Spring 2014

UNDERGROUND NATURAL GAS STORAGE: AN EXAMINATION OF PROPERTY VALUES IN INDIANA

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Graduate School ETD Form 9
(Revised 01/14)

PURDUE UNIVERSITY
GRADUATE SCHOOL
Thesis/Dissertation Acceptance

This is to certify that the thesis/dissertation prepared

By Michaela Jellicoe

Entitled
UNDERGROUND NATURAL GAS STORAGE: AN EXAMINATION OF PROPERTY VALUES IN INDIANA

For the degree of Master of Science

Is approved by the final examining committee:

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Approved by: Gerald E. Shively 04/24/2014

Head of the Department Graduate Program Date

UNDERGROUND NATURAL GAS STORAGE: AN EXAMINATION OF PROPERTY VALUES IN INDIANA

A Thesis

Submitted to the Faculty

of

Purdue University

by

Michaela Jellicoe

In Partial Fulfillment of the

Requirements for the Degree

of

Master of Science

May 2014

Purdue University

West Lafayette, Indiana

ACKNOWLEDGEMENTS

First and foremost I would like to thank my advisor Dr. Michael Delgado, for allowing me the freedom to explore my interests and providing me with an amazing educational experience, as well as the guidance I needed to narrow my focus and embark on this fascinating project. I would also like to thank my committee members, Dr. Gerald Shively and Dr. Juan Sesmero for their support and advice throughout this process.

Enormous thanks to my parents Winoma Wallace Jellicoe and Gary Jellicoe, for always believing in me and providing me with love, support and at times the push I needed to make it through this process. Last, but certainly not least, I would like to thank Patrick Taylor for taking a leap of faith and leaving his life in Washington to go on this journey with me despite the personal sacrifice. Without his encouragement this project never would have been possible.

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ABSTRACT

Jellicoe, Michaela. M.S., Purdue University, May 2014. Underground Natural Gas Storage: An Examination of Property Values in Indiana. Major Professor: Michael Delgado.

Recent years have seen increased discussion of issues related to natural gas, generally focusing on perceived risks associated with natural gas extraction. One aspect of natural gas extraction that has received little attention is the impact of natural gas storage on surrounding areas. Further, recent advances in horizontal drilling and hydraulic fracturing extraction techniques have greatly increased production of natural gas wells, and will likely increase demand for natural gas storage. Like other natural gas wells, underground storage wells have the potential for environmental and amenity impacts. The impacts of these risks may be reflected by a reduction in the values of nearby properties. This thesis tests the hypothesis that properties located on or near natural gas storage fields have relatively lower values, holding everything else constant.

To test the hypothesis that natural gas storage facilities bear statistically significant environmental and amenity risks, this analysis uses a semi-log hedonic property model through which to assess the impact of natural gas storage proximity and intensity on property values. The model also explores interaction effects of natural gas storage with public water, and allows for nonlinear effects. The dataset consists of a sample of 1,512 single-family residential property sales in 16 counties across the State of Indiana from 2004 to 2013. In addition to property sales data, the dataset includes housing characteristics such as size of the house, size of the property, year of construction, measures of building quality, distance to the nearest street, census block demographics, and in particular public water.

Results indicate that both distance to the nearest natural gas storage well and distance to the nearest observation well have significantly nonlinear impacts on housing values, both indicating that housing values generally increase by approximately 9.2 to 10.03 percent with further distance from storage activity. The results also indicate housing values decrease by approximately 0.43 percent with increased intensity of storage activities. Additionally, the results demonstrate that homes without access to public water see statistically significant impacts of larger magnitude than homes with public water due to increased intensity of underground natural gas storage activities.

CHAPTER 1. INTRODUCTION

Over the past few years discussion regarding issues related to natural gas have increased dramatically. Generally the discussion has focused on the risks of hydraulic fracturing. Other sectors of the natural gas industry have received little attention to date, including underground natural gas storage. Yet, underground natural gas storage has potential risks, including both health, environmental, and amenity impacts. Using the hedonic property method, I test the hypothesis that the risks of underground natural gas storage activities may be reflected by a decrease in property values of nearby properties.

Recent advances in the extraction of natural gas have made activities relating to natural gas a topic of growing public discourse. Advances in hydraulic fracturing have been essential in increasing natural gas extraction, especially in the United States. Hydraulic fracturing requires large quantities of water, which are mixed with various chemicals and are pumped into the ground at very high pressures. Films like *Gasland* and *The Promised Land* have pulled issues related to hydraulic fracturing and the natural gas industry in general into the public eye, as have articles that have appeared in publications like the *New York Times* and *Forbes*. *The Los Angeles Times* published an article in February 2014 discussing a potential ban on hydraulic fracturing in Los Angeles due to concerns about drinking water safety and the potential for seismic activity from hydraulic fracturing activities. In March 2014, *Forbes* published an article about seismic activity in Ohio occurring near hydraulic fracturing activities, which were temporarily suspended until the safety of the activities could be assured. Media reports like these have increased public awareness of issues related to the natural gas industry.

Technological advances, such as advances in hydraulic fracturing, have made previously economically unrecoverable sources of unconventional natural gas economically feasible. Prior to these advancements unconventional sources of natural gas, in which the natural gas is trapped in the tight pore spaces of deep underground formations, could not be extracted without prohibitively significant costs. From 1998 to 2008 unconventional natural gas production increased almost 65 percent (Arthur, Bohm and Layne 2008). One important unconventional natural gas resource is shale reservoirs. Just one of the shale resources, the Marcellus Shale is estimated to contain enough natural gas to provide 20 years of supply to the United States (Skone and Booz Allen, Inc 2012). Between all of the shale gas reservoirs across the United States, the U.S. EnergyInformation Administration (US EIA) estimates 827 Trillion cubic feet of natural gas are recoverable given currently available technology (National Energy Technology Laboratory 2011).

After the natural gas is extracted from the underground formation through wells, pipelines transport it to processing plants, where it is prepared for consumption. Then, natural gas is transported via pipeline for immediate consumption, or for underground storage (U.S. Energy Information Administration 2013). At the underground storage field, natural gas is injected into underground formations, such as an abandoned or otherwise useless aquifer, salt cavern, or most commonly a depleted natural gas or oil reservoir (U.S. Energy Information Administration 2004). The stored gas is then available for re-extraction at a later time. The primary purpose of the network of underground natural gas storage wells is to provide an inventory of harvested natural gas that can be used to meet peak demand. Demand for natural gas is traditionally seasonal, with peaks occurring during the winter heating season; but production in natural gas is not seasonal. Storage is used by the industry to meet times of high demand and plays an important role in the supply chain of the natural gas industry.

Now, as natural gas production increases, the demand for underground storage fields may also increase. It is possible that the quantities of natural gas produced during periods of low consumer demand could exceed the available storage capacity, given the possible increases in production. In addition, with harsh winters like that of 2013-2014, demand for natural gas could exceed available supplies from storage and production during the winter leading to a potential for increases in demand for storage capacity. A recent (March 2014) *Chicago Sun-Times* article reports that levels of natural gas in storage are lower than they have been since 2008 because of high demand during the winter.

Underground natural gas storage is used throughout the United States, with clusters of storage located in the consuming markets on the East Coast and in the Midwest. One state within the Midwest region that has underground natural gas storage fields is Indiana. The US EIA estimated, in 2012, a total storage capacity of 110,749 Million cubic feet of natural gas stored in depleted gas reservoirs and aquifers, known as underground storage fields. Figure 1.1 shows a map of underground storage wells used to inject and withdraw natural gas into storage fields as well as observation wells used to monitor storage fields across the state of Indiana. The counties covered by this analysis appear in grey shading in the figure. A typical storage field can encompass hundreds or thousands of acres underground, depending on the structure of the formation. Above ground, a storage field has several wells to inject and withdraw the gas, as well as a multitude of observation wells. A well used for underground storage includes the aboveground valve assemblies of the wellhead, compression facilities, electric equipment, pipeline facilities and processing equipment, and storage fields also have underground gathering lines (Federal Energy Regulatory Commission 2013).

Many of the wells and storage fields in Indiana are located in rural areas; however there are some that can be found within city limits or just beyond. Figures 1.2 and 1.3 show two comparative examples of storage fields in Indiana. Figure 1.2 is an image of the storage field located in Clark County, Indiana. The imagery shows that the storage field is located close to a few housing developments. The storage field shown in Figure 1.3 is located in Monroe County, Indiana. This storage formation is located a few miles outside of Bloomington, Indiana, which can be seen in the lower left corner of the image. The shadowed area in the image is a representation of the boundaries of the depleted reservoir used to store the natural gas. Figure 1.2 does not show boundaries for the storage field because the natural gas at this facility is stored in an aquifer formation. The symbols representing the storage wells provide clues to the boundaries of the aquifer storage formation. Many of the storage fields in Indiana were established as early as or earlier than the 1960s.

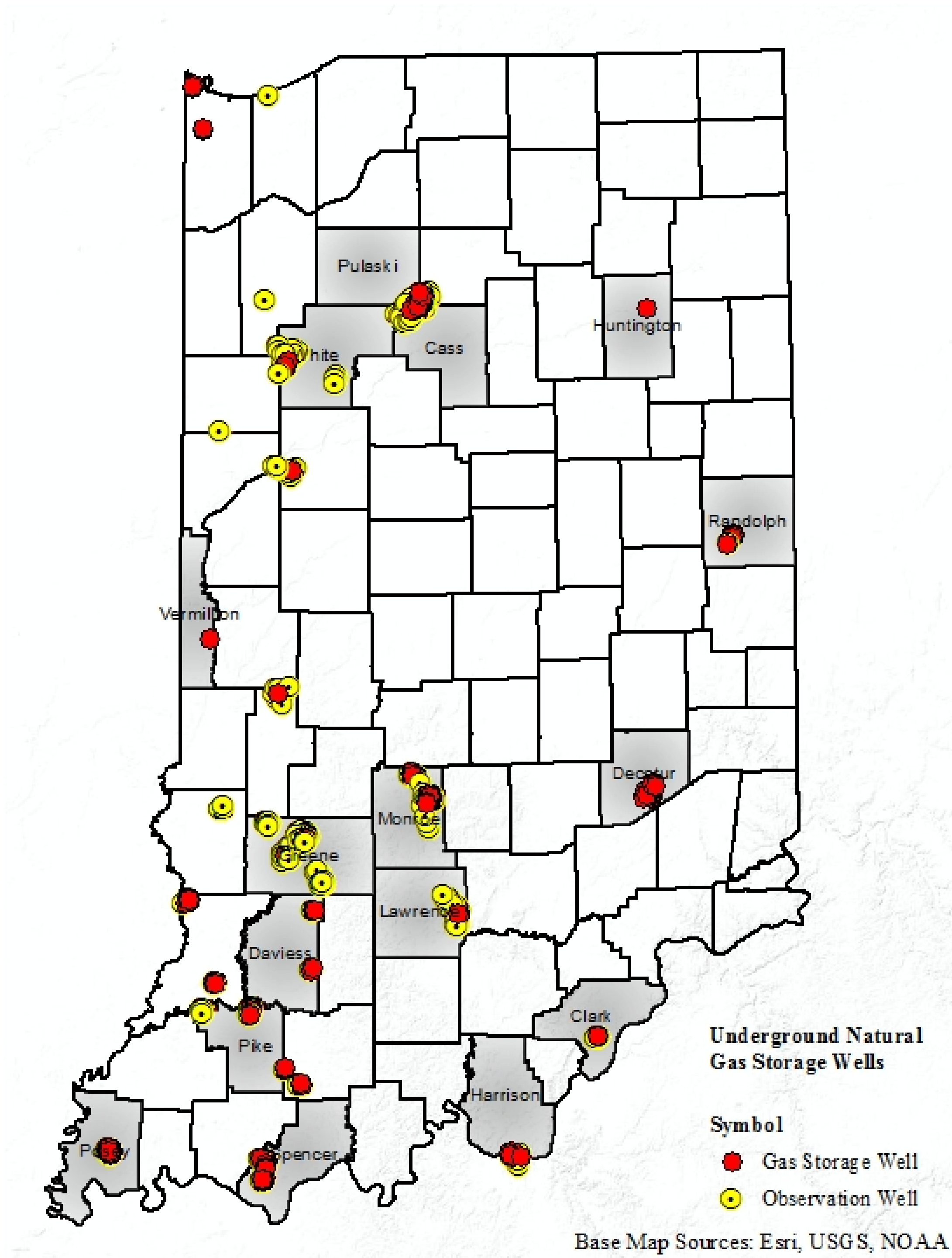


Figure 1.1 Underground Natural Gas Storage and Observation Wells in Indiana

Figure 1.2 Underground Natural Gas Storage Wells in Clark Co., Indiana

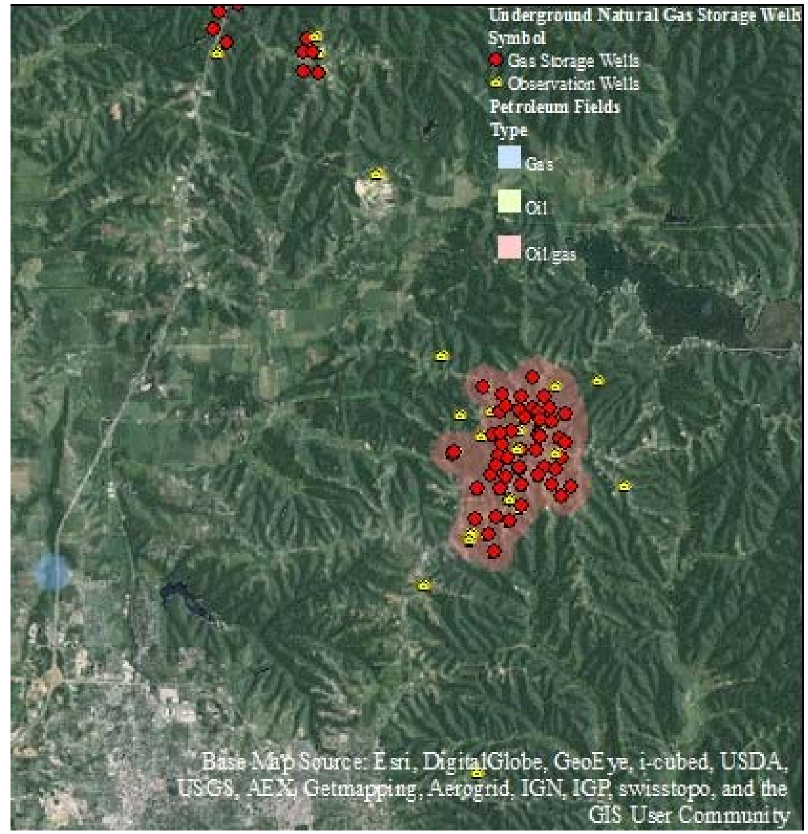


Figure 1.3 Underground Natural Gas Storage in Monroe Co., Indiana

Media attention directed at natural gas extraction activities has heightened awareness on the potential for environmental risks, especially regarding ground and surface water contamination. Like the extraction of natural gas, underground storage poses inherent environmental risks, including:

- migration of the natural gas out of the formation posing the possibility of migration into groundwater sources (Miyazaki 2009);
- failure of well casings and cement that protects the formations above and below the well from contamination (this risk could increase as the well ages) (Miyazaki 2009);
- slow leakage from the wellhead (known as off-gassing), including possible methane emissions (U.S. Environmental Protection Agency 2013);
- penetration of the formation by another well, including a water well.

In addition, there are also some amenity impacts due to the infrastructure associated with the storage field:

- natural gas pipelines require (noisy) compressor stations in order to keep the lines pressurized (Federal Energy Regulatory Commission 2013);
- wellheads provide slight visual impacts.

Miyazaki cites several cases of natural gas migration, leakage and wellhead or well casing failure that resulted in consequences of varying severity. One case cited occurred in Kansas in 2001: natural gas migrated out of the formation, which resulted in two fatalities and a lawsuit seeking damages for losses in property values and business. Although regulatory agencies and regulations are in place in order to prevent cases like the instance in Kansas, underground natural gas storage facilities still pose environmental risks and amenity impacts.

Increased attention on the environmental and health risks of natural gas extraction may increase the perception of risk related to other aspects of the natural gas industry among the public and homeowners, including underground natural gas storage. These environmental and amenity externalities may be reflected in the property values of nearby homes. The perception of risk, or an amenity impact like noise, can mean that one house associated with the risk will have a lower value than a house that is imperceptibly different except for that associated risk. For example, a house located close to a noisy compressor station associated with underground natural gas storage may be less desirable than a home of equal quality and attributes not located close to a compressor station. Perceived risk from living above a storage field, even without the presence of a well or visible compressor station, could reduce property values.

These different sources of environmental risk or damage provide an opportunity for analysis. First, I hypothesize that properties located over the storage field have lower property values, relative to properties not located over the field. Second, I conjecture that properties located near underground storage well sites have lower values, relative to properties located at a distance.

The negative externalities posed by both the storage wells and fields can be determined through the use of a hedonic pricing analysis. Hedonic pricing analysis is a method commonly used to estimate a value for goods that are not sold in a market; these goods can include environmental quality or air quality. Recently, Heintzelman and Tuttle (2012) used this method to quantify the impact on nearby properties of wind turbines. According to hedonic theory, a property is a bundle of attributes, including bedrooms, square footage, acreage, distance to the nearest street, and even proximity to underground natural gas storage fields. Using a quasi-experimental framework with real market data on property sales and information on property attributes it is possible to use econometric theory to decompose the value of the property into estimates for the value of each attribute holding all others constant. In particular it is possible to estimate the impact of a treatment variable such as proximity to a well site on property values, holding all other attributes constant.

I use a semi-log hedonic price function to estimate the impact of proximity to underground natural gas storage fields and wells on property values in Indiana. Indiana is an ideal location for assessment of the impacts of underground natural gas storage because storage activities are relatively isolated from other natural resource extraction activities. This is not true of other areas with heavy concentration of natural gas activities, like in Pennsylvania. This isolation reduces the econometric burdens of identifying any potential negative externalities. My data include a set of 1,512 residential property sales between 2004 and 2013 in 16 counties across Indiana. In addition to data on housing attributes I also collect data on underground natural gas storage, oil extraction and natural gas extraction well locations. Using the locations of wells and housing transactions throughout Indiana, proximity measures and intensity measures are calculated using ArcGIS mapping tools. These proximity and intensity measures are the treatment variables used in the hedonic price analysis, they include the distance from each housing transaction to the nearest storage field and well site, and the count of all wells within a two-mile radius. Regressions that use the housing sales, attributes, and treatment variables allow me to identify any differences in home values induced by proximity to storage wells or fields, or by intensity of well activity, while controlling for other confounding factors.

A more thorough understanding of the risks and benefits associated with the underground storage of natural gas may aid policymakers as the demand for storage rises. Further quantifying the externalities associated with underground natural gas storage provides an important measure of one aspect of natural gas production that has yet to receive much attention. Finally, understanding the negative externalities of natural gas storage could be of interest to policymakers working to maintain up-to-date regulations for environmental protection.

CHAPTER 2. PRIOR LITERATURE

Little economic literature exists on the impact of externalities associated with underground natural gas storage. Despite that underground natural gas storage is a common practice, to my knowledge no prior study examines the impact of these activities on nearby properties. The recent technological advances in extracting underground sources of natural gas have increased attention on the natural gas industry and the risks associated with natural gas extraction. In order to gain further understanding about the impacts of natural gas extraction and provide policymakers with a more complete picture of natural gas extraction recent econometric literature has examined the impacts of hydraulic fracturing activities on nearby property values. However, these recent studies have not yet broached on the subject of underground natural gas storage, therefore the prior literature available focuses on natural gas extraction activities rather than underground storage activities. With the increasing attention on the environmental and amenity impacts of natural gas extraction it is important to extend these studies into the other aspects of the natural gas industry, particularly underground natural gas storage.

Given the increases in production due to unconventional natural gas extraction, the natural gas industry will have to adapt in order to respond to these changes, including response regarding underground natural gas storage. The literature that focuses on the impacts of natural gas and oil extraction activities on housing values use similar methods to this study, and although natural gas extraction and underground natural gas storage differ in many ways they are both part of the same overall industry. In addition to the literature on natural gas extraction and hydraulic fracturing, Guignet (2013) studies the impact of leaking underground storage tanks on nearby property values. Using the hedonic method Guignet (2013) finds that homes near leaking underground storage tanks whose private wells were tested for contamination saw an 11 percent decrease in value.

Hedonic models are commonly applied to issues relating to energy, environmental quality and amenity impacts. These models have been used to study the impact on property values of nuclear power plants (Gamble and Downing 1982), petroleum refineries (Flower and Ragas 1994), hog operations (Palmquist, Roka and Vukina 1997), water quality (Leggett and Bockstael 2000), and wind power facilities (Heintzelman and Tuttle 2012). Each of these studies finds differing magnitude and significance of impacts on property values. Gamble and Downing find no significant impact on nearby property values due to proximity and visibility of nuclear power plants. When studying the impact of hog operations on property values, Palmquist, Roka and Vukina find a very localized impact, which decreases as the saturation of hog operations increases. Flower and Ragas find differing impacts from different refineries. They find that properties near one refinery with larger surrounding buffer zones see almost no negative impacts or only temporary impacts due to “environmental events”. In contrast they find that properties near a more visible refinery see a significant long-lasting negative effects after an event (Flower and Ragas 1994). When applying a hedonic model to the impact of water quality in the Chesapeake Bay on nearby property values Leggett and Bockstael find that improving water quality could result in a benefit of over $12 million across all properties in the study. Heintzelman and Tuttle’s examination of the impact of wind power facilities on property values finds significant negative impacts.

Recently some econometric literature has focused on the impacts of hydraulic fracturing on property values, due to the increased attention on the natural gas industry. Gopalakrishnan and Klaiber (2014) examine the impact of unconventional shale gas extraction and hydraulic fracturing activities on home values in Washington County, Pennsylvania. They hypothesize that there is the potential for both real and perceived environmental risks due to shale gas extraction, which may be capitalized into home values. Within their study they look at the risk for groundwater contamination, noting that shale gas extraction uses large quantities of water and that the byproduct of this water use contains many different contaminants, and additionally that there are growing concerns over methane leakage. The authors also examine land use patterns. Shale gas activities primarily occur on agricultural lands, the land use patterns of surrounding properties can influence homebuyer's expectations for future shale gas activity. Gopalakrishnan and Klaiber hypothesize that by including land use pattern data in their study they can determine the specific impact of the perceived risk of future shale gas activity on home values.

This study uses a dataset of 3,646 single-family home sales between 2008 and mid-2010. The authors chose Washington County because of the population density of the area combined with the proximity to shale gas activities. They also gather information on both drilling and permitting for shale gas extraction within the county. The permitting data allows Gopalakrishnan and Klaiber to look at the early stages of shale gas extraction, with the theory that the positive impacts of shale extraction should be capitalized in the later stages of extraction, which would allow them to differentiate between the positive impacts and the negative impacts of the activities. Their study employs a Box-Cox regression to assist with model specification, which leads them to use a square-root transformation throughout their regressions. They also use several different explanatory variables for the treatment effect, including the total number of shale wells and an interaction between the number of shale wells and the proximity to a major highway.

Gopalakrishnan and Klaiber find that for shale gas activity within one mile of a property and the activity occurring no more than six months before the sale of the property the housing attributes have the expected signs. Additionally they find that homes located nearer to major roadways are impacted at a larger magnitude. They find that the variable for the count of shale gas wells is significant and negative. The marginal reduction in home value for one additional shale well within one mile of a property and with permitting within six months of the home sale is $3,596.47. In addition, homes with private well water and properties with agricultural land surrounding the property experience a larger negative impact. They find a negative marginal willingness to pay between $4,244.75 and $8,288.27 for homes with well water, depending on the percentage of surrounding agricultural lands. In order to explore the spatial and temporal range of the impact they vary the spatial buffer between 0.75 miles and two miles and the time period between six months and 12 months. They find that the impact is largest when the wells are located closer to the property and the permits are acquired within six months of the sale. The impact becomes insignificant when the buffer exceeds one mile or the permit was acquired within a year of the home sale.

Another recent study examining property value impacts of hydraulic fracturing is the work by Muehlenbachs, Spiller and Timmins (2012) examining externalities associated with shale gas development – in particular those associated with potential and perceived risk from groundwater contamination. In order to quantify the impact of shale gas activity as capitalized into housing values their paper uses the hedonic pricing model. Their study also focuses on Washington County, Pennsylvania from 2004 to 2009, culminating in a dataset of 19,055 housing sales. Beyond data describing the characteristics of the house, Muehlenbachs, Spiller and Timmins also collect census data, data on the Public Water Service Areas in the county and data on permitted wells within the county. The authors use two models, a triple-difference estimator and a simple cross-section, property-fixed effects regression in order to differentiate the risk of groundwater contamination from other externalities and estimate the effect of shale gas activity on properties that depend on different water sources. Their model is designed to control for unobserved variables, the property-fixed effects control for temporally-varying sources of unobserved variables and the triple-difference estimator is used to control for time-varying unobserved variables. The authors use very specific treatment and control groups in order to separate negative externalities associated with shale gas activity from any positive amenities.

The authors define a specific geographic buffer range of 2,000-meters distance from permitted wells for their study, since the authors presume that the proximity effects are localized. At this buffer range they assume there is no further effect from the wells on the housing transaction. In addition, the authors create a small homogenous geographic area by looking only at houses 1,000 meters on either side of the public water source border. These geographic definitions allow the authors to create subsamples for use with the triple-difference estimator. Their results conclude that there is a general increase in property values in proximity to shale gas wells of up to 11 percent for homes within 2,000 meters of a shale gas well. However, they also find that houses without public water receive an overall negative impact, and this impact becomes more pronounced when cities are excluded from the dataset. Their results show a decrease in property values of about 24 percent for homes using private sources of drinking water. They do note that gas companies tend to locate in areas with lower property values, which can cause the negative proximity effects of groundwater dependent homes to be more pronounced. Their general conclusion is that there is an overall positive impact due to shale gas development, most likely caused by lease payments, but there are quantifiable negative impacts on property values for homes relying on groundwater.

Boxall, Chan and McMillan (2005) conduct another study researching the impact of oil and gas facilities on residential property values. Prior to this study all reports on the impact of oil and gas facilities were consultant reports for the industry. Their study employs the hedonic model to quantify the impact of oil and gas facilities, particularly "sour" gas production, on residential housing values. They focus on these impacts in Central Alberta, Canada, where "sour" gas is commonly produced and which experienced an expansion in the oil and gas industry at the time. "Sour" gas is gas that contains over one percent of hydrogen sulfide. Residents located near the oil and gas facilities may experience both amenity, and health and safety risks associated with sour gas.

The authors employ a hedonic price analysis with the spatial error model in order to quantify any potential impacts. They use a double log specification as well as two health risk and two amenity specifications. Additionally the authors incorporate spatial dependency into their model using a spatial lag model and a spatial error model. Their study focuses on 30 townships and parts of six others around Calgary, this region has oil and gas facilities ranging in density from sparse to thick. The authors use a dataset of 532 housing transactions, but they do note that their attribute data lacks information on additional buildings, which could detract from the explanatory power of their regressions. Boxall, Chan and McMillan use a four kilometer buffer range around each property in order to determine treatment variables, including the number of natural gas wells within the buffer range and the number of sour gas wells specifically. They established this four kilometer buffer based on evidence from energy experts that it is the maximum range of impact extending from oil and gas facilities. In order to examine the impacts from health risks the authors determine the number of emergency response zones each property is located within, an index representing the possible volume of escaped hydrogen sulfide, and an index for the annual volume of hydrogen sulfide gas flared at flaring oil batteries within four kilometers of each property. Using these treatment variables and methodology the author's results strongly suggest that oil and gas facilities have significant negative impacts on the values of nearby rural residential properties. These negative impacts can reduce property values between four and eight percent. Both amenity and hazard attributes were found to have negative effects. They also find that the sour gas wells have a higher impact than other wells.

Much of the prior literature focuses on examining any negative externalities associated with oil and gas facilities, however Weber (2012) examines the potential positive impacts of the industry. Weber employs a difference-in-difference approach to study the economic gains associated with natural gas booms. In order to fully understand the impacts his data covers a long time period, 1999 to 2008, which attempts to capture all of the economic impacts from initial infrastructure development through the production process and the impact of royalty payments and tax revenue. Weber also uses a large geographic region for the study, including all counties experiencing natural gas booms in Colorado, Wyoming and Texas, resulting in data from 188 counties. Prior to this study previous work employed input-output methodology across an entire state to examine the economic impacts of oil and gas facilities. Weber focuses on regions experiencing natural gas booms and employs a more precise method for examining the economic impacts. Using this methodology Weber finds that the natural gas booms are associated with higher growth in total employment, and wage and salary income. Weber does note that oil and gas production is associated with temporary workers, and this could be an impact not captured within the results. Also, the increased tax revenue from the natural gas boom could provide benefits to residents through reductions in taxes as well as increases in public services.

One piece of literature that employs hedonic methods to estimate the impact of petroleum product storage on property values is Guignet (2013), which estimates the welfare impact of groundwater pollution caused by leaking underground storage tanks. This paper, although not addressing natural gas storage in underground formations, does address the possible negative externalities associated with groundwater contamination from the storage of products such as gasoline. In order to disentangle the price associated with a leaking storage tank as compared to the other amenities and disamenities associated with underground storage tanks Guignet uses home and neighborhood attributes, neighborhood fixed effects, and also uses data on both leaking and non-leaking storage tanks. This study employs a spatial difference-in-difference model using a dataset of 132,840 housing transactions from three Maryland counties from 1996 to 2007. The results of this study indicate that a leaking underground storage tank has little effect on nearby housing values, and this remains the same when the house relies on a private well.

One important contribution of this paper to the literature though is that Guignet uses both proximity and property specific measures of contamination and buyer information. Prior literature primarily uses proximity as a proxy for environmental quality, Guignet hypothesizes that proximity may not be the best measure of environmental quality. In his study he gathers information on which homes had groundwater well tests as well as correspondence from the Maryland Department of Environmental Quality. Using both proximity and the more specific measures of environmental quality Guignet finds that the results vary greatly depending on the measure of environmental quality used. This piece of literature indicates that when information about a household's level of information on a perceived risk or disamenity is available it could be a better measure to use in order to quantify environmental quality. Based on the findings of this literature I use both proximity and a measure for intensity in order to examine the impact of underground natural gas storage on nearby home values.

CHAPTER 3. BACKGROUND

3.1 The Natural Gas Industry

Underground natural gas storage is a key aspect of the natural gas industry. After natural gas is extracted from underground formations containing hydrocarbons, it is processed to remove water and other non-hydrocarbons from the natural gas; it is then transported by pipeline to consumers. Figure 3.1 demonstrates, in general, the steps involved in the natural gas industry, from extraction through consumption. Traditionally demand for natural gas has been seasonal, with peaks in demand occurring in the winter when natural gas is used for heating, but production of natural gas is not seasonal. In order to compensate for the timing differences between supply and demand, the natural gas industry started using underground formations to store excess supplies of natural gas when demand was low for later use when demand is high. As the natural gas industry has evolved the market has discovered more uses for underground storage of natural gas beyond providing a supply during peak demand periods.

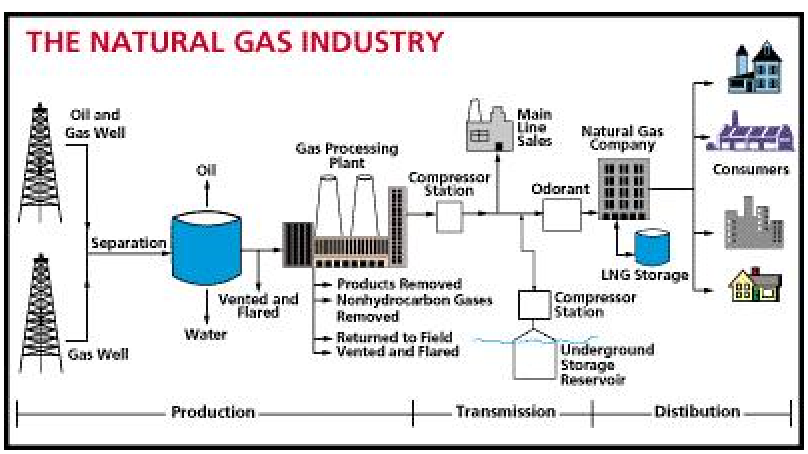


Figure 3.1 The Natural Gas Industry (U.S. Energy Information Administration 2013)

Oil and gas production has been occurring in the United States since the 1800s (Arthur, Bohm and Layne 2008). Underground natural gas storage has been an important aspect in the natural gas industry since the early 1900s (Federal Energy Regulatory Commission 2004). Recent technological advancements in natural gas extraction have made large resources of natural gas contained in unconventional reservoirs economically feasible for extraction. These advancements and increases in production have increased public attention on the natural gas industry as a whole. Both natural gas extraction and underground natural gas storage have amenity and environmental impacts, which can have impacts on homeowner perceptions and on property values.

3.2 Unconventional Natural Gas and Hydraulic Fracturing

Oil and gas reservoirs have been in production throughout the United States since the 1800s. The first natural gas well drilled in the country was in the Devonian Shale, in 1821 (Arthur, Bohm and Layne 2008). Today unconventional gas reservoirs are an important part of energy production. From 1998 to 2008 unconventional natural gas production increased almost 65 percent (Arthur, Bohm and Layne 2008). Shale gas is an important unconventional natural gas resource found throughout the country, and until recent technological advances, extraction of these resources was not economically feasible. The natural gas in shale formations is trapped in tight spaces in the rock, and unlike natural gas reservoirs extracted in the past, the natural gas molecules do not flow through these formations, significantly reducing ease of extraction. Recent advances in the technologies used in natural gas extraction have made these shale gas formations easier and cheaper to extract, and now shale gas is a growing and important economically feasible resource.

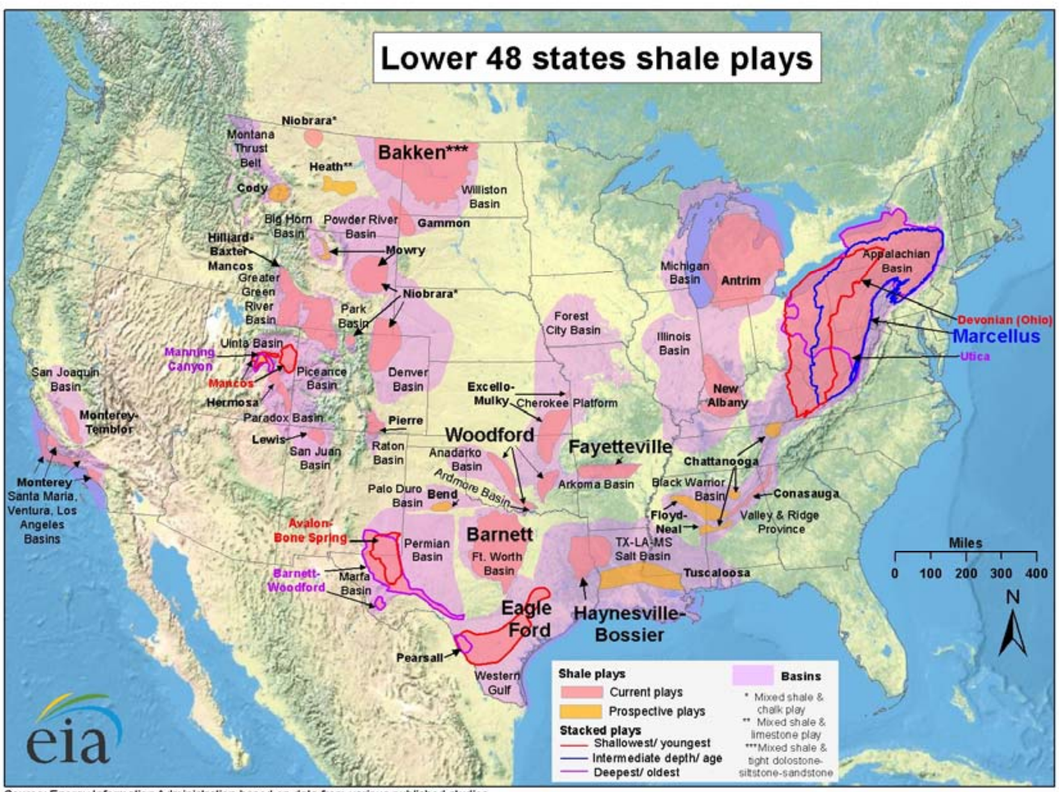
Four technological advances have been essential in making shale gas extraction the fast growing industry it is today. Hydraulic fracturing is the use of highly pressurized fluids in order to stimulate oil and gas reservoirs through the creation of microscopic fractures. Advances in hydraulic fracturing have made well stimulation more efficient and effective. The ability to drill long horizontal fractures have allowed for much greater exposure to the target area. In addition the advancement of “slickwater” fracturing fluids require less power to pump huge volumes of highly pressurized water over the long distances of the horizontal wells. Also, the development of multi-well pads allow for more than one wellbore on a well pad, which increases the ability to access the natural gas resources within the shale formations (Cornell University Cooperative Extension 2011).

Conventional gas reservoirs have gas stored in the pore spaces between the individual grains of the rock. In these wells the pore spaces connect, allowing the fluids to flow more freely. The flow of the gas between pores is an essential aspect of the production of natural gas (Sjolander, et al. n.d.). Horizontal and vertical fractures occur naturally within these formations, which increase the productive ability of these reservoirs. Natural gas wells are drilled into a gas bearing formation with the hope of intersecting the naturally occurring fractures, so that the gas can flow freely into the wellbore and up to the surface.

Unconventional gas reservoirs have gas contained in tight spaces. The hydrocarbons cannot flow through these tight pore spaces. Shale gas is one type of unconventional gas reservoir. These formations have oil and gas bearing rocks, but they have limited natural permeability, even with the occurrence of fractures. The low permeability of shale gas requires the use of stimulation in order to increase the permeability (Sjolander, et al. n.d.). Other types of unconventional reservoirs include tight gas, which produces natural gas from low-porosity sandstones and carbonate reservoirs, and coal bed natural gas, which is produced from coal seams (Groundwater Protection Council and ALL Consulting 2009).

Throughout the United States oil and natural gas are stored in rock formations. Conventional gas reservoirs were the first to be extracted. Now as conventional gas reservoir production is declining, unconventional gas reservoirs are becoming a much more important and productive resource. Shale gas is an important unconventional natural gas resource. The Marcellus Shale alone is estimated to provide 20 years of natural gas supply to the United States (Skone and Booz Allen, Inc 2012). Until recently, shale gas extraction was not economically feasible, but with advances in technology, primarily horizontal drilling and hydraulic fracturing, these resources have become much more viable and productive.

Shale gas reservoirs have been discovered throughout the United States. The largest of these reservoirs are the Marcellus Shale in the Appalachian Basin, which covers 95,000 square miles; the New Albany in the Illinois Basin at 43,500 square miles; the Antrim Shale, covering 12,000 square miles; and the Woodford Shale covering 11,000 square miles (National Energy Technology Laboratory 2011). Figure 3.2 is a map of the largest unconventional reservoirs in the Lower 48 in the United States. The New Albany Shale gas reservoir extends into the southeastern region of Indiana. Production of natural gas has started in the Barnett Shale, the Fayetteville Shale and the Marcellus Shale. Within the state of Indiana exploration is focused on the New Albany Shale (Indiana Geological Survey 2011).



Source: Energy Information Administration based on data from various published studies.
Updated: May 9, 2011

Figure 3.2 Shale Gas Plays of the Lower 48 States (U.S. Energy Information Administration 2011)

These formations are deep below the surface of the Earth, and are far below the base of the treatable water sources. Of the active gas shales in the United States, the Marcellus Shale formation lies 4,000 to 8,500 feet below the surface, the Barnett Shale lies at a depth of 6,500 to 8,500 feet and the Fayetteville Shale lies at 1,000 to 7,000 feet (Arthur, Bohm and Layne 2008). In the New Albany Shale, wells in Harrison County have been drilled at depths of 500 to 1,200 feet and around 2,000 feet in Daviess County (Indiana Geological Survey 2011). The depth to the base of treatable water resources in the Marcellus Shale is about 850 feet, about 1,200 feet in the Barnett Shale and 500 feet in the Fayetteville Shale (Arthur, Bohm and Layne 2008). Between the shale gas formations and the aquifers there are layers of impermeable rock preventing the migration of natural gas into the groundwater resources (Arthur, Bohm and Layne 2008).

The US EIA Annual Energy Outlook for 2012 estimated 187 Tcf of unproved technically recoverable reserves in the Appalachian Basin, the largest basin. The US EIA Annual Energy Outlook for 2012 estimated 11 Tcf of unproved technically recoverable reserves in the Illinois Basin, which includes the New Albany Shale. Unproved technically recoverable reserves refers to the "quantities of oil and gas that can be estimated with reasonable certainty to be commercially recoverable, from a given date forward, from known reservoirs and under current economic conditions, operating methods, and government regulations but have not been proven to exist based on accepted geologic information, such as drilling or other accepted practices" (Penn State Extension 2012). The Annual Energy Outlook also estimated 19 Tcf of unproved technically recoverable reserves in the Fort Worth Basin, 18 Tcf in the Michigan Basin and 10 Tcf in the San Juan Basin. In total the Annual Energy Outlook estimates 482 Tcf of natural gas that is recoverable from shale gas reservoirs in the United States. With these projected quantities of natural gas, shale gas formations are an important factor in the future of energy production in the United States.

Early well development required dynamiting the bottom of a vertical wellbore. Sometimes the release of pressure from these reservoirs pushed the gas to the surface, however, the gas primarily flowed into a cistern. These early wells were plentiful at first, however over time production slowed. In order to increase the production of these wells, producers started using hydraulic fracturing. Hydraulic fracturing was first used in 1947 by the oil and gas industry in order to increase production from the wells. They found that hydraulic fracturing unproductive wells was about half as expensive as drilling a new well (Sjolander, et al. n.d.).

Until the recent technological developments in drilling, wells were all vertically drilled wells. These wells were originally drilled into shallow formations, with the hope of intersecting the natural fractures in the formation, allowing for easy extraction of the hydrocarbons. Over time these vertical wells produce less, especially in unconventional reservoirs, as they can only gather the molecules from the formations nearby. In order to intersect more of the natural fractures in the shale formations, the oil and gas industry developed a method of drilling a horizontal wellbore. To drill horizontally the leading drill pipe is steered in an arc so that the bore turns in a horizontal direction (Sjolander, et al. n.d.). These horizontal wells can have lateral legs that extend over 5,000 feet, all intersecting the layer of shale gas (Sjolander, et al. n.d.). In contrast, in the Marcellus Shale a vertical well may be exposed to as little as 50 feet of the producing formation (Arthur, Bohm and Layne 2008). Figure 3.3 depicts the differences between the wellbores of a conventional well and an unconventional well, as well as some of the differences between the general geologic characteristics of unconventional and conventional oil and gas sources.

Now, unconventional shale formations are an economically feasible source of natural gas. Four advances in extraction methods made this possible: hydraulic fracturing, horizontal drilling, advances in fracturing fluids, and multi-well pads. Hydraulic fracturing aids in stimulating the natural gas formations. Hydraulic fracturing started as early as the 1900s, using foam fluid. Foam fluid is a nitrogen-based foam combined with some water, which is highly pressurized; this method uses the nitrogen bubbles in the foam to stimulate the formation (Virginia Department of Mines Minerals and Energy 2006). Horizontal drilling allows for long lateral wellbores, which access much more of the thin layer of shale gas.

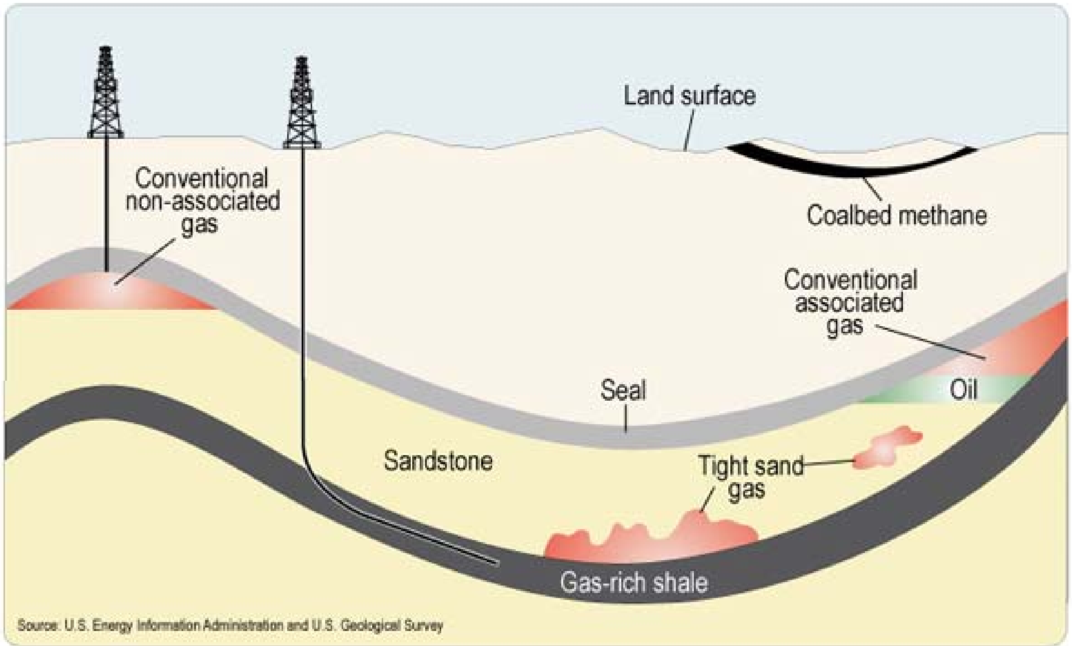


Figure 3.3 Schematic Geology of Natural Gas Resources (U.S. Energy Information Administration 2012c)

Various advances in the types of fluids used in hydraulic fracturing were made during the 1980s through the 1990s, including cross-linked fracturing fluids, which can carry more propping agent, like sand, to prop open the microscopic fractures created during hydraulic fracturing. Slickwater fracturing fluids can reduce the amount of power required to pump large volumes of water and propping agent into the well over long distances and at high pressures, multi-stage slickwater fracturing also increases the amount of propping agent delivered deep into each fracture. All of these advances in hydraulic fracturing increase the ability to create and preserve the microscopic fractures that allow the hydrocarbon molecules to pass out of the shale formation and into the wellbore. In addition the advancement of multi-well pads allow for multiple wellbores on a single pad, which increases access to the gas inventory. These multi-well pads also reduce impacts on the environment and visual impacts of the well pad, by decreasing surface disturbances, less well pads are needed to access the natural gas. The first use of multi-well pads and cluster drilling occurred in 2007 (Cornell University Cooperative Extension 2011).

All of these technologies are essential in making extraction of natural gas from shale formations economically feasible. Today all of these technologies come together to make productive natural gas wells in the United States. The process is highly scientific and is designed differently for each target area. Computer simulation and modeling are used to develop specifications for the volume of fluid used as well as the quantity and type of proppant, the material used to prevent the newly created fractures from closing due to the extreme pressure at that depth below the ground, used in order to optimize the production of natural gas. This process involves analyzing the characteristics of the formation including the depth, porosity, thermal maturity, as well as looking at past drilling operations (Pennsylvania Department of Environmental Protection n.d.).

A well consists of several layers of protective casings. These casings are constructed with steel pipe and cement. Each layer progresses deeper into the wellbore and adds protection for sources of groundwater from sources of contamination. The initial layer is called the “drive pipe” which is installed after the well is drilled and it prevents the wellbore from caving in (Pennsylvania Department of Environmental Protection n.d.). Each subsequent casing has a smaller diameter; the space between the steel pipe and the outer casing is filled with cement all the way to the surface as an added source of protection. Every layer of casing is designed specifically to protect groundwater resources from the natural gas in the formations below, and also isolate any sources of coal from the wellbore (Pennsylvania Department of Environmental Protection n.d.). The final and innermost casing is called the “production string,” which is installed at the production interval, or the zone where the natural gas bearing formation occurs. This pipe is used to transport the hydrocarbons extracted from the production zone to the surface for collection. This innermost layer, or the production interval can extend up to several hundred feet in a vertical well, and up to several thousand feet in a horizontal well, and this production interval is the deepest part of the wellbore (Pennsylvania Department of Environmental Protection n.d.). All of the casing strings must be installed before any hydraulic fracturing operations can begin.

3.3 Risks of Natural Gas Extraction

Natural gas extraction, like any other form of resource extraction, poses certain environmental risks and causes certain impacts, both positive and negative. Hydraulic fracturing and horizontal drilling pose a different set of risks than methods used in more conventional natural gas extraction. The extensive use of water in hydraulic fracturing poses special environmental risks for operators of shale gas wells. Beyond the protection of groundwater during the drilling, hydraulic fracturing also requires the disposal of the contaminated flowback that comes back up from the well after the hydraulic fracturing process. In addition, shale gas extraction can also pose risks of air pollution, accidents and spills, deterioration of local infrastructure, and more.

One of the primary environmental concerns associated with natural gas extraction and especially shale gas extraction that requires hydraulic fracturing is the prevention of ground and surface water contamination. Contamination of this kind can occur through many avenues in the extraction process. The first step in the extraction process is the drilling of the well. In order to drill through the many layers of rock, deep into the shale that is the production zone, the drill bits must be lubricated. In addition the cuttings along with mud are transported back to the surface. The drill cuttings and mud often contain certain amounts of diesel, heavy metals, mineral oils and synthetic alternatives, and acids. Through this process there is a risk that the contamination will leak into nearby groundwater sources, posing environmental as well as health risks for those that use the water (Muehlenbachs, Spiller and Timmins 2012).

Any penetration of a groundwater source poses risks for contamination. Horizontal wells aid in the mitigation of this risk. A horizontal well intersects with a much larger region of the production formation, compared to traditional vertical wells. This means that fewer wells are required to extract the same quantity of gas, and there are fewer instances of wells penetrating the shallow aquifers that supply drinking water. Horizontal wells also allow for multiple wellbores from one well pad, this also decreases the risk of groundwater contamination. One of the most important methods that well operators use in order to decrease the risk of groundwater contamination is to install well casings and cement down the entire wellbore and have added casings in the zones that are particularly sensitive (Grubert and Kitasei 2010).

The improper or faulty installation of a well casing or cement can also pose risks for groundwater contamination (Gopalakrishnan and Klaiber 2014). Deep shale gas formations have natural layers of rock considered to be impermeable that protect the groundwater resources above from the hydrocarbons and other harmful chemicals trapped in the tight shale formations (Arthur, Bohm and Layne 2008). In order to prevent contamination of groundwater resources when a well is drilled through these protective layers, a system of casings and cement are installed. These casings, especially those at the upper stages of the well are essential in protecting groundwater resources from the variety of substances that come out of a natural gas well. If a casing is improperly installed the flowback and produced water can contaminate groundwater resources as they return to the surface through the wells (Moniz, Jacoby and Meggs 2010).

Another risk from the improper installation of well casings is leakage of methane into groundwater sources as well as the fluid migration. Methane is naturally occurring in many rock formations underground, and it is possible that methane could migrate through the shale formation. The methane gases coming from sources in the production formation differ in composition than those in the layers closer to the shallow aquifers, which allows scientists to determine the approximate depth of the source. Osborne, et al. in their 2011 study found increased contamination from methane occurring in the deep rock formations in groundwater sources in Pennsylvania. Although the study does not prove causality, there is a strong possibility that the methane leakage could come from leaky well casings. The methane contamination could also come in part from the methane traveling through the natural horizontal and vertical fractures, which were also stimulated through the hydraulic fracturing process and could possibly create greater connectivity to the layers above (Osborn, et al. 2011).

The process of natural gas extraction can also release fluids known as “formation water” (Grubert and Kitasei 2010). Formation water is the water that has been trapped inside the reservoir rock for millions of years. This water is contaminated with heavy metals, salts and even Naturally Occurring Radioactive Materials (NORM). Formation water returns to the surface in different quantities depending on the depth of the producing formation, however no matter what the quantity of this formation water, it still poses a risk for groundwater contamination (Gopalakrishnan and Klaiber 2014).

In addition to the formation water, hydraulic fracturing also produces flowback water. Flowback water, combined with formation water creates the wastewater that well operators must treat or recycle. Hydraulic fracturing requires from two to eight million gallons of water, and between 10 and 40 percent of the water returns to the surface within the first 30 days of production (Gopalakrishnan and Klaiber 2014). These quantities of wastewater pose one of the biggest challenges for well operators as well as government and residents. Improper well casings pose the potential for groundwater contamination from the flowback water.

Even if the well casings are entirely secure, wastewater remains an important issue for the safe extraction of shale gas. The wastewater is first collected and stored onsite, either in storage tanks or ponds. If these storage methods fail, there is a potential for the contamination of surface water sources. After the wastewater is stored, it must be disposed of and well operators have a variety of options. One of these is to inject the wastewater into deep injection wells. Well operators can also treat the water onsite, so that it can be reused in the hydraulic fracturing process. However, onsite treatment can be expensive for the operator and it still poses certain risks for surface water contamination. Wastewater can also be treated in surface evaporation ponds. There is limited geographic space for evaporation ponds and they also pose environmental risks of surface water contamination. Finally flowback water can also be treated at municipal or special treatment plants.

The element of accident is also always present in the extraction of natural gas. Natural gas wells are subject to accidents. There can be blowouts, as well as improper well construction, which can lead to water contamination (Grubert and Kitasei 2010). Blowouts can be caused by unexpected high-pressure gas, which is accompanied by large releases of gas or polluted water. Improperly constructed well casings can allow contaminants to leak into nearby sources of water (Muehlenbachs, Spiller and Timmins 2012). Throughout the process of constructing and extracting the natural gas from a shale gas well there are possibilities for accidents and spills, which present a risk for contaminating surface water sources, which is both an environmental and health risk.

Surface water is not only contaminated through spills and accidents, it is also impacted through the surface activities required for natural gas extraction. There are a wide range of surface activities that can impact these water resources. Transportation activities can stress nearby stream banks, which can contribute to erosion and add sediments to surface water. The transportation needs of hydraulic fracturing include truck traffic from the construction of the well pad, as well as industrial activity, and even trucking water into and out of the site, all of these activities add stress to the road system (Grubert and Kitasei 2010). There are methods that can be used to mitigate certain amounts of this damage, which can be dramatic due to the sheer amount of surface activity required for natural gas extraction. Road planning and reducing truck traffic can help protect stream banks, and prevent some erosion (Grubert and Kitasei 2010).

Water quantity is another important environmental risk from the extraction of shale gas resources. Natural gas extraction, hydraulic fracturing in particular, requires large quantities of water. An unconventional well can use between one and nine million gallons of water during the hydraulic fracturing process (Pennsylvania Department of Environmental Protection n.d.). The quantity of water required depends on the number of fracturing stages required for the well (Arthur, Bohm and Layne 2008). Water availability is an especially pertinent issue when stream flow is low. In times when stream flows are low even small withdrawals can have an impact on the aquatic life of the region (Grubert and Kitasei 2010).

Another environmental risk posed by natural gas extraction is air pollution. The process of natural gas extraction can lead to escaped gases, including nitrous oxides and volatile organic compounds (VOCs). Combined, these create ozone. In addition natural gas extraction can also release other hazardous air pollutants, including methane and greenhouse gases (Muehlenbachs, Spiller and Timmins 2012). Air pollution is an issue throughout the process of extraction through the processing and power generation of natural gas (Grubert and Kitasei 2010).

Overall, with the disturbance from the well pads, the new roads and pipelines involved in the process of natural gas can result in dramatic impact on the landscape. These landscape impacts can have significant impacts on the region's ecosystem, particularly the flora and fauna (Slonecker, et al. 2012). Not only do landscape disturbances pose environmental risks and even some health risks from stream contamination, but they also create negative community impacts. Road damage, noise and visual disturbances are all impacts to the community from the process of extracting natural gas from shale formations.

3.4 Underground Natural Gas Storage

The first use of an underground storage well in a depleted reservoir was in Welland County, Ontario, Canada in 1915. The following year operations began at the first facility in the United States, near Buffalo, New York in the Zoar field (Federal Energy Regulatory Commission 2004). There were nine facilities across six U.S. states by 1930 and after World War II storage gained even more popularity. However, prior to 1950 almost all of the natural gas storage facilities were located in depleted natural gas reservoirs (Storage of Natural Gas 2014). The US EIA divides the Lower 48 states into three regions regarding natural gas storage, the West, the East and the Producing Region. Figure 3.4 shows how natural gas storage is distributed throughout the United States, with depleted natural gas reservoir storage facilities spread across the United States, salt caverns concentrated in the Gulf Coast, and aquifers concentrated in the Upper Midwest. Although the Gulf Coast and south is considered the "Producing Region," the recent technological advances in extracting unconventional natural gas resources allow for the production of natural gas in all three regions (U.S. Energy Information Administration 2014).

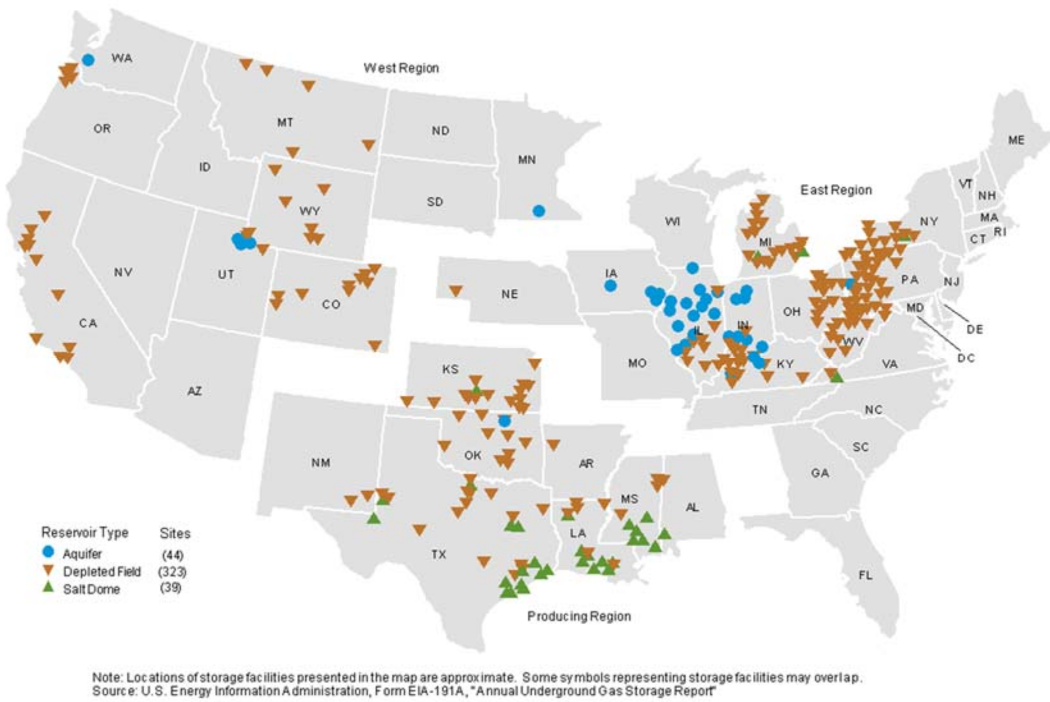


Figure 3.4 U.S. Lower-48 States Active Underground Natural Gas Storage Facilities, by Type (December 31, 2012) (U.S. Energy Information Administration 2012d)

According to the US EIA, total underground storage capacity in the United States was 8,991,335 Million cubic feet in 2012. This figure represents the "present developed maximum operating capacity" (U.S. Energy Information Administration n.d.). Total storage capacity was 8,402,216 Million cubic feet. In 2013 storage capacity increased by two percent, with these gains concentrated in the West and the Producing regions. Total storage capacity in Indiana decreased from 114,294 Million cubic feet in 2007 to 110,749 Million cubic feet in 2012 (U.S. Energy Information Administration 2014). According to the US EIA's Form EIA-191 data from 2012, there were 21 underground natural gas storage wells in Indiana. These wells are operated by seven companies and are located in 14 counties across Indiana. Ten of the total storage fields are depleted natural gas reservoir type storage and the remaining 11 storage fields are aquifer type storage. In total they report a working gas capacity of 31,042,061 Million cubic feet, a total field capacity of 105,960,920 Million cubic feet and a maximum daily delivery of 703,782 Million cubic feet (U.S. Energy Information Administration 2012b).

Certain geologic characteristics are required for an underground formation to be suitable for natural gas storage. In order for an underground formation to be suitable for natural gas storage it must have a layer of porous and permeable rock where the natural gas is stored and an “entrapment” or a layer of impermeable rock that stops the migration of the natural gas out of the porous rock layer (Dawson and Carpenter 1963). There are three types of geologic formations commonly used for natural gas storage: depleted natural gas reservoirs, aquifers and salt caverns. Each of these types of underground formations have differing geologic characteristics, which impact the capacity and deliverability of the storage facility. Figure 3.5 shows the very basic differences between the three types of underground storage facilities. Deliverability is the amount of natural gas that can be withdrawn from the facility each day (U.S. Energy Information Administration 2004). A formation is chosen for development into an underground storage facility based on the geography of the formation and its geology. Storage facilities need to be located near to a market and they must be located near transportation infrastructure, so the natural gas can be withdrawn from storage and transported to consumers. Additionally, an underground storage facility chosen for storage must be porous enough to hold quantities of natural gas. It must also be permeable enough to allow the hydrocarbons to be withdrawn from the formation (Storage of Natural Gas 2014).

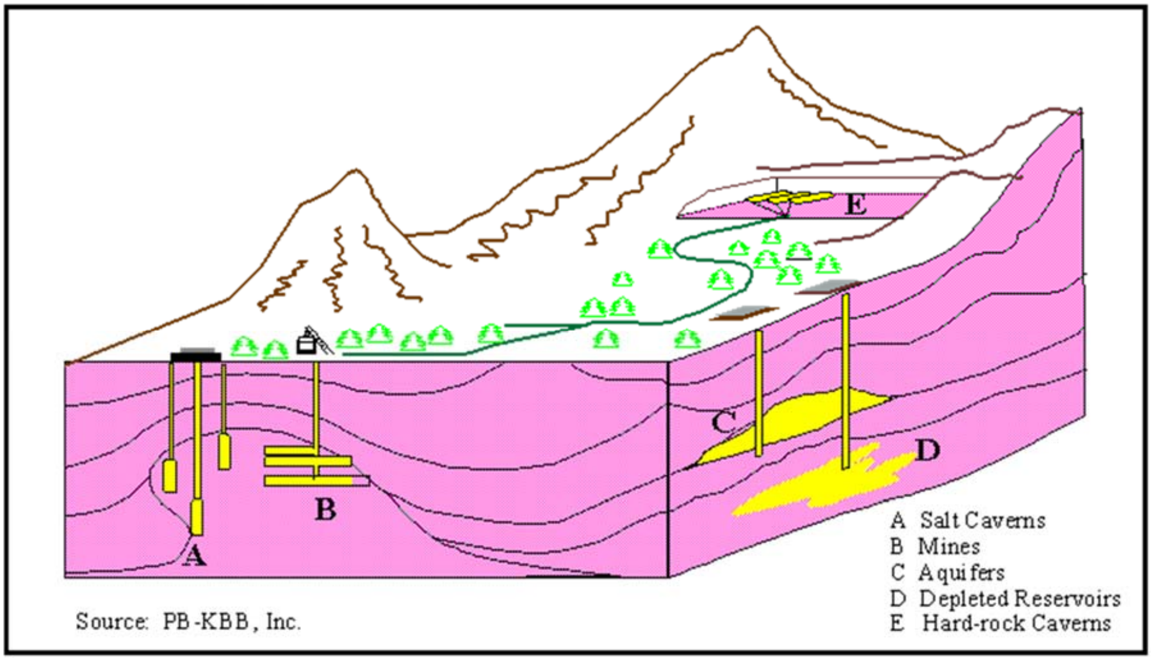
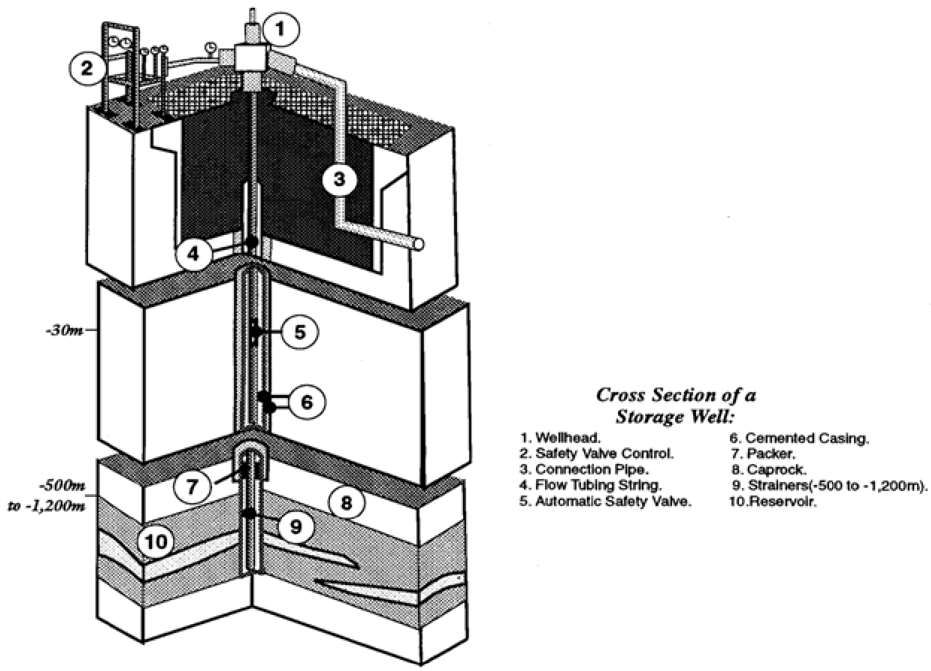


Figure 3.5 Types of Underground Natural Gas Storage Facilities (U.S. Energy Information Administration 2004)

Once a formation is chosen for storage it is reconditioned for use as a storage facility. In addition to setting up the underground formation for use as a storage facility certain aboveground equipment must be installed in order to operate the storage facility. A storage facility requires wells for injection and withdrawal, as well as wells for observation and possibly wells for water supply and disposal. Wells include wellhead valve assemblies. Other equipment can include gathering lines, metering facilities, compression facilities, dehydration units and generators or transformers (Federal Energy Regulatory Commission 2013). Once the underground storage formation is ready for use and the required equipment has been installed the gas is injected into the formation through a wellhead, which builds pressure within the formation as natural gas is added. This pressure is required in order to allow for the extraction of the gas at a later time. Because pressure is required for the withdrawal of the natural gas, in an underground storage field there is a certain amount of gas that can never be extracted, called “cushion” gas (Storage of Natural Gas 2014). The gas contained within the storage field that is available to be extracted is called “working” gas. Each type of storage well has different proportions of “working” gas and “cushion” gas, which depends on the geology of the formation, the facility equipment and operations (U.S. Energy Information Administration 2004).

The most common type of underground formation used for storage are depleted natural gas or oil reservoirs (U.S. Energy Information Administration 2004). Figure 3.6 is an image of the typical depleted reservoir wellbore, including the surface valve assemblies. Depleted reservoirs have several benefits. Developing an underground storage reservoir requires knowledge of the geological conditions, which usually can only be obtained through subsurface testing. In the case of depleted reservoirs this information is already readily available, from the records of the holes drilled during the period of production (Dawson and Carpenter 1963). Since these formations have already held natural gas, they are known to be capable of storage and the geological characteristics of the formation are well known, which can reduce operating costs. Additionally, depleted reservoirs also already have equipment in place from the prior extraction activities, so the storage operator can use the equipment already in place, also reducing the cost of converting the formation for use as a storage facility (Storage of Natural Gas 2014).

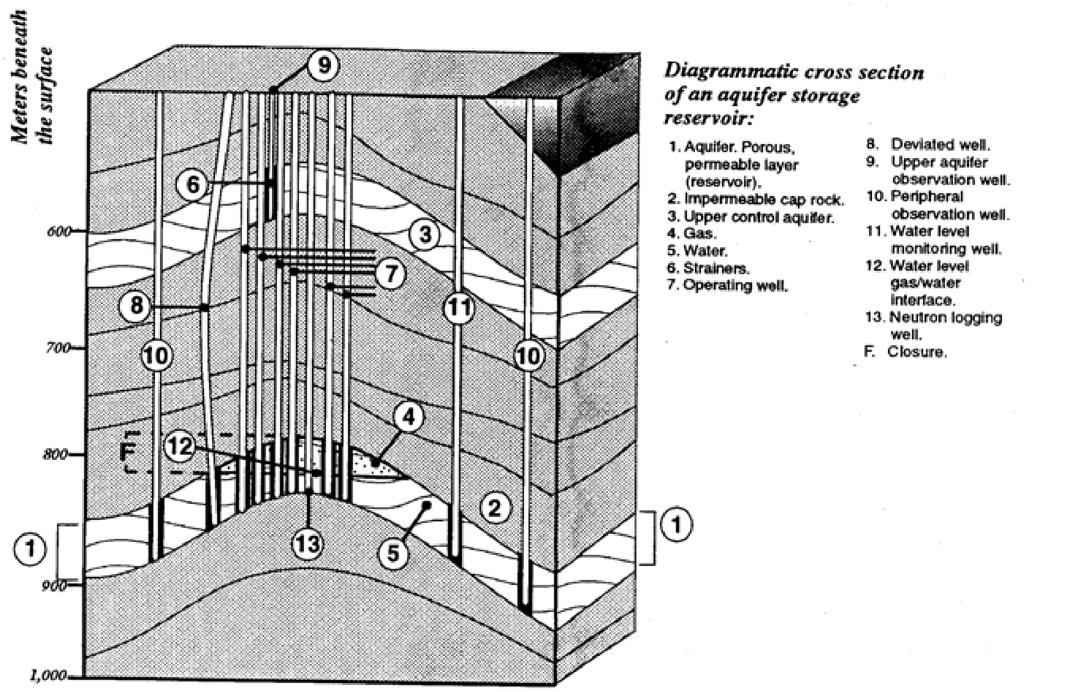
A typical depleted reservoir storage field requires about 50 percent cushion gas (Federal Energy Regulatory Commission 2004). They also have an injection-withdrawal cycle that takes a year. The typical injection period lasts from April through October, and the withdrawal period lasts from November to March. Due to the low deliverability of these types of facilities, or the low amount of natural gas that can be extracted daily, they are used to meet long-term seasonal demand (Storage of Natural Gas 2014).



Source: Gaz de France, "Underground Storages Facilities" (June 1992): Recreated by Energy Information Administration, Office of Planning Management, and Information Services.

Figure 3.6 Depleted Reservoir Storage Well Cross Section (U.S. Energy Information Administration 2008b)

Aquifers are another option for underground natural gas storage. Like a natural gas reservoir, an aquifer is an underground porous rock formation that holds water instead of natural gas. Some of these types of formations can be reconditioned for use as a natural gas storage facility. Figure 3.7 shows a cross section of the typical wellbore for an aquifer storage field. Aquifer storage fields are more expensive to develop than depleted reservoirs. There is less previously collected information on the geological attributes of the formation and the collection of this information can be costly. Additionally, some information on the characteristics of the formation can only be learned after further development of the storage facility. All of the infrastructure for the storage facility operations must also be developed, since there is no previously installed equipment (Storage of Natural Gas 2014).



Source: Gaz de France, "Underground Storages Facilities" (June 1992): Recreated by Energy Information Administration, Office of Planning, Management, and Information Services.

Figure 3.7 Aquifer Storage Well Cross Section (U.S. Energy Information Administration 2008a)

Since an aquifer also already contains water, more pressure is required to inject the natural gas, as the gas must displace the water, which requires more specialized equipment. Additionally, the presence of water in the formation can also mean that the already processed natural gas that was injected into the formation requires further processing once it is removed from the storage facility. Due to the presence of water in the aquifer there are also increased regulations from the United States Environmental Protection Agency to prevent any groundwater contamination, and the unique geology of an aquifer can pose an increase in risk of migration, or the gas moving out of the designated storage formation into other strata of the subsurface (Storage of Natural Gas 2014). Migration of the natural gas not only increases risk of contamination, but it also presents a risk for losses in supply.

An aquifer storage facility is typically used to meet long-term storage demands like depleted reservoir storage facilities and generally have the same injection and withdrawal cycle. However, they require a larger percentage of cushion gas, which can range from 50 to 80 percent. Altogether the many characteristics of an aquifer mean that they are much more costly to develop than a depleted reservoir and are a much less desirable option. There are some regions in the United States where there are relatively few options for depleted reservoir storage fields, particularly the Upper Midwest.

The third and final type of underground natural gas storage formation are salt caverns. Salt caverns are developed from salt dome formations or bedded salt formations (U.S. Energy Information Administration 2004). A salt dome is a very thick underground formation that is created by natural salt deposits, which through a natural leaching process has a structure similar to a dome. A salt bed is a thinner and wider salt deposit formation, which is typically less desirable than a salt dome for development into an underground natural gas storage facility. In order to recondition a salt dome or bed into a salt cavern a process called "salt cavern leaching" is undertaken. In this process certain amounts of the salt deposit are dissolved and removed from the formation, which leaves behind a cavern (Storage of Natural Gas 2014).

Salt caverns have high development costs, due to the process of salt cavern leaching, which includes costly brine disposal (Federal Energy Regulatory Commission 2004). However, they are a high deliverability type of facility, and most recent increases in storage have occurred in this type of storage field (U.S. Energy Information Administration 2014). High deliverability storage facilities have much shorter injection and withdrawal cycles, with gas being available within an hours notice, making them ideal for emergency and peak load situations (Storage of Natural Gas 2014). Due to increases in natural gas fired electricity generation and the changes in regulation, high deliverability storage sites are highly desirable (U.S. Energy Information Administration 2004). They are typically much smaller in capacity than the average depleted reservoir storage facility, which makes them unsuitable to meet long-term seasonal demands (Storage of Natural Gas 2014). In addition to being high deliverability they require a much lower percentage of cushion gas than either depleted reservoir or aquifer storage facilities, ranging from 20 to 30 percent (Federal Energy Regulatory Commission 2004). Salt caverns also have very strong walls that reduce degradation of the reservoir. They also allow very little escape of gas once injected. Most salt cavern storage facilities are located in the Gulf Coast region (U.S. Energy Information Administration 2004).

Developing any underground natural gas storage project is a costly investment. Investment in cushion gas is one of the most costly aspects of developing a storage project (Federal Energy Regulatory Commission 2004). When natural gas prices are low storage projects that require larger investment in cushion gas become more desirable, like aquifer type storage facilities (Storage of Natural Gas 2014). New advances in technology allow for owners and operators of underground natural gas storage fields to reengineer existing storage fields in order to increase the proportion of working gas to cushion gas within the facility. This allows for the expansion of underground natural gas storage without the considerable investment required for developing an entirely new storage facility (Federal Energy Regulatory Commission 2004). While natural gas production has increased dramatically in the past few years, there has not been a similar increase in underground natural gas storage during the same time period. However, given the size of the investment required for a new underground storage project, it is possible that an increase in storage could follow in time. Investors may take some time before deciding to make the investment, especially given the discussion on the benefits and costs of exporting natural gas, which can be seen in the work of Tyner and Sarica (2013).

3.5 Underground Natural Gas Storage Operation and Regulation

Today, underground natural gas storage is used for more than just meeting seasonal demand. With the increase in natural gas fired electricity generation there is an increase in demand for natural gas in the summer. Underground storage also provides insurance against any unexpected events that could disrupt supply (Storage of Natural Gas 2014). A change in Federal Energy Regulatory Commission regulations in 1994 required all interstate pipeline companies under their jurisdiction to operate in "open access". Open access means that the interstate pipeline companies still control the portion of the working gas capacity required to maintain their pipelines and storage facilities, but a large portion of their working gas capacity must be available to third parties for leasing. Prior to this change in regulation the interstate pipeline companies had complete control over the working gas capacity in their pipelines and storage facilities (U.S. Energy Information Administration 2004). This change in regulation allowed more actors to participate in the industry and allows actors in the industry to use natural gas for commercial purposes, withdrawing natural gas when the prices are high and injecting gas when the prices are low (Storage of Natural Gas 2014).

After the natural gas storage industry became open access the variety of owners and operators increased. There are four primary types of owners and operators of natural gas storage facilities: interstate pipeline companies, intrastate pipeline companies, local distribution companies, and independent storage providers. The open access regulation means that now the owners and operators do not necessarily own all of the natural gas within their storage facility, in fact most of the working gas in storage facilities is under lease. Interstate pipeline companies use natural gas storage to balance differences in the timing of supply and demand of natural gas (U.S. Energy Information Administration 2004), and to keep their pipelines filled in order to operate at maximum efficiency (Dawson and Carpenter 1963). Intrastate pipeline companies use natural gas storage for similar purposes as interstate pipeline companies, however they also serve end-use customers. Both interstate and intrastate pipeline companies lease a large portion of their storage capacity to other industry participants. Local distribution companies serve the natural gas needs of local customers and use storage facilities to serve this purpose. They have also been able to use storage capacity for lease to third parties, which are often marketers (U.S. Energy Information Administration 2004).

Any owner or operator that is involved in interstate commerce is under the jurisdiction of the Federal Energy Regulatory Commission. This regulatory agency approves the location, construction and operation of any storage field to be involved in interstate commerce. All other owners and operators are under the jurisdiction of the state regulatory agency in the state where their operations are located (Federal Energy Regulatory Commission 2013). In the state of Indiana, the Department of Natural

Resources regulates underground natural gas storage owners and operators (Indiana Department of Natural Resources n.d.b).

The Department of Natural Resources Division of Oil and Gas is the specific division that administers rules and regulations relating to the production of petroleum products. The Division of Oil and Gas was established in 1947. They have the responsibility for regulating the activities relating to the exploration and production of petroleum products, including permitting, drilling, completion, production, plugging, and abandonment activities. Underground natural gas storage facilities are considered Class II injection wells and the Division of Oil and Gas administers the specific regulations for these types of wells (Indiana Department of Natural Resources n.d.b). Class II injection wells are wells that inject fluids, which can refer to well stimulation or underground natural gas storage. The Division of Oil and Gas regulate the permitting of Class II injection wells, the exempting of aquifers for use as an underground storage facility, operating requirements for Class II injection wells and monitoring and reporting requirements for Class II injection wells (Article 16. Oil and Gas 2014).

Underground natural gas storage facilities must make certain agreements with landowners impacted by their activities, similar to those made for the exploration and production of natural gas. When a company interested in developing underground natural gas storage files an application with the Federal Energy Regulatory Commission they must also notify any landowner that could be impacted by the activity. This includes all landowners located above the geologic formation intended for natural gas storage (Federal Energy Regulatory Commission 2013). The size and location of any underground storage field is determined by the geologic formation, and these formations can encompass hundreds or even thousands of acres underground. In addition to notifying impacted landowners the pre-filing process required by the Federal Energy Regulatory Commission includes a program of community outreach, which includes open houses and other processes to notify all stakeholders of the project and gather input regarding the project from all stakeholders (Federal Energy Regulatory Commission 2012). The Indiana Department of Natural Resources does not require public notice upon the filing of a permit application for an underground natural gas storage facility, for those facilities not under the jurisdiction of the Federal Energy Regulatory Commission (Indiana Department of Natural Resources n.d.c).

Owners and operators of storage facilities must obtain at the very least the mineral rights to the underground storage facility. In the case when the owner or operator does not own the mineral rights for the underground formation they must establish a storage lease or easement agreement with the owners of the mineral rights. A previous landowner can attach a storage lease or agreement to a land deed and in the case of a property sale or transfer of ownership a new property owner can receive compensation for use. In the case where some surface facilities are necessary the company must also obtain a lease or easement for access to these facilities. In the case that a landowner and the storage company cannot come to an agreement regarding either mineral rights or surface access the company can go to court, and in some cases the court can grant the company the ability to access these rights through eminent domain (Federal Energy Regulatory Commission 2013).

3.6 Impacts of Underground Natural Gas Storage

Much of an underground storage field is located underground and does not require surface facilities on every property, therefore landowners may have very little visual impact due to the presence of an underground storage facility. However, the storage company may have reserved rights of access in order to conduct any necessary monitoring activities. In the cases where there are surface facilities, these landowners will have an agreement with the storage company involving compensation for the use of the land. These landowners will also see more visual impact due to the storage facility. In addition to some visual impacts, landowners with compression stations on their property or even landowners located near a compression station may experience some noise impacts. The Federal Energy Regulatory Commission does have rules regarding acceptable noise levels. In the case of new or modified compression stations the noise level cannot exceed an average level of 55 decibels at any “pre-existing noise sensitive area” (Federal Energy Regulatory Commission 2013). A noise sensitive area includes areas with schools, hospitals or residences (Federal Energy Regulatory Commission 2013).

Beyond the noise and visual impacts related to underground natural gas storage, there are other potential environmental issues associated with underground natural gas storage. Natural gas storage poses some risk of migration – i.e., leakage of natural gas from the underground formation. When an underground storage formation is developed it is important for the owners or operators to conduct a thorough analysis of the formation itself and any previously drilled wells. It is possible that natural gas can migrate out of the formation vertically through existing wells. In the event that a well is leaking, especially in an urban area or where homes are located, the natural gas can pose a risk to homeowners through the accumulation of natural gas within homes (Miyazaki 2009).

Over time wells and abandoned wells can degrade, and age can increase the risks of failure in wellheads, increasing risks for migration of the natural gas through these pathways (Miyazaki 2009). Federal and state agencies have specific requirements for the construction of natural gas wells. There are also regulations for the abandonment and plugging of wells. These regulations are designed to protect formations above the natural gas storage well from contamination, including sources of groundwater. Despite these regulations well casings can corrode over time. The corrosion of well casings can lead to natural gas migration and it can also lead to the migration of brines from deeper formations into shallower ones (Rupp 2011). This type of migration of natural gas and even brines can pose a risk to sources of groundwater. It is possible for natural gas to migrate out of the portion of an underground storage formation that is designated as a storage facility.

There are several examples of wellhead or well casing failure, leakage, and natural gas migration in recent years, cited by Miyazaki (2009). In Colorado, a property owner filed a lawsuit against an underground storage facility in 1998, claiming that a groundwater aquifer was contaminated by the storage facility. The natural gas had not actually migrated out of the property included within the underground storage facility, but some quantities of natural gas were discovered in the aquifer. As a result of this lawsuit the storage facility was decommissioned. The more extreme cases of migration and risk are linked to salt cavern type storage facilities. One example occurred in Texas in 2004, in which well casing failure caused an explosion, which led to a second explosion and as a result the loss of between 30 and 60 million dollars of gas, and the temporary evacuation of nearby residents (Miyazaki 2009). The consequences of events like these can range from financial losses to the storage operator and local business, to the evacuation of nearby residents, and even fatalities. Beyond the damage to companies and residents there are also environmental consequences of these events, including soil and groundwater contamination (Miyazaki 2009). Although salt cavern underground natural gas storage facilities have had more severe examples of failure in recent years, any negative attention on the risks to nearby residents due to underground natural gas storage fields can increase risk perceptions for homeowners located near one of these facilities, even those that are not salt cavern storage facilities.

When the working gas in an underground storage facility is not recycled properly it can move from the higher-pressure areas to lower pressure areas of the formation. When this occurs there is the chance for loss of the natural gas, which increases the cost for the owners and operators of the underground storage facility (Federal Energy Regulatory Commission 2004). In addition to the potential for losses, this type of migration can pose risks to other underground formations, including sources of groundwater. Aquifer storage facilities sometimes have different geological characteristics that can at times lead to poorer retention of natural gas than other types of storage facilities. Owners and operators of natural gas storage facilities with these types of characteristics must install more wells in order to collect any natural gas that migrates out of the formation (Storage of Natural Gas 2014). As there is the risk of loss due to migration, there is the potential for any natural gas that escapes collection to pose a risk for contamination.

Methane emissions are another environmental risk associated with natural gas storage. This methane can potentially come from "off-gassing" from the wellhead or from emissions from the compressor stations (U.S. Environmental Protection Agency 2013). In addition to methane emissions, methane from oil and natural gas formations can contaminate water wells. Methane in water wells can be hazardous. Although it is not explosive when dissolved in water, when exposed to the air methane in groundwater can become hazardous, especially in confined spaces. When methane is in concentrations between five and 15 percent it can be ignited by as little as a nearby electrical outlet. Homeowners relying on well water can educate themselves on the signs of methane in their well water, which include bubbling noises in the well and gas bubbles in the water. Although there are no established federal and state water quality standards for methane in drinking water there are recommendations for safe levels of methane in the water. If a homeowner discovers concentrations in excess of 28 milligrams per liter they should contact their local health department. Homeowners also have options for removing methane from their well, wells can be vented to reduce methane in the water or for more extreme situations homeowners can have aeration systems installed (Indiana Department of Natural Resources n.d.a).

Underground natural gas storage poses a possibility of a variety of sources of groundwater contamination, including brine from deep levels of the subsurface and methane. Homeowners with access to a public water system are not at as high of a risk for these types of hazards. Federal and state laws require that providers of public drinking water have a schedule for monitoring and reporting to their state department, in Indiana this is the Department of Environmental Management. The U.S. Environmental Protection Agency sets standards for acceptable levels of contaminants as mandated by the Safe Drinking Water Act. The Safe Drinking Water Act regulates any public water system that serves greater than 25 people, and the State of Indiana is responsible for enforcing these regulations. When a violation of these regulations occurs, the water provider is required to send out a public notice of the violation. These federal and state regulations are in place to protect the public from instances of dangerous water contamination (Indiana Department of Environmental Management n.d.). Households that receive water from a source that serves less than 25 people do not have the same level of protections established by regulations. Water received from these systems does not have the same level of testing requirements.

CHAPTER 4. METHODOLOGY

The hedonic pricing framework provides a method for measuring externalities, or in fact any type of attribute that is not traded in a market, by virtue of breaking a house into the many attributes that a consumer considers when making a purchasing decision. These attributes can include qualities that are not traded in their own market, attributes like air quality, water quality, noise, or the perception of risk from proximity to an underground natural gas storage facility. According to Rosen (1974) the hedonic hypothesis is that "goods are valued for their utility-bearing attributes or characteristics." Using this hypothesis and theoretical framework combined with quasi-experimental methods, or the collection of observed prices and attributes, it is possible to recover an estimate of a consumer's marginal willingness to pay for individual attributes included in the hedonic price function.

Although not the first to use the hedonic price model, Rosen (1974) first standardized the use of the hedonic price model to determine a consumer's marginal willingness to pay for the attributes of a property. Rosen's model provides the traditional theory used in hedonic price models, and the associated assumptions for these models. Houses are not a homogeneous product; they are in fact a group of attributes, or a bundle of attributes. Within the housing market there are a wide variety of combinations of these bundles of attributes, therefore the market for houses is a differentiated product market (Parmeter and Pope 2012). The hedonic price model assumes competitive equilibrium; in which consumers and producers interact to each maximize their wellbeing within the differentiated product market.

There are four essential assumptions in the traditional hedonic price model. First, buyers and sellers are assumed to have comprehensive information about both prices and quantities. Second, the market is assumed to be competitive. Third, buyers and sellers are price-takers, ensuring that neither borrowers nor sellers can influence market prices (Parmeter and Pope 2012). Fourth, the market is assumed to be "sufficiently large," that there are enough combinations of different attribute bundles (houses), which makes the consumer's choice seem to be a choice from a continuously varying set of attributes (Rosen 1974). Additionally, if the consumer chooses from a continuously varying set of attributes, or their choice is one of a bundle of attributes, it is impossible for a seller to unbundle these attributes and sell in different markets. Therefore the bundle of attributes that comprise a house are always sold in the differentiated product market, the housing market (Parmeter and Pope 2012).

Consumers and producers are both utility and profit maximizers; by examining the optimal conditions for both consumers and producers it is possible to identify a market equilibrium, or the hedonic price function. Parmeter and Pope (2012) summarize both the consumer and producer sides of the hedonic price function as outlined by Rosen (1974). Consumers base their purchasing decisions on a price function – $P(z)$, where z is a vector of housing attributes $P(z) = P(z_1, \ldots, z_n)$. The consumer bases their purchasing decisions on the price function and tries to maximize their utility. Assuming that the consumer only purchases one good or bundle of attributes and that the consumer has a concave utility function; $U(x, z)$, where x is a composite of all other commodities and z is the vector of housing attributes. In addition, the consumer has a budget $y = x + P(z)$, where y represents the consumers income. The first order conditions derived from the consumers utility maximization problem, show that the slope of the hedonic price function, or the price of one attribute, is equal to the marginal rate of substitution between one attribute and all other consumption, holding all other attributes fixed:

$$P_z(z) = {}^{U_z}/_{U_x}. \tag{1}$$

The consumer makes a "bid" for a property in the housing market. Rosen (1974) describes the maximum bid with a bid function, $\gamma(z, u, y)$. The bid function holds utility and income fixed, and represents a family of indifference curves. These indifference curves show the consumer's levels of indifference between an attribute and all other consumption. In essence the bid function represents the consumer side of the hedonic price function: $P(z) = \gamma(z, u, y)$. Substituting the consumer's bid function for the hedonic price function in their utility maximization problem results in the first order conditions, which show that the consumer's bid for an attribute is equal to the marginal rate of substitution between one attribute and all other consumption. Thus for a consumer to have higher utility the bid must be lower leaving more income for all other consumption:

$$\gamma_z(z, u, y) = U_z/U_x. \tag{2}$$

Next, assume that producers are profit maximizing. Producers have the cost function $C(M, z; v)$, in which M is the quantity of houses and v are the production parameters varying across producers. The cost function is assumed to be convex and have a positive marginal cost for M and z. The producer's profit maximization problem leads to first order conditions, which show that the marginal revenue of more of an attribute is equal to the marginal cost of production for that additional attribute, and that the marginal cost of selling an additional unit is equal to the price:

$$MP_z(z) = C_z(M, z) \tag{3}$$
$$P(z) = C_M(M, z). \tag{4}$$

Analogous to the consumer's bid function, producers have an offer curve, representing the different combinations of attributes they are willing to offer for a certain price. This offer curve is represented by the function $\omega(z; \pi)$. Substituting the offer curve into the cost function reveals first order conditions (5) and (6) that demonstrate that the marginal offer price holding profit constant is equal to the marginal cost of production. Also, the marginal offer price holding attribute levels constant is constant. Therefore, holding attributes and cost constant, in order to increase profit the producer must offer a higher price:

$$M\omega_z = C_z(M, z) \tag{5}$$

$$\omega_\pi = {}^{1}\!/_{M}. \tag{6}$$

Combining the producer's profit maximization problem and the consumer's utility maximization problem leads to a set of equilibrium prices, known as the hedonic price function. These equilibrium prices occur at the points of tangency between the bid and offer curves. The first order conditions of the consumer's utility function show that the consumer's optimal bid is tangent to the hedonic price function, which leads to the conclusion that the hedonic price function represents an upper envelope of the consumer's bids in equilibrium. Similarly, the producer's profit maximization problem first order conditions demonstrate that the producer's optimal offer is tangent to the hedonic price function, and therefore the hedonic price function also represents the lower envelope of the producers offers. The points of tangency between the optimal bids and offers define the hedonic price function. Figure 4.1 illustrates the hedonic price function and points of tangency in the bid and offer curves. From the hedonic price function it is possible to determine the marginal willingness to pay for an attribute, since the marginal price of an attribute is equal to the marginal willingness to pay for the attribute.

Based on the theoretical framework outlined by Rosen (1974) and aptly restated by Parmeter and Pope (2012), it is possible to recover the marginal willingness to pay for an attribute by defining an equation with price of a house as a function of many housing attributes, as well as the environmental or quality attribute under examination. Quasi-experiments and the hedonic method have been used together to estimate the marginal willingness to pay for a wide variety of environmental externalities, such as the impact of wind farms by Heintzelman and Tuttle (2012).

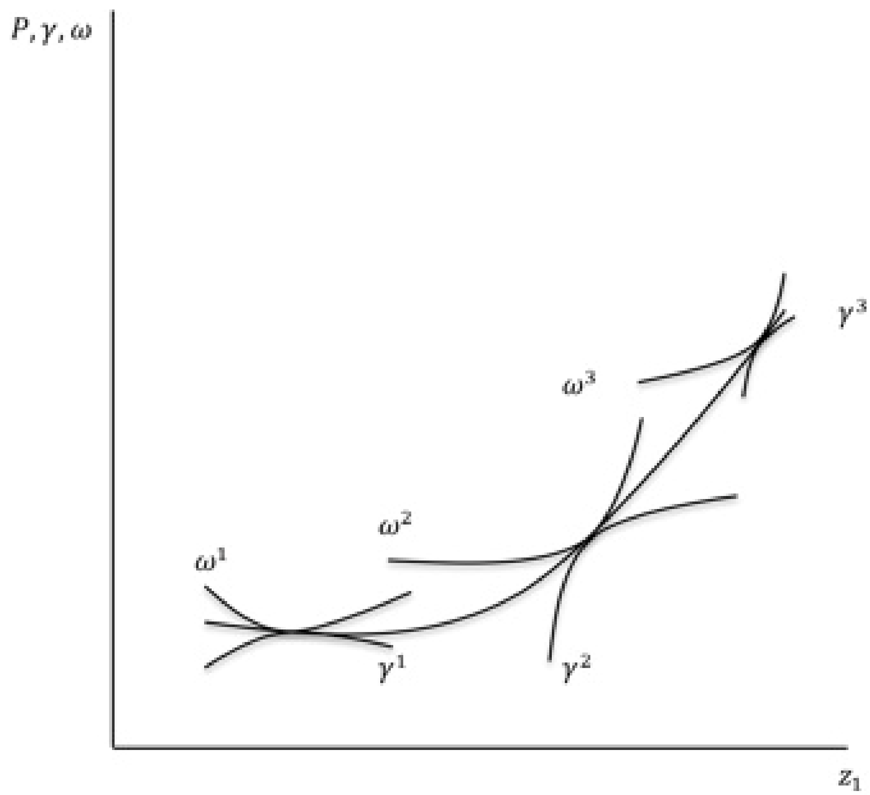


Figure 4.1 Hedonic Market Equilibrium (Recreated from Parmeter and Pope (2012))

The hedonic price function can be linear or nonlinear. The specification of functional form of the price function is essential in estimating accurate marginal willingness to pay. There are a variety of common functional forms used in estimating marginal willingness to pay. Heintzelman and Tuttle (2012) employ a log-linear specification for their estimates. Other studies employ a log-linear or linear Box-Cox regression based on the findings of Cropper, Deck and McConnell (1988). Little literature exists on which functional form is best when employing hedonic price functions. There are many functional forms commonly used within hedonic price analysis. Taylor (2003) outlines several of these functional forms, including linear, log-linear, double-log, quadratic, and quadratic Box-Cox. Most of these common forms include non-linearities, and including non-linearities in the function is considered to be important because price is most likely not impacted at a constant rate by all characteristics (Taylor 2003). Of the common forms, the log-linear functional form is one of the most common, and was recently used by Heintzelman and Tuttle (2012). According to Cropper, Deck and McConnell (1988) the semi-log form is one of the options that performs best under some types of misspecification. Additionally, Gopalakrishnan and Klaiber (2014) employ both a semi-log functional form and a Box-Cox form and find qualitatively the same results between the two. I employ the log-linear functional form, similar to that used by Heintzelman and Tuttle (2012) for my hedonic price function:

$$\ln P_{ij} = \alpha_j + \beta z_{ij} + \delta x_{ij} + \varepsilon_{ij}. \quad (7)$$

In the hedonic price equation outlined in (7), α_j represents the spatial fixed effects (county), z_{ij} are the treatment variables, x_{ij} are the set of explanatory or attribute variables, and ε_{ij} is the error term. In my analysis z_{ij} are the variables measuring the impact of underground natural gas storage, either the proximity variables or the intensity variables. I include spatial fixed effects in order to control for omitted variables bias. Omitted variables bias occurs when explanatory variables that are unobserved by the researcher and are correlated with observed variables are left out of the regression. They are instead accounted for in the error term. The error term should account for random variation in the data, but omitted variables captured by the error term introduce bias into the estimates (Parmeter and Pope 2012). Fixed effects include dummy variables for specified divisions of geographic regions, such as counties, which can account for unobserved variables that occur within the geographic region specified (Heintzelman and Tuttle 2012).

The coefficient estimates on the treatment variables provides the marginal willingness to pay for housing attributes. However, interpretation of the coefficients in a log-linear specification is required. In a log-linear specification the percentage change in price is equal to 100β. Therefore when examining proximity treatment attributes a coefficient of -β implies a 100β percent decrease in property values for a one unit increase in distance (meters or kilometers) to the proximity variable. Conversely a coefficient of β implies a 100β percent increase in property values for a one unit increase in distance. Additionally one can use marginal effects to evaluate the average impact of the treatment on housing values over larger changes in the treatment, for instance a one kilometer change versus a one meter change.

CHAPTER 5. DATA

5.1 Overview

Hedonic pricing analysis requires the use of property transaction data within a certain geographic region that defines the market under analysis. In addition to transaction data, it is necessary to have a set of attributes describing each transacted property, and a set of treatment variables. Attribute variables describe the property in detail, which allows for the differentiation of the impact of treatment variables from the value of standard details of a property. Treatment variables are used as a measure of the impact on the value of a home within the market. In this case the treatment variables consist of distance to one of seven types of natural gas or oil wells, distance to and indicator variables for the presence of underground natural gas or oil fields, and measures for the intensity of well activity.

My final data set consists of a sample of 1,512 single-family residential properties in 16 counties across the state of Indiana, from 2004 to 2013. The counties included in the analysis are Cass, Clark, Daviess, Decatur, Fulton, Greene, Harrison, Huntington, Knox, Lawrence, Monroe, Pike, Posey, Pulaski, Randolph, Spencer, Vermillion, and White counties. Each observation constitutes an arms-length property sale. In addition, 529 of the 1,512 observations are repeat sales, or parcels that transacted more than once within the study period. The following sections describe the process of collecting and cleaning undertaken resulting in this final data set.

Econometric identification has been a large portion of discussion in most recent work on valuing the externalities associated with hydraulic fracturing in general. Gopalakrishnan and Klaiber (2014) especially work through this issue in their recent work on hydraulic fracturing. Previous studies have focused on Washington County, Pennsylvania, which is located in the southwestern region of the state. Although this is the region where hydraulic fracturing activities are concentrated, this region also has coal and oil extraction activities. In addition, as demonstrated in Figure 3.4, southwestern Pennsylvania also has concentrations of underground natural gas storage activities. Together these other activities pose difficulties for identifying and quantifying the value of externalities associated with a single activity, when there are so many similar activities located within the same region. The advantage of looking at Indiana within this study is that the underground natural gas storage activities are relatively isolated from other natural resource related activities. Indiana does have the potential for unconventional natural gas extraction activities; however, to date those activities have been relatively limited. Thus focusing on Indiana potentially minimizes the difficulties posed in econometric identification of the externalities related to underground natural gas storage specifically.

5.2 Well Data

The Indiana Geological Survey's Petroleum Database Management System provided a list of all wells in the state of Indiana, including natural gas storage wells, observation wells, oil extraction wells, and natural gas extraction wells. This data includes details about each well found within the State, including construction completion dates, representing the date when the well is ready for production, which can be used to determine the age of the well. Most importantly, the data provides a classification for each well and the corresponding latitude and longitude coordinates. Table 5.1 provides a breakdown of the wells by county, contained within the list of wells provided by the Petroleum Database Management System.

Table 5.1 Housing Sales, Underground Natural Gas Storage and Extraction Wells by County

County	Housing Sales	Gas Storage	Observation	Abandoned Gas Storage	Abandoned Observation	Gas Extraction	Gas and Oil Extraction	Oil Extraction
Cass	90	33	32	15	1	0	0	0
Clark	276	14	5	0	0	0	0	0
Daviess	111	7	0	3	0	29	1	163
Decatur	34	34	0	27	0	509	0	0
Greene	89	163	59	20	7	19	9	117
Harrison	10	44	7	6	2	207	0	0
Huntington	245	3	0	0	0	0	0	18
Lawrence	55	49	20	0	0	0	0	0
Monroe	214	61	19	0	2	1	0	3
Pike	238	49	7	13	4	12	3	660
Posey	22	60	1	0	0	12	1	1136
Pulaski	1	4	6	7	1	0	0	3
Randolph	24	15	1	28	6	32	0	5
Spencer	45	45	1	3	1	27	2	447
Vermillion	17	1	0	10	7	2	0	0
White	41	38	21	8	13	0	0	0
Total	1512	620	179	140	44	850	16	2552

In addition, the Indiana Department of Natural Resources maintains a list of active and inactive wells associated with natural gas storage. This data source includes the classification of each well as either a natural gas storage well or an observation well. Additionally this well data includes the latitudinal and longitudinal coordinates for each well, the name of the underground storage field where they are located, and the completion date for the well.

From the latitudinal and longitudinal coordinates provided by the Petroleum Database Management System and the Indiana Department of Natural Resources, I pinpoint the exact location of each well using ArcGIS Desktop 10.1 software. I create a graphical representation for each type of well on a map of Indiana, visually representing the location of the wells spread across the state. In addition, I overlay the USA Counties Layer Package from Esri Data & Maps on the map of wells in order to determine which counties within the state have active underground natural gas storage wells and observation wells located within their boundaries. Twenty-three counties throughout the state have natural gas storage related wells within their boundaries; these counties represent the geographical region to be studied in this analysis.

5.3 Housing Transaction Data

Every county within the state of Indiana is required to collect a sales disclosure form for each housing transaction that occurs within that county. These sales disclosures are submitted to the Department of Local Government and Finance, which maintains a database for the entire state. Using this database I collect detailed sales information for every housing transaction occurring within the counties of interest for the years from 2008 through 2012. The Department of Local Government and Finance's Sales Disclosure database only allows for the searching of one county at a time, requiring that the dataset of sales disclosures be collected by county and later combined into a single database.

Using the Sales Disclosure's online database I compile a dataset of 55,688 sales observations within 22 counties in the state of Indiana. The search provides transactions occurring primarily between 2004 through 2012, however it also includes outlying transactions from 2002 to 2008 and 2012 to 2013. One county from the original list of counties did not have data within the selected time period on the Sales Disclosure Database. The data collected from the Department of Local Government and Finance contains the parcel number associated with each sale; the sale date; sale price; detailed information about the buyer and seller; and important notes about each individual sale. However, the data does not include any attribute data, or descriptive data about the house or utilities.

In addition to the Sales Disclosure Database provided by the State of Indiana, many counties maintain their own databases of sales disclosures and property information. Using these individual resources I compile a second set of housing transactions for each county. Benton, Dubois, Greene, Knox, Pike, Posey, Pulaski, Randolph, Spencer, Sullivan, and Vermillion counties use WTH GIS's ThinkGIS to provide Geographic Information Service (GIS) mapping services for their counties, including a sales search tool. Cass, Clark, Harrison, Lawrence, and Monroe counties use Enterprise GIS by 39 Degrees North, LLC to provide GIS mapping services for their counties, including a sales search tool. The Tippecanoe County Assessor's webpage provides a parcel search tool, which can compile a dataset of sales within the county. White County has a database for parcel information, including sales information, on their Assessor's website. Daviess, Decatur, Fulton, and Huntington counties do not have a county database to search for sales information. Using these independent county resources I assembled a dataset of 59,770 sales observations within 17 counties in the state of Indiana. Since the data from the Department of Local Government and Finance has data for more counties than the data collected from individual sources and combining the two sources would result in primarily repeated observations, I only use the dataset compiled from the Department of Local Government and Finance.

In order to reduce the sample size and create a dataset of arms-length residential sales I clean the data from both data sources and each county. I remove all observations that are not classified as single-family residential homes (property codes 510 through 515). In addition, I remove all $0 and $1 sales from the dataset. These sales are more likely to represent family or business transactions rather than a market sale, or an arms-length sale. Every sale is associated with a parcel number; however, since the dataset contains repeat sales it is necessary to assign a unique identification number to each sale.

Neither the Department of Local Government and Finance or the individual county's search tools provide housing attribute data with the transaction data. Attribute data of this kind is equally as important as the sales information and the treatment effect data. In order to determine how to acquire the attribute data I contacted each county included in the study. Unfortunately the counties do not collect housing attribute data in a single dataset. However, the county assessor's offices do maintain property records for every parcel within their county. These property records are used primarily to determine the assessed value of each property for tax purposes. For the purposes of this study, all of the attribute data for each parcel is collected by the county assessor's office. In addition these county offices maintain free online databases, either on their own website or on their GIS website. Using these individual sources it is possible to collect the information for each parcel included in both sets of transaction data.

5.4 Geocoding of Housing Transactions

After collecting the preliminary transaction the next step is to confirm their location using GIS software. Determining the location of each property allows for the creation of treatment variables that require information on distances to petroleum wells and fields. The property transactions provided by the Department of Local Government and Finance includes a street address for each property. Some of the observations had errors in the street addresses; all of these observations are removed from the dataset.

In order to convert a street address into a location on a GIS map I use the 10.0 North America Geocode Service provided in ArcGIS Desktop 10.1. This service converts street addresses housed in excel files into X and Y coordinates on the map. Once all of the housing transactions are geocoded, I add the new housing transaction shape file to the map containing Indiana counties, petroleum wells and petroleum fields. This new map provides a visual representation of the housing transactions in comparison to the location of natural gas storage wells and fields.

5.5 Buffer Zones

Unfortunately, given the size of the transaction data, 55,688 transactions from the Department of Local Government and Finance, it is an unreasonably large task to manually compile the attribute data for the purposes of this analysis. According to prior literature the range of impact of natural gas activity on nearby homes is limited. Muehlenbachs, Spiller and Timmins (2012) specify a buffer range for the impact of hydraulic fracturing activities of 2,000 meters. Boxall, Chan and McMillan (2005) define a four-kilometer range around each property to determine their treatment variables, based on evidence from energy experts that four kilometers is the maximum range of impact extending from oil and gas facilities. Additionally, Gopalakrishnan and Klaiber (2014) find that the impacts of hydraulic fracturing activities on home values become insignificant at a range greater than one mile. Therefore, in order to reduce the size of the dataset and include only the most relevant housing transactions for the study, I decide to find a buffer range around the underground natural gas storage wells and the underground formations where the natural gas is stored. Based on the evidence gathered from comparing housing transactions at a variety of buffer ranges, as well as evidence from previous literature I can focus on a suitable range around the treatment area.

The Indiana Geological Survey compiles, in addition to the extensive well data, a set of data on the location, size and type of underground fields across the state of Indiana that produce oil and natural gas. This data is available for observation in a Map Service through ArcGIS online. The metadata from the Map Service, titled Petroleum Fields, describes the layer, "Comparing digital lines from IGS Misc Map 58 (MM58) with ¼ mile buffers of productive petroleum wells. New petroleum field outlines were then manually digitized on screen using the shape information from MM58 and the buffer extents. In some cases, the IGS Petroleum Exploration Map (PEM) series was consulted to verify spatial and attribute data. Petroleum well information was queried from the Indiana Geological Survey Petroleum Database Management System." I overlay the well location map on the Petroleum Fields map in order to identify and determine the location of each underground natural gas or oil formation used to store natural gas.

After determining which of the many underground formations in Indiana are used to store natural gas, I use ArcGIS Desktop 10.1 to build a map containing all of the underground storage fields, all of the different types of petroleum wells, and all of the housing transactions. The first step in building this map is to add a county map of Indiana to the Map Service created by the Indiana Geological Survey of the petroleum fields in the state. ArcGIS Online provides access to a wide variety of maps, including a county map for the entire United States using data from Esri, TomTom, the Department of Commerce, the Census Bureau, the U.S. Department of Agriculture, the National

Agricultural Statistics Survey, and the United States Central Intelligence Agency. I limit the size of this map to include only counties within the state of Indiana. In order to create the buffer zones around the underground storage fields I need to be able to access the data in the Petroleum Fields map, unfortunately the Map Service does not allow any editing to the layer. Users of ArcGIS often share maps that they have created or edited using their online servers, however in order to preserve the data included in their maps, creators have the option to prevent any editing while still sharing their map. This makes it necessary to use the drawing tools provided in ArcGIS Desktop 10.1 to recreate the boundaries of the petroleum fields being used for natural gas storage. In essence I create my own layer of petroleum fields, which allows me to create a buffer around any field or group of natural gas storage wells. In addition I use the limited petroleum field map to calculate any intersections of housing transactions and petroleum fields, and the distance from an individual property to a petroleum field.

I then add the layer of petroleum and other types of wells previously created. This layer includes the well data provided by both the Petroleum Database Management System and the Indiana Department of Natural Resources. Within this layer, it is possible to select certain wells based on their classification. I use the Buffer tool in ArcGIS 10.1 to create buffers around groupings of active natural gas storage wells and observation wells, and petroleum fields used for natural gas storage. The groupings of wells I define as all wells within 0.5 miles of another well, in order to remove any outliers from the buffer range. I did not create buffers for groups of natural gas storage wells that intersected a petroleum field, since these two buffers would simply intersect. In addition, I did not create a buffer around the two largest petroleum fields, the Trenton Field and the Laconia Consol. NAS, which are both so large that they cover several counties worth of land. If included when creating buffers, those buffers would not accurately limit the housing data to those homes close to natural gas storage. Instead I use the groupings of natural gas storage wells within those two fields in their place. Using these selected attributes I create a map layer for each of several possible ranges, five miles, four miles, three miles, two miles, 1.5 miles, and one mile.

5.6 Data Cleaning

Once the housing transactions and the buffer zones are mapped, I am able to compare the number of housing transactions contained within each separate buffer zone. At the five mile distance the dataset of housing transactions contains 12,458 observations, at the four mile distance the dataset consists of 8,917 observations, at three miles there are 6,042 observation, at two miles there are 2,798 observations, at 1.5 miles there are 2,007 observations, and at the one mile distance the dataset contains 1,179 sales. Prior literature on natural gas extraction has found little impact beyond a maximum of 4 kilometers (approximately 2.5 miles), and the size of the dataset at two miles is both large enough for the study and small enough to allow for the collection of attribute data. Therefore, I use the set of housing sales located within the two mile buffer zone, giving me a starting dataset consisting of 2,798 observations.

Before starting to collect the attribute data I clean the data of any addresses that are not geocoded to an exact postal address. The geocoding service will pinpoint an address to the most precise location possible, however some of the addresses included in the dataset can only be located to the city, zip code, or street level, I remove all of these observations from the dataset. In addition I remove any observations classified as Tied or Unmatched. An unmatched observation is an observation that the geocoding service cannot pinpoint a location for, and a tied observation is an observation that the geocoding service found two separate locations that match the address provided.

5.7 Attribute Data

In order to conduct a hedonic pricing analysis it is essential to have a set of variables describing as many attributes of a house as possible. This includes, in particular, the size of the house, the size of the property, the number of bedrooms, number of bathrooms, number of garages, public utilities, year the house was constructed, and a quality measure for the home. All of this data is available to the public on the property report cards created and updated by the Assessors Office of each county. However, the property cards vary drastically in format and information between each county. I therefore attempt to create a consistent format for housing each piece of information contained in the different report cards, allowing me to leave any missing information blank while gathering as much data as possible for each individual property. All data that can be described as a number is described as such in the final dataset, also any variable that can be described as a binary variable is described as such in the final dataset. Some of the variables, such as construction year or the condition rating of the home, I originally enter in the format used in the property record cards, which I later convert to the appropriate number or binary format.

I collect the attribute data for Cass, Clark, Harrison, and Monroe counties from their 39 Degrees North GIS mapping services. Daviess county data comes from their Property Tax Assessment page provided by xsoftin.com. Decatur county attribute data comes from their Beacon GIS mapping service. Dubois county data comes from the Dubois County Assessor's webpage. Fulton, Knox, Pike, Posey, Pulaski, Randolph, Spencer, and Vermillion counties data comes from their ThinkGIS mapping service. Sullivan County also uses ThinkGIS's mapping service, however all of the property cards for the properties included in my dataset were blank, thus I removed Sullivan County from the dataset, resulting in the removal of 44 observations from the dataset. Tippecanoe county data comes from their Tippecanoe County Parcel and Sales Data Search page; however the data was very incomplete resulting in the removal of all Tippecanoe County observations from the dataset, resulting in the removal of 33 observations from the dataset. Lastly, White county data comes from their County Assessor's webpage.

As each county's data is collected by different people and maintained by different county governments there is significant variation in what data is available for the housing transactions within each county. Recent hedonic pricing analyses on natural gas extraction using hydraulic fracturing have found significant impacts on housing values when the home does not have access to public water; therefore the variable for public water is of particular importance for this analysis. When a house has access to public water it does not necessarily mean that the home uses the public water, but simply having the ability to connect with a source of public water mitigates any risk associated with groundwater contamination. One county, Dubois County, is completely lacking in public utility attribute information on their property cards. I contact the county assessor's office in order to determine if the lack of information indicates a lack of public utilities in the home or if it is in fact a deficit in the information. I determine that this county does not use that section of the property report card, and thus I remove all Dubois county transactions from the analysis due to the incompleteness of the data. This results in the removal of 169 observations from the dataset. Additionally, any properties with missing property report cards, properties with differences in property codes between the original transaction data and the property report card, any properties without homes or with mobile homes are also removed from the dataset. All observations missing data on key variables were removed, these key variables include access to public water, number of bedrooms, number of bathrooms, finished square feet, size of the lot, number of stories, number of fireplaces, number of full and half bathrooms, age of the home, building quality indicators, number of garages, and number of pools. This resulted in the removal of 265 observations from the dataset.

In addition to the attribute data included in the property report cards I also collect data on the distance to the nearest street, census tracts, demographic variables, school districts, distance to the nearest public school, and whether the property is located in an urban area. All of this data I collect using ArcGIS Online resources and the tools provided in ArcGIS Desktop 10.1. Using the detailed primary and secondary streets data from the North America Detailed Streets Layer Package I calculate the distance from each housing transaction to the nearest secondary street in the North America Detailed Streets Layer Package. Secondary streets include primary limited-access roads or interstates, primary US and state highways, and secondary state and county highways.

I also determine the census block for each housing transaction, using the USA Census Tract Boundaries layer file. In addition to providing the Census Block for each housing transaction the USA Census Tract Boundaries file also contains some demographic data. I add further demographic variables by matching census blocks to their corresponding data from the 2010 Census Demographic Profile 1 and the 2010 Census Population & Housing Unit Counts. From this data I add variables for the percent of high school graduates, the percent of the population holding a bachelor's degree, the percent of the population with a graduate or a professional degree, the percent of unemployed, the median household income, mean household income, the “percentage of families and people whose income in the past 12 months is below the poverty level,” the median age, the percent at age 65 or over, the percent white, and the percent black. Table 5.2 contains summary statistics for the demographic variables in the final dataset.

In addition, I determine the school district for each housing transaction using the School Districts layer from the DOE U.S. Schools layer package, represented as a binary variable for each school district in the dataset. The DOE U.S. Schools layer package also contains data on all public schools in 2008 in the Public Schools in 2008 layer, which I use to calculate the distance from each housing transaction to the nearest public school in meters.

Another important variable that I add is a binary variable representing whether a housing transaction is located within an urban area. Using ArcDesktop 10.1 and the USA Urban Areas layer package available on ArcGIS Online I determine which housing transactions intersect one of the urban areas. The layer package contains boundaries for the Census 2010 Urbanized Areas and Urban Clusters. An Urbanized Area “consists of contiguous, densely settled census block groups (BGs) and census blocks that meet minimum population density requirements (1000ppsm/500ppsm), along with the adjacent densely settled census blocks that together encompass a population of at least 50,000 people.” An Urban Cluster “consists of contiguous, densely settled census BGs and census blocks that together encompass a population of at least 2,500 people, but fewer than 50,000 people.” Table 5.3 describes the final set of housing attributes, including a binary variable for homes intersecting an urban area and the distance to the nearest street.

Table 5.3 includes some descriptive statistics worthy of slight explanation. The minimum sales price is $10. As mentioned previously all $0 and $1 sales were removed from the data set, in order to ensure arms-length sales. The cut-off point for the definition of an arms-length sale is ambiguous, thus the decision to includes sales as low as $10 is a judgment call. Within this study I err on the side of caution and include these sales. That being said the data set only includes 122 sales of less than $10,000, and preliminary regression results excluding these sales are negligibly different from those reported throughout this thesis. In addition, the minimum value for lot size is zero. This variable data comes from the sales disclosures, and is reported by the seller. Some of these lots are very small, thus the acreage is rounded to zero. Data about legal acreage or lot size collected from the property report cards for each property is missing in many observations, and many of these are also reported as zero. Preliminary regression results using alternative measures of lot size, although a much smaller data set, are negligibly different than the results reported here. Finished living area also has a minimum value of zero. This is possible because some of the properties included in this data set are very small and poor quality homes. Additionally this variable measures the amount of area that is finished, not total unfinished area. It is possible for a home to be livable, yet have no finished square feet.

Figure 5.1 is a graphical representation of the distribution of sales price across the data set. The majority of sales are less than $100,000. Each of the different types of data collected are visually represented in Appendix A. These figures include representations of the counties included within the analysis, the school districts within the analysis, the primary and secondary streets throughout Indiana, and combinations of counties and different types of petroleum wells. There are also figures for each of the buffer zones and housing sales within the different counties of analysis, which include all of the different types of petroleum related wells, streets and urban areas.

Table 5.2 Summary Statistics for Census Block Demographic Variables

Variable	n	Mean	Std Dev	Min	Max
Percent high school graduate	1512	39.92	0.21	9	54.00
Percent bachelors degree graduate	1512	10.45	0.14	4.10	28.30
Percent graduate or professional degree graduate	1512	7.45	0.15	0.40	39.60
Percent unemployed	1512	8.08	0.09	2.10	14.10
Median household income ($)	1512	49365.80	262.46	25750	71336
Mean household income ($)	1512	59316.72	287.82	41416	83740
Percent living below poverty level	1512	7.48	0.13	1.90	25.60
Median age (years)	1512	40.85	0.09	26.70	47.70
Percent 65 years and over	1512	15.35	0.09	10	22.90
Percent white	1512	97.26	0.11	80.40	100
Percent black	1512	1.74	0.07	0	12.10

Table 5.3 Summary Statistics for Hedonic Attributes

Variable	n	Mean	Std Dev	Min	Max
Sale Price ($)	1512	94559.90	2192.91	10	625000
Lot size (acres)	1512	1.01	2.96	0	75.42
Height of home (number of stories)	1512	1.22	0.39	1	3
Finished living area (sq Ft)	1512	1664.52	798.91	0	9478
Fireplaces	1512	0.43	0.74	0	4
Bedrooms	1512	2.77	0.80	0	9
Full bathrooms	1512	1.47	0.65	0	5
Half bathrooms	1512	0.23	0.43	0	2
Age of home (years)	1512	56.97	1.05	0	194
Age^2	1512	4898.20	5336.26	0	37636
Distance to nearest major road (meters)	1512	819.77	1195.64	0.13	8480.89
Excellent grade building quality indicator	1512	0.08	0.27	0	1
Good grade building quality indicator	1512	0.40	0.49	0	1
Average grade building quality indicator	1512	0.51	0.50	0	1
Poor grade building quality indicator	1512	0.02	0.13	0	1
Urbanized area indicator	1512	0.29	0.45	0	1
Garages	1512	0.85	0.55	0	3
Pools	1512	0.05	0.21	0	1
Public water indicator	1512	0.68	0.47	0	1

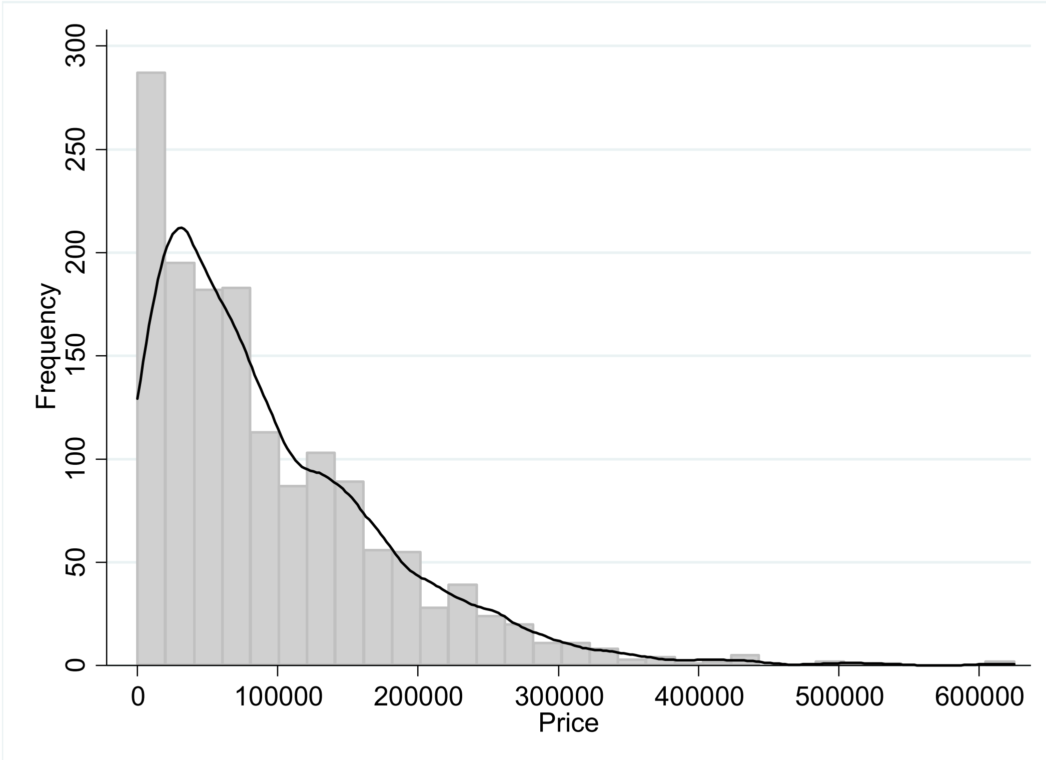


Figure 5.1 Frequency of Sales Price Histogram and Distribution

5.8 Repeat Sales

The Department of Local Government and Finance search results include all property transactions that occurred in the time period selected for the search. Unfortunately, the search tool on the website returned some observations that are actually exact repeats of the same transaction. These transactions would create inaccuracy in the results of the analysis; therefore they were removed from the final dataset, resulting in a removal of 252 observations. All remaining repeat sales are identified in the dataset with a dummy variable. Additionally some of the legitimate transactions occurred on the same day, these observations are identified with another dummy variable specific to same day sales of the same parcel. Within the final dataset 529 of the 1,512 housing transactions are repeat transactions. Table 5.4 contains summary statistics for the hedonic attributes in the limited repeat sales data.

Table 5.4 Summary Statistics for Repeat Sales Hedonic Variables

Variable	n	Mean	Std Dev	Min	Max
Sale Price ($)	529	75136.34	74053.08	10	425000
Lot size (acres)	529	0.67	1.25	0	8.84
Height of home (number of stories)	529	1.25	0.40	1	2.50
Finished living area (sq Ft)	529	1657.62	789.33	148	6348
Fireplaces	529	0.43	0.80	0	4
Bedrooms	529	2.79	0.73	0	6
Full bathrooms	529	1.46	0.65	0	4
Half bathrooms	529	0.17	0.38	0	1
Age of home (years)	529	62.87	41.47	0	141
Age^2	529	5669.18	5362.01	0	19881
Distance to nearest major road (meters)	529	779.80	1029.94	0.18	6811.51
Excellent grade building quality indicator	529	0.05	0.23	0	1
Good grade building quality indicator	529	0.32	0.47	0	1
Average grade building quality indicator	529	0.61	0.49	0	1
Poor grade building quality indicator	529	0.01	0.11	0	1
Urbanized area indicator	529	0.38	0.48	0	1
Garages	529	0.79	0.53	0	2
Pools	529	0.05	0.22	0	1
Public water indicator	529	0.72	0.45	0	1

5.9 Treatment Variables

In order to identify any impact of underground natural gas storage on property values, it is necessary to create some treatment variables. Proximity is commonly used as a measure of impact because the data to determine distance is often readily available. Guignet (2013) suggests that distance may not be the most accurate measure of impact; however this literature accepts that the data for other measures may not be available. In order to provide this analysis with the widest range for measures of impact I include both proximity variables and a measure representing the intensity of natural gas storage activities for each property.

ArcDesktop 10.1 provides a variety of tools for measuring the distance from one feature on a map to another. In the case of this analysis I use the Near tool to measure the distance from each property to the nearest well of each type, this includes natural gas storage wells, observation wells, abandoned natural gas storage wells, abandoned observation wells, natural gas extraction wells, extraction wells that produce both natural gas, and oil extraction wells. Additionally I use the Near tool to calculate the distance from each property to the nearest petroleum field in order to provide a measure for the impact of being located near an underground formation containing natural gas or oil. All those properties intersecting, or located above a petroleum field, are identified with a dummy variable. Table 5.5 provides summary statistics for the proximity treatment variables used in this analysis. In addition Table 5.6 provides summary statistics for the proximity treatment variables used in the limited repeat sales data. Figure 5.2 is a graphical representation of the distribution of distance to the nearest gas storage well across the dataset. In addition Figure 5.3 provides a graphical representation of distance to the nearest gas storage well by the sale price of the home.

Table 5.5 Summary Statistics for Underground Natural Gas and Extraction Well Proximity Variables

Variable	n	Mean	Std Dev	Min	Max
Natural gas storage field indicator	1512	0.11	0.32	0	1.00
Distance to nearest natural gas or oil field (meters)	1512	9016.73	9930.79	0	33899.07
Distance to nearest natural gas storage well (meters)	1512	2454.12	1642.99	45.70	14478.08
Distance to nearest observation well (meters)	1512	17349.66	30476.98	20.80	86008.57
Distance to nearest abandoned natural gas storage well (meters)	1512	34506.38	30663.68	27.48	87241.88
Distance to nearest abandoned observation well (meters)	1512	32605.90	29543.88	87.90	89982.54
Distance to nearest natural gas extraction well (meters)	1512	17962.23	16042.42	46.58	71598.61
Distance to nearest natural gas and oil extraction well (meters)	1512	55099.26	40000.87	2797.28	142298.10
Distance to nearest oil extraction well (meters)	1512	23086.81	26380.49	79.21	87356.56

Table 5.6 Summary Statistics for Repeat Sales Underground Natural Gas Storage and Extraction Well Proximity Variables

Variable	n	Mean	Std Dev	Min	Max
Natural gas storage field indicator	529	0.11	0.31	0	1
Distance to nearest natural gas or oil field (meters)	529	9750.22	9496.57	0	33899.07
Distance to nearest natural gas storage well (meters)	529	2297.86	1574.07	95.52	13853.58
Distance to nearest observation well (meters)	529	22623.03	34059.79	58.34	83621.99
Distance to nearest abandoned natural gas storage well (meters)	529	39161.19	32577.04	144.08	86277.90
Distance to nearest abandoned observation well (meters)	529	36178.74	31716.53	95.73	85944.72
Distance to nearest natural gas extraction well (meters)	529	19517.15	15930.06	217.46	71167.29
Distance to nearest natural gas and oil extraction well (meters)	529	56069.51	38548.86	2937.71	139460.60
Distance to nearest oil extraction well (meters)	529	22162.39	23618.93	334.76	80562.41

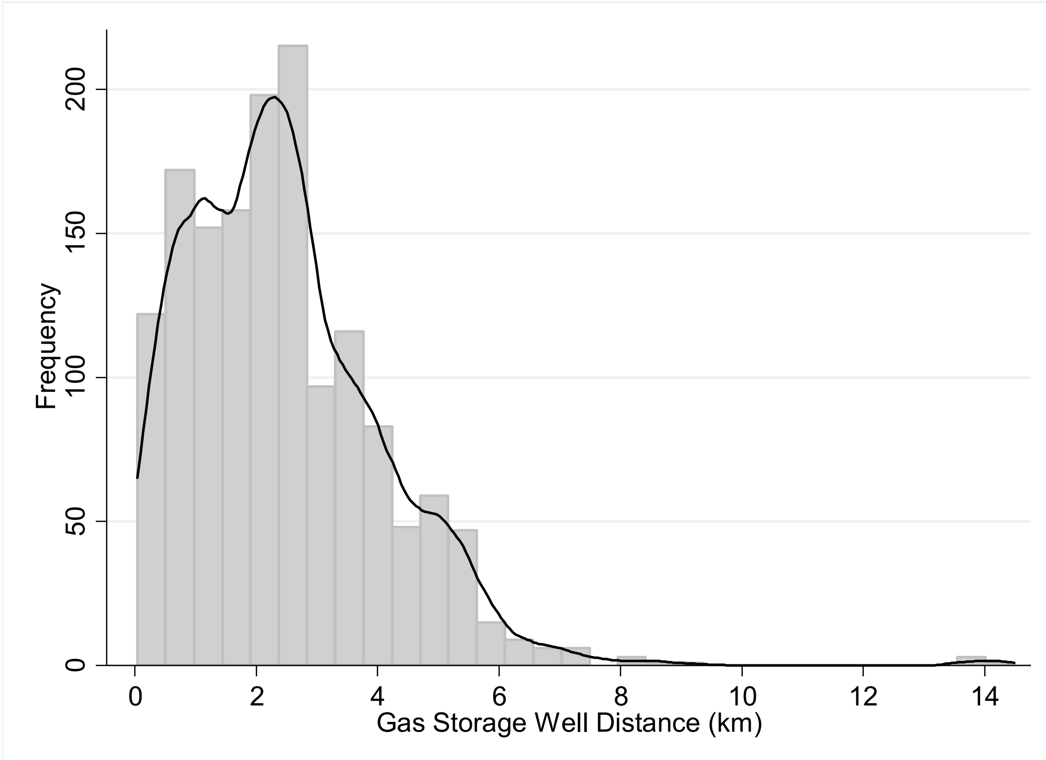


Figure 5.2 Frequency of Gas Storage Well Distance Histogram and Distribution

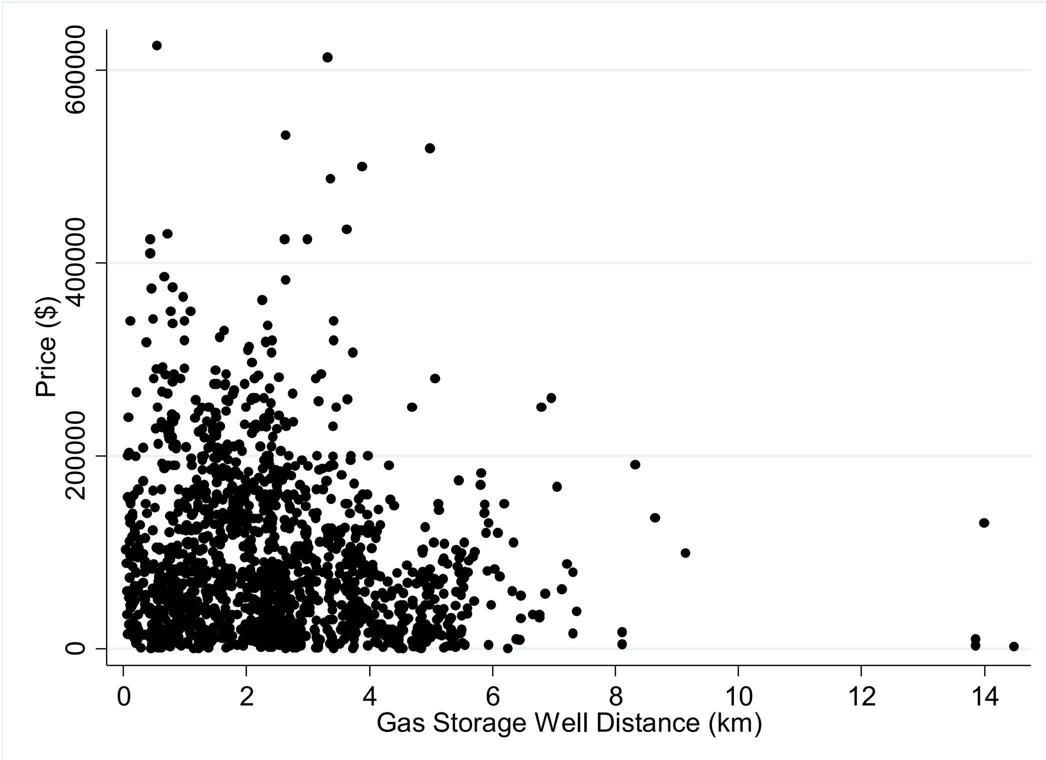


Figure 5.3 Gas Storage Well Distance by Sales Price

Another way to measure impact is by creating a measure for the intensity of well activity for each property. I use a combination of variables in order to represent the intensity of well activity. First I use the Point Distance tool in ArcDesktop 10.1 to create a table including the distance from each property to all natural gas storage wells in a two-mile radius. I repeat this process to create tables for the distance from each property to all observation wells, all abandoned natural gas storage wells, all abandoned observation wells, all natural gas extraction wells, all natural gas and oil extraction wells, and all oil extraction wells within a two-mile radius. Additionally I use the same process to create tables for all natural gas storage related wells combined, all extraction related wells combined, all abandoned natural gas storage related wells, and all of the preceding types of wells combined.

These tables include an identification number for each property, an identification number for each well within the specified radius and the distance from the property to each well. Using the collapse command in STATA 13 I distill these tables into three variables, a count of each type of well for each property, the average distance from a type of well to each property and the minimum distance from a well to each property. In addition I use STATA 13 to create a binary variable specifying which properties have higher intensity. In order to determine the threshold of wells that indicates greater intensity, I create histograms of the well count variables. Based on these histograms I determine the threshold for each type of well. This threshold is 20 wells or greater for the combined count of all wells, 20 wells for the count of all underground natural gas storage related wells, five wells for the count of all types of extraction wells combined, 15 wells for natural gas storage injection/withdrawal wells and two wells for all abandoned underground natural gas storage related wells combined. This binary variable can be used as a term to interact with the count variables and create an intensity measure that accounts for number of wells and distance combined. Table 5.7 contains summary statistics for all of these measures of well intensity.

This thesis focuses on underground natural gas storage, however, several of the proximity and intensity variables calculated are actually distance and intensity of extraction wells. Although these variables are not directly related to underground natural gas storage, examining their impacts on property values within the context of underground natural gas storage may provide further insight into the impacts of natural gas storage in comparison to natural gas extraction. In addition, these variables provide additional information about the geographic regions in which the property transactions included in the dataset are located. A comparison of different types of underground natural gas storage activities as well as extraction activities within the context of underground natural gas storage may provide valuable insight into the impacts of underground natural gas storage in particular.

Table 5.7 Summary Statistics for Underground Natural Gas Storage and Extraction Well Intensity Measures

Variable	n	Mean	Std Dev	Min	Max
All Wells Intensity Measure (Count of all wells within 2 miles)	1512	20.65344	22.61718	0	222
Storage Intensity Measure (Count of all Gas Storage and Observation wells within 2 miles)	1512	15.39947	20.06295	0	78
Gas Storage Wells Only Intensity Measure (Count of all Gas Storage wells within 2 miles)	1512	11.62235	15.64204	0	60
Observation Wells Intensity Measure (Count of all Observation wells within 2 miles)	1512	3.777116	5.248799	0	20
Abandoned Gas Storage Intensity Measure (Count of all Abandoned Gas Storage wells within 2 miles)	1512	1.171958	3.200067	0	25
Extraction Wells Only Intensity Measure (Count of all Extraction wells within 2 miles)	1512	3.684524	12.55886	0	222
All Wells Threshold Binary Variable (Indicator for homes with 20 or more wells within 2 miles)	1512	0.297619	0.4573623	0	1
Storage Wells Threshold Binary Variable (Indicator for homes with 20 or more wells within 2 miles)	1512	0.2222222	0.4158773	0	1
Gas Storage Wells Threshold Binary Variable (Indicator for homes with 15 or more wells within 2 miles)	1512	0.1792328	0.383674	0	1
ExtractionWells Threshold Binary Variable (Indicator for homes with 2 or more wells within 2 miles)	1512	0.1646825	0.3710165	0	1

CHAPTER 6. RESULTS

6.1 Overview

Throughout this analysis I use the log-linear model specification, $\ln P_{ij} = \alpha_j + \beta z_{ij} + \delta x_{ij} + \varepsilon_{ij}$. In addition, I include different combinations of spatial and temporal fixed effects to account for unobservable factors that may be correlated with the variables in the model. The temporal fixed effects are a set of year dummy variables, with 2008 as the base year for comparison. The spatial fixed effects include a set of county dummy variables with White County as the base region of analysis, and a set of school district dummy variables to specify smaller spatial regions. In models using school district fixed effects I use the Metropolitan School District of Mount Vernon in Posey County and South Spencer County School Corporation in Spencer County as the base regions of analysis.

I use dummy variables for school districts instead of an indicator for each specific school because my data spans 16 counties across the state of Indiana. Within these 16 counties, my data intersects 23 school districts. Although this method may not capture the impacts on housing values due to differing qualities of schools within a particular district, it would not be possible to include an indicator for each school, since there are over 100 public schools within those 23 school districts. Inclusion of so many indicators would lead to a loss in degrees of freedom, which may lead to multicollinearity issues. Further, it is common in applied hedonic models to control at the school district level.

I estimate a variety of log-linear regressions, and within each different model specification I use a variety of treatment variables to explore the impact of underground natural gas storage on housing values. Although not all combinations of fixed effects results are reported in the tables found within this chapter they can be found in Appendix C. First I use a set of proximity variables, measured in meters, to each different type of petroleum well, and to petroleum fields. This set of proximity variables includes distance to the nearest petroleum field, distance to the nearest natural gas storage wells, distance to the nearest observation well, distance to the nearest natural gas extraction well, distance to the nearest oil and gas extraction well, and distance to the nearest oil extraction well. Each of these different treatment variables allows me to explore the differences in impact each of these wells has on property values, and allows me to thoroughly explore the impact of underground natural gas storage under different conditions. Using variables related to natural gas and oil extraction in addition to variables directly related to underground natural gas storage provides me with an opportunity to compare the impacts of petroleum extraction activities within the context of underground natural gas storage with the direct impacts of underground natural gas storage activities. Second I have a binary variable indicating if a home is located over a petroleum field, which allows me to differentiate homes on top of a field from homes located near the field.

Another set of treatment variables used in this analysis is a measure of intensity through the count of wells within two-miles of each home. These intensity measures allow me to examine the impact that the concentration of petroleum related activity has on homes, in particular the impact that the concentration of underground natural gas storage related activities has on nearby property values. The set of intensity treatment variables includes the number of any type of wells located within two-miles of a home, the number of storage related wells located within two-miles of a home, the count of underground natural gas storage wells, the count of observation wells, the count of abandoned natural gas storage wells, and the count of all types of extraction wells combined. I use a count of wells to measure intensity of storage related activities because a home with a larger number of wells nearby should see a greater intensity of underground natural gas storage activity as compared to a home with only one or two wells nearby. In addition to the simple count intensity measures, I use binary variables to indicate which homes have a count of wells beyond a specified threshold. These threshold binary variables allow me to explore the impact that greater intensity of underground natural gas storage activities has on nearby property values.

I also interact the proximity variables with several characteristic indicators in order to examine the specific impact that underground natural gas storage has on homes with different characteristics. I explore the interaction between proximity and a binary variable for homes with access to public water, the interaction between proximity and the binary variable indicating whether or not the home is within an urban area, and the interaction between the lot size of a home and proximity. Previous studies have found that homes with access to public water see a less significant impact of shale activity on property values (Muehlenbachs, Spiller and Timmins 2012). Additionally, Parsons (1990) argues that the size of a parcel's lot can have an impact on the magnitude of impact due to attributes related to location. Each of these models provide unique insight into the impact of underground natural gas storage, as well as other petroleum related activities, on property values, as well as ensuring that the primary results are robust.

6.2 Hedonic Attribute Results

In order to provide an initial benchmark set of results, I run a variety of regressions using only the basic hedonic attributes. Table 6.1 presents the initial estimation results of these regressions. Model 1 shows the results without the inclusion of any fixed effects, while Models 2 through 6 show the results of regressions including combinations of county level and year fixed effects. Models 7 and 8 include a set of census block group demographic variables, with and without county level and year fixed effects. These regression results indicate that the hedonic attributes have the expected impacts on housing values.

As expected, homeowners prefer larger properties and larger homes of higher quality with more amenities. Estimation results from Model 4, which includes both year and county level dummies, indicate that for an increase in one acre in lot size property values see a 3.84 percent increase in value. Model 6, which includes school district level and year fixed effects, results indicate that a one acre increase in acreage results in a 3.76 percent increase in property values. Additionally, for a one square foot increase in finished living area property values see a 0.02 percent increase in value. The number of bedrooms and bathrooms are insignificant in Model 4, however this is common when a variable for the square footage of the house is included in the hedonic price function, because the square footage accounts for much of the impact due to larger number of bedrooms and bathrooms. I would expect that a home with more square feet would also have more bedrooms and bathrooms, therefore the individual impact of bedrooms and bathrooms becomes insignificant when accounting for square footage as well.

The number of fireplaces is positive and significant also, representing a 9.96 percent increase in value for an additional fireplace. Variables like fireplaces and garages commonly are a bundling effect in hedonic regressions such as these. An addition of a single fireplace often represents more than just the fireplace and therefore captures these impacts as a bundle. A home with a fireplace commonly has additional attributes that a homebuyer considers attractive, the same effect occurs with garages. Thus the large positive and significant impact of both fireplaces and garages may be capturing the impacts of other bundled characteristics of a home.

Age is negative and significant: for each additional year of age property values decrease by 0.98 percent. The model also shows that age is nonlinear, because the squared age variable is significant at the 10 percent level. When the age of a home is at the mean value, 56.97 years, a home sees a decrease in value of 0.51 percent. The turning point at which a home sees an increase in value due to an additional year can be calculated as $x = |\delta_1/2\delta_2|$, in which δ_1 is the coefficient on Age and δ_2 is the coefficient on Age^2. In Model 4, this turning point is 119.5 years, and in Model 6 the turning point is 104.8 years. This indicates that in general as a home ages it loses value, however once it reaches a certain age home buyers begin to value some historical or age related amenity of the home.

Following Halvorsen and Palmquist's (1980) interpretation of the impact of dummy variable coefficients, I can determine the impact of the dummy variables representing different quality grading for homes. Halvorsen and Palmquist determined that the percentage effect of a dummy variable on price in a log-linear model can be calculated by $100(e^{\delta_1} - 1)$, where δ_1 is the coefficient on the dummy variable. In Model 4 a home with excellent grade building quality sees a 537.7 percent increase over a poor grade home. A good grade home sees a 458.84 percent increase, and an average grade home sees a 215.69 percent increase. The magnitude of these coefficients is very large, however when looked at within the context of the average price of homes within each group of building quality indicators the magnitude is reasonable. Homes within the poor building quality group, the base group, have an average sale price of $18,120.59. In comparison, the average grade building quality group has an average sale price of $48,166.06, the good building quality group has an average price of $126,574, and the excellent grade group has an average sale price of $254,227. Given the enormous difference in average sale price between poor quality homes and excellent quality homes, a 537.7 percent increase in value for an excellent home compared to a poor quality home is reasonable.

The primary difference between the county level fixed effects model and the school district level fixed effects model is the significance of the full bathrooms variable. This variable is insignificant in the county level fixed effects model; however it becomes significant at the five percent level when school district fixed effects are employed. The hedonic attribute estimation results remain consistent throughout the different models employed, including those models where census block demographic variables are included, and are generally consistent in sign and magnitude with prior expectations.

Table 6.1 Hedonic Attribute Estimation Results

Variable	(1)	(2)	(3)	(4)
Lot size (acres)	0.0423**	0.0387**	0.0416**	0.0384**
	0.0094	0.0093	0.0094	0.0094
Height of home (number of stories)	-0.1322	-0.1248	-0.1300	-0.1262
	0.0827	0.0826	0.0830	0.0829
Finished living area (sq Ft)	0.0002**	0.0002*	0.0002**	0.0002**
	0.0001	0.0001	0.0001	0.0001
Fireplaces	0.0858*	0.1023**	0.0825**	0.0996**
	0.0408	0.0408	0.0410	0.0410
Bedrooms	-0.0031	-0.0050	-0.0012	-0.0034
	0.0385	0.0382	0.0387	0.0384
Full bathrooms	0.1038	0.0934	0.1080*	0.0975
	0.0640	0.0634	0.0643	0.0637
Half bathrooms	0.0318	-0.0065	0.0247	-0.0120
	0.0713	0.0707	0.0717	0.0712
Age of home (years)	-0.0122**	-0.0098**	-0.0121**	-0.0098**
	0.0031	0.0031	0.0031	0.0032
Age^2	0.000038*	0.000041*	0.000038*	0.000041*
	0.000022	0.000021	0.000022	0.000022
Distance to nearest major road (meters)	0.000066**	0.000008	0.000066**	0.000008
	0.000024	0.000032	0.000024	0.000032
Excellent grade building quality indicator	2.0235**	1.8454**	2.0315**	1.8527**
	0.2558	0.2558	0.2567	0.2568
Good grade building quality indicator	1.8122**	1.7107**	1.8208**	1.7207**
	0.2215	0.2208	0.2225	0.2219
Average grade building quality indicator	1.2655**	1.1425**	1.2736**	1.1496**
	0.2147	0.2127	0.2157	0.2136
Poor grade building quality indicator	-	-	-	-
	-	-	-	-
Urbanized area indicator	0.1467**	-0.2041	0.1387**	-0.2019
	0.0662	0.1278	0.0668	0.1282
Garages	0.2300**	0.2358**	0.2334**	0.2372**
	0.0521	0.0514	0.0524	0.0517
Pools	0.1551	0.1039	0.1670	0.1129
	0.1284	0.1272	0.1295	0.1284
Public water indicator	-0.0907	0.0362	-0.0864	0.0392
	0.0596	0.0811	0.0599	0.0816
Constant	9.2143**	9.5379**	9.1671**	9.5347**
	0.2618	0.3187	0.2782	0.3298
County Dummies?	No	Yes	No	Yes
School District Dummies?	No	No	No	No
Year Dummies?	No	No	Yes	Yes
Sample Size	1512	1512	1512	1512
R^2	0.4038	0.4372	0.4061	0.4393

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*).

Table 6.1, continued

Variable	(5)	(6)	(7)	(8)
Lot size (acres)	0.0379**	0.0376**	0.0376**	0.0381**
	0.0093	0.0094	0.0094	0.0094
Height of home (number of stories)	-0.1195	-0.1206	-0.1325	-0.1234
	0.0826	0.0829	0.0823	0.0829
Finished living area (sq Ft)	0.0002**	0.0002**	0.0002**	0.0002**
	0.0001	0.0001	0.0001	0.0001
Fireplaces	0.1023**	0.0993**	0.0904**	0.0999**
	0.0409	0.0411	0.0407	0.0412
Bedrooms	-0.0008	0.0015	-0.0078	-0.0038
	0.0384	0.0385	0.0382	0.0386
Full bathrooms	0.1013	0.1049*	0.0988	0.1070*
	0.0633	0.0635	0.0633	0.0638
Half bathrooms	-0.0218	-0.0298	0.0378	-0.0141
	0.0709	0.0715	0.0705	0.0714
Age of home (years)	-0.0128**	-0.0130**	-0.0094**	-0.0113**
	0.0033	0.0034	0.0032	0.0033
Age^2	0.000061**	0.000062**	0.0000	0.0001**
	0.000022	0.000023	0.0000	0.0000
Distance to nearest major road (meters)	0.000004	0.000003	0.0000	0.0000
	0.000033	0.000033	0.0000	0.0000
Excellent grade building quality indicator	1.8951**	1.9105**	1.9040**	1.8847**
	0.2566	0.2577	0.2545	0.2584
Good grade building quality indicator	1.7055**	1.7213**	1.6728**	1.7328**
	0.2206	0.2217	0.2198	0.2226
Average grade building quality indicator	1.1065**	1.1177**	1.1448**	1.1601**
	0.2125	0.2134	0.2131	0.2145
Poor grade building quality indicator	-	-	-	-
	-	-	-	-
Urbanized area indicator	-0.2113*	-0.2106	0.0441	-0.2990**
	0.1278	0.1282	0.1061	0.1512
Garages	0.2344**	0.2353**	0.2342**	0.2351**
	0.0515	0.0517	0.0517	0.0518
Pools	0.0872	0.0955	0.1286	0.1264
	0.1277	0.1288	0.1273	0.1289
Public water indicator	-0.0272	-0.0269	-0.0646	0.0033
	0.0819	0.0823	0.0682	0.0843
Constant	9.3242**	9.3057**	9.6964**	12.0710**
	0.2985	0.3116	0.7309	1.2471
County Dummies?	No	No	No	Yes
School District Dummies?	Yes	Yes	No	No
Year Dummies?	No	Yes	No	Yes
Demographic Variables?	No	No	Yes	Yes
Sample Size	1512	1512	1512	1512
R^2	0.4407	0.4431	0.4222	0.4436

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*).

6.3 Proximity Treatment Variable Results

After determining that the hedonic attributes of the dataset have the expected signs and significance I add the simple proximity variables to the regressions. Table 6.2 contains the results of the proximity treatment variable estimation results. Models 1 through 9 do not include any fixed effects, while Models 10 through 18 include both county level and year fixed effects. Additionally, results for models that include different combinations of fixed effects, including school district effects can be found in Appendix C. The results of the models in Appendix C with year fixed effects only are similar to those within Models 1 through 9 of Table 6.2 and the results of the models with spatial fixed effects only are similar to the results of Models 10 through 18.

In the model specifications using proximity variables without fixed effects, distance to the nearest gas or oil field, distance to the nearest natural gas storage well, distance to the nearest observation well, distance to the nearest abandoned natural gas storage wells, distance to the nearest gas or oil extraction well, and distance to the nearest oil extraction well are all significant at the 10 percent level. The results in Model 2 indicate that a one kilometer increase in distance to the nearest natural gas or oil field results in a 1.7 percent increase in property value. Model 3 indicates that a one kilometer increase in distance to the nearest natural gas storage well results in a five percent decrease in value, and Model 4 indicates that a one kilometer increase in distance to the nearest observation well results in a 0.3 percent decrease in property value. Results from Models 8 and 9 indicate that a one kilometer increase in distance to the nearest oil or gas well, or the nearest oil well results in a 0.3 to 0.5 percent increase in property value.

The proximity treatment variables in the models without any fixed effects indicate that homes see a decrease in property values due to an increase in distance to underground natural gas storage wells. This result is contrary to my hypothesis; however it is possible that some of the impact captured by the treatment variable is in fact due to spatial differences in homes. When I add the county level fixed effects to the model the coefficients on distance to the nearest natural gas or oil field, distance to the nearest natural gas storage well, and distance to the nearest observation well become insignificant. The county level fixed effects model indicates that there are some differences in home values captured by the fixed effects that bias the estimates of the regression results when the fixed effects are not included. In addition, when county level fixed effects are added distance to the nearest gas extraction well becomes significant while distance to the nearest natural gas or oil field becomes insignificant. The sign on the proximity variables for gas extraction wells, and gas and oil wells also have a negative sign rather than the positive sign in the models without fixed effects. These basic linear functional form results indicate that the impact on housing values due to underground natural gas storage activity may be insignificant. However, a more complex functional form, including quadratic and cubic terms may be more enlightening if there are significant nonlinearities that have been neglected in the simple model. In addition, the changes in significance due to the addition of fixed effects could imply that there is some interaction between petroleum related activities and homes in urban areas.

Table 6.2 Proximity Variable Estimation Results

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Natural gas storage field indicator	-0.0961	-	-	-	-	-	-	-	-
	0.0903	-	-	-	-	-	-	-	-
Distance to nearest natural gas or oil field (kilometers)	-	0.017**	-	-	-	-	-	-	-
	-	0.0041	-	-	-	-	-	-	-
Distance to nearest natural gas storage well (kilometers)	-	-	-0.05**	-	-	-	-	-	-
	-	-	0.017	-	-	-	-	-	-
Distance to nearest observation well (kilometers)	-	-	-	-0.0031**	-	-	-	-	-
	-	-	-	0.0012	-	-	-	-	-
Distance to nearest abandoned natural gas storage well (kilometers)	-	-	-	-	0.0035**	-	-	-	-
	-	-	-	-	0.0013	-	-	-	-
Distance to nearest abandoned observation well (kilometers)	-	-	-	-	-	0.0028*	-	-	-
	-	-	-	-	-	0.0015	-	-	-
Distance to nearest natural gas extraction well (kilometers)	-	-	-	-	-	-	0.002	-	-
	-	-	-	-	-	-	0.0018	-	-
Distance to nearest natural gas and oil extraction well (kilometers)	-	-	-	-	-	-	-	0.0027**	-
	-	-	-	-	-	-	-	0.00076	-
Distance to nearest oil extraction well (kilometers)	-	-	-	-	-	-	-	-	0.0053**
	-	-	-	-	-	-	-	-	0.0015
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	No	No	No	No	No	No	No	No	No
Year Dummies?	No	No	No	No	No	No	No	No	No
Sample Size	1512	1512	1512	1512	1512	1512	1512	1512	1512
R^2	0.4043	0.4103	0.4072	0.4067	0.4068	0.4052	0.4043	0.4087	0.4092

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table 6.2, continued

Variable	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Natural gas storage field indicator	-0.067	-	-	-	-	-	-	-	-
	0.120	-	-	-	-	-	-	-	-
Distance to nearest natural gas or oil field	-	-0.02	-	-	-	-	-	-	-
(kilometers)	-	0.019	-	-	-	-	-	-	-
Distance to nearest natural gas storage well	-	-	-0.00071	-	-	-	-	-	-
(kilometers)	-	-	0.026	-	-	-	-	-	-
Distance to nearest observation well	-	-	-	0.0034	-	-	-	-	-
(kilometers)	-	-	-	0.024	-	-	-	-	-
Distance to nearest abandoned natural gas	-	-	-	-	-0.014	-	-	-	-
storage well (kilometers)	-	-	-	-	0.018	-	-	-	-
Distance to nearest abandoned observation	-	-	-	-	-	0.016	-	-	-
well (kilometers)	-	-	-	-	-	0.010	-	-	-
Distance to nearest natural gas extraction	-	-	-	-	-	-	-0.032**	-	-
well (kilometers)	-	-	-	-	-	-	0.017	-	-
Distance to nearest natural gas and oil	-	-	-	-	-	-	-	-0.034**	-
extraction well (kilometers)	-	-	-	-	-	-	-	0.013	-
Distance to nearest oil extraction well	-	-	-	-	-	-	-	-	-0.024
(kilometers)	-	-	-	-	-	-	-	-	0.016
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sample Size	1512	1512	1512	1512	1512	1512	1512	1512	1512
R^2	0.4395	0.4398	0.4393	0.4393	0.4396	0.4403	0.4407	0.4421	0.4401

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

6.4 Proximity Treatment Variable and Water Interaction Results

Previous literature analyzing the impact of shale gas extraction on nearby property values has found little impact due to proximity variables alone, however when an interaction with water source is added results indicate that homes without access to public water do see a significant negative impact on property values (Muehlenbachs, Spiller and Timmins 2012). Underground natural gas storage, and natural gas and oil extraction activities present risks for groundwater contamination, which are greater for homeowners relying on well water instead of a public water source. I hypothesize that although the impact on property values due to proximity of underground natural gas storage appears to be insignificant in the simple linear models, it is possible that adding an interaction term to the regressions will show an impact with statistical significance for homes without access to public water.

Models 1 through 9 in Table 6.3 show the estimation results from the proximity treatment variable and public water indicator regressions without spatial or temporal fixed effects. The only water interaction term that is significant is the water interaction term with distance to the nearest observation well. For the interaction term with water, when a home has access to public water ($z = 1$), the percent impact on property values can be calculated as $\%\Delta p = 100(\beta_1 + \beta_3)$ for the simple equation $\ln p = c + \beta_1 x + \beta_2 z + \beta_3 xz$, where x is the proximity treatment variable and z is the binary variable for access to public water. The coefficient on the interaction term between public water and proximity to an observation well indicates that when a home has access to public water, a one kilometer increase in distance to the nearest observation well results in a 0.06 percent decrease in value. Additionally, in the regressions without fixed effects, distance to the nearest natural gas field is significant and positive, representing a one percent increase in value for a one kilometer increase in distance to the nearest oil or gas field. The variable for proximity to an abandoned observation well is positive and significant, as is distance to the nearest oil extraction well.

Given that adding spatial and temporal fixed effects to the original proximity regressions identified an impact due to geographic region that was captured within the proximity estimates, it is equally reasonable that these effects are present in the water interaction models. Models 10 through 18 in Table 6.3 include county and year fixed effects as well as proximity variables and water interaction terms. When the fixed effects are added to the regression, distance to the nearest natural gas or oil field becomes insignificant as does distance to the nearest oil extraction well. The significance of the water interaction term with proximity to the nearest observation well decreases in significance from the five percent level to the 10 percent level and the magnitude decreases, however the coefficient does remain negative. Distance to the nearest gas extraction well and distance to the nearest gas and oil extraction well become positive at the 10 percent level, and each results in an approximate 3.4 percent decrease in value for a one kilometer increase in distance to the nearest extraction well.

The changes in significance seen in the water interaction and proximity results mirror the changes in significance seen in the basic proximity treatment variable regressions when temporal and spatial fixed effects are added. This indicates that the underground natural gas storage well proximity variables catch some impact due to variations in location rather than actual impact due to the proximity of storage. These results also indicate that the impact of underground natural gas storage activities on nearby homes is very limited, even when accounting for differences in water sources.

Table 6.3 Proximity Variable and Public Water Access Interaction Estimation Results

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Natural gas storage field indicator	-0.0597	-	-	-	-	-
	0.1608	-	-	-	-	-
Natural gas storage field indicator X Public Water	-0.0524	-	-	-	-	-
	0.1912	-	-	-	-	-
Distance to nearest natural gas or oil field (kilometers)	-	0.014**	-	-	-	-
	-	0.0052	-	-	-	-
Distance to nearest natural gas or oil field (kilometers) X	-	0.0051	-	-	-	-
Public Water	-	0.0059	-	-	-	-
Distance to nearest natural gas storage well (kilometers)	-	-	-0.045	-	-	-
	-	-	0.03	-	-	-
Distance to nearest natural gas storage well (kilometers)	-	-	-0.0066	-	-	-
X Public Water	-	-	0.036	-	-	-
Distance to nearest observation well (kilometers)	-	-	-	0.00066	-	-
	-	-	-	0.0017	-	-
Distance to nearest observation well (kilometers) X	-	-	-	-0.0069**	-	-
Public Water	-	-	-	0.0022	-	-
Distance to nearest abandoned natural gas storage well	-	-	-	-	0.0028	-
(kilometers)	-	-	-	-	0.0018	-
Distance to nearest abandoned natural gas storage well	-	-	-	-	0.0011	-
(kilometers) X Public water	-	-	-	-	0.0021	-
Distance to nearest abandoned observation well	-	-	-	-	-	0.004**
(kilometers)	-	-	-	-	-	0.0019
Distance to nearest abandoned observation well	-	-	-	-	-	-0.0022
(kilometers) X Public Water	-	-	-	-	-	0.0022
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	No	No	No	No	No	No
Year Dummies?	No	No	No	No	No	No
Sample Size	1512	1512	1512	1512	1512	1512
R^2	0.4043	0.4031	0.4072	0.4107	0.4069	0.4057

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table 6.3, continued

Variable	(7)	(8)	(9)	(10)	(11)	(12)
Natural gas storage field indicator	-	-	-	0.1604	-	-
	-	-	-	0.2363	-	-
Natural gas storage field indicator X Public Water	-	-	-	-0.2670	-	-
	-	-	-	0.2396	-	-
Distance to nearest natural gas or oil field (kilometers)	-	-	-	-	-0.023	-
	-	-	-	-	0.020	-
Distance to nearest natural gas or oil field (kilometers) X	-	-	-	-	0.0055	-
Public Water	-	-	-	-	0.0070	-
Distance to nearest natural gas storage well (kilometers)	-	-	-	-	-	-0.028
	-	-	-	-	-	0.034
Distance to nearest natural gas storage well (kilometers)	-	-	-	-	-	0.051
X Public Water	-	-	-	-	-	0.041
Distance to nearest natural gas extraction well	-0.00019	-	-	-	-	-
(kilometers)	0.0034	-	-	-	-	-
Distance to nearest natural gas extraction well	0.003	-	-	-	-	-
(kilometers) X Public Water	0.0039	-	-	-	-	-
Distance to nearest natural gas and oil extraction well	-	0.0014	-	-	-	-
(kilometers)	-	0.0013	-	-	-	-
Distance to nearest natural gas and oil extraction well	-	0.0018	-	-	-	-
(kilometers) X Public Water	-	0.0015	-	-	-	-
Distance to nearest oil extraction well (kilometers)	-	-	0.0042**	-	-	-
	-	-	0.0018	-	-	-
Distance to nearest oil extraction well (kilometers) X	-	-	0.0024	-	-	-
Public Water	-	-	0.0023	-	-	-
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	No	No	No	Yes	Yes	Yes
Year Dummies?	No	No	No	Yes	Yes	Yes
Sample Size	1512	1512	1512	1512	1512	1512
R^2	0.4045	0.4093	0.4096	0.4399	0.44	0.4399

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table 6.3, continued

Variable	(13)	(14)	(15)	(16)	(17)	(18)
Distance to nearest observation well (kilometers)	0.0012	-	-	-	-	-
	0.0244	-	-	-	-	-
Distance to nearest observation well (kilometers) X	-0.0044*	-	-	-	-	-
Public Water	0.0024	-	-	-	-	-
Distance to nearest abandoned natural gas storage well	-	-0.014	-	-	-	-
(kilometers)	-	0.018	-	-	-	-
Distance to nearest abandoned natural gas storage well	-	-0.00037	-	-	-	-
(kilometers) X Public water	-	0.0026	-	-	-	-
Distance to nearest abandoned observation well	-	-	0.016	-	-	-
(kilometers)	-	-	0.011	-	-	-
Distance to nearest abandoned observation well	-	-	-0.00064	-	-	-
(kilometers) X Public Water	-	-	0.0026	-	-	-
Distance to nearest natural gas extraction well	-	-	-	-0.034**	-	-
(kilometers)	-	-	-	0.017	-	-
Distance to nearest natural gas extraction well	-	-	-	0.0050	-	-
(kilometers) X Public Water	-	-	-	0.0048	-	-
Distance to nearest natural gas and oil extraction well	-	-	-	-	-0.033**	-
(kilometers)	-	-	-	-	0.013	-
Distance to nearest natural gas and oil extraction well	-	-	-	-	0.0017	-
(kilometers) X Public Water	-	-	-	-	0.0018	-
Distance to nearest oil extraction well (kilometers)	-	-	-	-	-	-0.023
	-	-	-	-	-	0.016
Distance to nearest oil extraction well (kilometers) X	-	-	-	-	-	0.0017
Public Water	-	-	-	-	-	0.0026
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies?	Yes	Yes	Yes	Yes	Yes	Yes
Sample Size	1512	1512	1512	1512	1512	1512
R^2	0.4407	0.4396	0.4403	0.4411	0.4424	0.4403

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

6.5 Quadratic Functional Form Specification Results

In order to capture potential nonlinear impacts from underground natural gas storage activities on housing values, I run regressions similar to the basic proximity treatment variable regressions, this time including squared proximity terms. This squared proximity term allows the impact of the type of petroleum activity in question to be nonlinear. I run regressions with and without fixed effects. Table 6.4 includes estimation results for the regressions without any fixed effects and for those including both county and year fixed effects. The estimation results from regressions with only spatial fixed effects can be found in Appendix C.

Models 1 through 8 do not include any type of fixed effects. These results show significance for a nonlinear functional form for distance to the nearest observation well, distance to the nearest abandoned natural gas storage well, distance to the nearest abandoned observation well, and distance to the nearest gas and oil extraction well. The percentage impact on housing values from an additional meter of distance from any of the proximity treatment variables can be calculated as $100(\beta_1 + 2\beta_2 z)$, in which β_1 is the coefficient of the linear proximity term, β_2 is the coefficient on the quadratic proximity term and z is the proximity term. When the functional form is nonlinear the impact on housing values is dependent on the distance itself. At a distance of 1,000 meters or one kilometer from the nearest observation well, there is a decrease in value of 4.45 percent for an additional kilometer of distance. At the mean distance, 17,349.66 meters, the impact is a decrease in value of 2.72 percent per additional kilometer of distance. This demonstrates that the negative impact is decreasing as distance increases. A negative impact for an increase in distance is contrary to the hypothesis that underground natural gas storage activities have a negative impact on property values. However, these model results do not contain any fixed effects, which have in previous regressions captured some spatial impacts on housing values.

When county level and year fixed effects are included the estimation results change dramatically. Proximity to the nearest observation well, abandoned natural gas storage well, abandoned observation well, and distance to the nearest gas and oil extraction well all become insignificant. This change indicates that some spatial impact on home values was being captured in the initial estimation results. Both the linear and quadratic proximity terms become significant in the fixed effect estimation results. At a distance of one kilometer the impact of an additional kilometer of distance increases property values by 9.2 percent. At the mean distance, 2,454.12 meters, the impact of an additional kilometer of distance is 5.13 percent. These results indicate that the impact of underground natural gas storage wells is nonlinear and decreasing as distance increases, which would be expected logically since as distance increases an additional kilometer of distance becomes less important. Additionally, both terms are jointly significant at a distance of one kilometer, with a joint variance of 1.78×10^{-9} and a joint standard deviation of 4.22×10^{-5}, therefore the quadratic term is significant at the five percent level. However the terms become insignificant at the mean distance. Joint significance of the linear and quadratic terms indicates that the impact of underground natural gas storage wells is quadratic and significant, at a distance of one kilometer from a home, but the impact is no longer significant at a distance of 2.45 kilometers or greater.

Table 6.4 Quadratic Functional Form Specification Estimation Results

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Distance to nearest natural gas or oil field	0.0138	-	-	-	-	-
(kilometers)	0.0153	-	-	-	-	-
Distance to nearest natural gas or oil field	0.0000996	-	-	-	-	-
(kilometers) squared	0.000501	-	-	-	-	-
Distance to nearest natural gas storage well	-	0.0577	-	-	-	-
(kilometers)	-	0.0351	-	-	-	-
Distance to nearest natural gas storage well	-	-0.0145**	-	-	-	-
(kilometers) squared	-	0.00418	-	-	-	-
Distance to nearest observation well (kilometers)	-	-	-0.0456**	-	-	-
	-	-	0.0132	-	-	-
Distance to nearest observation well (kilometers)	-	-	0.000525**	-	-	-
squared	-	-	0.000162	-	-	-
Distance to nearest abandoned natural gas	-	-	-	0.0268**	-	-
storage well (kilometers)	-	-	-	0.00414	-	-
Distance to nearest abandoned natural gas	-	-	-	-0.000312**	-	-
storage well (kilometers) squared	-	-	-	0.0000527	-	-
Distance to nearest abandoned observation well	-	-	-	-	0.0309**	-
(kilometers)	-	-	-	-	0.00454	-
Distance to nearest abandoned observation well	-	-	-	-	-0.000326**	-
(kilometers) squared	-	-	-	-	0.0000498	-
Distance to nearest natural gas extraction well	-	-	-	-	-	0.00992
(kilometers)	-	-	-	-	-	0.00730
Distance to nearest natural gas extraction well	-	-	-	-	-	-0.000129
(kilometers) squared	-	-	-	-	-	0.000115
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	No	No	No	No	No	No
Year Dummies?	No	No	No	No	No	No
Sample Size	1512	1512	1512	1512	1512	1512
R^2	0.4104	0.412	0.4108	0.4204	0.4219	0.4048

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table 6.4, continued

Variable	(7)	(8)	(9)	(10)	(11)	(12)
Distance to nearest natural gas or oil field (kilometers)	-	-	0.0286	-	-	-
	-	-	0.0277	-	-	-
Distance to nearest natural gas or oil field (kilometers)	-	-	-0.00259**	-	-	-
squared	-	-	0.00105	-	-	-
Distance to nearest natural gas storage well (kilometers)	-	-	-	0.122**	-	-
	-	-	-	0.0458	-	-
Distance to nearest natural gas storage well (kilometers)	-	-	-	-0.0144**	-	-
squared	-	-	-	0.00441	-	-
Distance to nearest observation well (kilometers)	-	-	-	-	0.00534	-
	-	-	-	-	0.0306	-
Distance to nearest observation well (kilometers)	-	-	-	-	-0.0000359	-
squared	-	-	-	-	0.000346	-
Distance to nearest abandoned natural gas storage well	-	-	-	-	-	-0.0273
(kilometers)	-	-	-	-	-	0.0317
Distance to nearest abandoned natural gas storage well	-	-	-	-	-	0.000174
(kilometers) squared	-	-	-	-	-	0.000353
Distance to nearest natural gas and oil extraction well	0.0153**	-	-	-	-	-
(kilometers)	0.00346	-	-	-	-	-
Distance to nearest natural gas and oil extraction well	-0.0000922**	-	-	-	-	-
(kilometers) squared	0.0000245	-	-	-	-	-
Distance to nearest oil extraction well (kilometers)	-	-0.00326	-	-	-	-
	-	0.00537	-	-	-	-
Distance to nearest oil extraction well (kilometers)	-	0.000114*	-	-	-	-
squared	-	0.0000688	-	-	-	-
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	No	No	Yes	Yes	Yes	Yes
Year Dummies?	No	No	Yes	Yes	Yes	Yes
Sample Size	1512	1512	1512	1512	1512	1512
R^2	0.4142	0.4103	0.4421	0.4434	0.4393	0.4397

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table 6.4, continued

Variable	(13)	(14)	(15)	(16)
Distance to nearest abandoned observation well (kilometers)	0.0277	-	-	-
	0.0179	-	-	-
Distance to nearest abandoned observation well (kilometers) squared	-0.000253	-	-	-
	0.000315	-	-	-
Distance to nearest natural gas extraction well (kilometers)	-	-0.0323	-	-
	-	0.025	-	-
Distance to nearest natural gas extraction well (kilometers) squared	-	0.0000126	-	-
	-	0.000485	-	-
Distance to nearest natural gas and oil extraction well (kilometers)	-	-	-0.0249	-
	-	-	0.0204	-
Distance to nearest natural gas and oil extraction well (kilometers) squared	-	-	-0.000114	-
	-	-	0.000194	-
Distance to nearest oil extraction well (kilometers)	-	-	-	0.0116
	-	-	-	0.0213
Distance to nearest oil extraction well (kilometers) squared	-	-	-	-0.000767**
	-	-	-	0.000298
Hedonic Attributes?	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	Yes
Year Dummies?	Yes	Yes	Yes	Yes
Sample Size	1512	1512	1512	1512
R^2	0.4405	0.4407	0.4422	0.4426

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

6.6 Cubic Functional Form Specification Results

Given that the spatial and temporal fixed effects have been important in controlling for unobservable variables in the proximity treatment variable regressions so far, the estimation results presented within this section and all following will only report those regressions that included fixed effects when applicable. All estimation results for models without fixed effects or those with only spatial or only temporal fixed effects can be found in Appendix C.

The nonlinear estimation results clearly indicate that there is a significant nonlinear impact due to proximity of underground natural gas storage wells. It follows that other types of wells could have nonlinear impacts as well; therefore I include a cubic proximity term in Models 1 through 8 in Table 6.5. These results indicate that the linear, quadratic and cubic proximity variables for observation wells, Model 3, are significant. In order to calculate the percentage impact on property values I use the equation: $100(\beta_1 + 2\beta_2 z + 3\beta_3 z^2)$, in which z is the proximity treatment variable, β_1 is the coefficient on the linear term, β_2 is the coefficient on the quadratic term, and β_3 is the coefficient on the cubic term. As in the quadratic functional form specification, the impact of proximity on home values is dependent on proximity. In the case of the proximity to an observation well, at a distance of one kilometer the impact is an increase in value of 10.03 percent. The three proximity terms are jointly significant at a distance of one kilometer, and at greater distances as well. This indicates that the impact of an observation well on home values is cubic and an increase in distance at one kilometer has a positive impact on value. Further, the shape of the cubic function implies that the relationship between distance and price is not only non-linear, but the marginal impact can flatten at larger distances.

In addition to observation wells, the linear and nonlinear proximity terms for oil extraction wells are significant at the five percent level. At a distance of one kilometer an increase in distance to the nearest oil extraction well results in a 6.5 percent increase in housing values. At the mean distance to the nearest oil extraction well, 23,086.81 meters or 23.09 kilometers, the impact of a one kilometer increase in distance is a decrease of 10.79 percent in housing value. However, the nonlinear terms are significant at the 10 percent level at one kilometer and are insignificant at distances greater 2.5 kilometers approximately. This indicates that the impact due to proximity oil extraction wells is cubic, but it is insignificant at larger distances.

These results indicate that homeowners prefer homes at greater distances from oil extraction wells, however the impact becomes increasingly less significant the farther away a home is from an oil extraction well. Comparatively, the impact due to proximity to an observation well is greater in magnitude at a distance of one kilometer than the impact of an oil extraction well at one-kilometer distance. In addition, the significance of the impact due to proximity to an observation does not become insignificant at greater distances, thus homeowners prefer homes located at greater distance from observation wells and this impact continues to impact their decisions even at distances greater than 2.5 kilometers. These results imply that the magnitude of some underground natural gas storage activities has a greater impact than do oil extraction activities and that this preference continues to have an impact at greater distances than the distance at which homeowners no longer consider distance to the nearest oil extraction well.

Table 6.5 Cubic Functional Form Specification Estimation Results

Variable	(1)	(2)	(3)	(4)
Distance to nearest natural gas or oil field (kilometers)	0.0434	-	-	-
	0.0494	-	-	-
Distance to nearest natural gas or oil field (kilometers)	-0.00481	-	-	-
squared	0.00623	-	-	-
Distance to nearest natural gas or oil field (kilometers)	0.0000512	-	-	-
cubed	0.000141	-	-	-
Distance to nearest natural gas storage well	-	0.0326	-	-
(kilometers)	-	0.0913	-	-
Distance to nearest natural gas storage well	-	0.00986	-	-
(kilometers) squared	-	0.0217	-	-
Distance to nearest natural gas storage well	-	-0.00136	-	-
(kilometers) cubed	-	0.00119	-	-
Distance to nearest observation well (kilometers)	-	-	0.139**	-
	-	-	0.0457	-
Distance to nearest observation well (kilometers)	-	-	-0.0164**	-
squared	-	-	0.00419	-
Distance to nearest observation well (kilometers) cubed	-	-	0.000129*	-
	-	-	0.0000329	-
Distance to nearest abandoned natural gas storage well	-	-	-	0.0198
(kilometers)	-	-	-	0.0369
Distance to nearest abandoned natural gas storage well	-	-	-	-0.00248**
(kilometers) squared	-	-	-	0.00113
Distance to nearest abandoned natural gas storage well	-	-	-	0.0000259**
(kilometers) cubed	-	-	-	0.0000104
Hedonic Attributes?	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	Yes
Year Dummies?	Yes	Yes	Yes	Yes
Sample Size	1512	1512	1512	1512
R^2	0.4421	0.4439	0.4452	0.442

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table 6.5, continued

Variable	(5)	(6)	(7)	(8)
Distance to nearest abandoned observation well	0.0434	-	-	-
(kilometers)	0.0309	-	-	-
Distance to nearest abandoned observation well	-0.000855	-	-	-
(kilometers) squared	0.00101	-	-	-
Distance to nearest abandoned observation well	0.00000491	-	-	-
(kilometers) cubed	0.00000786	-	-	-
Distance to nearest natural gas extraction well	-	-0.0179	-	-
(kilometers)	-	0.0408	-	-
Distance to nearest natural gas extraction well	-	-0.000759	-	-
(kilometers) squared	-	0.0018	-	-
Distance to nearest natural gas extraction well	-	0.00000792	-	-
(kilometers) cubed	-	0.0000177	-	-
Distance to nearest natural gas and oil extraction well	-	-	-0.0312	-
(kilometers)	-	-	0.0296	-
Distance to nearest natural gas and oil extraction well	-	-	0.0000815	-
(kilometers) squared	-	-	0.000697	-
Distance to nearest natural gas and oil extraction well	-	-	-0.00000114	-
(kilometers) cubed	-	-	0.00000392	-
Distance to nearest oil extraction well (kilometers)	-	-	-	0.0747**
	-	-	-	0.0334
Distance to nearest oil extraction well (kilometers)	-	-	-	-0.00501**
squared	-	-	-	0.00175
Distance to nearest oil extraction well (kilometers)	-	-	-	0.0000343**
cubed	-	-	-	0.000014
Hedonic Attributes?	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	Yes
Year Dummies?	Yes	Yes	Yes	Yes
Sample Size	1512	1512	1512	1512
R^2	0.4407	0.4408	0.4422	0.4449

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

6.7 Proximity Treatment Variable and Urban Interaction Results

In order to determine if homes in urban areas receive a different impact from proximity to petroleum related activities, I interact the proximity treatment variables and the binary variable for urban areas. The estimation results in Table 6.6 indicate that there are statistically significant interaction effects between proximity and urban areas. The interaction effect on natural gas storage wells, observation wells, abandoned natural gas storage wells, abandoned observation wells, gas and oil extraction wells, and oil extraction wells are all significant. A home within an urban area sees a 16.33 percent increase in value due to an increase in distance of one kilometer from the nearest natural gas storage well. The baseline impact of underground natural gas storage wells is negative, but insignificant.

The impact due to observation well proximity for a home within an urban area is a decrease of 1.56 percent per kilometer. As with underground natural gas storage wells, the baseline effect of distance to the nearest observation well is negative, but insignificant. This indicates that the magnitude of the negative impact of increasing distance to the nearest observation well is increased for urban homes. This effect is also seen in the coefficients for distance to the nearest abandoned natural gas storage well and the urban interaction term. It is possible that the negative effect is caused by the fact that most of the urban homes located near petroleum extraction and storage activities are located on the edge of the urban area and would see an increase in distance from the center of the urban area when distance to the nearest well is increased, which may be the cause of the decrease in property value. This effect may not be reflected in underground natural gas storage wells because the mean distance to an underground natural gas storage well for an urban home is significantly less than the mean distance to an observation well for an urban home, as can been seen in Table C.16.

Both the baseline proximity variable and the interaction effect for distance to the nearest abandoned observation well are significant, and indicate that a home within an urban area sees an increase in value of 0.4 percent, while homes that are not within an urban area see an increase in value of 1.9 percent. However, the baseline effect and the interaction term on abandoned observation wells are not jointly significant. This indicates that proximity to the nearest abandoned observation well combined with the impact on urban homes specifically does not have an overall impact on housing values.

Distance to the nearest natural gas and oil extraction well and the interaction term are individually significant at the five percent level, and are jointly significant at the 10 percent level. The impact on an urban home of an additional kilometer distance from the nearest gas and oil extraction well is a decrease in value of 2.37 percent, while a non-urban home sees a decrease in value of 3.06 percent. The joint significance of these two terms indicates that the impact of distance to the nearest gas and oil extraction well combined with the impact on urban homes specifically does have an overall impact on housing values. The interaction term between oil extraction wells and the urban binary variable is significant at the 10 percent level and urban property values see a 1.32 percent decrease in value due to an additional kilometer in distance from the nearest oil extraction well. As with the negative impact on urban homes due to increasing distance to the nearest observation well, the overall decrease in value due to increasing distance to the nearest gas and oil, and oil extraction well may be due to a simultaneous increase in distance from the center of the urban area. However, the results also indicate that urban homes see a decrease in value of lesser magnitude than non-urban homes, which indicates that urbanity of a home provides an insulating effect against the negative impact of increasing distance to the nearest gas and oil, or oil extraction well.

When the urban interaction is added to the regressions there are almost no baseline effects of statistical significance. However, the urban interaction is significant for many of the proximity variables. Overall the results indicate that urban homes are insulated from the impacts due to proximity to petroleum related activities, whether the baseline impact is positive or negative in sign. The difference in sign of the baseline effect for underground natural gas storage wells and observation wells, compared to the results of the nonlinear models may be due to the fact that both of these treatment variables have significant nonlinear effects, which are not accounted for within these interaction models.

Table 6.6 Proximity Variable and Urban Term Interaction Estimation Results

Variable	(1)	(2)	(3)	(4)
Distance to nearest natural gas or oil field (kilometers)	-0.0205	-	-	-
	0.0193	-	-	-
Distance to nearest natural gas or oil field (kilometers) X Urban Indicator	0.007	-	-	-
	0.0156	-	-	-
Distance to nearest natural gas storage well (kilometers)	-	-0.0257	-	-
	-	0.0278	-	-
Distance to nearest natural gas storage well (kilometers) X Urban Indicator	-	0.189**	-	-
	-	0.0762	-	-
Distance to nearest observation well (kilometers)	-	-	-0.00772	-
	-	-	0.0247	-
Distance to nearest observation well (kilometers) X Urban Indicator	-	-	-0.0079**	-
	-	-	0.0031	-
Distance to nearest abandoned natural gas storage well (kilometers)	-	-	-	-0.00967
	-	-	-	0.0176
Distance to nearest abandoned natural gas storage well (kilometers) X Urban Indicator	-	-	-	-0.0208**
	-	-	-	0.0078
Hedonic Attributes?	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	Yes
Year Dummies?	Yes	Yes	Yes	Yes
Sample Size	1512	1512	1512	1512
R^2	0.4398	0.4417	0.4418	0.4423

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table 6.6, continued

Variable	(5)	(6)	(7)	(8)
Distance to nearest abandoned observation well (kilometers)	0.0189*	-	-	-
	0.0102	-	-	-
Distance to nearest abandoned observation well (kilometers) X Urban Indicator	-0.0152**	-	-	-
	0.00582	-	-	-
Distance to nearest natural gas extraction well (kilometers)	-	-0.0321*	-	-
	-	0.0167	-	-
Distance to nearest natural gas extraction well (kilometers) X Urban Indicator	-	0.00977	-	-
	-	0.0159	-	-
Distance to nearest natural gas and oil extraction well (kilometers)	-	-	-0.0306**	-
	-	-	0.013	-
Distance to nearest natural gas and oil extraction well (kilometers) X Urban Indicator	-	-	0.0073*	-
	-	-	0.00438	-
Distance to nearest oil extraction well (kilometers)	-	-	-	-0.0203
	-	-	-	0.0165
Distance to nearest oil extraction well (kilometers) X Urban Indicator	-	-	-	0.0071*
	-	-	-	0.00425
Hedonic Attributes?	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	Yes
Year Dummies?	Yes	Yes	Yes	Yes
Sample Size	1512	1512	1512	1512
R^2	0.4428	0.4409	0.4431	0.4412

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

6.8 Proximity Treatment Variable and Lot Size Interaction Results

In order to test for a relationship between the size of the lot associated with a home and the proximity to a petroleum extraction or storage related activity I include an interaction term between the continuous variable Lot Size and the continuous proximity treatment variables. Parsons (1990) argues that neglecting to weight a treatment effect, or any attribute that is dependent on location, by lot size could lead to bias in the estimates of the impact of these attributes. If the attributes dependent on location are weighted by lot size their impact becomes dependent on the size of the lot; for example a larger lot could see a smaller impact from proximity to natural gas storage wells than a home with a small lot. Table 6.7 presents the results from regressions in which proximity treatment effects are weighted by the size of the lot. As demonstrated in the model none of the interaction terms are statistically significant. Two of the proximity treatment variables are statistically significant at the 10 percent level, distance to the nearest natural gas extraction well and distance to the nearest gas and oil extraction well. However, when comparing these results to those in Table 6.2, Models 16 and 17, it is clear that the sign and magnitude of the results from the lot size weighted models are not materially different from the basic proximity treatment effect regressions. These results indicate that overall there is little if any interaction between lot size and the proximity treatment effects and that the impacts on housing values is unlikely to be dependent on the size of the property in terms of acres.

Table 6.7 Proximity Variable and Lot Size Interaction Estimation Results

Variable	(1)	(2)	(3)	(4)
Distance to nearest natural gas or oil field (kilometers)	-0.032	-	-	-
	0.0211	-	-	-
Distance to nearest natural gas or oil field (kilometers) X Lot Size	0.00308	-	-	-
	0.00223	-	-	-
Distance to nearest natural gas storage well (kilometers)	-	-0.00785	-	-
	-	0.0289	-	-
Distance to nearest natural gas storage well (kilometers) X Lot Size	-	0.00441	-	-
	-	0.00788	-	-
Distance to nearest observation well (kilometers)	-	-	0.00423	-
	-	-	0.0244	-
Distance to nearest observation well (kilometers) X Lot Size	-	-	0.00039	-
	-	-	0.000436	-
Distance to nearest abandoned natural gas storage well (kilometers)	-	-	-	-0.0141
	-	-	-	0.0175
Distance to nearest abandoned natural gas storage well (kilometers) X Lot Size	-	-	-	0.000114
	-	-	-	0.000455
Hedonic Attributes?	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	Yes
Year Dummies?	Yes	Yes	Yes	Yes
Sample Size	1512	1512	1512	1512
R^2	0.4405	0.4395	0.4396	0.4396

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table 6.7, continued

Variable	(5)	(6)	(7)	(8)
Distance to nearest abandoned observation well (kilometers)	0.0157	-	-	-
	0.0102	-	-	-
Distance to nearest abandoned observation well (kilometers) X Lot Size	0.000172	-	-	-
	0.000434	-	-	-
Distance to nearest natural gas extraction well (kilometers)	-	-0.0349**	-	-
	-	0.0169	-	-
Distance to nearest natural gas extraction well (kilometers) X Lot Size	-	0.00155	-	-
	-	0.00146	-	-
Distance to nearest natural gas and oil extraction well (kilometers)	-	-	-0.0341**	-
	-	-	0.0128	-
Distance to nearest natural gas and oil extraction well (kilometers) X Lot Size	-	-	-0.0000439	-
	-	-	0.000302	-
Distance to nearest oil extraction well (kilometers)	-	-	-	-0.0236
	-	-	-	0.0164
Distance to nearest oil extraction well (kilometers) X Lot Size	-	-	-	-0.000152
	-	-	-	0.000449
Hedonic Attributes?	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	Yes
Year Dummies?	Yes	Yes	Yes	Yes
Sample Size	1512	1512	1512	1512
R^2	0.4403	0.4412	0.4421	0.4402

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

6.9 Intensity Treatment Variable Results

Proximity is one simple way to measure the impact of underground natural gas storage on nearby property values, however it is likely that factors more complex than proximity are influential in a buyer's purchasing decision and therefore in the marginal willingness to pay for underground natural gas storage activities. Guignet (2013) finds more significant impacts due to underground leaking storage tanks when using water well tests and measures of property owner knowledge of the leaking storage tank. His study suggests that proximity may not be the best measure of environmental quality. In order to use a different measure of the impact of underground natural gas storage on nearby property values I also use models with measures of intensity for petroleum extraction and natural gas storage related activities. The measures of intensity used are a count of different types of wells within two miles of a home. These count variables include the count of all types of wells, the count of storage related wells, the count of underground natural gas storage wells, the count of observation wells, the count of abandoned storage related wells, and the count of extraction related wells within two miles.

Results from the models employing a measure of intensity rather than a proximity variable are included in Table 6.8. The results indicate that in general higher intensity, more wells within two miles, decreases property values. Abandoned underground storage related well intensity, extraction well intensity and the overall intensity of well variables are not significant. However, all of the variables related to underground natural gas storage are significant at the 10 percent level. An additional storage related well of any type decreases property value by 0.43 percent. A decrease of 0.43 percent at the mean sale price, $94,559.90 is a loss in value of $406.61, and at the maximum sale price, $625,000 is a loss of $2687.50. An additional underground natural gas storage well leads to a reduction in value of 0.48 percent, and an additional observation well leads to a reduction in value of 2.64 percent. The results of the models employing measures of intensity indicate that underground natural gas storage wells do have a statistically significant and large negative impact on nearby property values.

Table 6.8 Intensity Variable Estimation Results

Variable	(1)	(2)	(3)	(4)	(5)	(6)
All Wells Intensity Measure (Count of wells within 2 miles)	-0.0262	-	-	-	-	-
	0.0166	-	-	-	-	-
Storage Intensity Measure (Count of all Gas Storage and Observation wells within 2 miles)	-	-0.0431*	-	-	-	-
	-	0.0241	-	-	-	-
Gas Storage Wells Only Intensity Measure (Count of all Gas Storage wells within 2 miles)	-	-	-0.0477*	-	-	-
	-	-	0.0281	-	-	-
Observation Wells Intensity Measure (Count of all Observation wells within 2 miles)	-	-	-	-0.264*	-	-
	-	-	-	0.138	-	-
Abandoned Gas Storage Intensity Measure (Count of all Abandoned Gas Storage wells within 2 miles)	-	-	-	-	0.0773	-
	-	-	-	-	0.130	-
ExtractionWells Only Intensity Measure (Count of all Extraction wells within 2 miles)	-	-	-	-	-	-0.015
	-	-	-	-	-	0.0246
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies?	Yes	Yes	Yes	Yes	Yes	Yes
Sample Size	1512	1512	1512	1512	1512	1512
R^2	0.4403	0.4406	0.4404	0.4407	0.4395	0.4395

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1. All results reported are scaled by a factor of 10.

6.10 Intensity Treatment Variable and Water Interaction Results

As with the proximity treatment effects it is possible that the impact due to the intensity of well activity could be more significant when accounting for homes dependent on different sources of water, as demonstrated by Muehlenbachs, Spiller and Timmins (2012). In order to account for differences in sources of water I add an interaction term between the intensity measures and the binary variable for access to public water. The estimation results for these models can be found in Table 6.9.

The interaction terms and intensity measures are all significant at the five percent level for all models related to underground natural gas storage, Models 2 through 5. These significant variables include intensity of abandoned underground natural gas storage related activities. An additional storage related well leads to a decrease of 0.31 percent in nearby property values with access to public water. A home with public water sees a decrease in value of 0.32 percent for an additional underground natural gas storage well. For an additional observation well the decrease in value is 2.33 percent. These results imply that homes with access to public water see an overall negative impact due to increased intensity of underground natural gas storage related activities. An increase of one abandoned storage well increases property value for a home without access to public water by 2.57 percent, however for a home with access to public water there is a decrease in value of 1.46 percent. The result for abandoned storage well seems contrary, however, except for observation well intensity, the intensity measures and interaction terms are all jointly insignificant. This implies that homes with access to public water are not impacted by underground storage related activities.

A home without access to public water sees a decrease in value of 1.32 percent for an additional storage related well. This percentage loss in value is much larger in magnitude than for a home with access to public water. At the mean sale price of $94,559.90, this is a $1,248.19 reduction in value. Homes without access to public water see a decrease in value of 1.53 percent for an additional underground natural gas storage well, and a decrease of 6.12 percent for an additional observation well. These results demonstrate that homes without access to public water see statistically significant and larger magnitude impacts due to underground natural gas storage activities.

Interestingly observation wells seem to consistently have impacts of larger magnitude than underground natural gas storage wells. An observation well is used to monitor the storage field, in order to ensure that no natural gas is migrating out of the formation. The larger magnitude impact of observation wells could be due to the fact that when the need for monitoring of a facility is apparent homeowners experience an increased perception of risk, as compared to the actual operation of the facility. As with the results presented in Guignet (2013), homeowners with greater information see greater impacts due to leaking underground storage tanks. A homeowner located near an observation well may have greater information about the risks due to the underground natural gas storage facility.

Table 6.9 Intensity Variable and Water Access Interaction Estimation Results

Variable	(1)	(2)	(3)	(4)	(5)	(6)
All Wells Intensity Measure (Count of wells within 2 miles)	-0.0538**	-	-	-	-	-
	0.0269	-	-	-	-	-
All Wells Intensity Measure (Count of wells within 2 miles) X	0.0397	-	-	-	-	-
Public Water Indicator	0.0304	-	-	-	-	-
Storage Intensity Measure (Count of all Gas Storage and	-	-0.132**	-	-	-	-
Observation wells within 2 miles)	-	0.0440	-	-	-	-
Storage Intensity Measure (Count of all Gas Storage and	-	0.101**	-	-	-	-
Observation wells within 2 miles) X Public Water Indicator	-	0.0418	-	-	-	-
Gas Storage Wells Only Intensity Measure (Count of all Gas	-	-	-0.153**	-	-	-
Storage wells within 2 miles)	-	-	0.0543	-	-	-
Gas Storage Wells Only Intensity Measure (Count of all Gas	-	-	0.121**	-	-	-
Storage wells within 2 miles) X Public Water Indicator	-	-	0.0534	-	-	-
Observation Wells Intensity Measure (Count of all Observation	-	-	-	-0.612**	-	-
wells within 2 miles)	-	-	-	0.202	-	-
Observation Wells Intensity Measure (Count of all Observation	-	-	-	0.379**	-	-
wells within 2 miles) X Public Water Indicator	-	-	-	0.160	-	-
Abandoned Gas Storage Intensity Measure (Count of all	-	-	-	-	0.257**	-
Abandoned Gas Storage wells within 2 miles)	-	-	-	-	0.146	-
Abandoned Gas Storage Intensity Measure (Count of all	-	-	-	-	-0.403**	-
Abandoned Gas Storage wells within 2 miles) X Public Water	-	-	-	-	0.148	-
ExtractionWells Only Intensity Measure (Count of all Extraction	-	-	-	-	-	-0.0270
wells within 2 miles)	-	-	-	-	-	0.0319
ExtractionWells Only Intensity Measure (Count of all Extraction	-	-	-	-	-	0.0274
wells within 2 miles) X Public Water Indicator	-	-	-	-	-	0.0466
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies?	Yes	Yes	Yes	Yes	Yes	Yes
Sample Size	1512	1512	1512	1512	1512	1512
R^2	0.4409	0.4428	0.4424	0.4429	0.4423	0.4396

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1. All results reported are scaled by a factor of 10.

6.11 Intensity Threshold Treatment Variable Results

In order to examine the impact of higher intensity of storage related activities on nearby homes I use a binary variable to differentiate homes with a higher intensity of petroleum related activities from those with lower intensity. The results presented in Models 1 through 4 indicate that the threshold variables are not statistically significant, or that homes with higher intensity of petroleum related activities do not see a specific impact due to the higher intensity of wells.

Table 6.10 Threshold Intensity Variable Estimation Results

Variable	(1)	(2)	(3)	(4)
All Wells Threshold Binary Variable (Indicator for homes with 20 or more wells within 2 miles)	-0.243	-	-	-
	0.655	-	-	-
Storage Wells Threshold Binary Variable (Indicator for homes with 20 or more wells within 2 miles)	-	-0.355	-	-
	-	0.715	-	-
Gas Storage Wells Threshold Binary Variable (Indicator for homes with 15 or more wells within 2 miles)	-	-	0.820	-
	-	-	0.756	-
ExtractionWells Threshold Binary Variable (Indicator for homes with 2 or more wells within 2 miles)	-	-	-	-0.918
	-	-	-	0.835
Hedonic Attributes?	Yes	Yes	Yes	Yes
County Dummies?	No	No	No	No
Year Dummies?	No	No	No	No
Sample Size	1512	1512	1512	1512
R^2	0.4039	0.4039	0.4043	0.4043

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1. All results reported are scaled by a factor of 10.

6.12 Repeat Sales Hedonic Attribute Results

My data consists of 529 repeat sales, or homes that transacted more than one time during the time period of analysis. A repeat sales analysis is essentially a parcel level fixed effects analysis, therefore allowing me to control for unobserved characteristics at the parcel level. The repeat sales approach was used by Palmquist (1982) within the field of environmental economics. Heintzelman and Tuttle (2012) use a repeat sales approach within their study of the impact of wind power facilities on nearby property values.

Estimation results from models using only basic hedonic attributes are in Table 6.11. These results indicate that homeowners within the repeat sales dataset behave as expected. Homeowners in general prefer a larger property size, better building quality and more amenities. An increase of one acre in lot size increases property value by 9.24 percent, looking at Model 3 results. The addition of a fireplace increases property value by 14.29 percent. The primary difference illustrated in the repeat sales approach from the full dataset models is that the variable for full bathrooms becomes significant at the five percent level, and the increase of one full bathroom leads to an increase in value of 31.69 percent. Additionally, homeowners prefer more garages, the addition of one garage results in an increase in value of 20.23 percent. As with the estimation results for the hedonic variables in the full dataset, variables such as fireplaces, full bathrooms and garages may be capturing the effects of bundles of attributes, rather than only the impact of the attribute represented. A home with more full bathrooms may have other attractive attributes, as may a home with more fireplaces or more garages.

In addition age of home has a nonlinear impact on home value. The increase of one year in age reduces property value by 0.89 percent at the mean value for age, 62.87 years. For a home of only one year in age the addition of a year decreases property value by 1.37 percent. The turning point at which age has a positive impact on property value is 88.46 years.

The results from Model 3 also indicate that a home with excellent grade building quality has an increase of 250.7 percent in value over homes of poor building quality. Good grade homes see an increase of 192.12 percent in value and average grade homes see an increase of 118.26 percent of poor building quality homes. The impacts due to these building quality indicators are large in magnitude, however, as with the results from the full dataset, the average price of an excellent grade home is drastically larger than the average sale price of a poor grade home. Overall these results indicate that homeowner preferences within this repeat sales data is as expected.

Table 6.11 Repeat Sales Hedonic Attribute Estimation Results

Variable	(1)	(2)	(3)
Lot size (acres)	0.0972**	0.0914**	0.0924**
	0.0398	0.0450	0.0451
Height of home (number of stories)	-0.2042	-0.2187*	-0.2105*
	0.1247	0.1276	0.1279
Finished living area (sq Ft)	0.000114	0.000094	0.000084
	0.000086	0.000086	0.000087
Fireplaces	0.1292**	0.1545**	0.1429**
	0.0630	0.0671	0.0673
Bedrooms	-0.0433	-0.0093	0.0138
	0.0670	0.0684	0.0688
Full bathrooms	0.3376**	0.2941**	0.3169**
	0.1038	0.1064	0.1065
Half bathrooms	-0.0251	-0.0446	-0.0737
	0.1278	0.1308	0.1316
Age of home (years)	-0.0164**	-0.0144**	-0.0138**
	0.0054	0.0056	0.0056
Age^2	0.000081**	0.000083**	0.000078**
	0.0000	0.0000	0.0000
Distance to nearest major road (meters)	0.0001**	0.0000	0.0000
	0.0000	0.0001	0.0001
Excellent grade building quality indicator	1.3224**	1.1859**	1.2548**
	0.4790	0.5227	0.5230
Good grade building quality indicator	0.9685**	1.0205**	1.0720**
	0.4213	0.4596	0.4599
Average grade building quality indicator	0.6941*	0.7620*	0.7805*
	0.4139	0.4466	0.4458
Poor grade building quality indicator	-	-	-
	-	-	-
Urbanized area indicator	0.3898**	0.0987	0.0651
	0.1020	0.2286	0.2303
Garages	0.1941**	0.1929**	0.2023**
	0.0901	0.0933	0.0944
Pools	0.3912*	0.2170	0.2328
	0.2012	0.2088	0.2084
Public water indicator	-0.1977*	-0.0915	-0.0944
	0.1018	0.1378	0.1383
Constant	9.7698	9.9954	9.6365
	0.4853	0.5910	0.6120
County Dummies?	No	Yes	Yes
Year Dummies?	No	No	Yes
Sample Size	529	529	529
R^2	0.4191	0.4550	0.4638

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*).

6.13 Repeat Sales Proximity Treatment Variable Results

Estimation results from the repeat sales models including proximity treatment variables are included in Table 6.12. When parcel level fixed effects are controlled for all of the proximity treatment effects become insignificant. These estimation results could be due to the fact that when controlling for parcel level fixed effects locational unobserved attributes that were being captured within the proximity variables in prior models are now captured within the parcel level effects. However, it is also possible that the size of the sample could reduce the explanatory powers of these estimates.

6.14 Repeat Sales Proximity Treatment Variable and Water Interaction Results

In order to further examine the impacts of underground natural gas storage on nearby housing values using the repeat sales dataset, I also run some regressions using interaction terms between the proximity terms and the public water indicator. The results from the repeat sales public water interaction models can be found in Table 6.13. The interaction term and the proximity variable are all insignificant except in Model 3. Model 3 indicates that a home with access to public water sees an increase in value of four percent per kilometer increase in distance to the nearest underground natural gas storage well. However, these two terms are not jointly significant, indicating that the impact of underground natural gas storage for homes with access to public water is statistically insignificant. As with the models including only proximity variables, it is possible that the small size of the repeat sales dataset decreases the explanatory power of these results.

Table 6.12 Repeat Sales Proximity Variable Estimation Results

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Natural gas storage field indicator	-0.1799	-	-	-	-	-	-	-	-
	0.2041	-	-	-	-	-	-	-	-
Distance to nearest natural gas or oil	-	-0.0141	-	-	-	-	-	-	-
field (kilometers)	-	0.0342	-	-	-	-	-	-	-
Distance to nearest natural gas storage	-	-	-0.0619	-	-	-	-	-	-
well (kilometers)	-	-	0.0488	-	-	-	-	-	-
Distance to nearest observation well	-	-	-	-0.0268	-	-	-	-	-
(kilometers)	-	-	-	0.0499	-	-	-	-	-
Distance to nearest abandoned natural	-	-	-	-	0.00919	-	-	-	-
gas storage well (kilometers)	-	-	-	-	0.0351	-	-	-	-
Distance to nearest abandoned	-	-	-	-	-	0.0294	-	-	-
observation well (kilometers)	-	-	-	-	-	0.0207	-	-	-
Distance to nearest natural gas	-	-	-	-	-	-	-0.0288	-	-
extraction well (kilometers)	-	-	-	-	-	-	0.0320	-	-
Distance to nearest natural gas and oil	-	-	-	-	-	-	-	-0.00304	-
extraction well (kilometers)	-	-	-	-	-	-	-	0.0232	-
Distance to nearest oil extraction well	-	-	-	-	-	-	-	-	-0.0125
(kilometers)	-	-	-	-	-	-	-	-	0.0309
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sample Size	529	529	529	529	529	529	529	529	529
R^2	0.4646	0.4639	0.4655	0.4641	0.4638	0.4659	0.4646	0.4638	0.4639

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table 6.13 Repeat Sales Proximity Variable and Public Water Access Interaction Results

Variable	(1)	(2)	(3)	(4)	(5)
Natural gas storage field indicator	-0.2066	-	-	-	-
	0.4904	-	-	-	-
Natural gas storage field indicator X Public Water	0.0287	-	-	-	-
	0.4794	-	-	-	-
Distance to nearest natural gas or oil field (kilometers)	-	-0.0177	-	-	-
	-	0.0351	-	-	-
Distance to nearest natural gas or oil field (kilometers) X Public Water	-	0.00608	-	-	-
	-	0.0124	-	-	-
Distance to nearest natural gas storage well (kilometers)	-	-	-0.122**	-	-
	-	-	0.0554	-	-
Distance to nearest natural gas storage well (kilometers) X Public Water	-	-	0.162**	-	-
	-	-	0.0717	-	-
Distance to nearest observation well (kilometers)	-	-	-	-0.0339	-
	-	-	-	0.0501	-
Distance to nearest observation well (kilometers) X Public Water	-	-	-	-0.00507	-
	-	-	-	0.00382	-
Distance to nearest abandoned natural gas storage well (kilometers)	-	-	-	-	0.00879
	-	-	-	-	0.0354
Distance to nearest abandoned natural gas storage well (kilometers) X Public water	-	-	-	-	0.000347
	-	-	-	-	0.00433
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	Yes	Yes
Year Dummies?	Yes	Yes	Yes	Yes	Yes
Sample Size	529	529	529	529	529
R^2	0.4646	0.4642	0.471	0.466	0.4638

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table 6.13, continued

Variable	(6)	(7)	(8)	(9)
Distance to nearest abandoned observation well (kilometers)	0.0295	-	-	-
	0.0214	-	-	-
Distance to nearest abandoned observation well (kilometers) X Public Water	-0.0000602	-	-	-
	0.00437	-	-	-
Distance to nearest natural gas extraction well (kilometers)	-	-0.022	-	-
	-	0.0324	-	-
Distance to nearest natural gas extraction well (kilometers) X Public Water	-	-0.00997	-	-
	-	0.00825	-	-
Distance to nearest natural gas and oil extraction well (kilometers)	-	-	-0.00433	-
	-	-	0.0233	-
Distance to nearest natural gas and oil extraction well (kilometers) X Public Water	-	-	-0.00239	-
	-	-	0.00317	-
Distance to nearest oil extraction well (kilometers)	-	-	-	-0.0124
	-	-	-	0.0309
Distance to nearest oil extraction well (kilometers) X Public Water	-	-	-	0.00261
	-	-	-	0.00464
Hedonic Attributes?	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	Yes
Year Dummies?	Yes	Yes	Yes	Yes
Sample Size	529	529	529	529
R^2	0.4659	0.4662	0.4644	0.4643

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

CHAPTER 7. CONCLUSIONS

As the natural gas industry continues to adapt to the increases in supply due to shale gas extraction, and to increasing demand for natural gas, so too will policy relating to the natural gas industry. Increased attention on the environmental impacts of hydraulic fracturing and activities required to extract unconventional sources of natural gas may also spread to other aspects of the natural gas industry. Natural gas transportation and storage may come under the same level of scrutiny that natural gas extraction currently faces. Given the changing conditions for the industry, knowledge about the costs and benefits of all aspects of the industry may be of benefit to the industry and policymakers as they adapt to the changing conditions of the industry.

The environmental and amenity risks to properties and nearby residents from natural gas related activities are not new, however, attention on these issues has the potential to increase the perception of risk due to increased awareness. As demonstrated by Miyazaki (2009), underground natural gas storage fields have risks, ranging from mild to as extreme as fatalities. Although these risks have been publicized upon the occurrence of any event, previous literature has not attempted to value the impact of these types of facilities on nearby property values. In the climate of increasing attention to the natural gas industry, now is a particularly good time to pre-empt any need for increased understanding of the costs and benefits of underground natural gas storage.

By employing the hedonic method to a set of data for home sales within Indiana, I am able to recover an estimate for the impact of underground natural gas storage related activities on nearby housing values. Results from county level and year fixed effects models strongly suggest that there is a negative impact on property values due to proximity to underground natural gas storage activities. Proximity to the nearest underground storage well is well modeled with a quadratic functional form, which indicates that a home within one kilometer of an underground natural gas storage well sees an increase of 9.4 percent due to an additional kilometer of distance from the well. Distance to the nearest observation well has a cubic functional form and for a home located within one kilometer of an observation well an additional kilometer of distance results in an increase in value of 10.03 percent. In addition, my results suggest that homes located in urban areas are insulated against the impacts of underground natural gas storage wells.

Intensity of underground natural gas storage activity also has an impact on property values. The fixed effects models employing intensity treatment effects demonstrate that an additional storage related well within two miles decreases property values by 0.43 percent, an additional underground natural gas storage well decreases property values by 0.48 percent, and an additional observation well decreases value by 2.64 percent. This leads to the conclusion that intensity of storage related activities has a significant negative impact on property values. In addition, when water interaction terms are added to the fixed effect intensity models I find that homes with access to public water see a smaller impact due to underground natural gas storage related intensity than homes without access to public water. These results also are a general indication that much of the perceived risk regarding underground natural gas storage activities is related to the risk of groundwater contamination. This public water access interaction was not found in the proximity models with water interaction terms, which could mean that the intensity of storage related activities nearby increases perceived risk of groundwater contamination while simple proximity does not.

When the proximity variables are employed using repeat sales data the results become insignificant, which could mean that proximity treatment variables in the county level fixed effects model were capturing locational attributes specific to the parcel. However, this dataset is relatively small. Increasing the size of the sample used in the repeat sales model could make the importance of parcel level fixed effects more clear. Overall, my results demonstrate that homes in Indiana within proximity to underground natural gas storage activities suffer negative externalities due to these activities. These impacts become more pronounced for homes without access to public water, and homes within urban areas are in general insulated from these impacts.

Policymakers and industry participants can use these results in order to improve regulations related to underground natural gas storage as well as improve lease agreements with homeowners for any future development of underground natural gas storage facilities. My results demonstrate that homeowners with leases or easement agreements for mineral rights may not be compensated fully under current conditions. Within the current environment of increasing demand for natural gas throughout the year, industry participants may be planning projects related to storage of natural gas. With a more complete understanding of the impacts of these facilities, industry participants working on any development of underground storage facilities can be more prepared to account for the full costs of these facilities, and respond to the environment of increased awareness of industry activities.

In addition, policymakers need to have a complete picture of the impacts of the natural gas industry in order to weigh the costs and benefits of any new or expanded industry activity. Currently, the natural gas industry is receiving more attention, and policymakers are expected to respond to the perception of risk within their constituents and help decide if the development new storage facilities outweigh the social costs. In this case increasing demand for natural gas could drive the need for new development of underground natural gas storage facilities. Using these results policymakers can help protect or properly compensate homeowners for the negative impacts of any underground natural gas storage related activities while also helping the natural gas industry respond to the energy demand throughout the country.

The quantification of impact may also help homeowners and the natural gas industry in negotiations for mineral rights access. The location of development for any new underground natural gas storage is limited by the geological requirements for the activity; however, a more complete understanding of the impacts on property values due to these activities can help the industry and stakeholders in any decisions regarding the development and use of underground natural gas storage. In addition, with this information about the impacts of underground natural gas storage on nearby properties, policymakers can have full information when deciding how to update regulations regarding underground natural gas storage facilities on private land as needed.

This study could also be applied to areas receiving more attention due to natural gas industry activities, including Pennsylvania and Texas. Although depending on the location of underground natural gas storage activities and the location of shale gas extraction activities it may be more difficult to disentangle the individual impacts due to underground natural gas storage activities from the impacts due to shale gas extraction in these regions than it is in a region like Indiana which has limited unconventional natural gas development.

An analysis of property values near an underground natural gas storage well that has experienced a failure event in the past could allow a researcher to recover estimates for the impact of underground natural gas storage activities within the context of extremely heightened local awareness and media attention. Prior literature has found some increases in the impact of petroleum activities when studied in the context of a negative event (Flower and Ragas 1994). These events have a higher probability of occurring within salt cavern type storage (Miyazaki 2009), therefore a study of this type would most likely need to focus on the Gulf Coast region where salt cavern underground natural gas storage is more common. This region is also experiencing an increase in shale gas extraction, which could confound any estimation results.

As Guignet (2013) demonstrates, a treatment variable that more accurately measures homeowner knowledge of a treatment effect can be a better proxy for environmental quality. Within the context of underground natural gas storage it may improve estimates to look at homes with private water that have been tested. This could provide more insight into the impact of underground natural gas storage on homes without access to public water. In addition, it could be interesting to discover which properties have current leases with underground natural gas storage facilities, if possible. These homeowners may have more knowledge about the activities related to underground natural gas storage. Looking at homes with and without leases could help in disentangling the effects of receiving compensation for the use of mineral rights versus the impact on nearby homes that do not have any type of agreement with the facility yet still receive some impact from the activities.

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APPENDICES

Appendix A Additional Figures

Figure A.1 Counties in Analysis

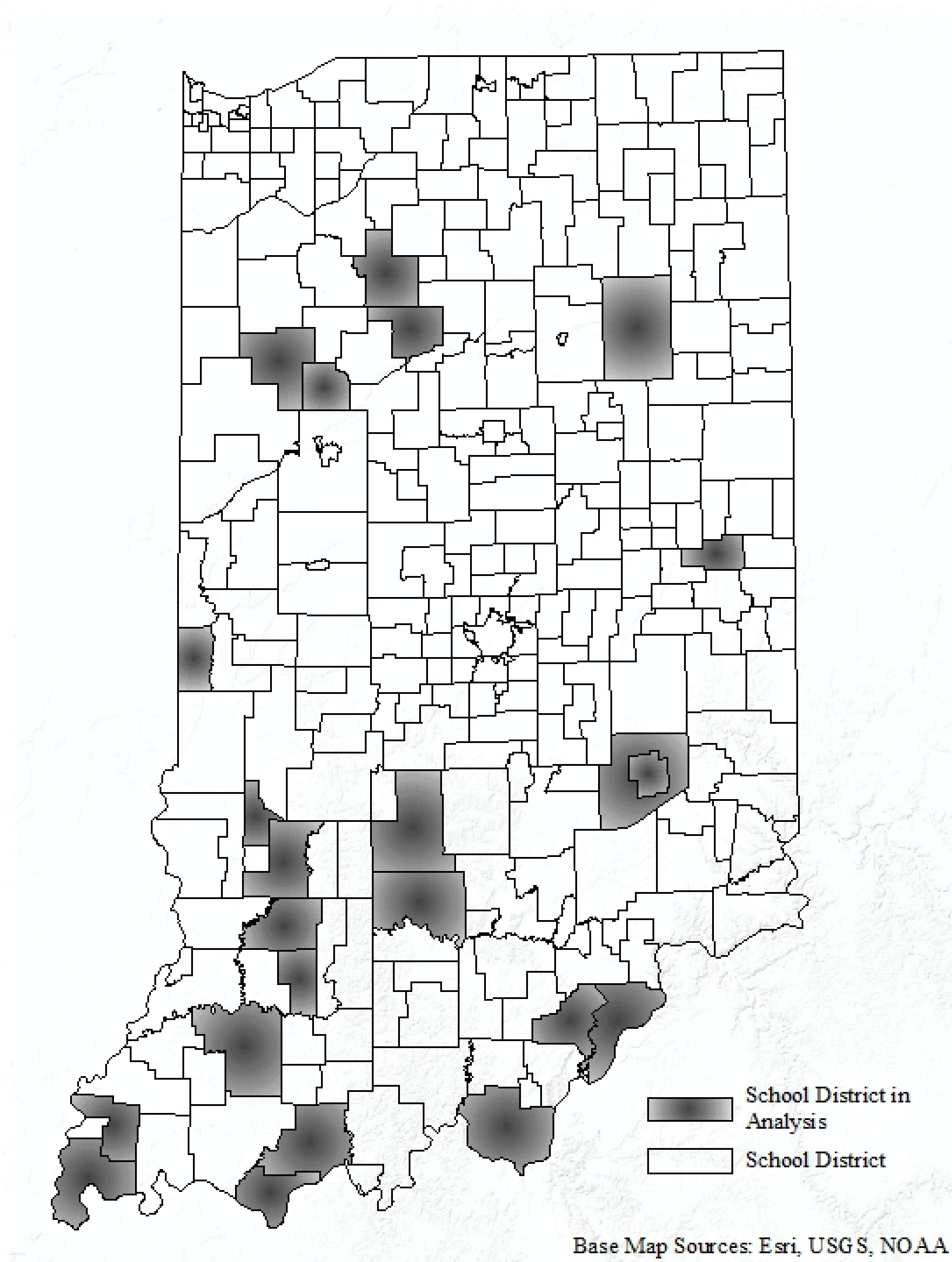


Figure A.2 School Districts in Analysis

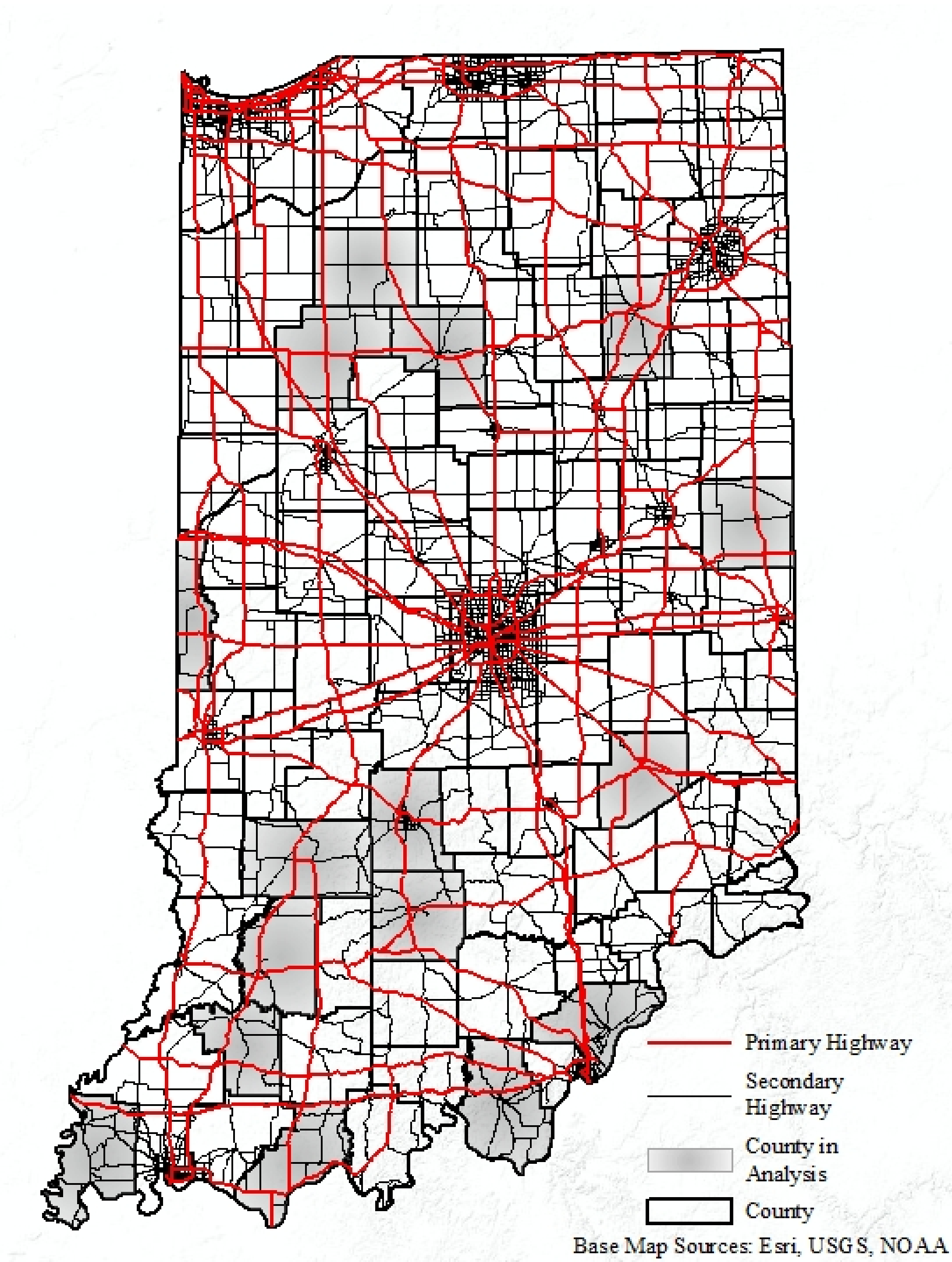


Figure A.3 Primary and Secondary Streets of Indiana

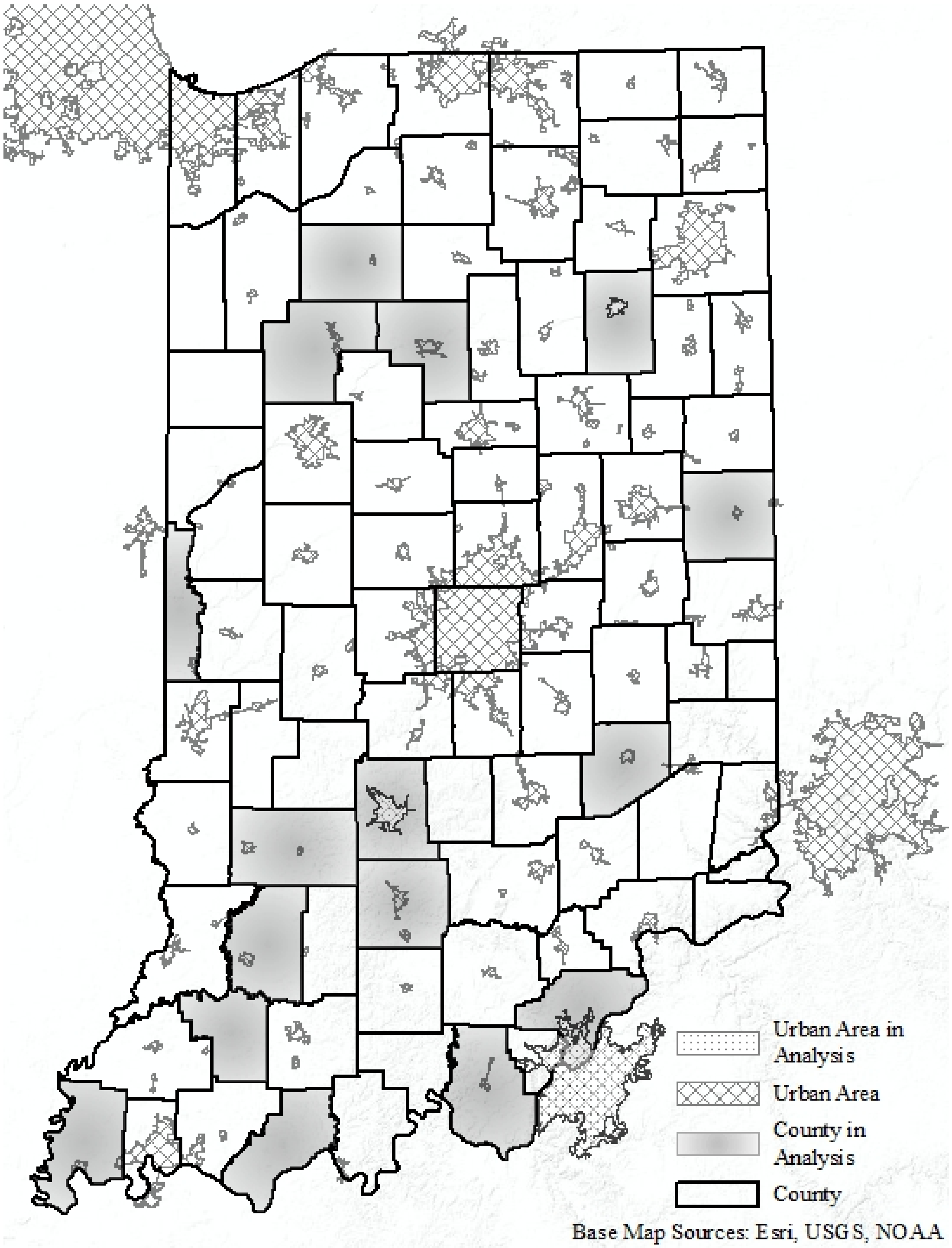


Figure A.4 Urban Areas in Analysis

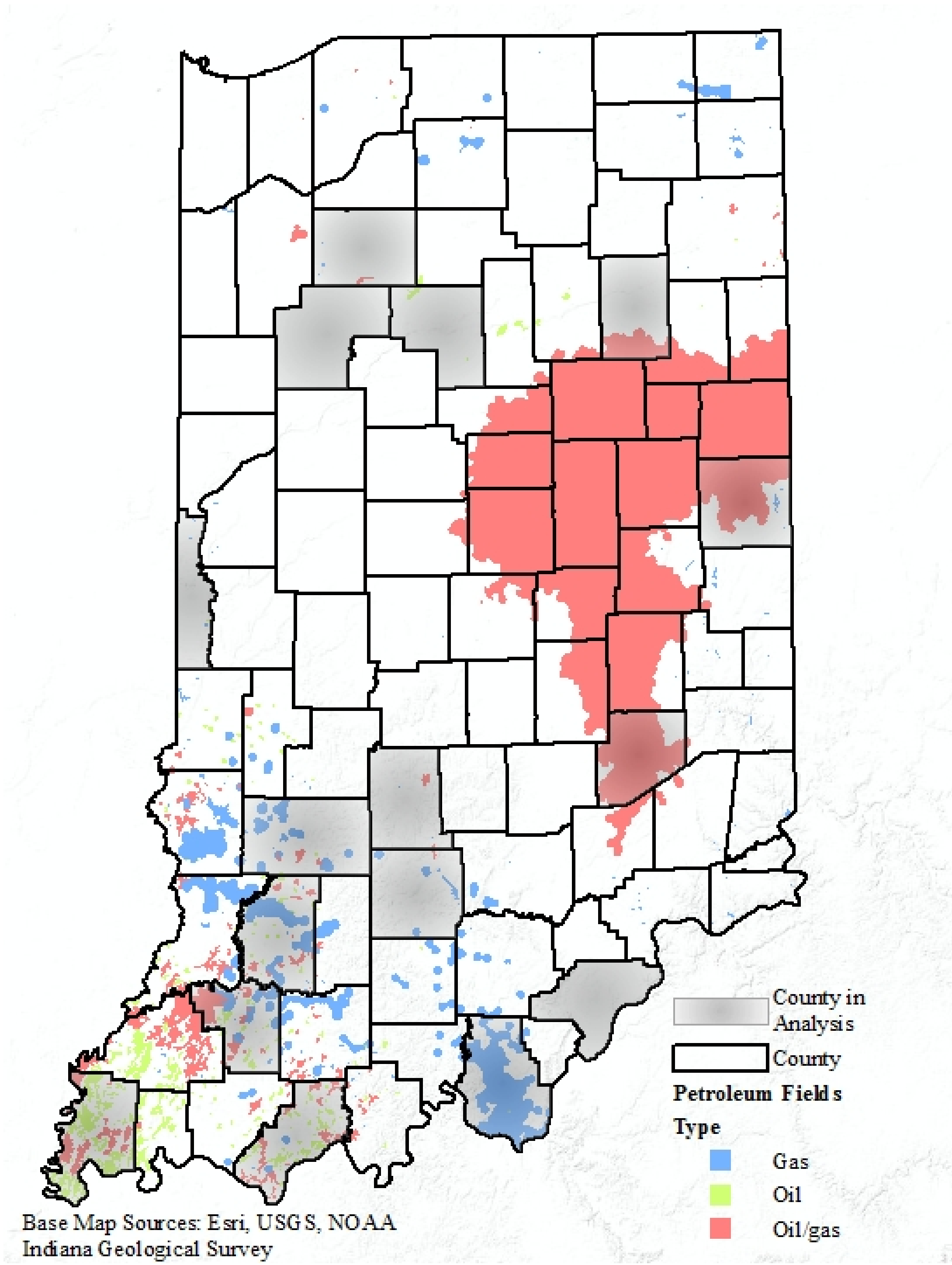


Figure A.5 Petroleum Fields in Indiana

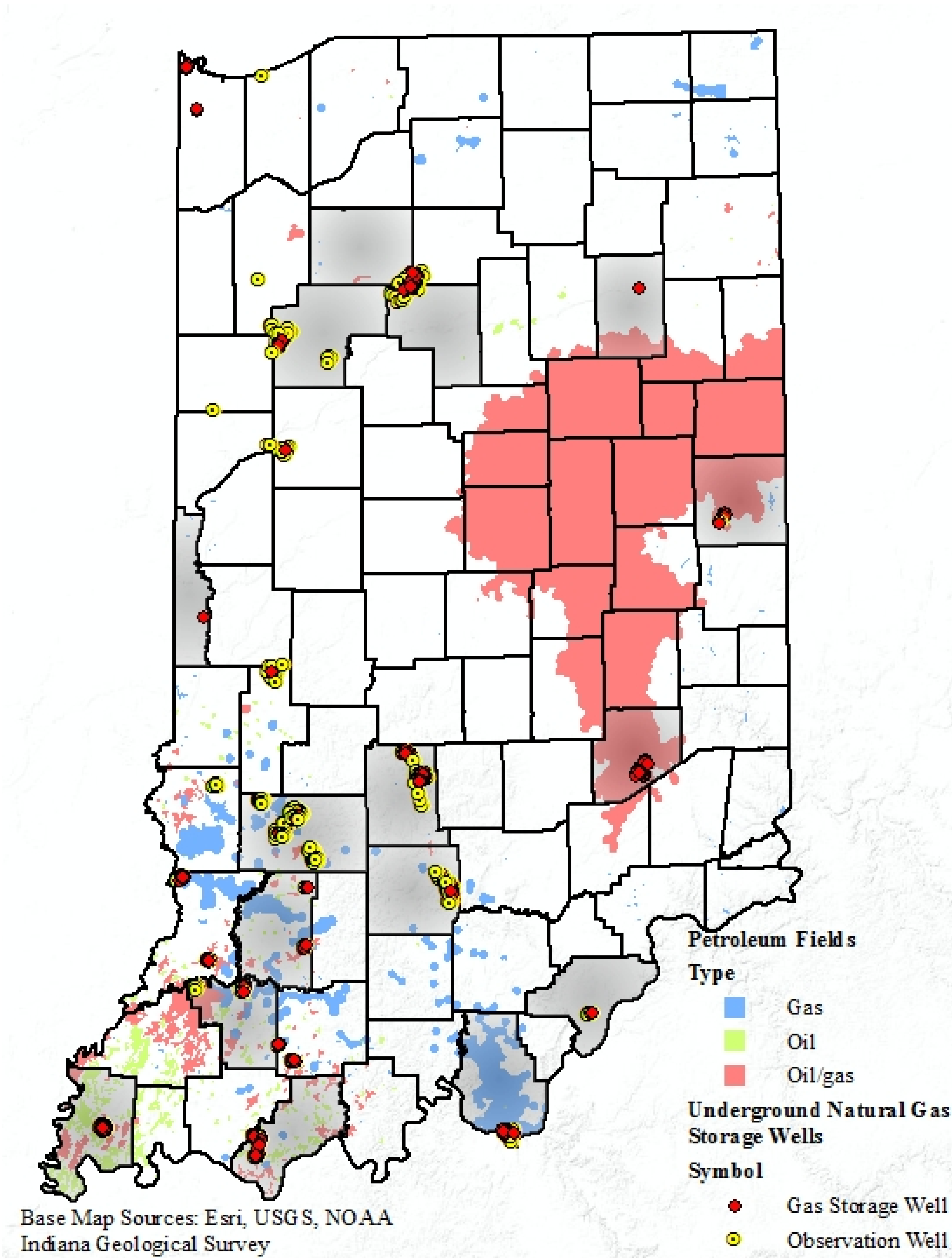


Figure A.6 Petroleum Fields and Underground Natural Gas Storage Wells

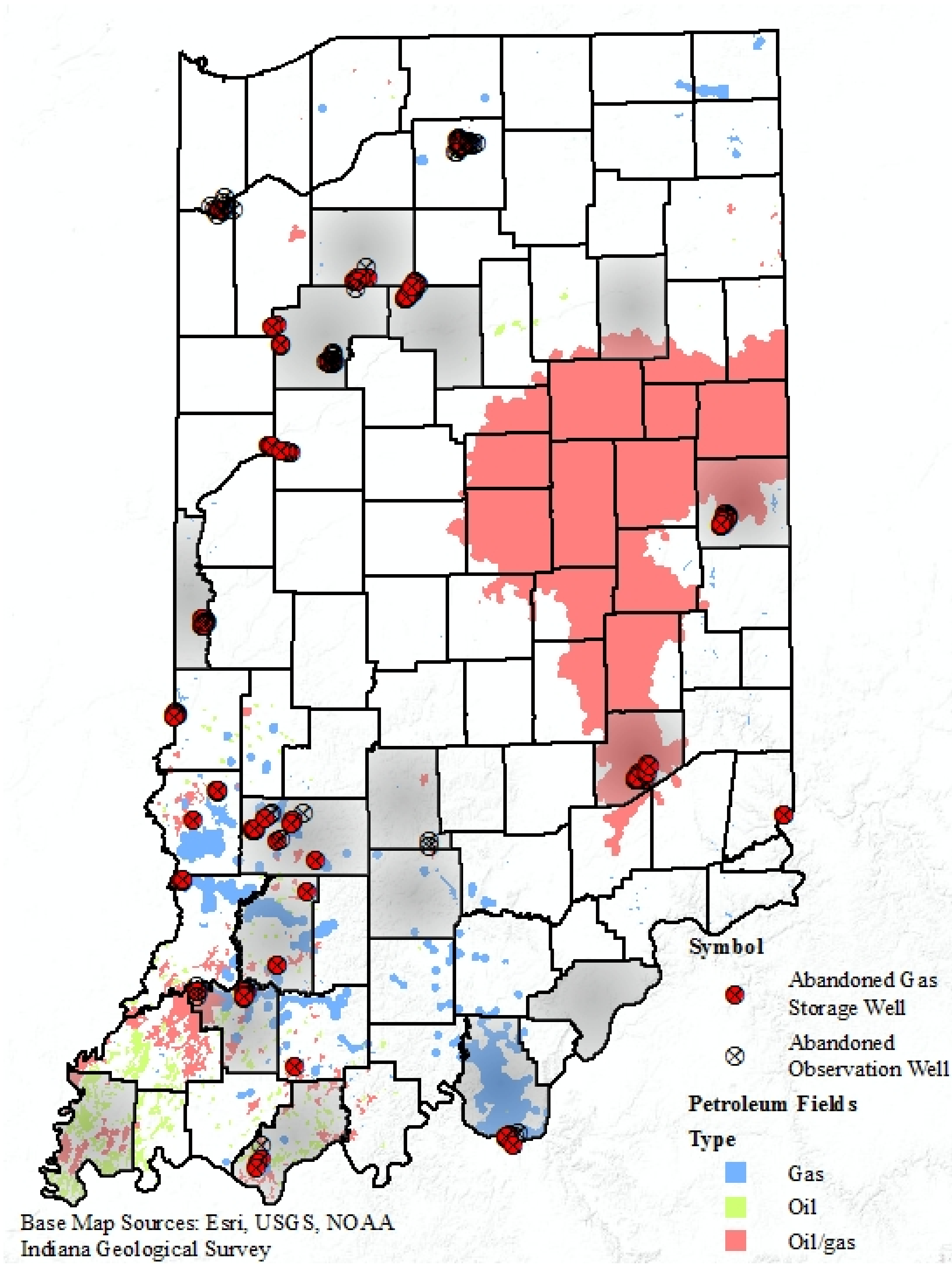


Figure A.7 Petroleum Fields and Abandoned Gas Storage Wells

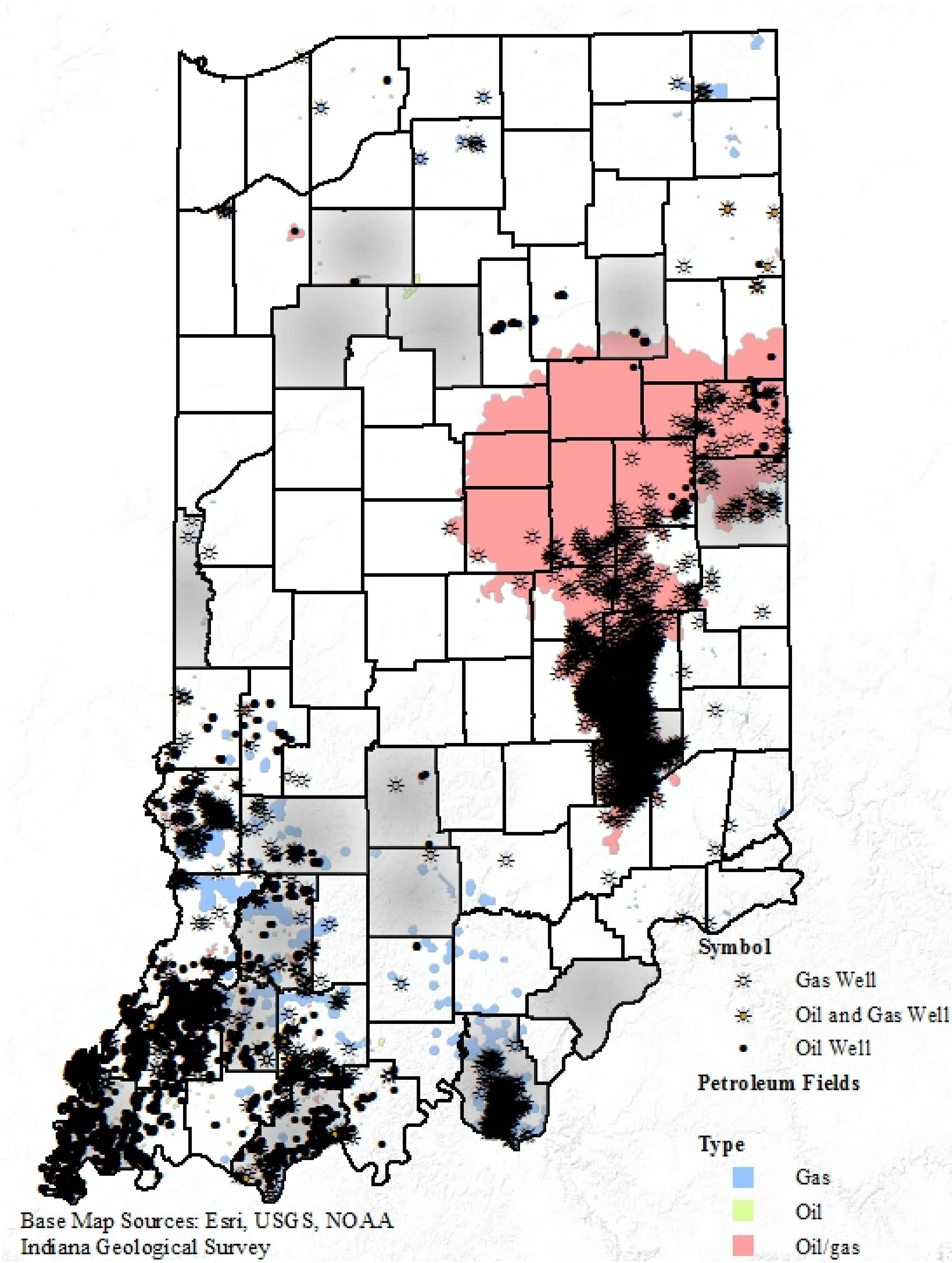


Figure A.8 Petroleum Fields and Extraction Wells

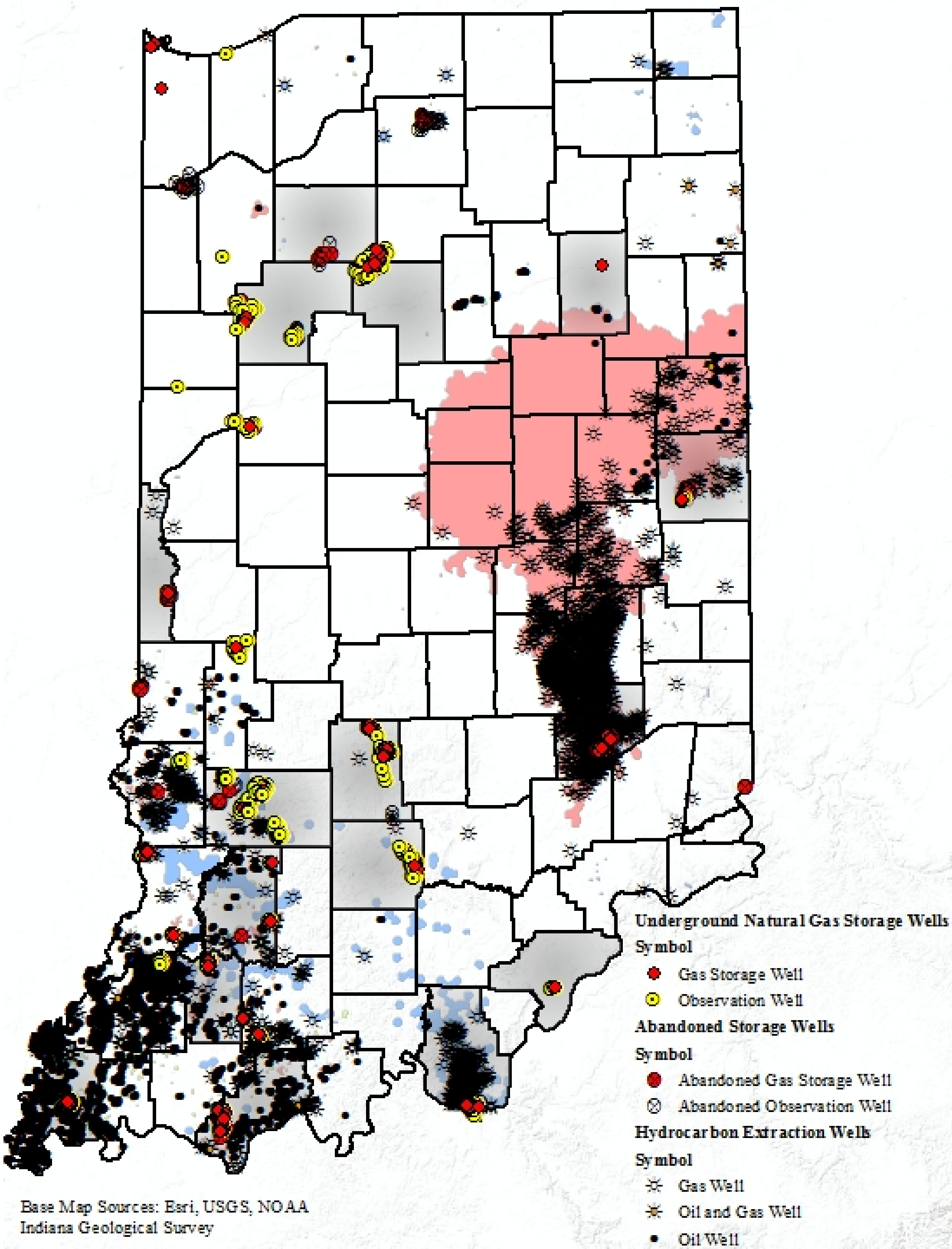


Figure A.9 Petroleum Fields and All Well Types Combined

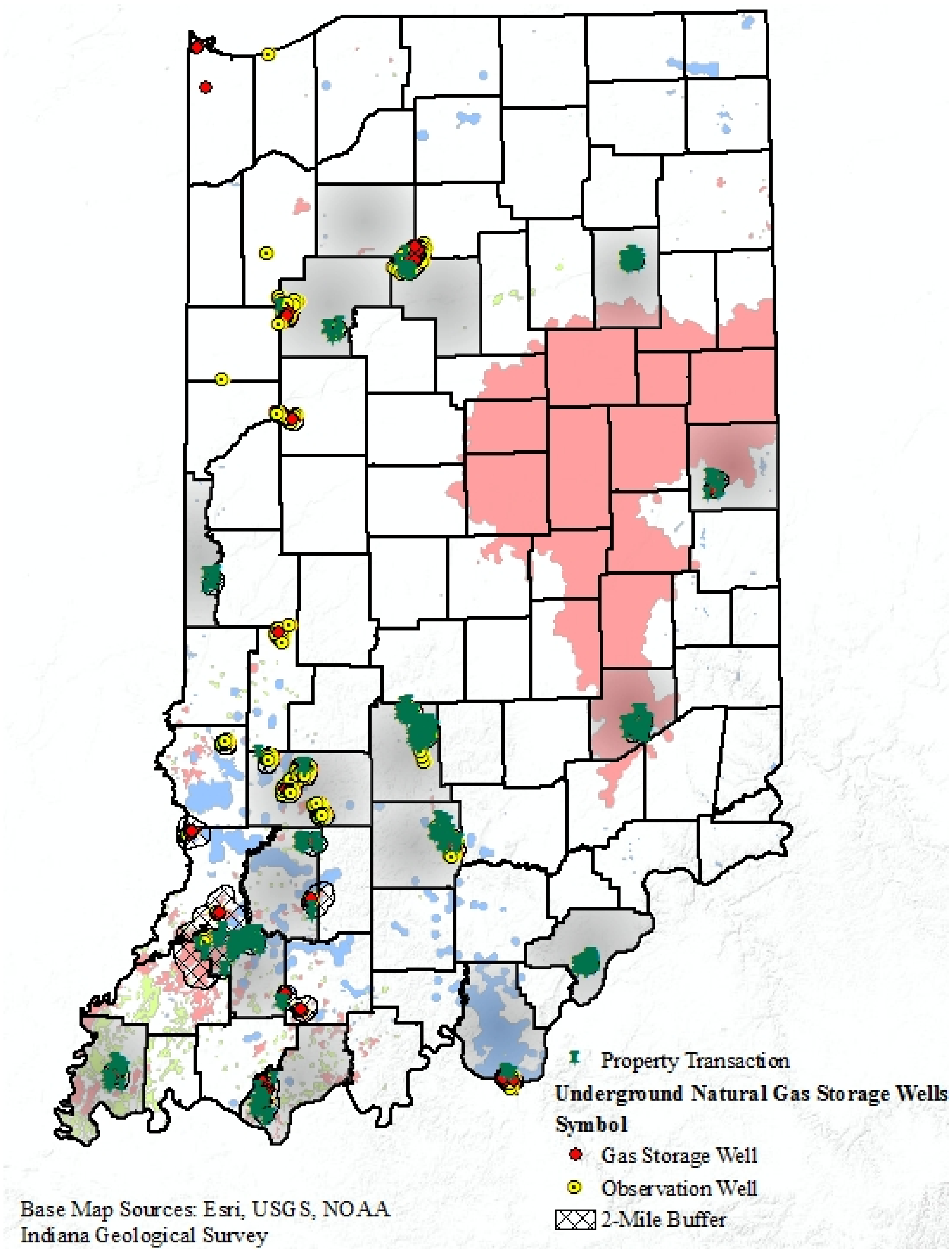


Figure A.10 Petroleum Fields with Home Sales in Analysis and Two-Mile Buffer Zones

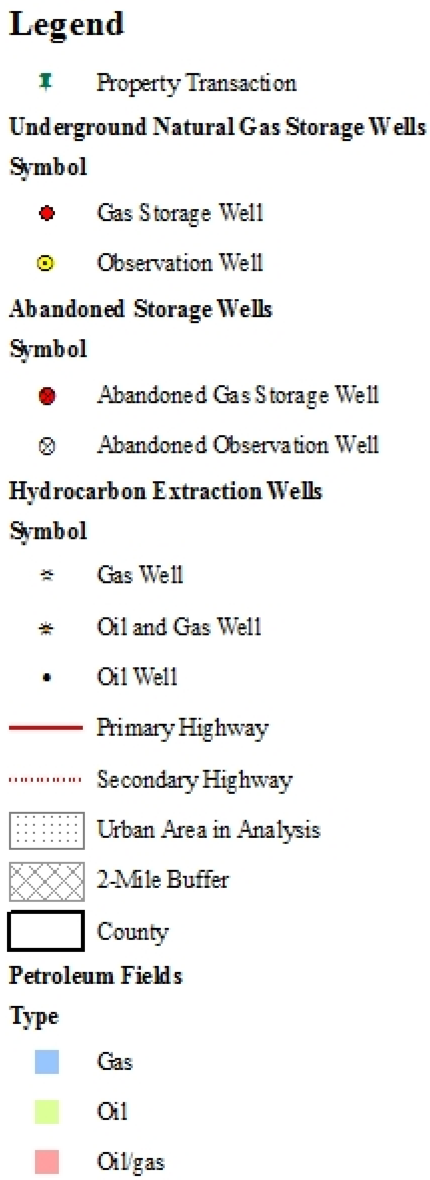


Figure A.11 Legend of Symbols

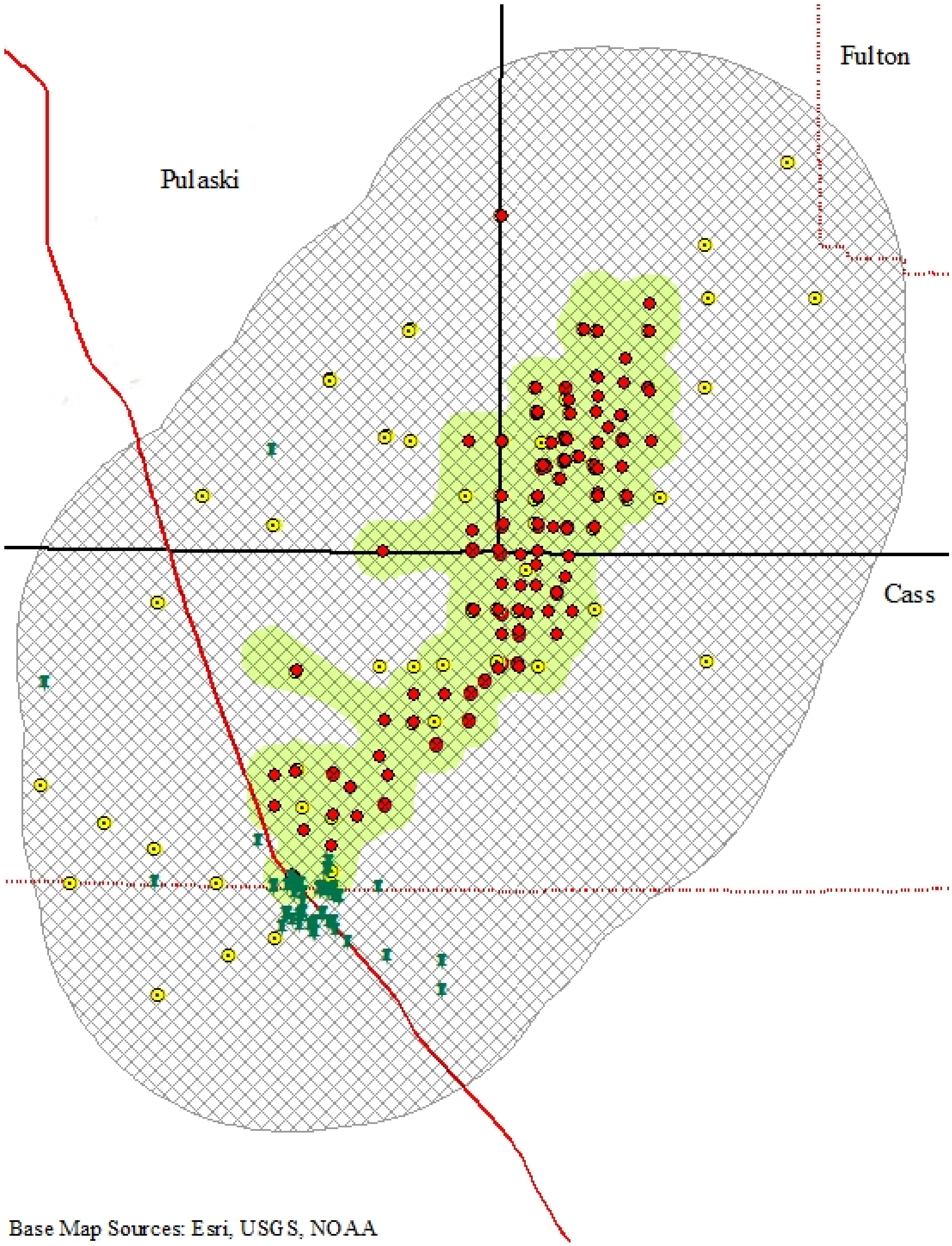


Figure A.12 Region of Analysis in Cass, Fulton and Pulaski Counties

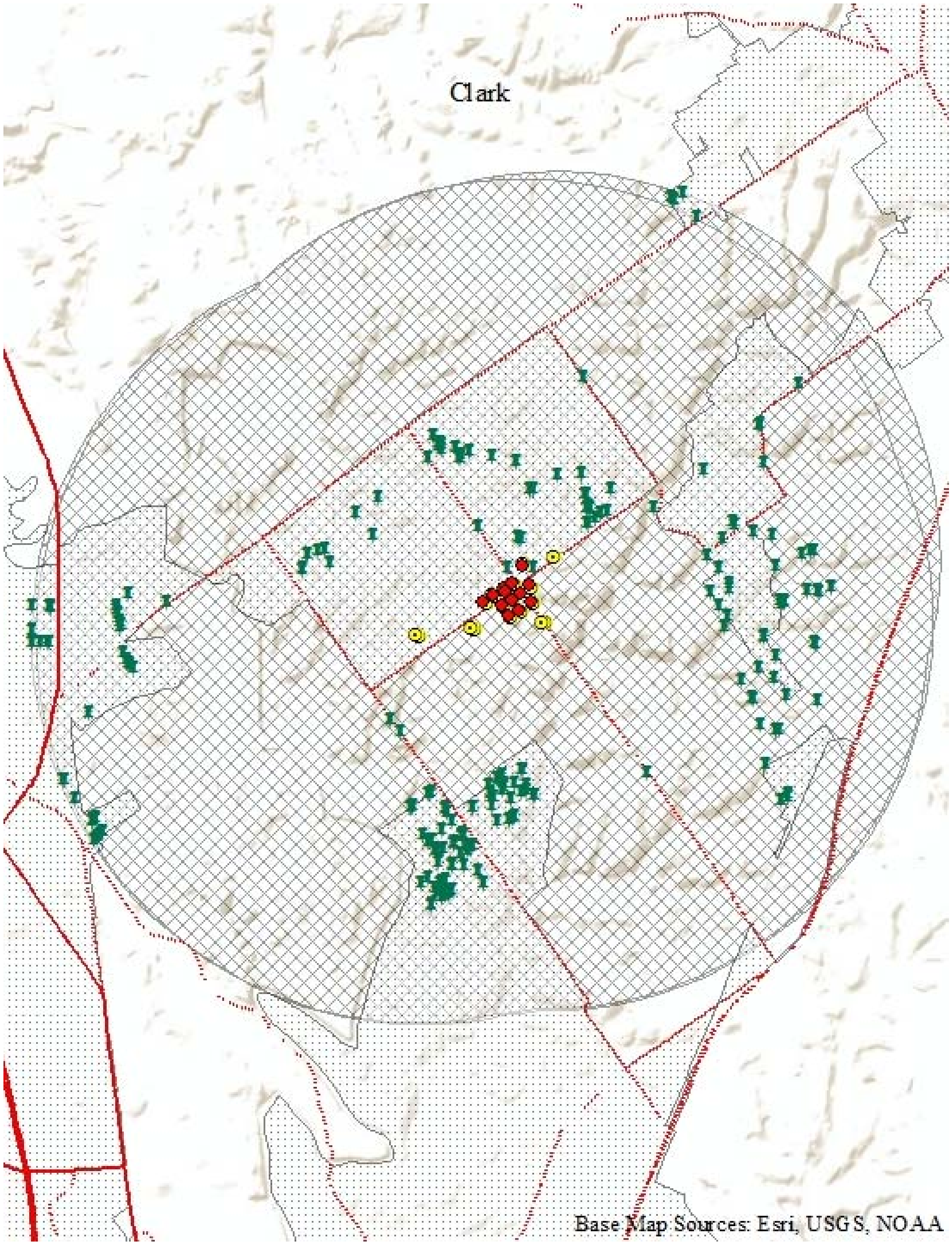


Figure A.13 Region of Analysis in Clark County

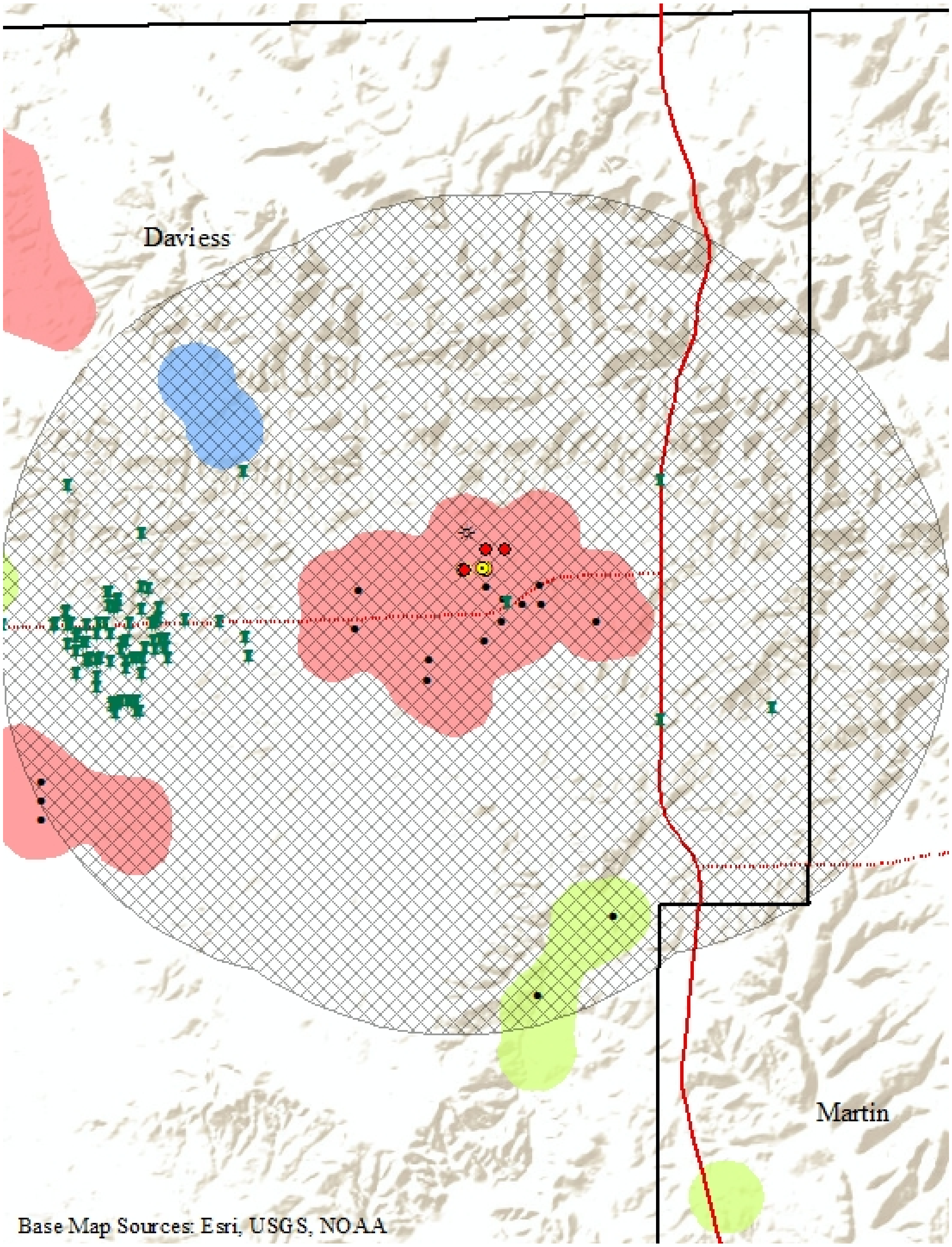


Figure A.14 First Region of Analysis in Daviess County

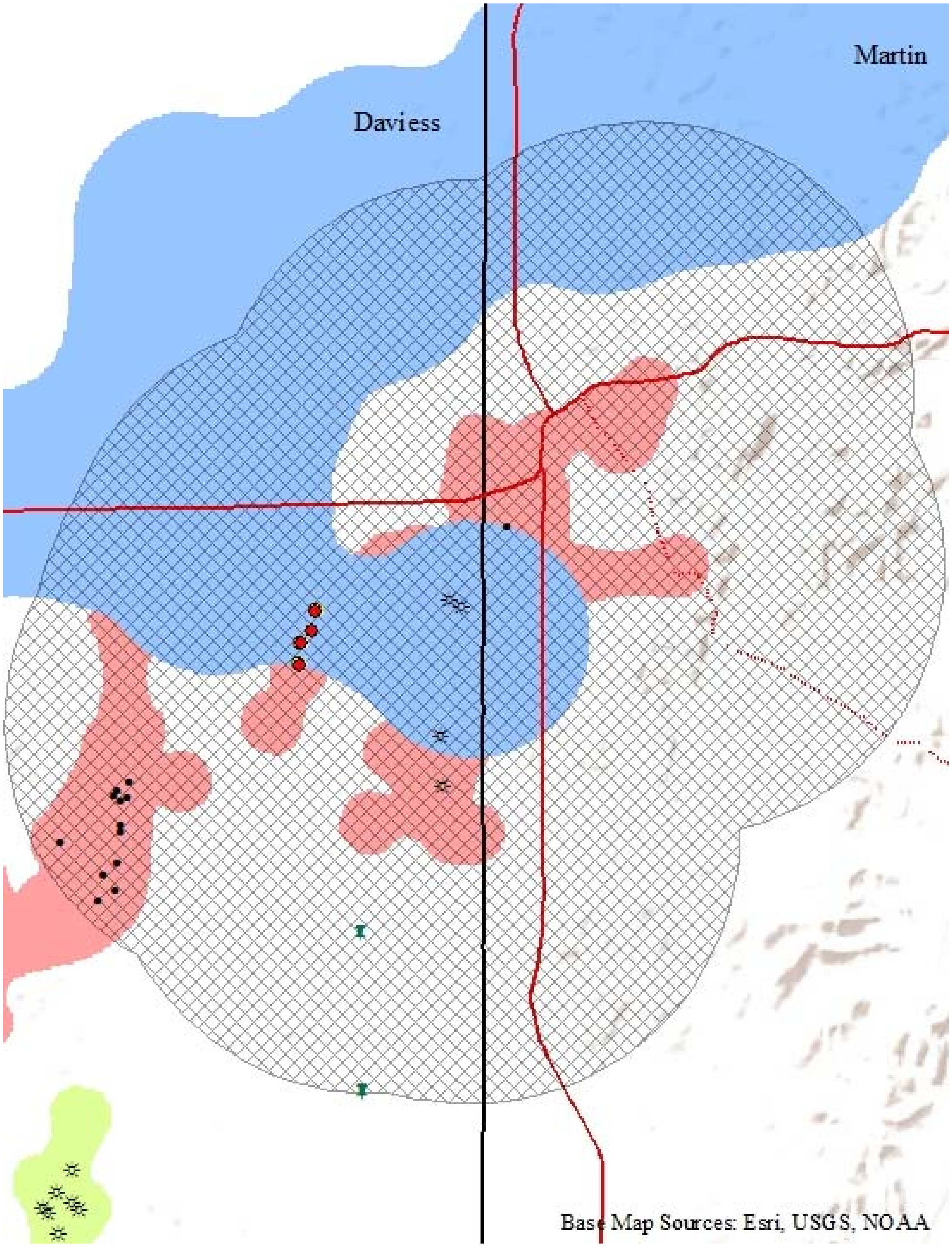


Figure A.15 Second Region of Analysis in Daviess County

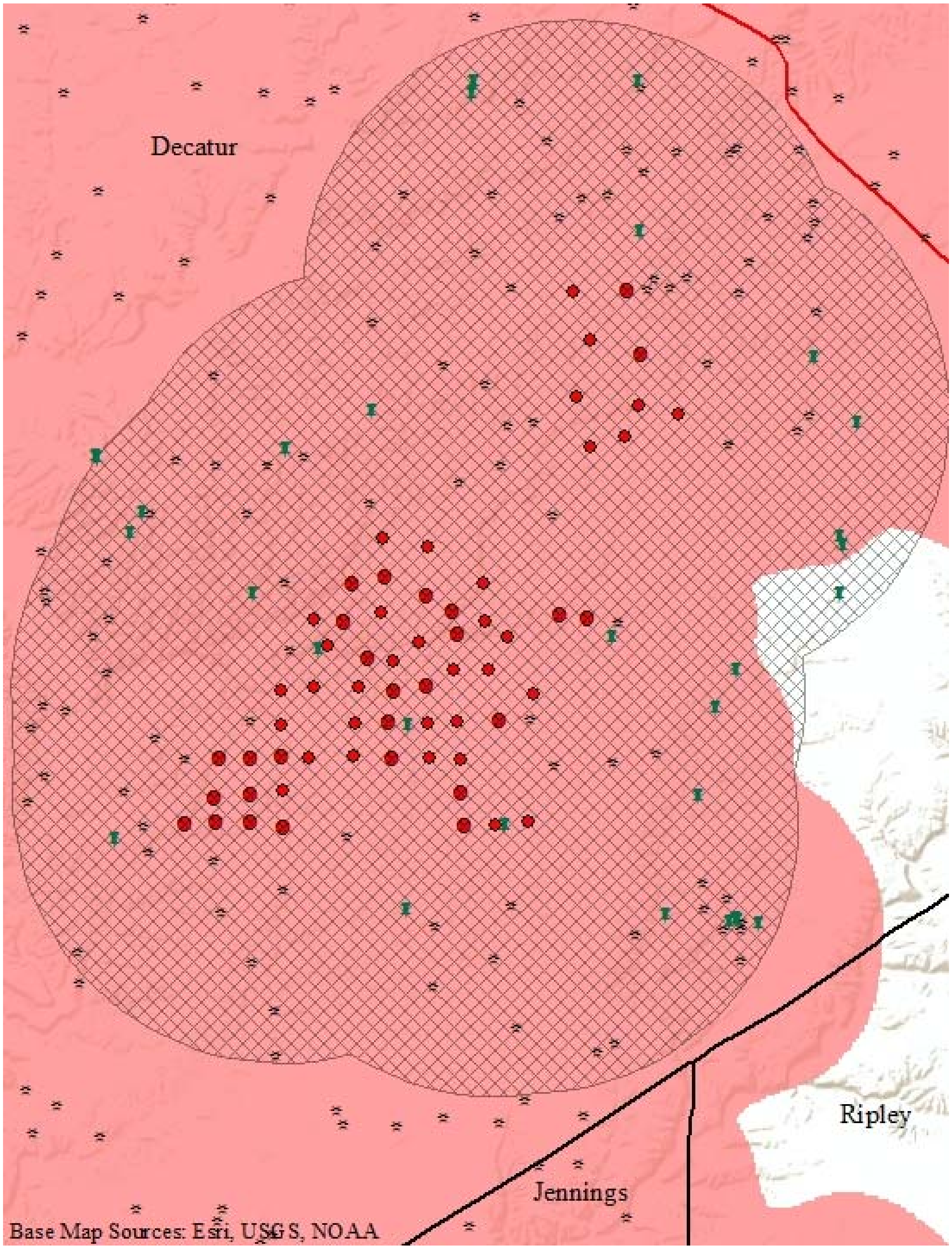


Figure A.16 Region of Analysis in Decatur County

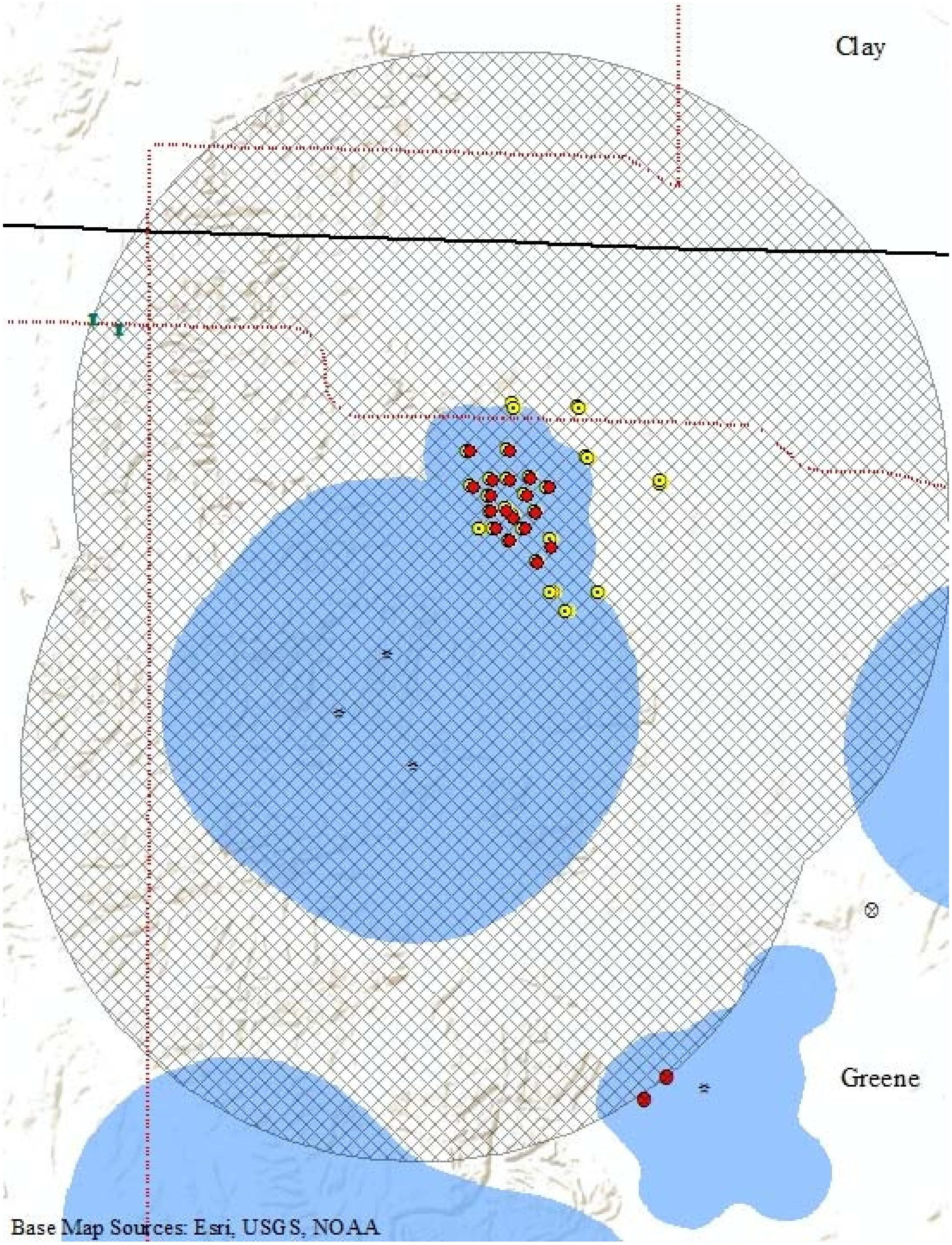


Figure A.17 First Region of Analysis in Greene County

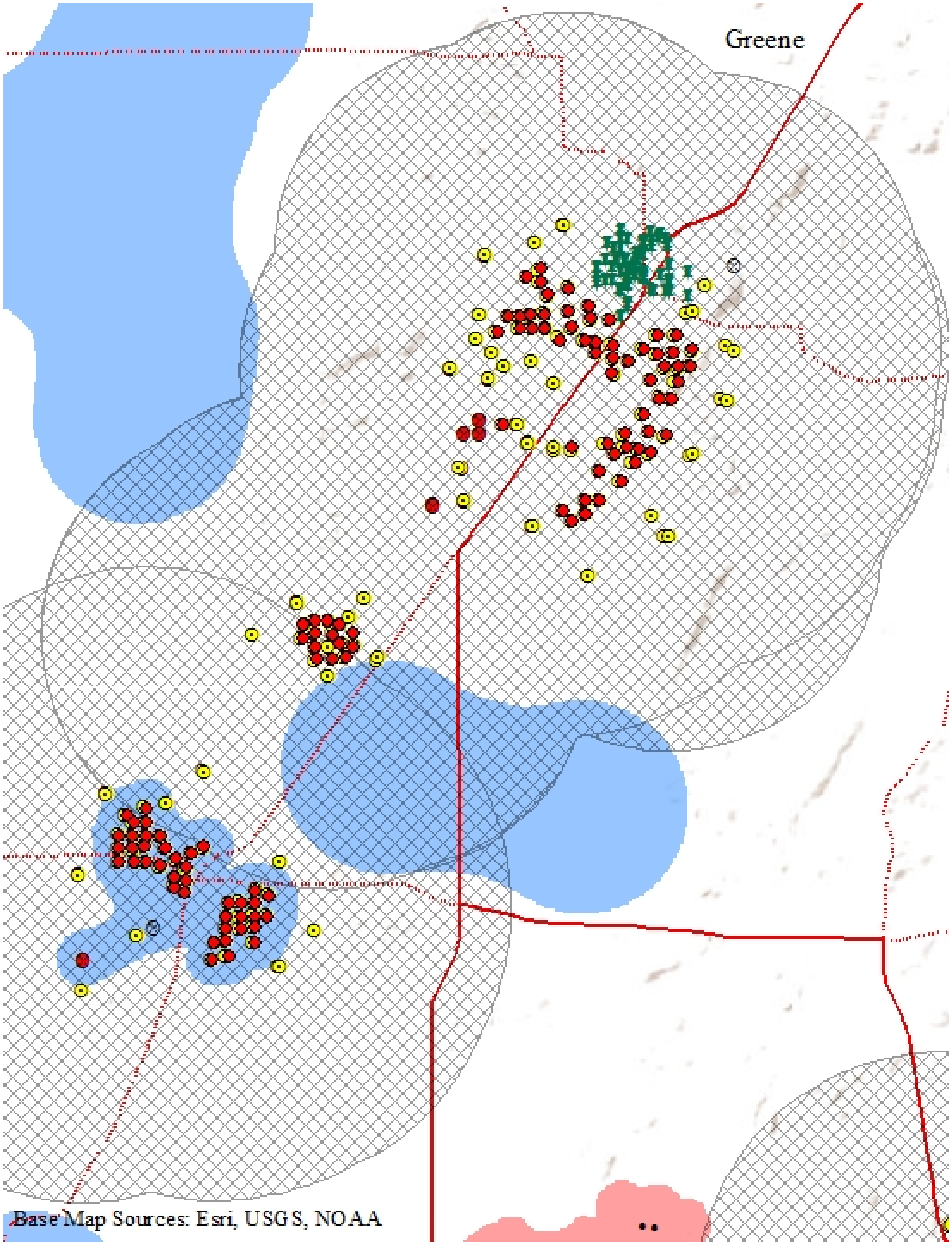


Figure A.18 Second Region of Analysis in Greene County

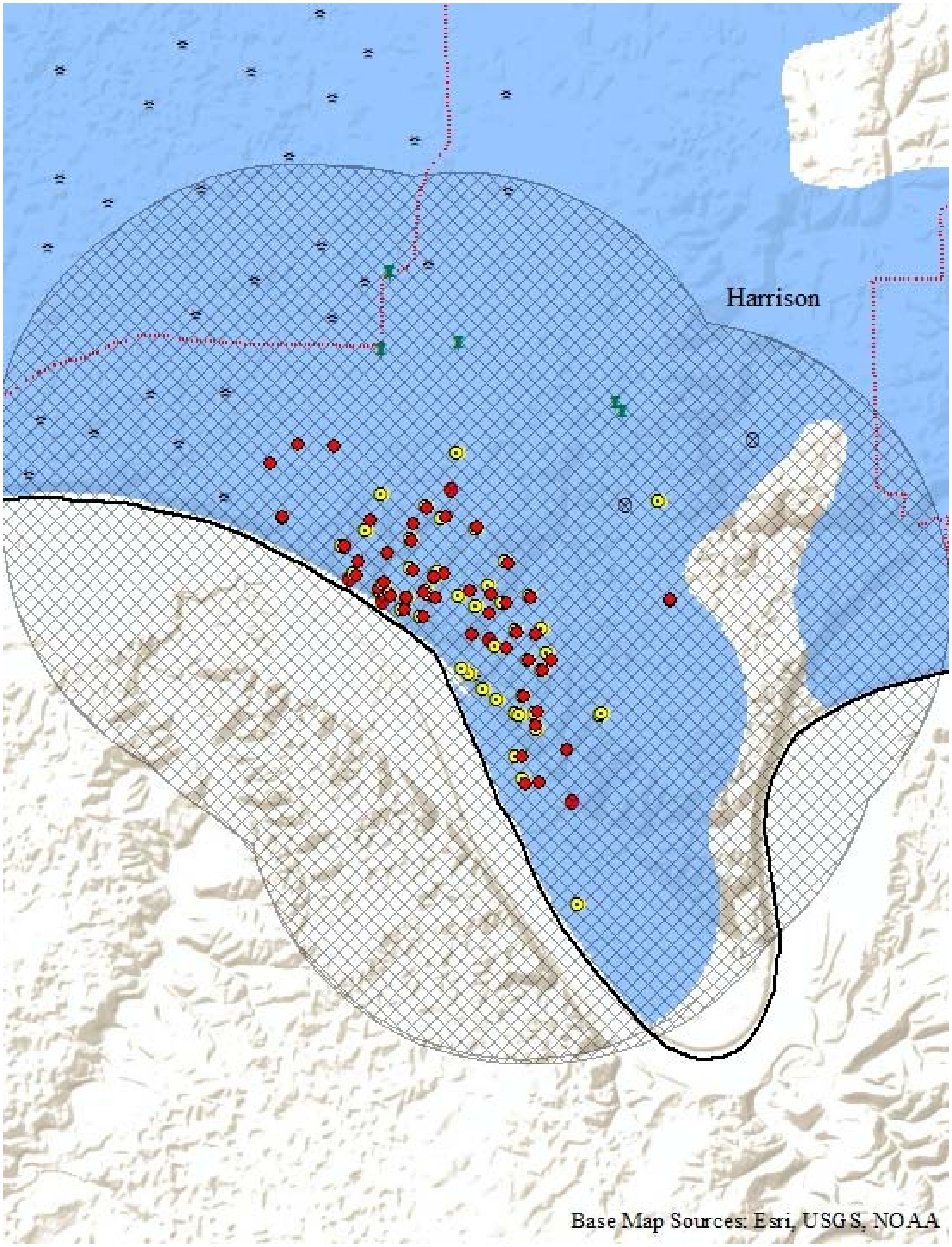


Figure A.19 Region of Analysis in Harrison County

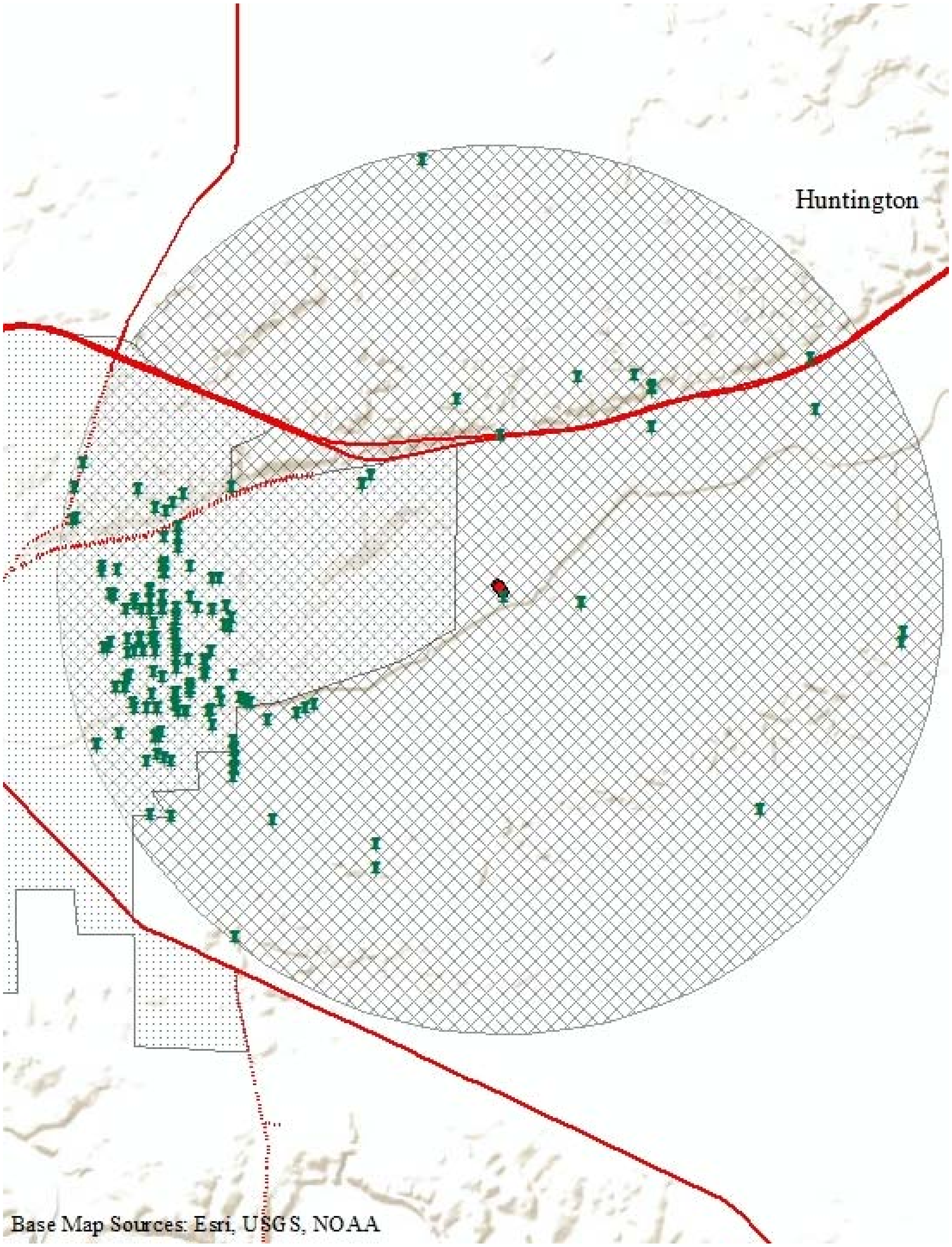


Figure A.20 Region of Analysis in Huntington County

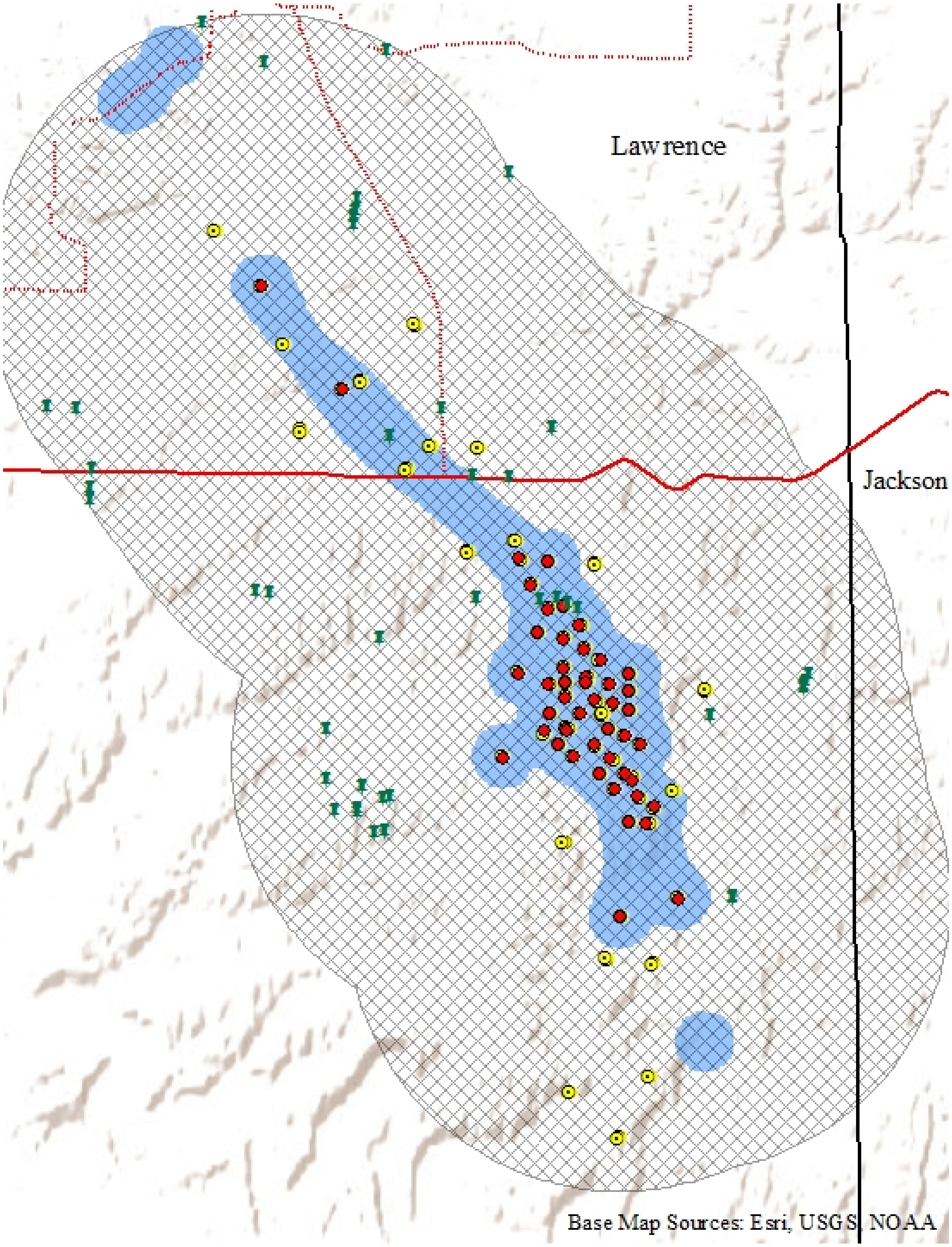
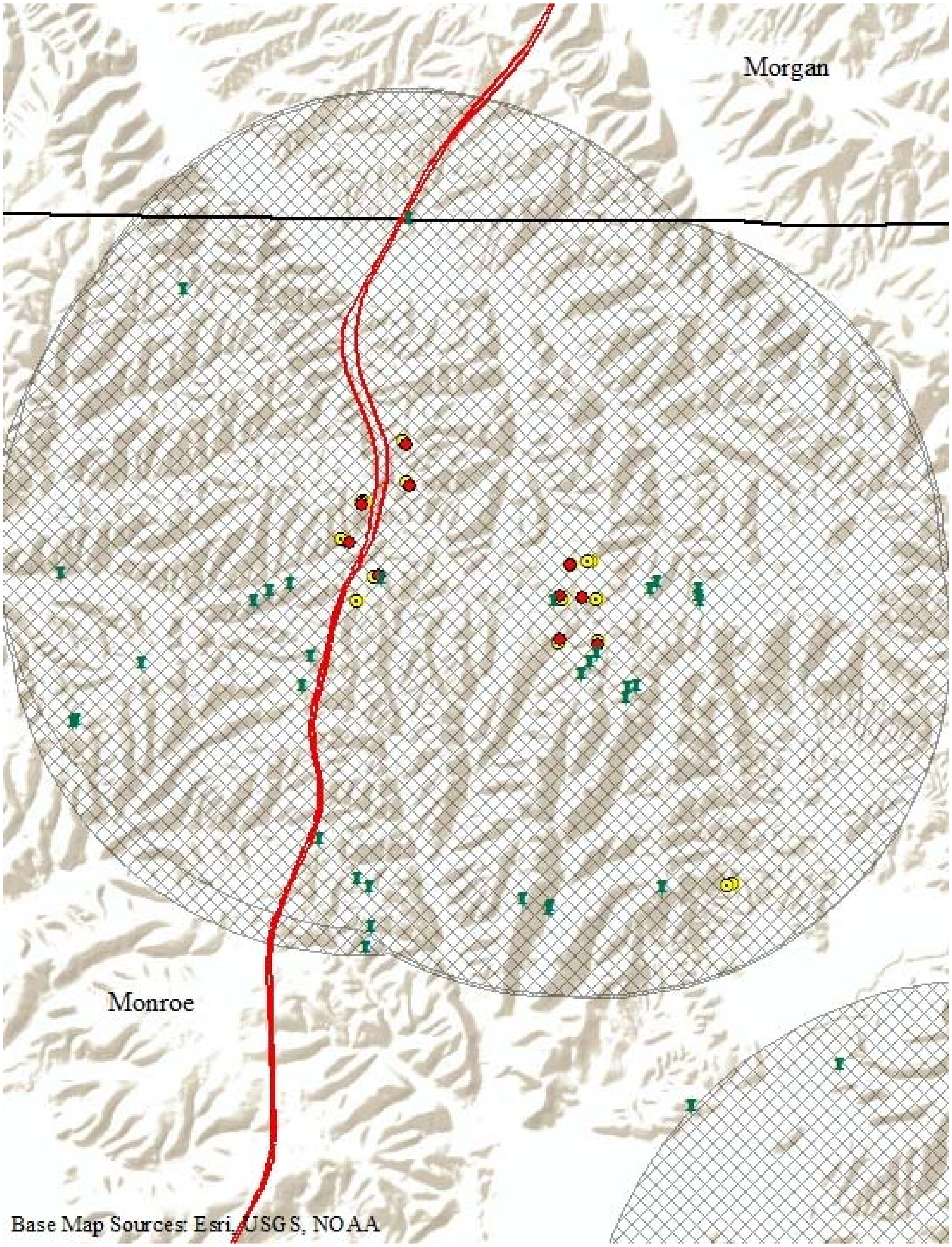


Figure A.21 Region of Analysis in Lawrence County



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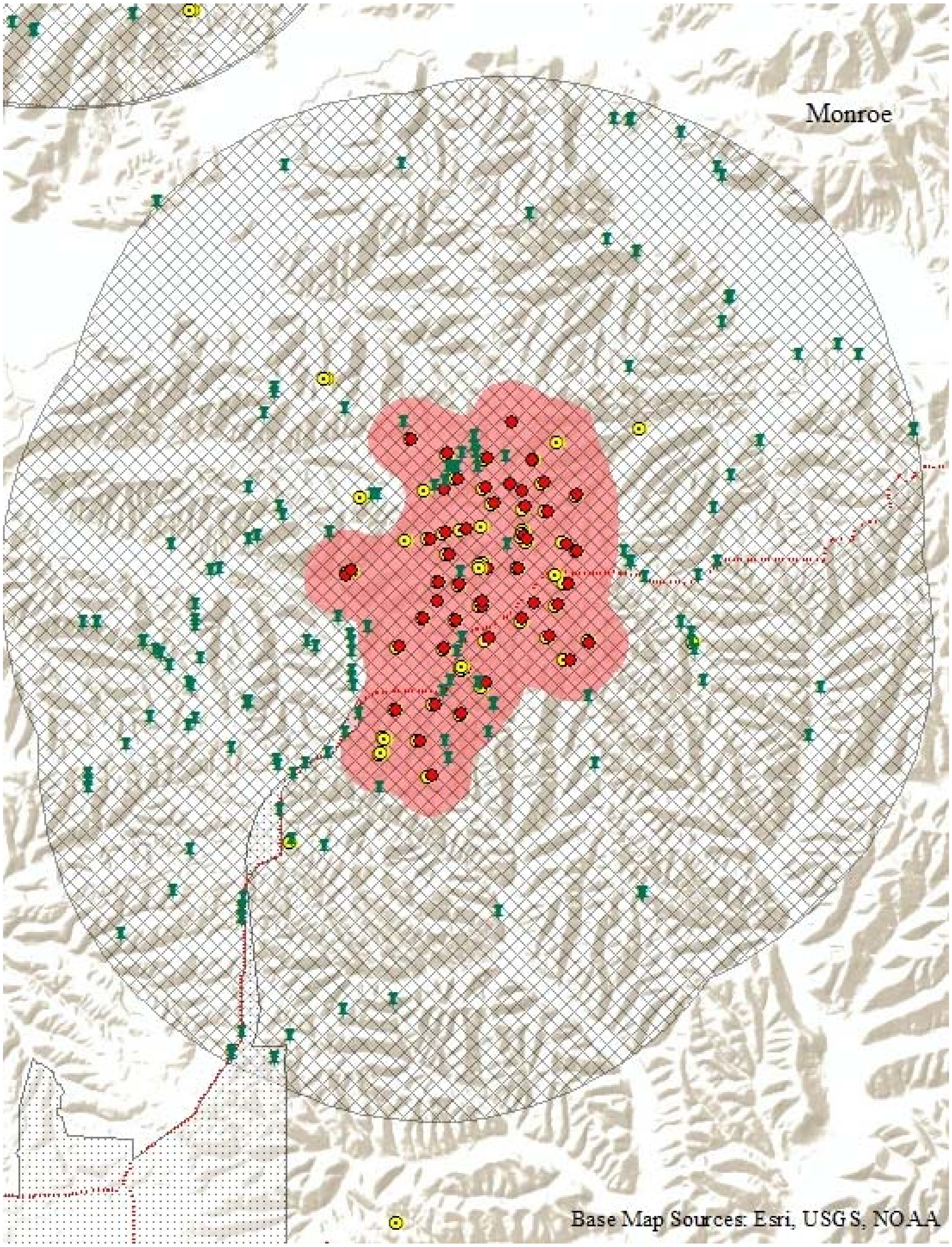

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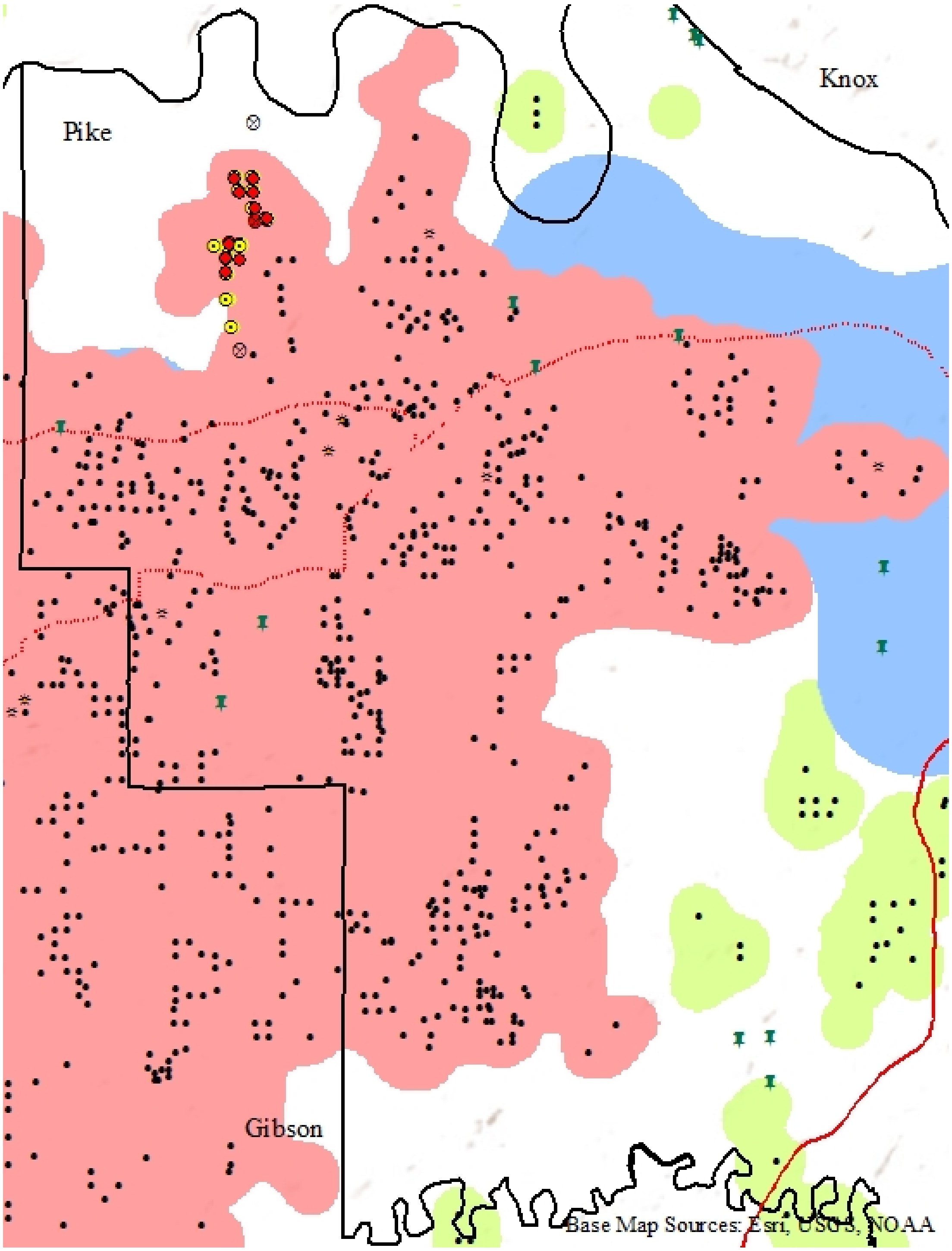
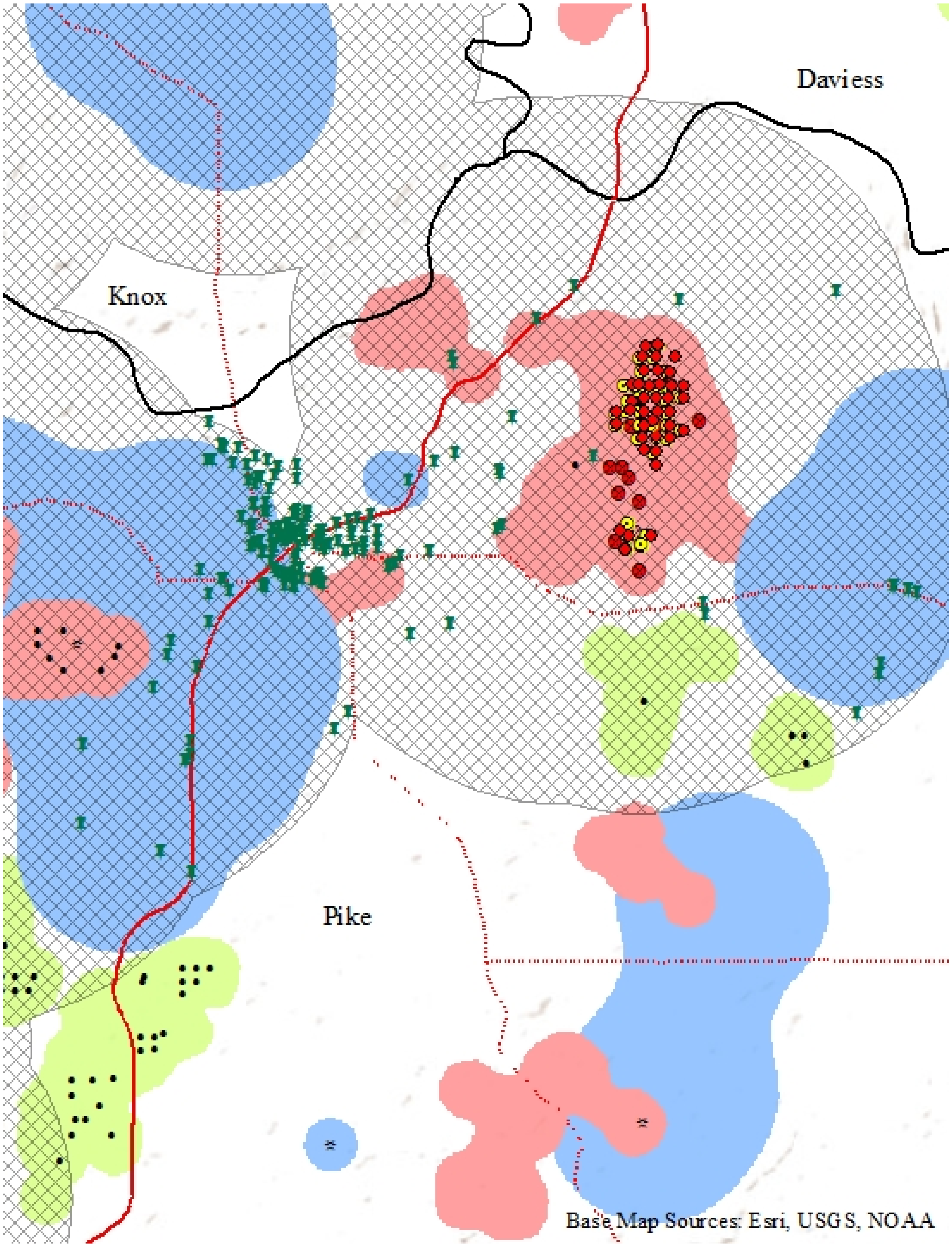


Figure A.24 First Region of Analysis in Pike County



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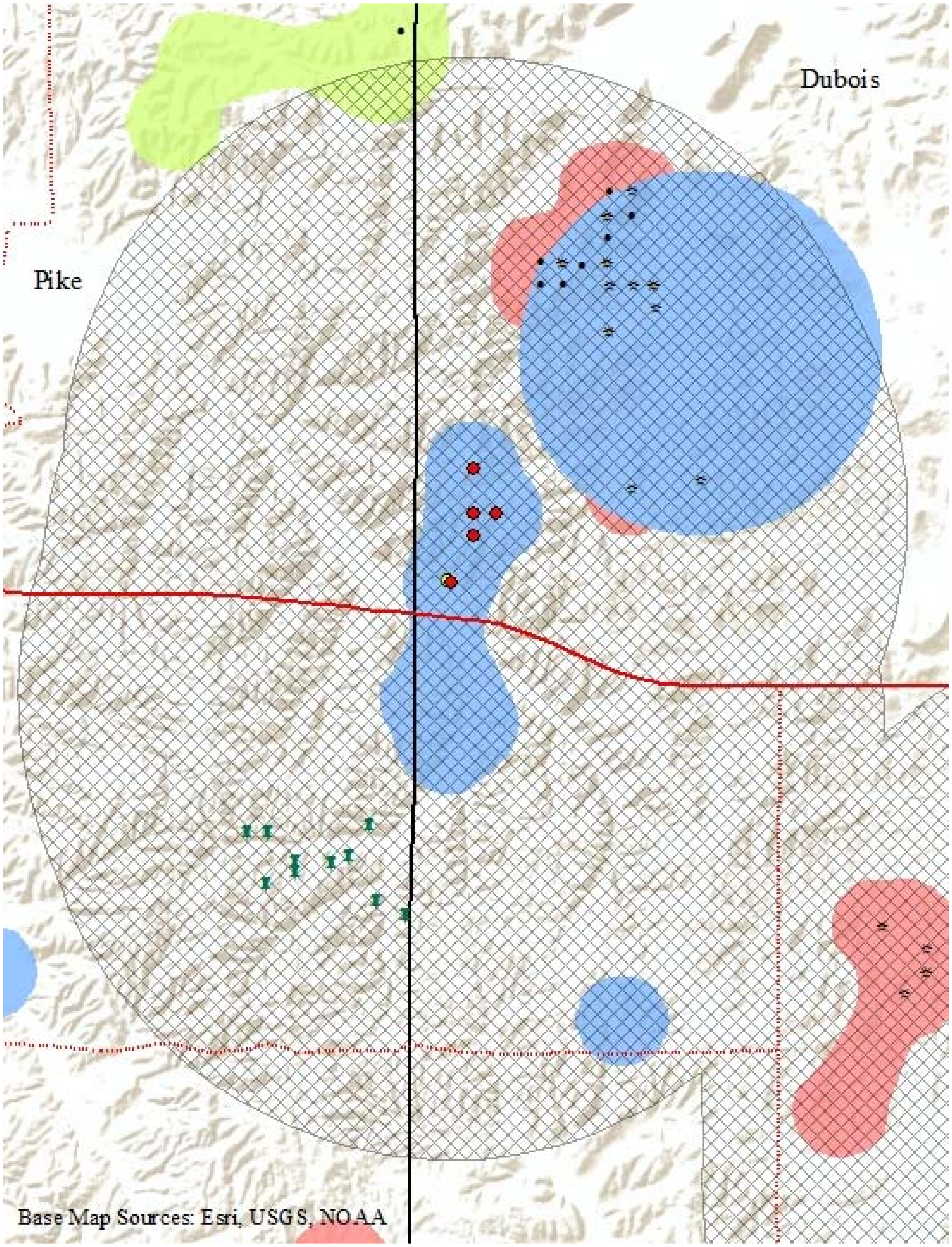


Figure A.26 Third Region of Analysis in Pike County

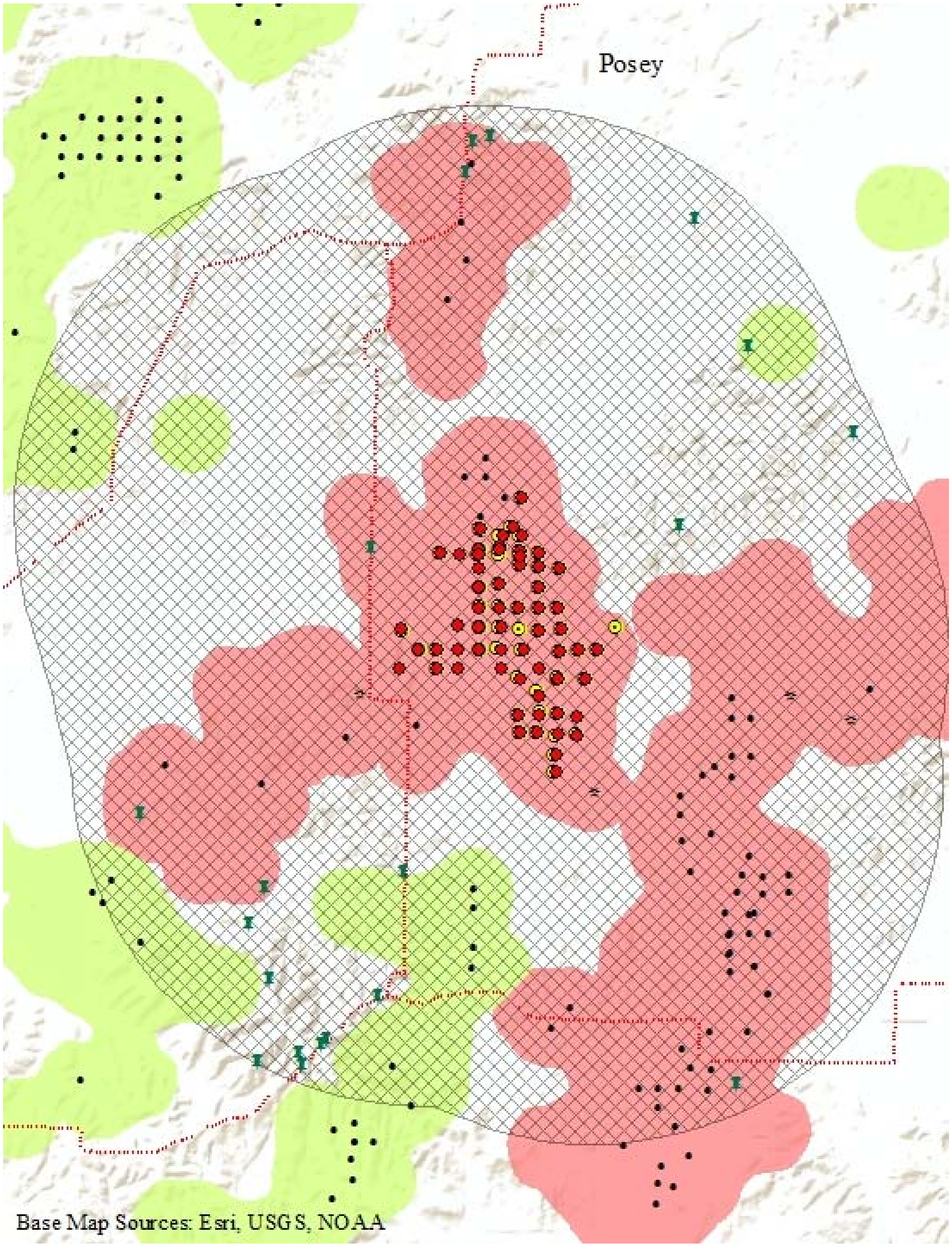
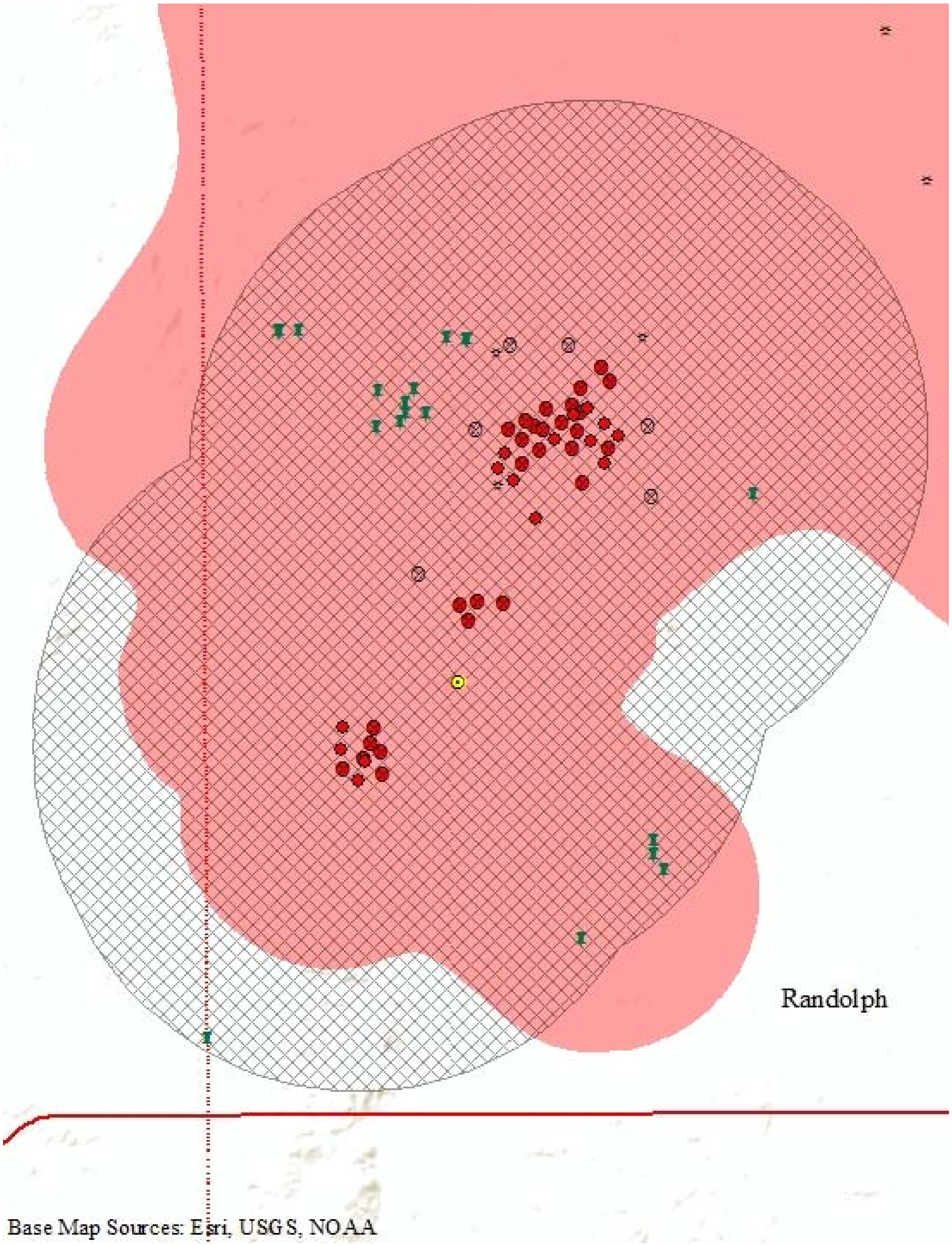


Figure A.27 Region of Analysis in Posey County



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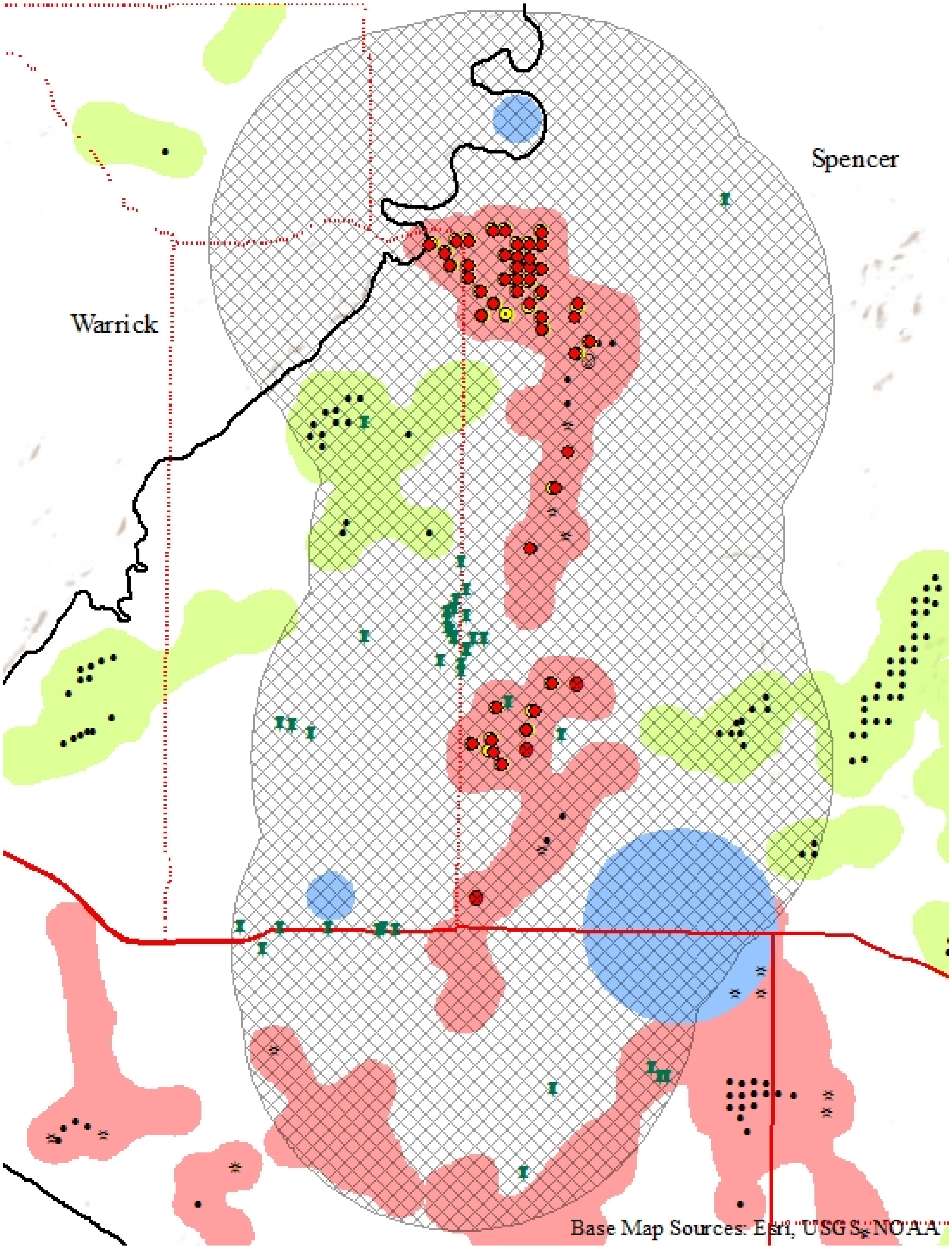

Figure A.29 Region of Analysis in Spencer County

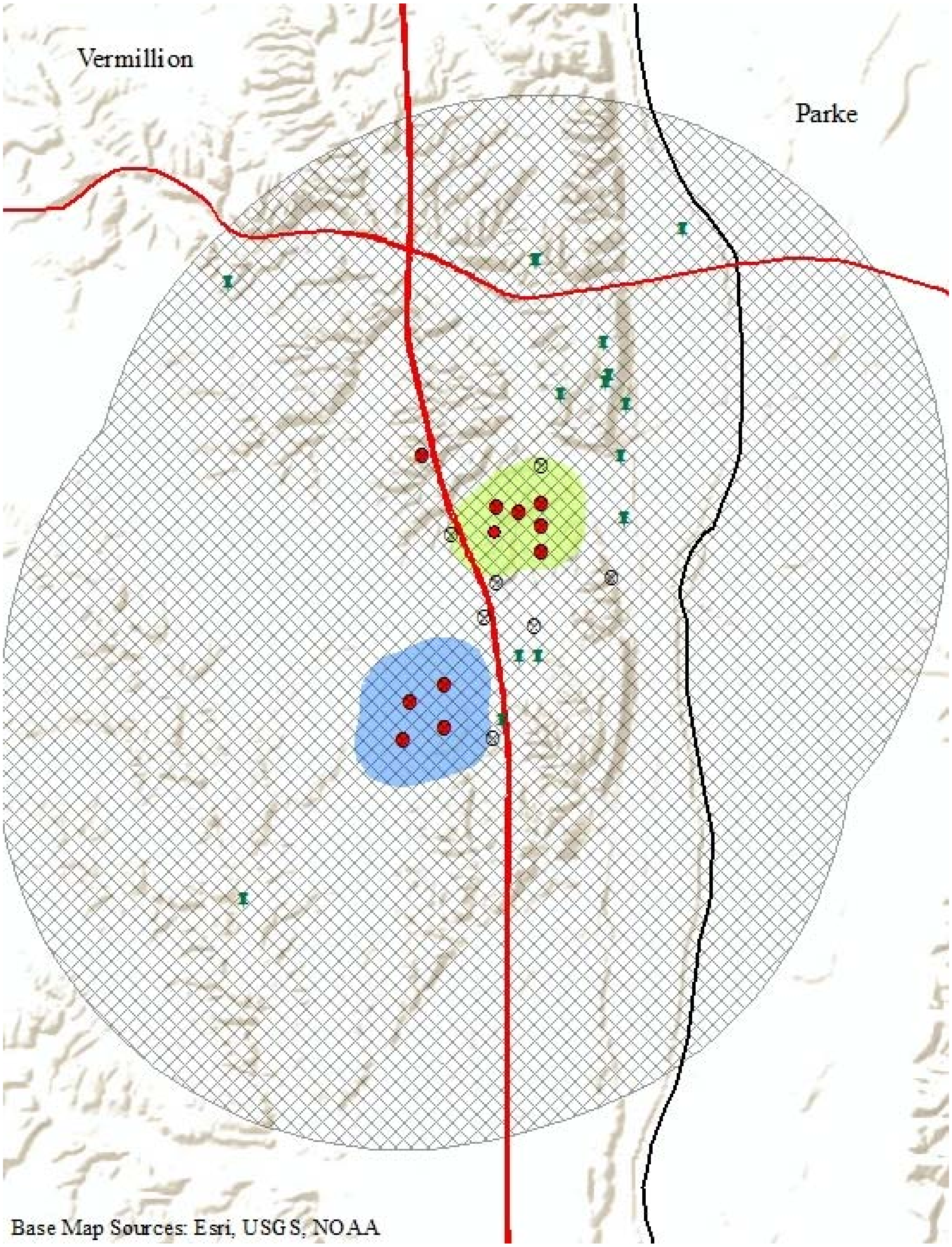

Figure A.30 Region of Analysis in Vermillion County

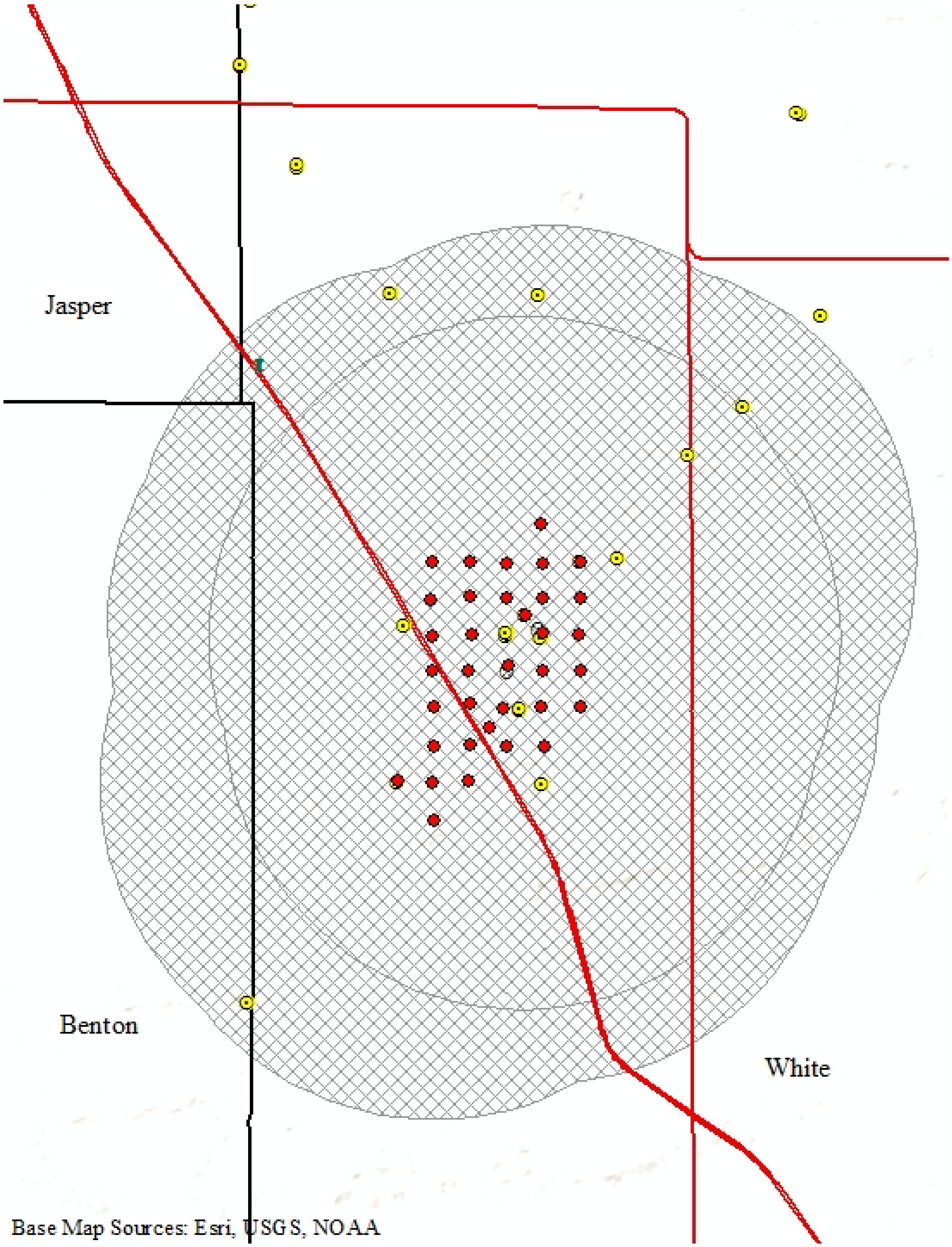

Figure A.31 First Region of Analysis in White County

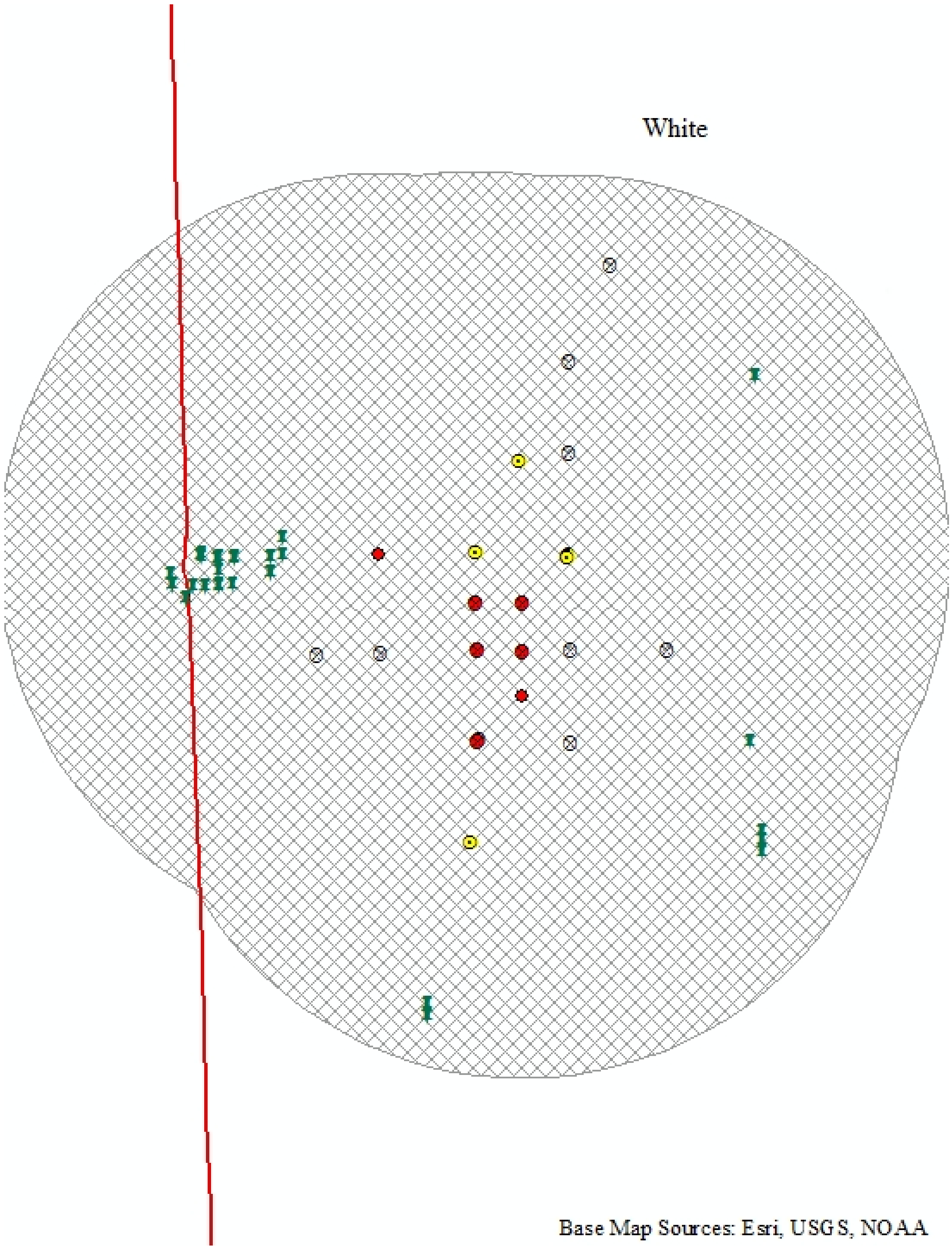

Figure A.32 Second Region of Analysis in White County

Appendix B Data Sources and Figure Credits

Data Sources

39 Degrees North, LLC. *Cass County, IN.* http://cassin.egis.39dn.com/# (accessed March 2013).

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Figure Credits

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Appendix C Additional Tables

Tables C.1 through C.11 include additional summary statistics for variables used in regressions throughout this analysis. This includes statistics for fixed effects terms, as well as interaction terms and nonlinear proximity effects.

Table C.1 Summary Statistics for County Indicators

Variable	n	Mean	Std Dev	Min	Max
Cass county indicator	1512	0.0595	0.2367	0	1
Clark county indicator	1512	0.1825	0.3864	0	1
Daviess county indicator	1512	0.0734	0.2609	0	1
Decatur county indicator	1512	0.0225	0.1483	0	1
Greene county indicator	1512	0.0589	0.2354	0	1
Harrison county indicator	1512	0.0066	0.0811	0	1
Huntington county indicator	1512	0.1620	0.3686	0	1
Lawrence county indicator	1512	0.0364	0.1873	0	1
Monroe county indicator	1512	0.1415	0.3487	0	1
Pike county indicator	1512	0.1574	0.3643	0	1
Posey county indicator	1512	0.0146	0.1198	0	1
Pulaski county indicator	1512	0.0007	0.0257	0	1
Randolph county indicator	1512	0.0159	0.1250	0	1
Spencer county indicator	1512	0.0298	0.1700	0	1
Vermillion county indicator	1512	0.0112	0.1055	0	1
White county indicator	1512	0.0271	0.1625	0	1

Table C.2 Summary Statistics for School District Indicators

Variable	n	Mean	Std Dev	Min	Max
Eastern Pulaski Community School Corporation indicator	1512	0.0006614	0.0257172	0	1
Huntington County Community School Corporation indicator	1512	0.162037	0.3686067	0	1
Pioneer Regional School Corporation indicator	1512	0.0595238	0.2366807	0	1
Tri-County School Corporation indicator	1512	0.0006614	0.0257172	0	1
Frontier School Corporation indicator	1512	0.026455	0.1605372	0	1
Union School Corporation indicator	1512	0.015873	0.1250256	0	1
South Vermillion Community School Corporation indicator	1512	0.0112434	0.1054719	0	1
Decatur County Community Schools indicator	1512	0.0112434	0.1054719	0	1
Greensburg Community Schools indicator	1512	0.0112434	0.1054719	0	1
Monroe County Community School Corporation indicator	1512	0.1415344	0.3486873	0	1
M S D Shakamak Schools indicator	1512	0.0013228	0.0363576	0	1
White River Valley School District indicator	1512	0.0575397	0.232948	0	1
North Lawrence Community Schools indicator	1512	0.0363757	0.187285	0	1
North Daviess Community Schools indicator	1512	0.0707672	0.2565204	0	1
Barr-Reeve Community School Corporation indicator	1512	0.0019841	0.0445141	0	1
Greater Clark County Schools indicator	1512	0.1541005	0.3611645	0	1
West Clark Community Schools indicator	1512	0.0284392	0.1662788	0	1
Pike County School Corporation indicator	1512	0.1580688	0.3649262	0	1
South Harrison Community Schools indicator	1512	0.0066138	0.0810824	0	1
M S D North Posey County Schools indicator	1512	0.0066138	0.0810824	0	1
North Spencer County School Corporation indicator	1512	0.0006614	0.0257172	0	1
M S D Mount Vernon indicator	1512	0.0079365	0.0887622	0	1
South Spencer County School Corporation indicator	1512	0.0291005	0.1681439	0	1

Table C.3 Summary Statistics for Year Indicators

Variable	n	Mean	Std Dev	Min	Max
2004 Sale indicator	1512	0.0007	0.0257	0	1
2005 Sale indicator	1512	0.0013	0.0364	0	1
2006 Sale indicator	1512	0.0013	0.0364	0	1
2007 Sale indicator	1512	0.0026	0.0514	0	1
2008 Sale indicator	1512	0.1157	0.3200	0	1
2009 Sale indicator	1512	0.2176	0.4127	0	1
2010 Sale indicator	1512	0.2202	0.4145	0	1
2011 Sale indicator	1512	0.2050	0.4039	0	1
2012 Sale indicator	1512	0.2295	0.4206	0	1
2013 Sale indicator	1512	0.0060	0.0769	0	1

Table C.4 Summary Statistics for Public Water Interaction Terms

Variable	n	Mean	Std Dev	Min	Max
Natural gas storage field indicator X Public Water	1512	0.07	0.26	0	1
Distance to nearest natural gas or oil field (meters) X Public Water	1512	5098.91	8008.76	0	31884.95
Distance to nearest natural gas storage well (meters) X Public Water	1512	1613.01	1757.00	0	8641.98
Distance to nearest observation well (meters) X Public Water	1512	11657.84	26269.58	0	84434.90
Distance to nearest abandoned natural gas storage well (meters) X Public water	1512	24221.31	30389.72	0	84225.27
Distance to nearest abandoned observation well (meters) X Public Water	1512	19852.26	28147.61	0	86986.13
Distance to nearest natural gas extraction well (meters) X Public Water	1512	12165.77	15885.68	0	71598.61
Distance to nearest natural gas and oil extraction well (meters) X Public Water	1512	35528.41	39887.70	0	137157.40
Distance to nearest oil extraction well (meters) X Public Water	1512	11453.14	18412.55	0	85930.77

Table C.5 Summary Statistics for Quadratic Proximity Variables

Variable	n	Mean	Std Dev	Min	Max
Distance to nearest natural gas or oil field squared	1512	1.80E+08	2.73E+08	0.00E+00	1.15E+09
Distance to nearest natural gas storage well squared	1512	8.72E+06	1.38E+07	2.09E+03	2.10E+08
Distance to nearest observation well squared	1512	1.23E+09	2.49E+09	4.33E+02	7.40E+09
Distance to nearest abandoned natural gas storage well squared	1512	2.13E+09	2.40E+09	7.55E+02	7.61E+09
Distance to nearest abandoned observation well squared	1512	1.94E+09	2.52E+09	7.73E+03	8.10E+09
Distance to nearest natural gas extraction well squared	1512	5.80E+08	9.66E+08	2.17E+03	5.13E+09
Distance to nearest natural gas and oil extraction well squared	1512	4.63E+09	5.37E+09	7.82E+06	2.02E+10
Distance to nearest oil extraction well squared	1512	1.23E+09	2.08E+09	6.27E+03	7.63E+09

Table C.6 Summary Statistics for Cubed Proximity Variables

Variable	n	Mean	Std Dev	Min	Max
Distance to nearest natural gas or oil field cubed	1512	4.24E+12	7.55E+12	0	3.90E+13
Distance to nearest natural gas storage well cubed	1512	4.13E+10	1.54E+11	95471.13	3.03E+12
Distance to nearest observation well cubed	1512	9.69E+13	1.99E+14	9005.245	6.36E+14
Distance to nearest abandoned natural gas storage well cubed	1512	1.44E+14	1.94E+14	20757.71	6.64E+14
Distance to nearest abandoned observation well cubed	1512	1.35E+14	2.10E+14	679265.9	7.29E+14
Distance to nearest natural gas extraction well cubed	1512	2.50E+13	6.00E+13	101069.3	3.67E+14
Distance to nearest natural gas and oil extraction well cubed	1512	4.63E+14	6.78E+14	2.19E+10	2.88E+15
Distance to nearest oil extraction well cubed	1512	8.20E+13	1.57E+14	496985.4	6.67E+14

Table C.7 Summary Statistics for Urban Interaction Terms

Variable	n	Mean	Std Dev	Min	Max
Natural gas storage field indicator X Urban Indicator	1512	0.0007	0.0257	0	1
Distance to nearest natural gas or oil field (meters) X Urban Indicator	1512	5733.55	9462.27	0	28166.39
Distance to nearest natural gas storage well (meters) X Urban Indicator	1512	643.24	1087.51	0	3806.51
Distance to nearest observation well (meters) X Urban Indicator	1512	10641.90	26623.11	0	80576.17
Distance to nearest abandoned natural gas storage well (meters) X Urban Indicator	1512	19326.56	31054.58	0	83290.17
Distance to nearest abandoned observation well (meters) X Urban Indicator	1512	18778.90	30526.81	0	82333.92
Distance to nearest natural gas extraction well (meters) X Urban Indicator	1512	7536.60	12087.97	0	34085.64
Distance to nearest natural gas and oil extraction well (meters) X Urban Indicator	1512	22433.52	38012.68	0	106000.70
Distance to nearest oil extraction well (meters) X Urban Indicator	1512	13150.28	25303.10	0	73729.68

Table C.8 Summary Statistics for Lot Size Interaction Terms

Variable	n	Mean	Std Dev	Min	Max
Natural gas storage field indicator X Lot Size	1512	0.1683	1.4243	0	40
Distance to nearest natural gas or oil field (meters) X Lot Size	1512	5558.00	17058.52	0	429925
Distance to nearest natural gas storage well (meters) X Lot Size	1512	2550.46	9833.18	0	292502
Distance to nearest observation well (meters) X Lot Size	1512	12223.26	75500.16	0	2459903
Distance to nearest abandoned natural gas storage well (meters) X Lot Size	1512	31594.73	83836.50	0	1855934
Distance to nearest abandoned observation well (meters) X Lot Size	1512	27635.66	91865.01	0	2577479
Distance to nearest natural gas extraction well (meters) X Lot Size	1512	12282.58	26598.57	0	455187
Distance to nearest natural gas and oil extraction well (meters) X Lot Size	1512	49872.24	130406.00	0	3131606
Distance to nearest oil extraction well (meters) X Lot Size	1512	18520.40	77388.20	0	2503529

Table C.9 Summary Statistics for Repeat Sales County Indicators

Variable	n	Mean	Std Dev	Min	Max
Cass county indicator	529	0.0699	0.2553	0	1
Clark county indicator	529	0.1607	0.3676	0	1
Daviess county indicator	529	0.0681	0.2521	0	1
Decatur county indicator	529	0.0076	0.0867	0	1
Greene county indicator	529	0.0737	0.2616	0	1
Harrison county indicator	529	0.0151	0.1222	0	1
Huntington county indicator	529	0.2514	0.4342	0	1
Lawrence county indicator	529	0.0340	0.1815	0	1
Monroe county indicator	529	0.1285	0.3350	0	1
Pike county indicator	529	0.1191	0.3242	0	1
Posey county indicator	529	0.0076	0.0867	0	1
Randolph county indicator	529	0.0113	0.1060	0	1
Spencer county indicator	529	0.0151	0.1222	0	1
Vermillion county indicator	529	0.0076	0.0867	0	1
White county indicator	529	0.0302	0.1714	0	1

Table C.10 Summary Statistics for Repeat Sales Year Indicators

Variable	n	Mean	Std Dev	Min	Max
2008 Sale indicator	529	0.0964	0.2954	0	1
2009 Sale indicator	529	0.2382	0.4264	0	1
2010 Sale indicator	529	0.2325	0.4228	0	1
2011 Sale indicator	529	0.2155	0.4116	0	1
2012 Sale indicator	529	0.2155	0.4116	0	1
2013 Sale indicator	529	0.0019	0.0435	0	1

Table C.11 Summary Statistics for Repeat Sales Public Water Interaction Terms

Variable	n	Mean	Std Dev	Min	Max
Natural gas storage field indicator X Public Water	529	0.07561	0.26463	0	1
Distance to nearest natural gas or oil field (meters) X Public Water	529	6534.88	8579.19	0	31208.92
Distance to nearest natural gas storage well (meters) X Public Water	529	1559.57	1563.59	0	6465.34
Distance to nearest observation well (meters) X Public Water	529	16961.45	31264.57	0	79645.55
Distance to nearest abandoned natural gas storage well (meters) X Public water	529	29752.12	33187.82	0	82330.49
Distance to nearest abandoned observation well (meters) X Public Water	529	25370.45	31953.22	0	82192.27
Distance to nearest natural gas extraction well (meters) X Public Water	529	14690.14	16482.04	0	67307.55
Distance to nearest natural gas and oil extraction well (meters) X Public Water	529	40814.97	40859.82	0	136978.20
Distance to nearest oil extraction well (meters) X Public Water	529	13796.07	19189.07	0	71685.14

Table C.12 presents additional models using proximity treatment variables. Models 1 through 9 use only county level fixed effects, while Models 10 through 18 employ only temporal fixed effects. Models 18 through 36 use combinations of school district fixed effects. The results presented within the models using only county level or school district level fixed effects as well as the school district fixed effects mirror those reported in Models 10 through 18 of Table 6.2. The results presented in the models using only temporal fixed effects mirror those presented in Models 1 through 9 of Table 6.2.

Table C.13 presents additional models using proximity treatment variables and water interaction terms. Models 1 through 9 present results from regressions employing only county level fixed effects. Models 10 through 18 use year fixed effects only, and Models 18 through 36 use combinations of temporal fixed effects and school district dummies. The results from the no fixed effects models and the county level and year fixed effects models reported in Chapter 6, are similar to those presented in this table.

Table C.14 presents additional quadratic functional form model results from models using only level fixed effects, which were sufficiently similar to the results presented in Models 9 through 16 as to not require additional explanation. Table C.15 present results from the cubic functional form model results. Models 1 through 8 do not use fixed effects, and Models 9 through 16 employ only county level fixed effects. The basic proximity treatment variable results indicated that county-level and year fixed effects captured some impacts that were being caught by the proximity treatment variables in the no fixed effects models, for this reason all models without fixed effects are contained within tables in this appendix. Additionally, the results presented in Models 9 through 16 mirror those reported in Table 6.5.

Tables C.16 and C.17 contain results from regressions including urban interactions or lot size interactions. As with the previous tables in this appendix, the results from Models 1 through 8 in both Table C.16 and C.17 do not employ fixed effects, which means that the results are biased. In addition, the results from Models 9 through 16 mirror those results reported in Tables 6.6 and 6.7 respectively.

Table C.18 and C.19 present additional intensity treatment variable results. Table C.18 includes results from intensity variable regressions without fixed effects and with county level fixed effects only. Table C.19 presents results from models with intensity measures and water interactions without fixed effects and with county level fixed effects only.

Tables C.20 and C.21 include additional results from regressions employing the repeat sales data. Table C.20 includes results from models using only proximity treatment variables without fixed effects and with county fixed effects only. Table C.21 presents results from regressions using proximity treatment variables and water interactions without fixed effects and with county level fixed effects only.

Table C.12 Additional Proximity Variable Estimation Results

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Natural gas storage field indicator	-0.0724	-	-	-	-	-	-	-	-
	0.119	-	-	-	-	-	-	-	-
Distance to nearest natural gas or oil field (kilometers)	-	-0.0196	-	-	-	-	-	-	-
	-	0.0192	-	-	-	-	-	-	-
Distance to nearest natural gas storage well (kilometers)	-	-	-0.00126	-	-	-	-	-	-
	-	-	0.0258	-	-	-	-	-	-
Distance to nearest observation well (kilometers)	-	-	-	0.00339	-	-	-	-	-
	-	-	-	0.0242	-	-	-	-	-
Distance to nearest abandoned natural gas storage well (kilometers)	-	-	-	-	-0.0135	-	-	-	-
	-	-	-	-	0.0175	-	-	-	-
Distance to nearest abandoned observation well (kilometers)	-	-	-	-	-	0.0162	-	-	-
	-	-	-	-	-	0.0102	-	-	-
Distance to nearest natural gas extraction well (kilometers)	-	-	-	-	-	-	-0.0321**	-	-
	-	-	-	-	-	-	0.0166	-	-
Distance to nearest natural gas and oil extraction well (kilometers)	-	-	-	-	-	-	-	-0.0333**	-
	-	-	-	-	-	-	-	0.0128	-
Distance to nearest oil extraction well (kilometers)	-	-	-	-	-	-	-	-	-0.023
	-	-	-	-	-	-	-	-	0.0163
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies?	No	No	No	No	No	No	No	No	No
Sample Size	1512	1512	1512	1512	1512	1512	1512	1512	1512
R^2	0.4374	0.4376	0.4372	0.4372	0.4374	0.4382	0.4386	0.4398	0.438

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.12, continued

Variable	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Natural gas storage field indicator	-0.0912	-	-	-	-	-	-	-	-
	0.0909	-	-	-	-	-	-	-	-
Distance to nearest natural gas or oil field kilo(meters)	-	0.0167**	-	-	-	-	-	-	-
	-	0.00414	-	-	-	-	-	-	-
Distance to nearest natural gas storage well (kilometers)	-	-	-0.05**	-	-	-	-	-	-
	-	-	0.017	-	-	-	-	-	-
Distance to nearest observation well (kilometers)	-	-	-	-0.00315**	-	-	-	-	-
	-	-	-	0.00117	-	-	-	-	-
Distance to nearest abandoned natural gas storage well (kilometers)	-	-	-	-	0.00335**	-	-	-	-
	-	-	-	-	0.00127	-	-	-	-
Distance to nearest abandoned observation well (kilometers)	-	-	-	-	-	0.00272*	-	-	-
	-	-	-	-	-	0.00147	-	-	-
Distance to nearest natural gas extraction well (kilometers)	-	-	-	-	-	-	0.00196	-	-
	-	-	-	-	-	-	0.00182	-	-
Distance to nearest natural gas and oil extraction well (kilometers)	-	-	-	-	-	-	-	0.00263**	-
	-	-	-	-	-	-	-	0.000762	-
Distance to nearest oil extraction well (kilometers)	-	-	-	-	-	-	-	-	0.00532**
	-	-	-	-	-	-	-	-	0.00145
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	No	No	No	No	No	No	No	No	No
Year Dummies?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sample Size	1512	1512	1512	1512	1512	1512	1512	1512	1512
R^2	0.4065	0.4125	0.4095	0.4089	0.4088	0.4074	0.4065	0.4108	0.4114

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.12, continued

Variable	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)
Natural gas storage field indicator	-0.0728	-	-	-	-	-	-	-	-
	0.119	-	-	-	-	-	-	-	-
Distance to nearest natural gas or oil field (kilometers)	-	-0.00104	-	-	-	-	-	-	-
	-	0.0205	-	-	-	-	-	-	-
Distance to nearest natural gas storage well (kilometers)	-	-	-0.0226	-	-	-	-	-	-
	-	-	0.0266	-	-	-	-	-	-
Distance to nearest observation well (kilometers)	-	-	-	-0.0117	-	-	-	-	-
	-	-	-	0.0247	-	-	-	-	-
Distance to nearest abandoned natural gas storage well (kilometers)	-	-	-	-	-0.00289	-	-	-	-
	-	-	-	-	0.00558	-	-	-	-
Distance to nearest abandoned observation well (kilometers)	-	-	-	-	-	0.00349	-	-	-
	-	-	-	-	-	0.00536	-	-	-
Distance to nearest natural gas extraction well (kilometers)	-	-	-	-	-	-	-0.0208	-	-
	-	-	-	-	-	-	0.0187	-	-
Distance to nearest natural gas and oil extraction well (kilometers)	-	-	-	-	-	-	-	-0.0232**	-
	-	-	-	-	-	-	-	0.0116	-
Distance to nearest oil extraction well (kilometers)	-	-	-	-	-	-	-	-	-0.0123
	-	-	-	-	-	-	-	-	0.0172
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
School District Dummies?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies?	No	No	No	No	No	No	No	No	No
Sample Size	1512	1512	1512	1512	1512	1512	1512	1512	1512
R^2	0.4408	0.4407	0.441	0.4408	0.4408	0.4409	0.4412	0.4422	0.4409

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.12, continued

Variable	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)
Natural gas storage field indicator	-0.0676	-	-	-	-	-	-	-	-
	0.1195	-	-	-	-	-	-	-	-
Distance to nearest natural gas or oil field (kilometers)	-	-0.00121	-	-	-	-	-	-	-
	-	0.0206	-	-	-	-	-	-	-
Distance to nearest natural gas storage well (kilometers)	-	-	-0.0225	-	-	-	-	-	-
	-	-	0.0267	-	-	-	-	-	-
Distance to nearest observation well (kilometers)	-	-	-	-0.0119	-	-	-	-	-
	-	-	-	0.0248	-	-	-	-	-
Distance to nearest abandoned natural gas storage well (kilometers)	-	-	-	-	-0.00312	-	-	-	-
	-	-	-	-	0.0056	-	-	-	-
Distance to nearest abandoned observation well (kilometers)	-	-	-	-	-	0.00327	-	-	-
	-	-	-	-	-	0.00538	-	-	-
Distance to nearest natural gas extraction well (kilometers)	-	-	-	-	-	-	-0.0204	-	-
	-	-	-	-	-	-	0.0188	-	-
Distance to nearest natural gas and oil extraction well (kilometers)	-	-	-	-	-	-	-	-0.0235**	-
	-	-	-	-	-	-	-	0.0116	-
Distance to nearest oil extraction well (kilometers)	-	-	-	-	-	-	-	-	-0.0123
	-	-	-	-	-	-	-	-	0.0173
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
School District Dummies?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sample Size	1512	1512	1512	1512	1512	1512	1512	1512	1512
R^2	0.4432	0.4431	0.4434	0.4432	0.4432	0.4432	0.4435	0.4446	0.4433

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.13 Additional Proximity Variable and Public Water Access Interaction Estimation Results

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Natural gas storage field indicator	0.143	-	-	-	-	-
	0.2351	-	-	-	-	-
Natural gas storage field indicator X Public Water	-0.2538	-	-	-	-	-
	0.2387	-	-	-	-	-
Distance to nearest natural gas or oil field (kilometers)	-	-0.0218	-	-	-	-
	-	0.0195	-	-	-	-
Distance to nearest natural gas or oil field (kilometers) X	-	0.00509	-	-	-	-
Public Water	-	0.00702	-	-	-	-
Distance to nearest natural gas storage well (kilometers)	-	-	-0.0285	-	-	-
	-	-	0.0337	-	-	-
Distance to nearest natural gas storage well (kilometers) X	-	-	0.0509	-	-	-
Public Water	-	-	0.0405	-	-	-
Distance to nearest observation well (kilometers)	-	-	-	0.00106	-	-
	-	-	-	0.0242	-	-
Distance to nearest observation well (kilometers) X Public	-	-	-	-0.00445*	-	-
Water	-	-	-	0.00237	-	-
Distance to nearest abandoned natural gas storage well	-	-	-	-	-0.0132	-
(kilometers)	-	-	-	-	0.0175	-
Distance to nearest abandoned natural gas storage well	-	-	-	-	-0.000576	-
(kilometers) X Public water	-	-	-	-	0.00259	-
Distance to nearest abandoned observation well	-	-	-	-	-	0.017
(kilometers)	-	-	-	-	-	0.0104
Distance to nearest abandoned observation well	-	-	-	-	-	-0.000857
(kilometers) X Public Water	-	-	-	-	-	0.00259
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies?	No	No	No	No	No	No
Sample Size	1512	1512	1512	1512	1512	1512
R^2	0.4378	0.4378	0.4378	0.4386	0.4375	0.4382

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.13, continued

Variable	(7)	(8)	(9)	(10)	(11)	(12)
Natural gas storage field indicator	-	-	-	-0.0433	-	-
	-	-	-	0.1616	-	-
Natural gas storage field indicator X Public Water	-	-	-	-0.0689	-	-
	-	-	-	0.1918	-	-
Distance to nearest natural gas or oil field (kilometers)	-	-	-	-	0.0138**	-
	-	-	-	-	0.00525	-
Distance to nearest natural gas or oil field (kilometers) X	-	-	-	-	0.00537	-
Public Water	-	-	-	-	0.00593	-
Distance to nearest natural gas storage well (kilometers)	-	-	-	-	-	-0.0458
	-	-	-	-	-	0.0301
Distance to nearest natural gas storage well (kilometers)	-	-	-	-	-	-0.00613
X Public Water	-	-	-	-	-	0.0359
Distance to nearest natural gas extraction well	-0.0343**	-	-	-	-	-
(kilometers)	0.0168	-	-	-	-	-
Distance to nearest natural gas extraction well	0.00471	-	-	-	-	-
(kilometers) X Public Water	0.00473	-	-	-	-	-
Distance to nearest natural gas and oil extraction well	-	-0.0324**	-	-	-	-
(kilometers)	-	0.0128	-	-	-	-
Distance to nearest natural gas and oil extraction well	-	0.00153	-	-	-	-
(kilometers) X Public Water	-	0.00181	-	-	-	-
Distance to nearest oil extraction well (kilometers)	-	-	-0.0228	-	-	-
	-	-	0.0163	-	-	-
Distance to nearest oil extraction well (kilometers) X	-	-	0.00149	-	-	-
Public Water	-	-	0.0026	-	-	-
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	No	No	No
Year Dummies?	No	No	No	Yes	Yes	Yes
Sample Size	1512	1512	1512	1512	1512	1512
R^2	0.4390	0.4401	0.4381	0.4065	0.4128	0.4095

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.13, continued

Variable	(13)	(14)	(15)	(16)	(17)	(18)
Distance to nearest observation well (kilometers)	0.000667	-	-	-	-	-
	0.00167	-	-	-	-	-
Distance to nearest observation well (kilometers) X	-0.00689**	-	-	-	-	-
Public Water	0.00217	-	-	-	-	-
Distance to nearest abandoned natural gas storage well	-	0.00262	-	-	-	-
(kilometers)	-	0.00178	-	-	-	-
Distance to nearest abandoned natural gas storage well	-	0.00121	-	-	-	-
(kilometers) X Public water	-	0.00206	-	-	-	-
Distance to nearest abandoned observation well	-	-	0.00394**	-	-	-
(kilometers)	-	-	0.00191	-	-	-
Distance to nearest abandoned observation well	-	-	-0.00218	-	-	-
(kilometers) X Public Water	-	-	0.0022	-	-	-
Distance to nearest natural gas extraction well	-	-	-	-0.000393	-	-
(kilometers)	-	-	-	0.00344	-	-
Distance to nearest natural gas extraction well	-	-	-	0.00318	-	-
(kilometers) X Public Water	-	-	-	0.00395	-	-
Distance to nearest natural gas and oil extraction well	-	-	-	-	0.00132	-
(kilometers)	-	-	-	-	0.00127	-
Distance to nearest natural gas and oil extraction well	-	-	-	-	0.0019	-
(kilometers) X Public Water	-	-	-	-	0.00148	-
Distance to nearest oil extraction well (kilometers)	-	-	-	-	-	0.00415**
	-	-	-	-	-	0.00179
Distance to nearest oil extraction well (kilometers) X	-	-	-	-	-	0.00256
Public Water	-	-	-	-	-	0.00228
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	No	No	No	No	No	No
Year Dummies?	Yes	Yes	Yes	Yes	Yes	Yes
Sample Size	1512	1512	1512	1512	1512	1512
R^2	0.4129	0.409	0.4078	0.4068	0.4114	0.4119

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.13, continued

Variable	(19)	(20)	(21)	(22)	(23)	(24)
Natural gas storage field indicator	0.0911	-	-	-	-	-
	0.2351	-	-	-	-	-
Natural gas storage field indicator X Public Water	-0.1932	-	-	-	-	-
	0.2389	-	-	-	-	-
Distance to nearest natural gas or oil field (kilometers)	-	-0.00176	-	-	-	-
	-	0.0211	-	-	-	-
Distance to nearest natural gas or oil field (kilometers) X	-	0.00111	-	-	-	-
Public Water	-	0.00727	-	-	-	-
Distance to nearest natural gas storage well (kilometers)	-	-	-0.0429	-	-	-
	-	-	0.0341	-	-	-
Distance to nearest natural gas storage well (kilometers)	-	-	0.0386	-	-	-
X Public Water	-	-	0.0404	-	-	-
Distance to nearest observation well (kilometers)	-	-	-	-0.0124	-	-
	-	-	-	0.0247	-	-
Distance to nearest observation well (kilometers) X	-	-	-	-0.00314	-	-
Public Water	-	-	-	0.00242	-	-
Distance to nearest abandoned natural gas storage well	-	-	-	-	-0.00216	-
(kilometers)	-	-	-	-	0.00591	-
Distance to nearest abandoned natural gas storage well	-	-	-	-	-0.000985	-
(kilometers) X Public water	-	-	-	-	0.00261	-
Distance to nearest abandoned observation well	-	-	-	-	-	0.00459
(kilometers)	-	-	-	-	-	0.00578
Distance to nearest abandoned observation well	-	-	-	-	-	-0.00135
(kilometers) X Public Water	-	-	-	-	-	0.00262
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes
School District Dummies?	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies?	No	No	No	No	No	No
Sample Size	1512	1512	1512	1512	1512	1512
R^2	0.4411	0.4407	0.4413	0.4414	0.4409	0.441

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.13, continued

Variable	(25)	(26)	(27)	(28)	(29)	(30)
Natural gas storage field indicator	-	-	-	0.1053	-	-
	-	-	-	0.2362	-	-
Natural gas storage field indicator X Public Water	-	-	-	-0.2035	-	-
	-	-	-	0.2397	-	-
Distance to nearest natural gas or oil field (kilometers)	-	-	-	-	-0.00203	-
	-	-	-	-	0.0212	-
Distance to nearest natural gas or oil field (kilometers) X	-	-	-	-	0.00126	-
Public Water	-	-	-	-	0.00729	-
Distance to nearest natural gas storage well (kilometers)	-	-	-	-	-	-0.0429
	-	-	-	-	-	0.0341
Distance to nearest natural gas storage well (kilometers)	-	-	-	-	-	0.0389
X Public Water	-	-	-	-	-	0.0406
Distance to nearest natural gas extraction well	-0.0225	-	-	-	-	-
(kilometers)	0.0188	-	-	-	-	-
Distance to nearest natural gas extraction well	0.00401	-	-	-	-	-
(kilometers) X Public Water	0.00477	-	-	-	-	-
Distance to nearest natural gas and oil extraction well	-	-0.023**	-	-	-	-
(kilometers)	-	0.0116	-	-	-	-
Distance to nearest natural gas and oil extraction well	-	0.000902	-	-	-	-
(kilometers) X Public Water	-	0.00185	-	-	-	-
Distance to nearest oil extraction well (kilometers)	-	-	-0.0121	-	-	-
	-	-	0.0172	-	-	-
Distance to nearest oil extraction well (kilometers) X	-	-	-0.000409	-	-	-
Public Water	-	-	0.00273	-	-	-
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes
School District Dummies?	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies?	No	No	No	Yes	Yes	Yes
Sample Size	1512	1512	1512	1512	1512	1512
R^2	0.4414	0.4423	0.4409	0.4435	0.4431	0.4437

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.13, continued

Variable	(31)	(32)	(33)	(34)	(35)	(36)
Distance to nearest observation well (kilometers)	-0.0125	-	-	-	-	-
	0.0248	-	-	-	-	-
Distance to nearest observation well (kilometers) X	-0.00303	-	-	-	-	-
Public Water	0.00243	-	-	-	-	-
Distance to nearest abandoned natural gas storage well	-	-0.00251	-	-	-	-
(kilometers)	-	0.00593	-	-	-	-
Distance to nearest abandoned natural gas storage well	-	-0.000812	-	-	-	-
(kilometers) X Public water	-	0.00262	-	-	-	-
Distance to nearest abandoned observation well	-	-	0.00421	-	-	-
(kilometers)	-	-	0.0058	-	-	-
Distance to nearest abandoned observation well	-	-	-0.00114	-	-	-
(kilometers) X Public Water	-	-	0.00264	-	-	-
Distance to nearest natural gas extraction well	-	-	-	-0.0222	-	-
(kilometers)	-	-	-	0.0189	-	-
Distance to nearest natural gas extraction well	-	-	-	0.00424	-	-
(kilometers) X Public Water	-	-	-	0.00478	-	-
Distance to nearest natural gas and oil extraction well	-	-	-	-	-0.0233**	-
(kilometers)	-	-	-	-	0.0116	-
Distance to nearest natural gas and oil extraction well	-	-	-	-	0.00104	-
(kilometers) X Public Water	-	-	-	-	0.00186	-
Distance to nearest oil extraction well (kilometers)	-	-	-	-	-	-0.0122
	-	-	-	-	-	0.0173
Distance to nearest oil extraction well (kilometers) X	-	-	-	-	-	-0.000256
Public Water	-	-	-	-	-	0.00274
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes
School District Dummies?	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies?	Yes	Yes	Yes	Yes	Yes	Yes
Sample Size	1512	1512	1512	1512	1512	1512
R^2	0.4438	0.4432	0.4433	0.4438	0.4448	0.4433

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.14 Additional Quadratic Functional Form Specification Estimation Results

Variable	(1)	(2)	(3)	(4)
Distance to nearest natural gas or oil field (kilometers)	0.0279	-	-	-
	0.0276	-	-	-
Distance to nearest natural gas or oil field (kilometers) squared	-0.00259**	-	-	-
	0.00105	-	-	-
Distance to nearest natural gas storage well (kilometers)	-	0.122**	-	-
	-	0.0457	-	-
Distance to nearest natural gas storage well (kilometers) squared	-	-0.0143**	-	-
	-	0.0044	-	-
Distance to nearest observation well (kilometers)	-	-	0.00471	-
	-	-	0.0305	-
Distance to nearest observation well (kilometers) squared	-	-	-0.0000246	-
	-	-	0.000346	-
Distance to nearest abandoned natural gas storage well (kilometers)	-	-	-	-0.0252
	-	-	-	0.0316
Distance to nearest abandoned natural gas storage well (kilometers) squared	-	-	-	0.000157
	-	-	-	0.000353
Hedonic Attributes?	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	Yes
Year Dummies?	No	No	No	No
Sample Size	1512	1512	1512	1512
R^2	0.4398	0.4412	0.4372	0.4375

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.14, continued

Variable	(5)	(6)	(7)	(8)
Distance to nearest abandoned observation well (kilometers)	0.0278	-	-	-
	0.0179	-	-	-
Distance to nearest abandoned observation well (kilometers) squared	-0.000246	-	-	-
	0.000314	-	-	-
Distance to nearest natural gas extraction well (kilometers)	-	-0.0311	-	-
	-	0.0249	-	-
Distance to nearest natural gas extraction well (kilometers) squared	-	-0.0000258	-	-
	-	0.000483	-	-
Distance to nearest natural gas and oil extraction well (kilometers)	-	-	-0.0245	-
	-	-	0.0204	-
Distance to nearest natural gas and oil extraction well (kilometers) squared	-	-	-0.000107	-
	-	-	0.000194	-
Distance to nearest oil extraction well (kilometers)	-	-	-	0.0107
	-	-	-	0.0212
Distance to nearest oil extraction well (kilometers) squared	-	-	-	-0.000735**
	-	-	-	0.000297
Hedonic Attributes?	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	Yes
Year Dummies?	No	No	No	No
Sample Size	1512	1512	1512	1512
R^2	0.4384	0.4386	0.4399	0.4403

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.15 Additional Cubic Functional Form Specification Estimation Results

Variable	(1)	(2)	(3)	(4)
Distance to nearest natural gas or oil field (kilometers)	-0.036	-	-	-
	0.0273	-	-	-
Distance to nearest natural gas or oil field (kilometers)	0.00585**	-	-	-
squared	0.00266	-	-	-
Distance to nearest natural gas or oil field (kilometers)	-0.00014**	-	-	-
cubed	0.0000635	-	-	-
Distance to nearest natural gas storage well	-	0.0957	-	-
(kilometers)	-	0.0849	-	-
Distance to nearest natural gas storage well	-	-0.0242	-	-
(kilometers) squared	-	0.0201	-	-
Distance to nearest natural gas storage well	-	0.000547	-	-
(kilometers) cubed	-	0.00111	-	-
Distance to nearest observation well (kilometers)	-	-	-0.0491**	-
	-	-	0.0204	-
Distance to nearest observation well (kilometers)	-	-	0.00066	-
squared	-	-	0.000612	-
Distance to nearest observation well (kilometers) cubed	-	-	-0.00000115	-
	-	-	0.00000501	-
Distance to nearest abandoned natural gas storage well	-	-	-	0.0179
(kilometers)	-	-	-	0.0222
Distance to nearest abandoned natural gas storage well	-	-	-	-0.000045
(kilometers) squared	-	-	-	0.000655
Distance to nearest abandoned natural gas storage well	-	-	-	-0.00000196
(kilometers) cubed	-	-	-	0.0000048
Hedonic Attributes?	Yes	Yes	Yes	Yes
County Dummies?	No	No	No	No
Year Dummies?	No	No	No	No
Sample Size	1512	1512	1512	1512
R^2	0.4123	0.4121	0.4108	0.4205

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.15, continued

Variable	(5)	(6)	(7)	(8)
Distance to nearest abandoned observation well	0.0279**	-	-	-
(kilometers)	0.00939	-	-	-
Distance to nearest abandoned observation well	-0.000212	-	-	-
(kilometers) squared	0.000314	-	-	-
Distance to nearest abandoned observation well	-0.000000953	-	-	-
(kilometers) cubed	0.00000258	-	-	-
Distance to nearest natural gas extraction well	-	0.0388**	-	-
(kilometers)	-	0.0138	-	-
Distance to nearest natural gas extraction well	-	-0.00141**	-	-
(kilometers) squared	-	0.000528	-	-
Distance to nearest natural gas extraction well	-	0.0000136**	-	-
(kilometers) cubed	-	0.00000549	-	-
Distance to nearest natural gas and oil extraction well	-	-	-0.000621	-
(kilometers)	-	-	0.00765	-
Distance to nearest natural gas and oil extraction well	-	-	0.00023*	-
(kilometers) squared	-	-	0.000144	-
Distance to nearest natural gas and oil extraction well	-	-	-0.00000172**	-
(kilometers)cubed	-	-	0.000000735	-
Distance to nearest oil extraction well (kilometers)	-	-	-	-0.0211**
	-	-	-	0.00956
Distance to nearest oil extraction well (kilometers)	-	-	-	0.0009**
squared	-	-	-	0.000355
Distance to nearest oil extraction well (kilometers)	-	-	-	-0.00000748**
cubed	-	-	-	0.00000332
Hedonic Attributes?	Yes	Yes	Yes	Yes
County Dummies?	No	No	No	No
Year Dummies?	No	No	No	No
Sample Size	1512	1512	1512	1512
R^2	0.4219	0.4073	0.4164	0.4123

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.15, continued

Variable	(9)	(10)	(11)	(12)
Distance to nearest natural gas or oil field (kilometers)	0.0416	-	-	-
	0.0492	-	-	-
Distance to nearest natural gas or oil field (kilometers) squared	-0.00458	-	-	-
	0.00621	-	-	-
Distance to nearest natural gas or oil field (kilometers) cubed	0.0000476	-	-	-
	0.000141	-	-	-
Distance to nearest natural gas storage well (kilometers)	-	0.039	-	-
	-	0.0911	-	-
Distance to nearest natural gas storage well (kilometers) squared	-	0.00792	-	-
	-	0.0217	-	-
Distance to nearest natural gas storage well (kilometers) cubed	-	-0.00125	-	-
	-	0.00119	-	-
Distance to nearest observation well (kilometers)	-	-	0.138**	-
	-	-	0.0455	-
Distance to nearest observation well (kilometers) squared	-	-	-0.0164**	-
	-	-	0.00418	-
Distance to nearest observation well (kilometers) cubed	-	-	0.000129**	-
	-	-	0.0000329	-
Distance to nearest abandoned natural gas storage well (kilometers)	-	-	-	0.0225
	-	-	-	0.0368
Distance to nearest abandoned natural gas storage well (kilometers) squared	-	-	-	-0.00254**
	-	-	-	0.00112
Distance to nearest abandoned natural gas storage well (kilometers) cubed	-	-	-	0.0000263**
	-	-	-	0.0000104
Hedonic Attributes?	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	Yes
Year Dummies?	No	No	No	No
Sample Size	1512	1512	1512	1512
R^2	0.4398	0.4416	0.4431	0.4399

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.15, continued

Variable	(13)	(14)	(15)	(16)
Distance to nearest abandoned observation well	0.0438	-	-	-
(kilometers)	0.0307	-	-	-
Distance to nearest abandoned observation well	-0.000861	-	-	-
(kilometers) squared	0.00101	-	-	-
Distance to nearest abandoned observation well	0.00000503	-	-	-
(kilometers) cubed	0.00000781	-	-	-
Distance to nearest natural gas extraction well	-	-0.0199	-	-
(kilometers)	-	0.0407	-	-
Distance to nearest natural gas extraction well	-	-0.000623	-	-
(kilometers) squared	-	0.00179	-	-
Distance to nearest natural gas extraction well	-	0.00000612	-	-
(kilometers) cubed	-	0.0000177	-	-
Distance to nearest natural gas and oil extraction well	-	-	-0.0278	-
(kilometers)	-	-	0.0295	-
Distance to nearest natural gas and oil extraction well	-	-	-0.00000378	-
(kilometers) squared	-	-	0.000695	-
Distance to nearest natural gas and oil extraction well	-	-	-0.000000605	-
(kilometers) cubed	-	-	0.00000391	-
Distance to nearest oil extraction well (kilometers)	-	-	-	0.0732**
	-	-	-	0.0332
Distance to nearest oil extraction well (kilometers)	-	-	-	-0.00494**
squared	-	-	-	0.00175
Distance to nearest oil extraction well (kilometers)	-	-	-	0.000034**
cubed	-	-	-	0.0000139
Hedonic Attributes?	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	Yes
Year Dummies?	No	No	No	No
Sample Size	1512	1512	1512	1512
R^2	0.4386	0.4387	0.4399	0.4425

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.16 Additional Proximity Variable and Urban Term Interaction Estimation Results

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Distance to nearest natural gas or oil field (kilometers)	0.014**	-	-	-	-	-
	0.00437	-	-	-	-	-
Distance to nearest natural gas or oil field (kilometers) X	0.0202*	-	-	-	-	-
Urban Indicator	0.0111	-	-	-	-	-
Distance to nearest natural gas storage well (kilometers)	-	-0.0613**	-	-	-	-
	-	0.0173	-	-	-	-
Distance to nearest natural gas storage well (kilometers)	-	0.215**	-	-	-	-
X Urban Indicator	-	0.0733	-	-	-	-
Distance to nearest observation well (kilometers)	-	-	0.00167	-	-	-
	-	-	0.00163	-	-	-
Distance to nearest observation well (kilometers) X	-	-	-0.0093**	-	-	-
Urban Indicator	-	-	0.00221	-	-	-
Distance to nearest abandoned natural gas storage well	-	-	-	0.0066**	-	-
(kilometers)	-	-	-	0.00133	-	-
Distance to nearest abandoned natural gas storage well	-	-	-	-0.0289**	-	-
(kilometers) X Urban Indicator	-	-	-	0.00443	-	-
Distance to nearest abandoned observation well	-	-	-	-	0.0075**	-
(kilometers)	-	-	-	-	0.00162	-
Distance to nearest abandoned observation well	-	-	-	-	-0.0257**	-
(kilometers) X Urban Indicator	-	-	-	-	0.004	-
Distance to nearest natural gas extraction well	-	-	-	-	-	0.000922
(kilometers)	-	-	-	-	-	0.00185
Distance to nearest natural gas extraction well	-	-	-	-	-	0.0325**
(kilometers) X Urban Indicator	-	-	-	-	-	0.0113
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	No	No	No	No	No	No
Year Dummies?	No	No	No	No	No	No
Sample Size	1512	1512	1512	1512	1512	1512
R^2	0.4416	0.4106	0.4136	0.4233	0.4212	0.4076

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.16, continued

Variable	(7)	(8)	(9)	(10)	(11)	(12)
Distance to nearest natural gas or oil field (kilometers)	-	-	-0.0197	-	-	-
	-	-	0.0192	-	-	-
Distance to nearest natural gas or oil field (kilometers) X	-	-	0.00777	-	-	-
Urban Indicator	-	-	0.0156	-	-	-
Distance to nearest natural gas storage well (kilometers)	-	-	-	-0.0253	-	-
	-	-	-	0.0277	-	-
Distance to nearest natural gas storage well (kilometers)	-	-	-	0.181**	-	-
X Urban Indicator	-	-	-	0.076	-	-
Distance to nearest observation well (kilometers)	-	-	-	-	-0.00764	-
	-	-	-	-	0.0246	-
Distance to nearest observation well (kilometers) X	-	-	-	-	-0.0079**	-
Urban Indicator	-	-	-	-	0.00309	-
Distance to nearest abandoned natural gas storage well	-	-	-	-	-	-0.0089
(kilometers)	-	-	-	-	-	0.0175
Distance to nearest abandoned natural gas storage well	-	-	-	-	-	-0.0208**
(kilometers) X Urban Indicator	-	-	-	-	-	0.00779
Distance to nearest natural gas and oil extraction well	0.0016**	-	-	-	-	-
(kilometers)	0.000806	-	-	-	-	-
Distance to nearest natural gas and oil extraction well	0.0084**	-	-	-	-	-
(kilometers) X Urban Indicator	0.00234	-	-	-	-	-
Distance to nearest oil extraction well (kilometers)	-	0.0023	-	-	-	-
	-	0.00182	-	-	-	-
Distance to nearest oil extraction well (kilometers) X	-	0.0076**	-	-	-	-
Urban Indicator	-	0.00279	-	-	-	-
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	No	No	Yes	Yes	Yes	Yes
Year Dummies?	No	No	No	No	No	No
Sample Size	1512	1512	1512	1512	1512	1512
R^2	0.4137	0.4121	0.4377	0.4394	0.4397	0.4401

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.16, continued

Variable	(13)	(14)	(15)	(16)
Distance to nearest abandoned observation well (kilometers)	0.0193*	-	-	-
	0.0102	-	-	-
Distance to nearest abandoned observation well (kilometers) X Urban Indicator	-0.0152**	-	-	-
	0.00581	-	-	-
Distance to nearest natural gas extraction well (kilometers)	-	-0.0323*	-	-
	-	0.0166	-	-
Distance to nearest natural gas extraction well (kilometers) X Urban Indicator	-	0.0103	-	-
	-	0.0159	-	-
Distance to nearest natural gas and oil extraction well (kilometers)	-	-	-0.0296**	-
	-	-	0.0129	-
Distance to nearest natural gas and oil extraction well (kilometers) X Urban Indicator	-	-	0.0074*	-
	-	-	0.00437	-
Distance to nearest oil extraction well (kilometers)	-	-	-	-0.0196
	-	-	-	0.0164
Distance to nearest oil extraction well (kilometers) X Urban Indicator	-	-	-	0.0072*
	-	-	-	0.00424
Hedonic Attributes?	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	Yes
Year Dummies?	No	No	No	No
Sample Size	1512	1512	1512	1512
R^2	0.4408	0.4388	0.4409	0.4391

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.17 Additional Proximity Variable and Lot Size Interaction Estimation Results

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Natural gas storage field indicator	-0.0475	-	-	-	-	-
	0.0956	-	-	-	-	-
Natural gas storage field indicator X Lot Size	-0.0351	-	-	-	-	-
	0.0227	-	-	-	-	-
Distance to nearest natural gas or oil field (kilometers)	-	0.015**	-	-	-	-
	-	0.00453	-	-	-	-
Distance to nearest natural gas or oil field (kilometers) X	-	0.00186	-	-	-	-
Lot Size	-	0.0021	-	-	-	-
Distance to nearest natural gas storage well (kilometers)	-	-	-0.0491**	-	-	-
	-	-	0.0191	-	-	-
Distance to nearest natural gas storage well (kilometers) X	-	-	-0.000382	-	-	-
Lot Size	-	-	0.00767	-	-	-
Distance to nearest observation well (kilometers)	-	-	-	-0.00347**	-	-
	-	-	-	0.00122	-	-
Distance to nearest observation well (kilometers) X Lot Size	-	-	-	0.00039	-	-
	-	-	-	0.000425	-	-
Distance to nearest abandoned natural gas storage well	-	-	-	-	0.00263*	-
(kilometers)	-	-	-	-	0.00137	-
Distance to nearest abandoned natural gas storage well	-	-	-	-	0.000661	-
(kilometers) X Lot Size	-	-	-	-	0.000445	-
Distance to nearest abandoned observation well	-	-	-	-	-	0.00233
(kilometers)	-	-	-	-	-	0.00153
Distance to nearest abandoned observation well	-	-	-	-	-	0.000413
(kilometers) X Lot Size	-	-	-	-	-	0.000431
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	No	No	No	No	No	No
Year Dummies?	No	No	No	No	No	No
Sample Size	1512	1512	1512	1512	1512	1512
R^2	0.4052	0.4106	0.4072	0.4070	0.4077	0.4056

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.17, continued

Variable	(7)	(8)	(9)	(10)	(11)	(12)
Natural gas storage field indicator	-	-	-	-0.0394	-	-
	-	-	-	0.1224	-	-
Natural gas storage field indicator X Lot Size	-	-	-	-0.0263	-	-
	-	-	-	0.0226	-	-
Distance to nearest natural gas or oil field (kilometers)	-	-	-	-	-0.0306	-
	-	-	-	-	0.021	-
Distance to nearest natural gas or oil field (kilometers) X	-	-	-	-	0.00292	-
Lot Size	-	-	-	-	0.00222	-
Distance to nearest natural gas storage well (kilometers)	-	-	-	-	-	-0.00817
	-	-	-	-	-	0.0288
Distance to nearest natural gas storage well (kilometers) X	-	-	-	-	-	0.00425
Lot Size	-	-	-	-	-	0.00786
Distance to nearest natural gas extraction well (kilometers)	0.00106	-	-	-	-	-
	0.00197	-	-	-	-	-
Distance to nearest natural gas extraction well (kilometers)	0.00173	-	-	-	-	-
X Lot Size	0.0014	-	-	-	-	-
Distance to nearest natural gas and oil extraction well	-	0.00257**	-	-	-	-
(kilometers)	-	0.00078	-	-	-	-
Distance to nearest natural gas and oil extraction well	-	0.000133	-	-	-	-
(kilometers) X Lot Size	-	0.000299	-	-	-	-
Distance to nearest oil extraction well (kilometers)	-	-	0.00587**	-	-	-
	-	-	0.00153	-	-	-
Distance to nearest oil extraction well (kilometers) X Lot	-	-	-0.0005	-	-	-
Size	-	-	0.000444	-	-	-
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	No	No	No	Yes	Yes	Yes
Year Dummies?	No	No	No	No	No	No
Sample Size	1512	1512	1512	1512	1512	1512
R^2	0.4049	0.4088	0.4097	0.4379	0.4383	0.4373

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.17, continued

Variable	(13)	(14)	(15)	(16)	(17)	(18)
Distance to nearest observation well (kilometers)	0.00426	-	-	-	-	-
	0.0243	-	-	-	-	-
Distance to nearest observation well (kilometers) X Lot Size	0.000396	-	-	-	-	-
	0.000435	-	-	-	-	-
Distance to nearest abandoned natural gas storage well	-	-0.0133	-	-	-	-
(kilometers)	-	0.0175	-	-	-	-
Distance to nearest abandoned natural gas storage well	-	0.000107	-	-	-	-
(kilometers) X Lot Size	-	0.000453	-	-	-	-
Distance to nearest abandoned observation well	-	-	0.0161	-	-	-
(kilometers)	-	-	0.0102	-	-	-
Distance to nearest abandoned observation well	-	-	0.000163	-	-	-
(kilometers) X Lot Size	-	-	0.000432	-	-	-
Distance to nearest natural gas extraction well (kilometers)	-	-	-	-0.0352**	-	-
	-	-	-	0.0169	-	-
Distance to nearest natural gas extraction well (kilometers)	-	-	-	0.00152	-	-
X Lot Size	-	-	-	0.00145	-	-
Distance to nearest natural gas and oil extraction well	-	-	-	-	-0.0332**	-
(kilometers)	-	-	-	-	0.0128	-
Distance to nearest natural gas and oil extraction well	-	-	-	-	-0.000042	-
(kilometers) X Lot Size	-	-	-	-	0.000301	-
Distance to nearest oil extraction well (kilometers)	-	-	-	-	-	-0.023
	-	-	-	-	-	0.0163
Distance to nearest oil extraction well (kilometers) X Lot	-	-	-	-	-	-0.000143
Size	-	-	-	-	-	0.000448
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies?	No	No	No	No	No	No
Sample Size	1512	1512	1512	1512	1512	1512
R^2	0.4375	0.4375	0.4382	0.4390	0.4398	0.4380

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.18 Additional Intensity Variable Estimation Results

Variable	(1)	(2)	(3)	(4)	(5)	(6)
All Wells Intensity Measure (Count of wells within 2 miles)	0.00089	-	-	-	-	-
	0.0126	-	-	-	-	-
Storage Intensity Measure (Count of all Gas Storage and Observation wells within 2 miles)	-	0.018	-	-	-	-
	-	0.0141	-	-	-	-
Gas Storage Wells Only Intensity Measure (Count of all Gas Storage wells within 2 miles)	-	-	0.024	-	-	-
	-	-	0.0179	-	-	-
Observation Wells Intensity Measure (Count of all Observation wells within 2 miles)	-	-	-	0.048	-	-
	-	-	-	0.0548	-	-
Abandoned Gas Storage Intensity Measure (Count of all Abandoned Gas Storage wells within 2 miles)	-	-	-	-	-0.128*	-
	-	-	-	-	0.0695	-
ExtractionWells Only Intensity Measure (Count of all Extraction wells within 2 miles)	-	-	-	-	-	-0.0302
	-	-	-	-	-	0.0227
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	No	No	No	No	No	No
Year Dummies?	No	No	No	No	No	No
Sample Size	1512	1512	1512	1512	1512	1512
R^2	0.4038	0.4045	0.4045	0.4041	0.4052	0.4045

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1. All results reported are scaled by a factor of 10.

Table C.18, continued

Variable	(7)	(8)	(9)	(10)	(11)	(12)
All Wells Intensity Measure (Count of wells within 2 miles)	-0.0272	-	-	-	-	-
	0.0165	-	-	-	-	-
Storage Intensity Measure (Count of all Gas Storage and Observation wells within 2 miles)	-	-0.0432*	-	-	-	-
	-	0.024	-	-	-	-
Gas Storage Wells Only Intensity Measure (Count of all Gas Storage wells within 2 miles)	-	-	-0.0476*	-	-	-
	-	-	0.028	-	-	-
Observation Wells Intensity Measure (Count of all Observation wells within 2 miles)	-	-	-	-0.269**	-	-
	-	-	-	0.137	-	-
Abandoned Gas Storage Intensity Measure (Count of all Abandoned Gas Storage wells within 2 miles)	-	-	-	-	0.0789	-
	-	-	-	-	0.1298	-
ExtractionWells Only Intensity Measure (Count of all Extraction wells within 2 miles)	-	-	-	-	-	-0.0174
	-	-	-	-	-	0.0244
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies?	No	No	No	No	No	No
Sample Size	1512	1512	1512	1512	1512	1512
R^2	0.4382	0.4384	0.4383	0.4387	0.4374	0.4374

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1. All results reported are scaled by a factor of 10.

Table C.19 Additional Intensity Variable and Water Access Interaction Estimation Results

Variable	(1)	(2)	(3)	(4)	(5)	(6)
All Wells Intensity Measure (Count of wells within 2 miles)	-0.0615**	-	-	-	-	-
	0.0248	-	-	-	-	-
All Wells Intensity Measure (Count of wells within 2 miles) X Public	0.0837**	-	-	-	-	-
Water Indicator	0.0287	-	-	-	-	-
Storage Intensity Measure (Count of all Gas Storage and Observation	-	-0.0814**	-	-	-	-
wells within 2 miles)	-	0.0341	-	-	-	-
Storage Intensity Measure (Count of all Gas Storage and Observation	-	0.121**	-	-	-	-
wells within 2 miles) X Public Water Indicator	-	0.0377	-	-	-	-
Gas Storage Wells Only Intensity Measure (Count of all Gas Storage	-	-	-0.106**	-	-	-
wells within 2 miles)	-	-	0.0438	-	-	-
Gas Storage Wells Only Intensity Measure (Count of all Gas Storage	-	-	0.157**	-	-	-
wells within 2 miles) X Public Water Indicator	-	-	0.0483	-	-	-
Observation Wells Intensity Measure (Count of all Observation wells	-	-	-	-0.254**	-	-
within 2 miles)	-	-	-	0.132	-	-
Observation Wells Intensity Measure (Count of all Observation wells	-	-	-	0.368**	-	-
within 2 miles) X Public Water Indicator	-	-	-	0.146	-	-
Abandoned Gas Storage Intensity Measure (Count of all Abandoned	-	-	-	-	-0.00731	-
Gas Storage wells within 2 miles)	-	-	-	-	0.106	-
Abandoned Gas Storage Intensity Measure (Count of all Abandoned	-	-	-	-	-0.207	-
Gas Storage wells within 2 miles) X Public Water Indicator	-	-	-	-	0.138	-
ExtractionWells Only Intensity Measure (Count of all Extraction wells	-	-	-	-	-	-0.0284
within 2 miles)	-	-	-	-	-	0.0297
ExtractionWells Only Intensity Measure (Count of all Extraction wells	-	-	-	-	-	-0.00422
within 2 miles) X Public Water Indicator	-	-	-	-	-	0.045
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	No	No	No	No	No	No
Year Dummies?	No	No	No	No	No	No
Sample Size	1512	1512	1512	1512	1512	1512
R^2	0.4072	0.4085	0.4087	0.4066	0.4061	0.4045

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1. All resultsreported are scaled by a factor of 10.

Table C.20 Additional Repeat Sales Proximity Variable Estimation Results

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Natural gas storage field indicator	-0.1450	-	-	-	-	-	-	-	-
	0.1501	-	-	-	-	-	-	-	-
Distance to nearest natural gas or oil field	-	0.0203**	-	-	-	-	-	-	-
(kilometers)	-	0.00699	-	-	-	-	-	-	-
Distance to nearest natural gas storage	-	-	-0.0855**	-	-	-	-	-	-
well (kilometers)	-	-	0.0286	-	-	-	-	-	-
Distance to nearest observation well	-	-	-	-0.00403**	-	-	-	-	-
(kilometers)	-	-	-	0.00195	-	-	-	-	-
Distance to nearest abandoned natural	-	-	-	-	0.00186	-	-	-	-
gas storage well (kilometers)	-	-	-	-	0.00231	-	-	-	-
Distance to nearest abandoned	-	-	-	-	-	0.000795	-	-	-
observation well (kilometers)	-	-	-	-	-	0.00267	-	-	-
Distance to nearest natural gas extraction	-	-	-	-	-	-	0.00163	-	-
well (kilometers)	-	-	-	-	-	-	0.0029	-	-
Distance to nearest natural gas and oil	-	-	-	-	-	-	-	0.00214*	-
extraction well (kilometers)	-	-	-	-	-	-	-	0.00124	-
Distance to nearest oil extraction well	-	-	-	-	-	-	-	-	0.00768**
(kilometers)	-	-	-	-	-	-	-	-	0.00266
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	No	No	No	No	No	No	No	No	No
Year Dummies?	No	No	No	No	No	No	No	No	No
Sample Size	529	529	529	529	529	529	529	529	529
R^2	0.4202	0.4285	0.4291	0.4239	0.4198	0.4192	0.4195	0.4225	0.4285

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.20, continued

Variable	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Natural gas storage field indicator	-0.1825	-	-	-	-	-	-	-	-
	0.204	-	-	-	-	-	-	-	-
Distance to nearest natural gas or oil field	-	-0.00603	-	-	-	-	-	-	-
(kilometers)	-	0.0342	-	-	-	-	-	-	-
Distance to nearest natural gas storage	-	-	-0.0681	-	-	-	-	-	-
well (kilometers)	-	-	0.0487	-	-	-	-	-	-
Distance to nearest observation well	-	-	-	-0.0324	-	-	-	-	-
(kilometers)	-	-	-	0.0497	-	-	-	-	-
Distance to nearest abandoned natural gas	-	-	-	-	0.00813	-	-	-	-
storage well (kilometers)	-	-	-	-	0.0351	-	-	-	-
Distance to nearest abandoned	-	-	-	-	-	0.0302	-	-	-
observation well (kilometers)	-	-	-	-	-	0.0207	-	-	-
Distance to nearest natural gas extraction	-	-	-	-	-	-	-0.0225	-	-
well (kilometers)	-	-	-	-	-	-	0.0319	-	-
Distance to nearest natural gas and oil	-	-	-	-	-	-	-	-0.00185	-
extraction well (kilometers)	-	-	-	-	-	-	-	0.0232	-
Distance to nearest oil extraction well	-	-	-	-	-	-	-	-	-0.0087
(kilometers)	-	-	-	-	-	-	-	-	0.0309
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies?	No	No	No	No	No	No	No	No	No
Sample Size	529	529	529	529	529	529	529	529	529
R^2	0.4559	0.455	0.4571	0.4555	0.4551	0.4573	0.4556	0.455	0.4551

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.21 Additional Repeat Sales Proximity Variable and Public Water Access Interaction Estimation Results

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Natural gas storage field indicator	0.0363	-	-	-	-	-
	0.2737	-	-	-	-	-
Natural gas storage field indicator X Public Water	-0.2507	-	-	-	-	-
	0.3165	-	-	-	-	-
Distance to nearest natural gas or oil field (kilometers)	-	0.0149	-	-	-	-
	-	0.00927	-	-	-	-
Distance to nearest natural gas or oil field (kilometers) X	-	0.00885	-	-	-	-
Public Water	-	0.01	-	-	-	-
Distance to nearest natural gas storage well (kilometers)	-	-	-0.149**	-	-	-
	-	-	0.0463	-	-	-
Distance to nearest natural gas storage well (kilometers)	-	-	0.103*	-	-	-
X Public Water	-	-	0.0589	-	-	-
Distance to nearest observation well (kilometers)	-	-	-	0.0000499	-	-
	-	-	-	0.00273	-	-
Distance to nearest observation well (kilometers) X	-	-	-	-0.00705**	-	-
Public Water	-	-	-	0.00331	-	-
Distance to nearest abandoned natural gas storage well	-	-	-	-	0.0011	-
(kilometers)	-	-	-	-	0.00291	-
Distance to nearest abandoned natural gas storage well	-	-	-	-	0.00144	-
(kilometers) X Public water	-	-	-	-	0.00335	-
Distance to nearest abandoned observation well	-	-	-	-	-	0.00127
(kilometers)	-	-	-	-	-	0.00326
Distance to nearest abandoned observation well	-	-	-	-	-	-0.000929
(kilometers) X Public Water	-	-	-	-	-	0.00365
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	No	No	No	No	No	No
Year Dummies?	No	No	No	No	No	No
Sample Size	529	529	529	529	529	529
R^2	0.4209	0.4294	0.4325	0.429	0.4201	0.4193

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.21, continued

Variable	(7)	(8)	(9)	(10)	(11)	(12)
Natural gas storage field indicator	-	-	-	-0.2323	-	-
	-	-	-	0.4872	-	-
Natural gas storage field indicator X Public Water	-	-	-	0.0536	-	-
	-	-	-	0.4764	-	-
Distance to nearest natural gas or oil field (kilometers)	-	-	-	-	-0.0093	-
	-	-	-	-	0.0349	-
Distance to nearest natural gas or oil field (kilometers) X	-	-	-	-	0.00563	-
Public Water	-	-	-	-	0.0123	-
Distance to nearest natural gas storage well (kilometers)	-	-	-	-	-	-0.128**
	-	-	-	-	-	0.0554
Distance to nearest natural gas storage well (kilometers)	-	-	-	-	-	0.161**
X Public Water	-	-	-	-	-	0.0718
Distance to nearest natural gas extraction well	0.00759	-	-	-	-	-
(kilometers)	0.00576	-	-	-	-	-
Distance to nearest natural gas extraction well	-0.00793	-	-	-	-	-
(kilometers) X Public Water	0.00662	-	-	-	-	-
Distance to nearest natural gas and oil extraction well	-	0.00401*	-	-	-	-
(kilometers)	-	0.00229	-	-	-	-
Distance to nearest natural gas and oil extraction well	-	-0.00252	-	-	-	-
(kilometers) X Public Water	-	0.00259	-	-	-	-
Distance to nearest oil extraction well (kilometers)	-	-	0.00619*	-	-	-
	-	-	0.00347	-	-	-
Distance to nearest oil extraction well (kilometers) X	-	-	0.00263	-	-	-
Public Water	-	-	0.00394	-	-	-
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	No	No	No	Yes	Yes	Yes
Year Dummies?	No	No	No	No	No	No
Sample Size	529	529	529	529	529	529
R^2	0.4211	0.4236	0.429	0.4559	0.4553	0.4626

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.

Table C.21, continued

Variable	(13)	(14)	(15)	(16)	(17)	(18)
Distance to nearest observation well (kilometers)	-0.0394	-	-	-	-	-
	0.0498	-	-	-	-	-
Distance to nearest observation well (kilometers) X	-0.00552	-	-	-	-	-
Public Water	0.0038	-	-	-	-	-
Distance to nearest abandoned natural gas storage well	-	0.0084	-	-	-	-
(kilometers)	-	0.0355	-	-	-	-
Distance to nearest abandoned natural gas storage well	-	-0.000238	-	-	-	-
(kilometers) X Public water	-	0.00434	-	-	-	-
Distance to nearest abandoned observation well	-	-	0.031	-	-	-
(kilometers)	-	-	0.0215	-	-	-
Distance to nearest abandoned observation well	-	-	-0.000692	-	-	-
(kilometers) X Public Water	-	-	0.00438	-	-	-
Distance to nearest natural gas extraction well	-	-	-	-0.0158	-	-
(kilometers)	-	-	-	0.0323	-	-
Distance to nearest natural gas extraction well	-	-	-	-0.0104	-	-
(kilometers) X Public Water	-	-	-	0.00814	-	-
Distance to nearest natural gas and oil extraction well	-	-	-	-	-0.00326	-
(kilometers)	-	-	-	-	0.0232	-
Distance to nearest natural gas and oil extraction well	-	-	-	-	-0.00256	-
(kilometers) X Public Water	-	-	-	-	0.00313	-
Distance to nearest oil extraction well (kilometers)	-	-	-	-	-	-0.00851
	-	-	-	-	-	0.0309
Distance to nearest oil extraction well (kilometers) X	-	-	-	-	-	0.00256
Public Water	-	-	-	-	-	0.00462
Hedonic Attributes?	Yes	Yes	Yes	Yes	Yes	Yes
County Dummies?	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies?	No	No	No	No	No	No
Sample Size	529	529	529	529	529	529
R^2	0.4578	0.4551	0.4574	0.4574	0.4558	0.4554

Statistical significance at a 5 percent level denoted with two asterisk (**). Statistical significance at a 10 percent level denoted with an asterisk (*). Hedonic regression results are nearly identical to those reported in Table 6.1.