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Potential Contamination Risk in Tennessee Aquifers from Oil and Gas Drilling

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ABSTRACT

The practice of drilling for oil and gas raises environmental concerns for potable drinking sources such as underground aquifers since contamination is an associated risk. About 16,000 oil and/or gas well permits are in existence in the state of Tennessee, according to public record. A large portion of the permits date back to as early as the 1960's while others pre-date state regulations requiring permits. Much research suggests that the presence of older wells introduce a greater risk of contamination. Therefore, the objective of this research is to assess the potential risk of contamination in Tennessee aquifers due to oil and natural gas drilling using temporal and spatial characteristics. This study uses public records that provide information on the wells' location, purpose, and depth. We take the dates and statuses of the well permits into account to determine which aquifers are at risk for contamination due to dated equipment, improper or defective sealing, poor management, etc. Using Esri's ArcMap software, we analyze the density of in-operation, pre-permit, plugged, and abandoned wells within each county to determine the relative threat of contamination. Furthermore, we combine this threat with groundwater usage data to determine where human population is most affected. This information may help manage and regulate old or abandoned wells by prioritizing those that pose a greater risk to groundwater supplies. Also, this information may be presented to governmental agencies to address the issue of missing data, and provide them with valuable insight into the practice of oil and gas drilling.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER ONE
INTRODUCTION

Understanding the relationship between the environment and drilling for oil and natural gas deserves considerable attention. Current research suggests that older and abandoned wells introduce greater risk of leaking unwanted fluids and gases into the surrounding environment, e.g. underground aquifers. Furthermore, the practice of hydraulic fracturing, or fracking, has steadily increased in drilling operations, and researchers are now looking to understand the impact of this unconventional method on older and abandoned wells. With information on fracking risks drillers can prevent contamination by developing better equipment and regulatory practices. A large portion of the well permits in Tennessee date back to as early as the beginning of the twentieth century when modern regulations that safeguarded against drilling risks did not exist. The abundance of pre-permit wells in the state poses a significant environmental concern because the state government lacks significant information about them. While the state has information on the location of these wells, their status (whether or not they are properly plugged) is unknown.

The commercial success and economic benefits of fracking have led to a great expansion of its practice in the Unites States over the last few years. As with any new resource extraction method, potential risks are not fully known at the onset of its development. Research into this topic reveals there is still much to learn about the environmental impacts, but we at least know that the chemicals, fluids, and gases associated with fracking are unwanted in groundwater. This study operates on the premise that risk varies for oil and gas drilling for a variety of reasons. By taking into account current research into the different factors that impact the integrity of oil and gas drilling as well as groundwater usage data, this study assesses the relative risk of contamination in Tennessee.

CHAPTER TWO
LITERATURE REVIEW

Before overviewing current research regarding the environmental impact of oil and gas drilling, it is important to examine the state of Tennessee's role in the oil and gas industry. Tennessee is not a significant contributor to the country's oil and gas reserves. Less than one million barrels of oil are produced in Tennessee annually compared to the tens and hundreds of millions of barrels produced by other states like Texas, California, and Alaska (Hatcher, 2013). However, potential for more drilling exists in the state since many areas remain unexplored. It is possible that as much as two-thirds of the state may be used for fracking operations in the future (Plosser, 2013). If Tennessee increases the amount of oil and gas production, regulations and policies may need to be adjusted to ensure environmental impacts do not become severe. Most fracking in Tennessee today occurs in the eastern and northern portion of the state in the Cumberland Plateau and Knox formations, which are part of the larger Chattanooga Shale formation (Plosser, 2013). This production area between Nashville and Knoxville could expand to other parts of the state where less is known about the geology.

In addition to being a low-producing state, Tennessee's modern fracking operations pose little threat to the environment. Tennessee's shallow shale means that drillers do not have drill as far as they would in states like Pennsylvania whose shale is often three times deeper. Because the shale is shallower Tennessee drillers can use nitrogen instead of large amounts of fluid to create fractures in the rock (Hatcher, 2013). The drilling techniques of today are safer than they were before the development of fracking. The issue of contamination from oil and gas drilling becomes more of a problem when examining its impact on older, abandoned wells rather than its direct impact on the environment.

One specific concern with fracking is when fracking fluids degrade water quality in underground aquifers. Gas and oil wells often have to drill through aquifer layers to reach the resource-bearing shale beneath. Researchers fear that methane is able to migrate upwards through the fissures created by fracking and into upper aquifer layers (Mooney, 2011), because evidence of high methane concentrations in drinking water wells close to oil and gas drilling operations. Scientists are able to differentiate between methane already present in the area and methane that has migrated from deep rock formations which supports theories that fracking could be causing incidences of methane contaminations in groundwater (Ernstoff and Ellis, 2013). High concentrations of methane in aquifers mean that people withdrawing groundwater will have to find other sources. In his 2012 article published in *Groundwater,* Tom Myers discusses two potential contamination pathways, advective transport and preferential flow, from fractured shale to aquifers during fracking operations. Advective transport is a passive motion by a fluid that contains the substance or substances which, in this context, are the fracking contaminants. Myers states advective transport could occur through sedimentary rock, fractures and faults, and abandoned wells or open boreholes. Preferential flow refers to the flow of water through porous materials such as fractured rock. Myers's study suggests that the average time preferential flow and advective transport take to transport contaminants may be decreased from tens of thousands of years to tens or hundreds of years. Although Tennessee drillers uses relatively little injection fluid for fracking, these potential pathways open gateways for other sources of contamination.

Few regulations existed at the beginning of the oil and gas industry in the United States. Wells that pre-date modern regulations are of utmost concern to researchers because they pose a greater environmental risk than modern day wells. High methane emissions, which accounted for 4-7% total anthropogenic methane emissions in Pennsylvania, were measured from abandoned oil and gas wells in the state (Kang, et. Al, 2014). Another study conducted in Canada found CO_2 leakage through plugged and abandoned wellbores (Pawar, et. al, 2009). One of the reasons that older wells introduce unwanted fluids into the surrounding environment is because of the fact that equipment tends to degrade over time. When the structural integrity of oil and gas rigs fail, contaminants are able to leak into the ground. On the other hand, newer wells constructed in the current era experience less leakage because of regulations, use of cement as isolation, and better record keeping (King and Valencia, 2014). This supports the idea that modern wells are not usually a direct cause of contamination because a low risk of failure exists. Instead, their role in contamination is an indirect one.

Researchers have used spatial modeling that consider socioeconomic factors when showing how contamination from oil and gas drilling affects different communities. Researchers found in one study that poor populations often inhabited areas with a high density of unconventional oil and gas wells in Pennsylvania by using spatial analysis and statistical t-tests (Ogneva-Himmelberger and Huang, 2015). By understanding where the risk is present, government and policy makers can make better decisions on the future of oil and gas drilling within their jurisdictions.

CHAPTER THREE

DATA AND METHODOLOGY

Data

Wells Permits

We acquired well permit data for Tennessee from the TDEC who keeps an updated database for the state. The 16,000 well permit records provide information on the name, location, status of well, purpose, etc. which we used to divide the wells into categories. We used well status to calculate risk. The different well statuses are as follows: abandoned, plugged, in-operation, and pre-permit. Different statuses have different levels of risk and are analyzed spatially to determine the state's high risk areas.

A 2010 Knoxville News Sentinel article reported that the National Park Service and the state of Tennessee were planning on plugging forty-five wells in the Big South Fork National Park area. We took this number of wells and calculated that 12.6% of the wells in the park in Tennessee were linked to possible groundwater contamination. Knowing that this statistic covers a relatively small sample area of Tennessee, we created three risk scenarios to estimate the number of people affected by groundwater contamination in each county which is later explained.

Groundwater

Groundwater data was downloaded from the USGS's website. This data showed various statistics on groundwater usage for every county in the United States. We used the groundwater withdrawals as wells as the population served by groundwater statistics to make our calculations.

Methods

We used kernel density, a tool that calculates the density of a variable (in this case, the different well types), to calculate relative risk based on our conceptual model equation. Because quantified values on the probability of contamination are lacking, absolute risk cannot be calculated. Research on this topic suggests what the relative risk of the different well types are when compared to each other, so relative risk is the basis of the conceptual model in this study. Pre-permit wells have the highest risk followed by abandoned, plugged, and in-operation wells. Because in-operation wells have an extremely low risk of contamination they do not directly contribute to the risk the same way that the other wells do. Since research suggests that the presence of abandoned and older wells with in-operation wells increase risk due to modern drilling techniques, the in-operation wells are used differently in the equation. Instead, the in-operation wells are used as an enhancing factor that is multiplied by the combined risks of the other well types. The conceptual model is an operation that integrates these different risk factors (the different well types) to determine overall relative risk. The exponential function was used for the in-operation well risk to ensure that even without the presence of in-operation wells, the risk of contamination still exists. If the exponential function is not used, then when in-operation wells are not present the combined risk of other wells that may be present will be multiplied by zero. If other wells are present in this situation then their risk is unaccounted for which provides an inaccurate assessment.

$$\text{Overall Relative Risk} = (\text{Presence}_{\text{Pre-permit}} + \text{Presence}_{\text{Abandoned}} + \text{Presence}_{\text{Plugged}}) \times \text{Exp}(\text{Presence}_{\text{In-operation}})$$

We performed the operation in ArcMap, a software developed by Esri. With the combined layers of Tennessee counties, aquifers, and kernel density operation, the highest risk areas could be determined visually.

In order to connect the threat with groundwater, groundwater usage data was found for each county in the state. USGS provides statistics on water usage for various purposes including domestic, commercial, and industrial operations. For the aim of this study, we used the population served by groundwater and total population statistics to calculate the percentage of people using groundwater in each county. Because the population served by groundwater statistic was lacking for Tennessee, we used linear regression to interpolate the missing data by taking the population served by groundwater statistic from other counties in the United States. The estimated Tennessee values were used against the total population in each county to calculate a ratio which shows how much of each county's population uses groundwater.

CHAPTER FOUR
RESULTS AND DISCUSSION

Well Distribution

Pre-permit Wells

Pre-permit wells in Tennessee are most distributed in the middle and northern part of the state. A high concentration is present along the Tennessee/Kentucky border as shown in Figure 1. These types of wells are of most concern because of their age and often unknown plugging status, so their presence increases contamination risk significantly.

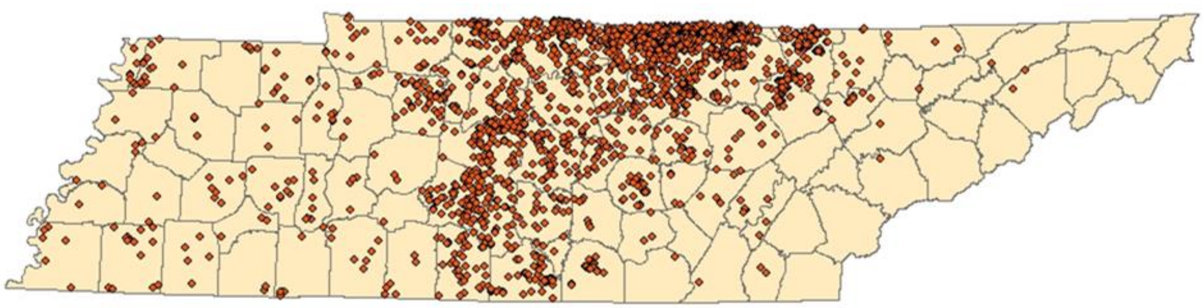

Figure 1. Pre-permit wells across the state of Tennessee.

Abandoned Wells

Abandoned wells in Tennessee are most concentrated in the northern part of the state between Knoxville and Nashville as shown in Figure 2. Their presence is of high concern because although no longer in operation, they have remained unplugged and consequently have an increased chance of leaking contaminants to the surrounding environment.

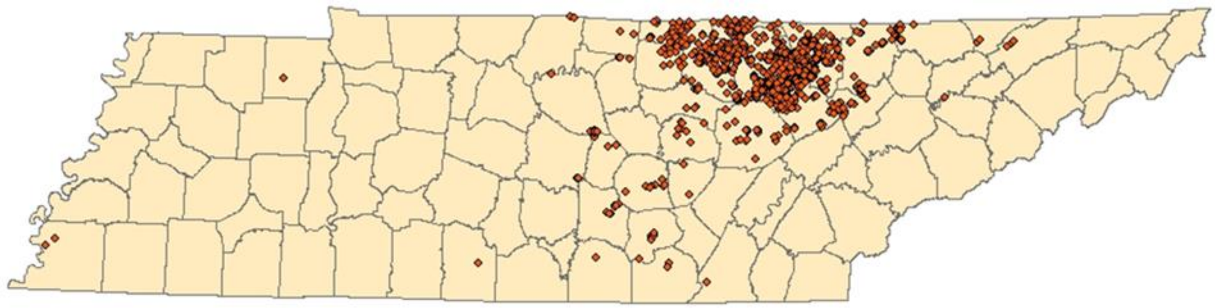

Figure 2. Abandoned wells across the state of Tennessee.

Plugged Wells

Plugged wells in Tennessee have a similar pattern to the abandoned wells as they are most concentrated in the northern part of the state between Knoxville and Nashville which is shown in Figure 3. However, plugged wells are more numerous than abandoned wells and their distribution carries farther south.

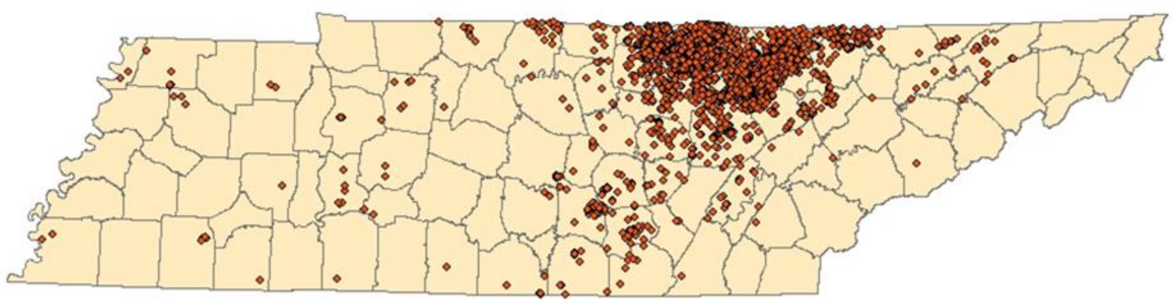

Figure 3. Plugged wells across the state of Tennessee

In-operation Wells

In-operation wells in Tennessee are also most concentrated in the northern part of the state between Knoxville and Nashville as shown in Figure 4. However, in-operation wells also have isolated pockets to the east, west, and south of this area.

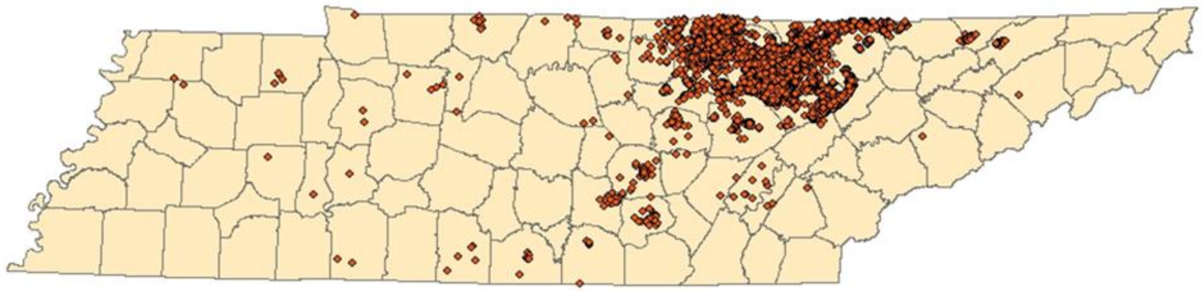

Figure 4. In-operation wells across the state of Tennessee.

Threat Distribution

The counties with high risk of contamination are Overton, Pickett, Clay, Fentress, Scott, Morgan, Sumner, Putnam, and Macon as shown in figure 5. Contamination risk varies from green to red in this figure with green designated as a low risk and red as a high risk. The high risk counties are all located in the eastern and northern section of Tennessee where most of the wells are located.

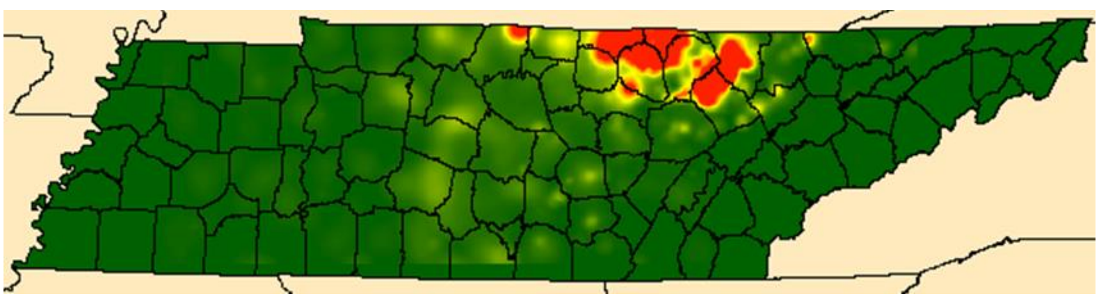

Figure 5. Overall Relative Risk

Figure 7 is a geologic map showing the different aquifers across the state was used to determine which aquifers would be potentially compromised. The aquifers found within the high risk counties are the Pennsylvanian Sandstone, Mississippian Sandstone, Ordovician Carbonate, and Cambrian-Ordovician Carbonate aquifers. The high risk counties withdraw little, if any groundwater. Since groundwater is not used in these areas, the risk of oil and gas drilling is probably not a concern. In counties where groundwater is used, oil and gas wells are not as abundant as in the high risk counties but some areas have a moderate amount of wells. The counties with highest number of people affected by groundwater contamination due to oil and gas drilling are Marion, Maury, Lincoln, and Marshall.

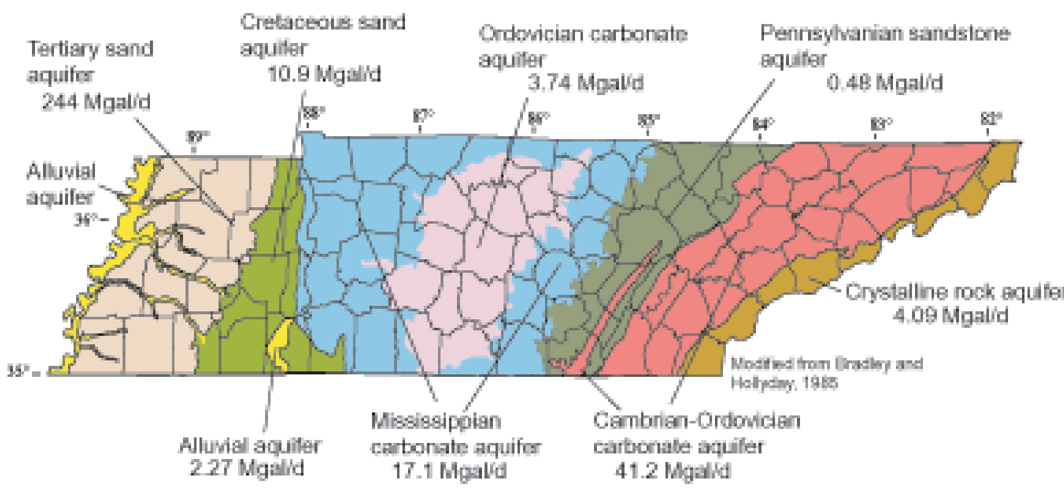

Figure 6. Map of Tennessee aquifers

Risk to Groundwater

We created three risk scenarios to estimate the number of people affected by groundwater contamination in each county. The risk scenarios of 10%, 15%, and 20% indicate the probability that well leakage will occur in each county (e.g., if the risk scenario is 10%, then 10% of wells are leaking in the area). These risk scenarios are based off of the Big South Fork National Park data.

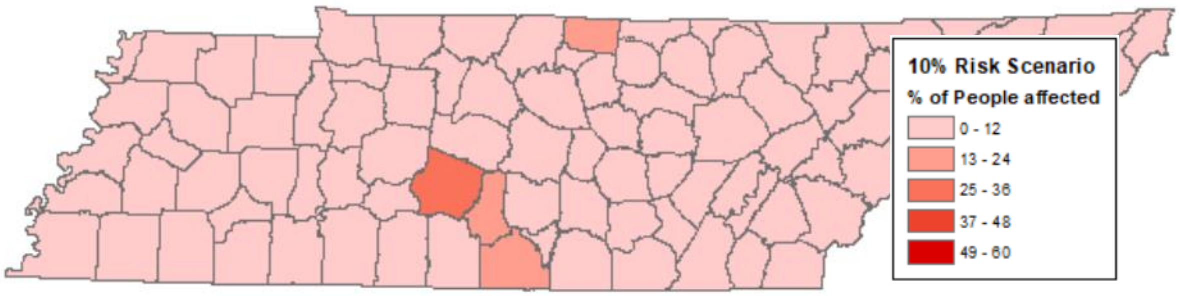

Figure 7. 10% Risk Scenario

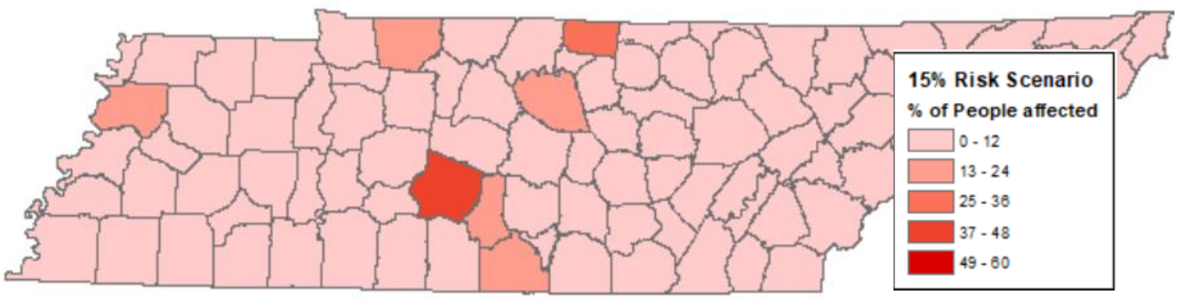

Figure 8. 15% Risk Scenario

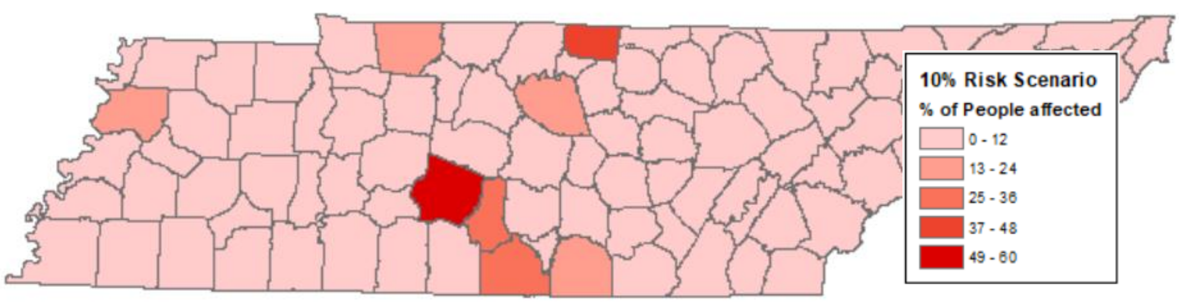

Figure 9. 20% Risk Scenario

Having high contamination risk in areas that use groundwater frequently increases the need to ensure the integrity of drilling operations in these areas. The socioeconomic characteristics of these areas are also important for understanding how communities could respond to the possibility of contamination. Areas that have high risk for contamination but have little monetary resources for protecting groundwater supplies will find it difficult to find solutions to the problem without outside help.

The results from this study are potentially helpful to TDEC's mission. Additional information on the spatial distribution of wells is available to them which they can use to develop a reclamation plan for plugging abandoned wells. Because the types of wells are divided into categories in this study, TDEC can prioritize areas for plugging. This study also could be used for determining where to drill, or rather, where not to drill in the future. High risk areas could be avoided and drillers could find more suitable areas that have a low risk.

More research is needed for determining the risk of fracking and other drilling operations. This study could be improved with more quantifiable data that is lacking at the moment. Further research on how current drilling operations affects abandoned or older wells would aid in vulnerability assessments. This study focused on providing a relative risk assessment which with more quantifiable data could give more concrete results.

CONCLUSIONS

The risk of contamination to groundwater due to oil and gas drilling exists in the state of Tennessee. This is particularly true for areas with a presence of older wells that pre-date permit regulations. The risk of contamination from oil and gas drilling is highest in the eastern and northern part of the state between Nashville and Knoxville. However, since little groundwater is used in this area human population is not greatly affected. Instead, the greatest risk of groundwater contamination is certain middle Tennessee counties. TDEC should focus on plugging unplugged wells in these areas to minimize the associated risk. More studies that need to be done to identify the at-risk populations as well as to understand the impact of fracking on older wells so that we can reduce future contamination.

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