A CASE STUDY - HYDRAULIC FRACTURING GEOGRAPHY:

THE CASE OF THE EAGLE FORD SHALE, TX, USA

THESIS

Presented to the Graduate Council of
Texas State University-San Marcos
In Partial Fulfillment
of the Requirements

for the Degree

Master of SCIENCE

by

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San Marcos, Texas
August 2012

A CASE STUDY – HYDRAULIC FRACTURING GEOGRAPHY:

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ACKNOWLEDGEMENTS

I have been fortunate to be surrounded and supported by an amazing group of people and I am thankful for the opportunity to publicly express my gratitude to them. Thank you Dr. Dixon. You took on a project when you decided to become my advisor and I am so thankful you did. Your patience and encouragement at each step has always been appreciated. A special thanks to Dr. Zhan and Dr. Butler as well, I am thankful that in the midst of all their activity, they accepted to be members of my committee.

I am thankful for my friend and colleague Danielle. Our walks and talks meant the world to me. Thank you for pushing me to strive for more and never letting me give up.

I must also extend a sincere thanks to Ernest. Without your assistance, I would have had much more work and stress. Your kindness was unbelievable.

My greatest thanks go to Russell. Your endless encouragement, the faith you have in me, and your love got me through each day.

This manuscript was submitted on May 8, 2012.

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ABSTRACT

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The use of horizontal drilling in conjunction with hydraulic fracturing has increased the ability of producers to extract natural gas and oil from previously non-viable areas. By extracting natural gas and oil from low permeability geologic plays, or shale plays, the United States may have enough natural gas to burn for the next one hundred years. However, there are growing concerns about the effect hydraulic fracturing may have on the environment and surrounding ecosystems. These activities cause an increased potential for surface water contamination resulting from spills, leaks, soil erosion, large amounts of truck traffic, and habitat disturbance. With increasing amounts of hydraulic fracturing activity in the Eagle Ford structure, there is a greater chance that a spill may occur and cause adverse effects on the hydrologic processes in the area. In order to determine the risk spills pose to hydrologic processes, hydraulic fracturing wells were identified and mapped to show the distance from wells to streams as well as determining that spills in the Eagle Ford structure were not spatially auto-correlated.

Chapter 1

INTRODUCTION

Hydraulic fracturing is the process of pumping large amounts of water, sand and chemical additives into a well in order to extract natural gas and oil from shale structures (U.S. EPA 2011). Hydraulic fracturing has made extraction of natural gas and oil from shale structures economical on a large scale from sources that were previously inaccessible. These shale structures were known but were not viewed as economical until now. Hydraulic fracturing is now used in 90 percent of oil and natural gas wells in the United States (Food and Water Watch 2010). The process expanded rapidly after 2005 when the Environmental Protection Agency (EPA) issued an exemption for hydraulic fracturing from the 2005 Energy Bill and Safe Drinking Water Act (U.S. EPA 2004). Since issuing this exemption, shale structures across the United States have seen a significant increase in the amount of wells drilled. The Eagle Ford structure is located in South Texas and has seen a large increase in the use of hydraulic fracturing over the last three years. Texas is the number one producer of natural gas in the United States, and the Eagle Ford structure is the second largest producing shale structure in the state (RRC 2011b). As hydraulic fracturing spread to the newly discovered Marcellus Shale formation along the North Eastern coast of the United States, a growing awareness and concern for environmental and health risks have risen, leading to important questions about the use of hydraulic fracturing and its effect on the environment (Urbina 2011b).

Problem/Purpose Statement

One hundred years ago, natural gas was considered the waste product of oil fields and was flared or vented off. This is in stark contrast to today's standards in which natural gas is embraced by the U.S. as a crucial component for energy's future. The use of horizontal drilling in conjunction with hydraulic fracturing has increased the ability of producers to extract natural gas and oil from previously non-viable areas. By extracting natural gas and oil from low permeability geologic plays, or shale plays, the United States may have enough natural gas to burn for the next one hundred years. Natural gas is cleaner burning than coal or oil and releases 43 percent less carbon dioxide than coal-burning power plants when used in efficient combined-cycle power plants. However, there are growing concerns about the effect hydraulic fracturing may have on the environment and surrounding ecosystems (Biello 2010; Trotta 2011; U.S. EIA 2012).

The process of hydraulic fracturing to extract natural gas and oil is one of the largest energy booms the United States has ever experienced. There are several factors that contribute to the rapid expansion of the use of hydraulic fracturing on shale structures. Hydraulic fracturing combined with horizontal drilling has provided the technology needed to extract these resources economically with faster return rates on initial investments. At the beginning of the rapid expansion of the industry, gas prices were increasing which made this a lucrative industry to join. The industry has also been exempted entirely or partially from the Safe Drinking Water Act, Clean Water Act, Clean Air Act, National Environmental Policy Act, Comprehensive Environmental Response, Compensation and Liability Act, Emergency Planning and Community Right to Know Act, Endangered Species Act and the Resource Conservation and Recovery Act. These exemptions give gas producers opportunities to invest heavily in hydraulic fracturing with few regulations (U.S. EPA 2004; Environmental Working Group 2012).

The major environmental concerns for hydraulic fracturing include water quantity use, contamination of ground and surface waters, wastewater disposal, air pollution, land degradation, road use, safety and maintenance and rural community impacts because of the “boom and bust” cycle of this industry (Rahm and Riha 2012). Surface water contamination because of spills is examined for this research.

One of the largest concerns is how hydraulic fracturing and its activities may affect water resources, their use, and potential contamination as a result of wide spread hydraulic fracturing activity in the Eagle Ford region. The water resources of south Texas are currently under the strain of a growing population that is expected to increase 175 percent by the year 2050. Texas is also experiencing the worst drought since the 1950s. Each well that is fractured uses three to six million gallons of water laced with chemical additives that are harmful to the environment and human health in small doses. These chemicals are brought to well pad sites by trucks and combined with water and sand on site. The flowback water is then stored in open pits around the well and contains potent chemicals and high salt levels. South Texas and the Eagle Ford shale region are already experiencing some of these negative impacts. Any surface spills can result in soil contamination or surface and groundwater contamination that would affect the primary livelihood of these communities, as well as send contaminated water downstream to Texas bays and estuaries. Falling water tables also cause problems for those who rely on private wells or irrigation systems for farming and ranching (Sansom 2008; Rahm 2011; Rahm and Riha 2012).

Trucks also bring water, sand, pipelines, on site compressors and other heavy equipment to a well pad site. Many times trucks are using rural county roads or dirt roads, contributing to erosion and runoff contamination. Pipeline networks may also need to be established which may cause further land degradation. During a well's life span, water must be trucked continuously to the site for each fracturing job. The wastewater that returns to the surface after fracturing is stored on site in massive storage pits that may or may not be properly lined. Most wastewater in Texas is eventually trucked to an underground injection site for hazardous materials or evaporates on site from the open storage pits. These activities cause an increased potential for surface water contamination resulting from spills, leaks, soil erosion, large amounts of truck traffic, and habitat disturbance. Other concerns include noise pollution, air pollution, land clearing, new pipeline networks, road safety and maintenance, impacts to the rural communities and the "boom and bust" cycle associated with extractive development (Crowe 2011b; Rahm 2011; Rahm and Riha 2012).

With increasing amounts of hydraulic fracturing activity in the Eagle Ford structure, there is a greater chance that a spill may occur and cause adverse effects on the hydrologic processes in the area. This research seeks to locate hydraulic fracturing wells in the Eagle Ford structure, determine the hydrologic vulnerability to spills and determine if spills are spatially auto-correlated. This analysis will also examine the greatest threats to watersheds and areas with an increased chance of exposure to spills and pollutants.

Research Questions

- Where are hydraulic fracturing wells located in relation to the Eagle Ford structure?
- What is the hydrologic vulnerability to spills in the Eagle Ford structure?
- Are spills spatially auto-correlated in the Eagle Ford structure?

Chapter 2

LITERATURE REVIEW

Concerns/Potential Impacts

Natural gas is an important part of our clean energy future and is viewed by many as a transitional fuel that will help replace conventional mineral oil and coal. However, shale oil and gas production pose serious environmental risks to regions across the United States that are experiencing a rapid industrial development of their land. Environmental impacts from the large scale of horizontal hydraulic fracturing include air pollution, surface and groundwater contamination, large water quantity usage, water withdrawal, wastewater storage and disposal, changes in land use, improper erosion and sediment controls, road building and overuse, truck traffic, the vast array of chemicals used, the risk of spills, and regulation concerns. Older drilling techniques used less equipment, less water, and produced less waste, but a shale gas well must be managed twenty four hours a day seven days a week, and requires a constant flow of workers, equipment and fluids to and from the site. If not managed correctly, the impacts of these operations will have serious impacts to regional environments (Reijnders 2009; Howarth, Santoro, and Ingraffea 2011; LaFrance 2011; Rahm 2011; Rahm and Riha 2012).

Concerns:

- Land Use
- Transportation
- Quality of Life
- Air Pollution
- Chemicals
- Water Quantity and Quality
- Wastewater: Disposal, Storage and Spill Risk

Land Use

A hydraulic fracturing site requires much more equipment, more water and produces more waste that needs to be stored on site. The amount of land needed to drill a horizontal well is almost double the amount needed to drill a vertical well. However, multiple wells can be drilled from one location using horizontal drilling which decreases the overall land use in comparison to a vertical well. The site itself will have facilities that include but are not limited to fluid storage tanks, sand storage units, chemical trucks, blending equipment, pumping equipment and a data monitoring van that manages the entire process. A typical site set-up is shown in Figure 1 (Symond and Jefferis 2009; Rahm 2011; Frac Focus 2012c).

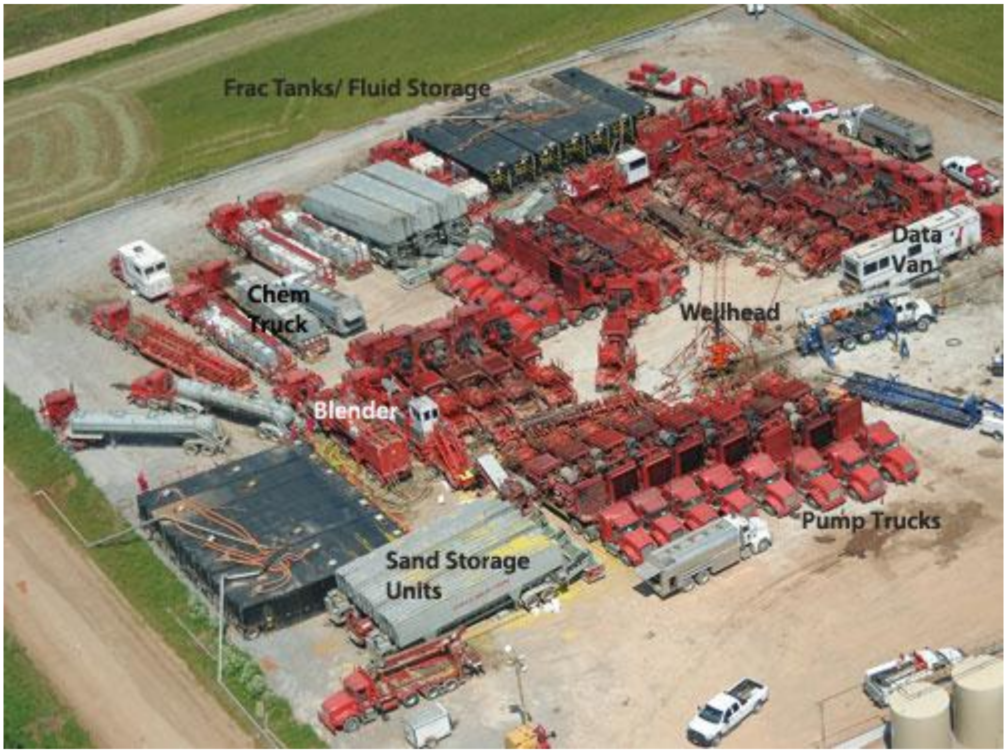


Figure 1. Typical site set up (Frac Focus 2012).

A well site should be constructed using best management practices set forth by the American Petroleum Institute (API) and the Independent Petroleum Association of America (IPAA). The guidance document created in 2004 by API and IPAA, titled, “Reasonable and Prudent Practices for Stabilization,” is a voluntary guidance document that, if implemented correctly, will “efficiently and effectively maximize control of storm water discharges,” at the well pad site (IPAA 2012). The industry created this document after the EPA and Congress exempted the oil and gas industries exploration and production operations from storm water discharges of sediment in 2006. This exemption means that the industry does not have to obtain a permit under the National Pollutant Discharge Elimination System as long as storm water runoff from a natural gas or oil site is not contaminated with oil, grease, or hazardous substances.

In preparation for fracturing of the well, waste pits need to be built to hold the flowback and other drilling cuttings and bits. These large open pits should be lined with special liners that will prevent fluid infiltration into the subsurface. If pits are not built to hold flowback fluids, then containers must be brought onsite to hold these fluids and other drilling operation waste. These open pits allow evaporation of chemicals into the surrounding air community and are known to leak fluids into the adjacent areas. Large spills of flowback fluids may also happen if any substantial rain event occurs and causes erosion, runoff or overflow from the pit (Frac Focus 2012b).

Transportation

Each new well in the Eagle Ford structure requires the construction of a well pad. To construct the well pad and bring in the equipment needed to perform the frac job, accessible roads need to be built many times. Any road leading to a well pad will see a substantial increase in truck traffic going to and from the well site. Trucks bring in pipes, fresh water, sand, chemical additives, the drill rig, bulldozers, graders, and other heavy equipment needed at the site. Almost 100 percent of water used by the natural gas and oil industry in the Eagle Ford structure is from underground aquifers and is being constantly trucked from the water well site to the well pad site. Materials and fluids are often transported from one site to another where they are treated in combination with fluids from other wells.

This increase in traffic on roads strains local infrastructure. It also increases the risk of spills and leaks that could happen during transportation, storage, or handling of the materials on site. Exhaust from trucks traveling to and from the site causes increases in air pollution in rural areas that are usually not exposed to large amounts of exhaust. There is also increased runoff and soil erosion that impairs local surface water and soils (Food and Water Watch 2010; Crowe 2011b; Fox News 2011; Frac Focus 2012b; Rahm and Riha 2012).

Quality of Life

Increase in traffic on roads strains local infrastructure and affects the quality of life in communities. Development within rural areas have a high potential to create boomtowns and unsustainable development, as well as cause environmental degradation (Ohl, Krauze, and Grunbuhel 2007; Aldrich 2008; Berger and Beckmann 2010; Nas et al. 2010). When a rural area sees a large amount of development and natural resource extraction in a short amount of time it is referred to as a boomtown. Boomtowns are associated with social upheaval and degradation of traditional lifestyles (Berger and Beckmann 2010). Rural areas are usually more open to economic stimulus that will be brought in with unwanted projects despite the negative impacts, though few residents fully comprehend the consequences. Areas with rapidly increasing population size are unable to maintain social networks and ties fracturing community bonds during the boom (Aldrich 2008).

Other problems that arise with an influx of outside workers into boomtowns include an increase in sexual predators, poaching, risk of pollution, crime, and changes in land use. All of these problems result in a decline of the quality of life (Ohl, Krauze, and Grunbuhel 2007; Lamelas et al. 2008; Berger and Beckman 2010; Nas et al. 2010).

Boomtowns result in unsustainable development because most of the money created in this boom does not stay in the area where the natural resources are being extracted. Instead, most of the money is sent to regions where outside workers originated from (Barbier 2007; Berger and Beckman 2010). The accumulation of personal wealth in the area, by land owners leasing land and receiving royalties, is at the expense of environmental degradation. Land owners find that revenues from areas of the economy that were once viable and sustainable, such as ranching and farming, are no longer so (Brody et al. 2006; Barbier 2007; Ohl, Krauze, and Grunbuhel 2007).

Air

The production of natural gas, like any fossil fuel industry, is an energy resource intensive process that contributes to the global greenhouse gas footprint. In 2009, the National Research Council stated that shale gas emissions may be greater than conventional gas emissions based on current extraction processes because of increased CO_2 emissions and methane naturally released in the process. Methane gas is a major component of natural gas and a potent greenhouse gas that is thirty times worse than carbon dioxide when contributing to climate change. According to research, the total greenhouse gas footprint for shale gas should consist of direct CO_2 emissions from end use consumption, indirect CO_2 emissions from fossil fuels used during extraction and development, transportation of the gas from trucks, any fugitive methane emissions, as well as the methane that is vented off gas wells.

A study examining the greenhouse gas footprint of shale gas based on the most recently available data from the EPA and the General Accountability Office, concluded that an average shale gas well will emit 3.6 to 7.9 percent of the total production of the well as methane into the atmosphere. At minimum, that amount is 30 percent more than the 1.7 to 6 percent estimate for conventional gas. The research was broken up into the following categories listed in

Table **1**. The best estimates determined for each category were conservative and did not take into account routine venting at wells, equipment leaks, accidents or emergency vents. On a twenty year horizon, the greenhouse gas footprint for shale gas is 20 percent greater than the greenhouse gas footprint for coal. Shale gas emissions are 18 percent lower than deep mined coal and 15 percent greater than surface mined coal emissions. Compared to oil, shale gas emissions are at least 50 percent greater than end oil emissions (Food and Water Watch 2010; Howarth, Santoro, and Ingraffea 2011).

Table 1. Estimates for Methane Loss (Howarth, Santoro and Ingraffea 2011).

Estimates for Methane Loss		
	Conventional Gas	Shale Gas
Emissions during well completion	0.01%	1.90%
Routine venting and equipment leaks at well site	0.3 to 1.9%	0.3 to 1.9%
Emissions during liquid unloading	0 to 0.26%	0 to 0.26%
Emissions during gas processing	0 to 0.19%	0 to 0.19%
Emissions during transport, storage, and distribution	1.4 to 3.6%	1.4 to 3.6%
Total Emissions	1.7 to 6.0%	3.6 to 7.9%

When considering the greenhouse gas footprint for shale oil, the life cycle emissions are 50 to 500 percent larger than conventional oil. This is taking into account direct CO_2 emissions from end use consumption and indirect CO_2 emissions from fossil fuels used to extract, develop and transport the oil (Reijnders 2009).

In 2008, natural gas was responsible for a fifth of all energy related carbon dioxide emissions in the United States. The amount of increased emissions from natural gas and oil extraction is not only causing a larger greenhouse gas footprint, but is also causing adverse health effects to individuals living in close proximity to a hydraulic fracturing well site. No conclusive studies have been completed on the adverse health effects of living near these sites, but the EPA's study on hydraulic fracturing, expected to be released at the end of 2012, should give some conclusive evidence on how this process is affecting air quality (Food and Water Watch 2010; Howarth, Santoro and Ingraffea 2011; U.S. EPA 2011).

Chemicals

Chemical additives serve many different purposes and make up 0.2 to 0.5 percent of the total concentration of the fracturing mix. This translates into 15,000 to 60,000 gallons of chemicals for a standard horizontal well that requires three million gallons of water (Food and Water Watch 2010). Traditionally, the exact chemical recipe used in a fracturing process has been kept secret by companies stating that it was proprietary information that helped protect their competitive advantage (Lustgarten 2011). Then, in late 2010 early 2011, the United States House of Representatives Committee on Energy and Commerce began an investigation to examine the practice of hydraulic fracturing in the United States. They asked fourteen leading oil and gas companies to provide them with the types and volumes of hydraulic fracturing products used in their fluids between 2005 and 2009. The final report by the committee showed that the fourteen companies had used over 2,500 hydraulic fracturing products (USHRCECMS 2011).

These products are used for a variety of applications and each is a mixture of chemicals or compounds designed to achieve a certain performance goal as seen in Table 2. The composition of products used varies by shale structure. Most oil and gas companies purchase products from third-party manufacturers but some companies create their own products. Several of these chemicals are harmless but others pose serious risks to human health and the environment (Western Organization of Resource Councils 2009; New York State Water Resources Institute 2010; USHRCECMS 2011).

Table 2. Products and purpose of products (Chesapeake Energy 2012).

Product	Purpose
Acid	Helps dissolve minerals and initiate cracks in the rock
Anti-bacterial Agent	Eliminates bacteria in the water that produces corrosive byproducts
Breaker	Allows a delayed breakdown of the gel
Clay stabilizer	Prevents formation clays from swelling
Corrosion inhibitor	Prevents corrosion of the pipe
Crosslinker	Maintains fluid viscosity as temperature increases
Friction reducer	"Slicks" the water to minimize friction
Gelling agent	Thickens the water to suspend the sand
Iron control	Prevents precipitation of metal in the pipe
pH Adjusting Agent	Maintains the effectiveness of other components, such as crosslinkers
Scale inhibitor	Prevents scale deposits downhole and in surface equipment
Surfactant	Increases the viscosity of the fracture fluid

Many of the fourteen companies were unable to provide the committee with a complete chemical makeup of their products because they do not have access to the proprietary product information. Oil and gas companies, Universal Well Services, Complete Production, Key Energy Services, and Trican, all reiterated that they obtain fracturing products from third-party manufacturers and that "product composition is proprietary to the respective vendor and not to the Company" (USHRCECMS 2011). Third-party manufacturers do provide a Material Safety Data Sheet (MSDS) detailing the product's chemical components. The Occupational Safety and Health Administration (OSHA) require chemical manufacturers to create a MSDS for every product they sell "as means to communicate potential health and safety hazards to employees and employers" (USHRCECMS 2011). The MSDS lists all hazardous ingredients that comprise of at least 1 percent of the product or 0.1 percent for a carcinogen. OSHA regulations also state that manufacturers may withhold the identity of any chemical components they consider to be 'trade secrets.' This means that oil and gas companies are injecting fluids with chemicals that they themselves cannot identify and have little understanding of the risks posed to human health and the environment (USHRCECMS 2011).

Of the 2,500 products identified, 650 contained chemicals that are known or possible human carcinogens regulated under the Safe Drinking Water Act (SDWA) or listed as hazardous air pollutants. Overall, these companies used 780 million gallons of hydraulic fracturing products in their fluids between 2005 and 2009. This volume does not include the amount of water added to the products before injection into the well. Of the 780 million gallons of products injected, companies used 94 million gallons of 279 products that contained at least one chemical that third-party manufacturers deemed proprietary. As well as using 11.4 million gallons of products containing a BTEX compound – benzene, toluene, xylene, and ethylbenzene. Of the 11.4 million gallons of BTEX compounds 83 percent of those fluids were used in Texas. Each BTEX compound is a regulated contaminant under the SDWA and a hazardous air pollutant under the Clean Air Act (CAA). The Department of Health and Human Services, the International Agency for Research on Cancer, and the EPA have determined that benzene is a human carcinogen. Any chronic exposure to benzene, toluene, ethylbenzene, or xylene can damage the central nervous system, liver, and kidneys (Restuccia 2011; USHRCECMS 2011).

The most widely used chemical in hydraulic fracturing products between 2005 and 2009 was methanol. Methanol was used in 342 products, is a hazardous air pollutant and a candidate for regulation under the SDWA (USHRCECMS 2011). Listed in Table 3 are the most widely used chemical components for this time period.

Table 3. Chemical components most often used in hydraulic fracturing products between 2005 and 2009 (USHRCECMS 2011).

Chemical Components	No. of Products Containing Chemical
Methanol (Methyl alcohol)	342
Isopropanol (Isopropyl alcohol, Propan-2-ol)	274
Crystalline silica - quartz (SiO2)	207
Ethylene glycol monobutyl ether (2-butoxyethanol)	126
Ethylene glycol (1,2-ethanediol)	119
Hydrotreated light petroleum distillates	89
Sodium hydroxide (Caustic soda)	80

As shown in Table 3, companies used 2-butoxyethanol (2-BE) as a foaming agent or surfactant in 126 products. 2-BE is easily absorbed and rapidly distributed in humans following inhalation, ingestion, or skin exposure. Studies have shown that exposure to 2-BE can cause hemolysis, and damage to the spleen, liver, and bone marrow. Companies injected 21.9 million gallons of products containing 2-BE between 2005 and 2009. Texas used the highest volume of products containing 2-BE, 12 million gallons.

These oil and gas companies also used hydraulic fracturing fluids containing twenty nine chemicals that are known carcinogens, regulated under the SDWA, or listed as a hazardous air pollutant (HAP) under the CAA. These twenty nine chemicals were a component of 652 different products used in hydraulic fracturing. The overall amount of fluids with carcinogens injected by these companies was 10.2 million gallons. Texas injected the most fracturing fluids containing a carcinogen using 3.9 million gallons of these fluids. Table 4 lists these toxic chemicals and their frequency of use (USHRCECMS 2011).

Table 4. Chemical components of concern (USHRCECMS 2011).

Chemical	Regulated Under or is Known to Be	Number of Products Used In
Methanol (Methyl alcohol)	HAP	342
Ethylene glycol (1,2-ethanediol)	HAP	119
Diesel19 Carcinogen,	SDWA, HAP	51
Naphthalene	Carcinogen, HAP	44
Xylene	SDWA	44
Hydrogen chloride (Hydrochloric acid)	HAP	42
Toluene	SDWA, HAP	29
Ethylbenzene	SDWA, HAP	28
Diethanolamine (2,2-iminodiethanol)	HAP	14
Formaldehyde	Carcinogen, HAP	12
Sulfuric acid	Carcinogen	9
Thiourea	Carcinogen	9
Benzyl chloride	Carcinogen, HAP	8
Cumene	HAP	6
Nitrilotriacetic acid	Carcinogen	6
Dimethyl formamide	HAP	5
Phenol	HAP	5
Benzene	Carcinogen, SDWA, HAP	3
Di (2-ethylhexyl) phthalate	Carcinogen, SDWA, HAP	3
Acrylamide	Carcinogen, SDWA, HAP	2
Hydrogen fluoride (Hydrofluoric acid)	HAP	2
Phthalic anhydride	HAP	2
Acetaldehyde Carcinogen,	HAP	1
Acetophenone	HAP	1
Copper	SDWA	1
Ethylene oxide	Carcinogen, HAP	1
Lead	Carcinogen, SDWA, HAP	1
Propylene oxide	Carcinogen, HAP	1
p-Xylene	HAP	1
Number of Products Containing a Component of Concern		652

In addition, these companies injected 32.2 million gallons of diesel fuel or hydraulic fracturing fluids containing diesel fuel in nineteen states. Sixteen million gallons of these diesel fluids were injected in Texas. Diesel fuels contain toxic constituents including BTEX compounds. The 2004 EPA report on hydraulic fracturing stated that the use of diesel fuel in fracturing fluids poses the greatest threat to underground sources of drinking water and thus did not exclude diesel fluids from the SDWA in the 2005 Energy Policy Act (U.S. EPA 2004; USHRCECMS 2011). Any company that does use diesel fuel in their hydraulic fracturing fluids must obtain a permit under the SDWA. Restuccia stated that no oil and gas companies have sought permits, and no state or federal regulators have issued permits for diesel fuel use in hydraulic fracturing. This is a violation of the SDWA and means that companies have not been performing the environmental reviews required by law (Restuccia 2011; USHRCECMS 2011).

These chemicals present the most obvious threat to the environment. Because of the long list of chemicals, it is difficult to detect contamination and extremely expensive to do routine surveillance monitoring (TEDX 2009; Restuccia 2011). Along with testing for the vast amount of chemicals used, there are unknown threats from proprietary chemicals used (Lustgarten 2011). Chemicals are transported along urban and rural roads and stored undiluted at well sites. Spills can and do occur along transportation routes and at the well site. The more wells drilled, the more chemicals are being transported and stored undiluted across a shale structure. There are also chronic risks from the use of these chemicals in watersheds. Unreported or under-remediated spills will result in contamination of surface and ground water resources as well as contaminating soils and habitats. Though, the amount of contamination and repercussions may not be known for decades.

Water

Major environmental concerns generally revolve around several key activities associated with shale gas development. Water resources, their use, and their potential contamination as a result of a wide range of development activities figure prominently among those concerns. Improper or poorly managed drilling, water withdrawal, or water treatment could potentially lead to water quantity and quality impacts (Rahm and Riha 2012). Spills along roadways or at the drilling site are inevitable as hydraulic fracturing activity increases. These spills, both reported and unreported, along with the use of chemicals in watersheds over time will cause chronic contamination (Rush 2010).

As more oil and gas wells are drilled, the potential for hydraulic fracturing to have long term effects on South Texas water tables continues to increase. Each well in the Eagle Ford structure uses three to six million gallons of water. Nearly 100 percent of the water used comes from groundwater withdrawn from the Carrizo-Wilcox and Gulf Coast Aquifers. These millions of gallons of water are being withdrawn very quickly which does not allow time for the aquifer to recharge. There is going to be far less water for homes, farms and ranches in this area in the future. This is a future that is expected to include droughts that will be more intense and last longer, along with a population growth of 175 percent for South Texas (Crowe 2011a).

Water has become so important that many property owners have started water mining to supply the oil and gas industry. Property owners sell water for 10 to 80 cents a barrel which is then transported by truck or temporary pipelines to a well site. This easy money is made possible by Texas' rule of capture which allows landowners' unrestricted access to whatever water is available from the ground even if this results in pumping the water table dry, which is exactly what is happening. Residents from Karnes and LaSalle counties have already seen drops in their well levels and this is expected to continue if the amount of pumping continues (Crowe 2011a).

Soon after Eagle Ford drilling activity increased, complaints of low water wells prompted the Evergreen Underground Water Conservation District to launch a new monitoring program in four counties where some of the heaviest drilling and fracking takes place, Atascosa, Frio, Karnes, and Wilson counties. The conservation district does not know how much water is being pulled from the area and has no real regulatory power to control the use of water for the oil and gas industry. Permits are required for water wells that support oil and gas operations, but there is no limit to the amount of water that can be withdrawn. Similar water issues played out in North Texas over the past decade with the Barnett Shale development. Pressure on the Trinity and Woodbine aquifers prompted the Texas Water Development Board (TWDB) to designate that region a priority groundwater area and form the Upper Trinity Groundwater Conservation District. A TWDB study found that oil and gas development in 2005 consumed 3 percent of all Trinity and Woodbine groundwater and was expected to increase up to 13 percent by 2025. These water withdrawals are complicating efforts of the TWDB to plan for sustainable water use over the next fifty years (Crowe 2011a; Crowe 2011b; Rahm and Riha 2012).

Surface water quality can be affected by all aspects of the hydraulic fracturing process. Spills pose the greatest threat and can happen along roadways or on site.

Wastewater, chemicals, diesel fuel, and other fluids used on site will contaminate the surrounding soil and water sources if a spill or accident occurs. Roadway runoff will also cause surface water contamination because of the increased amounts of truck traffic and the amount of road degradation they are causing. Soil erosion is also a concern because of the exemption for oil and gas companies from storm water discharges as long as the runoff from the site contains no hazardous materials, oil or grease. These threats to surface water may be enhanced by the fact that streams are connected across watersheds which eventually end up in the bays and estuaries of the Gulf of Mexico (Kusumastuti et al. 2008; Food and Water Watch 2010; Rush 2010; Rahm and Riha 2012).

A preliminary study by The Academy of Natural Sciences of Drexel University found an association between the increases in natural gas well density and decreases in water quality indicators. A number of statistically significant correlations emerged for both natural gas well density and riparian canopy cover. Specific conductance and total dissolved solids were positively correlated with density; greater well density led to higher levels of specific conductivity and total dissolved solids. High density sites have an average of 60 percent increases in specific conductivity values compared to low density sites. Macro-invertebrate indicators were negatively correlated with well density indicating decreasing water quality with increasing well density. Increased well density was also associated with elevated levels of chemical contaminants and degradation of macro-invertebrate community structure. This last finding suggested that there is an operational threshold of drilling intensity below which the impacts on surface waters are sustainable. Increasing well density increases the overall impacts of extraction as well as increasing the probability of an environmentally damaging event like a spill or leak occurring in a watershed (Anderson 2010).

Wastewater: Disposal, Storage, and Spill Risk

After fracturing a well, fracking fluid will return to the surface as wastewater. About 10 to 30 percent will return immediately and 30 to 70 percent will return over the lifetime of a well. Wastewater is considered highly toxic and contains hydraulic fracturing chemicals that were initially injected with the fracking fluid, high levels of total dissolved solids (TDS), and high salt levels that can be five times saltier than sea water. The typical TDS levels can exceed 100,000 milligrams per liter. Table **5** shows the typical wastewater versus fresh water constituent values for the Marcellus Shale (Weston 2009; Food and Water Watch 2010; Crowe 2011b).

Table 5. Typical wastewater vs. fresh water constituent values for Marcellus Shale (Weston 2009).

Marcellus Shale		
Parameter	Typical Surface Water Analysis (mg/1 or ppm)	Flowback Analysis (mg/1 or ppm)
TDS	< 500	20,000 to 300,000
Iron	< 2	0 to 25
Oil & Grease	< 15	0 to 1,000
Barium	< 2	0 to 1,000
Strontinum	< 4	0 to 5,000
pH	6 to 9	5 to 7.5

Only about 10 percent of wastewater is recycled in Texas. The majority of wastewater is stored on site in large open storage pits until it can be trucked to a deep well injection site for hazardous material or has evaporated from the pit (Crowe 2011b). Allowing wastewater to evaporate on site allows toxic, volatile chemicals to be released into the air. These wastewater pits are also known to leak or overflow, causing toxic spills (Western Organization of Resource Councils 2009). Some operators in the

Marcellus Shale are selling their waste rather than disposing of it. Because it is so salty they have been able to sell the waste to communities that spread it on roadways for de-icing in the winter or use it for dust control in the summer (Urbina 2011d).

Spills and Accidents

Hydraulic fracturing related spills and accidents have occurred across the United States. Appendix 1 includes just a few of these documented spills and accidents. These spills/accidents have caused fish kills, large fires, stream and soil contamination, groundwater contamination, increased erosion, livestock deaths, and air pollution. Some of these documented spills/accidents were not reported by the oil and gas company that caused them. Instead they were reported by a landowner or after a fish kill occurred the pollutants were traced back to the company. Oil and gas companies are supposed to report all spills/accidents to their governing agency, like the RRC in Texas, but this does not always happen. Then when these incidents occur, many times there has been inadequate action taken to resolve the issue, especially in Texas, where the RRC rarely cites violators or issues fines. More spills/accidents occur than are accounted for in public record, but by looking at Appendix 1 it is obvious these incidents should be better documented in order to protect the environment (Food and Water Watch 2010; Michaels, Simpson, and Wegner 2010; River Systems Institute at Texas State University-San Marcos 2010; Crowe 2011b; Elbein 2011; Rahm 2011).

Regulation

Governing Agencies

Under Texas law, the Texas Railroad Commission (RRC) regulates, enforces and has jurisdiction over matters related to the oil and gas industry and over all "oil and gas wells in Texas; persons owning or operating pipelines in Texas; and persons owning or engaging in drilling or operating oil and gas wells in Texas" (Groat and Grimshaw 2012). Contrary to other states, in Texas, the Texas Commission on Environmental Quality (TCEQ) is not the primary state regulatory agency with jurisdiction over oil and gas operations or the wastes produced during such operations. The RRC is responsible for community safety and stewardship of natural resources. At the same time, one of its missions is to promote development and economic vitality of the oil and gas industry. This is a potential conflict of interests that allows natural resources to fall victim to the promotion of the oil and gas industry (Elbein 2011; Kurth et al. 2011; Groat and Grimshaw 2012).

When determining the adequacy of water supplies, multiple authorities have overlapping jurisdiction in Texas. These include the TCEQ, thirty nine river authorities and special law districts, multiple aquifer authorities, almost 100 Groundwater Conservation Districts, sixteen Groundwater Management Areas and seven Priority Groundwater Management Areas. In addition, the Texas Water Development Board (TWDB) and its regional planning committees are responsible for producing a fifty year plan for water resources that is updated every five years. The TCEQ regulates permits for surface water retrieval. The first water retrieval application was filed in 2010 for San Antonio River water to be used in the Eagle Ford Shale. This permit seeks 65 million gallons a year for ten years (Kurth et al. 2011; Rahm 2011). Texas groundwater belongs to the owners of the land above it and may be used or sold as private property. A landowner has the right to take for use or sell all the water that he/she can capture from below their land. Because of this, Texas groundwater is essentially unregulated, and the oil and gas industry can withdraw as much groundwater as needed for their operations (Texas A&M University 2012).

In July 2011, the RRC created the Eagle Ford Task Force. The Task Force is comprised of local community leaders, local elected officials, water representatives, environmental groups, oil and gas producers, pipe companies, oil services companies (including a hydraulic fracturing company, a trucking company and a water resources management company), landowners, mineral owners and royalty owners. Their mission is to open lines of communication between all parties, establish best practices for developing the Eagle Ford Shale and promote economic benefits locally and statewide to ensure the RRC can keep up with industry development (Kurth et al. 2011).

Applicable Laws

Like all oil and gas operations in Texas, fracking operations require the RRC to issue a permit authorizing the drilling of a well. In addition, the RRC regulates the storage, transfer and disposal of oil and gas wastes. The RRC also regulates the casing and cementing of wells. The same laws that apply to conventional oil and gas operation also apply to hydraulic fracturing. The RRC states that these rules for construction have prevented even a single case of groundwater contamination from injected fluids. Therefore, unlike many states, the RRC does not require fluid injection permits for fracking. If federal regulations are amended to include fracking within the definition of Class II underground injection wells, then the RRC will have to follow suit (Kurth et al. 2011).

Texas did become the first state to require operators to disclose chemicals used in fracturing fluids in June 2011. Companies are required to disclose chemical ingredients of fracturing fluids and the volume of water used to the website fracfocus.org, operated by the Ground Water Protection Council and the Interstate Oil and Gas Compact Commission. However, companies will be able to withhold any information that it claims to be "trade secrets." Property owners and neighbors to the property owners will be able to challenge the trade secret designation. In addition, a means must be provided to supply the information to health professionals and emergency responders in case of an injury or other accident. The statute became effective September 1, 2011, but only applies to hydraulic fracturing treatments performed on a well for which an initial permit was issued on or after the date the initial rules adopted by the RRC of Texas (Elbein 2011; Kurth et al. 2011).

Exemptions for Oil and Gas Industry

The hydraulic fracturing industry has exemptions from parts of at least eight federal environmental laws. These laws were written to regulate most heavy industries in order to protect the environment from hazardous chemicals and intensive use. Some examples of how other industries are regulated where hydraulic fracturing is not are:

- Coal mine operators who want to inject toxic wastewater into the ground. They are required to get permission from the federal authorities. Oil and natural gas companies do not have to follow the same rules when injecting fracturing fluids into a well (Urbina 2011c).
- Sprawling steel plants with multiple buildings air pollution is added together when regulators decide whether certain strict rules will apply. At a hydraulic fracturing site, the toxic fumes from various parts of a compressor station or a

> storage tank, for example, are counted separately rather than cumulatively, so many overall fracturing operations are subject to looser caps on their emissions (Ubrina 2011c).

The laws and exemptions for hydraulic fracturing are shown in Appendix 2 (Environmental Working Group 2012; Groat and Grimshaw 2012; USFWS 2012).

Regulation Enforcement Concerns

Regulations have not kept pace with the industry's expansion, and the regulations that do exist are not enforced correctly. Concerns have been expressed that oil and gas industry interests regularly trump environmental concerns (Crowe 2011b). This was found to be true by the Sunset Commission Report in 2010 that revealed the RRC does not deter the oil and gas industry from environmental violations because it rarely cites violators or issues fines. The report called for major restructuring of the RRC, including adding more inspectors and greater budget reliance on fees and permits from the oil and gas industry in order to address encroachment of fracture drilling near the Eagle Ford Shale and the Barnett Shale. The report stated, "as the oil and gas industry continues to affect significantly populated areas of the state, the Commission needs an enforcement process that leaves little room for the public to question the agency's appropriate and consistent handling of identified violations" (Crowe 2011b). The Sunset Review also cited the Texas Water Development Board (TWDB), calling out a lack of coordination among state wide water planning efforts and the TWDB's lack of data that would enable informed conservation decisions. This data is extremely important for Texas because of the large population increase, which is expected to continue, and will affect water availability in rural and urban areas in the future (Crowe

2011b). In Pennsylvania, industry has outpaced regulators who fear that if they are too hard on the industry, companies will stop reporting their mistakes. This applies to Texas as well since regulators rely on companies to report their own spills, leaks or other mistakes made during the drilling process (Urbina 2011a).

The EPA stepped in and trumped the RRC in December 2010, stating that the agency was lax in its enforcement of the SDWA. The EPA issued an Imminent and Substantial Endangerment Order to protect drinking water in Parker County that had been contaminated with methane and benzene. The RRC has received multiple complaints from the landowners but has taken “inadequate action” against the gas company, and thus the EPA stepped in to protect the individuals from the contaminated water (Rahm 2011).

Any regulation that is to be effective in protecting the environment will depend not only on the content of the regulation, but also on how well the regulation is enforced by regulatory agencies. The enforcement and documentation of violations needs to also be addressed to amend any differing methods of collecting, organizing, recording and enforcement that may be happening. Complete records and an improved responsiveness of agencies to violations will be the first steps to addressing environmental concerns (Groat and Grimshaw 2012).

Chapter 3

STUDY AREA

Hydraulic fracturing is a process used to increase the yield of natural gas from rock pores in a shale structure (U.S. EPA 2011). Each structure has a sequence of events that is created to meet that structure's particular needs; therefore, while the individual structure requires a specific design, the overall process remains fundamentally the same (Frac Focus 2012a; Frac Focus 2012b). Companies will drill vertical and/or horizontal wells and then inject a mixture of fresh water, sand and chemical additives, called the fracking fluid, into the well. Fracking fluids are pumped into the well at an extremely high pressure in order to create fissures in the gas-bearing rock. The sand and additives keep these fissures propped open to allow oil and natural gas to flow uninhibited back up through the well where they are collected. After fracturing is complete, internal pressure forces some of the injected fracking fluids to rise to the surface over the next few days and weeks. Studies show that twenty to forty percent of the fracking fluid will remain underground. Recovered fracking fluids are referred to as flowback and may be stored in tanks or pits prior to disposal or recycling (Chesapeake Energy 2011; Earthworks 2011; U.S. EPA 2011).

Experimentation with fracturing techniques dates back to the nineteenth century, with an increase in application during the 1950s (U.S. EIA 2011). The first commercial use of hydraulic fracturing as a technology used to produce oil or natural gas occurred either in the Hugoton field of Kansas in 1946 or in Duncan, Oklahoma in 1949 (Frac Focus 2012a). In mid-1970, the U.S. Department of Energy, the Gas Research Institute and private operators formed a partnership to develop technologies that would extract natural gas for a commercial profit from the shallow Devonian shale located in the eastern United States. These progressing technologies eventually led to the practical application of horizontal drilling in the 1980s; however, it has only been in the last five years that shale gas has been recognized as an economically viable solution in the U.S. energy market (U.S. EIA 2011). Hydraulic fracturing has now been used on over one million producing oil or natural gas wells, and operators are now fracturing 35,000 wells each year (Frac Focus 2012b).

Recent hydraulic fracturing methods were first used to produce oil in 2007 from the Bakken structure in North Dakota and Montana. Today, fields in Texas, North Dakota, California and Colorado are projected to be yielding two million barrels a day by 2015. This means oil production will be raised by 20 percent over the next five years. Overall, the Bakken and Eagle Ford structures combined are expected to produce four billion barrels of oil (Fox News 2011).

The U.S. Energy Information Administration (EIA) estimated that recoverable gas resources in United States shale structures more than doubled from 2010 to 2011. The EIA predicts that by 2035, 45 percent of U.S. natural gas will be produced from shale structures. The total estimated amount of recoverable shale gas is at 616 trillion cubic feet (tcf) which is almost the same as Kuwait’s proven reserves. Texas is one of the top producers of natural gas and oil in the United States with three major shale structures: the Barnett, Eagle Ford and Haynesville-Bossier. In 2007, Texas produced

988 billion cubic feet (BCF) of shale gas and by 2009 production had risen to 1,789 BCF, accounting for 57 percent of shale gas produced in the United States that year. In 2009, the EIA projected the Eagle Ford structure to have twenty one trillion cubic feet of recoverable natural gas and three billion barrels of oil remaining. In 2011, the Eagle Ford Shale produced 243 BCF of natural gas and about 30.5 million barrels (Bbl) of oil. Rates of production are increasing dramatically and are expected to continue to rise (U.S. EIA 2011; Rahm 2011; RRC 2011b).

These large increases in production are because of the use of hydraulic fracturing and horizontal drilling. A vertical well will average fifty to one-hundred thousand cubic feet of gas production steadily over twenty to thirty years. Yet with horizontal drilling, recovery upfront is increased, which allows for a quicker recovery of drilling costs. Until recently, development of shale structures was disregarded because of the low rate of return on initial capital expenditure for companies. For any business, this type of prospect in increased profits and quicker recovery of initial development costs is an attractive option.

Hydraulic fracturing is considered to be more efficient and cost effective at extracting natural gas and oil than conventional natural gas. With improving technology, increased gas prices, and exemption from many federal laws, the extraction of unconventional gas sources grew from 28 percent to 46 percent in the United States from 1998 to 2008. Without hydraulic fracturing, up to 80 percent of unconventional production from shale structures would be impossible to recover on a practical basis (Symond and Jefferis 2009; Food and Water Watch 2010; Rahm 2011; Frac Focus 2012a).

The Eagle Ford structure is a shale formation. A shale formation is a fine-grained sedimentary rock that forms from the compression of silt and clay-sized mineral particles. Shale is laminated and fissile. In other words, the rock is made up of multiple thin layers that easily split into thin pieces along the laminations. Black organic shales are the source for natural gas and oil deposits which are often trapped within tiny pore spaces or absorbed into clay mineral particles that make up the shale (Geology.com 2012a).

The Eagle Ford shale structure is a hydrocarbon producing formation that has a significant importance to the natural gas industry because it produces both gas and oil more than other traditional shale plays. Natural gas and oil producing wells in the deeper part of the play contain a much higher carbonate shale percentage; which makes the Eagle Ford Shale brittle and easier to break (RRC 2011b; U.S. EIA 2011).

The Eagle Ford Shale is located in south Texas and has seen a large increase in oil and natural gas well activity beginning in 2008. Since that year, 3,477 oil and gas permits have been issued, and gas well production for 2011 has reached over 139 BCF. Oil production for 2011 was over 8,049,289 Bbl. There is a projected 21 tcf of natural gas and three billion barrels of oil now recoverable with the use of hydraulic fracturing. The Eagle Ford Shale is about 80.5 kilometers wide and 644 kilometers long with an average thickness of 76 meters. It is located between the Austin Chalk and Buda Lime at an approximate depth of 1,219 to 3,658 meters. The major operators in the Eagle Ford Shale are Petrohawk, Anadarko, Apache, Atlas, EOG, Lewis Petro, Geo Southern, Pioneer, SM Energy and XTO. There are sixteen fields covering twenty four counties located in Railroad Commission Districts 1 through 6. The counties used for this study include Atascosa, Bee, Brazos, Burleson, DeWitt, Dimmit, Fayette, Frio, Gonzales, Karnes, La Salle, Lavaca, Lee, Milam, Live Oak, Maverick, McMullen, Webb, Wilson and Zavala (RRC 2011b). The structure is located in the Rio Grande, Nueces, San Antonio, Guadalupe, Colorado and Lavaca Rivers watersheds (Sansom 2008; U.S. Geological Survey 2010; Census Finder 2012; Geology.com 2012b).

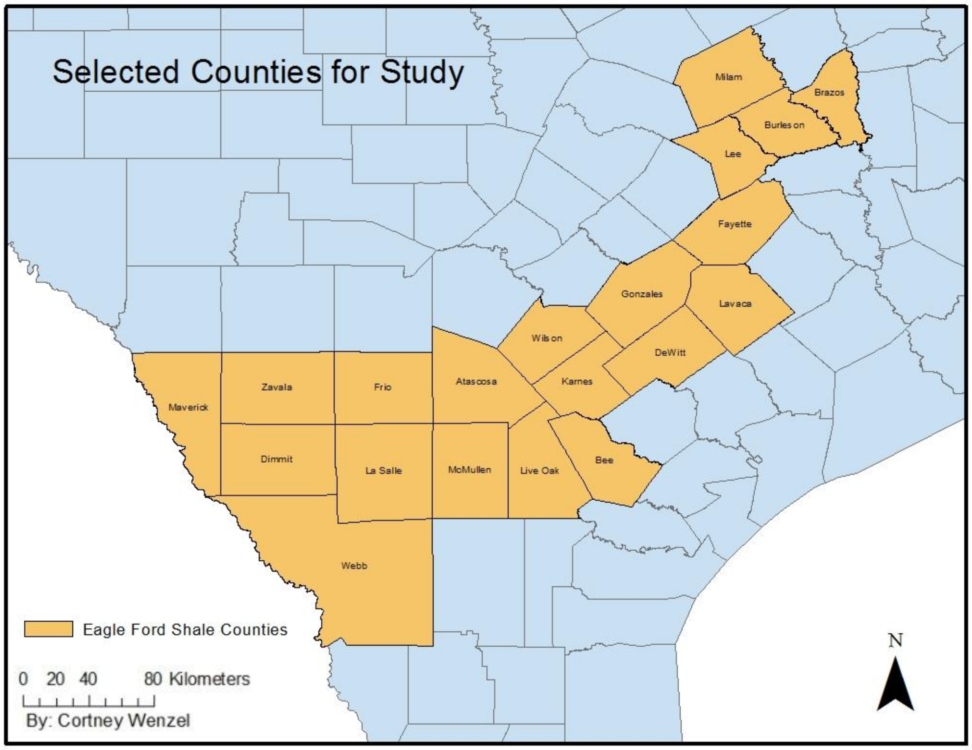


Figure 2. Map of Counties for study.

This area consists of rural communities that rely primarily on farming and ranching for income. Almost all water used for hydraulic fracturing in the Eagle Ford structure comes from underground aquifers, such as the Carrizo-Wilcox and the Gulf-Coast Aquifer, which relies on rainfall for recharge. The Eagle Ford area averages from 94 centimeters annual precipitation to the far east of the shale structure to 43 centimeters farthest west (Sansom 2008; Rahm 2011; Rahm and Riha 2012).

The Carrizo-Wilcox and Gulf-Coast Aquifers are both major Texas aquifers that extend from the Texas-Mexico border to the Louisiana border. The Carrizo-Wilcox Aquifer consists of the Wilcox Group and the overlying Carrizo Formation of the Claiborne Group. It is primarily composed of sand locally inter-bedded with gravel, silt, clay and lignite. The average saturated freshwater thickness is 204 meters. Irrigation pumping accounts for slightly more than half the water used, and pumping for municipal supply accounts for another 40 percent of water consumed from the Carrizo-Wilcox Aquifer (TWDB 2012a). The Gulf-Coast Aquifer consists of several aquifers, including the Jasper, Evangeline, and Chicot aquifers, which are composed of discontinuous sand, silt, clay, and gravel beds. The saturated freshwater thickness averages about 305 meters. The Gulf-Coast Aquifer is used for municipal, industrial, and irrigation purposes. In South Texas, groundwater use accounts for 65 percent of irrigation needs, 25 percent of municipal needs, and 5.5 percent for mining needs (TWDB 2012b). The Rio Grande, Nueces, San Antonio, Guadalupe, Lavaca, Colorado, and Brazos Rivers are the major rivers that flow through the study area. The rivers and their basins are listed in Figure **3**, Figure **4**, Figure **5**. Surface water accounts for 75 percent of municipal water use in South Texas. These river's characteristics are listed in Appendix 3 (Carroll 2012; Clay and Kleiner 2012; Donecker 2012; Hendrickson 2012; Metz 2012; Smyrl 2012; Weddle 2012). Overall water use of South Texas is expected to increase 68 percent by 2060 and with increased use for oil and gas production this region is expected to have water shortage problems during times of drought (TCPA 2008; TWDB 2012a).

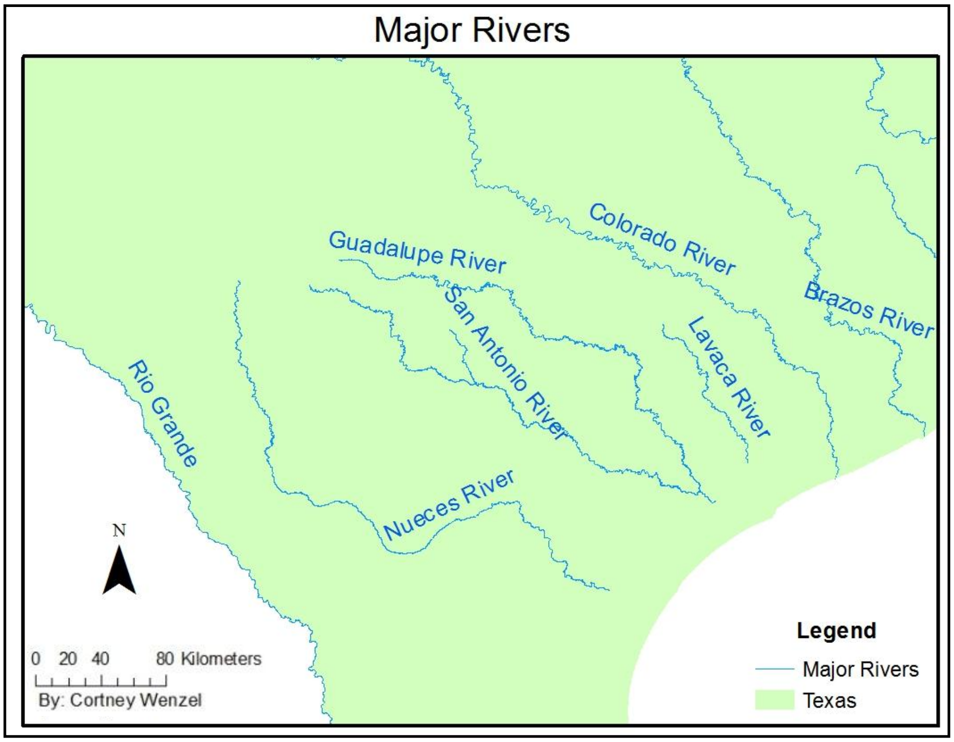


Figure 3. Major Rivers.

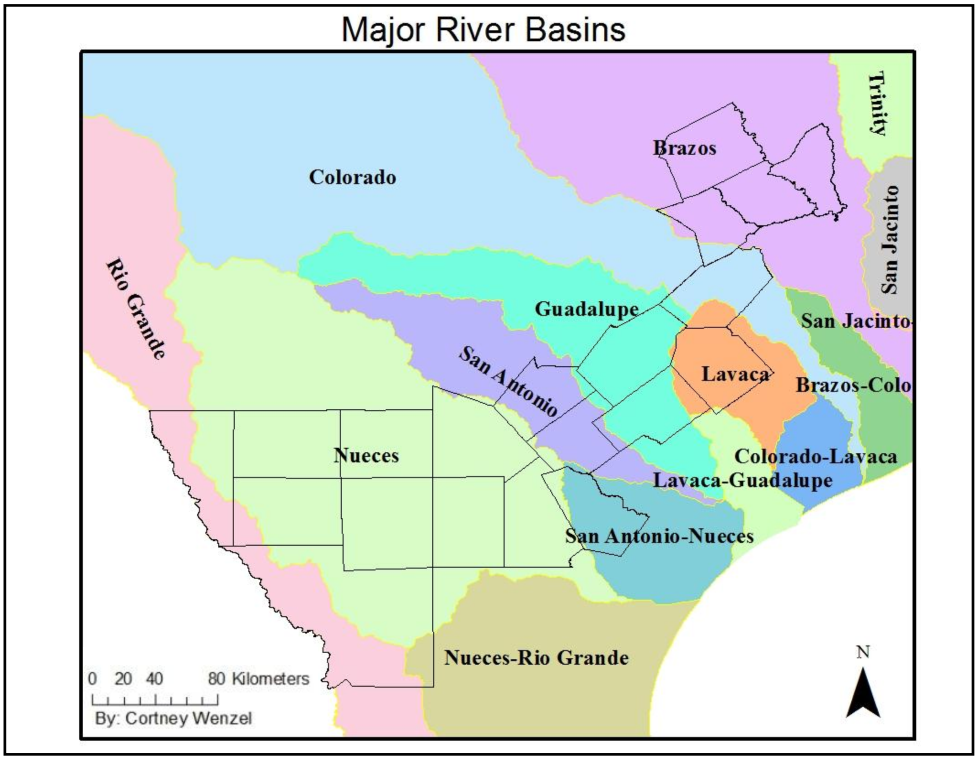


Figure 4. River Basins

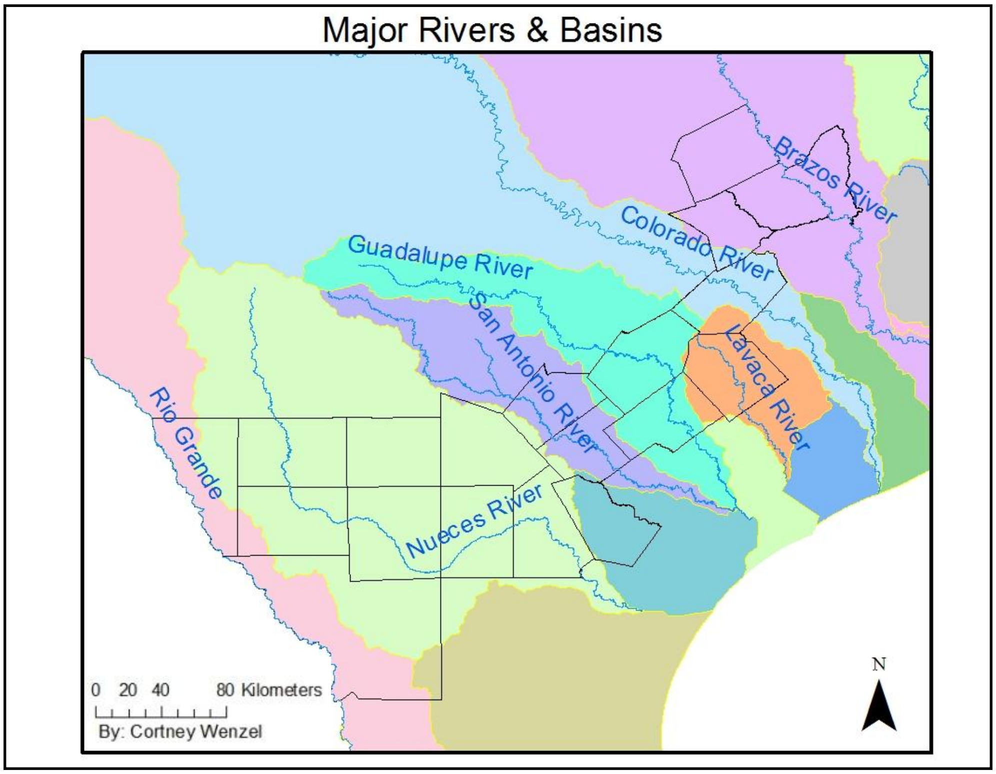


Figure 5. Major Rivers & Basins

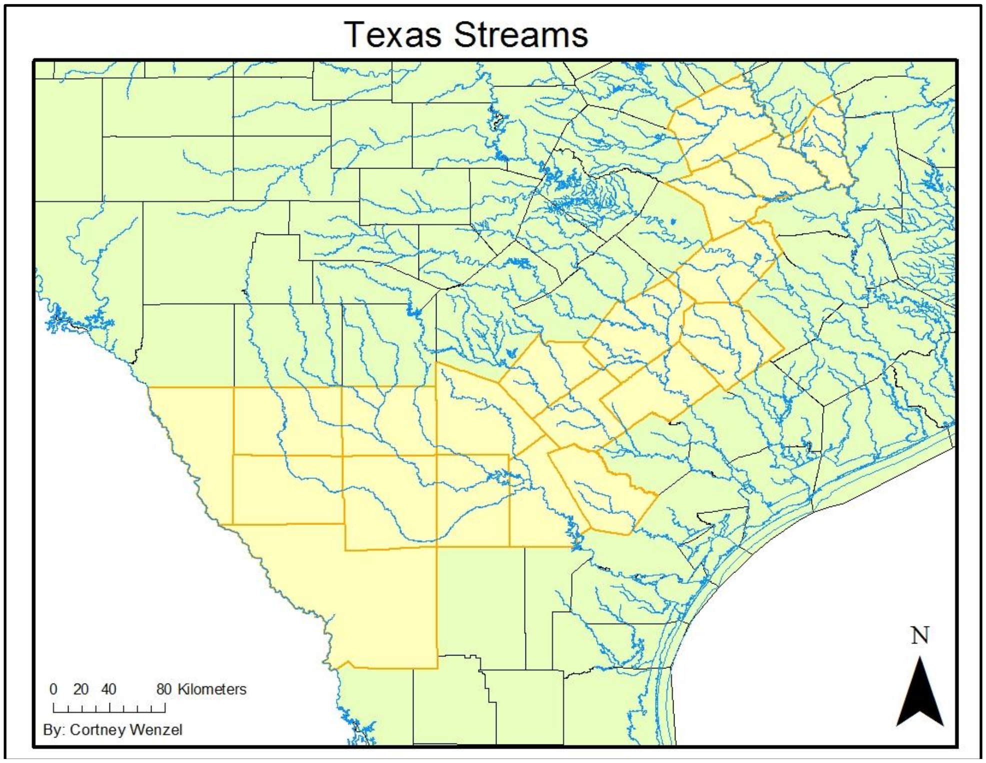


Figure 6. Texas Streams

Chapter 4

METHODOLOGY

Data

The data for spills in the Eagle Ford structure were obtained from the Railroad Commission of Texas' (RRC) 'Crude Oil, Gas Well Liquids or Associated Products H-8 Loss Reports' online (RRC 2011a). Reports from 2008 until September 2011 were used for this study. Geographic Information System (GIS) data for wells in the Eagle Ford structure were purchased from the RRC for twenty counties identified for this study (RRC 2012). Other GIS data that included major rivers, hill shades, and river basins, were obtained from the Texas Water Development Board and Stephen F. Austin University (Stephen F. Austin State University 2011; TWDB 2011).

Analysis

The first analysis used in this study is a statistical analysis using Moran's I. Moran's I measures the degree of spatial auto-correlation in areal data (Rogerson 2006). It uses a variable's location and attribute values simultaneously to evaluate whether the pattern expressed is clustered, dispersed, or random (ESRI Developer Networks 2010). Equation 1 shows Moran's I. The study will be used to determine if spills are spatially auto-correlated across 20 counties of the Eagle Ford structure.

$$I = \frac{n \sum i \sum j w_{ij}\, z_i z_j}{(n-1) \sum i \sum j\, w_{ij}} \tag{1}$$

For this equation n=20 regions and w_{ij} is a measure of the spatial proximity between regions I and j. The counties were each given an ID number, one through twenty, and the number of spills for each county was identified as shown in Table 6. The ID number for each county was labeled on a map in Figure 7. A binary connectivity definition of the county map resulted in a matrix, Table 7. The matrix was created to determine the weights (w_{ij}) or binary connectivity that represent whether or not two counties were contiguous or not. In this matrix if two counties were contiguous $w_{ij} = 1$, if not $w_{ij} = 0$ (Rogerson 2006). Then the mean (E[I]) and variance (V[I]) of I was used in a z statistic, shown in equation 2.

$$Z = \frac{I - E[I]}{\sqrt{V[I]}} \tag{2}$$

A Z-statistic was created to determine if any given pattern deviated significantly from a random pattern. The Z-statistic value was compared to the critical value found in a normal table. Moran’s I is interpreted much like a correlation coefficient. So if the end value is close to positive one, a strong spatial pattern exists, if the end value is close to negative one, a negative spatial pattern exists and if the end value is close to zero, it will mean the spills are random.

Table 6. Counties ID and spill count.

Selected Counties		
County ID	County	Total Spills
7	Atascosa	3
10	Bee	2
20	Brazos	11
19	Burleson	7
14	Dewitt	11
3	Dimmit	5
16	Fayette	8
5	Frio	10
13	Gonzales	2
11	Karnes	5
6	LaSalle	3
15	Lavaca	7
17	Lee	7
9	Live Oak	1
1	Maverick	0
8	McMullen	3
18	Milam	1
4	Webb	16
12	Wilson	0
2	Zavala	3

Table 7. Matrix created showing contiguous counties.

Matrix																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
5	0	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
6	0	1	1	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	1	1	0	1	1	0	1	1	0	0	0	0	0	0	0	0
8	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	1	0	1	1	0	1	1	1	0	0	0	0	0	0
12	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

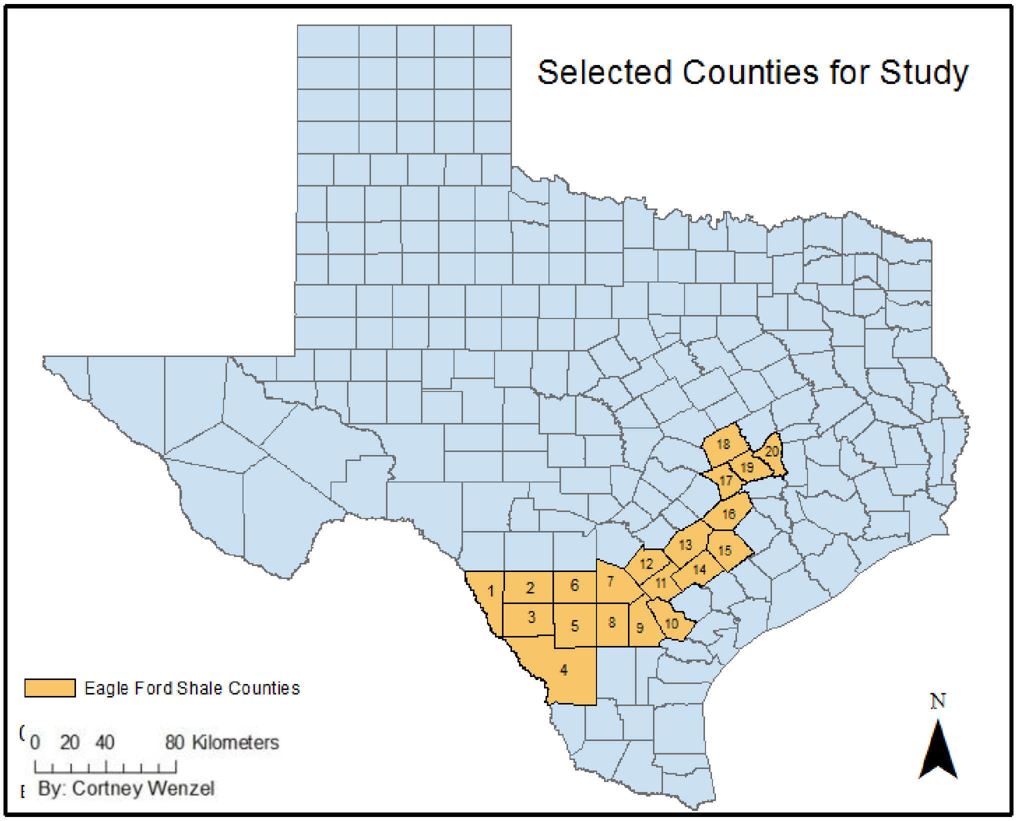


Figure 7. Map of counties according to ID number given.

The second method of analysis uses Geographic Information Systems (GIS). Hydraulic fracturing well locations were identified and mapped. Spill locations were identified and mapped. Then buffers were created to show the shortest, longest, and average distance from a well to a stream in order to determine how far a spill would need to travel before it reaches surface water.

Results

The mean number of spills was per county 5.26 and the variance was 22.36. In SPSS, the number of spills per county was transformed into z-scores. Then the quantities $a_i = \sum_j w_{ij} z_j$ were found. Here a_i represents the weighted sums of the z-scores, where counties that county i is connected to were summed. A linear regression was then used with *a* as the dependent variable and z as the independent variable. The regression coefficient was 0.246. This coefficient is the numerator used in calculating Moran's I. To determine the denominator another linear regression was performed. For the "y values," the sum of weights for each row in the matrix was found and shown in

Table **8**. The "x values" were all 1s because each one represented one county. The regression coefficient for the denominator was 3.75. By plugging in the numerator coefficient and denominator coefficient, Moran's I was found to equal 0.0656. The mean (E[I]), variance (V[I]), and Moran's I were used in the Z-static equation which equaled 0.027. This value was then compared to the critical value found in the normal table where a confidence level of 95% implied critical values of -1.96 and +1.96. The null hypothesis of a random distribution of spills was not rejected. Spills in the Eagle Ford Shale were a randomly distributed.

Table 8. "y values" and "x values" used to determine the denominator coefficient.

Matrix																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Y	X
1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1
2	1	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1
3	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	1
4	1	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4	1
5	0	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	6	1
6	0	1	1	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	5	1
7	0	0	0	0	1	1	0	1	1	0	1	1	0	0	0	0	0	0	0	0	6	1
8	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	4	1
9	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	4	1
10	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	2	1
11	0	0	0	0	0	0	1	0	1	1	0	1	1	1	0	0	0	0	0	0	6	1
12	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	3	1
13	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	0	0	0	0	5	1
14	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	3	1
15	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	3	1
16	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	3	1
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	3	1
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2	1
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	3	1
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1

For this study, a few relationships were also examined and should be taken into account. The categories obtained from the data set and were analyzed included: Cause of Loss, Type of Liquid Lost, Gross Loss, Recovered Loss, Net Loss, Type of Facility, Operator Name, and Counties. The total gross loss was 22,369 gallons and the total recovered loss was 19,007 gallons, which meant that 3,362 gallons of liquids were not recovered. The average gross loss was 189.2 gallons while the average amount recovered was 161 gallons. The one outlier was found in Brazos County which had a 15,000 gallon gross loss spill and all 15,000 gallons were recovered. Table 9 lists the amount lost and recovered by county. For Cause of Loss, Equipment Failure and Corrosion accounted for the largest amount of gallons spilled.

Table 9. Spills by county and amounts lost in gallons.

Amount Spilled by County			
County	Gross Loss	Recovered	Net Loss
Atascosa	330	9	321
Bee	438	809	29
Brazos	15,299	15,281	18
Burleson	702	439	263
De Witt	606	259	347
Dimmit	152	110	42
Fayette	394	308	86
Frio	153	165	348
Gonzales	46	40	6
Karnes	384	159	225
La Salle	150	95	55
Lavaca	714	539	175
Lee	466	335	131
Live Oak	10	10	0
Maverick	0	0	0
McMullen	444	0	444
Milam	90	0	90
Wilson	0	0	0
Webb	807	413	394
Zavala	50	16	34

The second method of analysis used Geographic Information Systems (GIS). Hydraulic fracturing wells were identified and mapped in Figure 8. There are a total of

19,203 oil, gas and combined wells, Table 10; a combined well is a well that produces both oil and natural gas. Spills were identified from the ‘Crude Oil, Gas Well Liquids or Associated Products H-8 Loss Reports’ by using their lease name, operator, field name, Lease number, gas permit number, and survey name (RRC 2011a). Some locations had to be identified using x,y coordinates that were given in spill reports. New layers were created for each county using the identified well’s American Petroleum Institute (API) number. A new layer was also created for the x,y coordinate spill sites. These spills sites are mapped in Figure 9. Once spill sites had been identified, buffers were created around streams at one point six kilometers and eight kilometers, Figure 10 and Figure 11. There were fourteen spills within one point six kilometers of a stream and 42 spills within eight kilometers of a stream. The average distance from a spill to a stream was three point eleven kilometers. The county and distance from a spill to a stream are shown in Tables 11 and 12.

Table 10. Oil, Gas, and Combined well totals by county.

County	Number of Active Oil, Gas, and Combined Wells
Bee	873
Atascosa	1,457
Brazos	273
Burleson	1,583
DeWitt	312
Dimmit	821
Fayette	349
Frio	773
Gonzales	127
Karnes	257
LaSalle	716
Lavaca	594
Lee	598
Live Oak	694
McMullen	1,505
Maverick	906
Milam	1,218
Webb	5,135
Wilson	629
Zavala	383
Total Wells	19,203

Table 11. Spills located within 1.6 kilometers of a stream.

County Spill was Located In	Kilometers from Stream
Brazos	0.74
Brazos	1.35
Brazos	0.86
Brazos	0.98
Brazos	1.28
Brazos	0.55
Brazos	0.85
Brazos	1.21
Burleson	0.78
Burleson	1.02
Fayette	1.21
Fayette	1.55
Fayette	1.25
Lavaca	1.56

Table 12. Spills located within 8 kilometers of a stream.

County Spill was Located In	Kilometers from Stream
Brazos	0.74
Brazos	1.28
Brazos	0.86
Brazos	3.66
Brazos	0.98
Brazos	0.85
Brazos	1.21
Brazos	1.35
Brazos	3.72
Brazos	0.55
Burleson	1.02
Burleson	1.94
Burleson	0.78
Burleson	2.75
DeWitt	7.8
DeWitt	5.55
Dimmit	7.37
Dimmit	2.88
Fayette	1.21
Fayette	2.55
Fayette	1.55
Fayette	1.25
Frio	3.29
Frio	3.49
Frio	3.42
Frio	2.23
Gonzales	4.88
Karnes	6.6
Karnes	4.86
Karnes	4.8
La Salle	4.59
Lavaca	1.56
Lavaca	2.73
Lavaca	2.46
Lavaca	4.59
Lavaca	4.54
Lee	2.66
Lee	5.8
McMullen	2.6
Milam	6.3
Webb	2.78

Webb	4.44

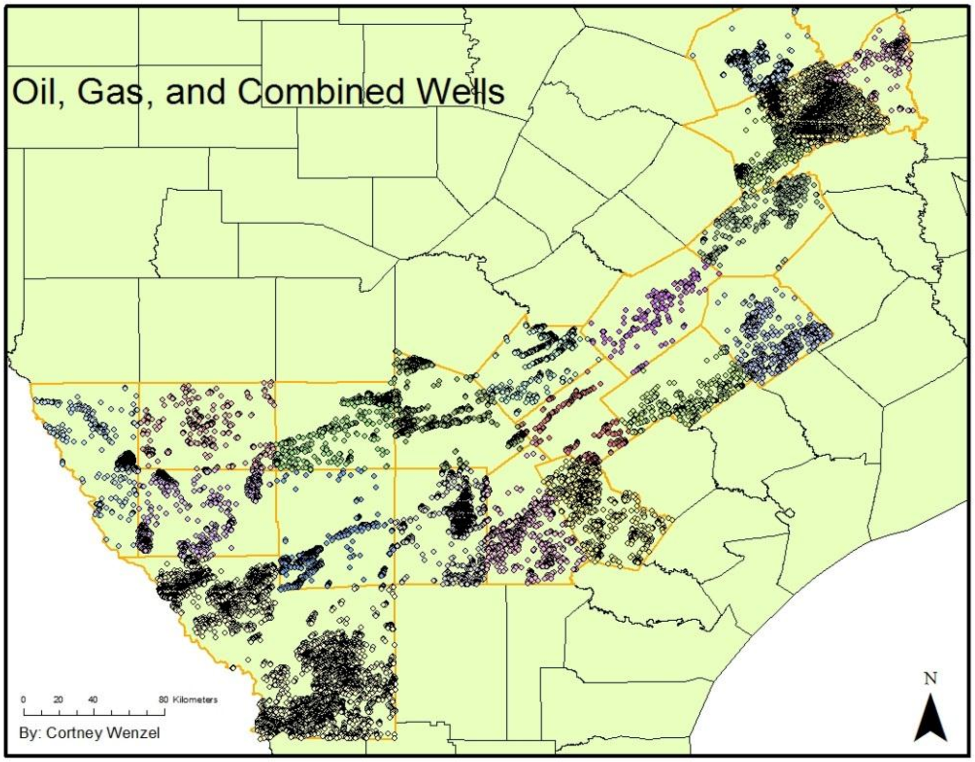


Figure 8. Oil, Gas, and Combined Wells.

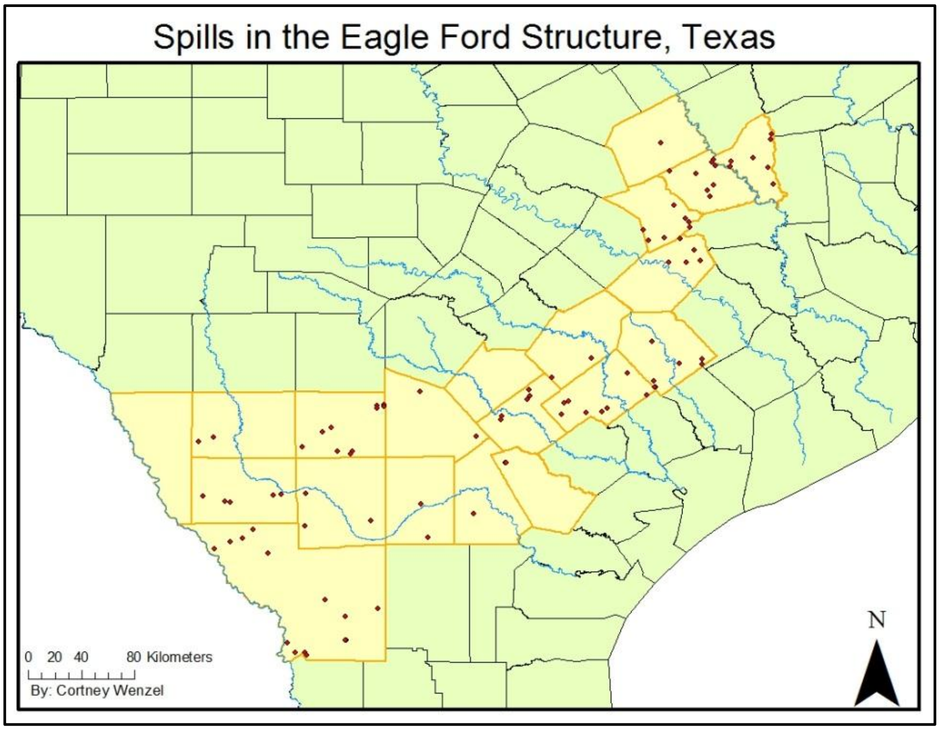


Figure 9. Spills in the Eagle Ford Structure.

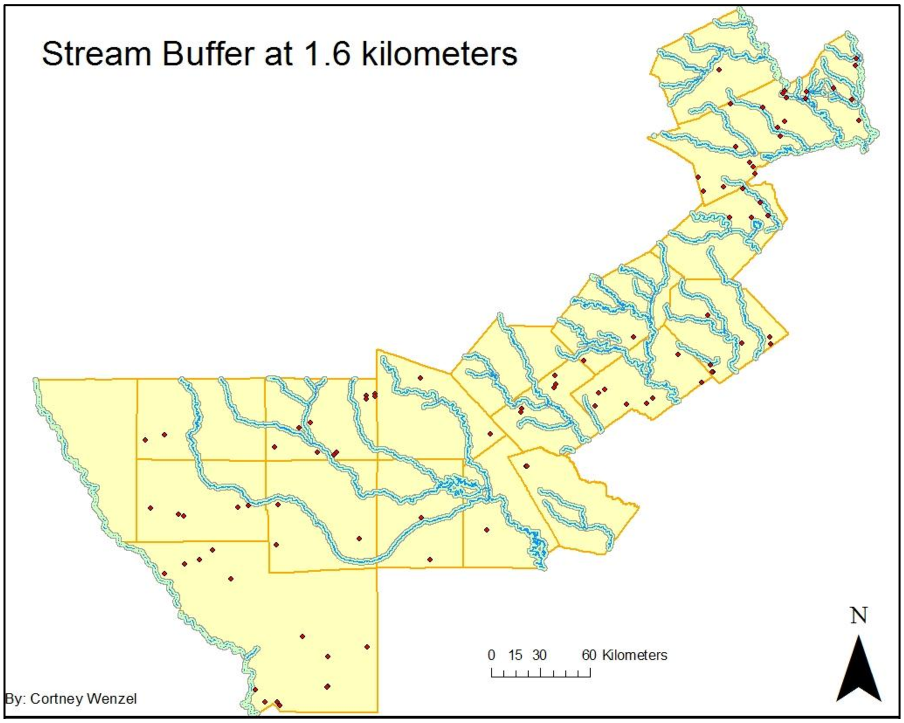


Figure 10. Stream Buffer at 1.6 kilometers.

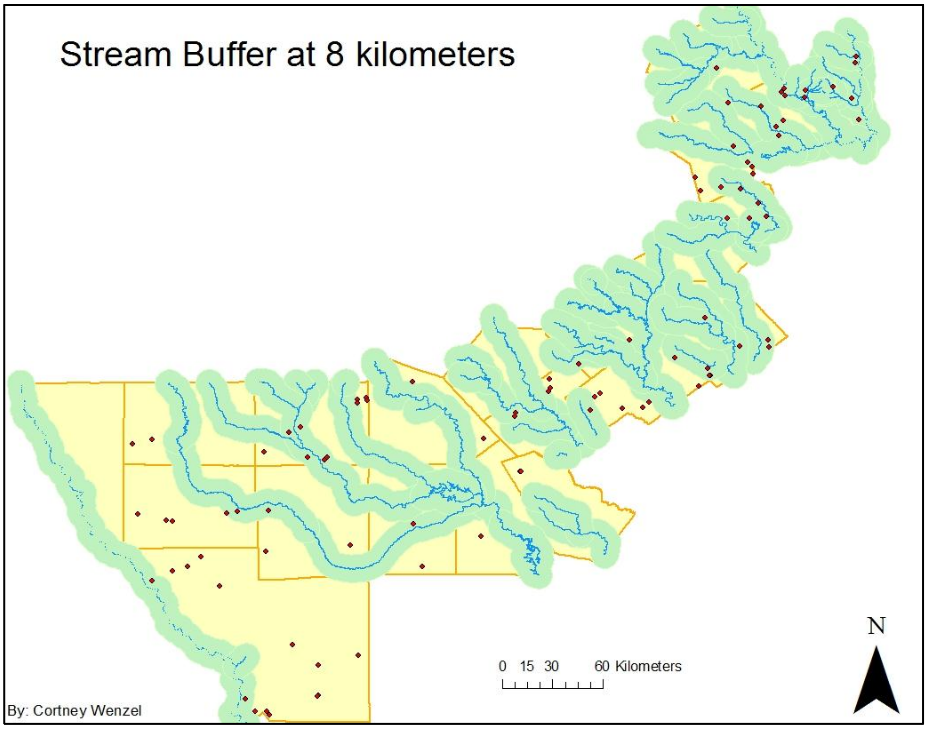


Figure 11. Stream Buffer at 8 kilometers.

Chapter 5

CONCLUSIONS

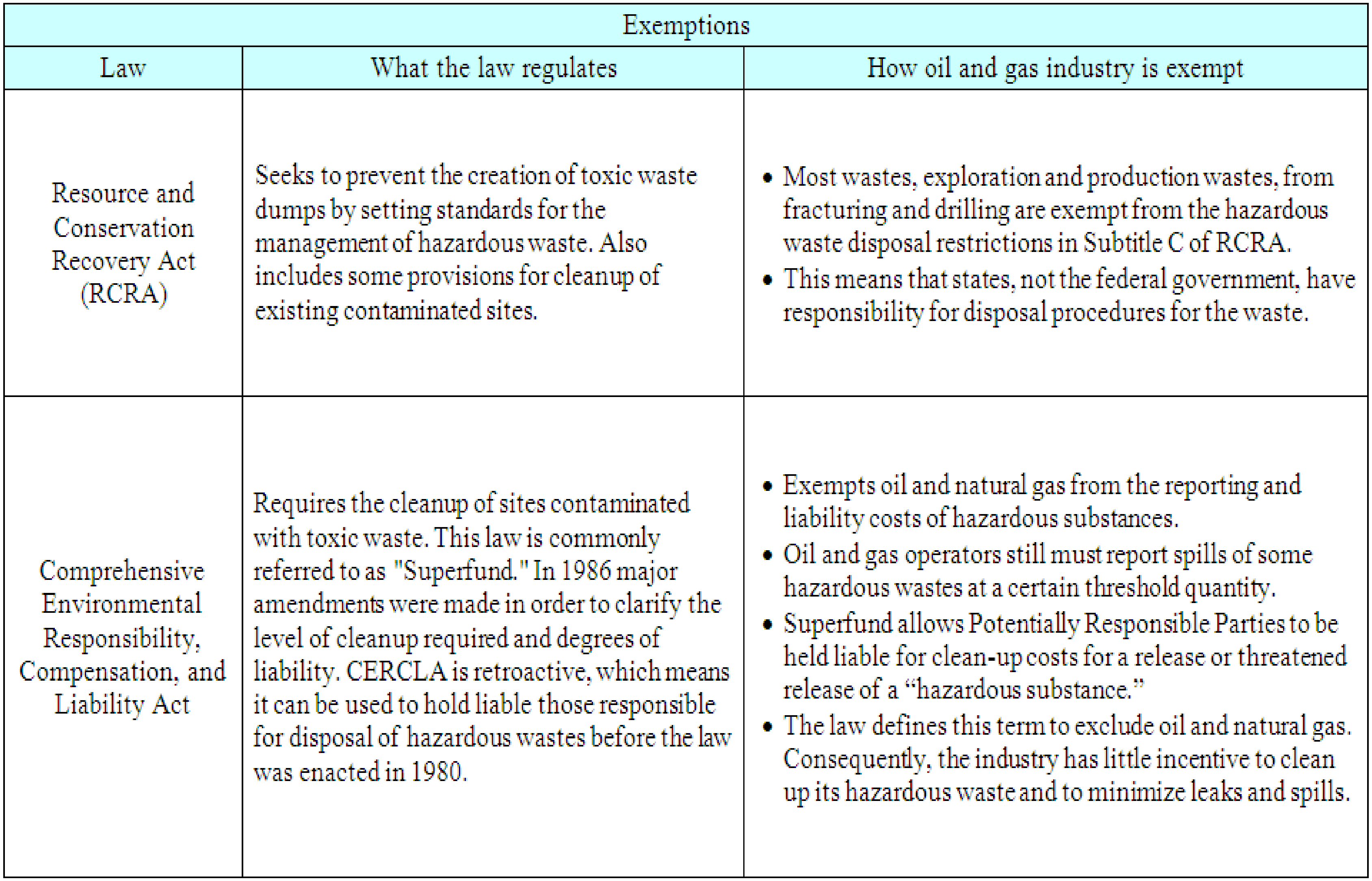
The greatest loss in spills came from Equipment Failure and Corrosion. Both of these causes could easily be fixed by operators and avoided in the future which would help protect the environment. These categories should be examined in future research to determine what effects each category may have on spills. Even though the spills were random and not spatially correlated, a correlation may be found in the future between operators and the largest amounts of spills, or spills may need to be spatially analyzed at a different scale, such as by gas or oil field. These are examples of the implications future research will address.

The cumulative environmental impacts of hydraulic fracturing on rural landscapes remains unknown, and the impacts of gas drilling operations continue to result in environmental degradation (Michaels, Simpson, and Wegner 2010). There is a need to assess these impacts to prevent further damage to our natural environment. Different environmental impacts occur at individual sites, but the cumulative impacts on watersheds and regions as a whole needs further research. This research gave a basic understanding of where wells are located in the Eagle Ford structure, where spills have occurred, and their geographical relation to streams. Future research should assess the cumulative impacts of all spills in a watershed and then in multiple watersheds as headwaters meet the Gulf of Mexico.

Documented Spills & Accidents

State	Cause of Spill/Accident	Resulting Consequences	Company Reported	Any Action Taken Against Company?	Fine Imposed
Arkansas	Fracking fluids improperly applied on land farms	Contaminated streams with abnormally high chloride concentrations from runoff	No	No	No
Colorado	Wastewater pit leaked 1.6 million gallons	Contaminated streams which reached the Colorado River	n/a	n/a	n/a
Louisiana	Fracking fluids leaked from well pad into pasture	17 cattle died slow, painful deaths	No	Yes	Yes - $22,000
Pennsylvania	Well explosion discharged 35,000 gallons of fracking fluid into a state forest	Forest vegetation died	n/a	Yes	Not yet
Pennsylvania	Fracking fluid discharge into stream	43 mile fish kill from overgrowth of algae that live in salty water	No	No	No
Pennsylvania	Fracking fluid discharge into stream	Fish and amphibian kill	Yes	Yes	Yes - $141,175
Pennsylvania	Wastewater pit and tank caught fire	Hazardous materials team responded to flames 100 feet high and 50 feet wide	Yes	No	No
Pennsylvania	8,000 gallons of lubricant gel spilled caused by failed pipe connections	Wetland contamination and fish kill	No	Yes	Yes - $56,650
Pennsylvania	Pump failure spilled 4,200 gallons of wastewater	Wetland contamination and Tioga River tributary stream contaminated	Yes	Yes	Yes - $15,506

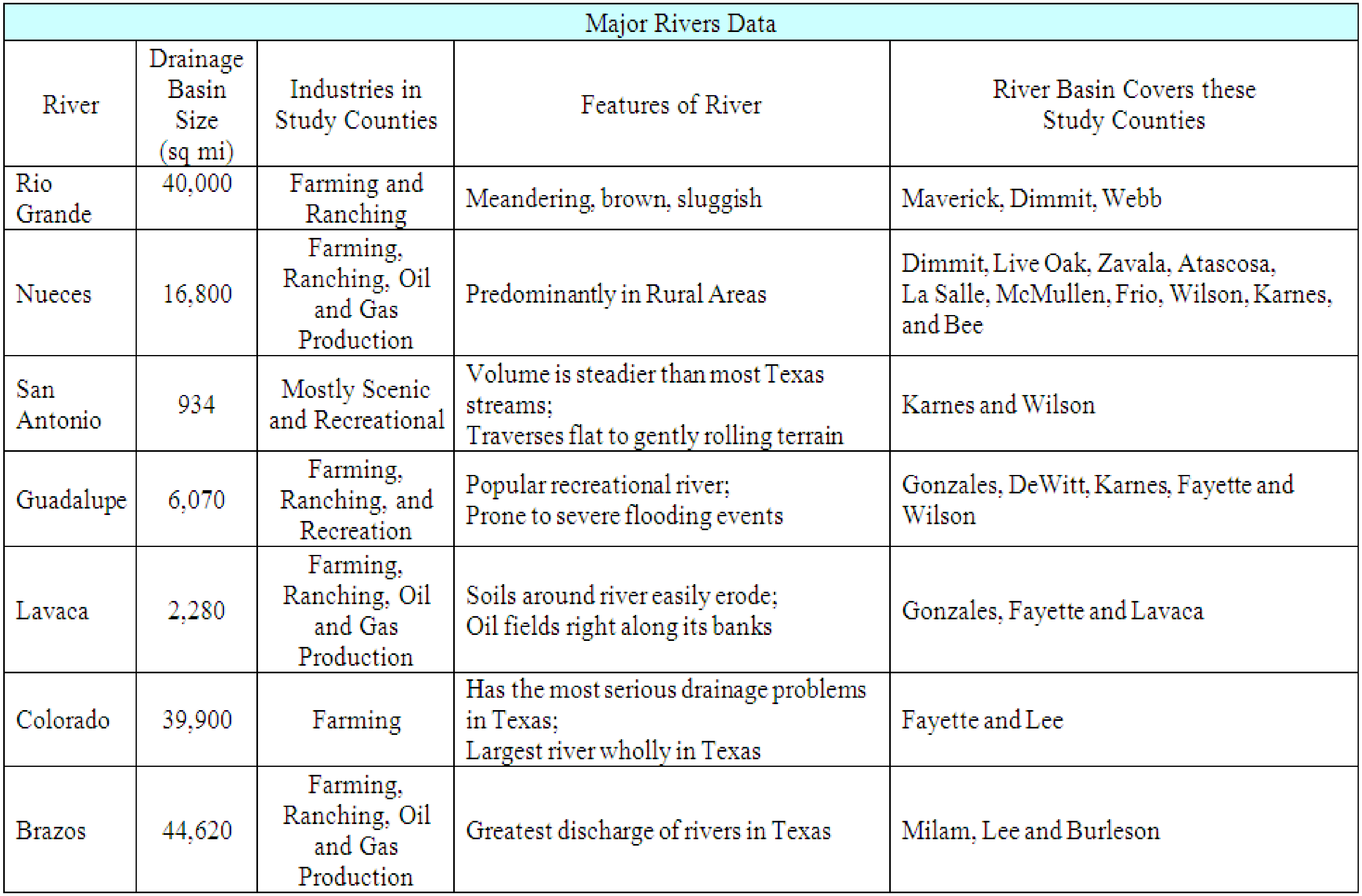
Pennsylvania	Broken transmission line leaked 250 barrels of fracking fluids	Contaminated a high quality warm water fishery receiving protections for its rich biodiversity	Yes	Yes	Yes - $140,000
Pennsylvania	Wastewater pit overflow	Contaminated a high quality watershed	No	Yes	Yes - $97,350
Texas	Methane migration into water wells	Contaminated water wells	No	Yes, by EPA, not RRC	Yes - Ordered to provide clean water
Texas	Chemicals leaked into air	Air pollution where 65% of households tested had toluene in their systems	No	Yes, by EPA, not RRC	No
Texas	Diesel exhaust	Air pollution, high concentrations of nitrogen oxide	No	No	No
Texas	Wastewater blowout	Soil contamination, no vegetation will grow	No	No	No
Texas	Wastewater pit overflow	Soil contamination and tanks on land contaminated	No	Yes	Yes - $35,000
West Virginia	Discharged petroleum based materials	Contaminated 3 miles of stream before it was contained	Yes	Yes	Yes - $10,000
Wyoming	Methane migration into water wells	17 water wells contaminated	n/a	Yes, by EPA	Yes - Ordered to provide clean water



Exemptions		
Law	What the law regulates	How oil and gas industry is exempt
Resource and Conservation Recovery Act (RCRA)	Seeks to prevent the creation of toxic waste dumps by setting standards for the management of hazardous waste. Also includes some provisions for cleanup of existing contaminated sites.	• Most wastes, exploration and production wastes, from fracturing and drilling are exempt from the hazardous waste disposal restrictions in Subtitle C of RCRA. • This means that states, not the federal government, have responsibility for disposal procedures for the waste.
Comprehensive Environmental Responsibility, Compensation, and Liability Act	Requires the cleanup of sites contaminated with toxic waste. This law is commonly referred to as "Superfund." In 1986 major amendments were made in order to clarify the level of cleanup required and degrees of liability. CERCLA is retroactive, which means it can be used to hold liable those responsible for disposal of hazardous wastes before the law was enacted in 1980.	• Exempts oil and natural gas from the reporting and liability costs of hazardous substances. • Oil and gas operators still must report spills of some hazardous wastes at a certain threshold quantity. • Superfund allows Potentially Responsible Parties to be held liable for clean-up costs for a release or threatened release of a "hazardous substance." • The law defines this term to exclude oil and natural gas. Consequently, the industry has little incentive to clean up its hazardous waste and to minimize leaks and spills.

Clean Water Act (CWA)	Establishes and maintains goals and standards for U.S. water quality and purity. It has been amended several times, most prominently in 1987 to increase controls on toxic pollutants, and in 1990, to more effectively address the hazard of oil spills.	• EPA and Congress exempt storm water discharges of sediment from oil and gas exploration and production operations in 2006. • The industry does not have to obtain a permit under the National Pollutant Discharge Elimination System as long as storm water runoff from a natural gas or oil site is not contaminated with oil, grease, or hazardous substances. • Oil and natural gas operators must obtain a storm water permit under the Clean Water Act for the construction of a well pad and access road that is one acre or greater.
Clean Air Act (CAA)	Sets goals and standards for the quality and purity of air in the United States.	• Drilling sites are not treated as an aggregated unit under the CAA. • EPA can set standards for individual small oil and gas facilities such as wells and pits if they are within a metropolitan area with a population greater than one million people. Yet much of the drilling occurs outside densely populated areas.
Endangered Species Act (ESA)	Is designed to protect and recover endangered and threatened species of fish, wildlife and plants in the United States and beyond. The law works in part by protecting species habitats.	• Operators must consult with the Fish and Wildlife Service and potentially obtain an incidental "take" permit if endangered or threatened species will be affected by well development. • Thus, permit holders can proceed with an activity, such as construction or other economic development that may result in the "incidental" taking of a listed species.

National Environmental Policy Act (NEPA)	Most important feature is its' requirement that federal agencies conduct thorough assessments of the environmental impacts of all major activities undertaken or funded by the federal government.	• Exempts certain oil and gas drilling activities, removing the need to conduct environmental impact statements on public land. • The exemption, enacted by Congress in 2005, effectively shifts the burden of proof to the public to prove that such activities would be unsafe.
Safe Drinking Water Act (SDWA)	Establishes drinking water standards for tap water safety, and requires rules for groundwater protection from underground injection; required new standards for common contaminants, and included public "right to know" requirements to inform consumers about their tap water.	• Applies only to waste from fracturing and drilling that is disposed of in underground injection control wells; operators need not obtain a SDWA underground injection control (UIC) permit for the fracturing operation itself. • If operators use diesel fuel in fracturing, however, they are not exempt from SDWA.
Emergency Planning and Community Right to Know Act	Requires companies to disclose information about toxic chemicals they release into the air and water and dispose of on land.	• Individual wells of the oil and natural gas industry need only report toxic releases of 2,000 pounds or more per facility to the community. This 2,000 pound threshold was increased in 2006 from the original 500 pounds to 2,000 pounds.



Major Rivers Data

River	Drainage Basin Size (sq mi)	Industries in Study Counties	Features of River	River Basin Covers these Study Counties
Rio Grande	40,000	Farming and Ranching	Meandering, brown, sluggish	Maverick, Dimmit, Webb
Nueces	16,800	Farming, Ranching, Oil and Gas Production	Predominantly in Rural Areas	Dimmit, Live Oak, Zavala, Atascosa, La Salle, McMullen, Frio, Wilson, Karnes, and Bee
San Antonio	934	Mostly Scenic and Recreational	Volume is steadier than most Texas streams; Traverses flat to gently rolling terrain	Karnes and Wilson
Guadalupe	6,070	Farming, Ranching, and Recreation	Popular recreational river; Prone to severe flooding events	Gonzales, DeWitt, Karnes, Fayette and Wilson
Lavaca	2,280	Farming, Ranching, Oil and Gas Production	Soils around river easily erode; Oil fields right along its banks	Gonzales, Fayette and Lavaca
Colorado	39,900	Farming	Has the most serious drainage problems in Texas; Largest river wholly in Texas	Fayette and Lee
Brazos	44,620	Farming, Ranching, Oil and Gas Production	Greatest discharge of rivers in Texas	Milam, Lee and Burleson

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