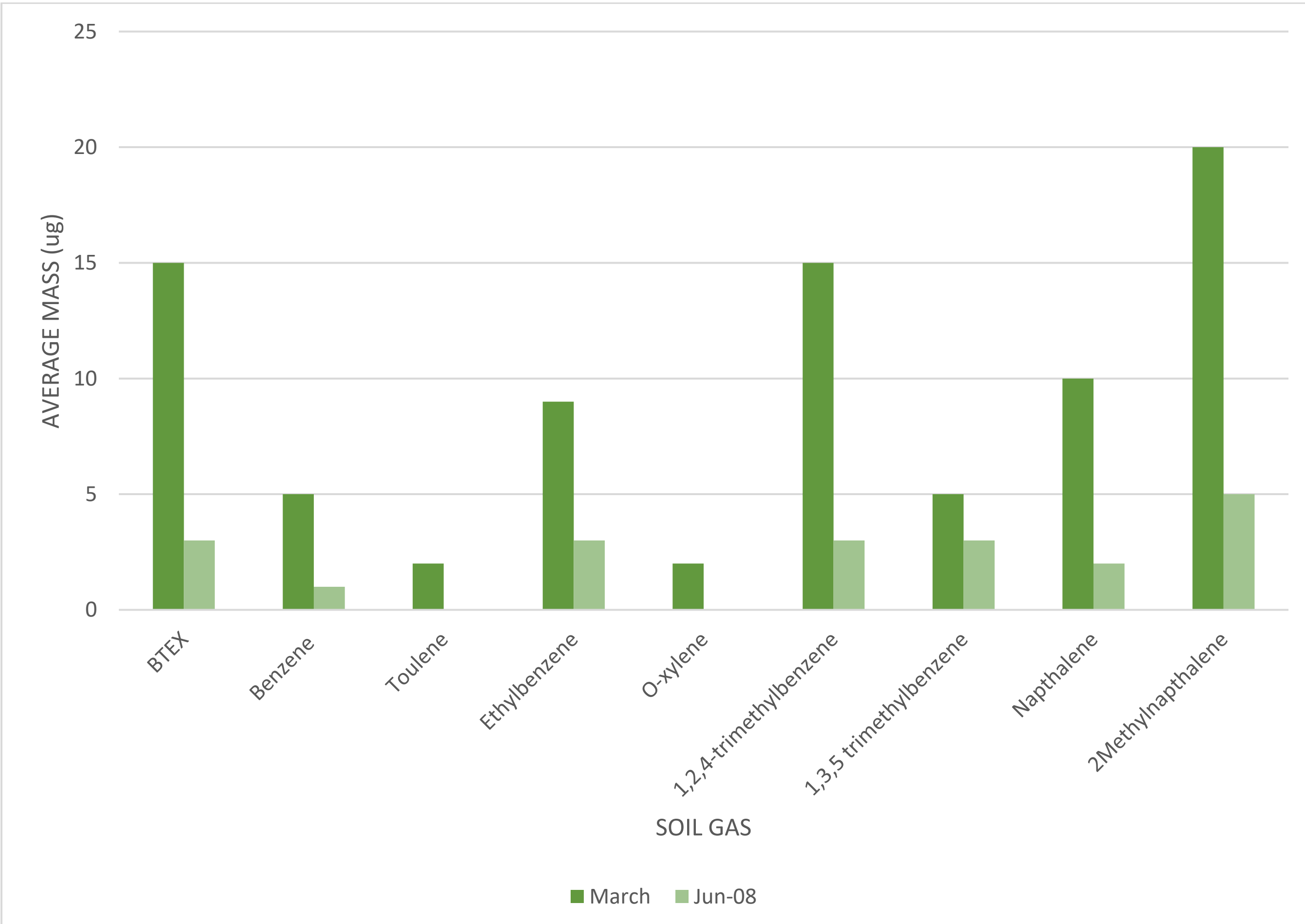


Source: Nichols et al., 2014

While phytoremediation was not a method of reimbursement which was approved by the State of North Carolina Underground Storage Tank (UST) Trust fund at the time of the study, the verification of this study was important for introducing phytoremediation as a viable method of treatment. (Nichols et al., 2014) The data collected from this study demonstrated a decrease in contaminants found in groundwater and soil over the course of the study. Table 4 shows the decrease in soil gas from March 2007 to June 2008. By the year 2013, the number of contaminants found in groundwater and in the Pasquotank River were considerably lower, a drop in 95 percent of contaminants as compared to the levels in 2006. (Kennen & Kirkwood, 2017)

Table 4

Average Soil Gas Decrease from 2007 to 2008



Source: Nichols et al., 2014

2.6.3 Westergasfabriek, Amsterdam, The Netherlands

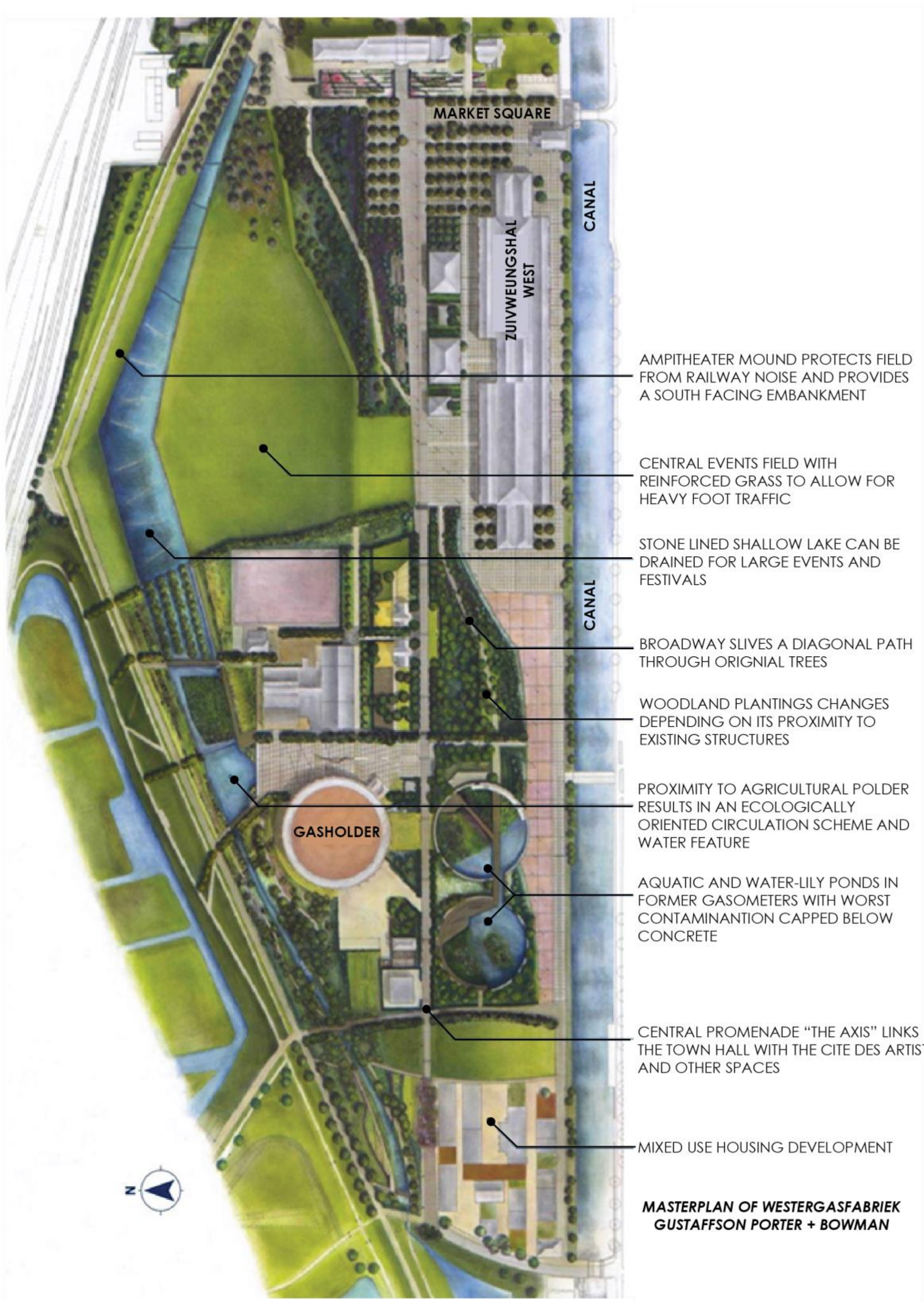
Westergasfabriek in Amsterdam, the Netherlands, is a mixed-use urban park that was home to a gas facility until 1967 (Westergasfabriek, 2008). Upon closing, the site was left heavily polluted with heavy metals, tar, cyanide, and asbestos, which made it difficult to repurpose the site which then was used as a storage site and repair workshop until the early 1990s.

In 1997, landscape architect Kathryn Gustafson, along with Francine Houben of Mecanoo Architects, won a competition to design a new master plan (Figure 2.19) for Westergasfabriek. Their design “Changement” “demonstrated an understanding and balance between contamination and accessibility, invention and interpretation, restoration and revelation” (Gustafson Porter + Bowman, 2006).

Westergasfabriek required separate contamination management plans for the buildings to be repurposed and the external environment which were designed by Arup Engineers. (Project Westergasfabriek, 2010) This project added the capping method for remediation, rather than exclusively using phytoremediation. Phytoremediation was implemented around watercourses and vegetation.

Soil studies which were done in 1990, showed that there was considerable contamination on the site, but it was not high enough to consider the site unusable. The results showed that there were high levels of tar, mineral oils, cyanide, and benzene present in the soil profile as well as the water table.

Figure 2.16: *Westergasfabriek Master Plan*



Source: Gustafson Porter + Bowman, 2006

Originally, the remediation method of dig and haul was selected, but due to the extensive amount of contaminated soil, the idea was rejected due to the high cost. The remediation plan which was created implemented an "isolation-plus variant" approach. This meant that the polluted ground would be isolated beneath a layer of cloth about 1 meter deep and clean soil would be placed on top. These areas were later planted by either plants that were installed for aesthetics and plants which were used in phytoremediation methods (Project Westergasfabriek, 2009). Plants such as willows and water-tolerant plants were used in phytoremediation methods throughout the park.

2.9 Conclusion to Literature Review

The precedent studies provided insights into the different approaches to phytoremediation and contaminants which can be treated. Studies of the contaminants which are present prior to the phytoremediation method were selected to help the researcher understand the importance of cross-disciplinary work for the landscape architecture profession. The need to understand the use of plants, the severity of contaminants, and the application of successful phytoremediation projects, allows us to examine the need for information not only in the landscape architecture profession but also in the allied professions.

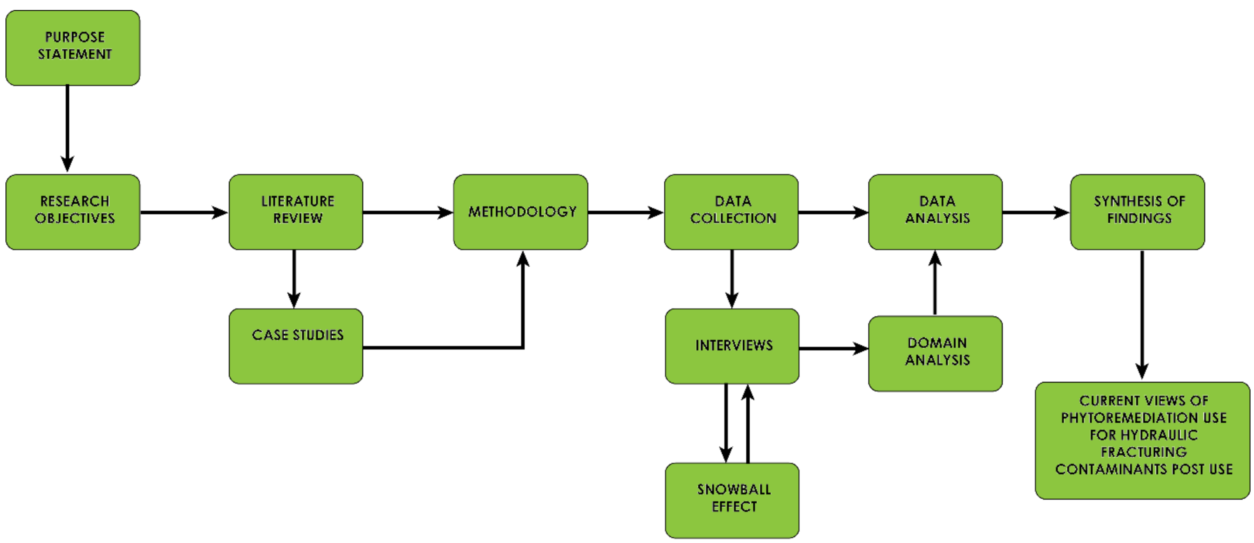
Chapter 3

Methodology

3.1 Introduction

This research used data collected from in-depth virtual and phone interviews to understand the current procedures conducted to treat flowback fluid contaminants that have seeped into the soil and how participants from design and science fields understand and apply phytoremediation to these situations. This study was carried out in a four-step process. The process includes literature review, precedent studies, interviews, findings and analysis, and a conclusion which will discuss the results and future research.

Figure 3.1 *Research Design Diagram*



3.2 Literature Review

This study reviewed the research literature of phytoremediation examining how it is used in sites polluted with VOCs, or highly toxic contaminants produced by heavy industrial uses, and the advantages of using it as a form of pollutant mitigation. Different methods which can be used in the treatment of pollutants were reviewed, along with the process each method uses for the extraction of contaminants.

The precedent studies helped in understanding the process that occurs when phytoremediation is used in different stages of a site's contamination. The projects were selected for purpose of studying similar types of pollutants and industries which used pollutants that are comparable to those utilized at hydraulic fracturing site. Studies of post-use of remediated brownfields were also explored to best understand the impact which the phytoremediation process has on the future use of land.

3.3 Interview

The primary goal of the interview data in this study was to assess attitudes about the use of plant materials to mitigate pollutants at fracturing sites; specifically, the attitudes held by professionals who deal with hydraulic fracturing on a regular basis. Interviews were conducted to understand the current methods used to remediate site pollutants, the possibility of phytoremediation as future use, the toxicity of the chemicals to human exposure, and the professionals' opinions on the potential advantages and benefits of phytoremediation. Discipline-specific interview questions were written and approved by the UTA Institutional Review Board (IRB). Potential participants were selected based on their expertise in hydraulic fracturing, soil science and hydrology, urban planning, and design in urban settings. A list of 60 professionals was created and invited to participate in the study. A list of interview questions was sent to each potential participant with a request to schedule a phone or virtual interview. Participants who agreed to the interview, but could not meet with the researcher, were given the opportunity to return the interview questions electronically through email.

3.4 Study Population and Location

Ten participants were chosen to participate in the study. They were selected based on their expertise in the subject of hydraulic fracturing, the remediation or study of contaminants in soil, or their experience in using polluted sites post use. The area of study was focused on hydraulic fracturing sites within Tarrant County, but the participants who were selected work within North Texas or were selected for their expertise despite not working on projects in the North Texas area.

3.5 Data Collection

The interview questions for the various professions were geared towards each person's specialty, but a portion of the questions remained the same across the interviews. The goal of the interviews was to obtain information regarding:

1. Understanding the process of pollutant clean-up for hydraulic fracturing
2. Identifying the current methods of treatment that are used
3. Learning about the process of phytoremediation and current attitudes towards the use
4. Exploring the different ways land is used post-cleanup

Interview questions were sent out to each participant, who had previously agreed to participate, through the researcher's university email. Participants were then given the option to schedule an interview with the researcher or submit their responses electronically.

During the interviews, the participants were asked for the recommendation of another potential participant for the interview process. This method is called snowball sampling (Sommer and Sommer, 2001) and is used to gather potential points of contact from our selected participants. Points of contact, which were given by participants, were contacted through the same method as the original participants.

3.6 Domain Analysis

The interview data was coded using Saldana's coding manual, which helped determine the first cycle and second cycle coding methods. The first cycle of coding used initial and descriptive coding. With initial coding, the goal is to remain open to all of the possible directions according to the data and to not personally set directions (Charmaz, 2006). The coded data was then analyzed by the Domain analysis method described by Atkinson and Haj (1996). Domain analysis allows the researcher to study the thoughts and discourse of the participants to find connections among the data. Data was then broken down and examined by the researcher comparing the similarities and differences the data revealed.

The second round of coding was conducted to describe the base topics in a qualitative study (Saldana, 2009). The second cycle of coding uses pattern coding to identify the emerging themes. Pattern codes are "explanatory or inferential codes, ones that identify an emergent theme, configuration, or explanation…" (Miles and Huberman, 1994, pg. 69). The outputs were organized using an online software from www.dedoose.com.

3.7 Research Limitations

The use of phytoremediation as a treatment for hydraulic fracturing is currently not a method that has been used by natural gas companies in the United States as a method of treatment. However, at locations where this method has been selected, the time of remediation has not surpassed a point where quantifiable information can be collected to support this method. These studies are not considered to be limitations, but the data which is available from these studies is. All data has been collected from previous research studies. This research also does not physically test the method in a current setting.

Chapter 4

Analysis and Findings

4.1 Introduction

This chapter describes the analysis of ten interviews that cross various professions and disciplines. The findings from the interviews are organized into the following goals:

- Understanding the current practices and processes used to treat fracturing fluid contaminants in Tarrant County
- Assessing experts' knowledge of phytoremediation, including current policies and regulations which must be followed for the closure of fracturing wells
- Exploring professionals' views on the future use of hydraulic fracturing sites

The domain analysis was conducted using the four-step process outlined by Atkinson & Haj (1996):

1. Identify the domain
2. Construct a taxonomy of subcategories
3. Specify the components
4. Relate the domains

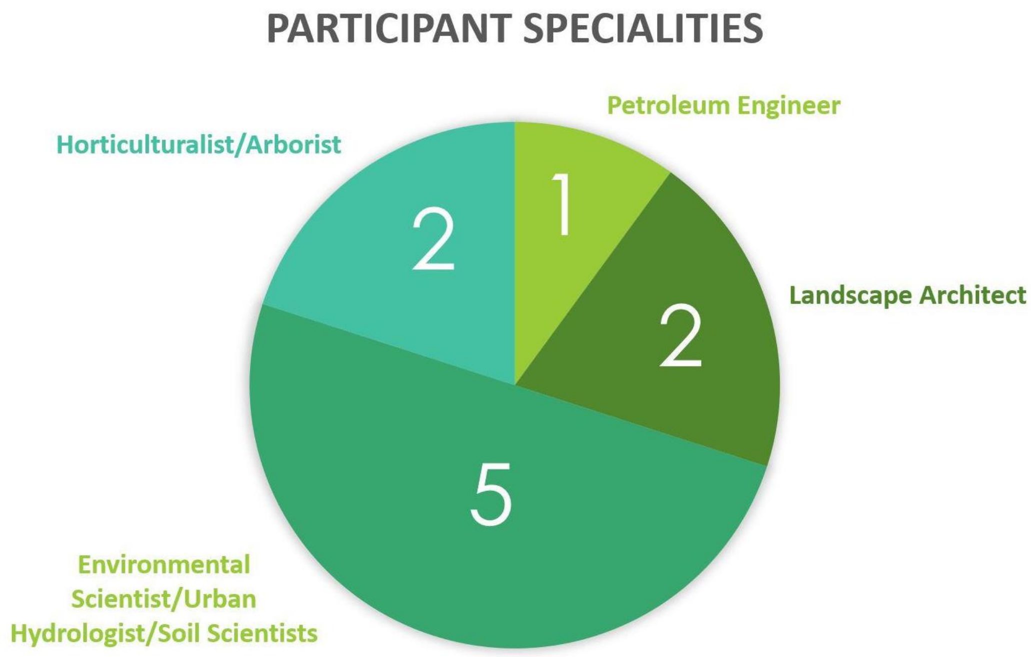
4.2 Domain Analysis of Interview Data

4.2.1. Initial Analysis of Collected Interview Data

During the initial selection phase for interview participants, 15 to 20 professionals within the field of petroleum engineering and hydraulic fracturing were contacted. Many of these participants denied the request for an interview due to confidentiality clauses with their clients or did not respond to the requests for the interview. Of the 15 to 20 professionals contacted, only one accepted the request for the interview.

A similar response was met when contacting landscape architects regarding the research topic. 30 landscape architects were contacted, all but two denied due to time commitment issues or the lack of knowledge in phytoremediation practices at this scale. Of the ten professionals who agreed to interview, six of the professionals were aware of the process of phytoremediation, but only three knew of the current practices regarding hydraulic fracturing. The others expressed interest in learning more, despite their lack of knowledge. The method of data collection for this research yielded a smaller than intended study group. The use of interviews could have benefited from a second source of data collection, such as a survey, who could have been sent out to collect data from professionals which could not accommodate an interview into their schedules.

Table 5:
Division of Participant [disciplines or professions]



All professionals discussed their experience with contaminants, such as volatile organic compounds (VOC) and heavy metals, and the problems which can arise when treating them. An environmental scientist and an arborist expressed the most knowledge over the process of phytoremediation and the use of this method in Tarrant County, as well as in metropolitan areas. The petroleum engineer and two environmental scientists expressed their preference for alternative methods of remediation, such as dig and haul, when asked about phytoremediation. This is due to the time constraint which they are subject to with phytoremediation and the total expense for this practice. All of the professionals expressed that protocols set by the Railroad Commission (RRC) and the Texas Commission on Environmental Quality (TCEQ) were followed when it comes to the process of closure for a hydraulic fracturing site, but standards set by the Environmental Protection Agency (EPA) are followed when it comes to human safety thresholds.

The first cycle of coding, which was organized using the Dedoose Software, created a variety of topics. The transcript with the highest number of coding inputs was that of the arborist who specializes in phytoremediation treatments, and a landscape architect had the least number of inputs.

After the initial coding, a second round of descriptive coding was done to clarify the data. Codes were derived from initial coding but were subcategorized under codes to create descriptive coding. The descriptive coding gave insight to the most repeated words during the interviews. The first cycle of coding resulted in the identification of the preliminary list of topics which are represented in Table 2 which highlights the recurring topics throughout the interview data without being specific on a certain grouping. This data is used to inform the second cycle of coding.

Table 6:

Preliminary List of Themes

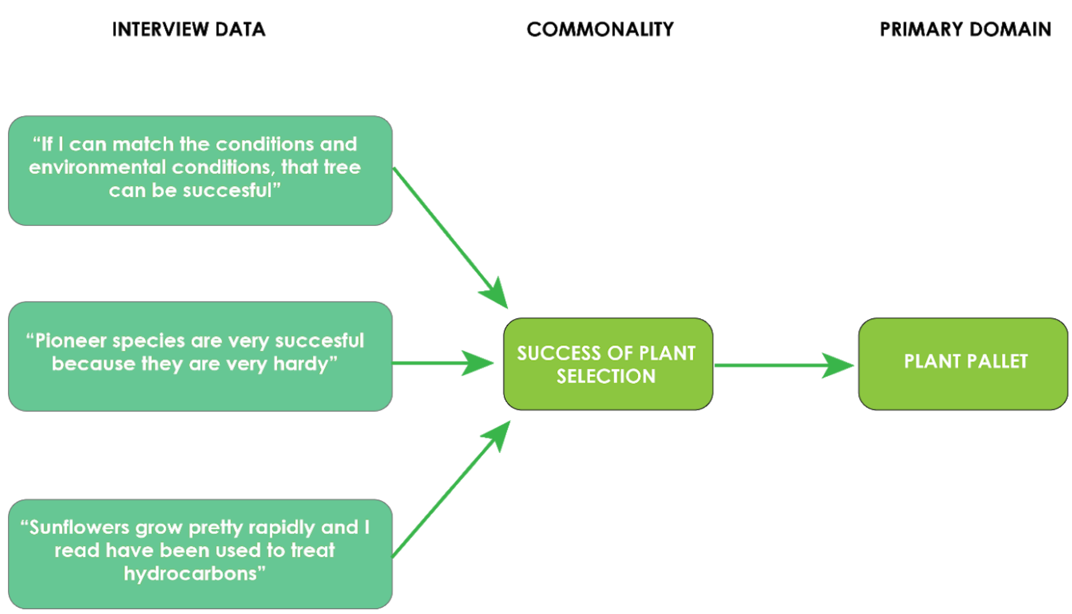
Theme	Subthemes
Contaminants	Ease of removal, Contaminants usually found at fracturing sites, Methods to contain contaminants, Possibility of leeching or runoff
Methods of Remediation	Dig and haul, Concrete cap, Phytoremediation, Biochar amendments, Molecular osmosis, Chemical treatment
Soil	Porosity of soil, Soil profile, Sustainability, Soil amendments, Lack of organic layer, Rhizobacteria
Plant	Native local plants, Introduced plants, Seeding, Plant sustainability, Invasive tendencies, Contaminant uptake, Maintenance, Root length, Arborist or Horticultural referral
Land Use	Abandonment, Buildings, Green spaces, Human safety, Reduction or elimination of contaminants, Post-use clean-up
Phytoremediation	Knowledge of the process, Problems that can be encountered, Use in the profession, Recommendation of the practice, Reasons phytoremediation isn't used
Policy	State level, Regional level, Recommendations to follow

4.2.2 Identifying the Domains

During this step, the researcher first identified the primary domains that kept occurring in the interview data. The purpose of examining themes was to identify the concerns of the participants instead of the researcher's predefined themes (Atkinson & Haj. 1996). This is done to avoid any confirmation bias which the researcher might have had in the study.

The second round of coding, known as pattern coding, was done to identify the primary domains. Pattern coding was used to categorize the data based on the commonalities which occur amongst the participants' data. From the recurrences, categories that encase the commonalities were formed. Figure 4.2 graphically represents how data from the interviews was recognized as a similar issue. Figure 4.2 shows how similar quotes were grouped into a singular commonality. From there these commonalities were grouped into one primary domain which encompassed all commonalities which occurred.

Table 7
Second Cycle of Coding Example



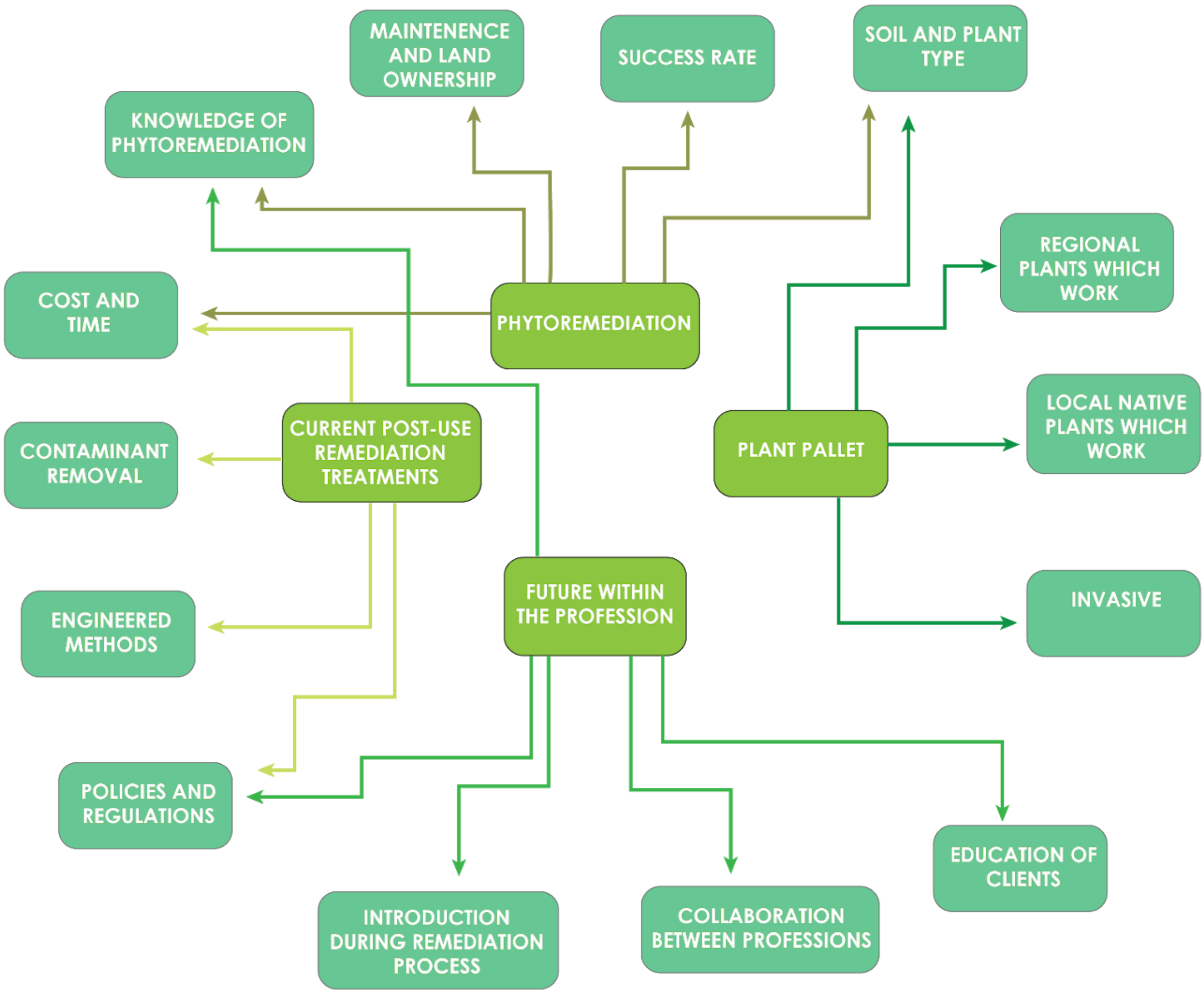
The primary domains which emerged from the second coding cycle were:

1. Current post-use remediation treatments
2. Phytoremediation
3. Plant pallet
4. Future within profession

4.2.3 Creating a Taxonomy of Subdomains

Subdomains were created from data which was arranged into groups under the primary domains (Atkinson & Haj, 1996). On some occasions, subcategories from one domain overlapped with another, showing an interrelationship between the two domains. For example, policies and recommendations fell under two domains, future within the profession and current post-use remediation treatments. Figure 4.3 shows the relationship between the primary domains and their subcategories.

Figure 4.3: *Taxonomic Analysis of Primary Domains*

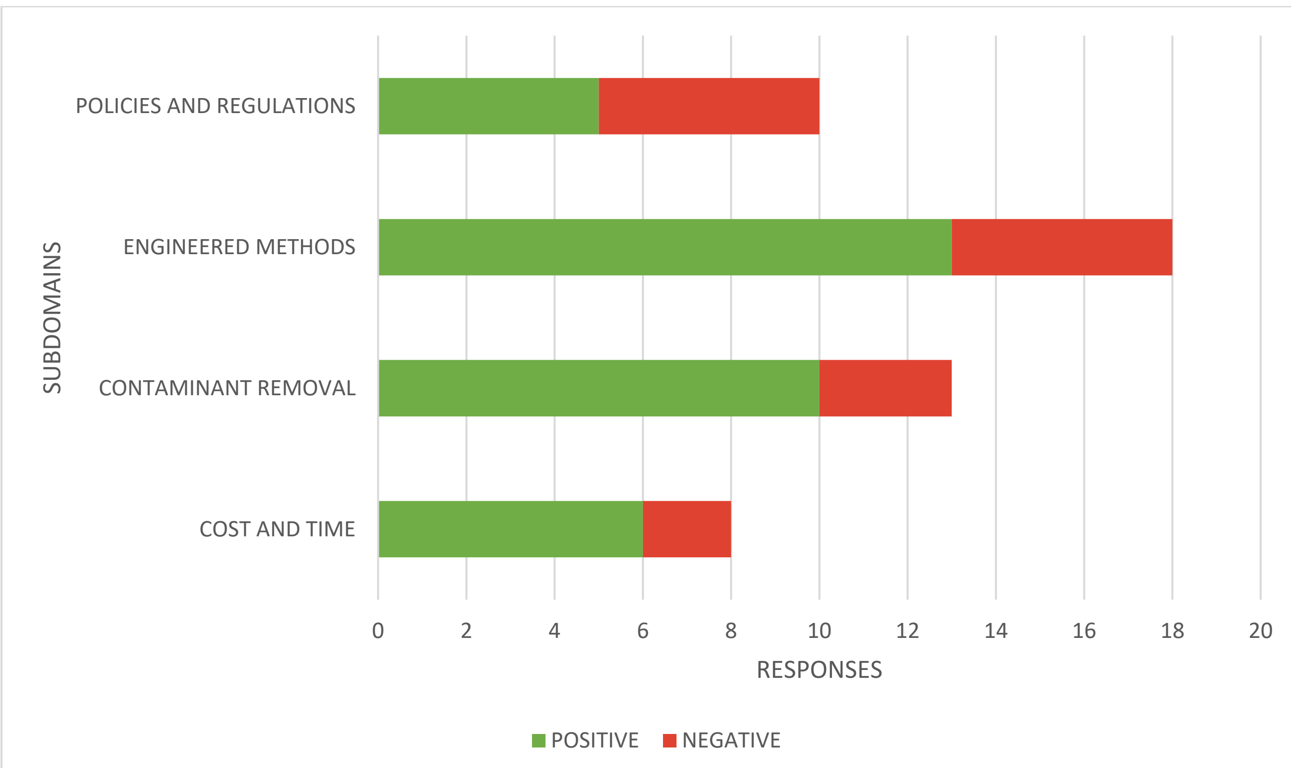


4.3 Findings – Specifying the Primary Domains

In this section, the domains were placed into the four primary categories, which were identified from the collected interview data. This data was collected based on the preliminary categories of questions. (see 3.5 Data Collection)

4.3.1 Current post-use remediation methods

Table 8
Current Post-Use Remediation Subdomain Mentions



Despite having different levels of knowledge on phytoremediation, all of the professionals expressed knowledge on the methods of remediation for contaminants in hydraulic fracturing or similar contaminants, such as petrochemicals or heavy metals. Many of the methods deployed are considered engineered methods versus the ecological alternative. As summarized by a professional in petroleum engineering and an environmental scientist, the method which is usually chosen is based on time and cost. Professionals which were more oriented towards the practices of the oil and natural gas industry expressed a preference for the methods “dig and haul”, which is the process of excavating the contaminated soil, moving it to another location for disposal, and filling the site with new soil. Or “plug and abandon”, in which the fluids which were not taken to another treatment location are reinserted into the well, and then sealed with a concrete plug and left abandoned for an allotted amount of time. In both of these methods, it was expressed that the sites are reseeded, but maintenance is left to the owner of the land.

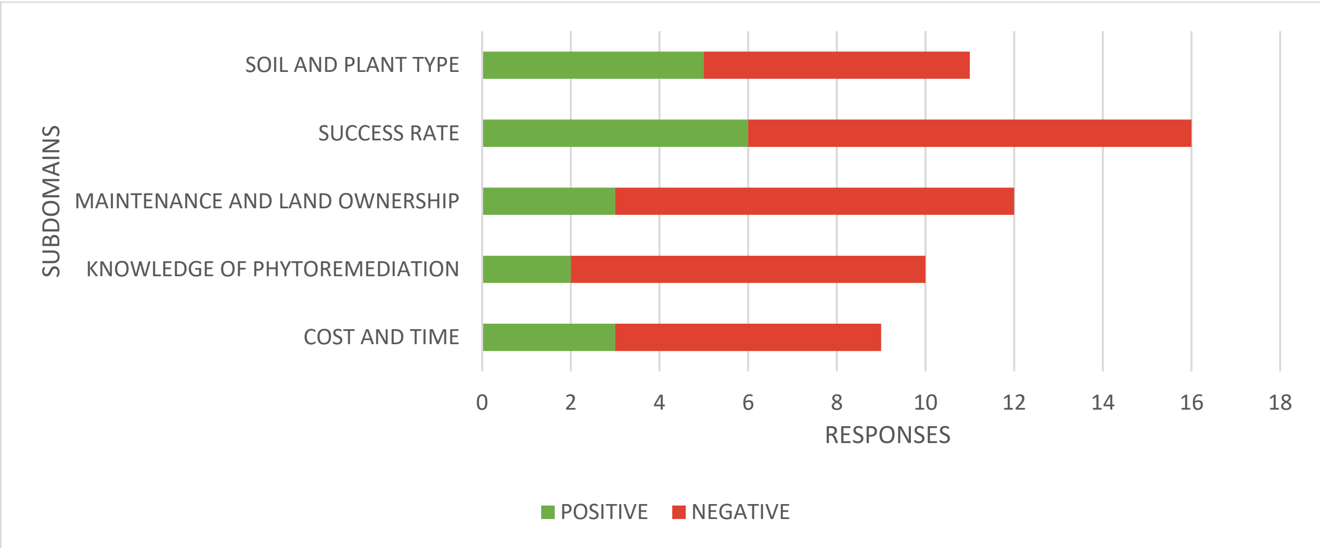
The data also revealed that participants who were recommended through the snowball effect (see section 3.5) had common schools of thought when it came to the type of remediation which they supported. Participants who were more oriented towards the natural gas industry favored the traditional methods. Whereas participants in the green industry preferred ecological methods, such as phytoremediation. Among the participants, there was a ratio of 6:4 with six participants showing a preference for traditional methods because they either are associated with the natural gas industry or had little to no knowledge on phytoremediation or other green alternatives.

Contaminants which that mentioned by the participants varied with the methods as well. Professionals who favored methods such as dig and haul mentioned that they were more concerned about chlorides found in natural gas than they were with TPH, or hydrocarbons. This concern is mentioned by an environmental scientist, “The typical issue is chlorides with oil and gas. TPH isn't really a big concern…”. Professionals who expressed a preference for phytoremediation said that the phytotechnology selected would depend on the type of contaminant, but that only high levels of contamination would deter them from using this method. In these situations, having various methods of treatment, or creating a system of treatments, also known as "treatment train", would be a more effective way to ensure the success of phytoremediation projects.

Every professional mentioned the need to follow policies and recommendations regarding natural gas and methods of remediation. Several stated that there are regulations set at the federal, state, and in some cases, local levels of government that must be followed in order to close or install a natural gas well. The policies referred to by the professionals about the hydraulic fracturing process were set by the Railroad Commission (RRC) and the Texas Commission on Environmental Quality (TCEQ) regarding the production and closure of the well, while the regulations in regard to human safety were set by the Environmental Protection Agency (EPA). The professionals who use phytoremediation refer to the regulations set by the EPA.

4.3.2 Phytoremediation

Table 9
Phytoremediation Subdomain Mentions



Phytoremediation methods were one of the original categories for questions due to the focus of this research. However, when asked, two of the interview participants were not aware of what phytoremediation was, six mentioned knowing about the process but not actively using it in their remediation projects, and two used phytoremediation as one of their preferred methods of remediation. The two that actively used phytoremediation mentioned a lack of knowledge amongst the allied fields, especially when collaborating with landscape architects. One of the professionals, an arborist, mentioned the importance of educating landscape architects in “the matters of remediation and reclamation”.

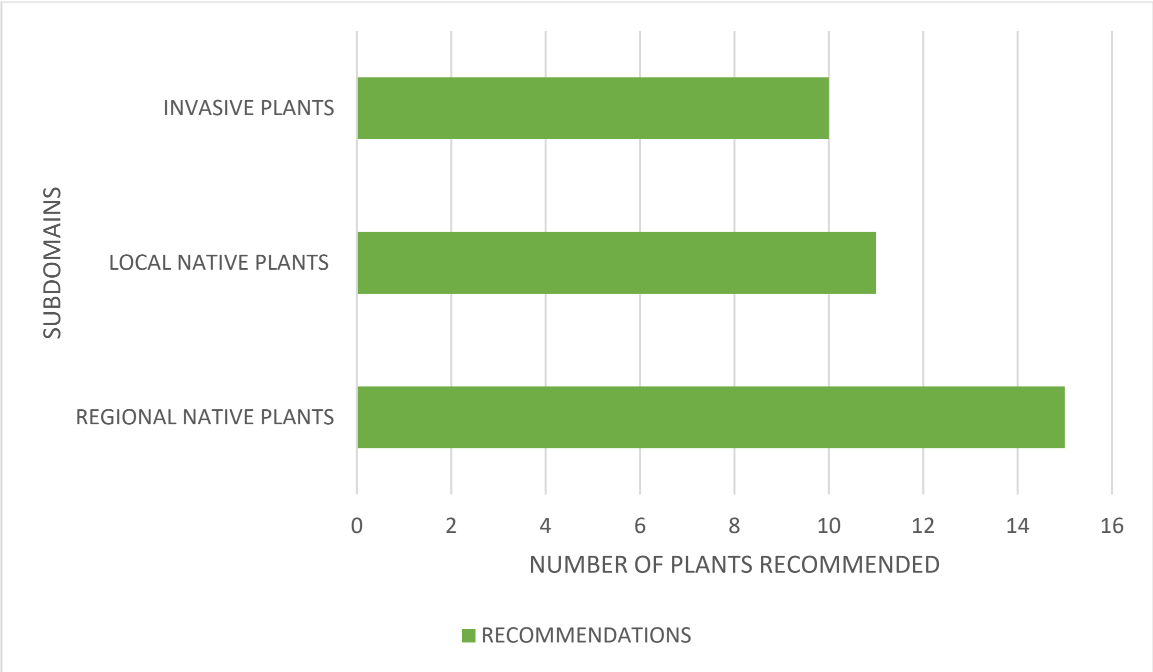
The professionals who mentioned that phytoremediation was not their preferred method described issues related to cost and time, maintenance, land ownership, and the success rate in respect to plant health. Cost and time relate to the amount of time that the phytoremediation method takes to be effective and the future land use of the hydraulic fracturing site. With plug and abandon, this is not as large of an issue since “the land is usually deemed safe to use after a few weeks" and the landowner only has to be wary of the preexisting conditions left behind by the well. Land which is projected to be sold for development usually is not considered for phytoremediation due to the clients’ “need to have the site free of contaminants as fast as possible”. In cases where time is not a constraint, “the cost of phytoremediation can discourage clients” or landowners causing them to select the cheaper, conventional methods.

If time were not an issue, the contaminants present could vary in the selected treatment method. This would allow for the selected phytoremediation method selected to treat the contaminant without the time constraint. In these cases, the maintenance of the site would be up to the company which installs the remediation treatment according to who is hired by the natural gas company, or to the landowner. If maintenance is to be done by the landowner, it is preferred that a specialist is hired to meet the standards for human safety, according to the interviewed professionals.

In the situation that the level of fracturing fluid contaminants is very high, the success rate of phytoremediation was questioned. This mainly relies on the phytotechnology method and plant selection. In high levels of contamination, participants said that the chance of the plant dying is 80 to 90 percent. “If the correct plants, native to the area, are selected, there is a higher chance of success than if introduced plants were used”. The soil profile affects contaminant uptake as well. If a soil is porous, such as a sandy soil, the plant will not have the ability to absorb or break down the contaminant before it is leeched off the site.

4.3.3 Plant Pallet

Table 10
Plant Pallet Plant Type Recommendations



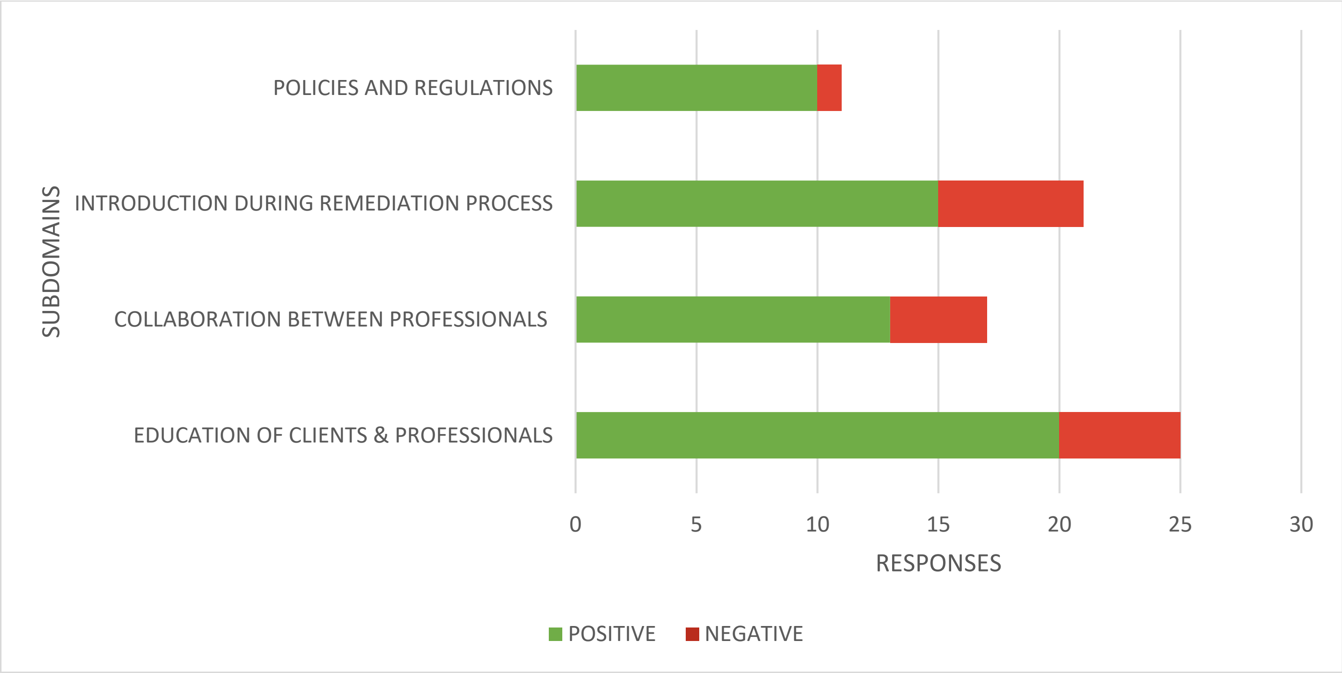
There was great debate amongst professionals over the effectiveness of regionally native plants and local native plants. Regionally native plants were considered to be plants that grow in a specified region but are not necessarily native. This group includes plants that have been introduced but are as effective as native plants in growing in the current environments. Local native plants were described as “plants which grow specifically to the ecoregion and climate zone”. However, there was not a concrete definition among the participants on what local native plants are, with some participants referring to regionally native and locally native plants as the same thing. The lack of a concrete definition among the participants over the two terms creates an issue regarding which level the participants are referring to.

An arborist recommended that professionals consider pioneer species when making a plant pallet selection for phytoremediation. These species are plants which “can handle harsh environments and are very hardy plants”. Pioneer plants can establish a large root system that penetrates the top 30 inches of soil are preferred, which allows them to create a favorable rhizosphere for treatment. Plants such as Switchgrass, Indian grass, and Johnsongrass were all recommended as potential candidates.

A horticulturalist recommended that plants that have been proven to be successful in phytoremediation processes be used over plants that have not been studied. Plants that have been proven, such as switchgrass and sunflowers, are plants that can be introduced into the area and can grow successfully. However, the issue with introduced plants is the potential for them to be invasive. Plants, such as the sunflower, have “the potential for rapid growth if they are being harvested”, but if they are planted in combination with another plant, the sunflower would outcompete the species. This is not always a negative, as stated by one of the participants: “for the growth of a singular species can offer an aesthetically pleasing experience to the land surrounding the fracturing site."

4.3.4 Future within the Profession

Table 11
Future within the Profession Subdomain Mentions



All ten participants said that there were gaps in information among the allied professions, especially when it came to landscape architects. Of the contacted participants within the profession of landscape architecture, many declined due to their lack of knowledge of phytoremediation, and of the two who agreed to participate in the study, both professed that many professionals who they collaborate with do not know phytoremediation practices outside of rain gardens, bioswales, and other water treatments.

This lack of information affects the professions when it comes to introducing phytoremediation to a project. "Ideally, having the professionals collaborate from the beginning of the project can help the flow and effectiveness of a project" stated the participating arborist. When projects are designed or commenced on contaminated sites without the proper knowledge or guidance, the chances of phytoremediation being used can decrease due to the lack of the required space necessary for plant growth and user safety.

The lack of knowledge about phytoremediation technologies has limited the push to have recommendations implemented by entities that promote the use of engineered methods such as the RRC. Due to the lack of these recommendations and policies, many professionals have found it difficult to explain the process to their clients. An environmental scientist stated that they "don't think that it's something that people think of and I think it's a lot more difficult to explain how it works and make them understand that this is a viable option". Along with the professions educating themselves on the potential of phytoremediation, creating a method to explain to their clients the process which is occurring would offer an expansion to possibilities for land use. Six of the ten professionals mentioned the need for demonstrations of phytoremediation in an aesthetically pleasing manner to promote the use amongst the general public.

4.4 Summary: Findings – Relating the Domains

The final step of domain analysis was to identify the relationship between the primary domains to help understand the bigger picture. In the second step of domain analysis, the taxonomic analysis identified the relationships between the primary domains and the subcategories. The specification of components done in the previous section helped us see the relationship between the domains.

The lack of regulations and knowledge of the use of phytoremediation on hydraulic fracturing sites leaves a scarcity of information. The data collected showed that there is a need for advocacy within the landscape architecture and allied professions, education of professionals of the practices, and provide the opportunity to study phytoremediation as a method to treat fracturing fluid contaminants.

Chapter 5

Conclusion

5.1 Introduction

This chapter provides a discussion of the collected interview data and the literature review to help provide a clear picture of what the use of phytoremediation methods within the landscape architecture field is, specifically with hydraulic fracturing sites within Tarrant County, Texas. This overview provides a synthesis of the documented findings and discusses the relevance towards the profession of landscape architecture and the allied fields.

5.2 Synthesis of Findings

After analyzing the data from the interview participants, it was determined that there is not a clear understanding of what phytoremediation is, nor how hydraulic fracturing sites can benefit from it in Tarrant County. The interview data, while somewhat biased to the participant's experience and expertise, showed that the use of phytoremediation is not a topic of common knowledge amongst the allied professions, especially among landscape architects. While phytoremediation is a method that is not commonly used, there are efforts from the profession to remediate hydraulic fracturing sites from the contaminants of fracturing fluids.

The study also addressed the way contaminants from fracturing fluids enter the surrounding soil and water come from a variety of variables, including the overflow of containment ponds, the transportation off the site, the failure of remediation, and the fracturing of wells. Due to the variety of ways contaminants leach into the soil, and subsequently the surrounding water bodies, remediation is a vital process for hydraulic fracturing sites.

Additionally, participants showed little to no knowledge, with the exception of the two participants who specialize in prairie restoration and horticulture, on the native plant pallet for the Tarrant County biomes. When asked, the participants knew of the ecoregions established by the EPA, but when asked about plants they knew which were native, many did not know of any. This became very apparent when asked about plants that have been studied to successfully work in phytoremediation applications. Many could only name switchgrass or eastern cottonwood as plants that could be used, both of which are regionally native, but not always locally native.

The policies and recommendations which need to be followed were known only by certain professionals. Participants who knew the information for these procedures are associated with the natural gas industry. Participants who are involved in the post-clean-up process of these fracturing sites are more aware of regulations which are set by the TCEQ and EPA than those set by the RRC, due to them only having to treat the contaminants and not the wells.

5.3 Conclusions and Discussion

Based on the findings, the researcher developed a more concrete understanding not only of the use of phytoremediation for the treatment of hydraulic fracturing contaminants. The results from the study identified the lack of information within the landscape architecture profession, the allied professions, and the natural gas industry. Having better access to information about the natural gas industry can help professions outside that field to make educated decisions on methods of treatment and future land use when it comes to hydraulic fracturing sites.

In the introduction chapter of this research the following questions were asked:

1. What are the current policies in place for Tarrant County which promote or hinder phytoremediation methods as a treatment of flowback fluid contaminants?
2. What regionally appropriate plants to the Tarrant County biomes could be used to effectively remediate pollutants on hydraulic fracturing sites?

3. What locally native plants to the Tarrant County biomes could be used to effectively remediate pollutants on hydraulic fracturing sites?
4. What are strategies that can be adopted by landscape architects and allied professions to promote phytoremediation in Tarrant County on hydraulic fracturing sites?

Currently, there are no policies set by the RRC which recommend phytoremediation as a method of remediation. The RRC prefers to promote methods that would assure that contaminants that have found their way into the soil of the site be removed in a quick method that allows for the land to be used for another purpose. The methods “dig and haul” and “plug and abandon” are considered relatively inexpensive for the natural gas company and the client when compared to phytoremediation. These costs can emerge from the cost of plants, labor, and the figurative cost of land left for extended amounts of time for treatment instead of being used for development. The RRC however, only sets policies regarding the cleanup and closure of natural gas wells and defers any policies related to human safety or environmental safety to the TCEQ and the EPA. The EPA does address the use of phytoremediation, but these are only written as recommendations, or “very strong suggestions", as stated by a participant in their interview.

Policies must be put into place by the RRC or the TCEQ within the state of Texas for phytoremediation to be the chosen method for the post-use remediation process of hydraulic fracturing sites. These two entities have a higher influence within the state and the practices of post-use remediation which take place. The only downfall would be the bias within the RRC towards the benefit of the natural gas industry. The RRC currently works in the favor of the natural gas industry and has policies that benefit the practices of this industry and not the environmental preservation and ecological restoration of these sites. Within the TCEQ, phytoremediation is not a method that is recommended for these types of contaminants. This is due to the risk factors that are set through the TCEQ and *in situ* methods. However, *in situ* is not the only form of remediation which can be used in the situation of the common contaminants found. To write these new policies more studies must be conducted on hydraulic fracturing sites, within the state of Texas and within Tarrant County.

Much of the information on these plants comes from studies on hydraulic fracturing sites outside of the Barnett Shale, with the most information published out of the Marcellus Shale in Pennsylvania. There are organizations that are working to promote the use of native plants in the reclamation of fracturing sites such as the International Phytotechnology Society (IPS) and within the state of Texas, the Native Prairies Association of Texas (NPAT). There are limitations to what extent these organizations can help. IPS is an international organization and provides information on phytoremediation and phytotechnology from across the world, but it is not always useful within Tarrant County, or Texas, due to the differing conditions. The plant list provided by IPS is a compilation of plants that could work in various locations and are not always plants that are native to the ecoregions. The risk for plants that could be invasive or harmful to the local flora and fauna exists without a deeper local plant knowledge. Organizations such as NPAT are working on the introduction of regionally native, and on occasions locally native plants, through the process of reseeding. However, their current reach in the restoration of hydraulic fracturing sites relates more to the surrounding areas for revegetation and reestablishment of ecosystems than the treatment of contaminants. From the data collected, it can be determined that there are regionally native plants that could be used, but there are not enough completed and longitudinal studies available to create an evidence-based local native plant pallet.

Landscape architects and designers have the capacity to influence the direction of what the post-use life of a hydraulic fracturing site can become. In many situations, it is turned into a new development site once the necessary measures have been taken. However, the concept of phytoremediation is one that has not been adopted in the profession beyond its application to stormwater management. An issue with this method is that while there is research on the different phytotechnology methods, it is presented in a scientific format which is difficult to comprehend without a science background (Kennen and Kirkwood, 2017).

Since phytoremediation and phytotechnologies are seen as future tools for the landscape architecture profession, the introduction to the possibilities should be something that is introduced early in the career. An interview participant stated that "landscape architecture students from major universities are graduating without the basic knowledge of environmental restoration or the methods on which to achieve it" (personal communication, March 25, 2021). The use of phytoremediation is commonly used in projects outside of the United States, however, for the purpose of this research, the four practices selected (see section 2.2) were the focus. Designers have found a way to incorporate these methods in combination with other methods or simply as the sole method of treatment into their designs for remediated public spaces (Todd, Landman, & Kelly, 2016). While the focus of this research was on hydraulic fracturing sites, the reach of phytoremediation is larger than the contaminants stated.

As the sprawl of cities begins, the need for these practices shall become more and more relevant as methods of treatment are needed to remediate contaminants found on sites proposed as green spaces. Designers will need to adapt their ways of approaching remediation design and learn to collaborate more fluidly with allied professions such as prairie restoration experts.

In places where hydraulic fracturing site remediation is not pressured for time, phytoremediation is a good option. These sites tend to be located on land that is considered rural or private property. Land which does not need to have an immediate turnaround can greatly benefit from phytoremediation since there is not a time limit to be met. On occasion, these sites also have low levels of contaminants. This could open the potential for collaboration with organizations, such as NPAT, to study plant performance and which combinations are best in these situations.

After analyzing everything which must be considered when it comes to incorporating phytoremediation within the landscape architecture profession, or an allied profession, the amount of knowledge needed prior to deciding a method is astounding. The case could be made that phytoremediation could become a specialty within the landscape architecture program, such as urban design, environmental design, or its own profession within itself. In the next section (5.5) future research questions are explored. These questions and speculations could help the profession define the specialty needed to practice using phytoremediation.

5.5 Future Research

There are many implications for the landscape architecture profession's engagement in phytoremediation use and in the remediation of hydraulic fracturing sites. The application of phytoremediation methods on hydraulic fracturing sites is not a sole profession's responsibility. While there is knowledge available on the subject, there are still many gaps to fill within the knowledge base of the allied professions. Environmental scientists have the need for information regarding the survival and efficiency of plants native to the state of Texas. Questions were raised about the hardiness of plants with large root systems, the percentage of contaminants a plant could absorb or treat, and the length of time which a plant would take to treat a chemical. Within the profession of petroleum engineering, the question of how designers could work with them to implement methods that could mitigate the disturbance to the local ecosystems.

As mentioned with regard to the policies, the lack of case studies performed within the state of Texas has limited the knowledge of plants that can be native to Texas that would work effectively with phytoremediation processes. The plants which are known to be successful within the few studies conducted in the state of Texas on natural gas spills and petrochemical spills have been introduced plants that can grow within the ecoregions found in Texas but are not necessarily considered to be native to certain areas. Plants such as *Populus deltoides* (Eastern Cottonwood), *Taxodium distichum* (Bald Cypress), and *Panicum vigatum* (Switchgrass) can be found in bottomland areas, whereas *Bouteloua gracilis* (Grama Grass) is considered an upland species. Upland areas are considered areas where there is a higher elevation, causing water to run down to lower areas. The bottomland area is considered a lower point of elevation, these areas are known for their tendency to be near bodies of water or flood. (Griffith, Bryce, Omernik, and Rogers, 2007). While there are native plants that work in the Tarrant County area, many of them are bottomland plants. This means that there is a lack of knowledge on plants that can survive in upland areas which are not subject to constantly growing in water.

Organizations such as IPS and NPAT have made great strides to promote both the use of phytoremediation and native plants for remediation. However, their current reach in the restoration of hydraulic fracturing sites relates more to the surrounding areas for revegetation and reestablishment of ecosystems than the treatment of contaminants. From the data collected, it can be determined that there are regionally native plants thati could be used, but there are not enough completed and longitudinal studies available to create an evidence-based local native plant pallet.

In the landscape architecture profession, there have been attempts to create this bridge between design and science before, such as in Kate Kennen and Niall Kirkwood's book *Phyto: Principles and resources for site remediation and landscape design.* These authors and landscape architects aimed to create a resource for design professionals for they "strongly support the notion that they [phytotechnologies] will form a new core subject within the study and practice of landscape architecture and land regeneration in the future" (Kennen and Kirkwood, 2017). Examining how these subjects can be integrated into the landscape architecture profession can lead to a future specialization within the profession, or potentially the creation of a new profession.

Research on the potential future land use of a hydraulic fracturing site is something that can benefit the profession as well. During the interview process, post-use of remediated fracturing sites was brought up, but never expanded on by participants. Those who chose to speak on the topic mentioned the preference of landowners towards building development. However, four professionals mentioned the idea of creating green spaces on the remediated sites. One of the four brought up the possibility of creating educational spaces where the community could have the opportunity to learn about phytoremediation as well.

This research indicated that the future of phytoremediation and hydraulic fracturing shows promise for landscape architects and designers. In addition to the questions raised above, this research raised other questions for future investigation:

1. Does land ownership affect the way hydraulic fracturing sites are remediated?
2. Can hydraulic fracturing sites be designed to have remediation of the pollutants designed from inception?

3. How would the natural gas industry benefit from having a landscape architect and environmental consultant collaborating to remediate hydraulic fracturing contaminants from its initial operation?
4. What are effective methods of continuing education which can raise the awareness of phytoremediation and phytotechnology methods for practicing landscape architects?
5. What future uses can hydraulic fracturing sites which have been remediated have?

5.6 Conclusion

This study covered the attitudes of the profession to the best of its abilities. The current attitudes allow us a small glimpse into where phytoremediation is currently in the year 2021. While phytoremediation is still considered a relatively innovative method, there are still many people within the profession of landscape architecture who do not know the abilities of phytoremediation or phytotechnology outside of rain gardens or bioswales. There is still much room for growth within the profession and within the study of phytoremediation as well. Seeing an increase of studies done in heavily polluted sites, whether they are coal ponds, heavy industry areas, brownfields, or hydraulic fracturing sites, can greatly help the advancement of this method.

This study initially started as a study of the methods used for the treatment of hydraulic fracturing contaminants. But as the lack of knowledge over the subject of phytoremediation and hydraulic fracturing became more and more prevalent, a study of the attitudes towards this issue and the reason why it was not being used became more suitable. While these attitudes are for the year 2021, attitudes within the profession should be studied periodically. This would allow professionals to view how opinions over phytoremediation have changed over time, and potentially allow for the study of methods in the future.

Appendix: Interview Questions

Interview Questions for Landscape Architects

1. How often does your firm work on projects that include hydraulic fracturing sites?
    a. If yes, how many projects have been done?
    b. Are any of these in an urban setting?
    c. What type of pollutants have you worked with?

2. Does your firm work with polluted sites?
    a. If yes, how often do you work on these sites?

3. What is the typical size of these polluted sites?

4. Where are these polluted sites often located?
    a. Are any of these within urban areas?

5. How often does your firm work with sites which have had a presence of VOCs or heavy metals?
    a. What was done to treat these sites before use?
    b. If phytoremediation was used, what type of uses were the sites given?
    c. What type of plants are typically used in these settings?

6. Is the analysis of these polluted sites done inhouse or are consultants hired?
    a. What type of consultants does your firm work with?

7. Has your company/firm ever been asked to work with a natural gas company on the treatment of a post use site?

8. Have you or your company/firm ever experienced an event where the pollution contamination was too great to be remediated using phytoremediation?
    a. What was done to treat the site?
    b. Follow up questions if necessary.

9. In urban settings, is phytoremediation a viable solution to pollutant treatment or would traditional methods, such as a concrete cap, be a better solution?

10. When it comes to human safety, who makes the decision when there is a level of present pollutants that is consider harmful within an urban context?
    a. How are the methods of treatment decided in these situations?
    b. Are certain methods, such as Biochar, that are preferred in urban settings?

11. In your opinion, how safe is a site once it is remediated?
    a. Is there a time frame which is best for the remediation of sites with VOC (Volatile organic compounds)?
    b. What are the recommended uses for land within urban areas that have these chemicals present?

*Follow up questions related to answers given to be used for clarification

Interview Questions for Planners

1. How often does your organization/firm work with natural gas companies to determine places suitable for hydraulic fracturing?
    a. Do you have any experience working with the extraction of pollutants from hydraulic fracturing?
    b. If yes, how many years of experience?
    c. What type of pollutants have you worked with?

2. What are the top three to five criteria when it comes to the determination of how hydraulic fracturing sites in urban areas are zoned?

3. Is there any adequate criteria which is placed on natural gas companies to ensure the safety of surrounding communities or urban spaces?

4. Does your organization/firm work with landscape architects in the post use planning of a hydraulic fracturing site?

5. How long does it take to change the zoning for a post use hydraulic fracturing site?

6. Does your organization/firm work with environmental engineers to help natural gas companies prevent pollution in sites?

7. Does your organization/firm take into consideration a natural gas company's ESG (Environmental, Social, Corporate Governance) plan or score?

8. In urban settings, is phytoremediation a viable solution for pollutant treatment or would traditional methods, such as a concrete cap, be a better solution?

9. When it comes to human safety, who makes the decision when there is a level of present pollutants that is consider harmful within an urban context?
    a. How are the methods of treatment decided in these situations?
    b. Are certain methods, such as Biochar, that are preferred in urban settings?

10. In your opinion, how safe is a site once it is remediated?
    a. Is there a time frame which is best for the remediation of sites with VOC (Volatile organic compounds)?
    b. What are the recommended uses for land within urban areas that have these chemicals present?

*Follow up questions related to answers given to be used for clarification

Interview Questions for Environmental Engineers or Environmental Scientists

1. Do you have any experience working with the remediation of spilled pollutants from hydraulic fracturing?
    a. If yes, how many years of experience?
    b. What type of pollutants have you worked with?

2. Have you ever worked with a landscape architect or landscape architecture firm on a remediation project?
    a. If so, at what point in the process was your company brought into the process?
    b. If no, has your company ever worked with a natural gas and oil company in the treatment of spilled contaminants or post use clean up?

3. How often does your company use phytoremediation as a method to remediate polluted sites?
    a. What are examples of the plants which your company typically uses in these cases?
    b. What consultants do you use to determine the correct plant use?

4. Have you or your company ever experienced an event where the pollution contamination was too great to be remediated using phytoremediation?
    a. What was done to treat the site?
    b. Follow up questions if necessary.

5. In urban settings, is phytoremediation a viable solution for pollutant treatment or would traditional methods, such as a concrete cap, be a better solution?

6. When it comes to human safety, who makes the decision when there is a level of present pollutants that is consider harmful within an urban context?

a. How are the methods of treatment decided in these situations?
b. Are certain methods, such as Biochar, that are preferred in urban settings?

7. How do you decide on the appropriate use for a site after it has been remediated?
    a. Is there a time frame which is best for the remediation of sites with VOC (Volatile organic compounds)?
    b. What are the recommended uses for land within urban areas that have these chemicals present?

*Follow up questions related to answers given to be used for clarification.

Interview Questions for Soil Scientists and Hydrologists

1. Do you have any experience working with the extraction of pollutants from hydraulic fracturing?
    a. If yes, how many years of experience?
    b. What type of pollutants have you worked with?

2. How long does it take the soil to absorb the pollutants from a spill?
    a. Does it take longer for heavy metals to settle or organic components?

3. Do soils with smaller porous spacing, such as clay, harder to remediate versus something more porous such as sand?

4. Is it easier to treat soils which are not found in locations with high water runoff?

5. Are treatment systems (treatment trains) better for the remediation of soil and water contamination?

6. Are sites which have been previously treated with Biochar still suitable for treatment using phytoremediation?
    a. Should the two methods be used together?

7. How does Biochar affect the make-up of the soil and the contaminants versus using phytoremediation?

8. In urban settings, is phytoremediation a viable solution to pollutant treatment or would traditional methods, such as a concrete cap, be a better solution?

9. When it comes to human safety, who makes the decision when there is a level of present pollutants that is consider harmful within an urban context?
    a. How are the methods of treatment decided in these situations?
    b. Are certain methods, such as Biochar, that are preferred in urban settings?

10. In your opinion, how safe is a site once it is remediated?
    a. Is there a time frame which is best for the remediation of sites with VOC (Volatile organic compounds)?
    b. What are the recommended uses for land within urban areas that have these chemicals present?

*Follow up questions related to answers given to be used for clarification

Interview Questions for Professionals Associated with Hydraulic Fracturing

1. How many years of experience do you have working with the extraction method of hydraulic fracturing?

2. In your time monitoring/installing hydraulic fracturing systems, how prone to spilling is the hydraulic fracturing fluid?

    a. Is there a measurement the quantity which could spill at the closure of a well?

3. How does your company plan for the reclamation, or clean-up for new use, of a fracturing site after it is no longer in use? If so, what are the methods used?

4. What is your company's process of sealing a well once it is no longer in use? How long is the monitoring process after the well is sealed?

5. Has your company explored the idea of the use of plants for treatment of spilled contaminants for the cleanup of well sites post use (called phytoremediation)?

6. Does your company currently help facilitate the process of revegetation of fracturing sites post use by planting new plants?

    a. What type of professional would makes these decisions?

7. How does your company currently help mitigate, or reduce, the number of pollutants which could be a threat to the surrounding users?

8. What is your company's top 3 to 5 criteria for selecting new locations for extraction wells in the urban context?

9. Does your company use the ESG (Environmental, Social, and Corporate Governance) scale?
    a. If yes, when was it adopted and why?
    b. What is the company's goal in using ESG besides scoring well?

10. How does your company respond when there is a spill of any dangerous substance to the general public?
    a. Are there special measures and/or treatment methods which are used?

11. How closely does your company work with the affiliated fields which will take over the site after use?
    a. If they work with them: which profession do they work in?

12. Does the company consult with an environmental scientist, engineers, or landscape architect prior to the installation of a fracturing well?

*Follow up questions related to answers given to be used for clarification

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