QUANTIFYING THE IMPACT TO SURFACE AND GROUND WATERS USING OKLAHOMA CORPORATION COMMISSION COMPLIANCE REPORTING

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Title of Study: QUANTIFYING THE IMPACT TO SURFACE AND GROUND WATERS USING OKLAHOMA CORPORATION COMMISSION COMPLIANCE REPORTING

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Abstract: Given increasing oil and gas drilling activity as a result of the new technologies of horizontal drilling and hydraulic fracturing, many Oklahomans have been concerned about pollution to surface and ground waters. Two studies were conducted to quantify the potential impact to the state waters using Oklahoma Corporation Commission (OCC) compliance reporting. The first study was focused on ground water and analyzed alleged pollution to water wells and documented salt water spills. A total of 38 water wells were allegedly reported contaminated by their owners between May, 2012 and May, 2013. Eight of these water wells were referred to pollution abatement by the OCC as confirmed cases of oil and gas related water pollution. Five of these incidents were surrounded by a mix of older and newer production wells and two incidents were surrounded exclusively by newer production wells. During the same period, 333 saltwater spills were recorded by the OCC. The potential of those spills to pollute shallow ground water was determined using DRASTIC indices assigned by the Oklahoma Water Resources Board. It was determined that 25% of the reported salt water spills had occurred above high or very high vulnerability aquifers. The second study focused on the potential impact from salt water spills to drinking water surface intakes using data from the OCC and the Oklahoma Department of Environmental Quality. It was concluded that 16 surface water bodies had been affected by salt water spills. The most proximal distance of a salt water spill to a surface drinking water intake was two miles.

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CHAPTER I

INTRODUCTION

1.1 General background

The dramatic increase in oil and gas production in Oklahoma has raised concern about the potential adverse environmental effects. Despite the complexity of the debate encompassing this topic and the new technologies of directional drilling and hydraulic fracturing, little to no quantitative data has been presented to the public on actual or potential impacts. The Energy Policy Act of 2005 exempts fluids used in hydraulic fracturing from regulatory action under the Clean Water Act, the Safe Water Drinking Act, and the Comprehensive Environmental Response, Compensation, and Liability Act. Thus, there is little federal oversight to protect surface or ground waters from oil and gas operations. Each state determines its own regulations and enforcement. In Oklahoma, the Oklahoma Corporation Commission (OCC) is committed to protecting the environment by regulating oil and gas practices in 76 counties. Under the Oklahoma Enabling Act of 1906, the Commission lacks jurisdiction over Osage County. The OCC records and maintains a history of violations related to oil and gas operations through the Environmental Compliance Reporting System (ECRS), which has recently transitioned into the Risk Based Data Management (RBDM) system. These databases provide information that will allow a systematic and relatively unbiased assessment of oil and gas impacts to the environment. Other state agencies such as the Oklahoma Water Resources Board (OWRB), the Oklahoma Department of Environmental Quality (ODEQ) and the United States Geological Survey (USGS) collect and maintain data pertaining to natural resources within the state. Data from all of these agencies was gathered, combined and analyzed to assess the potential impacts from oil and gas field activities to surface and ground waters in the state of Oklahoma.

1.1.2 Hydraulic fracturing

Hydraulic fracturing is the process by which unconventional reservoirs characterized by having very low porosity are optimized in order to enhance productivity. For this process, a single well pad is placed at the ground surface and a vertical borehole is drilled until it approaches the formation of interest then it starts turning to drill horizontally into this formation. Once drilling is completed, water mixed with proppants and sand is injected at high pressure in different stages to create artificial fissures in the formation that release gas and oil to flow to the surface. It is important to keep in mind that the incidents or violations related to oil and gas operations that will be presented in the following chapters include drilling, production and completion operations that in some cases may include the practice of hydraulic fracturing and in other cases the production will be from prior traditional conventional formations and drilling operations. Oil and gas operations dating prior to 1980 will be referred as old or historical since the OCC implemented strict production surface casing regulations in 1980. Figure 1.1 illustrates a modern drill rig on the left where horizontal drilling and hydraulic fracturing reach into an unconventional formation. To the right, a conventional reservoir is developed with a vertical rig. With the practice of directional drilling it is possible to have multiple wells underground with just one single well pad at the surface.

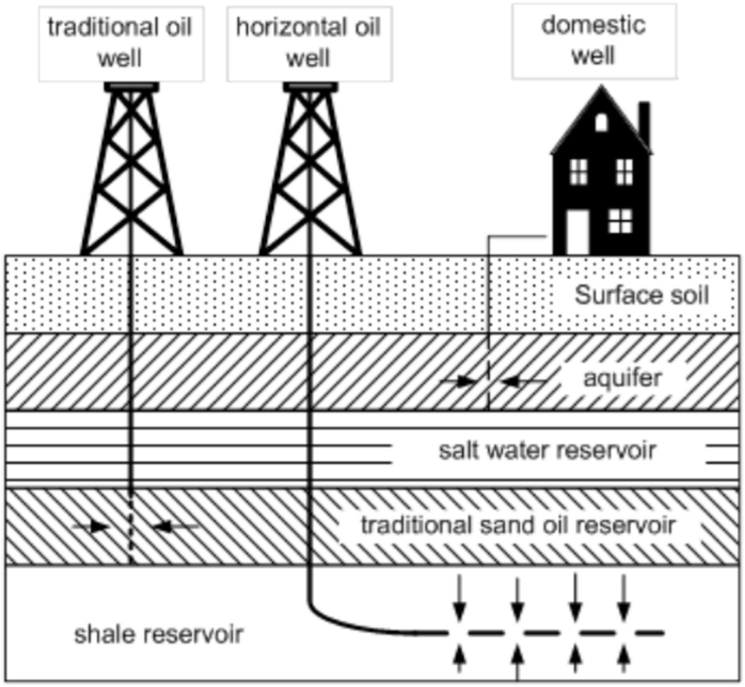

Figure 1.1: Illustration of oil and gas field during drilling operations from modern (horizontal drilling) design and traditional vertical drilling.

1.1.3 Potential spills and leaks in an oil and gas field

Figure 1.2 illustrates the sources of potential contamination to surface and ground waters in an oil field during production operations. Some of the sources for surface leaks are piping, wellheads and the stuffing box on pump jacks. Subsurface leaks can occur from flow lines and pipes located underground that transport fluids from the well head to the separator. Leaks that happen at the surface and are observable are usually addressed immediately and the contaminated soil is remediated before the pollutant travels any farther. However, leaks underground in buried flow lines are not immediately evident and have greater potential to affect the underlying aquifer. Spills typically occur after lightning strikes on storage tanks, equipment malfunction or transportation accidents. Spills are usually evident immediately since they involve a large volume release of a pollutant fluid onto the ground surface. Spills and leaks within the storage tank containment dike and liner have a relatively low potential to impact water resources.

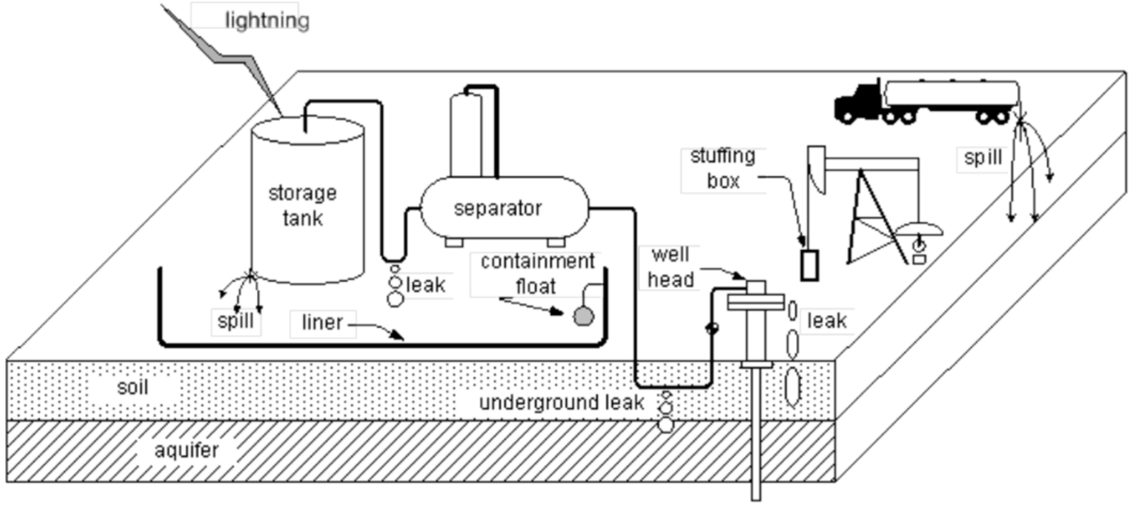

Figure 1.2: Illustration of an oil and gas field during production operations and potential sources of water pollution.

1.2 Objective

The overall objective of this study was to use public records to assess the potential scale and severity of current pollution resulting from oil and gas operations in the state of Oklahoma.

The tasks required to meet the objective are;

- Quantify private water wells allegedly polluted during the period from May 2012 to May 2013, and correlate their location with nearby oil and gas production wells.
- Quantify salt water spills that had occurred from May 2012 to May 2013, and determine the vulnerability of the underlining ground water aquifers. .
- Quantify the number of surface water bodies that had been contaminated by salt water spills from May 2012 to May 2013 and determine the proximity of these spills to public water supply intakes.

Chapter 3 addresses the first two tasks, while Chapter 4 addresses the third. Results and conclusions relevant to each task are presented in those chapters.

1.3 Recommendations for Future Work

The information contained in just one year (May 2012 to May 2013) of incidents related to oil and gas operations is vast and should be further examined. Based on this dataset, potential contamination to water in the state of Oklahoma could also be quantified by analyzing unplugged and abandoned wells as these may provide a contamination pathway for foreign fluids to be transported. Extending the sorting of the reported incidents to a decade may provide some valuable information regarding the risk of pollution to water wells as it may take a long time for pollutants to be transported and for pollution to be evident at the surface. With access to IHS database and industry data we could compare the counties most affected to the level of activity and predict the footprint left behind after years of production. It is also important to insist on the disclosure of public records especially for the water wells that were affected by the nearby oil and gas operations and referred to pollution abatement.

1.3.1 Effort that produced data

In order to obtain data it was important to first read and become informed about all state agencies and their different functions. After having a broad idea of the functionalities and responsibilities of each agency, it was determined that the OCC should be the first to be contacted. The OCC's Information Systems Services department provided a list of 20 years of incidents related to oil and gas operations dating from 1993 to 2013. This list was presented as an excel spreadsheet and was later analyzed and sorted through to route this research.

The OWRB website had their information and maps in shapefile (*.shp) format readily available for use in their website. The ODEQ's Watershed Planning Section was also contacted to obtain the most updated map that included locations of Public Water Supply (PWS) intakes in the state. Finally, to have a better understanding of the potential sources of oil, gas or produced water spills and leaks it was important to visit an oil and gas field during production operations.

1.3.2 Effort that did not produce desired data

Several efforts were unsuccessful in obtaining data for this analysis. After analyzing the incident list provided by the OCC, it was considered important to obtain as much information as possible on the water wells that were referred to pollution abatement. In an effort to acquire access to these records and laboratory results, the OCC pollution abatement personnel at the Jim Thorpe building in Oklahoma City was contacted in person, all four OCC district offices were contacted over the phone, and an open records request was filed and submitted to the OCC. Unfortunately, none of these efforts were successful in obtaining the desired data.

CHAPTER II

LITERATURE REVIEW

2.1 Overview

The exploitation of natural gas through directional drilling and hydraulic fracturing has produced an extremely attractive domestic energy source. Principal among the environmental and health risks of these practices is their potential to impact water resources. “Water management for unconventional shale gas extraction is one of the key issues that will dominate environmental debate surrounding the gas industry” (Vidic, et al., 2013). . This chapter will review current publications on hydraulic fracturing impacts on water resources. Only agency and peer reviewed literature has been referenced. No attempt has been made to review the popular press. Likewise, no attempt has been made to review impacts to natural resources other than water, or impacts due to activities beyond the drill pad, such as pipelines or rail transport.

Recently due to the increasing public concern about water management in the oil and gas industry and the potential for environmental and human health impacts associated with the release of untreated wastewater to the environment, the EPA studied the effects of water resources at a national level and prepared “Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources” (EPA, 2015). However, due to its recent publication and draft status, it is not reviewed here.

2.2 Surface water and groundwater effects

The pollution to surface water is evident immediately after a spill or large discharge of the pollutant fluid. Contamination to groundwater however, is less evident, but could be evaluated by analyzing the type of surface casing and protective barriers that were installed in the different drilling stages of a production well.

2.2.1 Spills

Accidental releases such as spills and leaks were considered in the EPA assessment draft and they stated that the potential impacts to drinking water resources from spills of hydraulic fracturing fluids depend on the characteristics of the spills, the fate transport and the toxicity of the chemicals spilled. Walton and Woocay (2013) consider the primary threat to surface and shallow groundwater from hydraulic fracturing to be from spilled or released material on the earth's surface. They state, "Wells are normally completed far below the depth of groundwater aquifers by about a factor of 10 (thousands of feet for gas versus hundreds of feet for useful water). For this reason the greatest threat to groundwater quality is from spills on the surface that infiltrate downward into the groundwater". The produced water that travels back up to the surface is stored in tank batteries that can leak. Also, there are cases in which the equipment and machinery have failed leading to blowouts or leaking valves, pipes and pumps. "Accidents will result in localized contamination of surface and shallow groundwater with any of the chemicals associated with drilling, hydraulic fracturing and gas production" (Walton and Woocay, 2013).

The EPA (USPEA, 2015) included some of the reasons that a spill would occur at a well pad: equipment failure, human error, failure of container integrity, and other causes such as weather and vandalism. They concluded that the number of identified cases of groundwater pollution was small compared to the number of hydraulically fractured wells. They considered limiting factors such as: insufficient pre and post-fracturing data on the quality of the water, the lack of long term systematic studies, and the inaccessibility to information on the practice of hydraulic fracturing.

2.2.2 Casing and groundwater protective barriers

The protective barriers shielding the freshwater zones and the surrounding environment from the contaminants inside the well consist of several layers of steel pipe casing and cement (Vidic et al., 2013). Current regulations in the state of Oklahoma indicate that surface steel casing should be installed 50 feet below the base of treatable water to protect the underlying aquifer. Ensuring the integrity of the casing during the injection of the fracing fluids and the return of the produced water to the surface is vital in order to prevent creating contamination pathways within the aquifer or in any of the overburden formations. A study conducted by Myers (2012) models the potential vertical contaminant transport from the shale to near surface aquifers. “A pathway for gas would also be a pathway for fluids and contaminants to advect from the fractured shale to the surface, although the transport time would be longer”. He concludes that the evidence for potential vertical contamination is strong, but there is no data to verify the pre-or post-fracturing properties of the shale and there are no monitoring systems to detect contaminant transport as he considered it in his models. On the other hand, DiGiulio et al. (2011) confirm that constituents associated with hydraulic fracturing of a coal gas bed have been found in the Wind River drinking aquifer at depths above the current production zone.

2.3 Groundwater Modeling

Economides and coauthors conducted several studies in an attempt to represent subsurface mobility of fluids and potential subsurface pathways during the process of hydraulic fracturing (Economides, et al., 2010, Economides and Wang 2010, Economides and Nikolaou 2011, Economides, Oligney and Lewis 2012; Liu, et al. 2012, Marongiu-Porcu, et al., 2013; Mikhailov, et al., 2011; Song, et al., 2011; Wang, et al., 2012; Wang and Economides,2012). Also, several law reviews have been presented on the subject (Anonymous, 2012; Coman, 2012; Wiseman, 2012; Shroeck and Karisny, 2013;). Fontenot et al., (2013) published a document that evaluated water wells near natural gas extraction sites in the Barnett formation and concluded that a focused study of groundwater pre and post hydraulic fracturing is required in order to make definitive conclusions about the origin of the elevated constituents in the water samples studied. Several models and simulations have been carried out by engineers and geologists such as Ajao et al. (2013), Asibor et al. (2013), Eshiet et al. (2013), Bhattachayra et al. (2013), dos Santos et al. (2011), Flewelling (2014), Fu et al. (2012), Gassiat (2013), Gordeev (2013), Hamidi (2014), Hooker (2013), and Tao et al. (2011). All these authors and more are running models in an attempt to characterize and represent the subsurface activity as different formations are being fractured and acidized. Scientists across the board researching, modeling and writing about the environmental effects of hydraulic fracturing agree that quantifying the environmental impacts given the available resources, data and funding is a difficult task at the moment. Several researchers encourage and propose the execution of different studies that would provide more information for their studies to be completed and offer a definitive or at least more informative answer as to whether these practices are safe and the extent of the footprint in a determined number of years. Ajani and Kelkar (2012) encourage the study of abandoned and inactive wells near a hydraulic fracturing site. The study that they conducted in Oklahoma found that "older wells were more likely to be negatively affected by the stresses applied by hydraulic fracturing in neighboring wells". With a little more collaboration from state agencies, federal agencies and oil and gas operators we could successfully analyze the impacts and take action in legislation based on real data. Vidic et al. (2013) noted,

> "Confidentiality requirements dictated by legal investigations, combined with the expedited rate of development and the limited funding for research, are substantial impediments to peer-reviewed research into environmental impacts. The development of predictive methods to accurately account for the entire fluid volume based on detailed geophysical and geochemical characteristics of the formation would allow for the better design of gas wells and hydraulic fracturing technology, which would undoubtedly help alleviate public concerns".

In summary, many authors have attempted to quantify current oil and gas production impacts to water resources either by site specific studies or detailed modeling of typical scenarios. Those efforts have meet limited success. In particular, it is difficult to translate those studies to other locations.

2.4 OCC Regulatory Data

One data source has remained ignored, at least in Oklahoma. The Oklahoma Corporation Commission (OCC) records and addresses drilling complaints through their older oil and gas division in an Environmental Compliance Reporting System (ECRS) and newer Risk Based Data Management (RBDM) system. A list of incidents was obtained to better understand potential contamination sources and magnitudes. These large databases cover decades of reported complaints. While the information on each incident is relatively nominal, it has been systematically collected and covers the entire state. Thus, there is a clear research opportunity to mine those data to quantify documented water resources impacts.

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CHAPTER III

QUANTIFYING THE IMPACT TO GROUND WATER USING OKLAHOMA CORPORATION COMISSION COMPLIANCE REPORTING

3.1 Abstract

The rapid increase of oil and gas production in Oklahoma has raised concern about contamination to ground water. The Oklahoma Corporation Commission (OCC) is committed to regulating oil and gas practices in Oklahoma to protect the environment. The OCC records and addresses drilling complaints through their oil and gas division in an Environmental Compliance Reporting System (ECRS) and has recently transitioned into a Risk Based Data Management (RBDM) system. A list of incidents was obtained to better understand potential contamination sources and magnitudes. Given that hydraulic fracturing has recently boomed and the effects of this practice are still uncertain, only the last year of incidents has been analyzed. It was found that in a year dating from May 2012 to May 2013, 38 private water wells had reportedly experienced changes in the quality of their water. These complaints were analyzed in depth by obtaining the complaint form and associating the location of the water well to production wells in close proximity. It was determined that eight water wells were referred to pollution abatement. Two of these water wells were surrounded exclusively by new production dating from 2010 to 2013. During the same period, 333 saltwater spills were recorded by the OCC. The potential of those spills to pollute

shallow ground water was determined using DRASTIC indices assigned by the Oklahoma Water Resources Board (OWRB). It was determined that 25% of the reported salt water spills had occurred above high or very high vulnerability aquifers.

3.2 Introduction

Groundwater is a reliable resource in many places today, but to keep the groundwater supply sustainable, risk assessments need to be conducted to keep groundwater a renewable resource (Twarakavi and Kaluarachchi, 2006). Ground water contamination can be minimized by delineating and monitoring vulnerable areas. OCC developed a map that delineates the Base of Treatable Water (BTW) or subsurface water that in its natural state is potentially useful for human consumption, livestock, irrigation, industrial, municipal, and recreational purposes. OWRB developed a series of maps that demarcate the most vulnerable parts of certain aquifers in the state based on the DRASTIC model that was created in 1987 by the Environmental Protection Agency (USEPA, 1987). It is the responsibility of the OCC to record and maintain a list of oil and gas drilling violations as well as drilling completions forms (1002A) for oil and gas production wells. This study incorporated OCC drilling compliance reporting to two different maps developed by the OCC and the OWRB. The objective was to analyze the water wells that were reported to be polluted and associate them to the oil and gas production wells in the vicinity and to determine the proximity of salt water spills to highly vulnerable aquifers.

3.2.1 Drilling in Oklahoma and Hydraulic Fracturing

The major geologic provinces of Oklahoma were identified by Cardott (2012) and are illustrated in Figure 3.1. The Woodford Shale (Late Devonian to Early Mississippian) is an important hydrocarbon source rock in the state (Comer and Hinch, 1987; Johnson and Cardott, 1992). Four clusters of wells identify Woodford Shale plays; the Arkoma Basin in eastern Oklahoma, the Anadarko Basin in western Oklahoma, the Ardmore Basin in southern Oklahoma, and the Cherokee Platform in northeast Oklahoma (Cardott, 2012). It was well known that the gas and oil reserves in Oklahoma were immense, and today the Woodford is categorized amongst the most prolific shale plays in the United States.

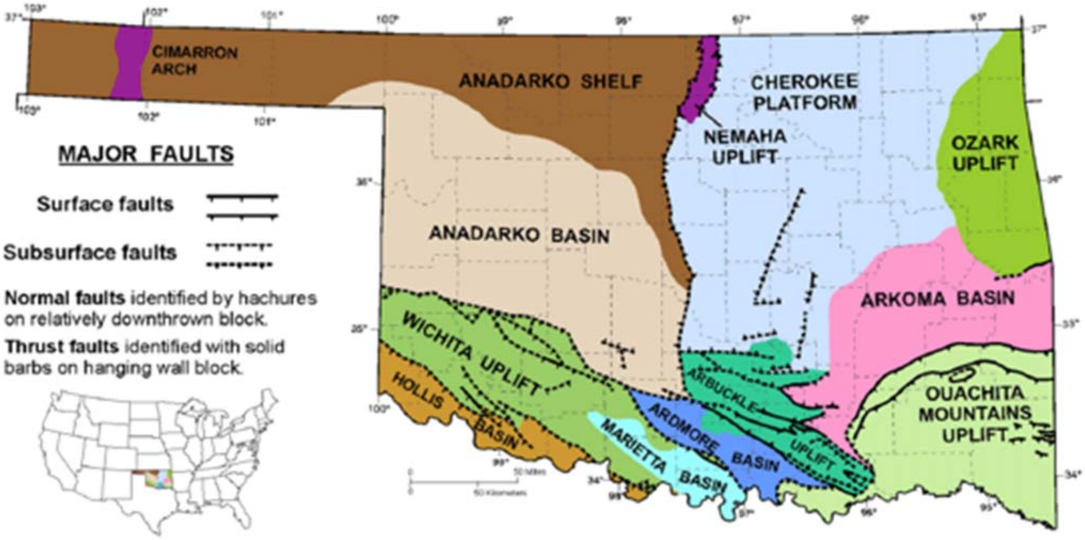

Figure 3.1: Major geologic provinces of Oklahoma (Cardott 2012).

Hydraulic fracturing (HF) increased drilling activity in Oklahoma and throughout the United States as the technology improved and made extraction from unconventional, less porous, sources more economically viable. HF is the process by which unconventional, low permeability oil and gas reservoirs are fractured and stimulated to increase productivity. It requires large amounts of water mixed with sand and/or other proppants and chemicals to be injected at high pressure into the producing shale. The pressure causes the shale to fracture and the sand and proppants prevent the created fractures from closing, thus providing a conductive pathway to the well. The combination of horizontal drilling and hydraulic fracturing has greatly increased the productivity of natural gas and oil wells. However, these new techniques have raised concerns about potential environmental impacts. Protection of freshwater aquifers from contamination by saltwater and/or oil and gas during the development of the Woodford Shale play is an issue of concern in Oklahoma.

3.2.2 Regulations

The Energy Policy Act of 2005 exempts fluids used in hydraulic fracturing from regulatory action under the Clean Water Act, the Safe Water Drinking Act, and the Comprehensive Environmental Response, Compensation, and Liability Act (Kosnik, 2007). Thus, there is little federal oversight to protect ground water from oil and gas drilling. Each state determines its own regulations and enforcement. In Oklahoma, the OCC is committed to protecting water resources by regulating oil and gas practices in 76 counties. Under the Oklahoma Enabling Act of 1906, the Commission lacks jurisdiction over Osage county. The OCC was formed in 1907 to regulate public service corporations, railroads, telephones, and telegraphs. In 1914 it started regulating oil and gas. At the time the organization was significantly understaffed and the lack of inspectors forced it to rely on an honor system in which the industry would self-regulate. Numerous oil spills and fires were unreported and unattended because each oil producer would determine what intolerable conditions in the oil fields were. Gas was flared and coal was wasted in large amounts, this alerted the federal government to extend its authority over Oklahoma (Boyd, 2008). In 1914 the OIPA (Oklahoma Independent Petroleum Association) advocated regulation of the industry, with the focus on prorationing, dividing and distributing funds and responsibilities. The state of Oklahoma continues to be independently regulated through the OCC. Under the Corporation Commission, Oil and Gas Conservation, Oklahoma Administrative Code 165:10, the OCC has determined that oil and gas wells are required to case wells from the ground surface to 50’ below BTW, approximately 10,000 ppm total dissolved solids (TDS), to protect fresh water aquifers from oil and gas, saline produced water, and drilling/fracing fluids. Since the 1980’s the OCC has worked on a series of BTW maps to help oil and gas drillers determine how much surface casing needed to be set in each well being drilled. These maps have been found to have inaccuracies due to the widely spaced data and the mapping techniques then available (Lord et al., 2009). Using the maps and properly interpolating between the points has occasionally been an issue, and these old paper maps could not be made widely available for use (Lord et al., 2009). An up to date

BTW map is now available online through the OWRB website as a shapefile (*.shp) and it is also available through the OCC as a PDF file. The OCC is also responsible for recording and addressing each oil and gas drilling incident reported through the Risk Based Data Management (RBDM) system. Prior to 2014, the Environmental Compliance Reporting System (ECRS) was used.

3.3 Methods

3.3.1 OCC data - ECRS records, drilling completion reports (1002A), and BTW

A list of the last twenty years of drilling incidents recorded into ECRS was obtained through staff of the OCC. The list contained 94,546 records from July 1993 to May 2013 and 100 columns for different fields containing information per record. The fields that were most accounted for in order to categorize these incidents were: allegations, findings and recommendations. The allegations field will usually provide with most of the information, but when this field was inconclusive or difficult to interpret the findings and recommendations fields would most likely include a description that would help better categorize the event. The list of incidents was obtained in August 2013 and contained mostly ECRS records with a tab of RBDM that included 21 records. A total of 2,078 incidents were selected from the extended list. These records included the last year in the list from May 2012 to May 2013. The latest incidents were reported in May 31, 2013. With the purpose of facilitating interpretation, these occurrences were classified into 13 categories; permit violations and posting of signs, water spills, oil spills, soil contamination, trash and debris left on site, unplugged wells, abandoned well and/or abandoned equipment on site, leaks such as from a stuffing box or well head, surface water that has been compromised by spills, water wells that had been altered, unrestored sites or sites that needed maintenance, leak/spill/discharge (a category for discharges of unknown fluid in unknown quantities) and a category that included all other unrelated violations. All of the water well related incidents were reported by home owners or land owners that had experienced changes in the quality of their water. The OCC responded to the complaint by sending an inspector to conduct an initial site visit to assess the incident by speaking to the individual that filed the complaint, inspecting the water and in most cases collecting a water sample for laboratory analysis. Concurring to the laboratory results the OCC proceeded to either dismiss the case or to refer it to pollution abatement for further testing and investigation. Based on the locations of these incidents that were referred to pollution abatement, drilling completion report forms (1002A) for production wells located within the same section, township and range as the complaint were attained through the OCC Imaging Web Application. These 1002A forms were analyzed and accounted for depth of surface casing, casing size, producing formation, year completed, and total depth. It is important to keep in mind that well design in 1914 was much different than the modern designs. Well drilling has evolved from the simple cable tool method to direct rotary and directional drilling. With the use of these more advanced drilling methods came the ability to drill deeper and larger diameter wells with complex completions. The casing diameter and depth of production wells from 1914 will vary greatly from the current drilling practices. In modern drilling practices it will often be seen that a F.O. (full-opening) tool was installed. Halliburton defines this tool as: F.O. multiple –stage cementer that is used to place any number of stages of cement or other fluids outside a casing string at different selected points along the casing. It will also be seen, not just in modern drilling but in some older or historical production wells (prior to 1980) at certain locations, that surface casing was and is currently set to distant depths well below the ground surface to ensure stability of the borehole given the composition and characteristics of the overburden lithology. The BTW map was obtained as a shapefile (*.shp) from the OWRB and the locations for the polluted water wells were plotted in ArcGIS 10.2 to determine the amount of surface casing that each production well should have set. This information (location of polluted water wells, 1002A forms and BTW) was gathered and correlated to determine whether historical and contemporary oil and gas drilling practices were in compliance with current OCC regulations.

3.3.2 OWRB data – DRASTIC index and aquifer vulnerability

The OWRB conducted a vulnerability assessment of 12 major Oklahoma aquifers using the DRASTIC index method. The aquifers included were: Central Oklahoma, Vamoosa-Ada, Rush Springs, Antlers, Elk City and High Plains. It also included Alluvium and Terrace Deposits such as Enid Isolated Terrace, Tillman Terrace, Cimarron River North and Canadian River. The USGS published digital data sets that describe the aquifer characteristics and created grid layers to calculate the DRASTIC index. With this information the OWRB and more specifically Osborn and Hardy (1999) computed the final DRASTIC indices and created aquifer vulnerability maps. DRASTIC is an acronym standing for Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone, and hydraulic Conductivity. From these parameters a DRASTIC index or vulnerability rating can be obtained. The higher the value for the DRASTIC index, the greater the vulnerability of that location of an aquifer. The index is computed by,

$$\text{Drastic Index} = D_rD_w+R_rR_w+A_rA_w+S_rS_w+T_rT_w+I_rI_w+C_rC_w,$$

where D is the depth to water, R is net recharge, A is aquifer media, S is soil media, T is topogrpahy, I is impact of the vadose, C is hydraulic conductivity and the subscripts w is a weighting and r is the rank (Aller, et al., 1987).

The locations in which salt water was spilled in a drilling site were plotted in the Oklahoma county map in ArcGIS 10.2. As the latitude and longitude coordinates were brought into ArcMap it was determined that four of the locations were not in the Oklahoma map but rather appeared to be in Arkansas. There are clearly discrepancies in the ECRS dataset. In an effort to determine an approximate location, the provided Section, Township and Range were converted to decimal latitude and longitude. As the converted decimal locations were compared to the provided decimal locations, the reported latitude match, but the longitude differed. Every longitude provided was offset from -0.0008 to 1.979 degrees. The cause of the offset could not be determined. However, the county listed in the dataset was in agreement with the converted location, and not with the provided decimal location.

3.4 Results

3.4.1 OCC – ECRS data

After analyzing the complaints reported from May 2012 to May 2013 it was determined that 38 private water wells had reportedly experienced changes in the quality of their water and 333 salt water spills had occurred. These incidents represent approximately 2% and 16% of the total complaints reported in this year, respectively. The locations for five of the water well related incidents were not included in the raw dataset and 174 salt water spills did not disclose the volume of the discharged pollutant. A total of 55 leaks that could classify as a spill were reported but the description is inconclusive and a volume of fluid was not specified. Thus, they were classified into their own separate category.

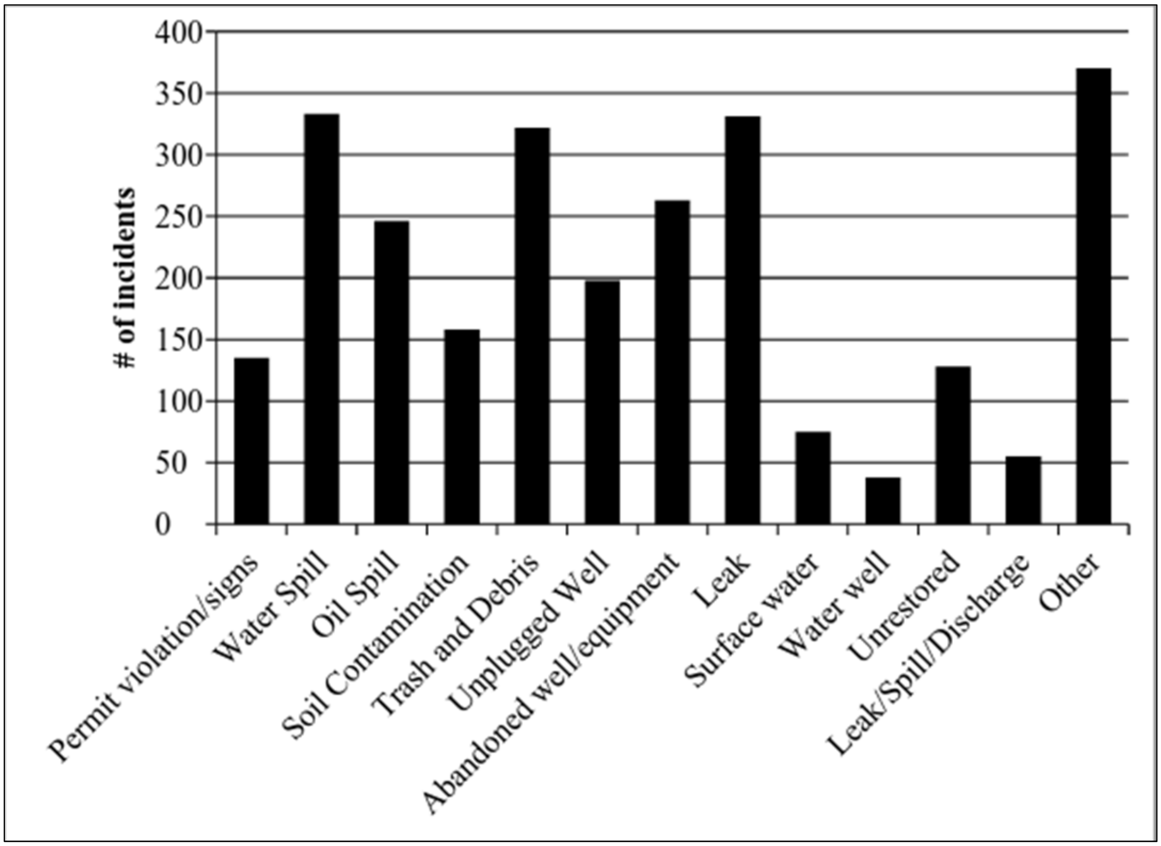

Figure 3.2: OCC categorized reported incidents from May 2012 to May 2013

Through this classification and sorting of the incidents it was also detemined that the counties that had been affected by the reported contamination of ground waters included: Alfalfa, Canadian, Carter, Cleveland, Creek, Custer, Dewey, Ellis, Garvin, Grady, Hughes, Kingfisher, Major, McClain, Noble, Nowata, Oklahoma, Okmulgee, Payne, Seminole, Stephens, and Washita. Figure 3.3 shows the distribution of ground water alleged reported pollution throughout the different counties. As shown, the county with the most reported polluted water wells was Creek with 16% of incidents reported within this category.

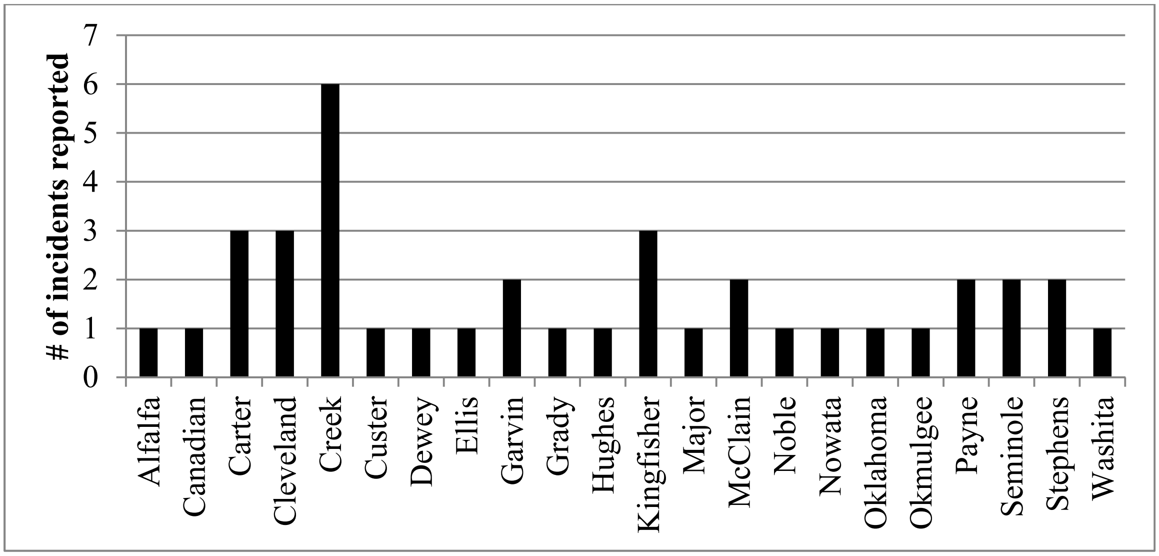

Figure 3.3: Counties that reported ground water contamination from May 2012 to May 2013

Landowners with water wells in their property are the only ones that can detect a change in the quality of their water, and it is also difficult to know with certainty what is affecting their water. Determining contamination pathways underground would require geophysical analysis and years, maybe decades, to be expressed at the surface. Water samples were collected for 29 of these water wells and 21 of the cases were dismissed after laboratory results determined that the pollution was not attributed to oil and/or gas operations. Some of the reasons for exclusion of these 21 cases were the solutes were consistent with agriculture pollution or the water wells were drilled deeper than BTW. In a few cases it was determined by observation that the water wells were distant from oil and gas production sites and the water was clear of any observable free hydrocarbons (rainbow, sheen). However, eight of the water related incidents were referred to pollution abatement. The author requested additional information on these eight incidents at the OCC Oklahoma City office and by telephone at each district office, but yielded no information. Likewise an open records request was made, but not answered.

3.4.2 OCC – Drilling completion reports

After identifying the water wells that had been affected and referred to pollution abatement, the complaints of interest were plotted in ArcGIS, as shown in Figure 3.4. Given the legal description (Section, Township and Range) of the incident, 1002A forms in the same section were retrieved from the OCC Imaging Oil and Gas records website. Table 3.1 summarizes the complaint, location and adjacent drilling activity. The reference number for each of the complaints will be used for this point on. Incident number 3 is located in McClain County but a specific location was not included in the raw dataset, thus it was omitted from the analysis.

Table 3.1: Water well complaints referred to pollution abatement from May 2012 to May 2013

Ref #	COMPLAINT	S	T	R	County	Years of production	BTW (ft)	Formations
1	18512OGDO10682	16	15N	07E	Creek	1941-2010	400	Wilcox
2	18512OGDO31603	18	11N	20W	Washita	2010	300	Woodford
3	18512OGDO32547				McClain			
4	18513OGDO10525	9	17N	07E	Creek	1914-1991	600	Oswego, Bartlesville, Prue
5	18513OGDO11344	16	28N	16E	Nowata	1918-2002	<100	Rowe Coal, Arbuckle, Oswego, Peru, Mississippi, Red Fork, Bartlesville
6	18513OGDO20616	7	14N	10W	Canadian	1968-1977-2010	<100	Oswego, Morrow, Springer, Woodford
7	18513OGDO31275	12	03S	02E	Carter	2012-2013	1600	Woodford
8	18513OGDO41215	20	06N	07E	Seminole	1927-1990	100	Senora

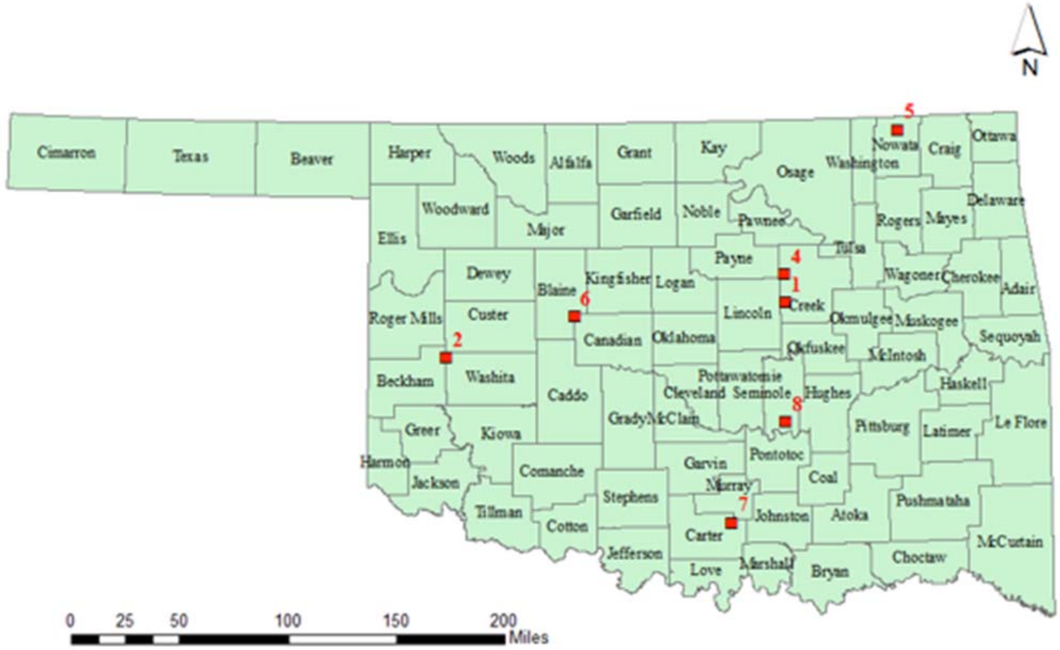

Figure 3.4: Location of water wells referred to pollution abatement

Complaint #1 – Creek County

A total of 26 drilling completion reports were obtained from the OCC Imaging website. Surface casing that was 10-¾" diameter was set in all wells dating from 1941 to 2009 to depths ranging from 102' to 266'. One well was drilled in 2010 and had 8-5/8" diameter casing set to a depth of 610' below the ground surface. The base of treatable water at this location is 400' below the ground surface. Figure 3.5 is an example of the map that includes the location of the water well that was referred to pollution abatement and the corresponding BTW. In this particular example the water well is located in Creek county and the nearest BTW contour line is 600' below the ground surface which implies that surface casing should be set to at least 650' below the ground surface.

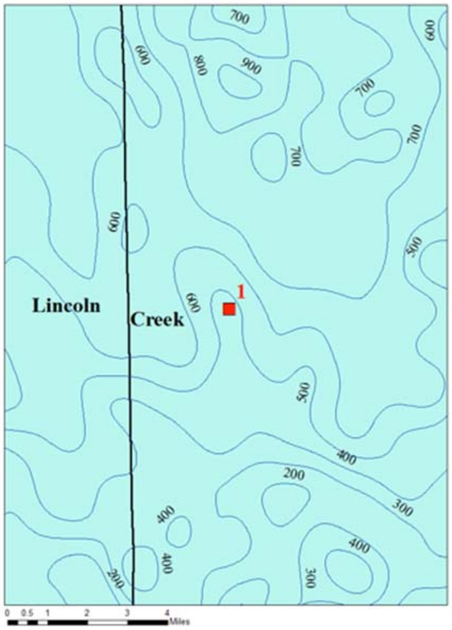

Figure 3.5 Example of maps developed that include the incident location and closest BTW

Complaint #2- Washita County

One production well was completed in 2010 and produced horizontally from the Woodford formation. Surface casing of 9-5/8" was set to a depth of 1510' below the ground surface. The depth of treatable water at this location is 300' below the ground surface.

Complaint # 3- McClain County

A location was not disclosed in the 1085 complaint form for this incident.

Complaint # 4- Creek County

A total of 139 drilling completion reports were obtained from the OCC Imaging website. A few water injection wells and water supply wells were included within these records. These wells were drilled into the Arbuckle and Bartlesville formations in the 1960's and usually had 8-5/8" casing set at the surface to depths ranging from 507' to 522' below the ground surface. One injection well drilled in 1914 had a 12" conductor followed by 10" diameter pipe to a depth of 770' below the ground surface. Oil production wells had casing ranging in diameter from 10-¾" to 8-½" set to depths ranging from 505' to 1142'. A few did not include surface casing as they were re-entry boreholes. The base of treatable water at this location is 600’ below the ground surface.

Complaint #5- Nowata County

A total of 34 drilling completion reports were obtained from the OCC imaging website. Many of the records included were re-entry completions forms from 1918. Modern re-entry wells may not report surface casing because the original surface casing is cemented in the hole. The remaining production wells had casing ranging in diameter from 7” and 10-½” and set to depths ranging from 8’ to 75’ below the ground surface. The depth of treatable water at this location is very close to the ground surface or less than 100’ below the ground surface.

Complaint # 6 - Canadian county

A total of six drilling completion reports were obtained from the OCC Imaging website. Surface casing of 8-5/8” was set to depths ranging from 1003’ to 1535’ below the ground surface. There was one well that was produced horizontally out of the Woodford formation and had a 13-3/8” surface casing installed to 1545’ below the ground surface. The depth of treatable water at this location is very close to the surface or less than 100’ below the ground surface. Personal communication with Dr. Jim Puckette of the Boone Pickens School of Geology at Oklahoma State University indicates that the geology of the area is complex and the Permian section rich in salt and anhydrite can affect the drilling fluid and the integrity of the borehole. For this reason, surface casing is set at deep distances well below the BTW.

Complaint #7- Carter County

There were four production wells in this area that produced horizontally out of the Woodford formation. Surface casing of 9-5/8” was set to depths ranging from 2000’ to 2032’. The base of treatable water at this location is 1600’ below the ground surface.

Complaint #8 – Seminole County

A total of 50 drilling reports were obtained through the OCC Imaging website. A few re-entry completion reports were included in which surface casing was not set. Surface casing ranging in diameter from 8-¼ to 12 ½” was set to distances ranging from 40 to 350’. The base of treatable water at this location is 100’ below the ground surface.

3.4.3 OWRB – Aquifer vulnerability data

According to the study completed by the OWRB areas of very high to high groundwater vulnerability are the four bedrock basins: Boone, Arbuckle-Simpson, Elk City and Blaine. The Boone, Arbuckle-Simpson and Blaine are composed of limestone and gypsum and contain karst features which act as conduits for contaminants. The Elk City basin has a shallow water table and allows for pollutants to travel through the shallow soil more rapidly (Osborn, Eckenstein et al., 1998). A map of the different hydrogeological basins is included as Figure 3.6 and a map of the overall vulnerability is included as Figure 3.7. The salt water spills reported from May 2012 to May 2013 were plotted in the different DRASTIC parameter layers to determine the DRASTIC index of each parameter and the overall vulnerability of the aquifers underlying the spill. Included in appendix A is a table that contains information on the locations of the salt water spills, DRASTIC indices and overall vulnerability within the aquifers and different hydrogeological basins.

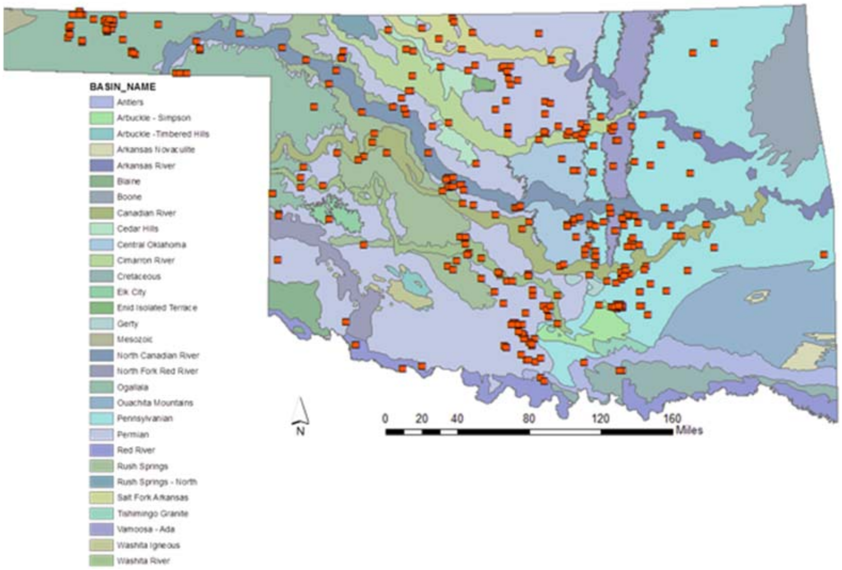

Figure 3.6: Oklahoma hydrogeological basins and OCC salt water spills reported from May 2012 to May 2013

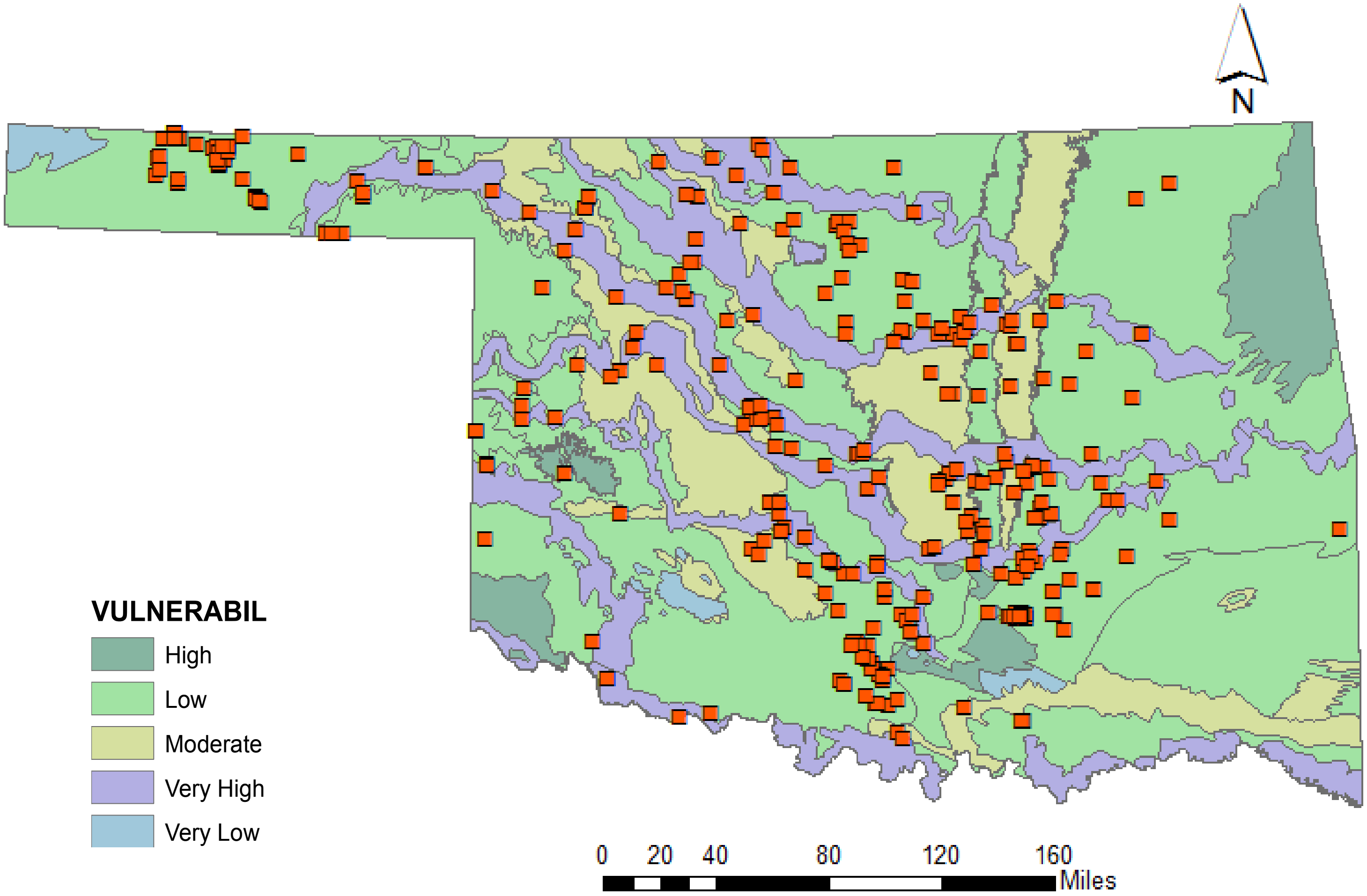

Figure 3.7: Overall aquifer vulnerability based on the DRASTIC index and locations of salt water spills

Depth to water – Refers to the depth to which the salt water that was spilled at the ground surface would have to travel in order to reach the aquifer. The shallower the distance the more vulnerable the aquifer would be. When the incidents reported were overlaid with the vulnerability map for depth to water it was found that the highest value assigned to the locations was seven out of ten for 81 incidents. The basins affected included the Arkansas River, Canadian River, Cimarron River, North Canadian River, Red River, Salt Fork Arkansas and Washita River. The vulnerability for each one of these basins was rated as very high. Over 24% of salt water spills within the dataset were located on very high vulnerability zones.

Net Recharge – Refers to the ease at which the aquifer refills. Recharge would transport salt water that spilled at the ground surface through the soil and into the water table. The greater the ease of recharge, the more vulnerable the aquifer would be. It was found that the highest value within the water spill incidents was six out of ten that occurred once in the Arbuckle-Simpson basin.

Aquifer media – Refers to the consolidated or unconsolidated rock and material that serves as an aquifer. The more porosity and fractures within the aquifer, the greater the vulnerability. The maximum value allocated within the incidents was six out of ten and was located in the Arbuckle-Simpson basin with a vulnerability described as high.

Soil media- Refers to the uppermost surficial layer of weathered soils the average a depth of about six feet below the ground surface. The amount of salt water that can infiltrate into the ground is dependent upon the soil material through which it is traveling. The less clay shrinks and swells, and the smaller the grain size of the soil, the less vulnerable the aquifer may be. The maximum vulnerability level within the incidents was eight. A total of three water spills were located in a level 8 and distributed between the Elk City and North Fork Red River basins. Both basins were categorized as high and very high vulnerability areas.

Topography – Refers to the slope of the surface land. Topography affects runoff and the amount of contaminant fluid that stays and infiltrates. The lower the slope, less runoff and the vulnerability is greater. The maximum value allocated within the salt water spill incidents was ten. A total of 120 incidents were located in a level ten zone and were distributed between the Cedar Hills, Cimarron River, Cretaceous, Elk City, North Canadian River, North Fork Red River, Ogallala, Red River, Salt Fork Arkansas, and Washita River basins. Ogallala and Cretaceous presented low vulnerabilities however the remaining basins were rated a high or very high. Also, the remaining spills were allocated a level nine which comes to represent 100% of incidents that are located in a very high vulnerability zone with respect to topography.

Impact of the vadose zone- Refers to the unsaturated zone that extends from the ground surface to the water table. The texture of the vadose determines the time of travel for the contaminant fluid. The highest vulnerability value allocated within the reported salt water spills was nine out of ten. One incident was plotted in level nine located in the Arbuckle-Simpson basin with a rating of high vulnerability.

Hydraulic Conductivity - Refers to the rate at which water flows through the pore space and/or fractures. The higher the conductivity, the more vulnerable the aquifer will be. The highest vulnerability level within the salt water spills reported was six. A total of 43 incidents were plotted in level six and distributed among the Arkansas River, Canadian River, North Fork Red River, Red River, Salt Fork Arkansas and Washita River. Very high vulnerability is accounted for 13% of water spills reported.

Overall Vulnerability – Based on the different factors that assign a DRASTIC index, the overall vulnerability is assessed. The overall vulnerability of Oklahoma aquifers with respect to reported water spills are shown in Figure 3.8. Two hundred and seventeen (65.2%) of incidents were located in areas of low vulnerability, 33 (9.9%) were in moderate areas, 2 (0.6%) were in high vulnerability areas and 81 (24.3%) were in very high vulnerability areas.

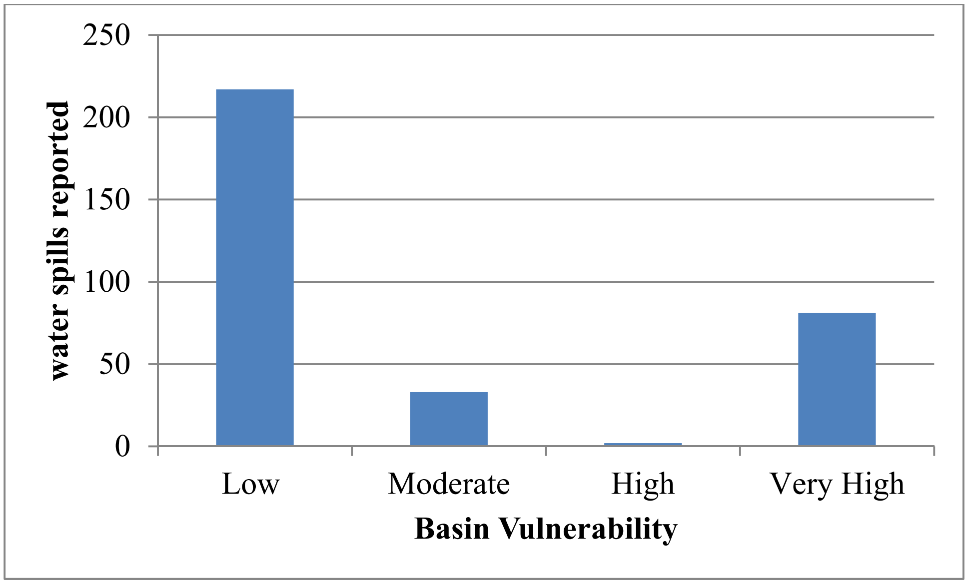

Figure 3.8: Overall basin vulnerability and number of salt water spills

The salt water spills were occurred in 16 aquifers (Antlers, Arbuckle-Simpson, Arkansas River, Canadian River, Cimarron River, East-Central Oklahoma, El Reno, Elk City, Garber-Wellington, Hennessey-Garber, North Canadian River, North Fork of the Red River, Rusk Springs, North Fork of the Arkansas River, Washita River and Western Oklahoma) and in the hydrogeological basins listed in Table 3.2. The El Reno minor bedrock aquifer located in the Permian hydrogeological basin experienced the most salt water spills at the ground surface. One salt water spill was documented in the Arbuckle-Simpson aquifer and one was documented in the Elk City aquifer. These two aquifers were included among the four bedrock aquifers that the OWRB characterized as the most vulnerable aquifers in the state.

3.5 Conclusions

The older production wells located in proximity to the affected water wells used conventional vertical drilling to produce out of the formations like the Wilcox, Oswego, Bartlesville, Prue, Rowe Coal, Arbuckle, Peru, Mississippi, Red Fork and Senora. The newer wells included in this paper were drilled horizontally and hydraulically fractured to produce out of the Woodford formation.

Table 3.2: Number of incidents reported by hydrogeological basin

Basin	**# of incidents**
Antlers	2
Arbuckle-Simpson	1
Arkansas River	2
Canadian River	18
Cedar Hills	2
Central Oklahoma	13
Cimarron River	14
Cretaceous	2
Elk City	1
North Canadian River	24
North Fork Red River	2
Ogallala	54
Pennsylvanian	70
Permian	91
Red River	4
Rush Springs	6
Salt Fork Arkansas	4
Vamoosa-Ada	10
Washita River	13

Consistent with current OCC regulations, the BTW and the minimal depth required for surface casing was determined for all production wells located in close proximity of the affected water wells. It was determined that the majority of older production wells did not comply with current OCC regulations while all newer production wells were in compliance and in most cases casing was set a large distance below the BTW in an effort not just to comply with the law, but to ensure the stability of the borehole in areas of complex susceptible geology. Eight water wells were referred to pollution abatement and two of these water wells were surrounded exclusively by new production dating from 2010 to 2013. Based on salt water spills incidents reported from May 2012 to May 2013 and DRASTIC indices assigned by the OWRB, a map of the overall vulnerability of the state aquifers was developed. With GIS analysis it was found that 25% of the reported salt water spills had occurred at the ground surface of a high or very high vulnerability aquifer. The Permian hydrogeological basin, and more specifically El Reno aquifer, which are assessed as a low vulnerability area, endured the most reported water spills, followed by the Pennsylvanian basin which is also characterized as a low vulnerability area. Combined, these analyses indicated that there is a relatively small, but non-zero, impact to ground water resources from current oil and gas operations in Oklahoma.

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CHAPTER IV

QUANTIFYING THE IMPACT OF PRODUCED WATER TO SURFACE WATER USING OKLAHOMA CORPORATION COMISSION COMPLIANCE REPORTING

4.1 Abstract

The dramatic increase in oil and gas production as a result of the new and evolving techniques of horizontal drilling and hydraulic fracturing have raised concerns about pollution to the environment and drinking water supplies. Produced waters are a big concern in the state of Oklahoma as spills and leaks of this pollutant fluid can travel into surface water bodies and alter the existing ecosystem as well as public drinking water supplies. The Oklahoma Corporation Commission (OCC) is committed to regulating oil and gas practices in Oklahoma to protect the environment. The OCC records and addresses drilling complaints through their oil and gas division in an Environmental Compliance Reporting System (ECRS) and has recently transitioned into a Risk Based Data Management (RBDM) system. The Oklahoma Department of Environmental Quality (ODEQ) regulates and maintains the quality of surface water and drinking water supplies. Data from these two agencies was combined to quantify the amount of salt water spills and the amount of reported surface water bodies affected by oil and gas operations and to determine the proximity of these spills and polluted water bodies to public supply water intakes.

It was found that 333 salt water or produced water spills were reported to the OCC from May 2012 to May 2013 and 16 of these spills had reached a surface water body. It was also determined that the closest distance between a salt water spill to an intake was two miles and the closest distance of a contaminated surface water body to an intake was three miles.

4.2 Introduction

Produced water is water from underground formations that is brought to the surface during oil or gas production. Produced water is the largest volume by-product or waste stream associated with oil and gas exploration and production (Clark and Veil, 2009). Surface water is water that has accumulated on the surface in the form of lakes, streams, creeks and ponds. Surface water contamination occurs when a pollutant, such as produced water (brines or salt water), comes in contact with the water collected in these water bodies. The contaminant fluid dissolves and mixes with the surface water and changes the chemical composition of it. The oil and gas industry produces a significant amount of produced water. This water is characterized by having a high content of salts and dissolved solids and in most cases it will also include natural occurring radioactive materials (Clark and Veil, 2009). Public water supply (PWS) is defined by the Safe Water Drinking Act as a system that provides water via piping or other constructed conveyances to the public for human consumption. This study incorporated data from the OCC to the locations of 1,600 PWS intakes maintained by the DEQ. The objective was to quantify the amount of salt water spills that occurred from May 2012 to May 2013 as well as the amount of these spills that reached a surface water body and to determine the proximity of salt water spills to surface water intakes.

4.2.1 OCC

The Energy Policy Act of 2005 exempts fluids used in hydraulic fracturing from regulatory action under the Clean Water Act, the Safe Water Drinking Act, and the Comprehensive Environmental

Response, Compensation, and Liability Act (Kosnik, 2007). Thus, there is little federal oversight to protect surface water from oil and gas drilling. Each state determines its own regulations and enforcement. In Oklahoma, the OCC is committed to protecting water resources by regulating oil and gas practices in 76 counties. Under the Oklahoma Enabling Act of 1906, the Commission lacks jurisdiction over Osage county. The OCC was formed in 1907 to regulate public service corporations, railroads, telephones, and telegraphs. In 1914 it started regulating oil and gas. At the time the organization was significantly understaffed and the lack of inspectors forced it to rely on an honor system in which the industry would self-regulate. Numerous oil spills and fires were unreported and unattended because each oil producer would determine what intolerable conditions in the oil fields were. Gas was flared and coal was wasted in large amounts, this alerted the federal government to extend its authority over Oklahoma (Boyd, 2008). In 1914 the OIPA (Oklahoma Independent Petroleum Association) advocated regulation of the industry, with the focus on prorationing, dividing and distributing funds and responsibilities. The state of Oklahoma continues to be independently regulated through the OCC. The OCC is also responsible for recording and addressing each oil and gas drilling incident reported through an Environmental Compliance Reporting System (ECRS) and/or Risk Based Data Management (RBDM) system. ECRS is software that the OCC used until 2013 to record oil and gas drilling complaints that were reported by companies or individuals.

4.2.2 ODEQ

The ODEQ through its Water Quality Division (WQD) regulates the different facilities that provide and distribute public drinking water. The Safe Water Drinking Act defines a Public Water Supply (PWS) as a system that delivers water via piping or other constructed conveyances to the public for human consumption. The ODEQ oversees 1,600 active water supply systems. Public water supply systems may receive their water from groundwater wells, surface water impoundments or reservoirs, or purchase water from other systems for their primary source of drinking water. A total of 203 systems use surface water as their source of water. (2013 State of

Oklahoma Public Water Supply Program Annual Compliance Report). WQD is also responsible for maintaining water quality standards in Oklahoma's lakes, rivers, and streams.

4.3 Methods

4.3.1 OCC data - ECRS records

A list of the last twenty years of drilling incidents recorded into ECRS was obtained through members of the OCC. The list contained 94,546 records from July 1993 to May 2013 and 100 columns for different fields containing information per record. The fields that were most accounted for in order to categorize these incidents were: allegations, findings and recommendations. The allegations field will usually provide with most of the information, but when this field was inconclusive or difficult to interpret the findings and recommendations fields would most likely include a description that would help better categorize the event. The list of incidents was obtained in August 2013 and contained mostly ECRS records with a tab of RBDM that included 21 records. A total of 2,078 incidents were selected from the extended list. These records included the last year in the list from May 2012 to May 2013. The latest incidents were reported in May 31, 2013. With the purpose of facilitating interpretation, these occurrences were classified into 13 categories; permit violations and posting of signs, water spills, oil spills, soil contamination, trash and debris left on site, unplugged wells, abandoned well and/or abandoned equipment on site, leaks such as from a stuffing box or well head, surface water that has been compromised by spills, water wells that had been altered, unrestored sites or sites that needed maintenance, leak/spill/discharge (a category for discharges of unknown fluid in unknown quantities) and a category that included all other unrelated violations. The locations in which salt water was spilled in a drilling site were plotted in the Oklahoma county map in ArcGIS 10.2. As the latitude and longitude coordinates were brought into ArcMap it was determined that four of the locations were not in the Oklahoma map but rather appeared to be in Arkansas. There are discrepancies in the ECRS dataset and the locations provided are not fully reliable. In an effort to determine an approximate location, the provided section, township and range were converted to decimal latitude and longitude. As the converted decimal locations were compared to the provided decimal locations it was noticed that these did not match. Every decimal longitude provided was offset at different degrees ranging from -0.0008 to 1.979. The county listed in the dataset was in agreement with the converted location and not with the provided decimal location.

4.3.2 ODEQ data – PWS map

An updated map in shapefile (*.shp) format was obtained in April 3, 2015 through direct contact with Joe Long, environmental programs specialist for ODEQ. This map contained the locations for 1,600 PWS intakes in the state of Oklahoma. The shapefile was brought into ArcGIS 10.2 and overlaid with the locations of the reported salt water spills.

4.4 Results

4.4.1 OCC – ECRS data

After analyzing the complaints reported from May 2012 to May 2013 it was determined that 333 salt water spills had occurred. These incidents represent approximately 16% of the total complaints reported in this year. A total of 75 creeks, ponds and lagoons were reported as contaminated of which 16 were affected by salt water spills. The legal land description for these 16 water bodies is included in Table 3. The remaining surface water bodies that were reported contaminated had been distressed by oil spills, observable hydrocarbons in the water, ecosystem alteration and fish kills.

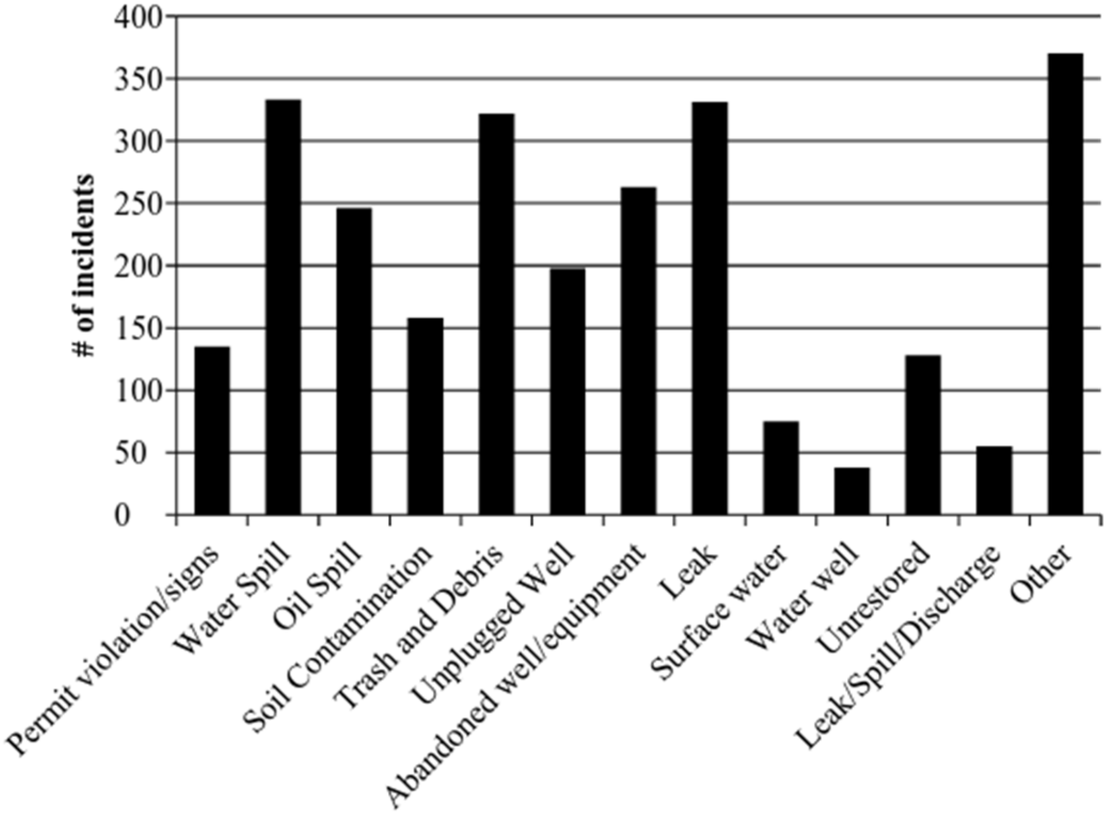

Figure 4.1: OCC number of incidents reported from May 2012 to May 2013

Through this classification and sorting of the incidents it was also determined that the counties that had reported contamination of surface waters included: Canadian, Carter, Coal, Creek, Custer, Dewey, Garfield, Garvin, Grady, Grant, Harmon, Jackson, Kingfisher, LeFlore, Logan, Marshall, McClain, Muskogee, Noble, Okfuskee, Oklahoma, Okmulgee, Pawnee, Payne, Pontotoc, Pottawatomie, Rogers, Seminole, Stephens, Texas and Tillman. Figure 4.2 shows the distribution of reported surface water pollution throughout the different counties. As it can be seen, the county with the most surface water complaints was Seminole with 12% of reported incidents.

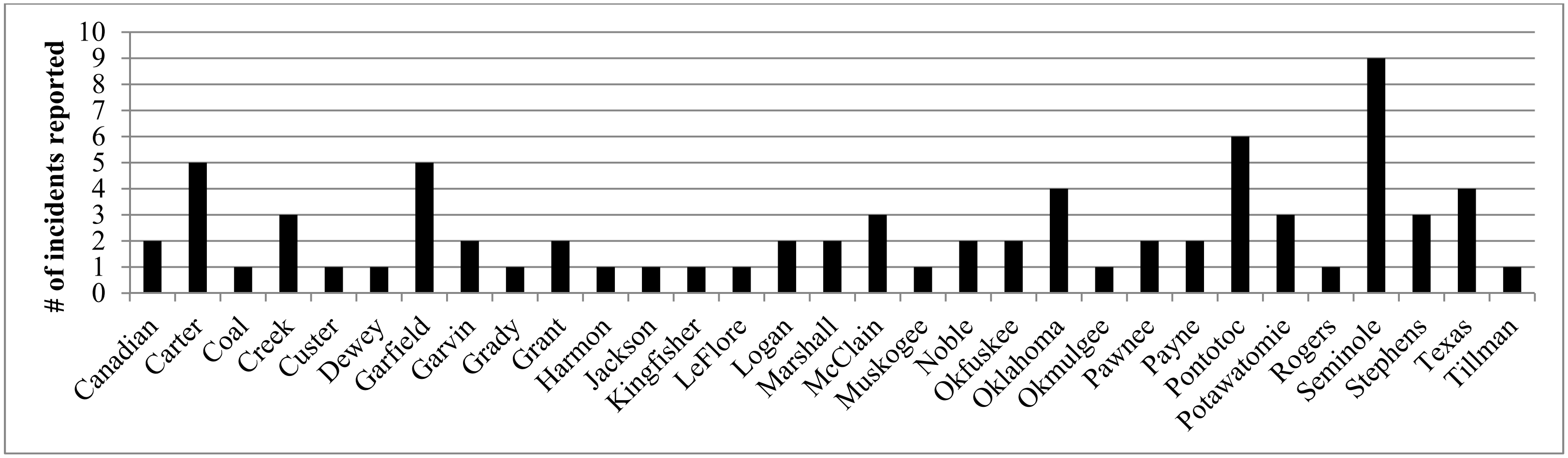

Figure 4.2: Counties that reported surface water contamination from May 2012 to May 2013

Table 4.1: Legal land location for surface water bodies affected by salt water spills

COMPLAINT #	S	T	R	MERIDIAN	COUNTY
18512OGDO21649	7	16N	15W	IM	DEWEY
18512OGDO22659	15	23N	04W	IM	GARFIELD
18512OGDO31207	8	03S	02W	IM	CARTER
18512OGDO32045	24	04S	03W	IM	CARTER
18512OGDO32344	11	03S	05W	IM	STEPHENS
18512OGDO32435	19	05N	02W	IM	MCCLAIN
18512OGDO32495	11	01N	03W	IM	GARVIN
18513OGDO10519	15	18N	04E	IM	PAYNE
18513OGDO20290	36	05N	13E	CM	TEXAS
18513OGDO21113	8	20N	05W	IM	GARFIELD
18513OGDO31112	11	06N	26W	IM	HARMON
18513OGDO40153	26	02N	06E	IM	PONTOTOC
18513OGDO41063	27	02N	07E	IM	PONTOTOC
18513OGDO41255	31	04S	04E	IM	MARSHALL
18513OGDO41341	9	09N	05E	IM	POTTAWATOMIE
18513OGDO41421	28	02N	07E	IM	PONTOTOC

4.4.2 OCC and DEQ – Overlaying salt water spills to PWS

The reported salt water spills were plotted in ArcGIS and overlaid by the PWS shapefile (*.shp).

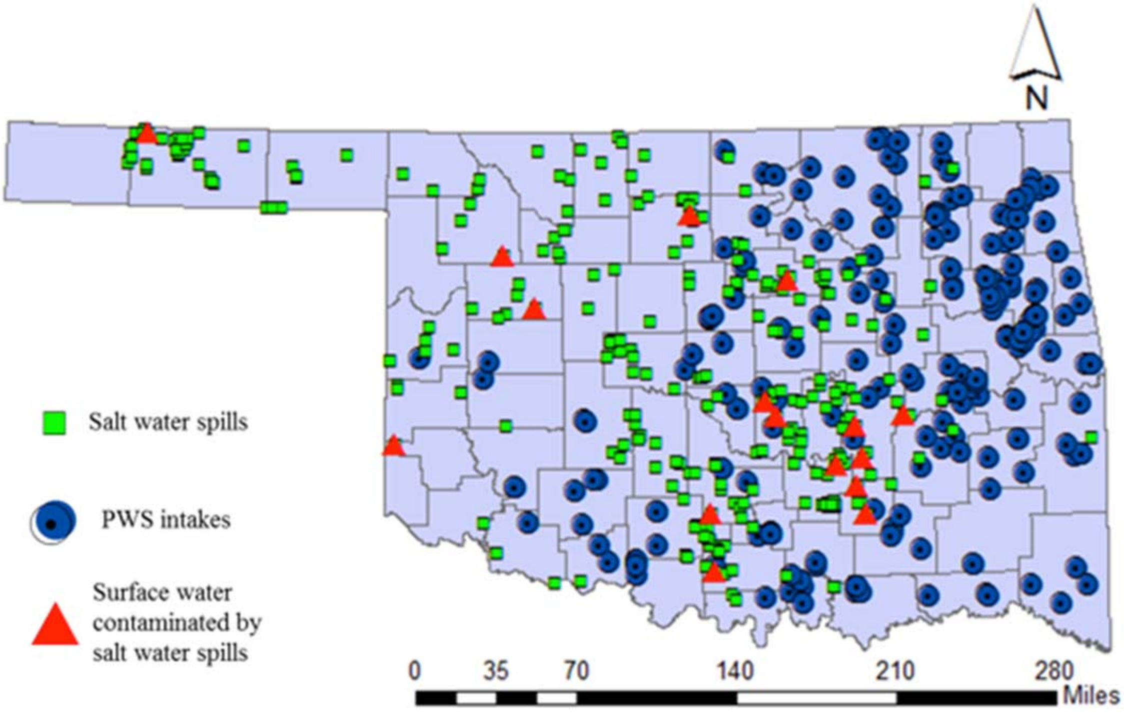

Figure 4.3: Proximity of salt water spills to PWS intakes

As it can be seen in the map, many of the salt water spills on the half eastern portion of the state are in close proximity to surface water intakes. The closest saltwater spill was documented two miles away from an intake. GIS Analysis determined that 30 incidents were within five miles of a surface water intake. Table 4.2 lists the proximity from the incident to the water intake and the number of saltwater spills that have occurred within this period of time. Out of a total of 333 saltwater spills reported in the state dating from May 2012 to May 2013, it was concluded that the probability of a salt water spill occurring at proximity of two miles within an intake is 0.3%, the probability of occurrence within of three to five miles is 9%, and within five to ten miles is 15%. Three miles was the closest distance of a polluted water surface body to an intake.

Table 4.2: Distance from PWS intakes to salt water spill incidents and counties affected

Proximity to intake	**# of incidents**	**Counties affected**
2 miles	1	Nowata
3 to 5 miles	30	Carter, Cleveland, Coal, Creek, Garvin, Kay, Lincoln, Marshall, McClain, Noble, Payne, Pittsburgh, Pottawatomie, Roger Mills
5 to 10 miles	51	Bryan, Canadian, Carter, Cleveland, Coal, Garvin, Hughes, LeFlore, Lincoln, McIntosh, Murray, Noble, Okfuskee, Oklahoma, Payne, Pottawatomie, Seminole, Tulsa
Total	82	

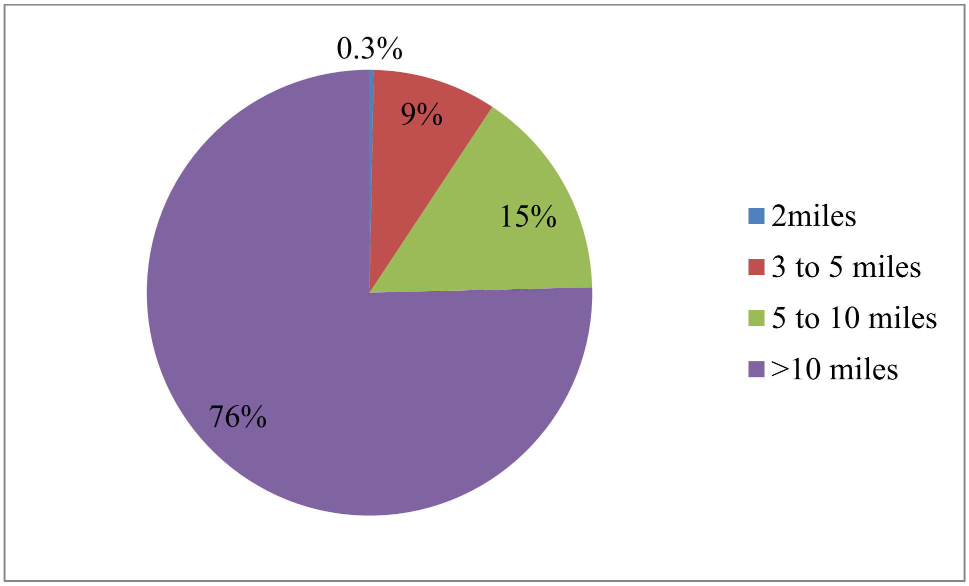

Figure 4.4: Probability of salt water spill within a determined distance of a PWS intake

4.5 Conclusions

Produced water is considered a hazardous waste for its high content in salts and dissolved solids as well as natural radioactive materials. Proper storage and disposal of this contaminant fluid is important in order to prevent runoff to surface water bodies. After analyzing and combining data resources from two state agencies, OCC and ODEQ, it was determined that 333 salt water spills and 75 cases of surface water pollution as a result of oil and gas operations were reported from May 2012 to May 2013. A total of 16 creeks and ponds were polluted by runoff from salt water spills. The closest proximity of a salt water spill to a PWS intake was two miles and the closest salt water polluted surface water body was located three miles from a PWS intake. The volume of the spilled salt water was included in 159 out of the 333 incidents. In order to better assess the potential contamination transport of these salt water spills it would be beneficial that an estimated volume of the pollutant fluid would be included for each entry in the raw dataset.

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