Evaluating the Impacts of Oil and Gas Activity: Hydraulic Fracturing in Selected Oklahoma Counties

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Oklahoma Cooperative Extension Service
Division of Agricultural Sciences and Natural Resources
Oklahoma State University

Evaluating the Impacts of Oil and Gas Activity: Hydraulic Fracturing in Selected Oklahoma Counties[1]

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Table of Contents

EXECUTIVE SUMMARY **6**
Background 6
Purpose 6
Results 7

SECTION ONE **9**
Introduction 9
Why Do We Care? 9
Technical Description of the Hydraulic Fracturing Process 9
Oil, Gas and Commodity Prices 10
Historic Overview: Energy in Oklahoma 10

SECTION TWO **11**
Counties Selected for Study 11
Overview of Selected Counties 11
Natural Gas Production by Selected Counties 11

SECTION THREE **14**
Federal Agency Roles in Oil and Gas Activity 14
Federal Emergency Management Agency 14
Federal Energy Regulatory Commission 14
United States Environmental Protection Agency (EPA) 14
U.S. Fish and Wildlife Service 14
United States Geological Survey 14
State Agency Roles in Oil and Gas Activity 14
Oklahoma Corporation Commission 15
Oklahoma Department of Environmental Quality (ODEQ) 15
Oklahoma Geological Survey 15
Oklahoma Office of Emergency Management 15
Oklahoma Water Resources Board 15
County Commissioners 15
Oklahoma Cooperative Extension Service (OCES) 15
The Recent Past Oil and Gas 16
Geology and Earthquakes 16
Seismicity Case Study: Stillwater, OK and Guy, AR 16
Well Activity, Fluid, and Drilling Mud Disposal 17
Flow-Back and Produced Water 17
Drilling Mud Disposal 19
Water 22
Water Quality 22
Water Quantity 22
Oil and Gas Activity and Water Permitting 22

SECTION FOUR **27**
Legal Overview for Oklahoma 27
Surface Owner Issues 27
Fracturing Fluid Regulation 28
Well Regulation 29
Water Use and Injection Well Control 29
Surface Water Pollution Prevention 29
Solid Waste Disposal 29
Air Quality Issues 29
General Legal and Policy Issues 29

SECTION FIVE **32**
Boomtown 32
Boomtown Defined 32
Boomtowns Not Apparent in Oklahoma 32
Retail Sales Reflect Relative Health 36
Highway Funds: Revenues and Expenditures 39
Community Characteristics 40
Population Gains and Losses 40
Median Household Income 40
Average Wage Per Job 40
Housing Characteristics 40
Building Permits 42
Median Housing Values 44
Housing Affordability 44
Gross Rent 44
Vacancy Rate 44
Units in Structure 44

SECTION SIX **47**
Summary/Conclusions 47
Coincidence Versus Causation 47
Factors That Have Been Considered But Not Included 47

REFERENCES CITED **48**

List of Tables

Table 1. Percent Change in Factors for Selected Counties (2000-2012) 8
Table 2. Oil and Gas Activity: Selected Counties and State (2000-2012) 12
Table 3. Oklahoma 90-Day Provisional-Temporary Permitted Acre-Feet per Year 25
Table 4. Provisional-Temporary Permitted Acre-Feet Water Use (2000-2014) 26
Table 5. Fracturing Fluid Information 28
Table 6. Potential Pollutants and Sources from Oil and Gas Activities 30
Table 7. Comparison of Employment Growth Rates 33
Table 8. Comparison of Employment Growth Rates 33
Table 9. Estimated Retail Sales for Selected Counties (2000-2015) 34
Table 10. Population Change Since 2000 36
Table 11. Median Household Income and Percent Change 41
Table 12. Average Wage Per Job 41
Table 13. Median Value of Owner-Occupied Housing Units 43
Table 14. Median Value of Owner-Occupied Housing Units: Percent Change 43
Table 15. Gross Rent 45
Table 16. Gross Rent: Percent Change 45
Table 17. Vacancy Rate 46
Table 18. Peak Year Impact: Factors Coincident with Oil/Gas Activity, 2000-2012 for Oil & Gas 48

List of Figures

Figure 1. Natural gas production in Oklahoma (1965-2015) 7
Figure 2. Crude oil production in Oklahoma (1980 to 2015) 8
Figure 3. Cutaway image of a typical drill site 9
Figure 4. Oil and Natural Gas Production in Oklahoma (1891-2012) 10
Figure 5. Map of counties included in the study 11
Figure 6. Oklahoma gas production peak years, selected counties (2000-2012) 12
Figure 7. Earthquakes of magnitude three or greater in Oklahoma 17
Figure 8. Oklahoma seismic hazard map (2014) 18
Figure 9. Chance of damage from an earthquake in 2016 18

Figure 10. Number of sites receiving drilling mud (1987-2014) 20
Figure 11. Water based mud application sites (1991-2014) 20
Figure 12. Oil based mud application sites (2000-2014) 21
Figure 13. Permitted groundwater by county 23
Figure 14. Permitted surface water by county 23
Figure 15. Permitted groundwater by purpose 23
Figure 16. Permitted surface water by purpose 24
Figure 17. Oklahoma county retail sales 24
Figure 18. Selected counties retail sales 35
Figure 19. Additional counties retail sales 35
Figure 20. Oklahoma state highway revenues and expenditures (2000-2014) 36
Figure 21. Alfalfa County highway revenues and expenditures (2000-2014) 36
Figure 22. Atoka County highway revenues and expenditures (2000-2014) 36
Figure 23. Canadian County highway revenues and expenditures (2000-2014) 36
Figure 24. Coal County highway revenues and expenditures (2000-2014) 36
Figure 25. Harmon County highway revenues and expenditures (2000-2014) 36
Figure 26. Jefferson County highway revenues and expenditures (2000-2014) 37
Figure 27. Noble County highway revenues and expenditures (2000-2014) 37
Figure 28. Oklahoma County highway revenues and expenditures (2000-2014) 37
Figure 29. Payne County highway revenues and expenditures (2000-2014) 37
Figure 30. Pittsburg County highway revenues and expenditures (2000-2014) 37
Figure 31. Pottawatomie County highway revenues and expenditures (2000-2014) 37
Figure 32. Roger Mills County highway revenues and expenditures (2000-2014) 39
Figure 33. Woods County highway revenues and expenditures (2000-2014) 39
Figure 34. Woodward County highway revenues and expenditures (2000-2014) 39
Figure 35. Community characteristics key findings among counties of interest 39
Figure 36. Building permits: Oklahoma City metropolitan area counties (2000-2013) 42
Figure 37. Building permits: Nonmetropolitan area counties (2000-2013) 42

Executive Summary

Background

Oil and gas exploration and production (referred to in the industry as E&P) is a broad-based system, encompassing everything from planning, investment, exploration, siting, development, input procurement and application, production, waste management, transport and distribution to markets and further joint venture capital development. The resurgence of the industry in recent years has been primarily the result of existing and new technologies—hydraulic fracturing coupled with the relatively new process of lateral and horizontal drilling. Additional technological advances in such aspects as chemical mix, water and mud recycling have further improved the recovery and waste management streams. Public institutional mechanisms also have evolved to improve oversight and compliance with practices that may be less harmful to the environment. However, there continue to be trade-offs that need discussion.

Purpose

The purpose of this study is to provide basic information for Extension professionals and local public managers about oil and gas activities in Oklahoma. Fourteen counties were selected to evaluate the impacts on a variety of physical and economic factors. Specifically, the study provides (1) production activity by county, (2) a summary of such physical factors as highway expenditures and water use, (3) estimates of economic impacts and (4) analysis of well activity and hydrofracturing fluid and drilling mud disposal. While the headlines are focused on earthquakes, there are many other important dimensions to the questions related to increased oil and gas activity, more recently through hydraulic fracturing and horizontal drilling.

Faculty at Oklahoma State University studied recent oil and gas activity and the impacts in selected Oklahoma counties for the study period of 2000-2012. Based on the results of the study, it can be concluded that this is a complex story with limited, generalized results. Coincidence is not causation. However, patterns do emerge that can assist in public planning and response to problems and opportunities arising when a local area is subjected to petroleum activities, such as hydraulic fracturing.

Specific highlights among the counties selected for the study include:

Oil production: Eight of the counties were active and produced oil at a higher rate of growth than the state; of these, five were also higher gas producers; six produced oil at a lower level; four of these were among the low gas producers. Oil and gas are typically produced from hydraulic fracturing wells, but vary by volume.

Natural Gas production: Seven of the 14 counties in the sample produced gas at a higher rate of growth than the state; seven produced below the state level.

Population: Nine counties experienced a population increase, four of which were high gas producers; five experienced a decrease in population, three of which were high gas producers. Canadian County experienced the greatest gain; Harmon County experienced the greatest loss; and both of these are relatively low gas producers.

Personal income: Six of the top gas-producing counties had higher personal income, while three of the low-producing counties were above the state level. The most significant gains were seen in Woodward, Roger Mills and Canadian counties. Interestingly, Woodward and Roger Mills counties are among the less-populous counties.

Median household income: Six of the top gas-producing counties had higher household income, while four of the bottom counties were higher household income than the state. In the 2005 and later estimates, Canadian, Oklahoma, Roger Mills, Woods and Woodward counties all featured median income higher than the state average. With populations less than 20,000, Roger Mills, Woods and Woodward are among the lesspopulated counties. Between 2000 and 2012, some least populous counties benefitted from major gains in median income. Roger Mills, Woods and Woodward counties experienced the largest percent change in median household income. Harmon, Oklahoma and Payne counties experienced the smallest percent change.

Average wage per job: Five of the top gas-producing counties had higher average wages per job, and four of the bottom counties were higher than the state. The largest percentage gains in average wage were experienced in Alfalfa, Roger Mills, Woods and Woodward counties. Despite having a loss in population, Woods County enjoyed the largest increase in average wage per job.

Highway expenditures: Nine of the sampled counties had higher highway expenditure growth rates than the state.

Water use: Nine of the sampled counties had higher temporary water use growth rates than the state level; (long-term water use remains under study).

Drilling mud use and disposal: Drilling mud use and disposal, typically on farm fields, has been shown to be relatively safe when done properly; economic analysis is anecdotal at this time. Disposal is generally done in the producing counties or adjacent counties.

Earthquake activity: Secondary literature shows that hydraulic fracturing typically does not cause earthquakes. However, millions of gallons of toxic saltwater are produced from the process and this "produced water" is typically disposed by deep injection into the subsurface. These deep injections are known as injection wells. Studies have concluded that injection wells are, in many cases, the cause of earthquakes, and this has been verified by U.S. Geological Service (USGS). Injections of produced water may not be in the producing counties.

Results

While counties may do well economically regardless of gas production, economic success is more likely if expanding gas production is part of the economy. The results also suggest that high gas-producing counties are more likely to have above average water use. The results are less certain on highway expenditures. While the boomtown effects of rapid economic growth followed by rapid economic decline are real, that phenomenon has not yet been observed in Oklahoma.

Data are a challenge. The key data for oil and gas production is only available in composite form through 2012. Scientific analysis can be applied to what is available, but anecdotal evidence is a fall-back 2012 and earlier. Mining income and employment is available through 2014 and may be a proxy indicator of oil and gas activity after 2012. Other caveats about interpretation of the data for the period include the severe recession of 2008 and the drought that began toward the end of the study period. Both events may distort economic data and water use. The major price declines in petroleum began in late 2014, resulting in reduced activity in the oil patch. However, oil and gas production has remained relatively high.

Conversations, observations and other data, such as mining income and employment, indicate a strong likelihood that much production, even peak production in some counties, occurred in 2013 and 2014, and production has been on the decline since late 2014, primarily because of the significant drop in oil and gas prices. Statewide, 2014 was a record breaker with 2,310.114 mcf. This amounts to about 8 percent of U.S. production for 2014. Review of the available data indicates trends in gas activity generally coincide or shortly precede increasing water use and highway expenses, and some economic activity. The latter is much more challenging to explain for reasons discussed later. Counties anticipating increased gas activity, or in the midst of it, will find it advantageous to devote some public discussion and possible policy decisions to manage the likely impacts, both positive and negative. Figures 1 and 2 provide information about natural gas and oil activity in Oklahoma.

The results are less certain on highway expenditures. Table 1 provides summary information about change in the counties of interest.

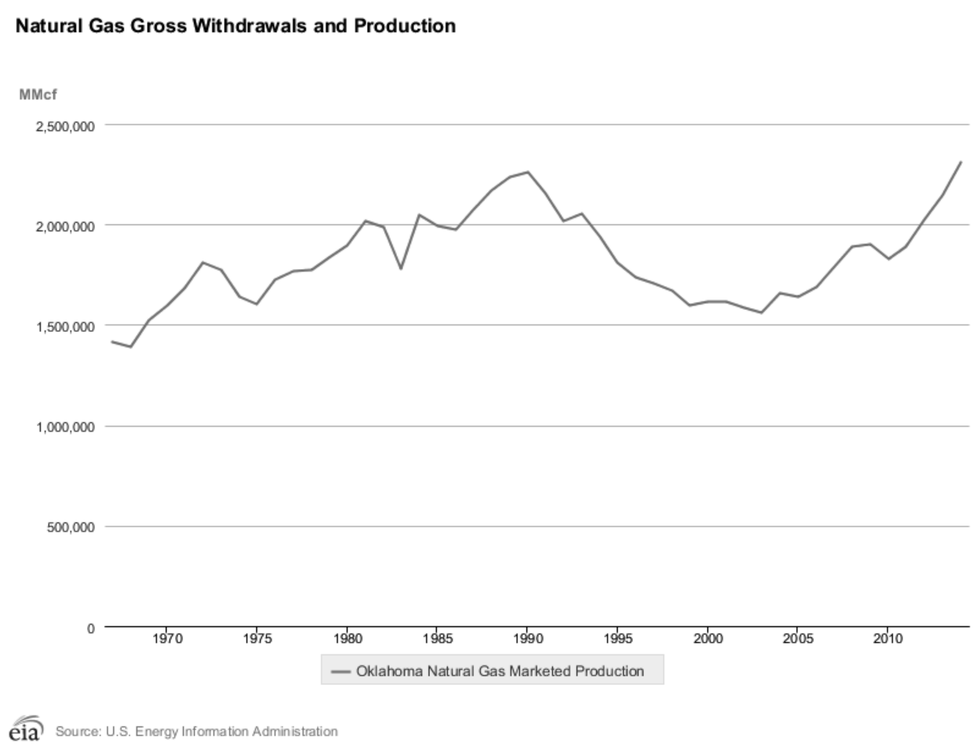

Figure 1. Natural gas production in Oklahoma (1965-2015).

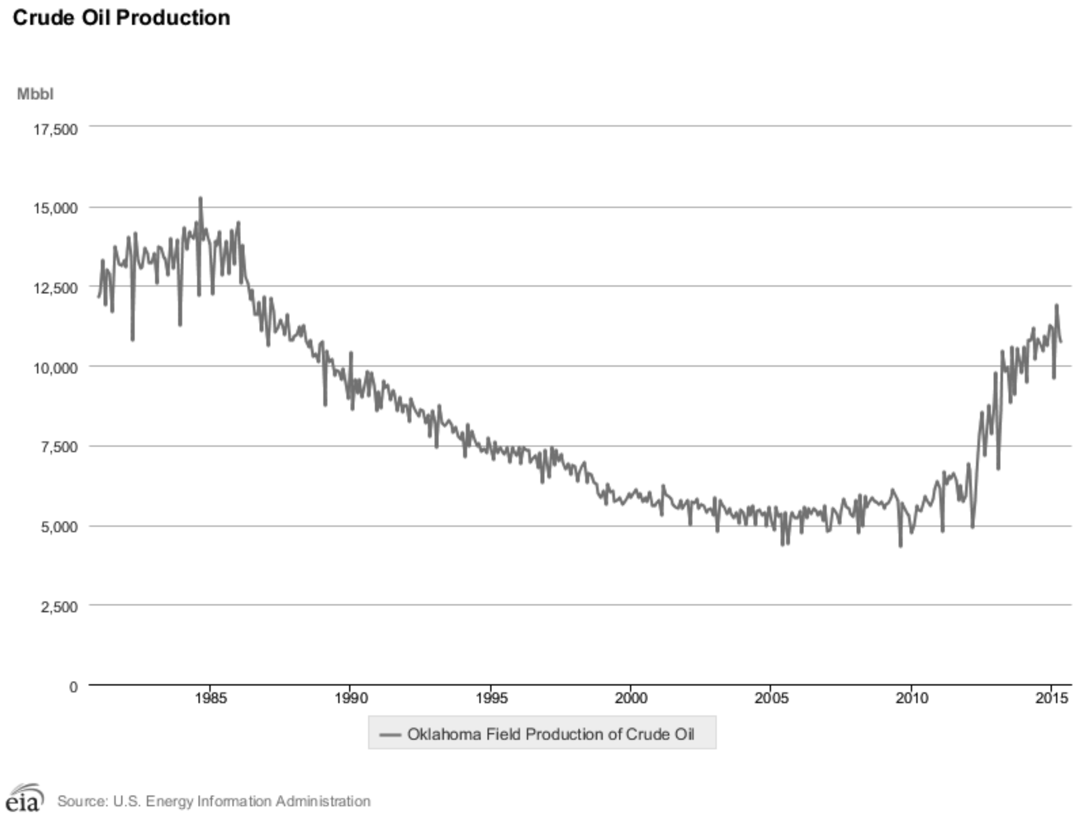

Figure 2. Crude oil production in Oklahoma (1980 to 2015).

Table 1. Percent Change in Factors for Selected Counties (2000-2012).

County/ state	*Gas production*	*Oil production*	*Hwy spending*	*Water use long term acre ft/ year acre ft/ year*	*Water use provisional temporary income*	*Personal income*	*Household wage/job*	*Average*
Alfalfa	6,461	479	160	68	1,461	82	39	104
Atoka	821	866	83	N/A	-5	70	48	40
Canadian	24	139	126	703	1,119	121	41	21
Coal	1,566	39	176	N/A	3,686	90	41	71
Harmon	0	-77	23	349	N/A	49	26	82
Jefferson	10	-11	72	N/A	N/A	38	51	58
Noble	4	11	49	-79	7,675	54	29	35
Oklahoma	16	-17	-1	-99	-95	81	29	60
Payne	223	-11	58	67	1,866	87	28	66
Pittsburg	191	512	65	N/A	1,324	86	44	66
Pottawatomie	163	-47	19	-7	34,700	79	35	48
Roger Mills	-30	275	71	477	753	131	79	92
Woods	2,616	493	63	536	9,581	100	75	108
Woodward	62	-11	45	748	-63	138	55	94
State	63	10	120		436	88 metro 78 non	34	56 metro 60 non

Note: All values measure percent change during 2000-2012.

SECTION ONE

Introduction

Why Do We Care?

The study of oil and gas activity is important because such activity is a cornerstone of economic activity in Oklahoma. Since 1969, mining activities have accounted for 4 to 14.8 percent of total earnings in the state, and 2.6 to 6.1 percent of total employment (Woods and Poole, 2015). By the beginning of the 21st century, efficient development had declined. Existing technology (hydraulic fracturing) was combined with new technology (horizontal drilling) to increase industry efficiency and renew oil and gas industry prominence.

Oklahoma is helping the U.S. to become a major competitive actor in the global oil and gas market. It is likely this activity will follow the classic "boom-bust" cycle with some unique issues. Oil and gas technologies have sparked intense public debate about potential benefits and costs. Hydraulic fracturing and horizontal drilling has brought numerous jobs and economic growth. However, concerns about earthquakes, legal issues, water use and quality, rural amenity disharmony and a host of social issues, including crime and traffic accidents remain. Not only has the state economy benefitted in this short time frame, the nation has also seen a resurgence in global competitiveness.

Technical Description of the Hydraulic Fracturing Process

Oil and gas deposits are located in formations deep underground (U.S. Environmental Protection Agency, 2014). Hydraulic fracturing was developed in the 1940s to release oil and gas from rock formations and wells that were no longer productive (Montgomery & Smith, 2010). Oklahoma was, in no small part, built on the economic success of the petroleum fields. However, by the end of the 20th century, oil and gas production had declined and could no longer compete with other fields, mostly outside the U.S. During the first decade of the 21st century, industry began applying hydraulic fracturing and horizontal drilling to underground shale plays, ushering a resurgent era of production for Oklahoma and the U.S. Figure 3 is a cutaway image of a typical drill site.

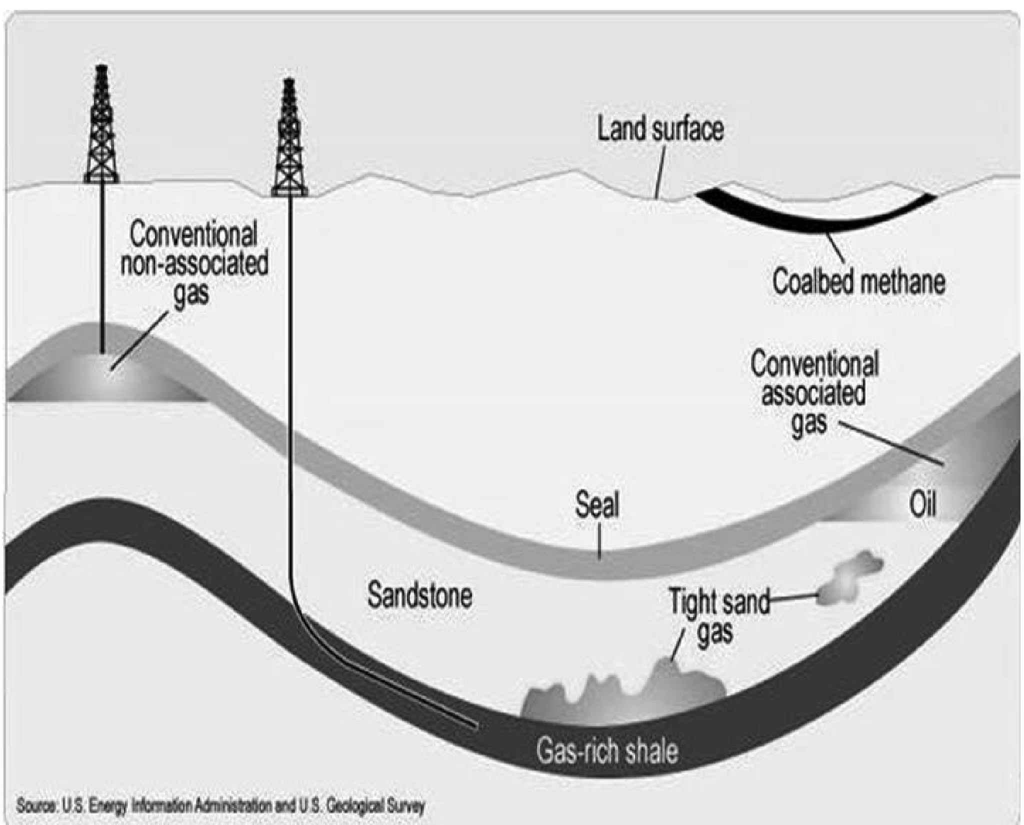

Figure 3. Cutaway image of a typical drill site.

Oil, Gas and Commodity Prices

There is evidence to suggest the prices of certain commodities, particularly corn, soybeans and cotton change with changes in oil and gas prices. This relationship stems from three phenomena:

- As the use of petroleum products increased in agricultural inputs through the 2000s, rising prices for oil and gas would drive up input costs for farmers;
- As oil prices rose throughout the late 2000s and early 2010s, the use of corn and soybeans for biofuel alternatives increased, raising demand and prices of these commodities;
- As the U.S. dollar weakened in the 2000s, corn exports rose due to the weakened U.S. dollar, so that even as domestic corn prices rose, exports did not decrease; simultaneously, imported oil became expensive due to the weakened dollar (Harri, Nalley & Hudson, 2009).

Historic Overview: Energy in Oklahoma

As noted by the Mid-Continent Oil and Gas Association of Oklahoma and cited by the Oklahoma Corporation Commission in the "2011 Report on Oil and Natural Gas Activity within the State of Oklahoma," oil and gas production began in 1897 with the first commercial well in Bartlesville. When Oklahoma became a state in 1907, it was the "biggest oil-producing state at the time" (p. 99). At this same time, the Corporation Commission was established to "regulate production to prevent waste" (p. 99). Prolific discovery lead to overproduction (p. 100). Drilling mud and pressurized water injection were used as early as 1930. As production increased, the state took action to manage resources, for example, with conservation law enacted in 1931.

In 1960, technology changed again to include steam injection and solvent displacement recovery methods. The price of oil began to wildly fluctuate, from $37.60 per barrel in 1982 to $11.15 per barrel in 1986 (p. 101). A natural gas production record was set in 1990 at 2.26 trillion cubic feet. By 2003, Oklahoma was ranked second in the nation in the production of natural gas (Oklahoma Corporation Commission, 2011). It is important to note that oil and gas activity has occurred for some time as indicated in Figure 4.

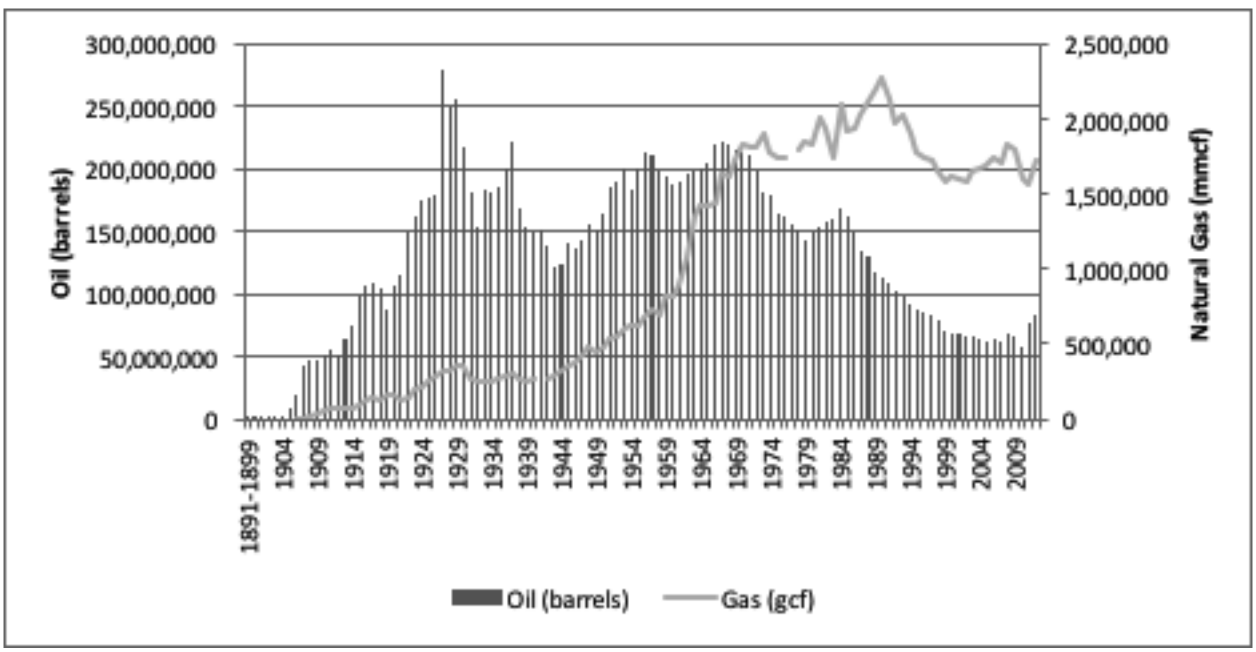

Figure 4. Oil and Natural Gas Production in Oklahoma (1891-2012).

Source: 2011 Report on Oil and Natural Gas Activity Within the State of Oklahoma (Oklahoma Corporation Commission, 2011).

SECTION TWO

Counties Selected for the Study

Fourteen counties were selected for this study based on oil and gas activity and level of economic development. Counties were selected to show relatively high and relatively low petroleum activity. Figure 5 is a map indicating the counties included in the study, shaded orange. See Table 2 for values related to production.

Overview of Selected Counties

The counties selected represent the diversity existing in Oklahoma. The counties are distributed to varying degrees across the four regions of Oklahoma: northwest, southwest, northeast and southeast, and are a mix of rural and urban areas. Certain counties known to have higher levels of oil and gas activity were first selected. Counties known to have little oil and gas activity also were chosen to provide a comparison group less affected by hydraulic fracturing.

Natural Gas Production by Selected Counties

The 14 counties included in the sample had various levels of output during the period of interest (2000-2012). Alfalfa, Atoka, Coal, Payne, Pittsburg, Pottawatomie and Woods were **above** the state percentage change in natural gas production. Canadian, Harmon, Jefferson, Noble, Oklahoma, Roger Mills and Woodward were **below** the state level of gas production.

Oil and gas activity varies widely among the selected counties. Linking policy action with data and data analysis is particularly challenging with respect to oil and gas. Annual compilations of user-friendly data by county and state level are typically at least three years behind. For oil production data, the latest information is 2011. For natural gas production data, 2012 is the latest information. Well site information is more current, but not easily compiled. Additionally, activity tends to be mobile. Thus, peak production varies by county and by year. While oil and gas production are sometimes coincident, it varies widely by site and county. Peak production years for oil and gas within counties tends to vary, but often is within a two-year frame. Thus, local challenges vary at any given time. Figure 6 is a map indicating the peak production years for the counties included in the study.

While there are similar trends during a five- to 10-year period for some counties and statewide production, state-level analysis can easily mask and misconstrue localized issues. For most counties active in natural gas production, the trend has been for significant increases since 2009 and 2010, as with the state. However, because production tends to occur in waves, companies tend to focus resources by field, maximize, then move to the next site. As seen in Figure 7, many active counties peaked by

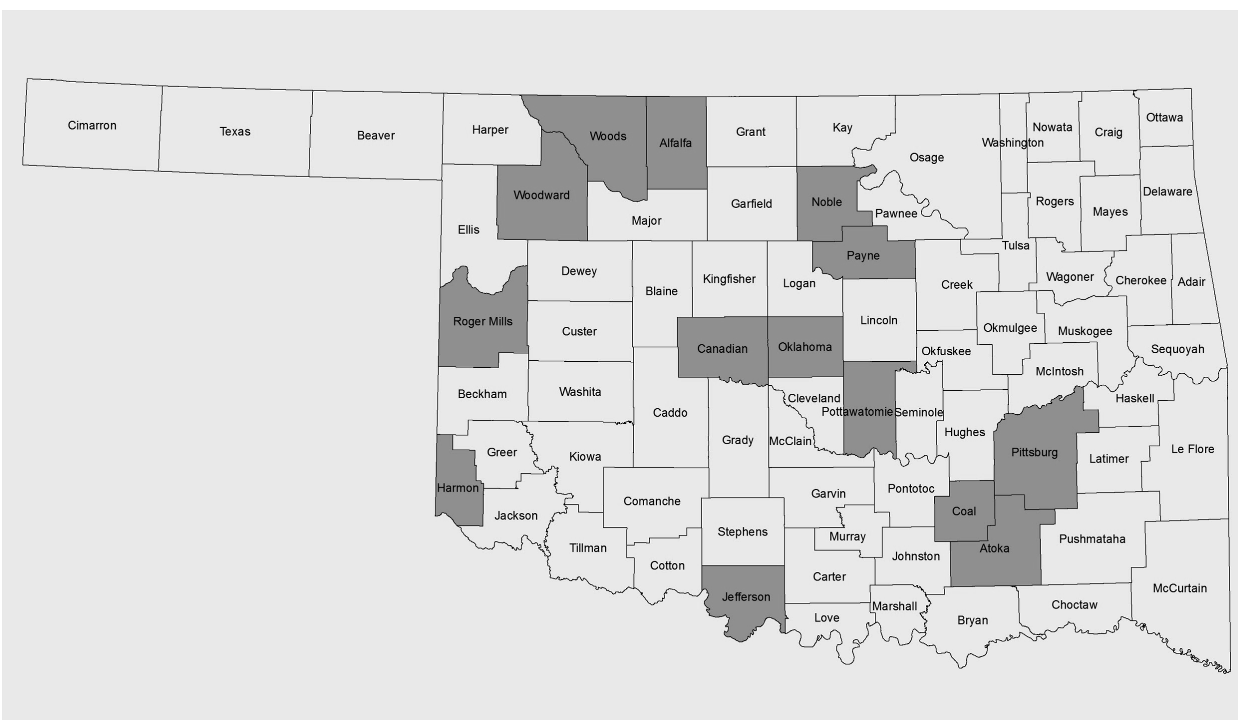

Figure 5. Counties included in the study.

Table 2. Oil and Gas Activity: Selected Counties and State (2000-2012).

Locale (county/state)	*Natural gas production (% change 2000-2012)*	*Peak gas production (mcf/ year)*	*Oil production (% change 2000-2012)*	*Peak oil production (bbl/ year)*
Alfalfa	6,461	419,606,514 (2012)	479	3,395,396 (2012)
Atoka	821	25,017,228 (2009)	866	30,813 (2008)
Canadian	24	88,315,080 (2010)	139	2,845,895 (2012)
Coal	1,566	110,273,848 (2010)	39	239,084 (2009)
Harmon	0	0 (2007)	-77	13,260
Jefferson	10	23,440 (2012)	-11	484,612 (2004)
Noble	4	5,528,130 (2009)	11	1,227,181 (2007)
Oklahoma	16	16,196,643 (2010)	-17	2,432,966 (2009)
Payne	223	8,791,281 (2006)	-11	832,774 (2001)
Pittsburg	191	190,666,608 (2012)	**	3,529 (2006)
Pottawatomie	163	11,639,817 (2006)	-47	1,736,495 (2000)
Roger Mills	-30	168,117,120 (2006)	275	3,284,303 (2012)
Woods	2,616	582,472,127 (2012)	493	3,715,901 (2012)
Woodward	62	54,142,940 (2009)	-11	458,871 (2006)
County average	866	120,056,400	152	1,478,649
State	63	2,645,682,367 (2012)	11	77,000,000 (2011)

* Pittsburg County had no production in 2000, so a growth rate cannot be calculated.

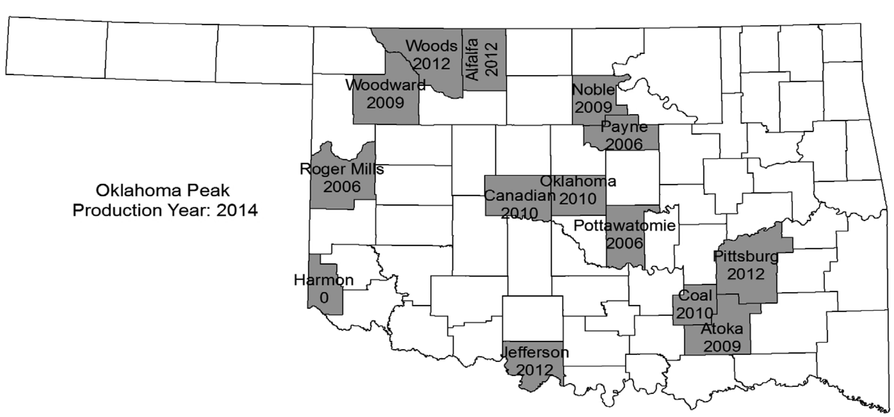

Figure 6. Oklahoma gas production peak years, selected counties (2000-2012).

2010, then dropped in production. For the period of the study (2000-2012) three counties peaked in 2006, three peaked in 2009, three peaked in 2010 and four peaked in 2012. One county had no gas production. Table 2 provides oil and gas data for the counties in the study.

Environmental issues are at the center of this discussion. The next two sections address this concern by looking at earthquakes, water and regulatory issues. The research will then turn to examining the economic and social impacts potentially associated with exploration and development in Section Five.

SECTION THREE

Federal Agency Roles in Oil and Gas Activity

Federal Emergency Management Agency

"FEMA's mission is to support citizens and first responders to ensure that the nation works together to build, sustain and improve its capability to prepare for, protect against, respond to, recover from and mitigate all hazards." For more information, visit www.fema.gov. FEMA has ten regional offices, and Oklahoma is part of Region VI. For more information, see http://www.fema.gov/region-vi-arkansas-louisiana-new-mexico-oklahoma-texas#.

Federal Energy Regulatory Commission

"The Federal Energy Regulatory Commission, or FERC, is an independent agency that regulates the interstate transmission of electricity, natural gas, and oil." For more information, please visit http://www.ferc.gov/about/ferc-does.asp.

United States Environmental Protection Agency (EPA)

"The mission of the Environmental Protection Agency (EPA) is to protect human health and the environment. When Congress writes an environmental law, the EPA implements it by writing regulations. Often, they set national standards that states and tribes enforce through their own regulations. If states and tribes fail to meet the national standards, EPA can help them. The EPA also enforces their regulations, and helps companies understand the requirements. The EPA operates regional offices, labs, and research centers around the nation." "The EPA's Underground Injection Control Program regulates the construction, operation, permitting, and closure of injection wells used to place fluids underground for storage or disposal." For more information, visit https://www3.epa.gov/ and https://www.epa.gov/uic. For information about
EPA in Oklahoma, visit https://www.epa.gov/ok.

U.S. Fish and Wildlife Service

"As the principal federal partner responsible for administering the Endangered Species Act (ESA), the U.S. Fish and Wildlife Service takes the lead in recovering and conserving our Nation's imperiled species by fostering partnerships, employing scientific excellence, and developing a workforce of conservation leaders." Oklahoma has several offices under the FWS. For more information, please visit http://www.fws.gov. Also visit http://www.fws.gov/offices/Directory/ListOffices.cfm?statecode=40.

United States Geological Survey

"The United States Geological Survey (USGS) is a science organization that provides impartial information on the health of ecosystems and environment, the threats of natural hazards, the natural resources relied upon by citizens, the impacts of climate and land-use change, and the core science systems that help the USGS provide timely, relevant, and useable information."

"The USGS mission is to serve the Nation by providing reliable scientific information to describe and understand the Earth; minimize loss of life and property from natural disasters; manage water, biological, energy, and mineral resources; and enhance and protect our quality of life."

"As the Nation's largest water, earth, and biological science and civilian mapping agency, the USGS collects, monitors, analyzes, and provides scientific understanding about natural resource conditions, issues, and problems. The diversity of their scientific expertise enables them to carry out large-scale, multi-disciplinary investigations and provide impartial scientific information to resource managers, planners, and other customers." The USGS focuses on six natural hazards mission area programs and activities, including earthquake hazards and the global seismographic network. For more information, please visit http://www.usgs.gov/aboutusgs/.

State Agency Roles in Oil and Gas Activity

Oklahoma Corporation Commission

"The Oklahoma Corporation Commission (OCC) is a regulatory agency for the State of Oklahoma with emphasis on fuel, oil and gas, public utilities and transportation industries. Their mission is to regulate laws and supervise activities associated with the exploration and production of oil and gas, the storage and dispensing of petroleum-based fuels, the establishment of rates and services of public utilities and operation of intrastate transportation that best serves the economic needs of the public. In the interests of the public, the Commission will oversee the conservation of natural resources to avoid waste, abate pollution of the environment, and balance the rights and needs of the people with those of the regulated entities which provide essential and desirable services for the benefit of Oklahoma and its citizens."

"The OCC is comprised of three elected commissioners who have judicial, legislative and administrative authority. The commissioners rule on all regulatory matters within Corporation Commission jurisdiction. Their orders are appealable only to the Oklahoma Supreme Court."

OCC's Oil and Gas Division has four district offices (Bristow, Kingfisher, Duncan and Ada). Each office has field inspectors for specific areas of the district. Observations of inappropriate spreading of mud and waste water from drilling operations, apparent leaks at well pads and water or air issues may be reported to the OCC. For more information, please visit http://www.occeweb.com.

Oklahoma Department of Environmental Quality (ODEQ)

"The mission of the Oklahoma Department of Environmental Quality (ODEQ) is to enhance the quality of life in Oklahoma and protect the health of its citizens by protecting, preserving and restoring the water, land, and air of the state, thus fostering a clean, attractive, healthy, prosperous and sustainable environment."

ODEQ regulates certain aspects of air quality (permitting, emissions inventory, compliance and enforcement, monitoring, toxics), water quality and land protection (including hazardous and solid waste disposal). They operate the State Environmental Laboratory Services Division, overseeing the organic and inorganic laboratories that provide analytical support to various programs within DEQ, other state agencies, the state's 1,700 public water supply systems and citizens who request services. Their Environmental Complaints Division addresses a range of citizens' environmental complaints. For more information, please visit http://www.deq.state.ok.us/

Oklahoma Geological Survey

"The Oklahoma Geological Survey (OGS) is a state agency for research and public service located on the Norman Campus of The University of Oklahoma and affiliated with the OU Mewbourne College of Earth and Energy. The Survey is chartered in the Oklahoma Constitution (70 OK Stat § 70-3310 (2014) (RTF) and is charged with investigating the state's land, water, mineral and energy resources and disseminating the results of those investigations to promote the wise use of Oklahoma's natural resources consistent with sound environmental practices."

The OGS "endeavors to accurately monitor, document, and investigate seismicity in the state of Oklahoma and to make all of this information readily available to the public." For more information, please visit http://www.ou.edu/ogs.

Oklahoma Office of Emergency Management

"The Oklahoma Department of Emergency Management (OEM) prepares for, responds to, recovers from and mitigates against disasters and emergencies. The department maintains the State Emergency Operations Center, which serves as a command center for reporting emergencies and coordinating state response activities. OEM delivers service to Oklahoma cities, towns and counties through the network of more than 400 local emergency managers."

"OEM also maintains, regularly updates and exercises the State Emergency Operations Plan. The department provides funding and/or assistance to more than 400 local emergency management departments throughout the state." For more information, please visit https://www.ok.gov/OEM.

Oklahoma Water Resources Board

"The mission of the OWRB is to protect and enhance the quality of life for Oklahomans by managing and improving the state's water resources to ensure clean and reliable water supplies, a strong economy and a safe and healthy environment." Primary duties and responsibilities of the OWRB include "water use appropriation and permitting, water quality monitoring and standards, financial assistance for water/wastewater systems, dam safety, floodplain management, water supply planning, technical studies and research and water resource mapping." The OWRB grants permits for ground and surface water use. Water use sectors include oil, gas, and mining; industrial; irrigation; public water supply; agriculture; and commercial. For more information, please visit http://www.owrb.ok.gov/about.

County Commissioners

County commissioners have governmental duties and responsibilities related to health, safety and welfare of county citizens. They oversee a wide variety of county projects including construction, budgets and highway systems. "County commissioners exercise the administrative powers given to them by the Oklahoma Statutes and the Oklahoma Constitution. Each county in Oklahoma is divided into three districts, and each district elects its own county commissioner. Each district's county commissioner is a member of the Board of County Commissioners, which administrates the county. Therefore, county commissioners have a responsibility to the entire county and not just their own district." Generally speaking, damage to roads and bridges and leaking water pipes could be reported to county commissioners. For more information, please visit the Handbook for County Commissioners of Oklahoma via http://agecon.okstate.edu/ctp/files/2014%20County%20Commissioner%20Handbook.pdf.

Oklahoma Cooperative Extension Service (OCES)

Oklahoma Cooperative Extension Service county educators and area, district and state specialists develop science-based educational programs to help Oklahomans solve local issues and concerns, promote leadership and manage resources wisely. To access a directory of County, Area and District Offices visit http://countyext2.okstate.edu/. For more information about OCES, please visit http://www.oces.okstate.edu/.

The Recent Past Geology of Oil and Gas

The primary changes in the petroleum industry during the past decade have been in the technology applied to resource extraction. Horizontal drilling now enables resources to be extracted laterally on the kilometer scale. This means that a well can extract from the subsurface a mile down and a mile to the side of the well. This ability to head into the subsurface in lateral directions is known as geo-steering, and the capabilities have increased significantly. Additionally, the industry is extracting from much different rock bodies. The formations that petroleum is being removed from were known for many years, but the technology to remove the material is new. This has led to different rates for fluid flow and new concerns for technology development.

Historically, water management has been insignificant for the industry as water needs for production were cheap and disposal of waste water was simple and inexpensive. The new technologies, along with increased demands on water resources, have changed the costs so significant resources need to be expended to manage water related to the petroleum industry. The ability for the various companies to react has varied, leading to unexpected costs and public concerns.

Geology and Earthquakes

The headline-capturing issue with respect to hydraulic fracturing has been induced seismicity, that is, earthquakes. Research has intensified in recent years, with most of the studies indicating low incidence from the process hydraulic fracturing itself. Rather, the deep well injection of the produced water has been shown to increase the likelihood of earthquakes. Most disposal wells do not cause seismicity. Instead, induced seismicity in Oklahoma can be traced to a few injection wells [National Research Council of the National Academies (Committee on Induced Seismicity Potential in Energy Technologies, 2012).

Seismicity Case Study: Stillwater, Okla. and Guy, Ark.

A review of the seismic and injection well data for two similar sites (Stillwater, Okla. and Guy, Ark.) is suggestive. Both sites went from near zero earthquakes 1.0 or higher to great increases in 2010 and beyond. Stillwater's incidences increased to 1,250 and Guy to more than 150. Coincident to this change, deep well injection continued unregulated. In 2011, the state of Arkansas issued a moratorium for injection wells; subsequently, earthquake activity dropped. There was no moratorium in Oklahoma, and earthquakes occurrences increased to 1250 in 2014.

The USGS and OGS issued a joint statement May 2, 2014, indicating the "rate of earthquakes in Oklahoma has increased remarkably since October 2013 - by about 50 percent - significantly increasing the chance for a damaging magnitude 5.5 or greater earthquake in central Oklahoma" (United States Geological Survey, 2014). Recent scientific studies support this concern. "Seismicity in central Oklahoma has increased dramatically starting in 2009, an increase inconsistent with any natural processes likely to occur in this geologically stable area. For central Oklahoma, it appears more likely that the remarkable increase in seismicity is the result of deep injection of wastewater associated with the rapid growth of oil and gas production" (McGarr, 2014).

The science behind injection well-induced seismicity has been recognized since the 1960s (McGarr, 2014). As Ellsworth (2013) and others have noted, deep well injection increases pressure. If there is an increase in pore pressure along a fault and a high-permeability pathway, earthquakes increases are likely. The research further shows, in some cases such as Rocky Mountain Arsenal, Colo., earthquakes may continue for a decade or more after injection ceases.

Injection induced seismicity is a mechanism tested "beyond reasonable doubt" (Rayleigh, Healy, & Bredehoeft, 1976). Injection-triggered earthquakes are more common than is generally recognized. Earthquakes are more likely to be triggered if injection reaches a critical rate, this critical rate may depend on local subsurface conditions, and thus, vary in different geographic regions (Frohlich, 2012).

Scientific research has supported the conclusions that a relative few injection wells are causing induced seismicity. More and larger earthquakes are occurring with probability for a larger earthquakes (5.0 or greater) increasing, public policy options and likely consequences are suggested:

1. Do nothing: USGS probability analysis of data suggests a significant earthquake is likely.
2. Shut down everything: No evidence is required and will have significant side effects to economy.
3. Limit existing high-volume injection wells: Could determine if earthquake rate slows within 12 to 24 months or less.
4. Attempt remediation: Is it possible to lower fluid pressure of active faults?

Figure 7 is a graph of Oklahoma earthquakes of magnitude three of greater.

Data are from OGS catalog of seismicity for Oklahoma from 1976 to 2015. Long-term average from 1976 to 1999 is 1.6 earthquakes per year. Some variation occurs in the earthquake count as geologic models cause the estimated size of an earthquake to vary by generally +/- 0.1 in magnitude. However, independent of earthquake catalog source, the exponential pattern of Oklahoma earthquakes is clear. Figures 8 and 9 indicate Oklahoma seismic hazards and chance of earthquakes.

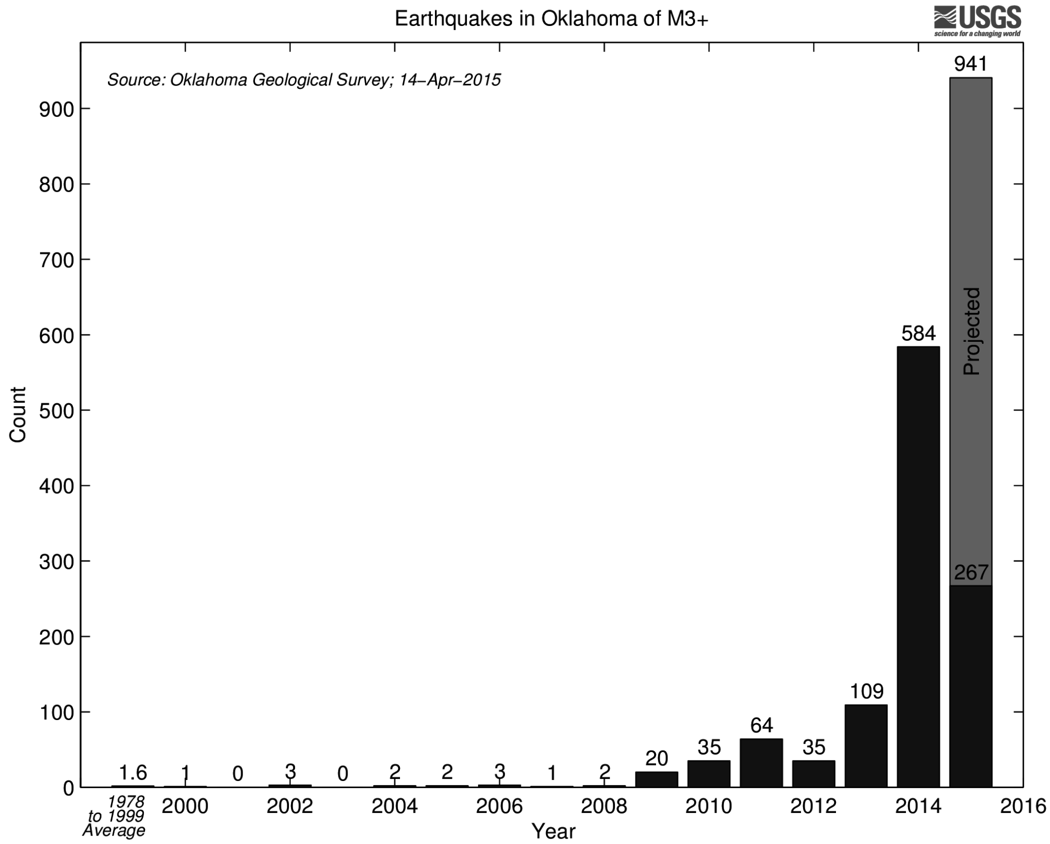

Figure 7. Earthquakes of magnitude three or greater in Oklahoma.
Source: United States Geological Survey National Earthquake Information Center (2016).

As noted by the USGS, final hazard maps for Modified Mercalli Intensity (MMI) and chance of damage for the western U.S. and the central and eastern U.S. (CEUS) based on averages of MMIs converted from peak horizontal ground acceleration and 1-hertz spectral acceleration. Figure 9 has a map of the western U.S. showing data based on the long-term 2014 National Seismic Hazard Model, and the map of the CEUS shows data based on the 2016 one-year model.

Fluid and Drilling Mud Disposal

Flow-Back and Produced Water

During the drilling process, naturally occurring water is often encountered which is known as produced waters. This water, which can be very saline depending on the geology of the strata, often flows to the surface. In addition, a portion of the water used in the hydrofracturing process (previously described process) will flow back to the surface; thus, the term "flow-back" is used to describe this water. Flow-back water is usually mixed with produced water, thus many drillers simply refer to any water that comes to the surface as flow-back. According to Argonne National Laboratory (Clark & Veil, 2009), around 2 billion gallons of flow-back water was produced in Oklahoma in 2007, comprising 11 percent of the total amount of flow-back water in the U.S.

Despite the emphasis on "exotic chemicals" by the popular media, the biggest concern with flow-back water is salinity, or salt content. While some flow-back water is low in salts, others are extremely saline and must be managed carefully to prevent damage to soils, plants, surface water and groundwater. Those who produce the wastewater must obtain a National Pollutant Discharge Elimination System (NPDES) permit if the intention is to discharge directly into surface waters, which is a viable method for water with little salinity. However, for flow-back water that is very saline, the most inexpensive option for disposal is deep well injection into an existing injection well. This practice is estimated to cost about $0.66 per 1,000 gallons, according to the U.S. Department of Energy (2012). While this method is heavily regulated by the EPA to safeguard groundwater protection, there are concerns about the potential for earthquakes when excessive injection is conducted under certain circumstances. In 2007, there were approximately 2.19 billion barrels of water injected. For the Mississippian play in Oklahoma, the only feasible method of disposal for produced and flow-back waters is deep well injection.

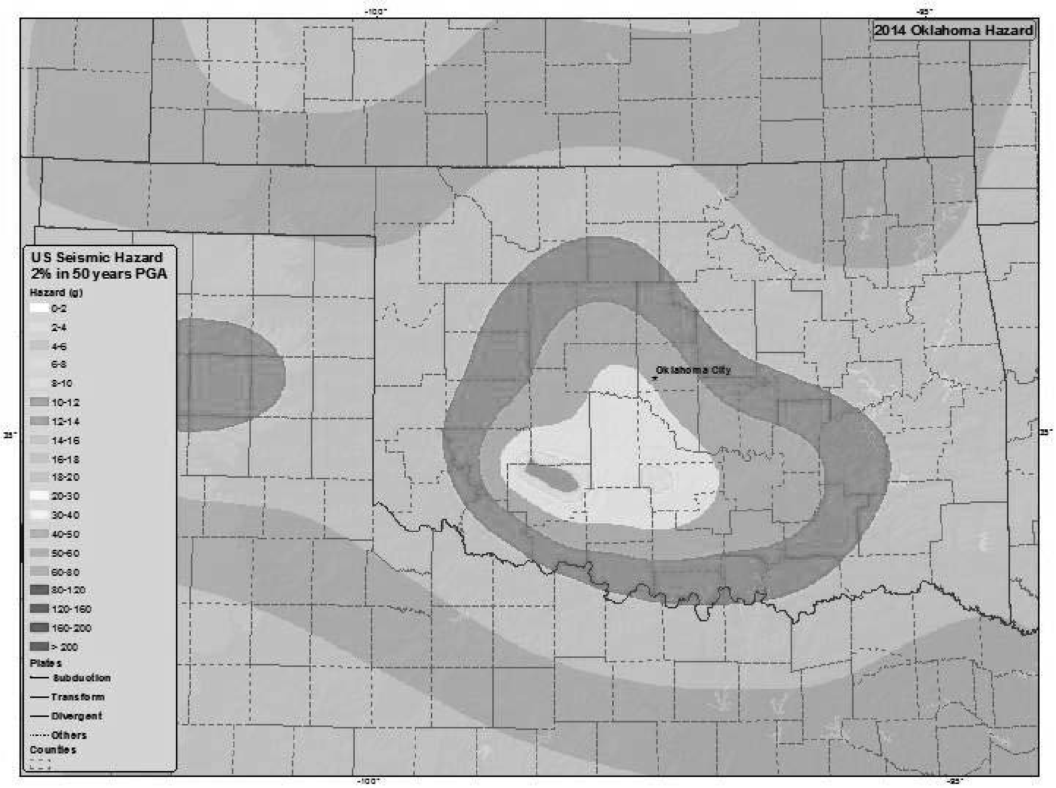

Figure 8. Oklahoma seismic hazard map (2014).
Source: United States Geological Survey (2014).

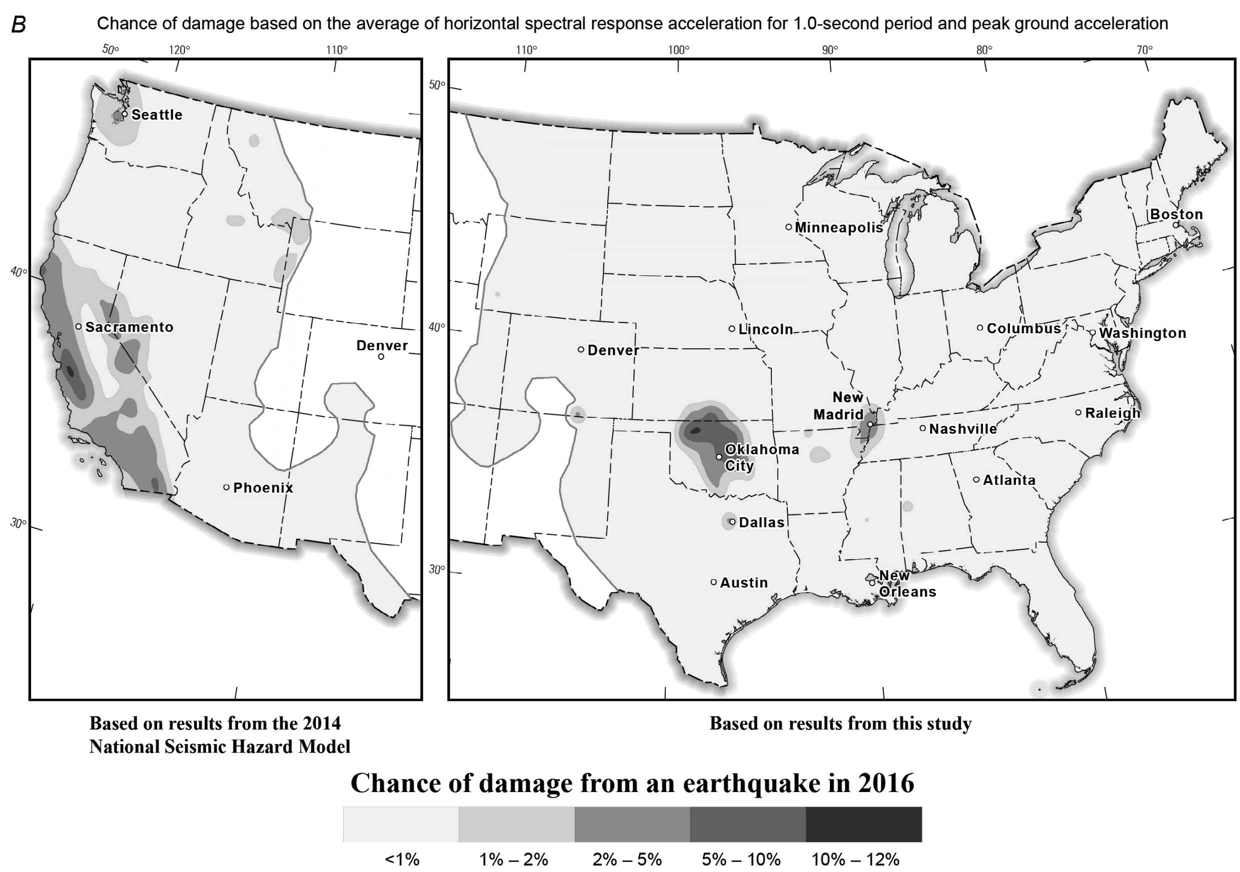

Figure 9. Chance of damage from an earthquake in 2016.

Drilling Mud Disposal

Drilling fluid serves several purposes during the drilling process, including temperature control and lubrication of the bit, sealing of the formation and suspension of drill cuttings. The drilling fluid is re-used and circulated until it can no longer perform its function for drilling. At that point, the spent material is referred to as mud, and must be disposed of. The two main types of drilling mud are water base mud (WBM) and oil base mud (OBM); the difference is due to the original base solution used in the initial drilling fluid. If water is used as the base fluid, then the result is WBM. Occasionally, diesel fuel is preferred as the base fluid at deeper drilling depths and also for the "curve" portion of the well. In that case, the spent material is known as OBM due to the presence of hydrocarbons from the original diesel fuel, not from geologic oil. The main risks associated with WBM are salinity (i.e. total salts) and sodicity (i.e. sodium salt). For OBM, the main constituent of concern is hydrocarbons. However, depending on the geologic strata at the well location, there is some slight possibility of trace metals. For example, some OBM has been shown to contain elevated levels of arsenic. The risk of encountering high levels of naturally occurring radioactive material (NORM) in drilling mud is extremely low; all research samples tested for NORM at Oklahoma State University have resulted in levels similar to what is found in non-contaminated soils. Instead of mud, the greatest risk of high levels of NORM is found in field production equipment with a history of contact with formation water.

The American Petroleum Institute (2000) estimated that 150 million barrels of drilling mud was produced in the U.S. from 1985 to 1995. Drilling mud may be disposed of through burial (i.e. reserve pits and commercial disposal) and land application. Currently, water base mud may be buried "as is" at a reserve pit or commercial disposal facility, but OBM is not permitted to be disposed of in reserve pits. Raw OBM must first be treated or appreciably diluted before it can be buried at a commercial disposal facility. However, reserve pits and commercial disposal facilities must have proper liner materials, either synthetic or earthen, to protect underlying groundwater. In Oklahoma, the Oklahoma Corporation Commission (OCC) specifies the liner requirements. However, there is some concern about the integrity of synthetic liners through long time periods. An earthen clay liner will not be effective for WBM with extremely high salt content. While the standard sodium-saturated bentonite clay liner serves as an excellent retardant for the downward movement of water, the ability of the clay liner to retard water movement through it decreases if the WBM is extremely saline. As a result, some commercial facilities have been shut down due to leaking.

Due to the potential long-term risks associated with reserve pits and commercial disposal, land application is becoming the preferred option for mud disposal. For sites to be eligible for receiving land application of drilling mud, it must meet certain soil and landscape requirements. For example, the site may not have excessive slope or shallow groundwater present, and location must maintain certain setback distances from roads, ditches, surface water bodies, well heads, etc. The soils must have proper drainage, so they are not poorly or excessively drained, and possess certain textures. If the site is to potentially receive WBM, then the soil must be tested for total dissolved salts and sodium absorption ratio; if either parameter is beyond threshold levels, then application is not permitted. In 1987, land application became a legal option for mud disposal. From 1987 to 2005, there have been approximately 30,000 registered land application jobs. Figure 10 illustrates the total sites that have received drilling mud since the inception of the program.

Landowners receive payment for drilling mud disposal on their property, based on the volume that they receive. Typical payments are $0.50 cents per barrel of WBM and $1.00 per barrel of OBM. Before any type of drilling mud is land applied, a site must meet certain requirements as specified by the OCC (Title 165:10-7-19 and 165:10-7-26 for WBM and OBM, respectively). Such requirements include depth to groundwater and limiting layers, slope, proximity to surface waters, soil texture, etc. A general introduction to the land application of drilling mud is found in Penn and Zhang (2013).

Water-based mud is disposed of as both a solid and liquid form, although the liquid form is dominant. Thus, most water-based mud is land applied by spraying from pressurized tanks. For WBM, the purpose of land application is to spread the salts over a large area, so the final concentration is non-hazardous to surface plants and also less mobile regarding leaching to groundwater. While the chloride-based salts contained in water-based mud are able to readily leach downward into the soil, i.e. movement as a "front" of salt, this salt front also dissipates in concentration as it leaches down. As a result, land application of WBM poses little threat to underlying groundwater. The biggest risk from land application of WBM is to the surface soil and plants. To this end, the OCC requires that the maximum amount of WBM that may be applied is 6,000 pounds total salt per acre. Therefore, proper land application of WBM requires knowledge of the salt concentration already present in the soil and in the WBM to be disposed of, and also control over the application rates of the material. Excessive land application of WBM may result in salinization of soils or formation of sodic soils. Saline soils create a difficult environment for plants due to the ability of salts to reduce plant-available water. Sodic soils are worse than saline soils since such soils have additional physical limitations because they drain poorly and are highly erosive. Saline and sodic soils often appear as bare spots in the landscape. The remedy for saline soils is found through rainfall or irrigation to leach salts out of the root zone, while sodic

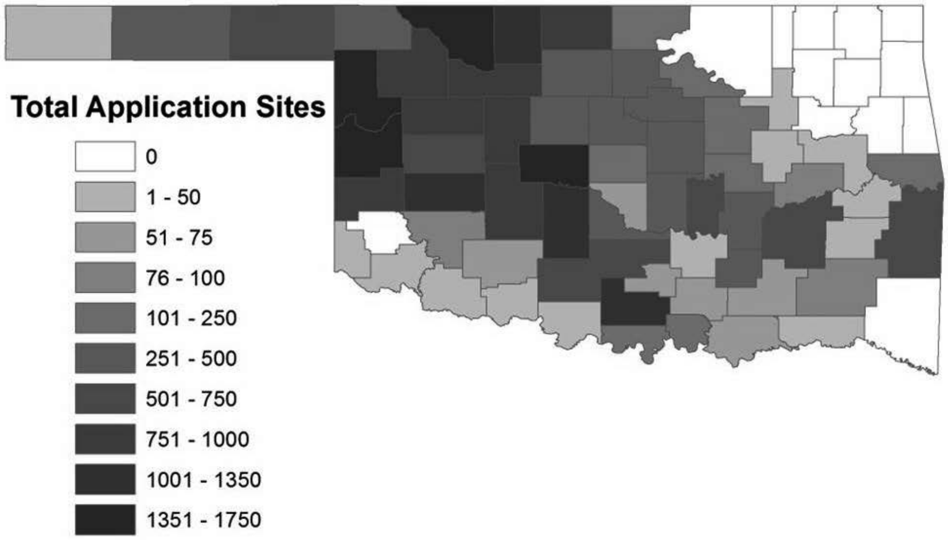

Figure 10. Number of sites receiving drilling mud (1987-2014).

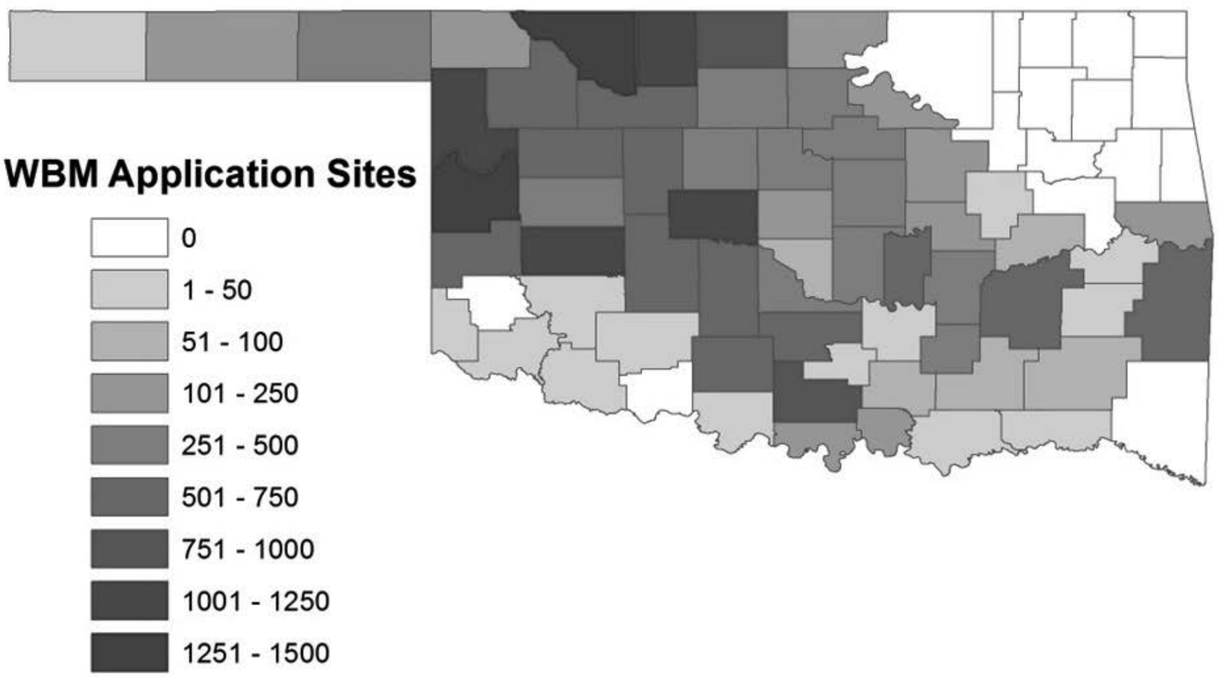

Figure 11. Water based mud application sites (1991-2014).

soils require the application of a highly soluble calcium source, such as gypsum.

Although 6,000 pounds salt per acre is the legal threshold for WBM application, landowners will significantly reduce risk of plant damage and minimize negative soil impacts if lower rates are applied. For example, research conducted at Oklahoma State University has shown that application of 4,000 pounds total salt per acre poses less impact compared to 6,000 pounds per acre. The use of lower application rates translates to providing a larger tract of land for application. Regardless, WBM is produced in much greater quantities and land applied at a greater amount compared to OBM. Some results of field studies of land application of WBM to wheat are found in Penn and Warren (C. Penn & Warren, 2014). Figure 11 illustrates the spatial distribution of sites that have received WBM by land application in Oklahoma.

For land application of OBM, the main risk is total petroleum hydrocarbons, or TPH. However, compared to WBM, this is a relatively short-term risk since hydrocarbons are able to degrade via microbial respiration into carbon dioxide and water. Oil-based mud occurs as a solid and is usually mixed with a bulking agent, typically gypsum or agricultural lime, before application. Therefore, the landowner can receive benefit from the application of the gypsum and lime. The application rate of OBM is limited based on the total amount of TPH applied (40,000 pounds TPH per acre) and total solids (200,000 pounds solids per acre). Therefore the OBM must first be tested for TPH concentration to determine the maximum application rate.

One of the forms of TPH that can occur in OBM is BTEX, which is an acronym for benzene, toluene, ethylbenzene and xylene. Fortunately, even for excessive application of OBM containing some of the highest BTEX levels, research at Oklahoma State University has shown that the BTEX does not leach beyond 6 inches, since the organic compounds readily degrade and volatilize. However, volatilization of BTEX could be an issue to the health of the driver of the land application vehicle if precautions are not taken. Fortunately, BTEX makes up only a small portion of TPH, which degrades quickly assuming standard soil conditions of moisture, temperature, oxygen and nutrients. In one study of land-applied OBM, 98 percent of TPH degraded in 170 days (C. J. Penn, Whitaker & Warren, 2014). For this reason, the general risk from land application of OBM is much less than WBM. More specifically, TPH degrades, but salts cannot degrade; salt can only move and change form. Similarly, soils that are over-applied with OBM will "heal" faster than sites over-applied with WBM. Rainfall is required for soils with excessive salts to recover, which can take appreciable time. Since much less OBM is produced compared to WBM, there are fewer sites in Oklahoma that have received OBM. Prior to 2000, there were very few sites that received OBM. Total OBM application sites since 1987 is around 5,000. Figure 12 provides information about OBM application sites.

Landowners should approach the potential for receiving drilling mud as an opportunity and also as a risk, therefore caution should be exercised. The opportunity for significant payment to be obtained is found, depending on the volume of mud to be disposed, which is a function of the size of the well being drilled. In general, the landowner should expect one growing season of decreased yield if the land application is done properly. While it is common

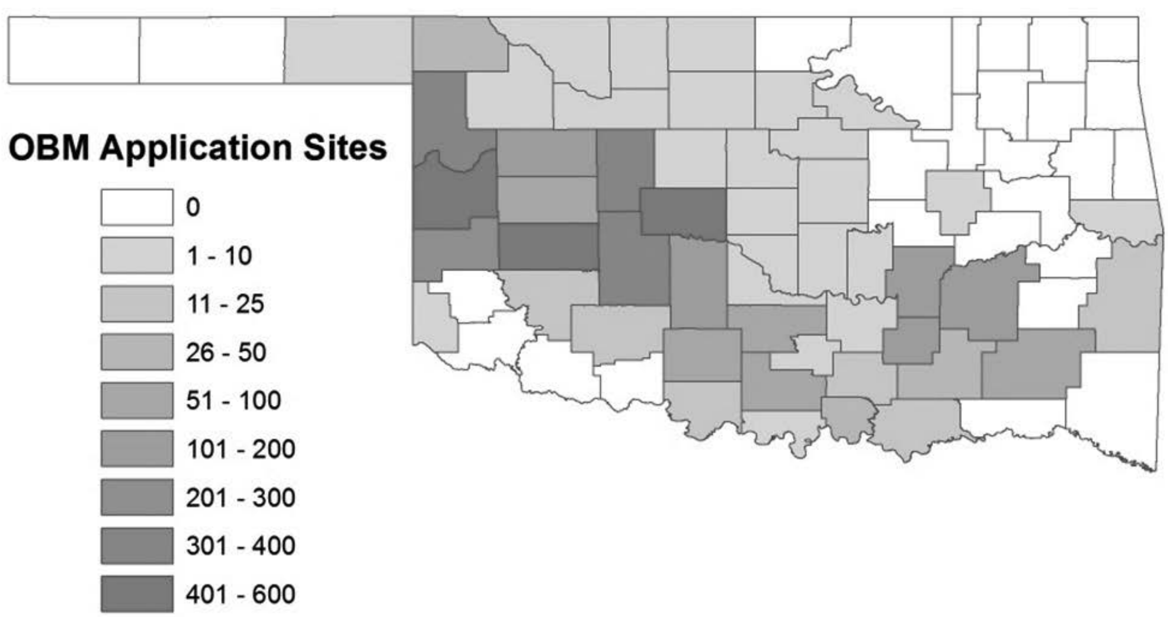

Figure 12. Oil based mud application sites (2000-2014).

for no decrease in yield to occur, the landowner should approach the situation with the expectation that it will decrease. If rainfall is depressed, then the amount of time required for recovery will be extended.

Essentially, the landowner receives payment to compensate them for potential yield reductions. On the other hand, if the mud is over applied, particularly for WBM, then the landowner can expect several growing seasons of reduced yields. Therefore, the most important variable regarding long-term risk is the quality of the land application company. Landowners should research a land application company prior to signing a contract. This will determine if the company has a good reputation with other customers. Specifically, a good land application company will follow the OCC rules and measure the background soil salt concentration, mud TPH or salt concentration and has control over the application rate. The best method to achieve control of the application rate is through a satellite guidance precision application system, analogous to what is often used in agriculture for application of fertilizers or pesticides. Application companies can quickly measure the salts concentration in their WBM using an electrical conductivity meter. Every land application truck should have one of these meters, and the driver should be trained in how to properly use the meter.

Water

Water Quality

Research on the impacts oil and gas activity on drinking water quality continues. Ongoing research questions include: (1) does the use of surface/ground water for oil and gas extraction significantly impact drinking water quantity; (2) does spilled hydraulic fracturing fluid impact drinking water; (3) do injection and fracturing impact drinking water; (4) what effects might surface spills on or near pads have on drinking water; and (5) does insufficiently treated hydraulic fracturing wastewater impact drinking water (U.S. Environmental Protection Agency, 2012). Groundwater contamination may be a result of faulty casing, which is meant to isolate the oil, gas, hydraulic fracturing fluids and other fluids from aquifers. Each state has casing regulations. One of the most frequent calls for additional research and data comes from those trying to ascertain the impacts of hydraulic fracturing activities on water supplies, with baseline water quality information in high demand for such research [see Geological Society of America (2014)].

Extension professionals provide programming to help landowners determine the baseline water conditions on their properties and to understand the issues involved. They also can connect landowners with agencies and institutions engaged in oil and gas related water quality research to help find volunteers and landowners willing to facilitate the collection of water quality data.

Water Quantity

Two factors to consider include water availability/scarcity and the potential impact of large volume withdrawal on drinking water. Research in this area continues. Extension has a long history of helping people deal with water quantity issues, and can use that experience to provide timely programming responses in areas facing issues of water scarcity. Beyond this, the allocation of water resources among competing industries is a delicate and often volatile policy issue. Extension has the opportunity to facilitate productive, well-informed public dialogue to help communities and states resolve issues in a fair and balanced manner.

Oil and Gas Activity and Water Permitting

Oil and gas activity typically receives water permits from the Oklahoma Water Resources Board (OWRB) for short- and long-term production activities. OWRB provides long-term permits under the broad categories of groundwater and surface water. More than 6.4 million acre-feet were used through permits in 2014, with about 2 percent going to oil and gas activity. Of that, about 74 percent was from groundwater and 26 percent was from surface water.

Figure 13 provides a description of permitted groundwater by county. Figure 14 provides a description of permitted surface water by county. Figure 16 provides a description of permitted groundwater by purpose. And finally, Figure 15 provides a description of permitted surface water by purpose. The following figures reflect conservative estimates, as not all private transactions may be captured in these data.

The OWRB also provides 90-day provisional-temporary permits. These permits allow temporary use of water for oil and gas activity. The provisional permits are often used for hydraulic fracturing. The state permitted 23 percent of the provisional temporary acre-feet for the oil/gas/mining industry in 2012, and 24 percent in 2014. This is the second leading category for provisional temporary permits (recreation is typically first).

Water is an essential ingredient in oil and gas extraction, and is especially important to the hydraulic fracturing process. As hydraulic fracturing was providing the way to tap these reserves during the 2010-2014 period, water use was greatly expanding in the state. Counties with expanding hydraulic fracturing activity tended to see greatly increased water use through provisional-temporary permits. Data for the 90-day provisional-temporary permits for oil, gas and mining use provide the number of permits and the amount of acre-feet per year. Most of this water use goes to oil and gas activity, and for the past decade, most of that went to the hydraulic fracturing process. Table 3 provides data for provisional-temporary permits during the study period.

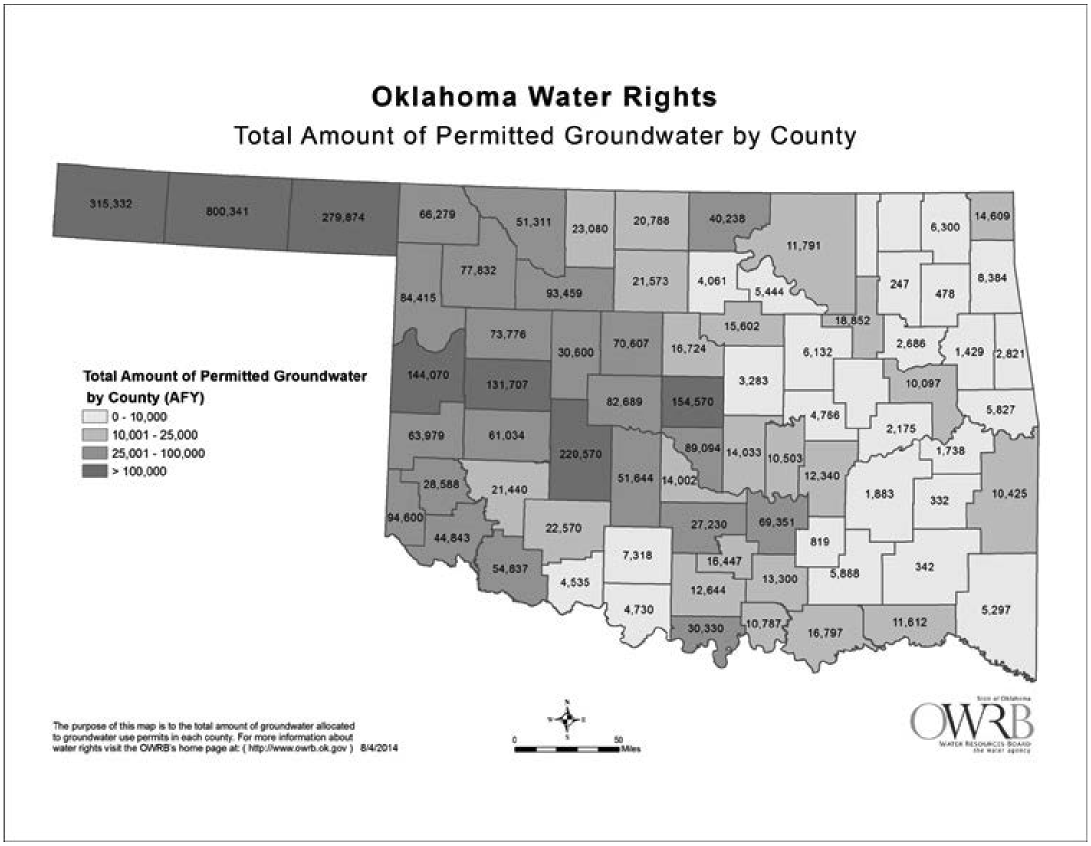

Figure 13. Permitted groundwater by county.

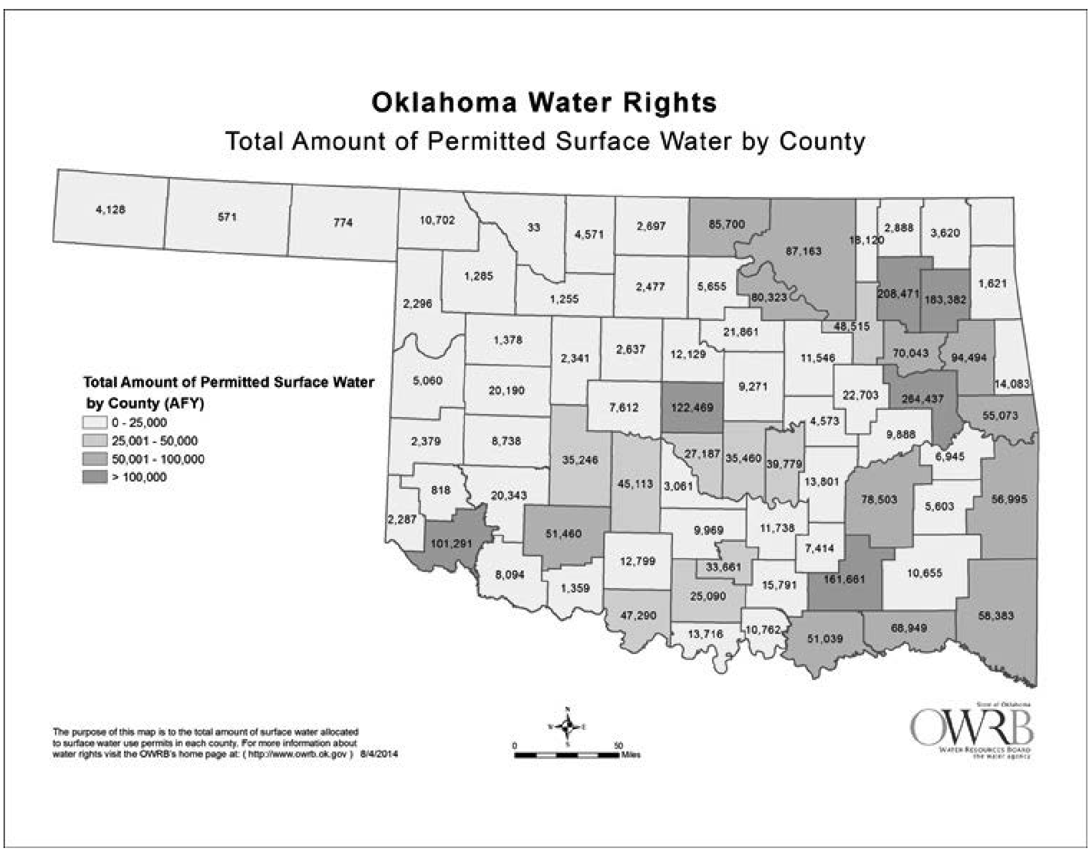

Figure 14. Permitted surface water by county.

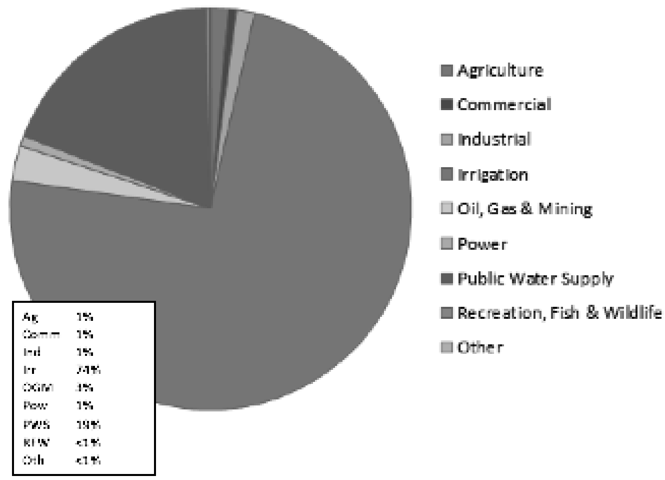

Figure 15. Permitted groundwater by purpose.

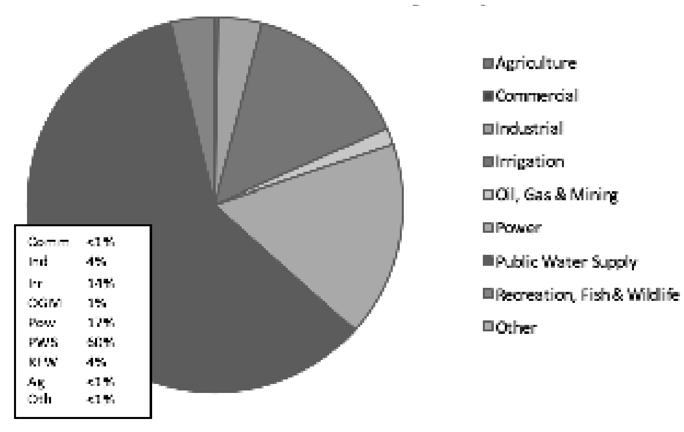

Figure 16. Permitted surface water by purpose.

Ownership of real estate carries with it a right to use the groundwater found beneath that land for domestic use without the need to apply for a permit. For the purposes of groundwater, domestic use is defined just as it is for stream water. These uses include: (1) household purposes; (2) producing farm and domestic animals (so long as the number of animals using the water is no more than the land could support in a natural grazing system); and (3) irrigation of land for the growing of gardens, orchards and lawns, but only up to three acres in area.

As with stream water, groundwater can also be used by non-household entities like businesses. Such entities do not need a permit for groundwater if it is used for the following purposes: (1) drinking water, (2) restroom use and (3) the watering of lawns. Businesses using water for these purposes must keep their use to less than 5 acre-feet per year. There is not a fixed limit as to how much groundwater can be used by the owner of the property for domestic use (with the exception of the 5 acre-feet limit for business entities).

Just as with stream water, a groundwater permit is required for a use that does not fit the definition of domestic use. These permits come in a variety of forms, primarily based on the duration of the use.

Regular

A simple permanent permit allows a particular amount of groundwater on a year-round basis to be used, and it lasts as long as the terms of the permit are followed. Note: this permit cannot be issued until after the hydrologic survey and the maximum yield of the groundwater basin reached by the well has been determined. For more information on completed maximum annual yield surveys, consult the OWRB Fact Sheet “Determination of Maximum Allowable Yield.”

While the OWRB has been working to complete these hydrologic surveys, there are still several groundwater basins that have not been surveyed. Because many basins do not have hydrologic surveys completed, regular permits may not be available for many areas. Thus, a temporary permit may be the best option for someone in need of groundwater use rights.

Temporary

A permit granting the use of water for a temporary period of time. Much like a regular permit, a temporary permit can be issued for groundwater basins, even if an OWRB hydrologic survey has not been completed for the basin. Additionally, temporary permits must be revalidated every year for as long as the permit lasts. The total amount of water granted under a temporary permit cannot exceed) acre-feet per acre of land dedicated to the permit, unless special circumstances are recognized by the board. For example, if a landowner wanted to obtain 10 acre-feet of groundwater, they would have to dedicate 5 acres of land to the permit (2 acre-feet of water per acre of property dedicated x 5 acres = 10 acre-feet of water). Dedicating land to a permit means obtaining the quantity of groundwater allocated to the land acreage described in the permit as owned by the landowner (or the applicant must have the actual owner’s permission to use its groundwater).

Special

A permit that can be applied for in addition to a regular permit or a temporary permit to add more water to total amount allowed under the permit. This permit is issued only with special circumstances as determined by OWRB. The permit can only be used for the specific purpose outlined in the permit. After that use is completed, the permit expires, and another permit cannot be issued for the same purpose. Special permits are limited to six months, and can only be renewed three times.

Table 3. Oklahoma 90-Day Provisional-Temporary Permitted Acre-Feet per Year

Year	*Agriculture*	*Commercial*	*Industry*	*Irrigation*	*Oil, Gas, & Mining*	*Power*	*Public Water Supply*	*Recreation, Fish & Wildlife*	*TOTAL*
2000	848		283	14,595	2,652		784		19,162
2001	210	6	197	4,980	2,914		5,917		14,223
2002	199	5	427	11,220	2,270		7,855	53	22,030
2003	102	643	901	11,498	3,233		5,766	615	22,758
2004	5,376		174	6,399	5,253		3,252	1,031	21,483
2005	35		118	3,751	5,472		5,702	446	15,524
2006	321	17	81	6,471	3,547		3,698	79	14,213
2007	93		264	626	4,229		3,427	70	8,709
2008			323	4,874	7,957		5,620		18,773
2009	160	2	442	4,900	6,486		2,870		14,859
2010	30		330	4,253	9,320	48	3,109	160	17,250
2011	357		2,016	13,071	15,569	1	3,259	36,650	71,012
2012	60	8	1,420	15,450	23,541		3,554	58,674	102,707
2013	No data	2	508	6,501	27,291		5,432	58,640	98,375
2014	No data	No data	438	8,306	17,480		3,010	43,980	73,213
Mean (yrs of data varies)	599.31 (2000-12)	48.79 (2000-13)	528.13 (2000-14)	7,793 (2000-14)	11,147.6 (2000-14)	4.08 (2000-11)	4,217 (2000-14)	13,359.87 (2000-14)	35,619.4 (2000-14)

Limited Quantity

This permit is administered by the Executive Director of the OWRB without the consent of the entire Board. The Executive Director can issue a regular permit to use 15 acre-feet of water in the year or term of the permit. The person applying for this permit must notify all the other landowners within 600 feet of the proposed well that an application for a Limited Quantity permit has been made. Neighboring landowners wishing to protest the permit have 10 days to protest to the OWRB.

Provisional Temporary

Last, put perhaps of greatest importance to this discussion, is the Provisional Temporary permit, often called a PTP. The PTP permit is authorized by the Executive Director of the OWRB rather than going through the usual permit application process. As a result of this more direct proceeding, no hearings are held, no application notice or data is published and no notice to surface estate owners is required on applications for this type of permit. However, the PTP is not renewable and does not give any permanent rights to groundwater use. Rather, the PTP only grants use of groundwater for a period less than 90 days. The most common use of these permits is for the short-term use of water in drilling oil and gas wells.

Table 4 provides data regarding the provisional-temporary permitted acre-feet water use during the study period. Alfalfa, Canadian, Coal, Jefferson, Pittsburg and Woods counties saw significant increases in both oil/gas production and water use.

Oklahoma alone produces nearly 60,000 acre feet of produced water per year (Guerra, Dahm, & Dundorf, 2011). Some flow-back water and produced water is placed in holding ponds or spread on the land. Table 4 provides data about the provisional-temporary permitted acre feet water use.

Equation 1.
x 325,000 gal/AF
divided by 42 gal per bbls
= 464,285,714 BW

Table 4. Provisional-Temporary Permitted Acre-Feet Water Use (2000-2014).

Locale (county)	*P-T AFY Average 2000-2009*	*P-T AFY Average 2010-2014*	*Percent Change*	*Peak acre-feet per year*	*Year of Peak*
Alfalfa	174	1,953	1,122	3,652	2012
Atoka	104	208	200	1,564	2014
Canadian	441	2,437	553	4,962	2012
Coal	338	501	148	1,198	2008
Harmon	N/A	N/A		N/A	N/A
Jefferson	55	95	173	410	2010
Noble	18	445	2,472	997	2013
Oklahoma	348	40	-870	1,348	2003
Payne	38	955	2,513	1,927	2014
Pittsburg	350	892	255	1,318	2010
Pottawatomie	23	253	1,100	1,044	2012
Roger Mills	260	700	269	938	2012
Woods	1,223	1,157	501	2,127	2013
Woodward	143	70	204	277	2002
State	17,173	73,820	430	102,707	2012

SECTION FOUR

Legal Overview for Oklahoma

Surface Owner Issues

In Oklahoma, as in most states, the surface estate may be owned separately from the mineral estate. The mineral estate carries the rights to explore for and produce the minerals (of which oil and gas are a part). Under Oklahoma law, the mineral estate is regarded as "dominant" and the surface estate as servient. Servient means that when the mineral and surface estates are owned by different parties, the surface estate must yield to the mineral estate and allow entry for exploration and production activities. To balance the interests of the mineral and surface estates, the Oklahoma Surface Damage Act prescribes procedures for estimating the damages to be sustained by the surface estate and compensating the surface owner. First, the surface owner must be notified about anticipated drilling operations. The landowner and drilling company then enter into damage negotiations. If no agreement is reached, the petroleum operator will ask the district court for appointment of appraisers (it should be noted here that once the request for appraisers is made, the company can enter the property, even if no agreement for the use of the surface has been reached). The appraisers - one selected by the surface owner, one selected by the petroleum operator and one mutually selected by those two appraisers) evaluate the property and make a report to the court. Once the report is filed, the parties can either accept the report and the amount of damages it specifies or they can ask for a determination of damages by trial.

The Oklahoma Surface Damage Act procedure does not apply to damages caused seismic exploration, based on *Anschutz Corp v. Sanders*, 734 P.2d 1290; seismic issues are instead handled by the Oklahoma Seismic Exploration Regulation Act discussed below.

The measure of "damages" under the SDA provides "(t)he damage standard intended by the Legislature under the Act is the <u>diminution in the fair market value of the surface property resulting from the drilling operations</u>…" [*see Ward Petroleum Corp. v. Stewart* (64 P.3d 1113)]. That results in a standard formula:

$$\text{Fair Market Value before the well} - \text{Fair Market Value after the well} = \text{Damages}$$

Some of the factors considered in the damages include:

- The location of the operations.
- The quality and value of the land used or disturbed by drilling.
- "Incidental features" resulting from drilling (side effects).
- Inconveniences in how the surface owner can use the property.
- Changes in physical condition of the property.
- Changes in the shape of the tract.
- Changes in accessibility.
- Destruction of native grasses or growing crops.
- Whether the damages are temporary or permanent.

This list is taken from jury instructions approved as a "proper statement of the law applicable to the case" in *Davis Oil Co. v. Cloud*, 766 P.2d 1347.

As mentioned above, the Surface Damages Act does not apply to seismic and geophysical operations, which instead fall under the purview of the Oklahoma Seismic Exploration Regulation Act. Oklahoma case law has fairly well established that it is the mineral owner's right to grant permission for seismic exploration of the property, without consulting the surface owner. Without protections similar to those afforded by the Surface Damage Act, this can leave surface owners exposed to the risk of property damage caused by seismic exploration. Nevertheless, potential liability for seismic operations may still apply if there is "unreasonable" use of the surface (excessive damage) or damage caused by explosives. Oklahoma law provides strict liability on the use of explosives (*Superior Oil Co. v. King*, 324 P.2d 847 (Okla, 1958), *Seismograph Service Corporation v. Buchanan*, 316 P.2d 185, 186-187 (Okla. 1957) 52 OS 318.23).

The fundamental rule of reasonableness in use of the surface estate for exploration remains, but additional protections for surface owners came in amendments to the Seismic Exploration Regulation Act via SB 243 and SB 1665 to state that the surface owner must be notified within 15 days prior to operations including the company name, anticipated date of exploration and surface description (see language of 52 Okla. Stat. 318.22). Seismic operations have to be permitted, and a performance bond posted (see Okla. Admin. Code 165:10-7-31). The exploration company must have a written agreement with the surface owner prior to commencing exploration activities. Although not an explicit requirement of the revised statute, its language implies compensation for the exploration activities is to be offered to the landowner, even if a "reasonable" amount of damage is anticipated. A rejection or failure to accept the agreement within 15 days of the postmark is equivalent to rejection. If the offer is deemed rejected, the case must be pursued either as a Small Claims Act case or a civil suit to obtain reasonable damages. The losing party must pay the prevailing party's costs and attorney fees (with the losing party defined as the party required to pay more or receive less than the original offering).

Fracturing Fluid Regulation

Oklahoma requires disclosure of fracturing fluid components used in the fracturing of a well within 60 days of the well's completion. As of the date of this report, there is no federal requirement for disclosure of fracturing fluid components or volumes on lands not subject to direct federal jurisdiction. Currently, the FracFocus website is used by Oklahoma and several other states as a clearinghouse of information for fracturing fluids. Table 5 provides a summary of fracturing fluid information. While the majority of material pumped into a well contains water and sand, other chemicals may be added per company preference, source water quality and site-specific characteristics of the target formation (Table 5).

Table 5. Fracturing Fluid Information.

Adaptive Type	*Main Compound(s)*	*Purpose*	*Common Use of Main Compound*
Diluted Acid (15%)	Hydrochloric acid or muriatic acid	Helps dissolve minerals and initiate cracks in the rock	Swimming pool chemical and cleaner
Biocide	Glutaraldehyde	Eliminates bacteria in the water that produce corrosive byproducts	Disinfectant; sterilize medical and dental equipment
Breaker	Ammonium persulfate	Allows a delayed breakdown of the gel polymer chains	Bleaching agent in detergent and hair cosmetics. Manufacture of household plastics
Corrosion Inhibitor	N,N-dimethyl formamide	Prevents the corrosion of the pipe	Used in pharmaceuticals, acrylic fibers, plastics
Crosslinker	Borate salts	Maintains fluid viscosity as temperature increases	Laundry detergents, hand soaps and cosmetics
Friction Reducer	Polyacrylamide	Minimizes friction between the fluid and the pipe	Water treatment, soil conditioner
	Mineral oil		Make-up remover, laxatives and candy
Gel	Guar gum or hydroxyethyl cellulose	Thickens the water to suspend the sand	Cosmetics, toothpaste, sauces, baked goods, ice cream
Iron Control	Citric acid	Prevents precipitation of metal oxides	Food additive, flavoring in food and beverages; Lemon Juice ~ 7% Citric Acid
KC1	Potassium chloride	Creates a brine carrier fluid	Low sodium table salt substitute
Oxygen Scavenger	Ammonium bisulfite	Removes oxygen from the water to protect the pipe from corrosion	Cosmetics, food and beverage processing, water treatment
pH Adjusting Agent	Sodium or potassium carbonate	Maintains the effectiveness of other components, such as crosslinkers	Washing soda, detergents, soap, water softener, glass and ceramics
Proppant	Silica, quartz sand	Allows the fractures to remain open so the gas can escape	Drinking water filtration, play sand, concreate, brick mortar
Scale Inhibitor	Ethylene glycol	Prevents scale deposits in the pipe	Automotive antifreeze, household cleaners and deicing agent
Surfactant	Isopropanolol	Used to increase the viscosity of the fracture fluid	Glass cleaner, antiperspirant, hair color

Note: The specific compounds used in a given fracturing operation will vary, depending on company preference, source water quality and site-specific characteristics of the target formation. The compounds shown are representative of the major compounds used in hydraulic fracturing of gas shales.

Source: U.S. Department of Energy Office of Fossil Energy and National Energy Technology Laboratory (April 2009).

Well Regulation

The Oklahoma Corporation Commission (OCC) is charged with oversight and regulation of well construction in Oklahoma (See Okla. Admin. Code 165:10-3). Such regulations are specific to casing, cementing and surface requirements.

Water Use and Injection Well Control

The federal Safe Drinking Water Act (SDWA) and the Underground Injection Control (UIC) program provide oversight for water use and injection wells. Class II covers saltwater disposal wells and natural gas storage wells. These may be injection fluids brought to the surface in connection with conventional oil and natural gas production for enhanced recovery of oil or natural gas; and for storage of hydrocarbons that are liquid at standard temperature and pressure (Oklahoma Class II wells covered by OAC 165:10-5).

Surface Water Pollution Prevention

The Clean Water Act (1972) exempts petroleum well sites from most regulatory requirements for stormwater management at the well site itself. However, if stormwater runoff from the well site comes in contact with industrial materials or pollutants on site, such requirements may then be triggered. Administration of such requirements is usually handled by general permits through required implementation of best management practices. There are also spill prevention, control and countermeasure (SPCC) requirements for well sites.

Solid Waste Disposal

The Resource Conservation and Recovery Act (RCRA) generally regulate solid waste. RCRA contains an exemption for "drilling fluids, produced waters and other wastes associated with the exploration, development or production of crude oil or natural gas" [42 U.S.C. § 6921(b)(2)(A)]. "Exploration and Production wastes" are those that come from down-hole, or otherwise been generated by contact with the oil and gas production stream during the removal of produced water or other contaminants from the product. This exemption does give states the option to regulate wastes. In fact, there are numerous OCC regulations for management and disposal of such wastes, including commercial disposal pits, soil farming and land application of wastes.

Air Quality Issues

There are a variety of potential pollutants from specific emission sources that have been identified with respect to oil and gas activities. Title V of the Clean Air Act requires processing facilities obtain major source permits if emitting:

- 100 tons per year (TPY) of criteria pollutant.
- 10 TPY of any one Hazardous Air Pollutant (HAP).
- 25 TPY of any combination of HAPs.
- In addition, Oklahoma generally requires minor source permits for compressor stations.

At the federal level, hydraulic fracturing wells regulated under the New Source Performance Standards (NSPS) are seeing a phased implementation of new permit requirements. Phase 1 covers the use of flares to manage volatile organic compounds (VOCs) emissions, and Phase 2 covers the use of "green completion" to separate gases from produced fluids. Table 6 provides information about potential pollutants and sources as related to oil and gas activity. Most of the oil and gas development in Oklahoma is under the regulatory authority of the Oklahoma Corporation Commission (OCC).

General Legal and Policy Issues

As with all law and public policy actions, there is ongoing evolution. One specific area of debate has been where the "locus" of control for oil and gas regulation should reside. Some argue that local jurisdictions (municipalities and counties) should have primary authority to regulate such activities, while others argue the state is the proper choice for such authority, and still others argue the federal government is the natural choice for such regulation. Following are the questions frequently asked relative to each potential level of regulatory authority:

Local level: Is there local knowledge about the situation? Is the locus of impact local? Are there available professional resources at the local level? Is there legal authorization for local regulation? What are the impacts to the industry from potentially non-uniform rules?

State level: Is there regional knowledge about the situation? Is there plenary statutory authority? Has there been a delegation of appropriate federal programs to the state? Is the state level removed from impacts?

Federal level: Is there access to superior expertise at the federal level? Is uniformity among states a primary objective? Is the agency removed from the situation/impacts?

For example, the Oklahoma State Legislature recently decided to generally deny local regulation of oil and gas activities through the enactment of 52 Okla. Stat. § 137.1, which states:

> A municipality, county or other political subdivision may enact reasonable ordinances, rules and regulations concerning road use, traffic, noise and odors incidental to oil and gas operations within its boundaries, provided such ordinances, rules and regulations are not inconsistent with any regulation established by Title 52 of the Oklahoma Statutes or the Corporation Commission. A

Table 6. Potential Pollutants and Sources from Oil and Gas Activities.

Onshore Exploration Source Type	*Specific emission sources*	*Potential pollutants*
Drilling rigs	Diesel engines to run electricity generators	SO2, NOX, VOC PM10, PM2.5, CO
	Drill mud degassing (open pits or storage tanks)	VOC
Gas well completion	Emission from flaring from the gas well completion phase	CO, NOX, VOC
	Emission from venting from the gas well completion phase	VOC
Oil well completion	Emission from flaring from the oil well completion phase	CO, NOX, VOC, SO2
	Emission from venting from the oil well completion phase	VOC
Gas well pneumatic devices	Fugitive emissions from pneumatic devices used during gas well exploration and production	VOC
Oil well pneumatic devices	Fugitive emissions from pneumatic devices used during oil well exploration and production	VOC

Source: Eastern Research Group (2007). Report for Texas Commission on Environmental Quality, Emissions from Oil and Gas Production Facilities: Final Report (p. 15).

> municipality, county or other political subdivision may also establish reasonable setbacks and fencing requirements for oil and gas well site locations as are reasonably necessary to protect the health, safety and welfare of its citizens but may not effectively prohibit or ban any oil and gas operations, including oil and gas exploration, drilling, fracture stimulation, completion, production, maintenance, plugging and abandonment, produced water disposal, secondary recovery operations, flow and gathering lines or pipeline infrastructure. All other regulations of oil and gas operations shall be subject to the exclusive jurisdiction of the Corporation Commission.

Some communities have or are considering limitations, such as setback and siting regulations, to minimize nuisances such as noise, air and visual pollution to neighbors.

Recent legislation authorizes the OCC to immediately shut down or restrict injection wells under its jurisdiction if an emergency exists (see House Bill 3158 (2016)). Additionally, the OCC recently imposed new policies to shut down or restrict injection wells if significant seismic activity results (OCC Oil and Gas Conservation Division Advisory, March 25, 2015). Earlier, OCC had issued restrictions on 347 injection wells in hopes of curbing the number of induced earthquakes. In July 2015, the OCC added new rules on injection wells to attempt to reduce the induced seismic activity. Expanding the "Areas of Interest" and adding restrictions for more than 200 wells, the OCC now requires operators of injection wells in 21 counties to show they have ceased all injection of water below the deepest rock formation. As of this writing, the OCC's most recent Area of Interest pronouncements encompass more than 10,000 square miles and 600 Arbuckle disposal wells in central and western Oklahoma. Operators of wells required to reduce water volume injected are now required to inject into shallower depths. These rules are still affecting only a small percentage of the state's 3,500 injection wells. The OCC has indicated the next step may be a limit on the volume that is injected into each well, if necessary.

Outside of the administrative process afforded by environmental regulations, affected parties must use the litigation process. The litigation process can trigger significant delays and expense. Further, those held liable for damages may use bankruptcy or dissolution proceedings as a means to cause fines and penalties to be vacated and some environmental liabilities to be voided. Based on these concerns, others have called for "bonding" programs that require petroleum companies to pay funds into escrow. This escrow will be used to pay environmental claims. Still others have called for modification of the federal Bankruptcy Code to prohibit the discharge of environmental liabilities. In any case, hydraulic fracturing has triggered debate over how the legal system handles the impacts of petroleum resource extraction. As less of a scientific issue and more of an economic and policy concern, the liability issues raise the need for Extension professionals to provide a facilitative role. Extension can help people connect with and gain access to the state and federal policy-makers affecting the legal rules of environmental liability. This issue also underscores the need for Extension information and programming regarding how to engage policymakers in an effective and informed manner.

For more information, please see publications: *Natural gas extraction; Issues and policy options;* and *A natural gas extraction policy alternatives matrix*," (Ferrell & Sanders, 2013a, 2013b, 2013c). Also see the articles, *The oil and gas boom: Basic information about oil and gas activities for Extension professionals* and *Framing a public issue for Extension: Challenges in oil and gas activity* (Peek, Penn, Sanders, Shideler & Ferrell, 2015; Peek, Sanders, et al., 2015).

SECTION FIVE

Boomtown

Boomtown Defined

The term boomtown refers to, "A town that experiences a sudden growth in business and population; a booming town" (Merriam-Webster, 2014). Boomtown communities are charged with managing rapid, often ad hoc, development. For example, the community may not be able to accommodate the rapid influx of workers and their families, putting pressure on local public and private goods and services, including utilities, schools, housing and local businesses. For a variety of reasons (e.g., lack of staffing/capacity, mismatch between expenditure and revenue cycles, bureaucracy), communities are slow to respond to the situation, so the actions taken are too little, too late. This often means buildings or infrastructure are built that have useful lives of 20 to 30 years, but the population boom is much shorter.

Boomtowns Not Apparent in Oklahoma

Since hydraulically fractured wells only take three months to construct, the population boom is likely to be very short, likely less than one year. The exception is if the community also happens to be a regional retail center, where crews might be housed to drill in the surrounding counties. Also, pipeline construction and maintenance crews might be more stable than drilling crews, since these activities take longer than drilling a well. Previous studies [see Gilmore (1976)] estimated that communities experiencing population growth exceeding 5 percent will experience difficulties meeting demand, and those which experience population growth exceeding 15 percent will experience "institutional breakdowns in the labor market, the housing market and the system for financing local public facilities" as quoted in Jaquet (2009). Given that the influx of population may or may not be reflected in population estimates, employment data was used to determine if any of the 14 counties experienced the "boomtown" effect.

As seen in Table 7, all counties except Atoka and Coal counties realized improvement in their employment growth rate between the period before and after the peak year of gas production. Only Payne County grew more than 5 percent during the subsequent growth period (2006-2007 for Payne County). However, this was before hydraulic fracturing was implemented in Oklahoma. Furthermore, only in Payne and Woodward counties were there dramatic shifts in the employment trend between employment growth in the year before and the year after peak production. Table 7 provides a comparison of employment growth rates before and after the peak year of gas production.

Table 8 shows the employment growth rates before and after peak oil production for the selected counties. Only Woodward County realized an employment growth rate greater than 5 percent in the period following peak oil production. Only Jefferson County realized a shift in employment trend greater than 5 percent between the before and after periods of peak oil production. Considering the values presented in Tables 7 and 8, the employment data does not suggest that a boomtown effect occurred in Oklahoma. These findings are consistent with those of Brown (2014), who found that while counties within the Federal Reserve Bank's Tenth District (which includes Oklahoma) did not realize employment or population shocks large enough to distort local labor markets.

While the quantitative analysis suggests that Oklahoma counties were not adversely affected by oil and gas development, some communities were affected by these activities. Anecdotal evidence shared with the researchers pointed to rises in wage levels in specific communities as local retailers and restaurants tried to compete with oil and gas companies for workers; another told of rental rates for housing increasing 2.5 times in one community due to a lack of available housing in the region. The empirical results suggest, however, that across the 14 counties, these effects were not typical or of significantly large size. Table 7 provides a comparison of employment growth rates: Year before/after peak gas production.

Another approach to examining the boomtown effect on Oklahoma counties is to consider changes in public revenue and expenditures. Due to the complexity of reporting revenue and expenditures (e.g., each county can have differently named and/or multiple funds used to support specific functions), the analysis focused on two, well-defined streams of revenue: Retail sales tax collections and highway fund revenues; it was also assumed that these revenues would be most directly impacted by oil and gas activity. Similarly, only highway fund expenditures are considered, since this is the only common fund across counties with a well-defined purpose (and one that is dramatically impacted by hydraulic fracturing).

Retail Sales Reflect Relative Economic Health

Retail sales tax collections indicate local economic health because they reflect both the volume of retail transactions occurring (driven by the number of people

Table 7. Comparison of Employment Growth Rates (Year Before/After Peak Gas Production).

	Total Employment (in thousands)					
County	*Max Yield Year*	*Prior Year*	*Max Yield Year*	*Next Year*	*Prior Growth*	*Subsequent Growth*
Alfalfa	2012	2.870	2.859	2.851	-0.4%	-0.3%
Atoka	2009	7.005	6.922	6.765	-1.2%	-2.3%
Canadian	2010	43.394	43.515	43.778	0.3%	0.6%
Coal	2010	2.482	2.473	2.453	-0.4%	-0.8%
Harmon	.					
Jefferson	2012	2.258	2.270	2.286	0.5%	0.7%
Noble	2009	6.707	6.620	6.547	-1.3%	-1.1%
Oklahoma	2010	533.896	533.336	535.366	-0.1%	0.4%
Payne	2006	44.997	45.666	48.029	1.5%	5.2%
Pittsburg	2012	24.479	24.701	24.944	0.9%	1.0%
Pottawatomie	2006	29.664	30.701	31.866	3.5%	3.8%
Roger Mills	2006	1.975	1.956	1.994	-1.0%	1.9%
Woods	2012	5.720	5.739	5.761	0.3%	0.4%
Woodward	2009	14.708	13.443	13.121	-8.6%	-2.4%

Data taken from Woods and Poole Oklahoma State Profile, 2014.

Table 8. Comparison of Employment Growth Rates (Year Before/After Peak Oil Production).

	Total Employment (in thousands)					
County	*Max Yield Year*	*Prior Year*	*Max Yield Year*	*Next Year*	*Prior Growth*	*Subsequent Growth*
Alfalfa	2012	2.870	2.859	2.851	-0.4%	-0.3%
Atoka	2008	6.986	7.005	6.922	0.3%	-1.2%
Canadian	2012	43.394	43.778	44.901	0.9%	2.6%
Coal	2009	2.46	2.482	2.473	0.9%	-0.4%
Harmon	2007	1.537	1.556	1.535	1.2%	-1.3%
Jefferson	2004	2.389	2.289	2.309	-4.2%	0.9%
Noble	2007	6.606	6.751	6.707	2.2%	-0.7%
Oklahoma	2009	541.263	533.896	533.336	-1.4%	-0.1%
Payne	2001	46.301	44.92	43.844	-3.0%	-2.4%
Pittsburg	2006	22.437	23.521	24.594	4.8%	4.6%
Pottawatomie	2000	28.888	29.554	29.172	2.3%	-1.3%
Roger Mills	2012	2.028	2.043	2.058	0.7%	0.7%
Woods	2012	5.72	5.739	5.761	0.3%	0.4%
Woodward	2006	12.832	13.458	14.171	4.9%	5.3%

Data taken from Woods and Poole Oklahoma State Profile, 2014.

Table 9. Estimated Retail Sales for Selected Counties (2000-2015).

Year	Alfalfa	Atoka	Canadian	Coal	Harmon	Jefferson	Noble	Oklahoma	Payne	Pittsburg	Pottawatomie	Roger Mills	Woods	Woodward
2000	$16,805,349	$54,866,487	$425,179,934	$13,789,175	$10,281,950	$18,582,793	$54,881,112	$8,583,888,237	$542,219,375	$286,836,705	$424,031,133	$8,537,833	$63,423,683	$175,222,595
2001	$17,787,087	$57,421,717	$452,309,030	$15,378,183	$10,836,550	$14,728,408	$56,476,282	$9,021,484,621	$578,842,525	$305,697,615	$451,262,183	$13,721,417	$66,800,867	$195,911,205
2002	$17,214,021	$60,384,193	$497,416,132	$15,207,250	$10,385,450	$19,376,110	$48,043,248	$9,208,190,609	$586,679,738	$318,901,950	$451,294,117	$13,761,633	$67,087,167	$202,399,671
2003	$16,295,327	$60,097,794	$499,391,233	$15,737,217	$10,281,350	$18,698,167	$50,926,747	$9,101,556,789	$588,438,649	$317,077,364	$455,864,092	$17,432,867	$64,862,300	$191,588,429
2004	$17,661,899	$60,458,835	$573,407,510	$17,116,533	$10,942,850	$18,630,267	$54,359,574	$9,555,404,256	$617,698,018	$322,648,833	$462,806,925	$17,727,783	$68,014,708	$215,152,986
2005	$17,275,628	$62,950,280	$613,429,159	$16,830,367	$11,645,750	$18,666,807	$53,435,697	$9,889,024,507	$647,931,638	$337,611,302	$486,794,475	$20,623,650	$70,455,723	$227,839,362
2006	$17,477,637	$65,796,226	$654,480,712	$18,925,250	$11,304,000	$19,912,063	$54,667,580	$10,552,896,332	$692,521,971	$373,277,475	$514,057,608	$23,641,167	$73,959,919	$252,409,843
2007	$19,820,540	$82,919,552	$693,360,507	$35,909,367	$12,544,600	$20,018,923	$57,332,797	$11,221,176,976	$734,486,044	$412,672,787	$537,862,288	$22,813,867	$74,498,767	$292,708,324
2008	$21,477,268	$84,002,302	$723,189,648	$39,676,500	$12,236,950	$20,546,610	$58,442,692	$11,634,314,064	$779,227,888	$457,703,334	$564,847,370	$23,094,483	$86,348,837	$309,395,048
2009	$26,843,074	$77,566,476	$788,273,450	$37,380,417	$11,952,500	$22,104,480	$57,308,696	$11,939,614,624	$812,631,870	$495,912,734	$585,421,360	$16,486,133	$94,770,069	$308,790,143
2010	$22,429,618	$73,052,824	$778,778,710	$23,621,700	$11,286,550	$21,615,940	$52,990,520	$11,151,745,343	$778,024,393	$422,075,086	$563,585,196	$11,846,733	$84,874,896	$259,257,948
2011	$26,442,762	$74,129,364	$830,987,232	$30,102,212	$11,684,392	$20,931,609	$57,779,994	$12,304,882,287	$811,235,653	$460,164,567	$593,371,882	$18,145,382	$86,481,560	$295,488,126
2012	$45,781,305	$82,021,045	$936,892,586	$30,234,813	$11,327,020	$22,225,087	$61,116,171	$12,963,923,837	$853,510,845	$481,407,568	$610,935,024	$30,023,380	$111,891,482	$342,548,973
2013	$71,268,838	$81,832,353	$966,345,140	$24,639,145	$11,611,155	$23,126,014	$74,400,495	$13,613,382,462	$937,688,194	$449,412,699	$629,298,866	$31,004,671	$147,971,953	$387,359,030
2014	$60,740,360	$84,102,693	$985,199,132	$28,216,013	$11,451,030	$22,179,317	$80,915,998	$13,994,685,878	$1,051,858,375	$440,609,235	$635,480,297	$24,957,934	$146,547,286	$391,105,012
2015	$57,921,710	$80,558,672	$1,046,604,394	$28,331,835	$10,909,111	$22,360,162	$77,452,261	$14,392,940,275	$1,025,436,676	$453,311,328	$641,677,916	$20,757,025	$160,267,264	$363,964,025

Cells shaded yellow reflect the year of peak oil production, while cells shaded blue reflect peak year of gas production; green shaded cells reflects peak year of production for both oil and gas.

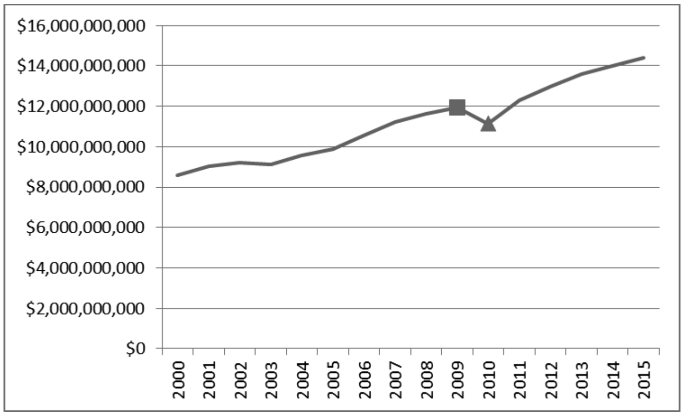

Figure 17. Oklahoma county retail sales.

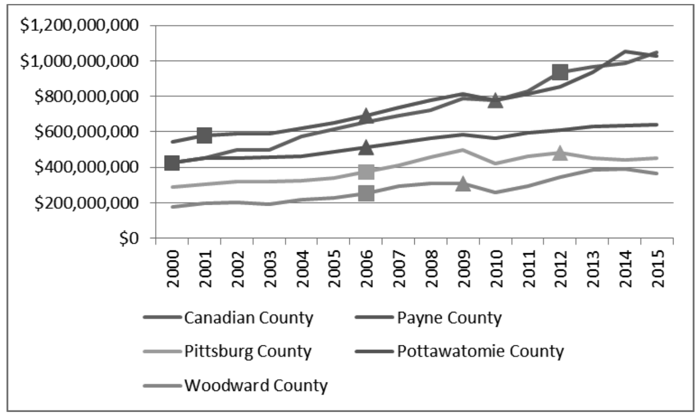

Figure 18. Selected counties retail sales.

shopping in the community) and the level of disposable income in the community. If either population (as a proxy for the volume of sales) or income changes, the amount of retail sales tax collections will change in the same way. Therefore, retail sales tax collections could identify hydraulic fracturing impacts due to an influx of workers into the community. An added benefit is that retail sales tax collection data are readily available from the Oklahoma Tax Commission. For the purposes of this study, annual city retail sales estimates are calculated by dividing retail sales tax collections by the local sales tax rate, then county retail sales are estimated by summing estimated retail sales across cities within the county. (The county retail sales tax collection data are problematic, and Oklahoma County did not collect retail sales taxes during the period examined.) If a county realized an influx of oil and gas workers, retail sales should increase as they purchase food and other necessities. However, as Figures 17 to 19 demonstrate, retail sales in the larger counties were more impacted by the economic recession than oil and gas activity. The smaller counties in our sample, presented in the third panel of Figure 19, demonstrated more variability in retail sales tax collections, but the peaks and troughs do not generally coincide with peak years of oil and gas production.

For example, Oklahoma County's peak year of production was 2010, which corresponds to a relative low point in retail sales, probably due to the economic recession's impact on household spending. See Table 9.

As evidenced in Table 9 and Figure 20, similar dips in revenue are noticed with the next tier of counties; with two counties realizing peak production in 2006 and one peaking in 2013, only Woodward County had a peak in 2009 that corresponds to a relative peak in retail sales. Canadian County had a similar pattern as Oklahoma County, in that its peak year of production of 2010 corresponds to a relative trough in retail sales.

Of the smallest counties, (reflected in Figure 21) only in Alfalfa and Woods counties do retail sales appear to have been impacted by hydraulic fracturing. Both of these counties experienced peak years of production in 2012, and both realized changes in the retail sales growth trend, suggesting a change in the local economy like an influx of oil and gas workers. Figures 19 through 21 provide data about retail sales during the study period.

Table 10. Population Change Since 2000.

County	*2000*	*2013*	*% Change*
Oklahoma (state)	3,450,451	3,850,568	11.60
Alfalfa*	6,092	5,847	-4.02
Atoka	13,876	13,898	0.16
Canadian*	87,729	126,123	43.76
Coal*	6,035	5,867	-2.78
Harmon	3,285	2,869	-12.66
Jefferson	6,820	6,432	-5.69
Noble	11,406	11,446	0.35
Oklahoma	660,581	755,245	14.33
Payne	68,201	79,066	15.93
Pittsburg*	43,944	44,703	1.73
Pottawatomie	65,505	71,158	8.63
Roger Mills*	3,432	3,743	9.06
Woods*	9,094	9,041	-0.58
Woodward*	18,489	21,221	14.78

*Indicates a high gas production county—production above the 2012 state average.
Sources: (U.S. Census Bureau, 2011, 2013)

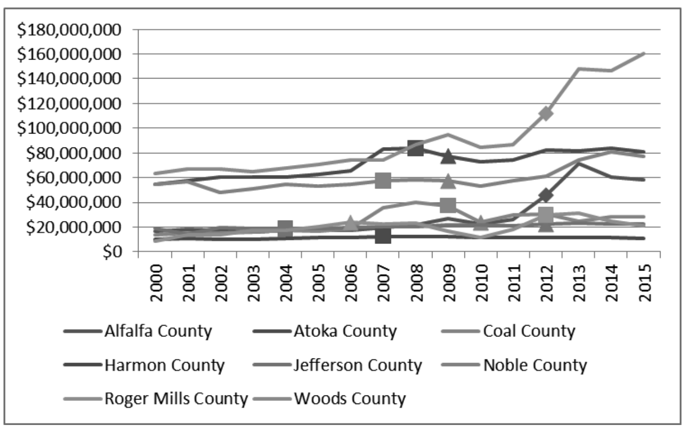

Figure 19. Additional counties retail sales.

▲ Represents peak year of gas production; ■ represents peak year of oil production; ◆represents year in which oil and gas production peaked.

Source: Compiled by Oklahoma Cooperative Extension Service using Oklahoma Tax Commission City Sales Tax Ledger Reports Data (Oklahoma Tax Commission, 2016).

Highway Funds: Revenues and Expenditures

Examination of the highway fund revenues and expenditures in each county displays a similarly unclear connection between hydraulic fracturing and road conditions as the retail sales analysis (Figures 20 through 34). First, it is important to note that counties must maintain balanced budgets from year to year, so expenditures and revenues are roughly equal in a given year. This explains the helix structure of the graph found in each of the counties. Second, most counties experienced a rapid rise in highway funding, but the trend change does not seem to coincide with hydraulic fracturing. Even when considering the temporal mismatch between revenues generated and expenditures (i.e., gross production taxes are not returned to counties until one year after they are collected), only three counties seem to have been impacted by hydraulic fracturing: Alfalfa, Coal and Payne counties. It is too difficult to determine if changes in other counties (e.g., Atoka County) were due to the recession, hydraulic fracturing, or continuations of previous trends (e.g., Canadian County).

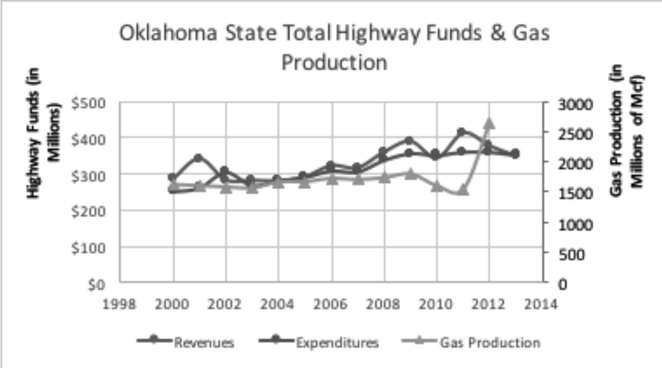

Figure 20. Oklahoma state highway revenues and expenditures (2000-2014).

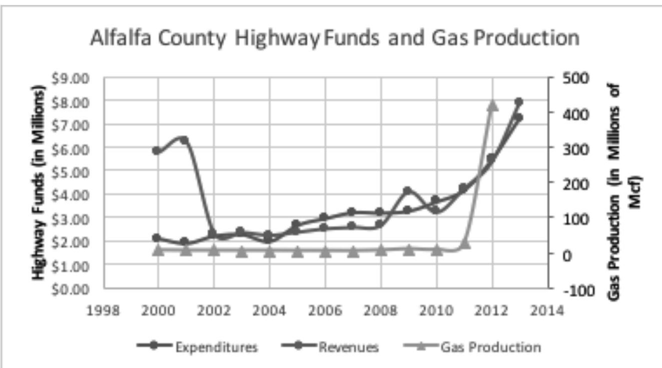

Figure 21. Alfalfa County highway revenues and expenditures (2000-2014).

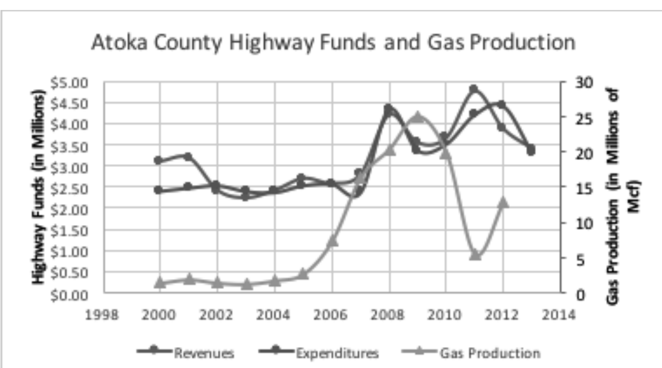

Figure 22. Atoka County highway revenues and expenditures (2000-2014).

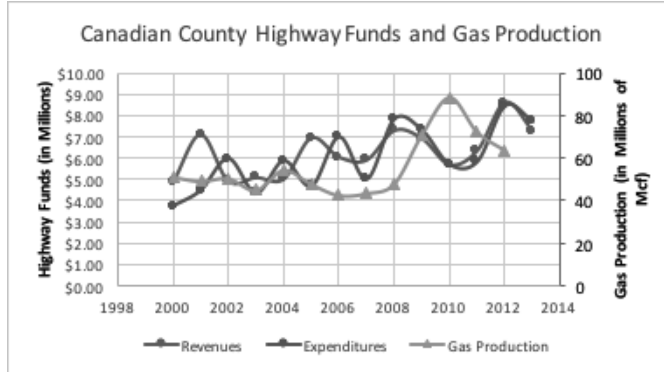

Figure 23. Canadian County highway revenues and expenditures (2000-2014).

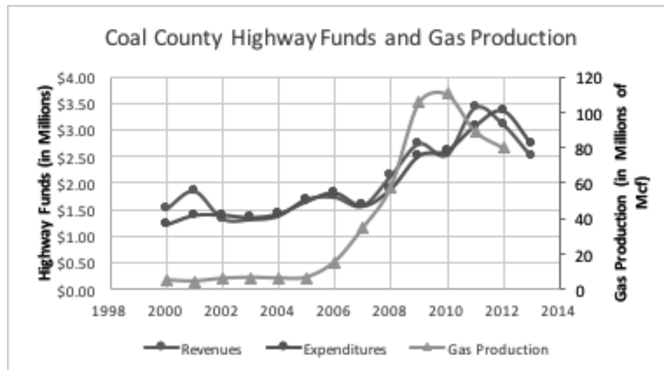

Figure 24. Coal County highway revenues and expenditures (2000-2014).

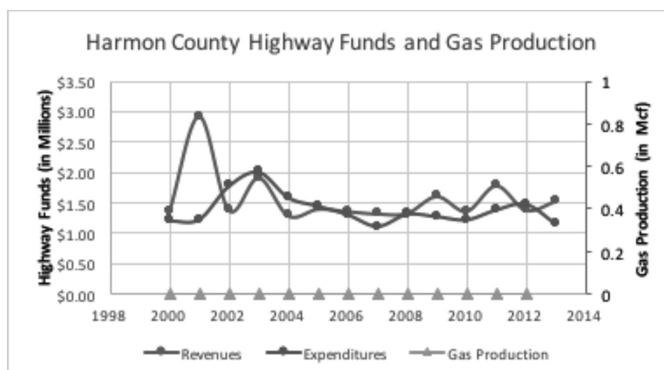

Figure 25. Harmon County highway revenues and expenditures (2000-2014).

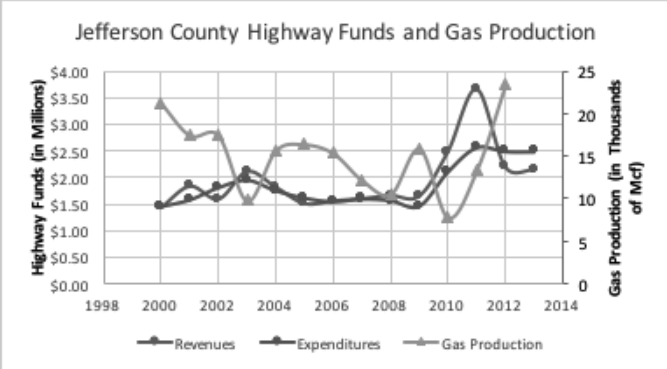

Figure 26. Jefferson County highway revenues and expenditures (2000-2014).

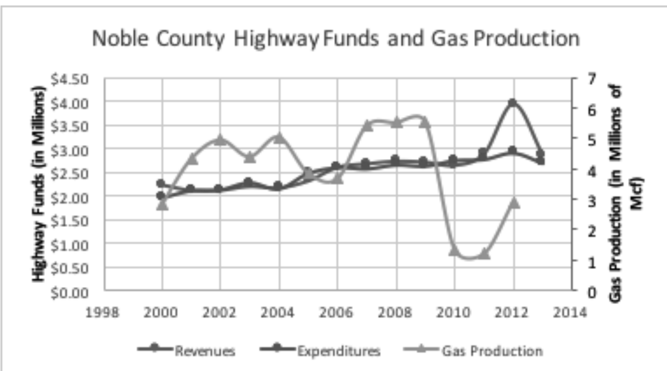

Figure 27. Noble County highway revenues and expenditures (2000-2014).

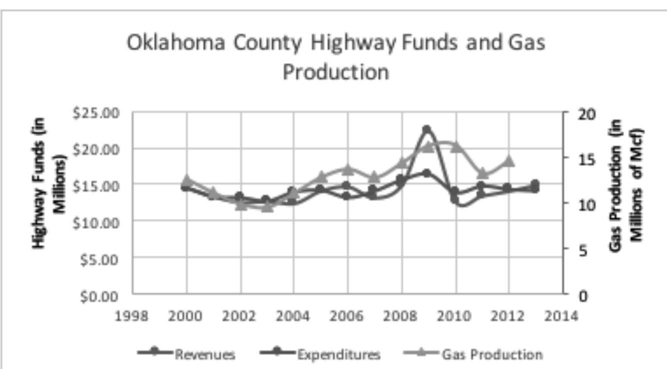

Figure 28. Oklahoma County highway revenues and expenditures (2000-2014).

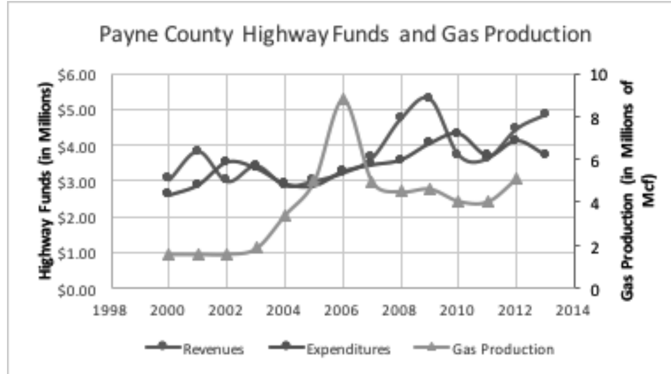

Figure 29. Payne County highway revenues and expenditures (2000-2014).

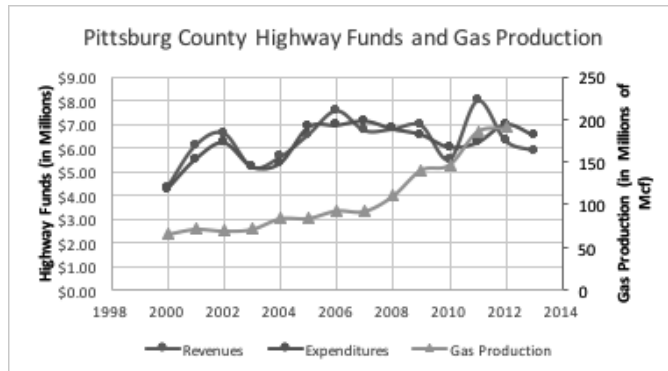

Figure 30. Pittsburg County highway revenues and expenditures (2000-2014).

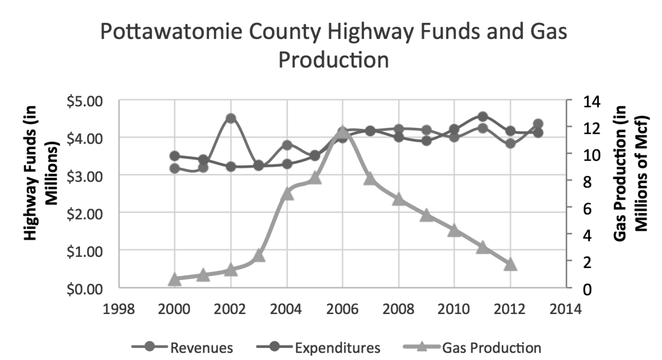

Figure 31. Pottawatomie County highway revenues and expenditures (2000-2014).

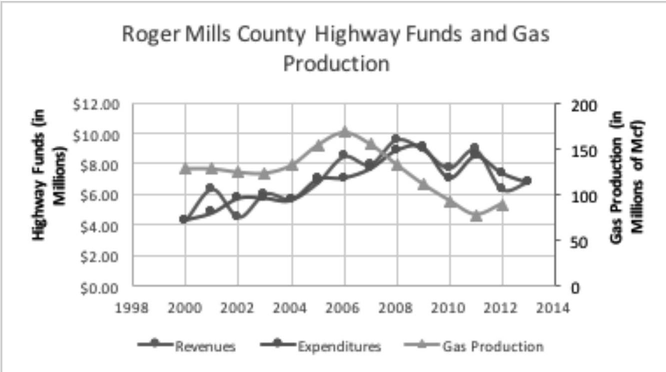

Figure 32. Roger Mills County highway revenues and expenditures (2000-2014).

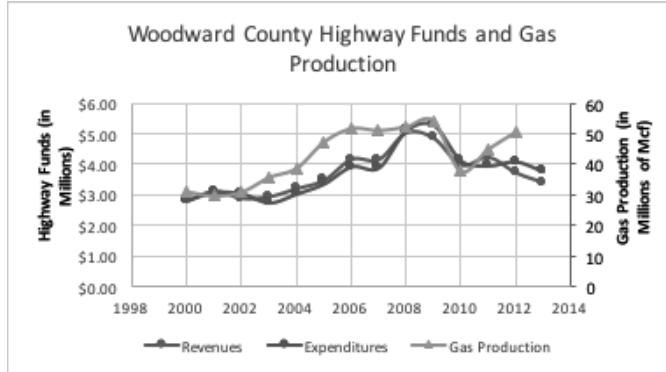

Figure 34. Woodward County highway revenues and expenditures (2000-2014).

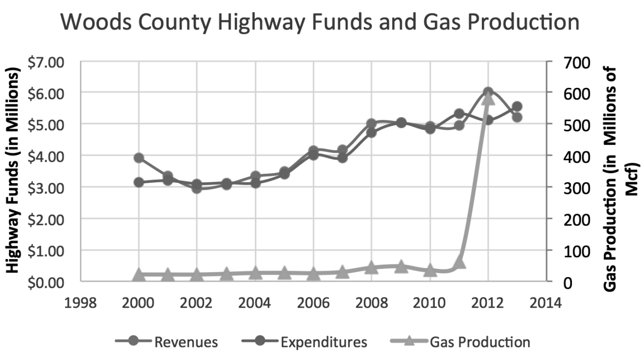

Figure 33. Woods County highway revenues and expenditures (2000-2014).

Community Characteristics

What is the relationship between oil and gas activity and selected community characteristics? Indicators, such as population, personal income, median household income, and average wage were used to establish background data and provide an understanding of county conditions and growth. Figure 35 highlights findings.

Figure 35. Community characteristics key findings among counties studied.

Population Gains and Losses

Since 2000, the population of Oklahoma increased by 11.5 percent. Of the counties featured here, 10 experienced a population increase while five experienced a decrease. Overall, the most populous counties were Canadian, Oklahoma, Payne and Pottawatomie. Canadian County gained the largest increase. The least populous counties were Harmon and Roger Mills. Harmon County experienced the greatest loss. Table 10 provides information regarding population increases and decreases.

Median Household Income

The term median household income is defined as follows:

> "Income of Households - This includes the income of the householder and all other individuals 15 years old and over in the household, whether they are related to the householder or not. Because many households consist of only one person, average household income is usually less than average family income. Although the household income statistics cover the past 12 months, the characteristics of individuals and the composition of households refer to the time of interview. Thus, the income of the household does not include amounts received by individuals who were members of the household during all or part of the past 12 months, if these individuals no longer resided in the household at the time of interview. Similarly, income amounts reported by individuals who did not reside in the household during the past 12 months but who were members of the household at the time of interview are included. However, the composition of most households was the same during the past 12 months as at the time of interview.
>
> The median divides the income distribution into two equal parts: one-half of the cases falling below the median income and one-half above the median. For households and families, the median income is based on the distribution of the total number of households and families including those with no income. The median income for individuals is based on individuals 15 years old and over with income. Median income for households, families and individuals is computed on the basis of a standard distribution" (U.S. Census Bureau, n.d.-c).

Since 2000, the state of Oklahoma and all counties in the study, except Harmon, experienced a consistent rise in median income. Only Canadian and Oklahoma counties medians were greater than the state average in all three time periods. In the 2005 and later estimates, Canadian, Oklahoma, Roger Mills, Woods and Woodward counties all featured median income larger than the state average. In sum, between 2000 and 2012, some least populous counties benefited from major gains in median income. In addition to having higher-than-average rates, Roger Mills, Woods, and Woodward counties experienced the largest percent change in median household income. Interestingly, with populations less than 20,000, Roger Mills, Woods and Woodward are among the less-populated counties. Harmon, Oklahoma and Payne counties experienced the smallest percent change. Table 11 provides information about median household income. Census data are used for analysis.

Average Wage Per Job

Since 2000, Oklahoma (state) and all counties of interest experienced a consistent rise in average wage. Average wage per job is an indicator to show how much the local economy can pay for labor. The largest percentage gains in average wage were experienced in Alfalfa (103.66), Roger Mills (91.67) Woods (108.24) and Woodward (93.52) counties. Interestingly, despite having a loss in population, Woods County enjoyed the largest increase in average wage per job. Even the lowest wage county from 2000 (Harmon) experienced a large gain by 2012. This gain was still not enough to meet the state average. Table 12 provides information about average wage per job. Oklahoma Department of Commerce data were used for analysis (Bureau of Labor Statistics).

Housing Characteristics

Housing characteristics, such as building permits, price, availability and quality were also examined to provide further context. Housing is an important economic indicator. Per the U.S. Census, both construction spending and homeownership rates are both economic indicators and used to evaluate economic conditions. Housing characteristics data are from the U.S. Census.

Building Permits

The term building permit refers to "The approval given by a local jurisdiction to proceed on a construction project" (https://www.census.gov/construction/nrc/definitions/index.html). The number of building permits issued is one indicator of growth. To better understand these data, the counties are divided into two groups:

- Counties in the Oklahoma City metropolitan area. This region has one-third of the total state population. The counties included in the OKC metro area featured by far the highest number of housing starts during the period of analysis.

Table 11. Median Household Income and Percent Change.

County	*2000*	*2005-2009*	*2000 to 2005-2009 (% change)*	*2010-2014*	*2005-2009 to 2010-2014 (% change)*	*2000-2010-2014 (% change)*
Oklahoma (state)	33,400	41,861	25.33	46,235	10.45	38.43
Alfalfa*	30,259	39,641	31.01	47,684	20.29	57.59
Atoka	24,752	30,990	25.20	37,519	21.07	51.58
Canadian*	45,439	59,015	29.88	64,200	8.79	41.29
Coal*	23,705	28,911	21.96	38,141	31.93	60.90
Harmon	22,365	31,531	40.98	31,285	-0.78	39.88
Jefferson	23,674	32,783	38.48	34,080	3.96	43.96
Noble	33,968	37,609	10.72	44,775	19.05	31.82
Oklahoma	35,063	41,862	19.39	46,584	11.28	32.86
Payne	28,733	34,255	19.22	37,637	9.87	30.99
Pittsburg*	28,679	38,521	34.32	41,339	7.32	44.14
Pottawatomie	31,573	38,836	23.00	44,250	13.94	40.15
Roger Mills*	30,078	50,089	66.53	53,194	6.20	76.85
Woods*	28,927	46,074	59.28	52,188	13.27	80.41
Woodward*	33,581	45,995	36.97	54,387	18.25	61.96

*Indicates a high gas production county, that is, above the 2012 state average
*5-Years Estimates Data

Table 12. Average Wage Per Job.

County	*2000*[1]	*2012*	*Percent Change*
Oklahoma (state, nonmetropolitan portion)	$30,766	36,907	20.0
Oklahoma City, OK (metropolitan statistical portion)	$38,134	44,627	17.0
Alfalfa*	$25,623	39,140	52.8
Atoka	$28,565	29,895	4.7
Canadian*	$44,594	40,467	-9.3
Coal*	$25,506	32,715	28.3
Harmon	$24,403	33,321	36.5
Jefferson	$25,911	30,626	18.2
Noble	$38,984	39,441	1.2
Oklahoma	$39,480	47,465	20.2
Payne	$28,611	35,529	24.2
Pittsburg*	$32,054	39,873	24.4
Pottawatomie	$29,427	32,717	11.2
Roger Mills*	$27,242	39,163	43.8
Woods*	$24,053	37,567	56.2
Woodward*	$31,407	45,585	45.1

*Indicates a high gas production county, that is, above the 2012 state average
[1] Values have been inflated to 2012 dollars to account for inflation

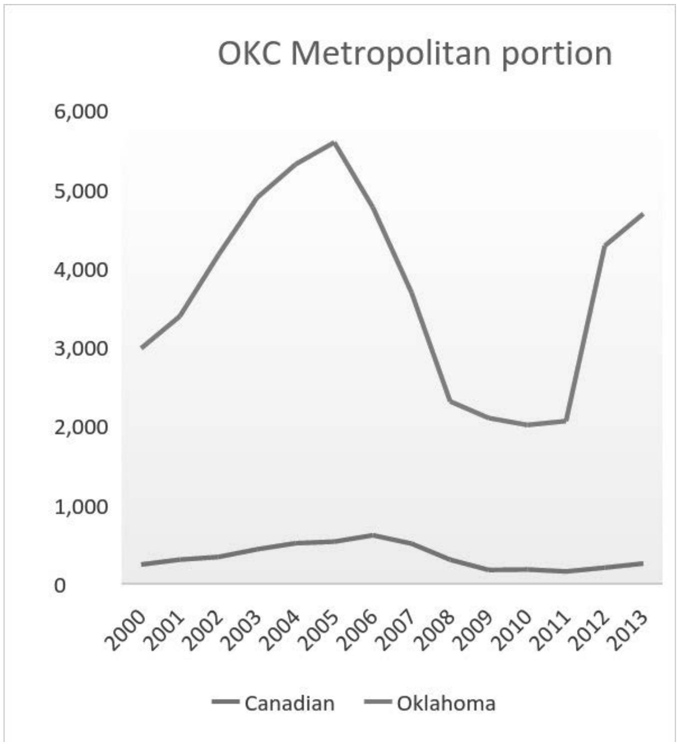

Figure 36. Building permits issued in Oklahoma City metropolitan area counties (2000-2013).

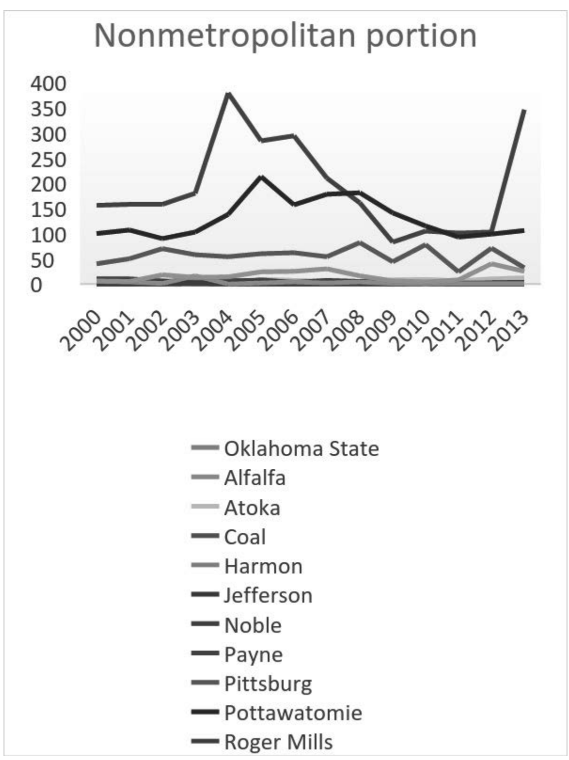

Figure 37. Building permits issued in nonmetropolitan area counties (2000-2013).

- Counties in the nonmetropolitan portion of Oklahoma. This group has some of the least populous counties, including Alfalfa and Harmon. The largest gain in building permits occurred between 2003 and 2006. Building permits later decreased between 2006 and 2011 only to increase again between 2011 and 2013.

Figure 36 shows the number of building permits in the counties inside the Oklahoma City metropolitan area, between 2000 and 2013.

Figure 37 shows the building permits for the counties at the nonmetropolitan portion of Oklahoma State during this same time. Notably, a sharp increase in building permits was seen in Payne and Pottawatomie counties. After peaking, these rates declined rapidly. The other counties featured more steady rates during the study period.

Median Housing Values

The term median housing value has two parts. “Value is the respondent’s estimate of how much the property (house and lot) would sell for if it were for sale. … The median divides the value distribution into two equal parts: one-half of the cases falling below the median value of the property (house and lot) and one-half above the median. Median value calculations are rounded to the nearest hundred dollars” (U.S. Census Bureau, n.d.).

Since 2000, the median value of owner-occupied housing units increased 56.72 percent in Oklahoma. Among the counties of interest, median value increased at a rate that was less than the average in the following counties: Harmon (53.57 percent), Noble (51.29 percent), Oklahoma (56.60 percent), Payne (42.41 percent) and Pottawatomie (46.94 percent).

Median housing points of interest

Other data show differences among the most- and least-populous counties in terms of median value of owner-occupied housing units. Canadian County had the highest median home value; Harmon County had the lowest. The three most-populous counties had the largest median values and are the only counties with median values higher than the state’s average. Counties with smaller populations, such as Harmon, Jefferson, Coal and Alfalfa had the smallest median values. Census data were used to construct median housing values data from the year 2000 (U.S. Census Bureau, 2003, p. 303). Five-year estimates data (2005-2009 and 2008-2012) were compiled from the Census American Fact Finder (U.S. Census Bureau, n.d.-a). Table 13 provides median values of owner-occupied housing units.

Some counties experienced significant gains in home value. Interestingly, some of the least-populated counties fared well when compared with the state’s average increase in median home value (56.72 percent). Since 2000, Alfalfa (114.14 percent), Roger Mills (105.38 percent), Coal

Table 13. Median Value of Owner-Occupied Housing Units.

County	*2000*	*2005-2009*	*2008-2012*
Oklahoma State	70,700	98,800	$115,000
Alfalfa*	29,000	46,500	$64,000
Atoka	43,800	65,700	$84,700
Canadian*	84,600	108,800	$141,600
Coal*	33,800	58,900	$71,900
Harmon	28,000	47,200	$46,400
Jefferson	33,300	48,500	$57,900
Noble	54,400	68,600	$84,200
Oklahoma	75,800	99,400	$129,800
Payne	79,700	97,300	$132,700
Pittsburg*	53,400	79,800	$89,400
Pottawatomie	60,500	85,600	$100,200
Roger Mills*	39,000	79,200	$86,500
Woods*	46,300	75,600	$88,000
Woodward*	61,100	90,100	$108,700

*Indicates a high gas production county, that is, above the 2012 state average
5-year estimates data

(97.93 percent) and Jefferson (86.49 percent) experienced significant gains in median value. Since 2000, both Alfalfa and Roger Mills counties experienced triple-digit gains. Roger Mills County experienced the most impressive increase in the median value of housing units in the early 2000s. During this time, the median value increased 103.08 percent, whereas the state average increase was 39.75 percent. However, on the end of this decade, Roger Mills County experienced stagnation; the median value increased just 1.14 percent, relative to the state's average of 12.15 percent.

At the same time, the most-populous counties such as Payne (42.41 percent), Pottawatomie (46.94 percent), Oklahoma (56.60 percent) and Canadian (57.33 percent) experienced average increases in these data. Notably, Harmon County is the only county of interest to have experienced a decrease in the median value of the housing units. Between 2005 and 2012, the average home value decreased 8.90 percent. Table 14 provides information regarding median values.

Table 14. Median Value of Owner-Occupied Housing Units: Percent Change.

County	*2000 to 2005-2009*	*2005-2009 to 2010-2014*	*2000 – 2010-2014*
Oklahoma State	39.75	16.40	62.66
Alfalfa*	60.34	37.63	120.69
Atoka	50.00	28.92	93.38
Canadian*	28.61	30.15	67.38
Coal*	74.26	22.07	112.72
Harmon	68.57	-1.69	65.71
Jefferson	45.65	19.38	73.87
Noble	26.10	22.74	54.78
Oklahoma	31.13	30.58	71.24
Payne	22.08	36.38	66.50
Pittsburg*	49.44	12.03	67.42
Pottawatomie	41.49	17.06	65.62
Roger Mills*	103.08	9.22	121.79
Woods*	63.28	16.40	90.06
Woodward*	47.46	20.64	77.91

*Indicates a high gas production county, that is, above the 2012 state average
5-year estimates data

Housing Affordability

The annual median wage for workers in the natural gas construction and extraction industries is $58,930 (U.S. Bureau of Labor Statistics, 2014). Higher-wage workers entering depressed housing markets are beneficial because they occupy housing that may have been vacant or otherwise marginalized. These new residents (temporary or permanent) are able to pay more for housing, potentially forcing lower resource consumers out of the market. Housing affordability is defined as 30 percent or less of income spent on housing costs, including rent or mortgage and utilities (U.S. Department of Housing and Urban Development, n.d.). “Workforce housing” is defined as shelter for those with incomes between 60 and 120 percent of area median income (Terwilliger, 2011). A change in income affects housing costs.

Gross Rent

Gross rent is “The amount of the contract rent plus the estimated average monthly cost of utilities (electricity, gas, water and sewer) and fuels (oil, coal, kerosene, wood, etc.), if these are paid for by the renter (or paid for the renter by someone else). Gross rent is intended to eliminate differentials, which result from varying practices with respect to the inclusion of utilities and fuels as part of the rental payment” (U.S. Census Bureau).

In 2000, Canadian, Oklahoma and Payne counties all featured gross rents larger than the state average. From 2005 to 2012, only Canadian and Oklahoma counties featured gross rents greater than the state average. These counties, along with five other counties (Cleveland, Grady, Lincoln, Logan, and McClain), are part of the Oklahoma City Metropolitan Area, where a bulk of the state’s population resides. This metropolitan area diverts the state average. For example, the gross rent average from 2005-2012 was $558 from the least populous counties and $777 from the Metropolitan counties (Oklahoma and Canadian). Census data were used to construct rent data from the year 2000 (U.S. Census Bureau, 2003, p. 365). Five-year estimates data (2005-2009 and 2008-2012) were compiled from the Census American Fact Finder (U.S. Census Bureau, n.d.-a). Table 15 provides gross rent values.

As seen in Table 16, some of the least populous counties had the largest gains in median value of gross rent. Since 2000, Alfalfa, Harmon and Roger Mills counties have followed an unusual trend. Initially, these counties had an increase in median gross rent greater than the state’s average. The value of the gross rent stagnated on the end of this decade. Only three counties had an increase smaller than the state’s average since 2000: Noble, Payne and Pottawatomie.

Vacancy Rate

The state vacancy average was 11.36 percent for 2000 and 13.5 percent for 2010. Vacancy rates in the counties studied are divergent. The three most populous counties had the smallest vacancy rates. Canadian County had the smallest rate in both data (7.32 percent for 2000; 8.6 percent for 2010), followed by Oklahoma (9.55 percent for 2000; 11.6 percent for 2010), and Payne (9.02 percent for 2000; 12.10 percent for 2010). On the other hand, least populous counties such as Harmon (23.13 percent for 2000; 28.0 percent for 2010), Alfalfa (22.35 percent for 2000; 26.8 percent for 2010) and Pittsburg (20.27 percent for 2000; 20.4 percent for 2010) had the highest rates of vacancies.

When vacancy rate and gross rent are combined, gross rent increased when demand increased, and vice versa. The three counties that had the highest occupancy rate of housing units also had the most expensive gross rent. The counties with high vacancy rates also had low gross rent, when compared to the state’s average and other counties of interest. Table 17 presents vacancy rates for the counties during the period of interest.

Census data were used to construct vacancy rate data from the year 2000 (U.S. Census Bureau, n.d.-b). Five-year estimates data (2005-2009 and 2008-2012) were compiled from the Census American Fact Finder (U.S. Census Bureau, n.d.-a). Regarding the vacant housing units percentage: Census used just one decimal to round the numbers. Here, two decimals were used to round the numbers. For example, for Alfalfa County is 22.4 percent. Here, the total number of vacant houses (633) was divided by the total number of houses (2,832) to compute the table value, that is, 22.35 percent.

Units in Structure

Five-year estimates data (2005-2009 and 2008-2012) were compiled from the Census American Fact Finder (U.S. Census Bureau, n.d.-a).

The housing norm of a single-family, detached house is strong in the counties of interest. Since 2000, single family, detached constituted the majority of the Oklahoma’s housing. It’s important to mention type of single-family dwelling. For example, a significant portion of the total housing units some counties were mobile homes: Atoka (18.8 percent), Pittsburg (15.9 percent), and Roger Mills (15.4 percent). These numbers are substantially larger than the state’s average (9.5 percent).

The number of those living in ‘boat, RVs, and vans’ decreased. In 2000, the state’s average was 0.4 percent of the population living in this kind of housing, at the end of that decade, this number decreased to 0.1 percent. Only two counties experienced an increase: Payne and Woodward. In 2000, Pittsburg County had 2.8 percent of

Table 15. Gross Rent.

County	*2000*	*2005-2009*	*2010-2014*
Oklahoma State	456	614	717
Alfalfa*	282	552	621
Atoka	327	430	592
Canadian*	510	738	859
Coal*	287	422	562
Harmon	274	475	457
Jefferson	261	387	456
Noble	388	557	590
Oklahoma	483	655	768
Payne	459	583	711
Pittsburg*	386	575	661
Pottawatomie	431	567	657
Roger Mills*	314	540	496
Woods*	359	487	594
Woodward*	396	580	654

*Indicates a high gas production county, that is, above the 2012 state average.
5-Year Estimates Data

Table 16. Gross Rent: Percent Change.

County	*2000 to 2005-2009*	*2005-2009 to 2010-2014*	*2000 – 2010-2014*
Oklahoma State	34.65	16.78	57.24
Alfalfa*	95.74	12.50	120.21
Atoka	31.50	37.67	81.04
Canadian*	44.71	16.40	68.43
Coal*	47.04	33.18	95.82
Harmon	73.36	-3.79	66.79
Jefferson	48.28	17.83	74.71
Noble	43.56	5.92	52.06
Oklahoma	35.61	17.25	59.01
Payne	27.02	21.96	54.90
Pittsburg*	48.96	14.96	71.24
Pottawatomie	31.55	15.87	52.44
Roger Mills*	71.97	-8.15	57.96
Woods*	35.65	21.97	65.46
Woodward*	46.46	12.76	65.15

*Indicates a high gas production county, that is, above the 2012 state average.
5-Year Estimates Data

Table 17. Vacancy Rate.

County	*2000*	*2005-2009*	*2010-2014*
Oklahoma State	11.36%	13.50%	13.71%
Alfalfa*	22.35%	26.80%	24.84%
Atoka	12.50%	15.50%	17.84%
Canadian*	7.32%	8.50%	8.11%
Coal*	13.52%	17.20%	16.45%
Harmon	23.13%	35.20%	24.19%
Jefferson	19.48%	25.00%	27.14%
Noble	11.37%	13.10%	14.46%
Oklahoma	9.55%	11.50%	11.16%
Payne	9.02%	15.14%	12.34%
Pittsburg*	20.27%	18.80%	18.85%
Pottawatomie	10.12%	13.50%	11.57%
Roger Mills*	18.35%	24.10%	31.43%
Woods*	17.99%	19.10%	23.94%
Woodward*	14.39%	11.20%	18.28%

*Indicates a high gas production county, that is, above the 2012 state average.
5-Year Estimates Data

its population living in 'boats, RVs, and vans', but this number decreased during that decade to 0.6 percent. Even with this decrease, Pittsburgh County had the highest number at the end of that decade. Some counties did not record residents living in this type of temporary housing (Alfalfa, Atoka, Coal, Harmon, Oklahoma, Roger Mills and Woods).

SECTION SIX

Summary/Conclusions

Coincidence Versus Causation

Coincidence, but not necessarily causation, is indicated as a result of data analysis and comparison of various aspects of change when oil and gas activity take place in a county over time. Rather, than use these coincident results as excuses to restrict or object to oil and gas activity, local managers may use this information to plan and prepare for the likely changes in their communities. It seems likely that there will be increased water use, highway expenses and mining income, but it is less clear that the standard measures of economic activity support coincident economic gains. The boomtown effect has not yet been observed in Oklahoma. Recent data on the downturn in oil prices could test boom-bust cycles, but research will not be available for a year or so. The induced seismicity remains a problem. While hydraulic fracturing is not directly at fault, research does indicate the deep-injection wells for produced water causes earthquakes. The produced water disposal problem would not exist were it not for the increased hydraulic fracturing activity. The national economy has benefited from the resurgence of activity using hydraulic fracturing and horizontal drilling. Table 18 provides information about selected impact factors coincident with oil and gas peak years.

Factors That Have Been Considered But Not Included

Limitations of time and resources precluded the authors from a more comprehensive approach that would have included other relevant factors. These include environmental issues such as air quality, water quality, habitat destruction, site remediation and energy options. It also includes socio-demographic factors, such as crime, road accident rates, infrastructure challenges (utility services, public education, etc.). Such economic considerations as workforce availability and the location of income and revenue also are included. Additionally, resources were not available to study all counties in the state. Those shortcomings may be corrected in the future.

Table 18. Peak Year Impact: Factors Coincident with Oil/Gas Activity, 2000-2012 for Oil & Gas.
[Categories with years in parentheses indicate data fields 2000-2015]

County	*Peak gas production year*	*Peak oil production year*	*Peak hwy expend year*	*Peak PT water use year*	*Peak employment year*	*Peak personal inc year*	*Peak mining income year*	*Unemployment rate lowest year*
Alfalfa	2012	2011	2012 (2014)	2012	2012 (2014)	2012	2011	2010
Atoka	2009	2008	2012	2008 (2014)	2008 (2015)	2012	2012 (2015)	2008
Canadian	2010	2011	2012 (2014)	2012	2012 (2015)	2012	2012 (2015)	2008
Coal	2010	2009	2012	2008	2012 (2015)	2012	2011	2008
Harmon	n/a	2007	2003	2008 (2015)	2001	2012	2012 (2015)	2008
Jefferson	2012	2004	2011 (2014)	2010	2000	2011	2003	2008
Noble	2009	2007	2012 (2014)	2012 (2013)	2012 (2015)	2012	2012 (2015)	2008
Oklahoma	2010	2009	2009	2003	2012 (2015)	2012	2008	2008
Payne	2006	2001	2010 (2014)	2012 (2014)	2007 (2015)	2012	2008	2007
Pittsburg	2012	2006	2007	2010	2008	2012	2012 (2015)	2008
Pottawatomie	2006	2000	2011	2012	2012 (2015)	2012	2008	2008
Roger Mills	2006	2011	2009	2012	2012 (2015)	2012	2011	2008
Woods	2012	2011	2011 (2014)	2012 (2013)	2012 (2015)	2012	2011	2008
Woodward	2009	2006	2009	2008 (2014)	2008 (2015)		2008	2008
State	2014	2014	2011 (2014)	2012	2012 (2015)		2008	2008

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Appendix: County and State Summaries

Appendix
County and State Summaries
Table of Contents

List of Appendix Figures

Alfalfa County

Figure A- 1. Alfalfa County oil and gas production. 55
Figure A- 2. Alfalfa County gas production and mining income. 55
Figure A- 3. Alfalfa County provisional-temporary water and gas production. 55
Figure A- 4. Alfalfa County long-term water use (acre feet per year). 56
Figure A- 5. Alfalfa County highway revenue and expenditures, and gas production. 56
Figure A- 6. Alfalfa County total income and gas production. 56
Figure A- 7. Alfalfa County total employment and gas production. 57
Figure A- 8. Alfalfa County unemployment rate and gas production. 57

Atoka County

Figure A- 9. Atoka County oil and gas production. 58
Figure A- 10. Atoka County gas production and mining income. 58
Figure A- 11. Atoka County provisional-temporary water and gas production. 58
Figure A- 12. Atoka County long-term water use (acre feet per year). 59
Figure A- 13. Atoka County highway revenue and expenditures, and gas production. 59
Figure A- 14. Atoka County total income and gas production. 59
Figure A- 15. Atoka County total employment and gas production. 60
Figure A- 16. Atoka County unemployment rate and gas production. 60

Canadian County

Figure A- 17. Canadian County oil and gas production. 61
Figure A- 18. Canadian County gas production and mining income. 61
Figure A- 19. Canadian County provisional-temporary water and gas production. 61
Figure A- 20. Canadian County long-term water use (acre feet per year). 62
Figure A- 21. Canadian County highway revenue and expenditures and gas production. 62
Figure A- 22. Canadian County total income and gas production. 62
Figure A- 23. Canadian County total employment and gas production. 63
Figure A- 24. Canadian County unemployment rate and gas production. 63

Coal County

Figure A- 25. Coal County oil and gas production. 64
Figure A- 26. Coal County gas production and mining income. 64
Figure A- 27. Coal County provisional-temporary water and gas production. 64
Figure A- 28. Coal County long-term water use (acre feet per year). 65
Figure A- 29. Coal County highway revenue and expenditures, and gas production. 65
Figure A- 30. Coal County total income and gas production. 65
Figure A- 31. Coal County total employment and gas production. 66
Figure A- 32. Coal County unemployment rate and gas production. 66

Harmon County

Figure A- 33. Harmon County mining employment. 67
Figure A- 34. Harmon County provisional-temporary water and gas production. 67
Figure A- 35. Harmon County highway revenue and expenditures. 68
Figure A- 36. Harmon County total employment. 68
Figure A- 37. Harmon County unemployment rate....68

Jefferson County

Figure A- 38. Jefferson County oil and gas production. 69
Figure A- 39. Jefferson County gas production and mining income. 69
Figure A- 40. Jefferson County provisional-temporary water and gas production. 69
Figure A- 41. Jefferson County long-term water use (acre feet per year). 70
Figure A- 42. Jefferson County highway revenue and expenditures, and gas production. 70
Figure A- 43. Jefferson County total income and gas production. 70
Figure A- 44. Jefferson County total employment and gas production. 71
Figure A- 45. Jefferson County gas production and mining income. 71

Noble County

Figure A- 46. Noble County oil and gas production. 72
Figure A- 47. Noble County gas production and mining income. 72
Figure A- 48. Noble County provisional-temporary water and gas production. 72
Figure A- 49. Noble County long-term water use (acre feet per year). 73
Figure A- 50. Noble County highway revenue and expenditures, and gas production. 73
Figure A- 51. Noble County total income and gas production. 73
Figure A- 52. Noble County total employment and gas production. 74
Figure A- 53. Noble County unemployment rate and gas production. 74

Oklahoma County

Figure A- 54. Oklahoma County oil and gas production. 75
Figure A- 55. Oklahoma County gas production and mining income. 75
Figure A- 56. Oklahoma County provisional-temporary water and gas production. 75
Figure A- 57. Oklahoma County long-term water use (acre feet per year). 76
Figure A- 58. Oklahoma County highway revenue and expenditures, and gas production. 76
Figure A- 59. Oklahoma County total income and gas production. 76
Figure A- 60. Oklahoma County total employment and gas production. 77
Figure A- 61. Oklahoma County unemployment rate. 77

Payne County

Figure A- 62. Payne County oil and gas production. 78
Figure A- 63. Payne County gas production and mining income. 78
Figure A- 64. Payne County provisional-temporary water and gas production. 78
Figure A- 65. Payne County long-term water use (acre feet per year). 79
Figure A- 66. Payne County highway revenue and expenditures, and gas production. 79
Figure A- 67. Payne County total income and gas production. 79
Figure A- 68. Payne County total employment and gas production. 80
Figure A- 69. Payne County unemployment rate and gas production. 80

Pittsburg County

Figure A- 70. Pittsburg County oil and gas production. 81
Figure A- 71. Pittsburg County gas production and mining income. 81
Figure A- 72. Pittsburg County provisional-temporary water and gas production. 81
Figure A- 73. Pittsburg County long-term water use (acre feet per year). 82
Figure A- 74. Pittsburg County highway revenue and expenditures, and gas production. 82
Figure A- 75. Pittsburg County total income and gas production. 82
Figure A- 76. Pittsburg County total employment and gas production. 83
Figure A- 77. Pittsburg County unemployment rate and gas production. 83

Pottawatomie County
Figure A- 78. Pottawatomie County oil and gas production. 84
Figure A- 79. Pottawatomie County gas production and mining income. 84
Figure A- 80. Pottawatomie County provisional-temporary water and gas production. 84
Figure A- 81. Pottawatomie County long-term water use (acre feet per year). 85
Figure A- 82. Pottawatomie County highway revenue and expenditures, and gas production. 85
Figure A- 83. Pottawatomie County total income and gas production. 85
Figure A- 84. Pottawatomie County total employment and gas production. 86
Figure A- 85. Pottawatomie County unemployment rate and gas production. 86

Roger Mills County
Figure A- 86. Roger Mills County oil and gas production. 87
Figure A- 87. Roger Mills County gas production and mining income. 87
Figure A- 88. Roger Mills County provisional-temporary water and gas production. 87
Figure A- 89. Roger Mills County long-term water use (acre feet per year). 88
Figure A- 90. Roger Mills County highway revenue and expenditures, and gas production. 88
Figure A- 91. Roger Mills County total income and gas production. 88
Figure A- 92. Roger Mills County total employment and gas production. 89
Figure A- 93. Roger Mills County unemployment rate and gas production. 89

Woods County
Figure A- 94. Woods County oil and gas production. 90
Figure A- 95. Woods County gas production and mining income. 90
Figure A- 96. Woods County provisional-temporary water and gas production. 90
Figure A- 97. Woods County long-term water use (acre feet per year). 91
Figure A- 98. Woods County highway revenue and expenditures, and gas production. 91
Figure A- 99. Woods County total income and gas production. 91
Figure A- 100. Woods County total employment and gas production. 92
Figure A- 101. Woods County unemployment rate and gas production. 92

Woodward County
Figure A- 102. Woodward County oil and gas production. 93
Figure A- 103. Woodward County gas production and mining income. 93
Figure A- 104. Woodward County provisional-temporary water and gas production. 93
Figure A- 105. Woodward County long-term water use (acre feet per year). 94
Figure A- 106. Woodward County highway revenue and expenditures, and gas production. 94
Figure A- 107. Woodward County total income and gas production. 94
Figure A- 108. Woodward County total employment and gas production. 95
Figure A- 109. Woodward County unemployment rate and gas production. 95

State of Oklahoma
Figure A- 110. Oklahoma state oil and gas production. 96
Figure A- 111. Oklahoma state gas production and mining income. 96
Figure A- 112. Oklahoma state provisional-temporary water and gas production. 96
Figure A- 113. Oklahoma state highway revenue and expenditures. 97
Figure A- 114. Oklahoma state total income and gas production. 97
Figure A- 115. Oklahoma state total employment and gas production. 97
Figure A- 116. Oklahoma state unemployment rate. 98

County and State Summaries

As noted, 14 counties in Oklahoma were selected for focused analysis of factors during the past several years:

- Oil and gas activity,
- Sector and total income,
- Temporary and long term water use,
- Highway revenue and expenditures,
- Total employment and the unemployment rate and
- General review of earthquake and drilling mud application activity in some counties

Seven counties (Alfalfa, Atoka, Coal, Payne, Pittsburg, Pottawatomie and Woods) had a percentage change in gas production above the state average, while seven counties (Canadian, Harmon, Jefferson, Noble, Oklahoma, Roger Mills and Woodward) had a percentage change in gas production below the state average. It is hypothesized that above average counties showed a higher impact on the key factors than did the below average counties.

For most of the above average counties, natural gas production helped propel county employment or income 10 to 30 percent higher after peak gas production in the county. Water use that increased in each county with increased gas production tends to decline after gas production declines. County highway revenue and expenditures remain higher even with the subsequent decline in natural gas production in the county.

Activities in the counties of interest follows.

Alfalfa County

Mining income peaked a year before gas production peaked and remained relatively high in subsequent years, indicating a strong impact from oil and gas activity. Provisional temporary water use preceded gas production by a year, but followed a similar pattern of increased activity. Long-term water began to increase at a slower rate, but continued an upward trend, suggesting a marginal substitution of long term water for temporary water use. Highway revenue and expenditures lagged gas production by one to two years, but grew sharply, suggesting that the county was getting more revenue from the oil and gas tax, and spending all or most of the revenue. County total income increased with increased gas production, then declined, but stabilized at a rate higher than the pre-gas boom period. County total employment increased with the increased gas production, but stayed on a trend that preceded the boom. The county unemployment rate declined as the gas production increased, suggesting a beneficial employment impact.

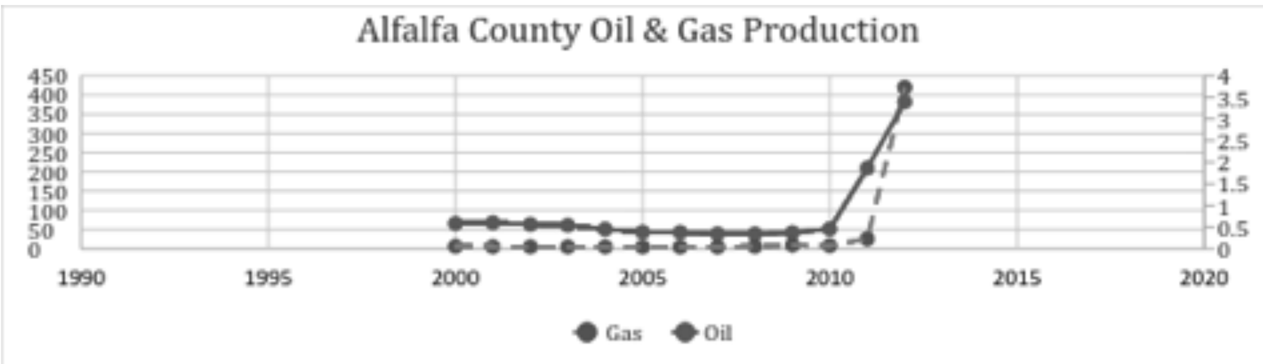


Figure A- 1. Alfalfa County oil and gas production.

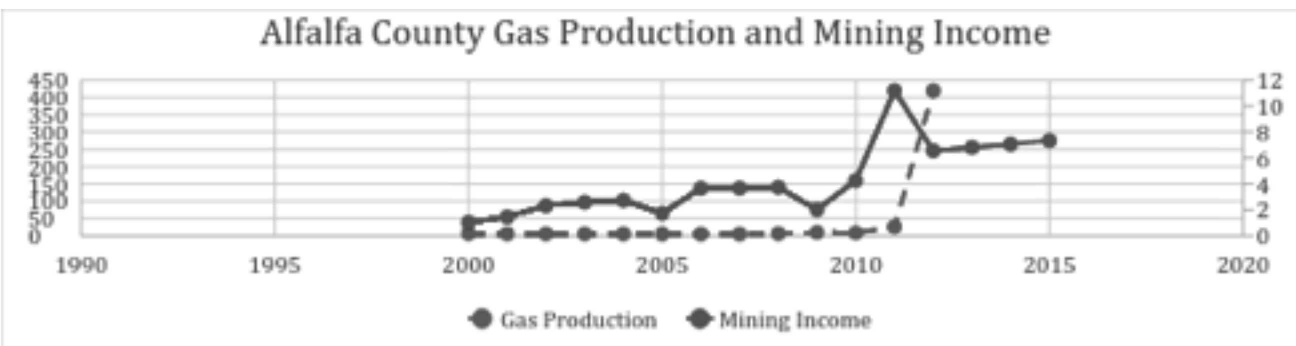


Figure A- 2. Alfalfa County gas production and mining income.

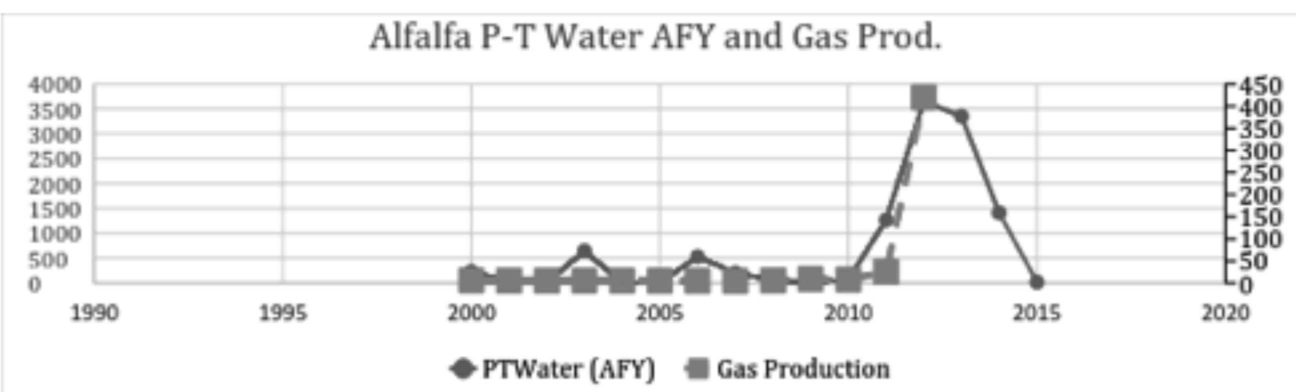


Figure A- 3. Alfalfa County provisional-temporary water and gas production.

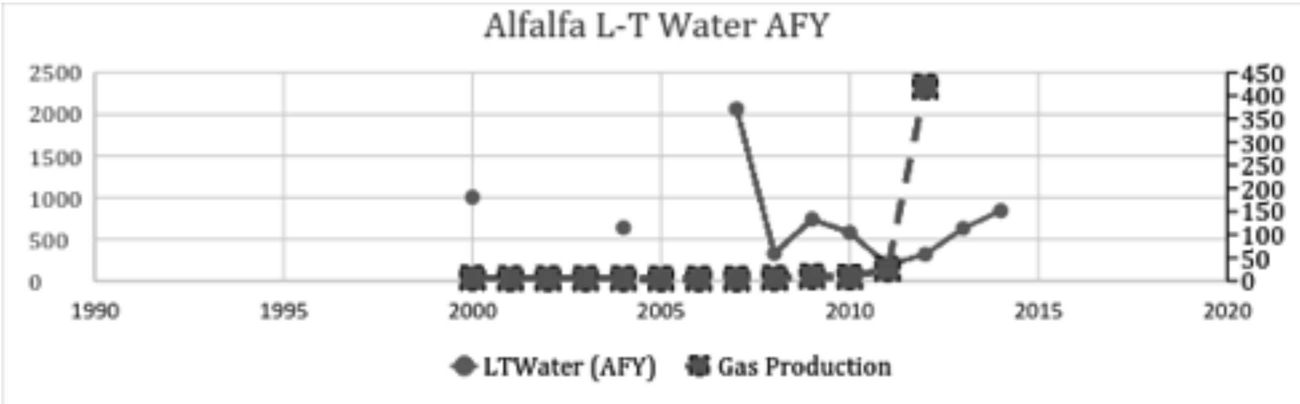


Figure A- 4. Alfalfa County long-term water use (acre feet per year).

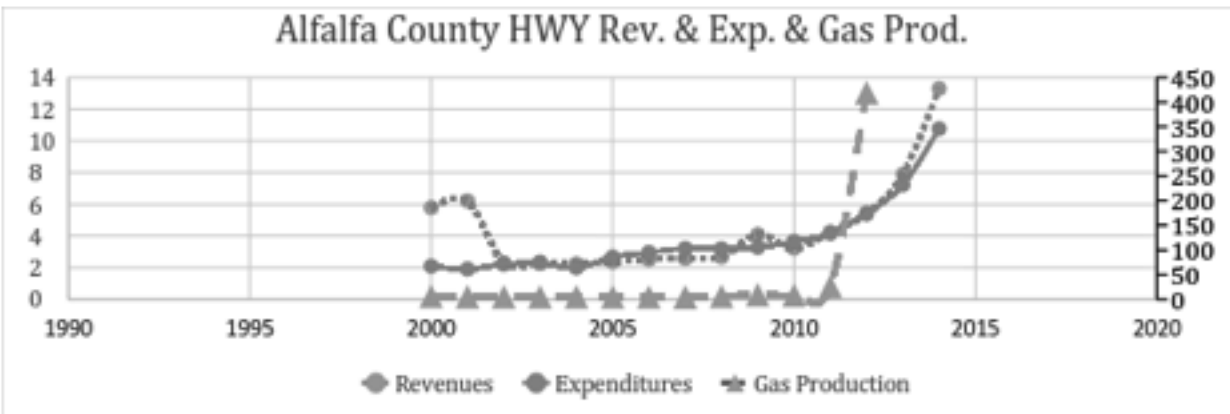


Figure A- 5. Alfalfa County highway revenue and expenditures, and gas production.

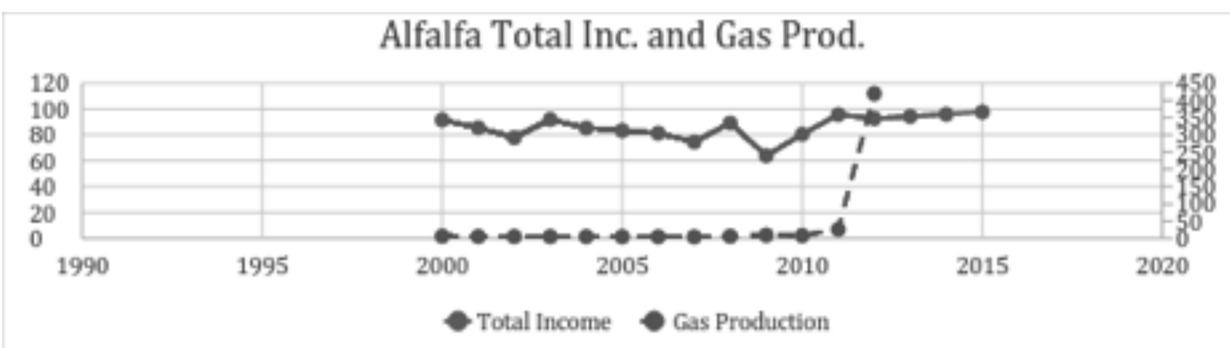


Figure A- 6. Alfalfa County total income and gas production.

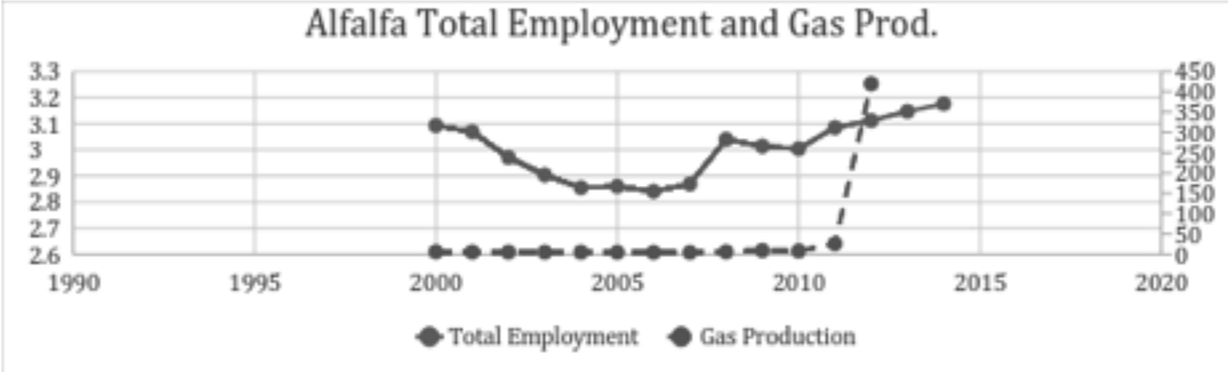


Figure A- 7. Alfalfa County total employment and gas production.

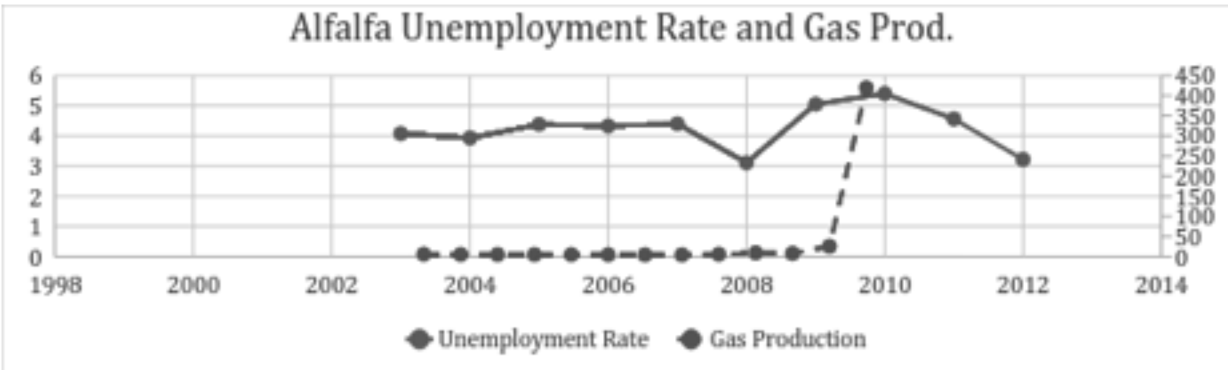


Figure A- 8. Alfalfa County unemployment rate and gas production.

Atoka County

Mining income is somewhat countercyclical to gas production levels, possibly suggesting production lags mining expenses. However, the trend for both mining income and gas production is positive. Temporary water use is somewhat related to gas production, while intermittent long term water use seems to be related. The natural gas peak in production seemed to shift highway revenue and expenditures to a higher trend line. It is not clear that total income for Atoka County is strongly related to gas production, but there is a correlation between total employment and gas production. Atoka unemployment rate is related to gas production, but not strongly.

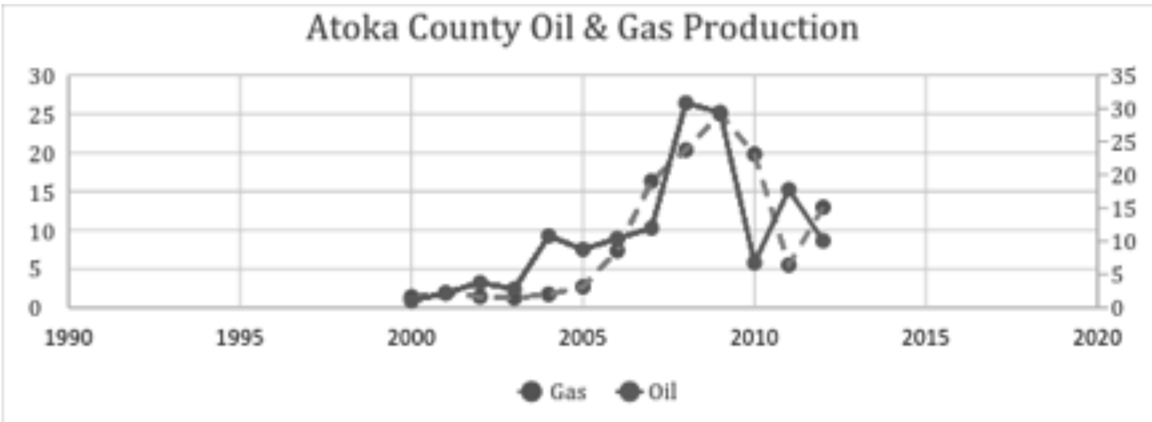


Figure A- 9. Atoka County oil and gas production.

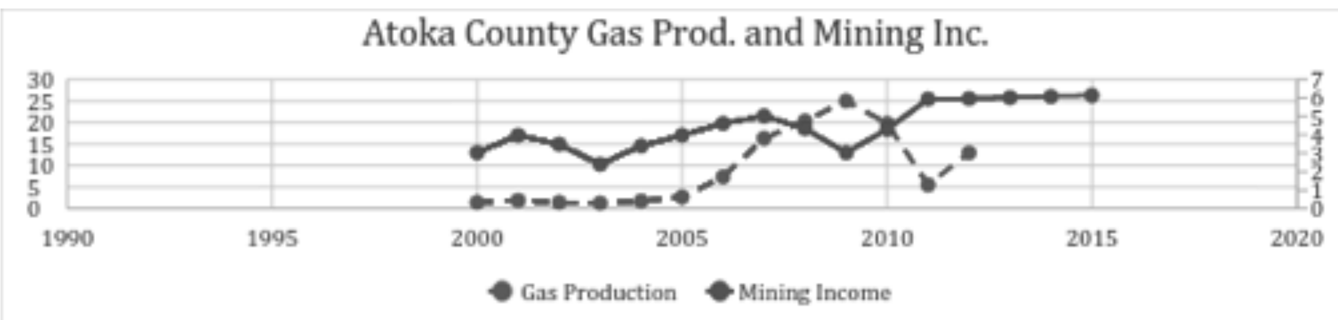


Figure A- 10. Atoka County gas production and mining income.

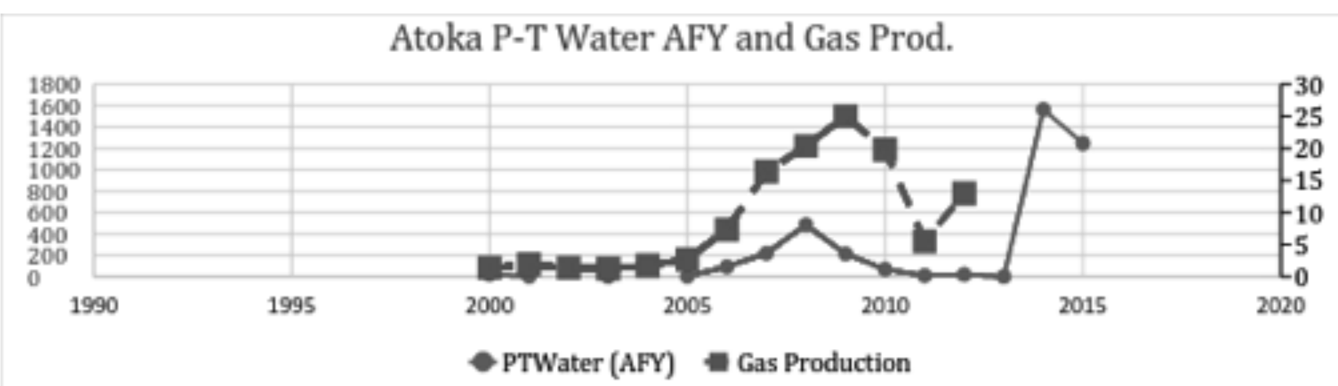


Figure A- 11. Atoka County provisional-temporary water and gas production.

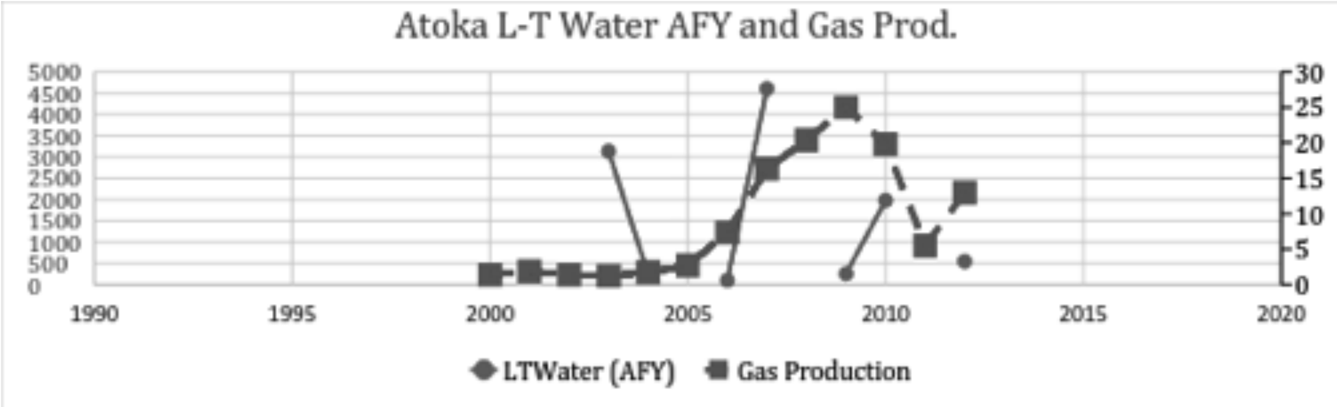


Figure A- 12. Atoka County long-term water use (acre feet per year).

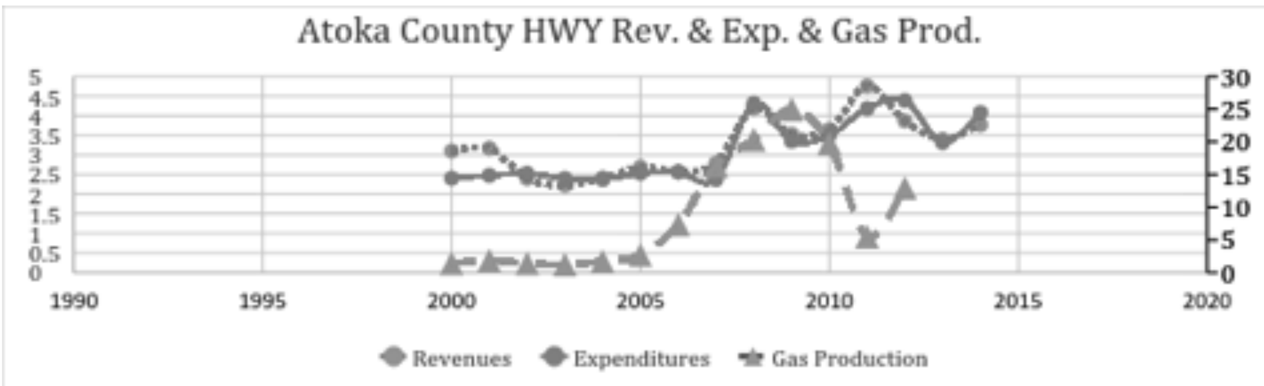


Figure A- 13. Atoka County highway revenue and expenditures, and gas production.

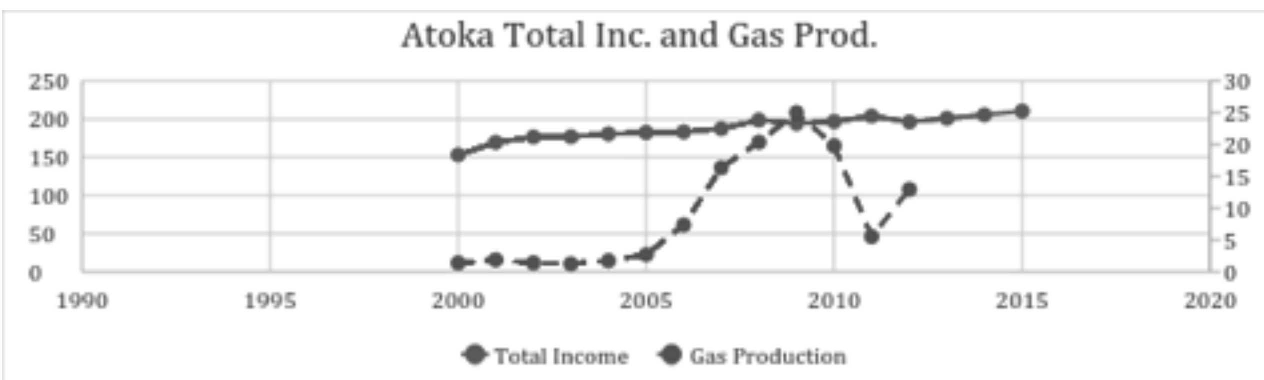


Figure A- 14. Atoka County total income and gas production.

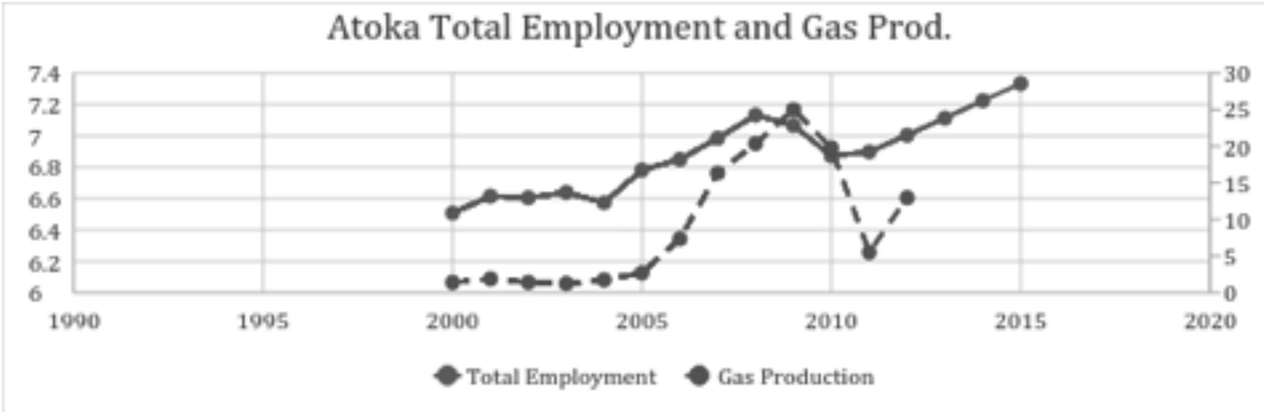


Figure A- 15. Atoka County total employment and gas production.

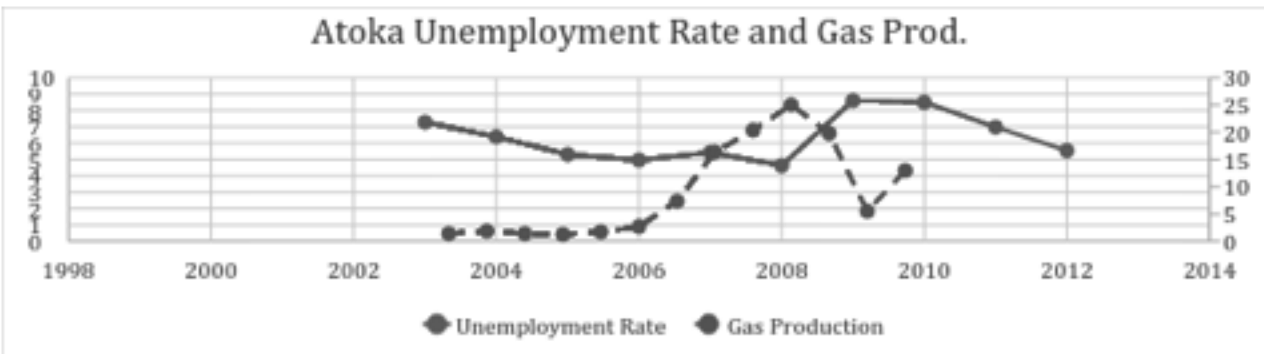


Figure A- 16. Atoka County unemployment rate and gas production.

Canadian County

Canadian County was a modest producer of oil and natural gas during the 2000-2012 period. Mining income has been on a relatively steady trend upward during that time. Temporary and long term water use rose and fell with increases and declines in natural gas production. Highway revenues and expenditures have continued to climb even after natural gas production declined. While gas production contributed to increased county total income and employment, those factors have continued to climb after gas production decreased. Oddly, the unemployment rate seems to increase with higher production and decrease with lower production.

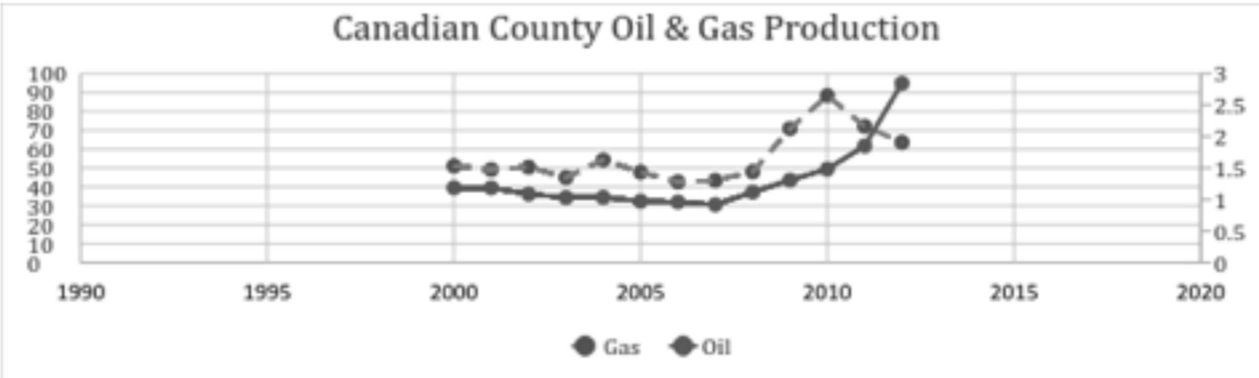


Figure A- 17. Canadian County oil and gas production.

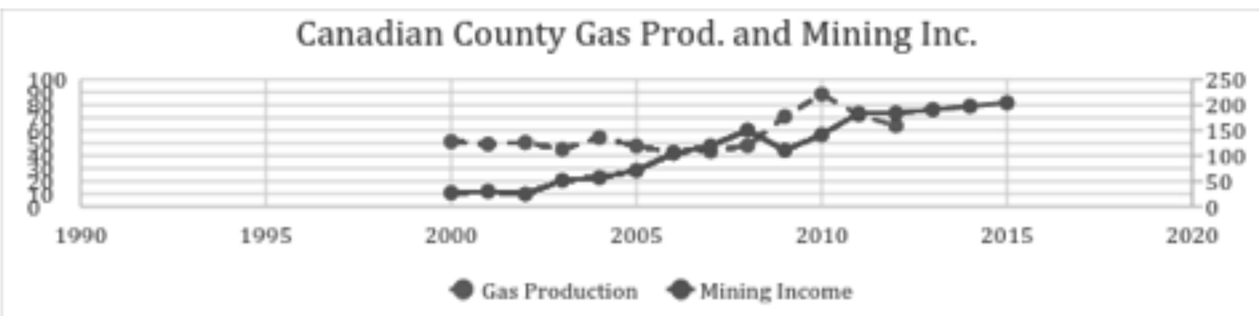


Figure A- 18. Canadian County gas production and mining income.

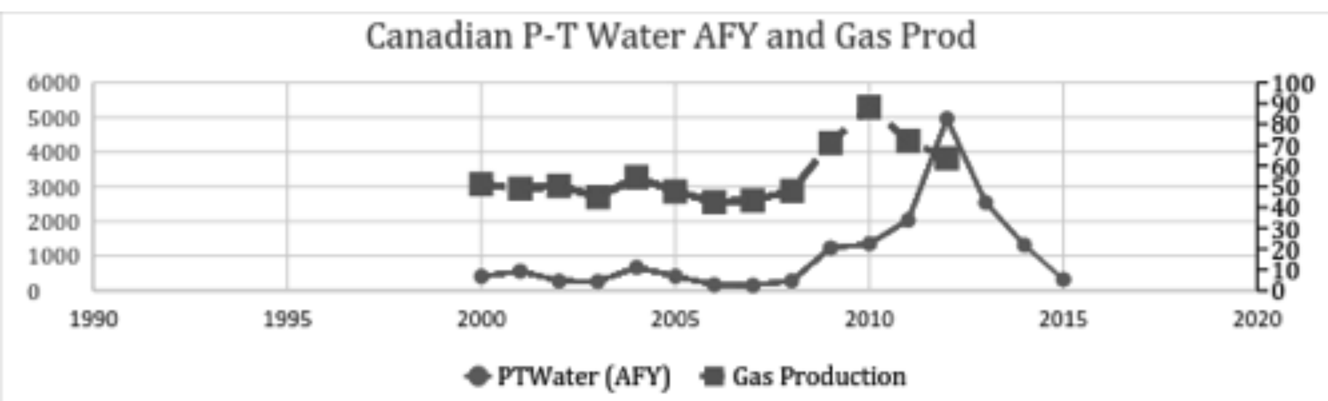


Figure A- 19. Canadian County provisional-temporary water and gas production.

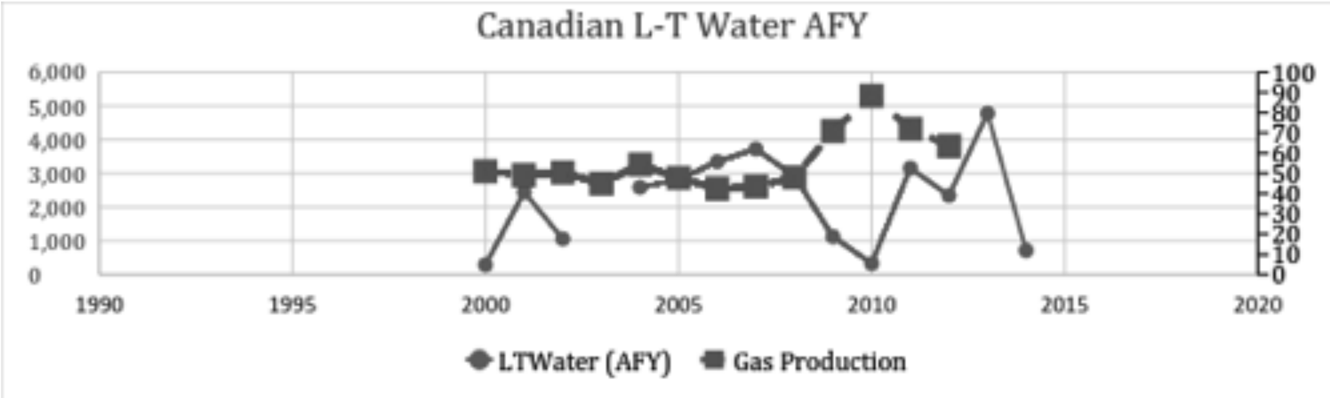


Figure A- 20. Canadian County long-term water use (acre feet per year).

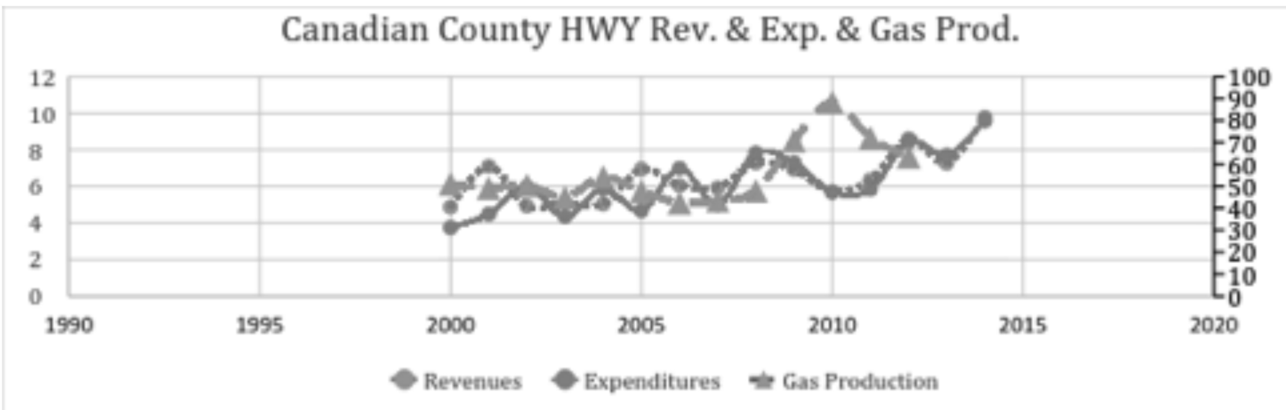


Figure A- 21. Canadian County highway revenue and expenditures and gas production.

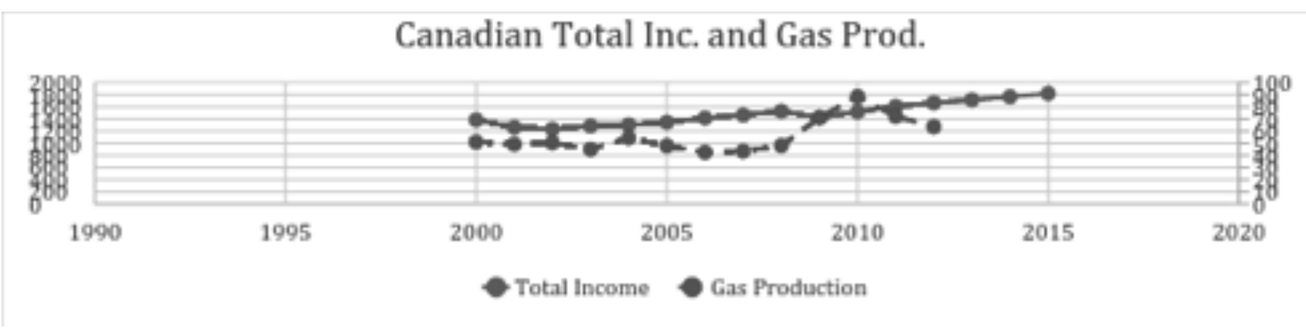


Figure A- 22. Canadian County total income and gas production.

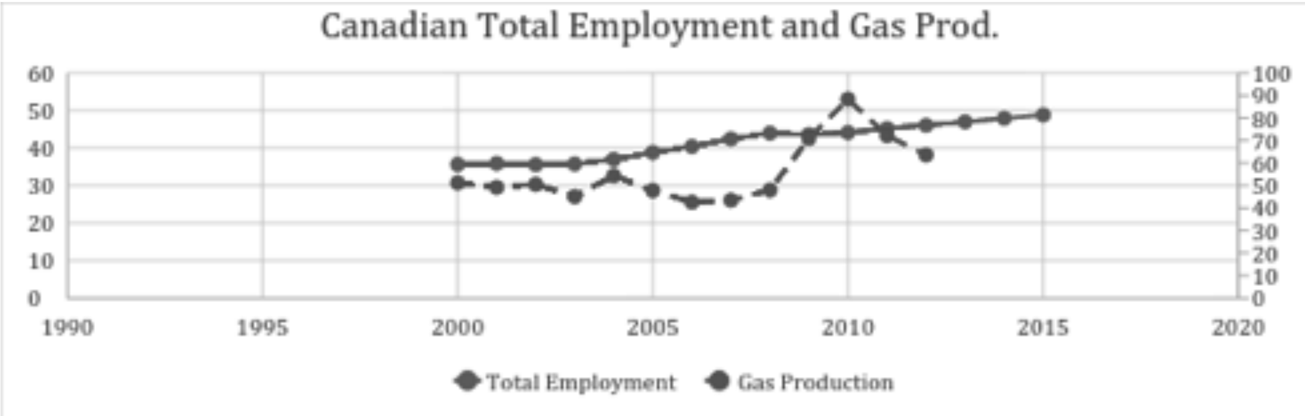


Figure A- 23. Canadian County total employment and gas production.

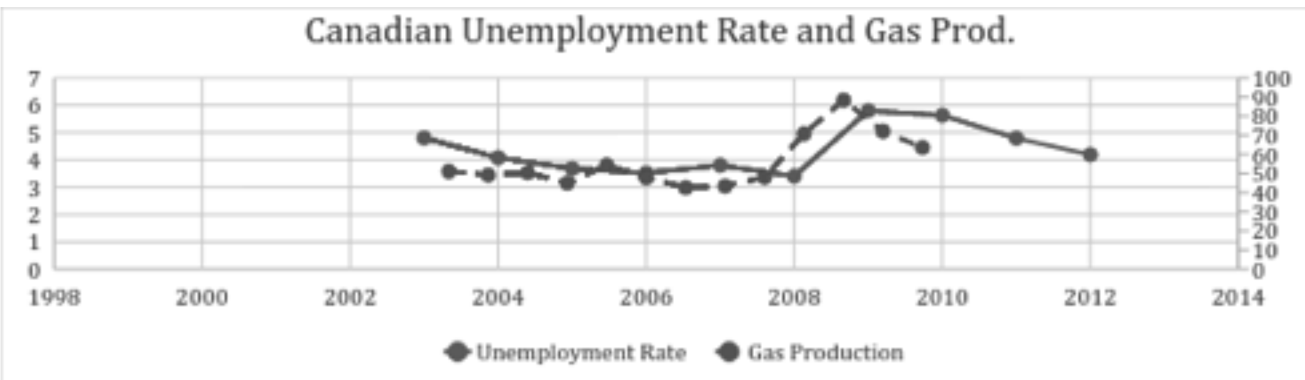


Figure A- 24. Canadian County unemployment rate and gas production.

Coal County

Coal County peak gas production was lagged a year by mining income. Peak temporary water preceded peak gas production by a year, and then dropped off as production declined. Highway revenue and expenditures increased with increased gas production and leveled off as gas production declined. County total employment trended up as gas production increased, and did not decline when production declined. In a counterintuitive trend, the county unemployment rate increased as gas production increased and declined as production declined.

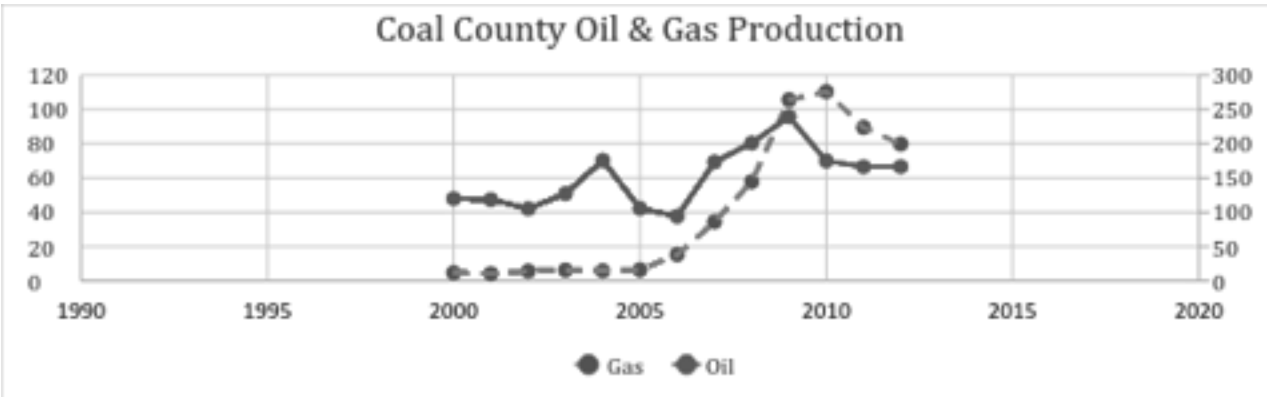


Figure A- 25. Coal County oil and gas production.

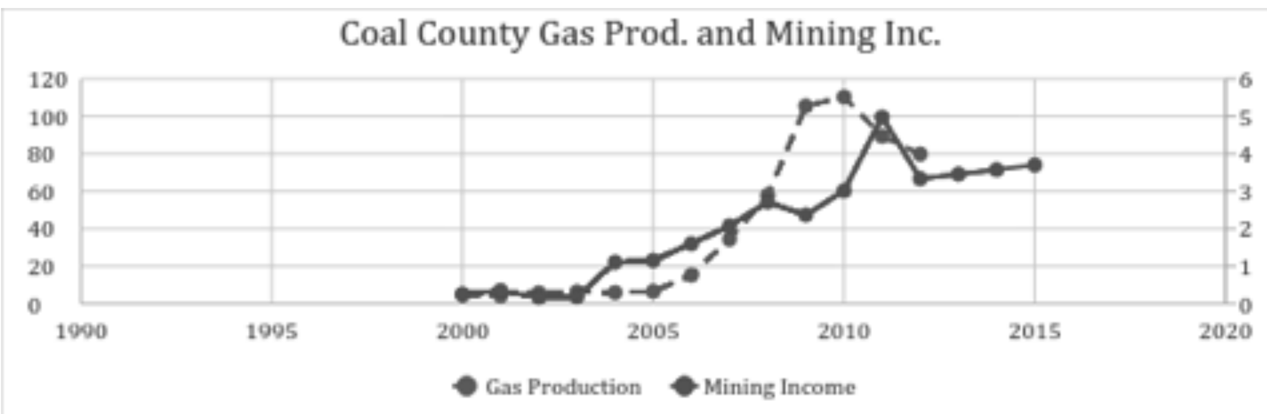


Figure A- 26. Coal County gas production and mining income.

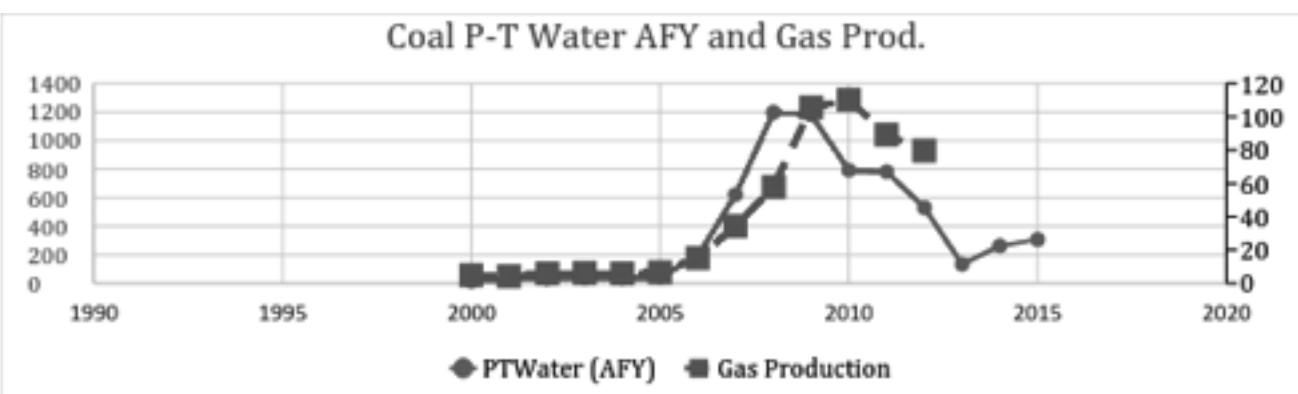


Figure A- 27. Coal County provisional-temporary water and gas production.

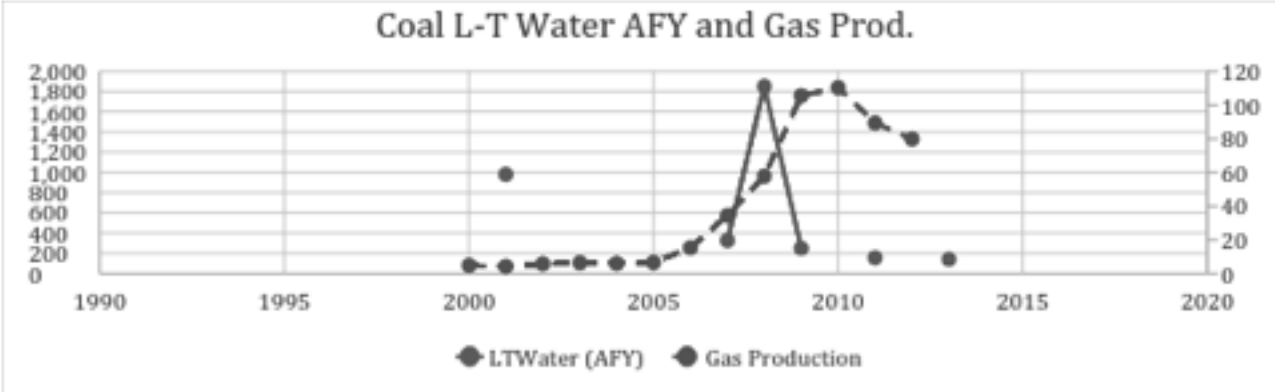


Figure A- 28. Coal County long-term water use (acre feet per year).

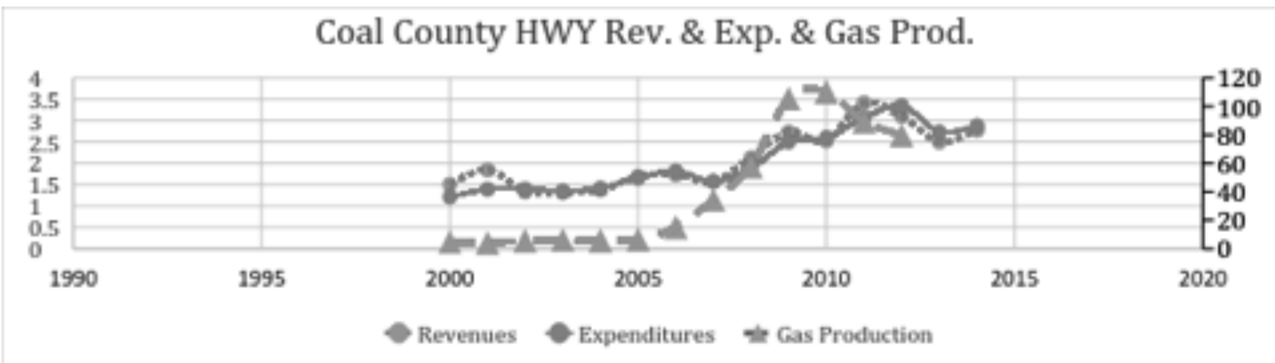


Figure A- 29. Coal County highway revenue and expenditures, and gas production.

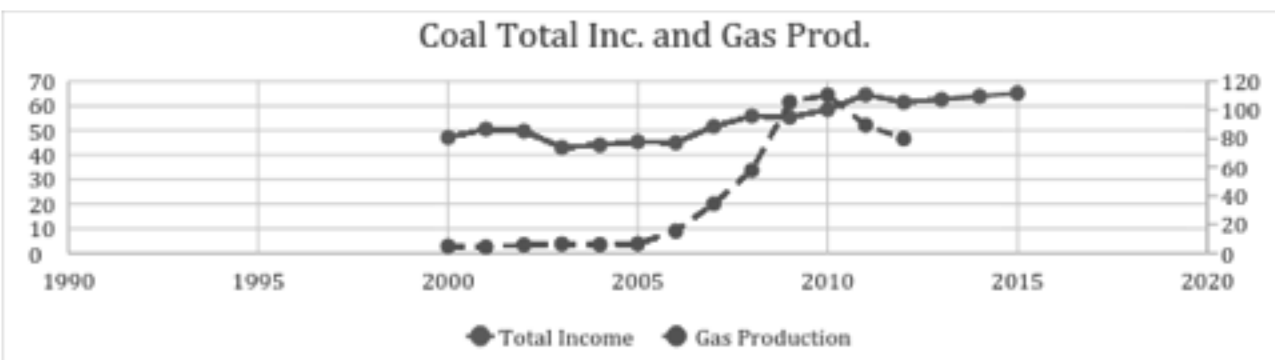


Figure A- 30. Coal County total income and gas production.

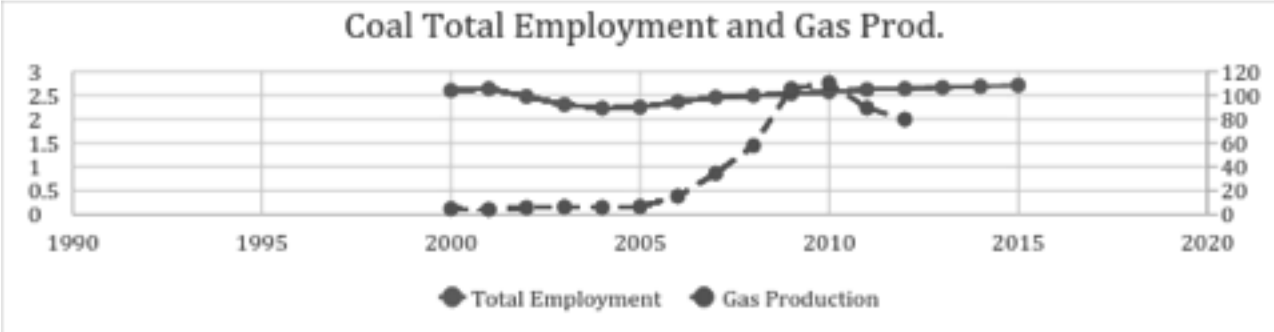


Figure A- 31. Coal County total employment and gas production.

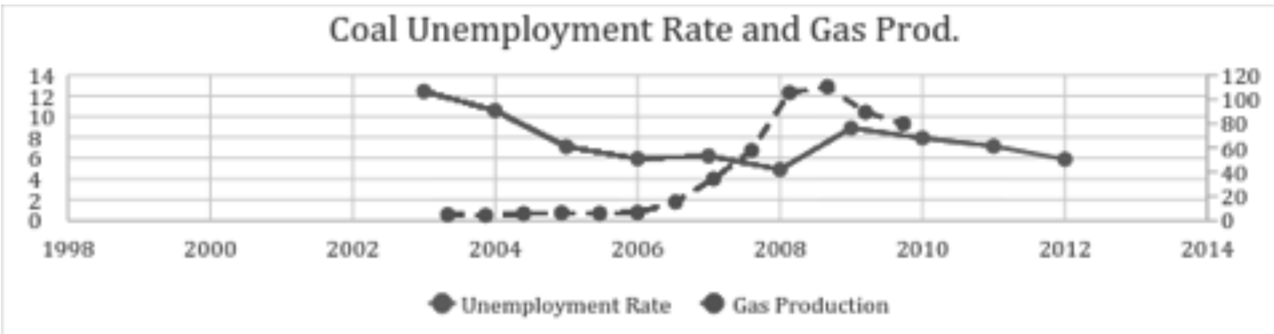


Figure A- 32. Coal County unemployment rate and gas production.

Harmon County

Harmon County had no gas production and very limited oil production. While mining employment increased, it is related to the gravel and gypsum activity in the county. Highway revenues and expenditures have not increased like gas-producing counties have. Total income and employment have risen for non-petroleum activity reasons.

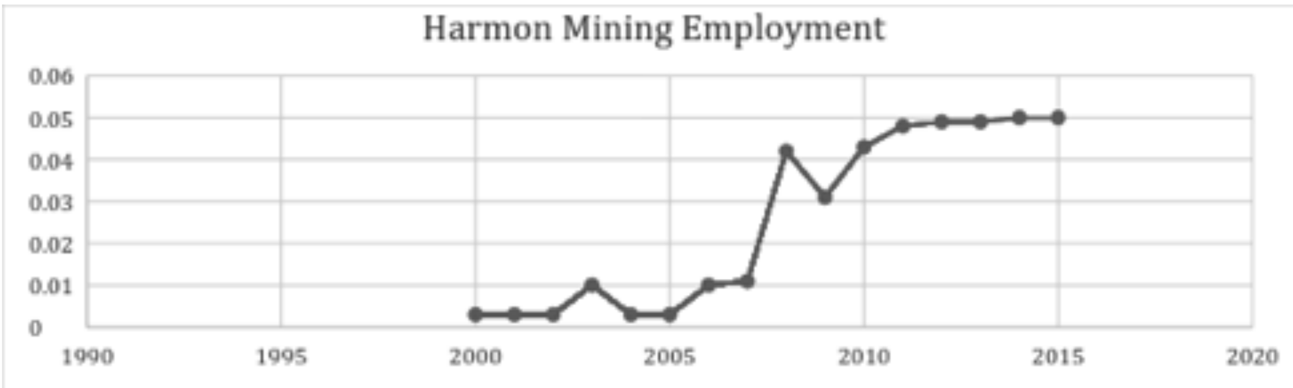


Figure A- 33. Harmon County mining employment.

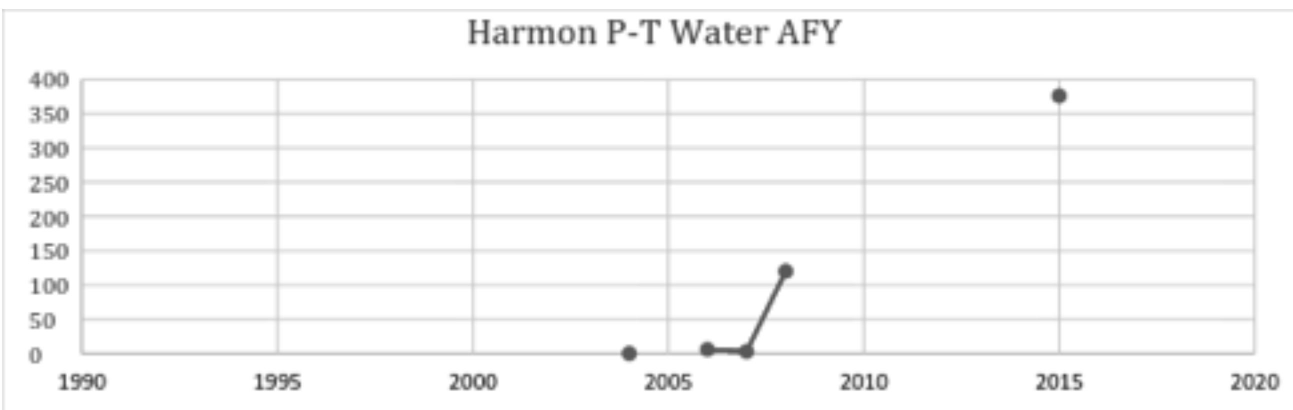


Figure A- 34. Harmon County provisional-temporary water and gas production.

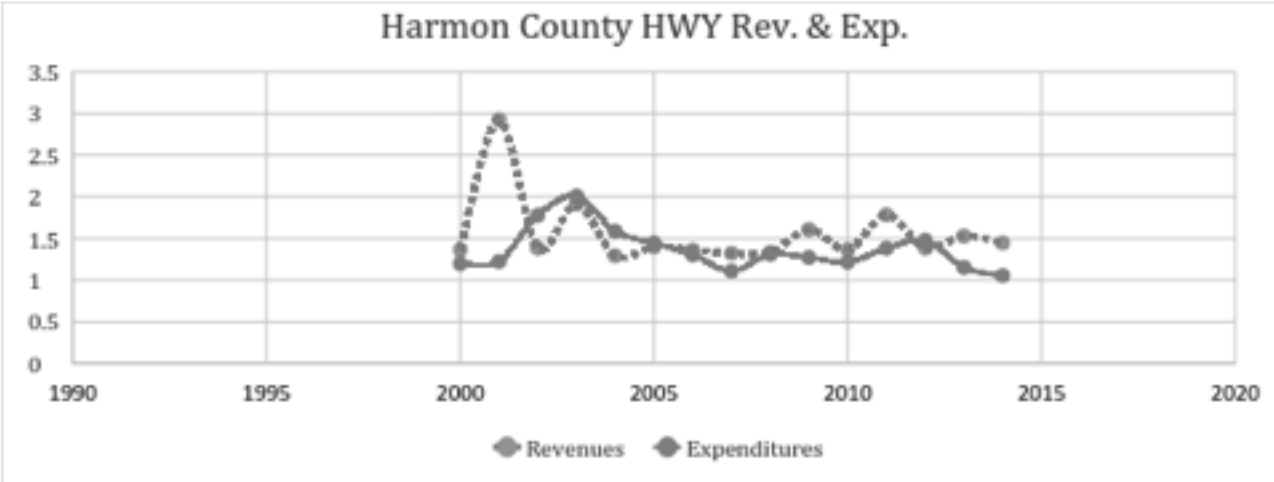


Figure A- 35. Harmon County highway revenue and expenditures.

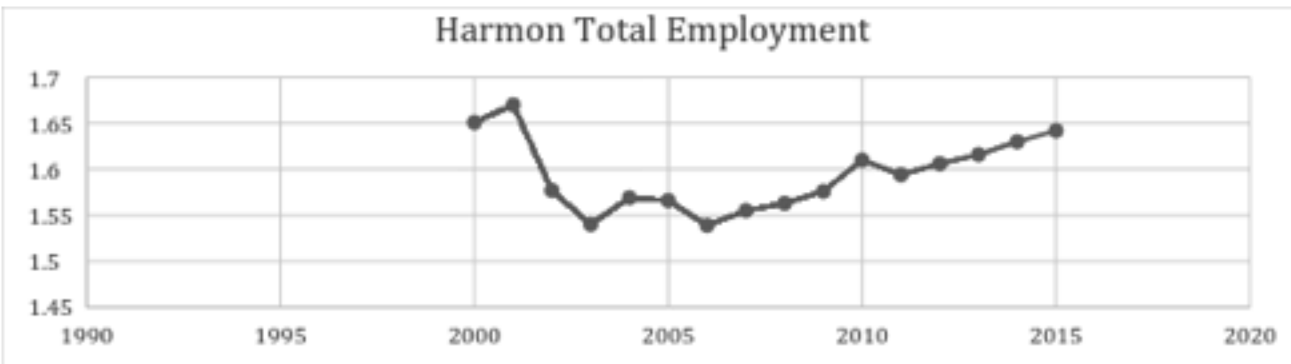


Figure A- 36. Harmon County total employment.

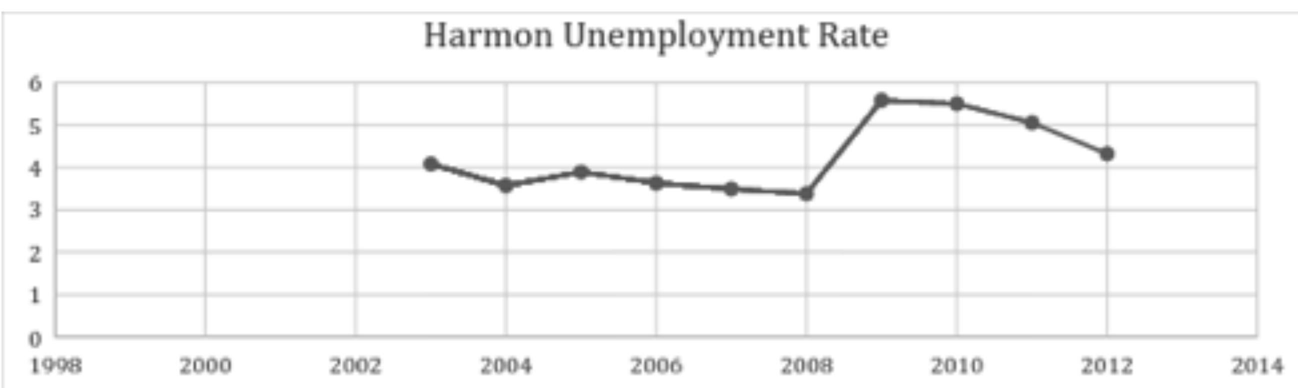


Figure A- 37. Harmon County unemployment rate.

Jefferson County

Natural gas production increased somewhat, spurring an increase in mining income. Temporary water use increased and long term water use was very sporadic. Highway revenue and expenditures have shown a three-fold increase, and that appears related to natural gas activity in the county. Total income and employment have been relatively steady during this time. Gas production seems to be inversely related to the county unemployment rate.

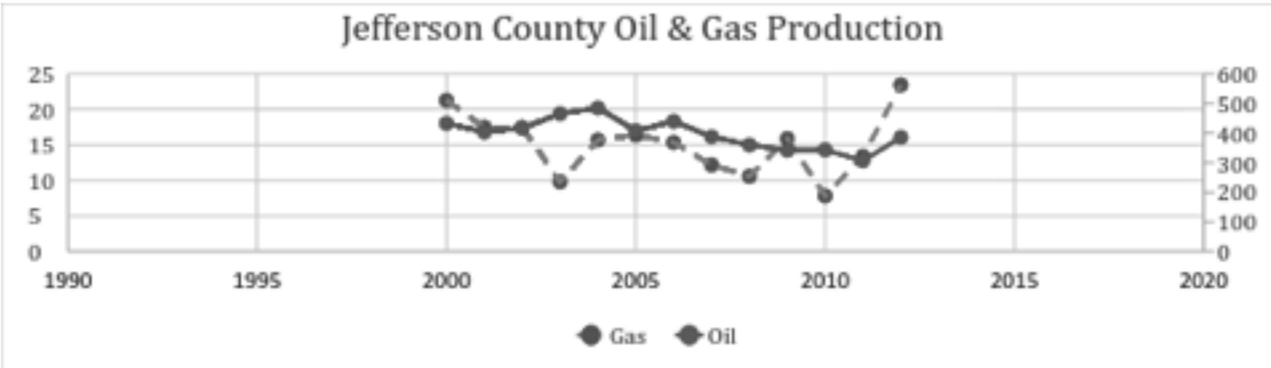


Figure A- 38. Jefferson County oil and gas production.

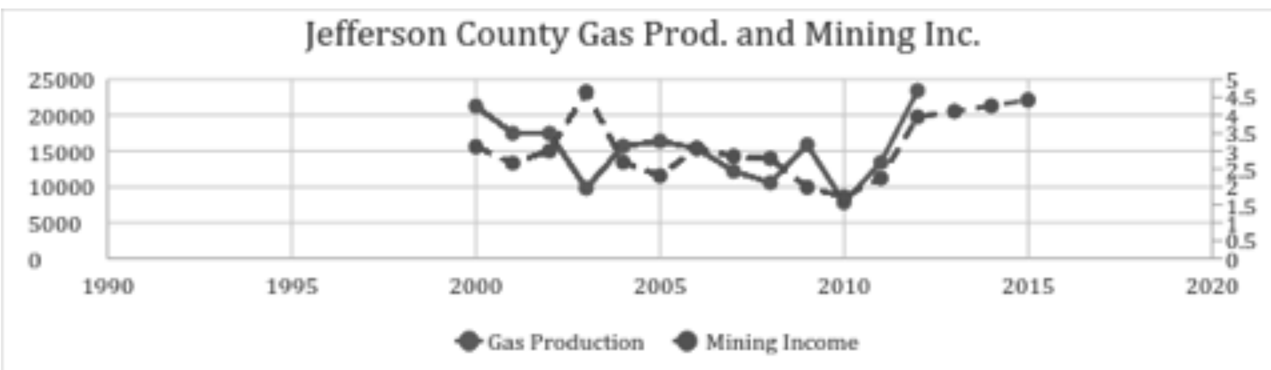


Figure A- 39. Jefferson County gas production and mining income.

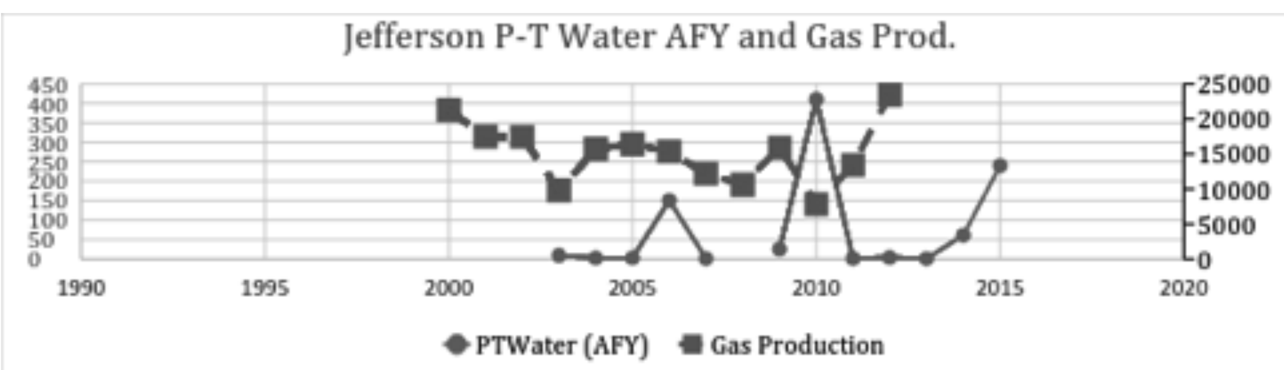


Figure A- 40. Jefferson County provisional-temporary water and gas production.

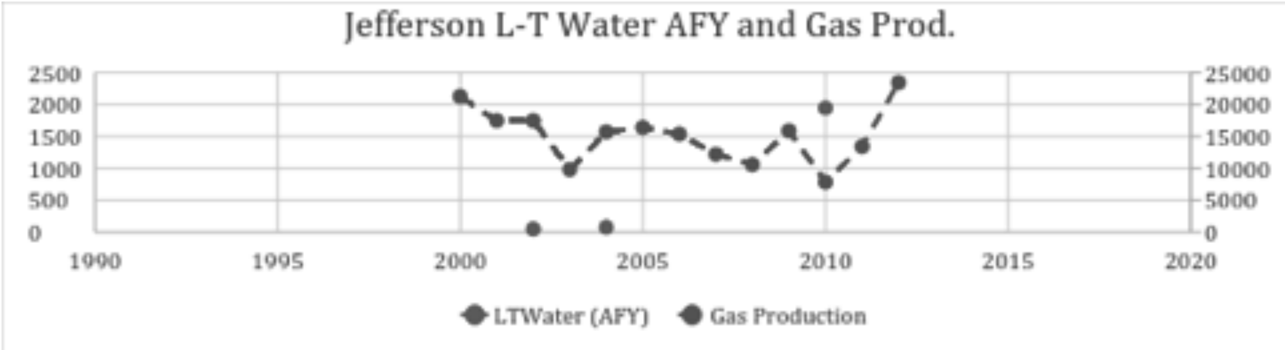


Figure A- 41. Jefferson County long-term water use (acre feet per year).

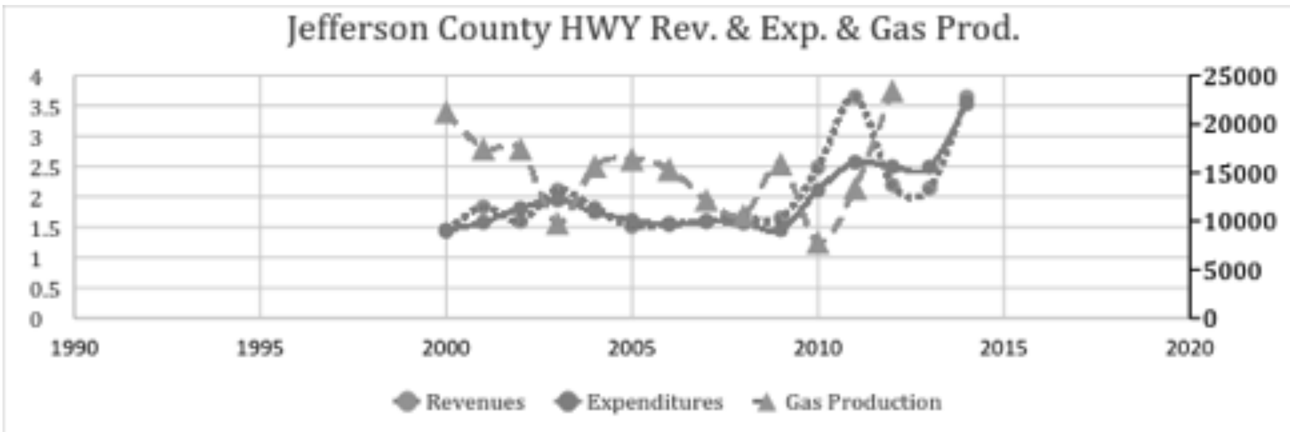


Figure A- 42. Jefferson County highway revenue and expenditures, and gas production.

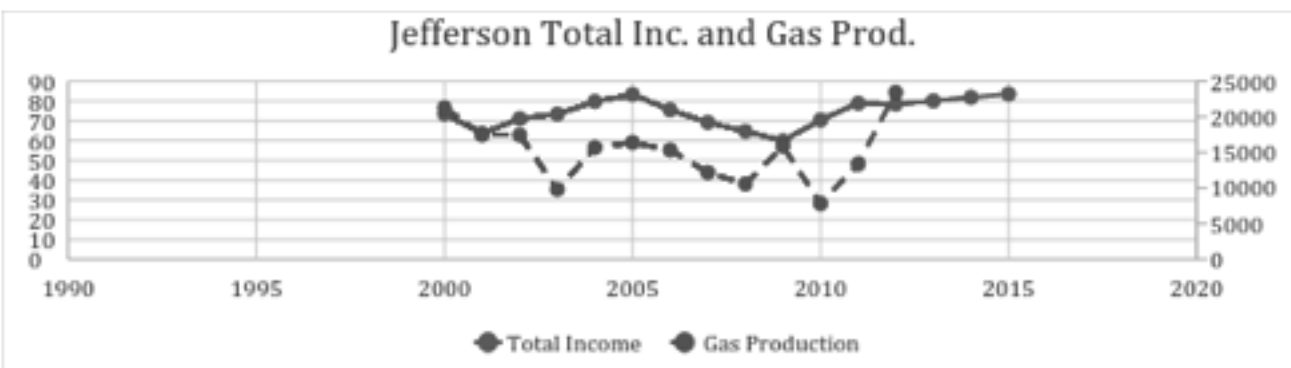


Figure A- 43. Jefferson County total income and gas production.

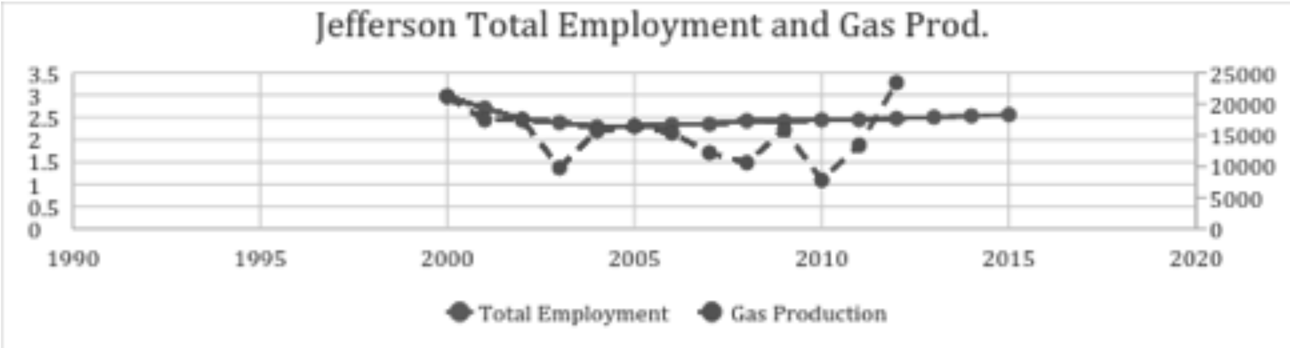


Figure A- 44. Jefferson County total employment and gas production.

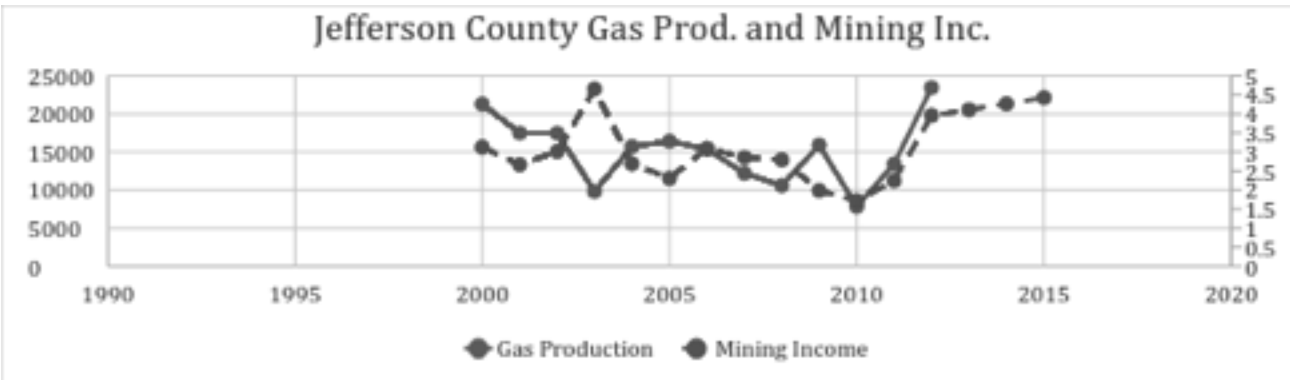


Figure A- 45. Jefferson County gas production and mining income.

Noble County

Noble County had a brief natural gas surge, quickly declined, then began to come back. Mining income has followed that pattern. Temporary water use did not really increase until the latest increase in gas production. Long-term water use has been very sporadic. Highway revenue and expenditures slightly increased with the early gas production in the 2007-2009 period, and has increased more markedly with the latest increase in gas production. It is not clear that gas production has been a key factor in total income and employment increases, suggesting the county is more economically diversified. That said, gas production does seem to be inversely related to the county unemployment rate.

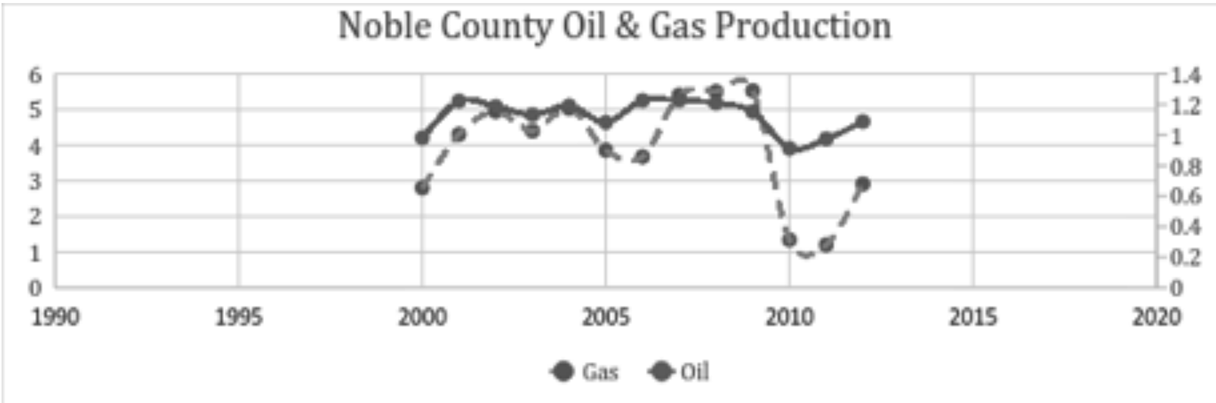


Figure A- 46. Noble County oil and gas production.

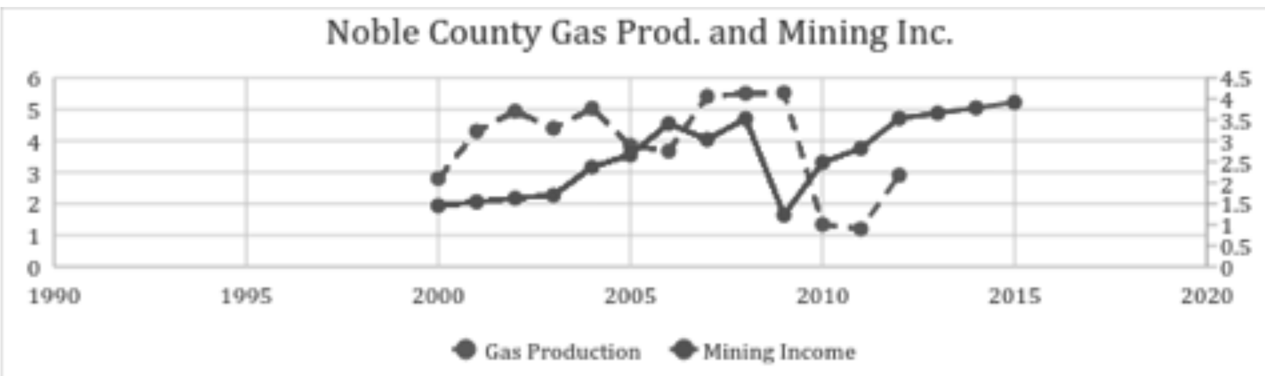


Figure A- 47. Noble County gas production and mining income.

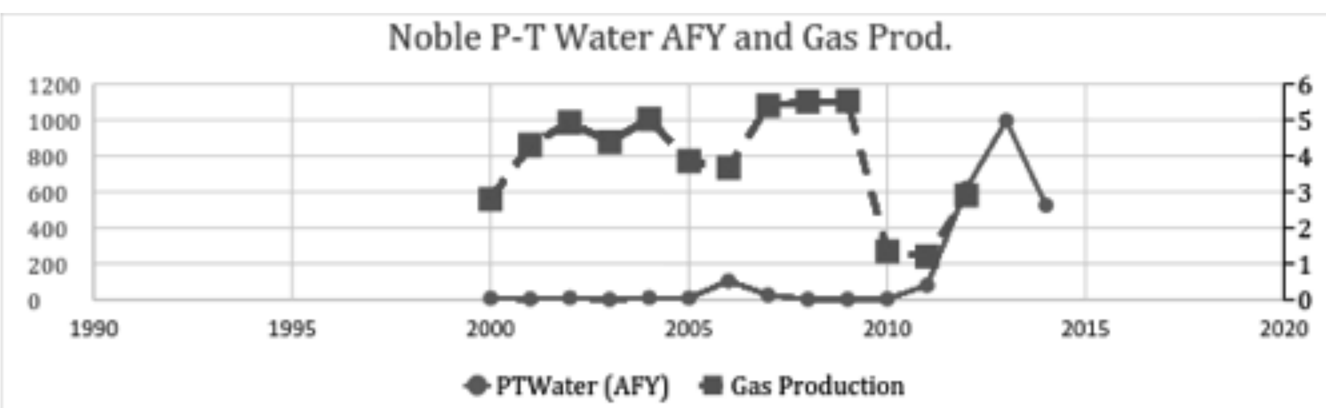


Figure A- 48. Noble County provisional-temporary water and gas production.

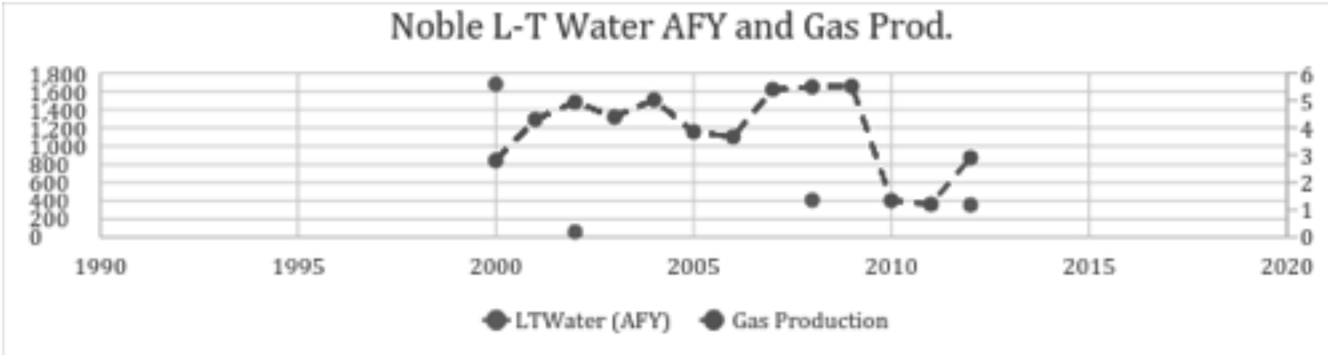


Figure A- 49. Noble County long-term water use (acre feet per year).

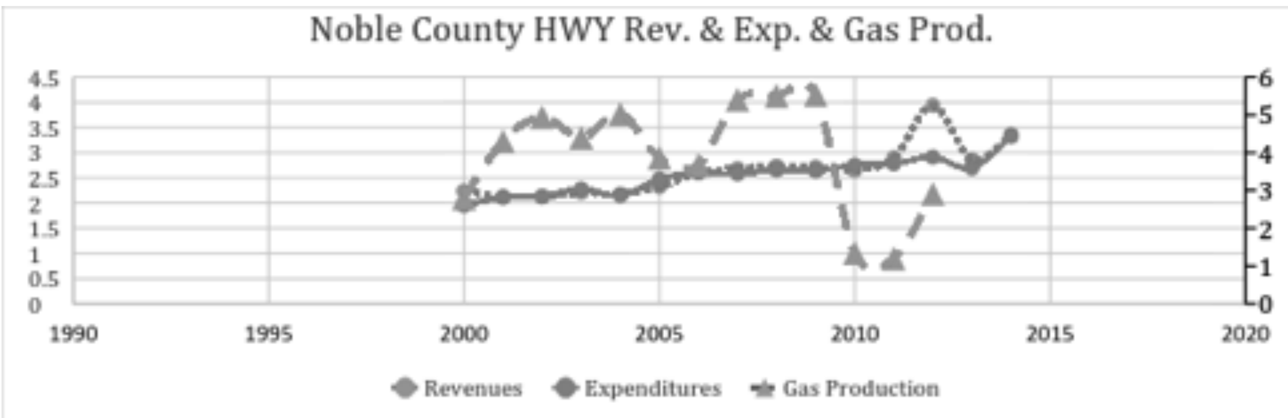


Figure A- 50. Noble County highway revenue and expenditures, and gas production.

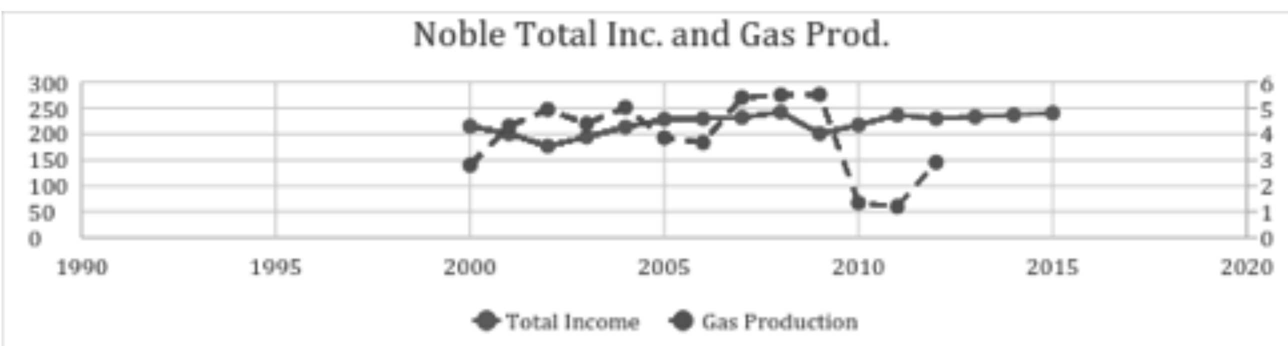


Figure A- 51. Noble County total income and gas production.

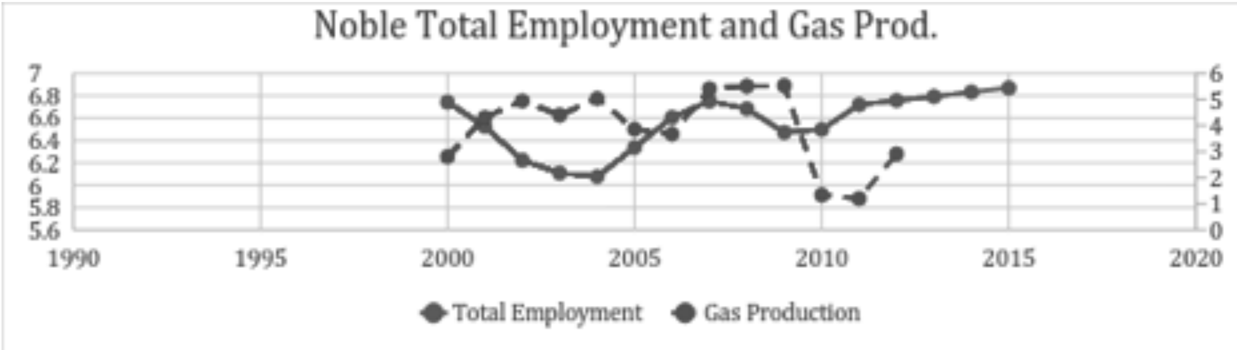


Figure A- 52. Noble County total employment and gas production.

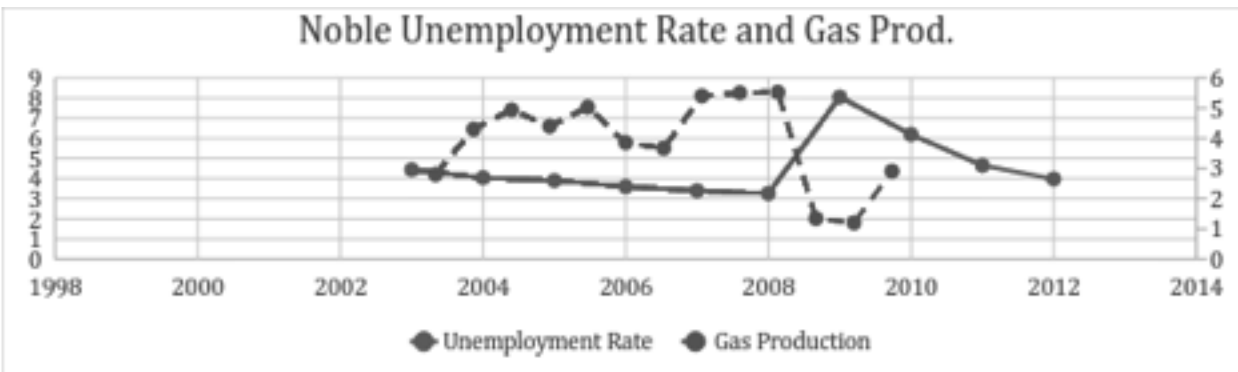


Figure A- 53. Noble County unemployment rate and gas production.

Oklahoma County

Oklahoma County has seen a marginal increase in natural gas production. Mining income has trended up. Temporary water use has mostly been insignificant, while long term water use showed little activity until 2014, but that was very dramatic with a five times increase. Total income and employment have trended up with the natural gas production activity. Gas activity is occasionally inversely related to the unemployment rate.

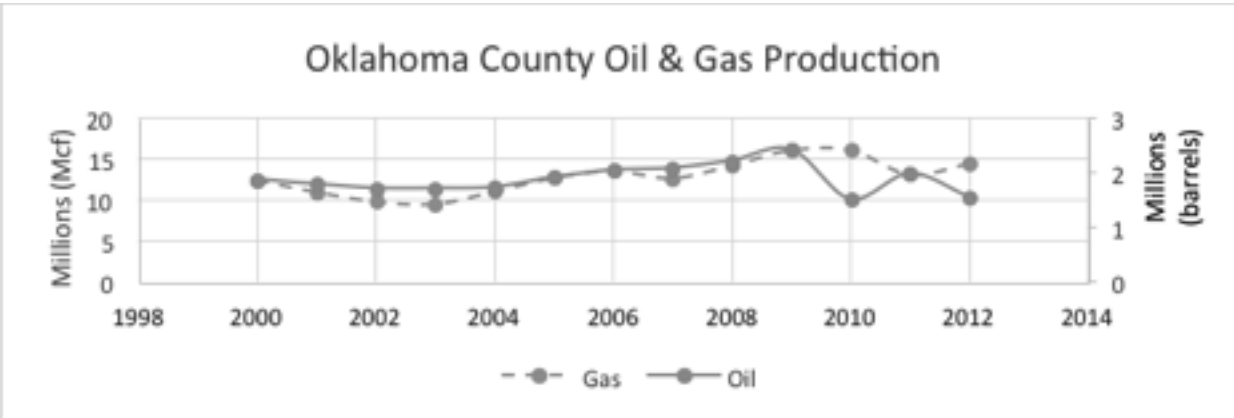


Figure A- 54. Oklahoma County oil and gas production.

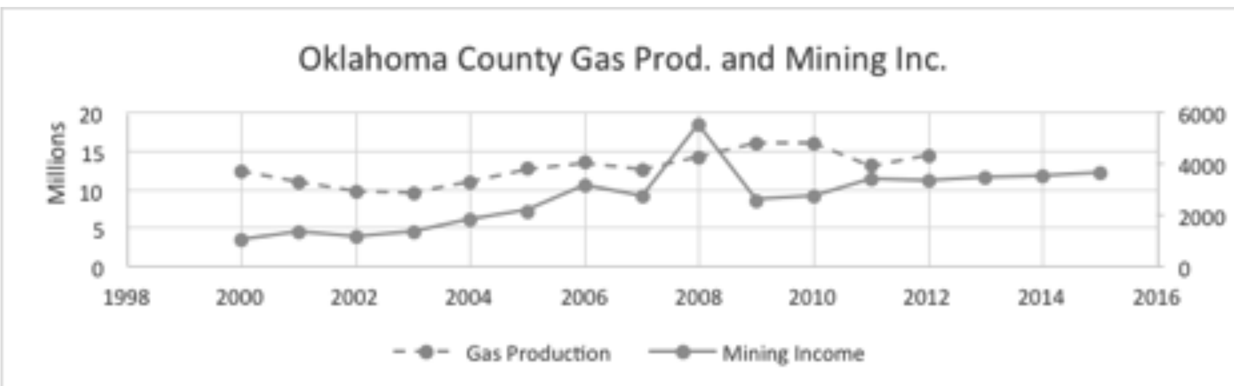


Figure A- 55. Oklahoma County gas production and mining income.

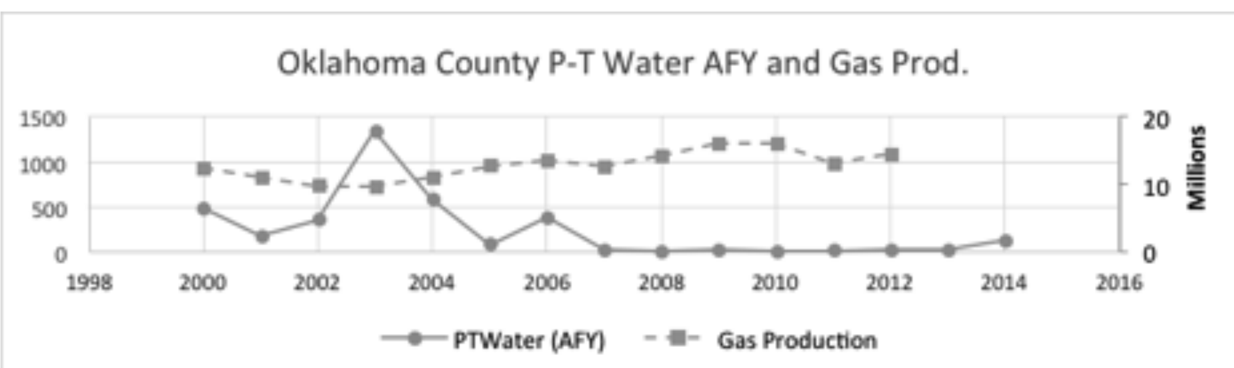


Figure A- 56. Oklahoma County provisional-temporary water and gas production.

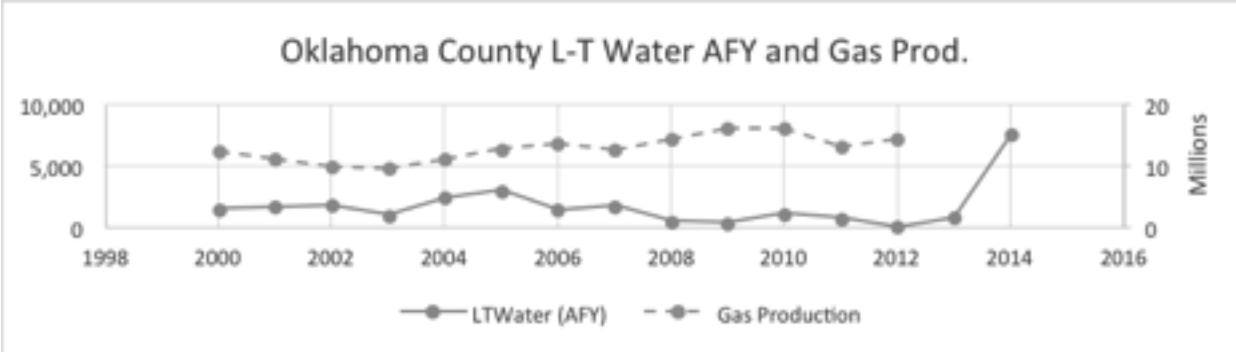


Figure A- 57. Oklahoma County long-term water use (acre feet per year).

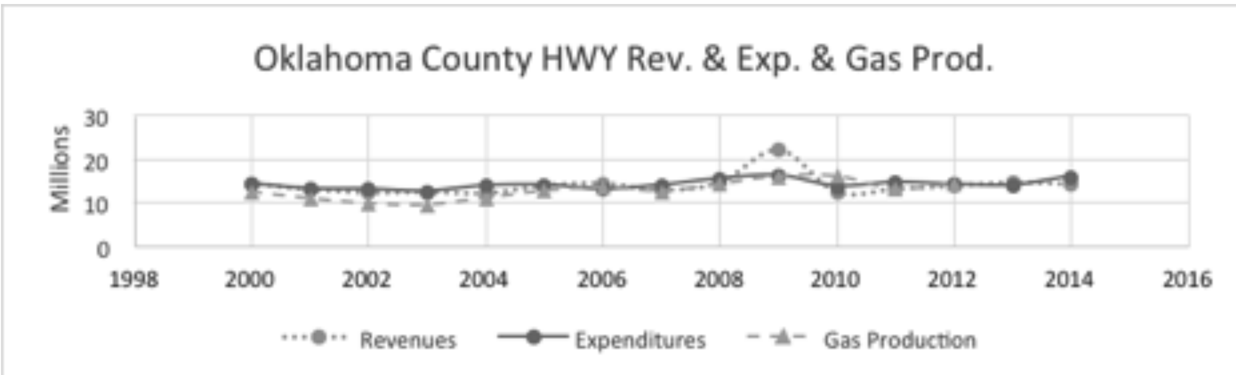


Figure A- 58. Oklahoma County highway revenue and expenditures, and gas production.

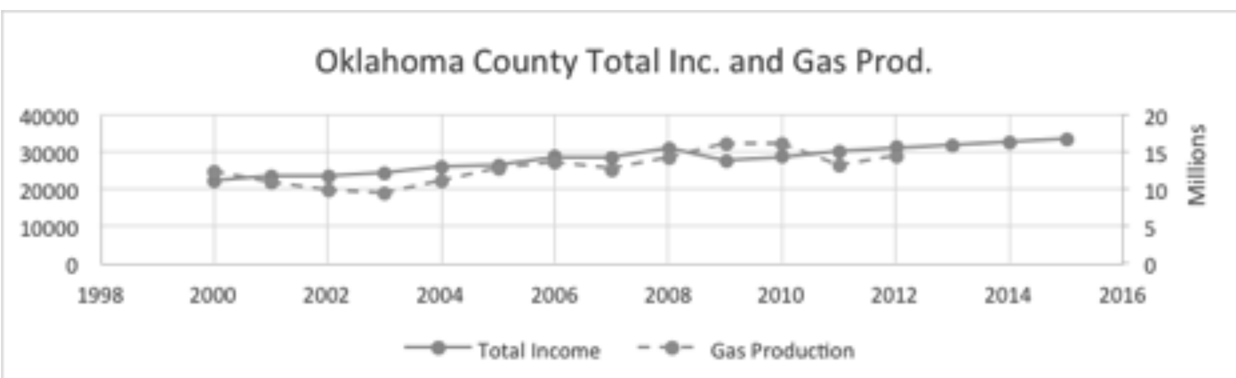


Figure A- 59. Oklahoma County total income and gas production.

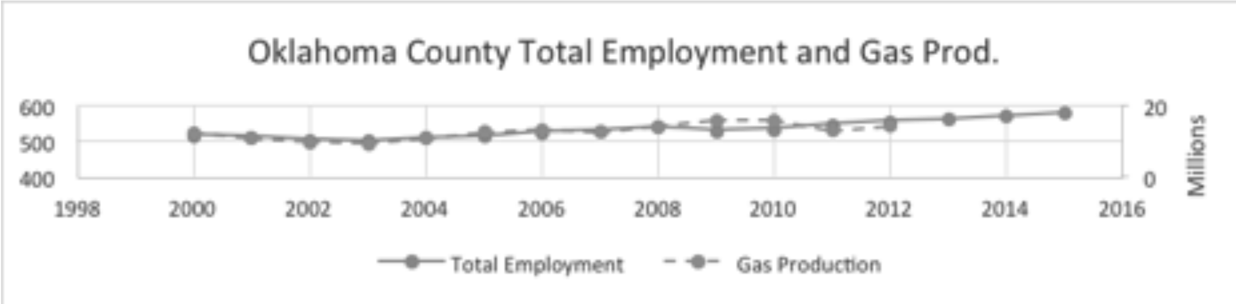


Figure A- 60. Oklahoma County total employment and gas production.

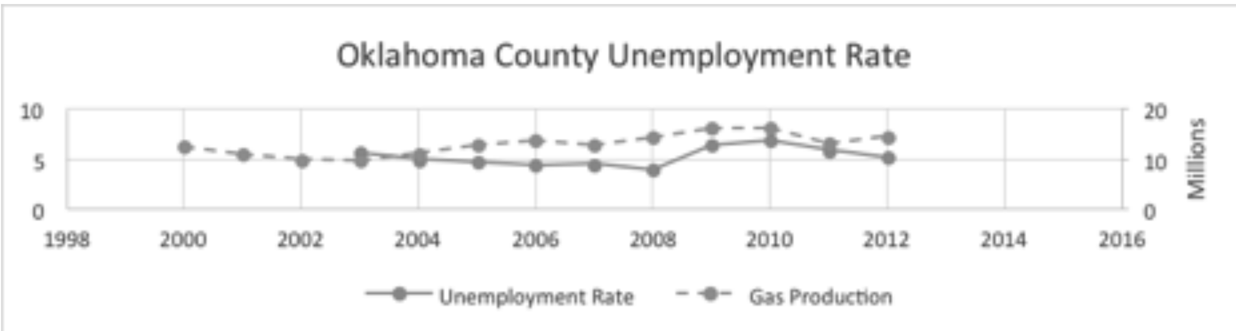


Figure A- 61. Oklahoma County unemployment rate.

Payne County

Mining income is weakly related to natural gas production. Gas production seems not to be related to highway revenue and expenditures. However, county gas production, total employment and the unemployment rate do seem to be strongly related.

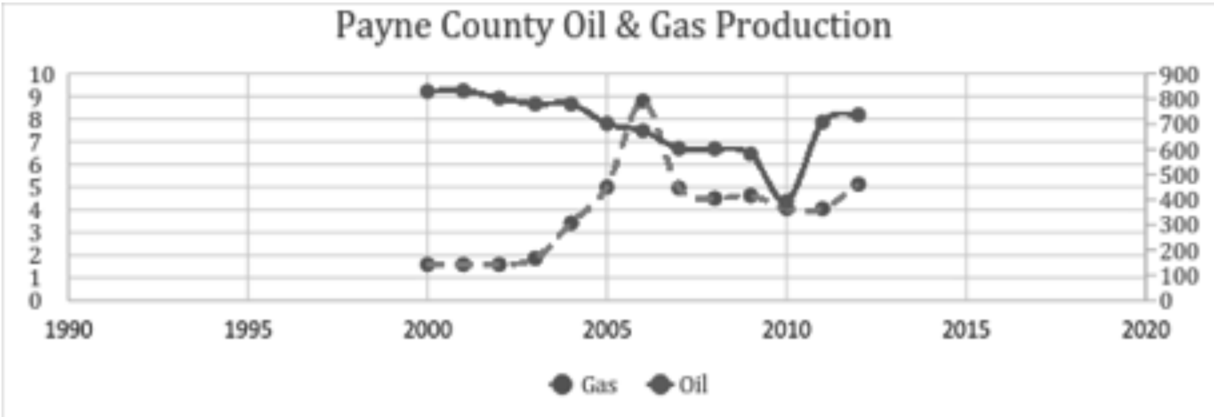


Figure A- 62. Payne County oil and gas production.

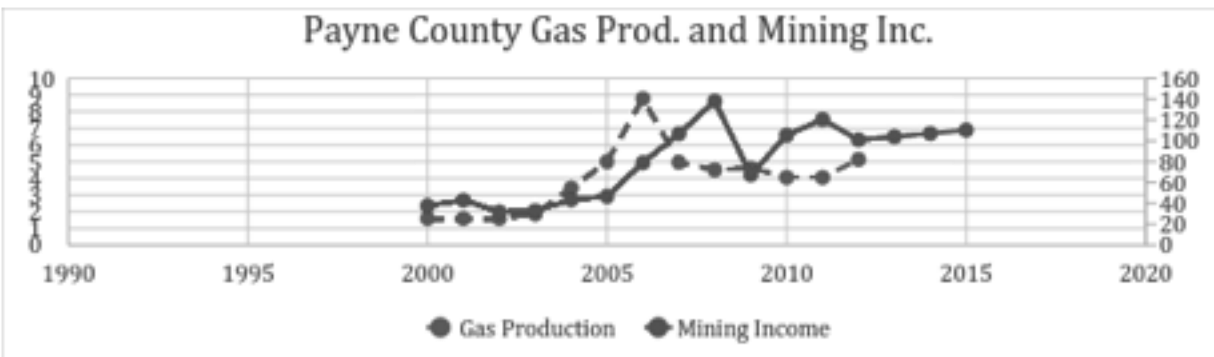


Figure A- 63. Payne County gas production and mining income.

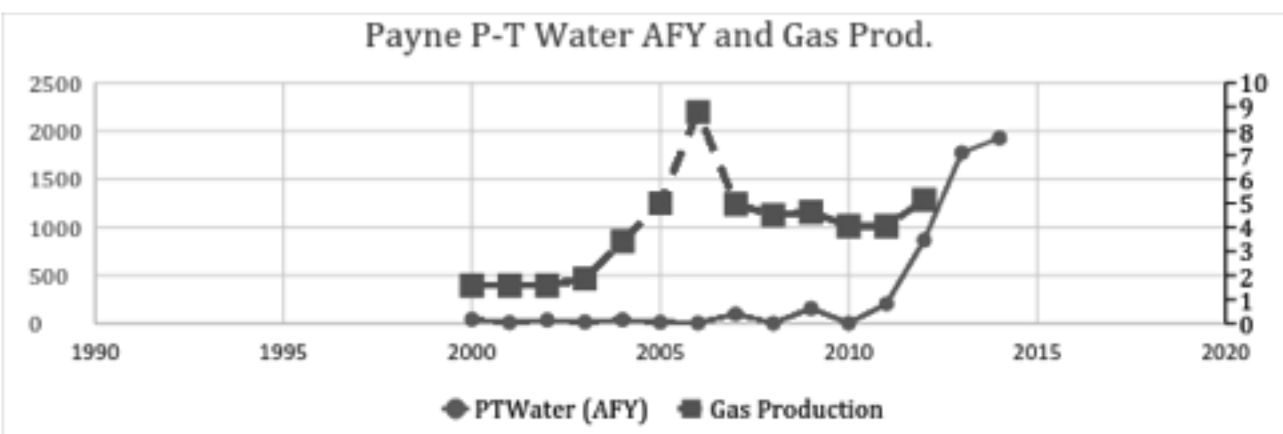


Figure A- 64. Payne County provisional-temporary water and gas production.

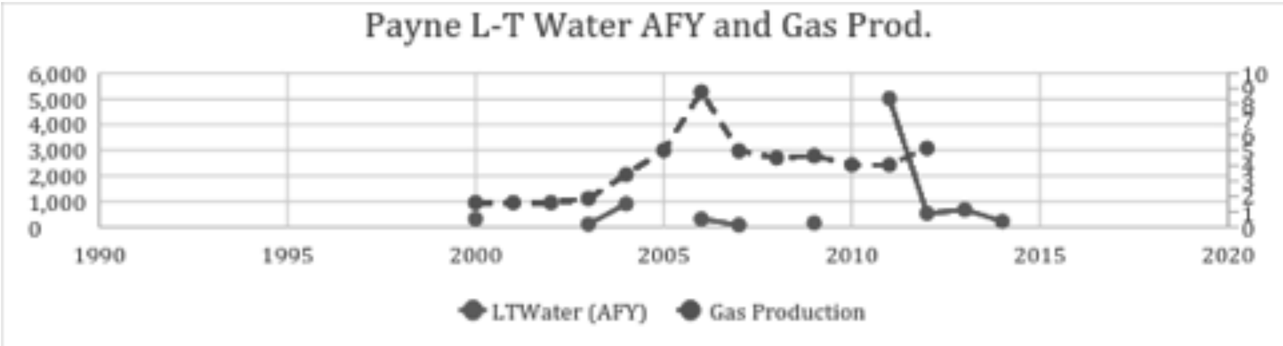


Figure A- 65. Payne County long-term water use (acre feet per year).

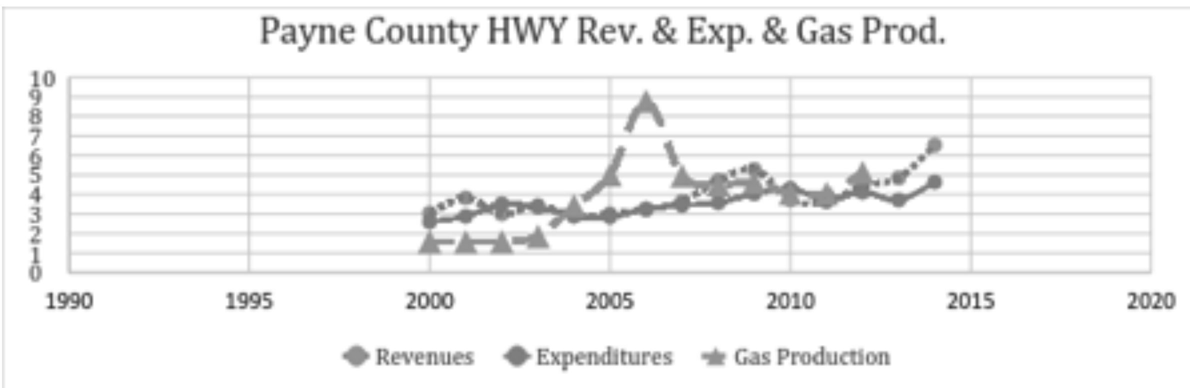
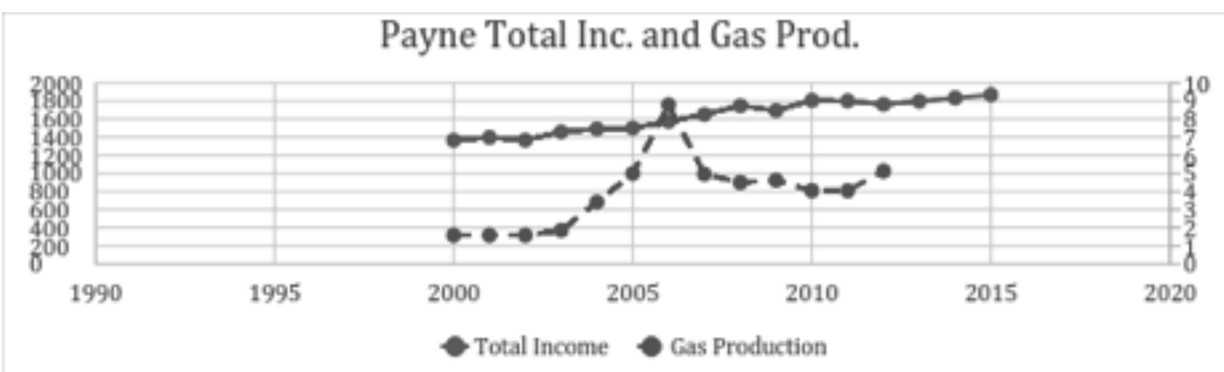


Figure A- 66. Payne County highway revenue and expenditures, and gas production.



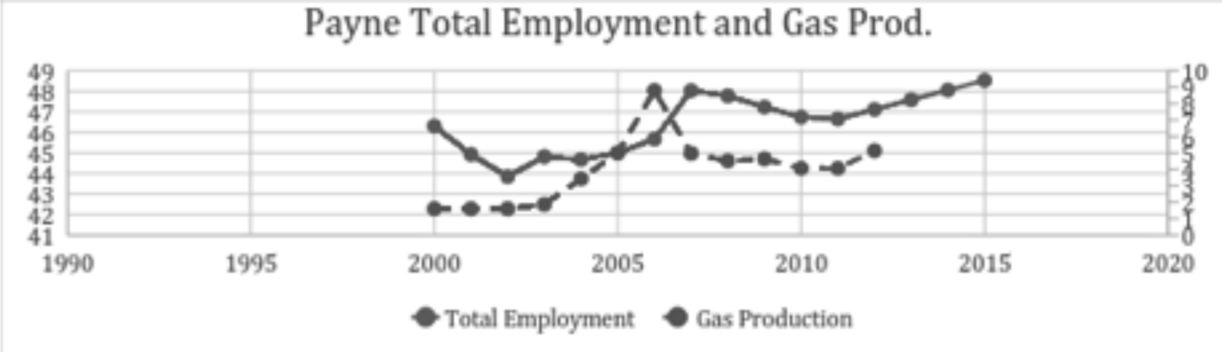


Figure A- 68. Payne County total employment and gas production.

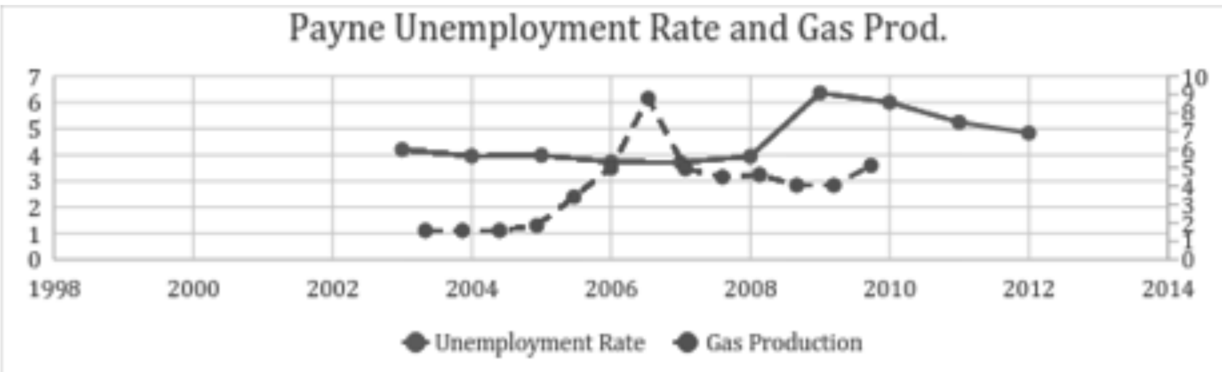


Figure A- 69. Payne County unemployment rate and gas production.

Pittsburg County

Natural gas production and mining income are strongly related. Temporary water use and highway revenue and expenditures are positively related. The relationship between gas production and county total employment and the unemployment rate is less clear.

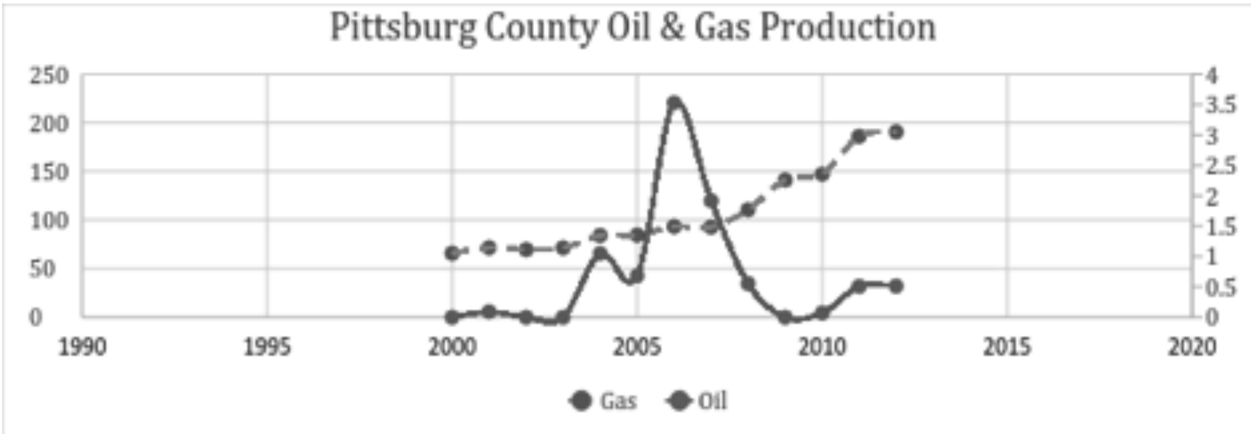


Figure A- 70. Pittsburg County oil and gas production.

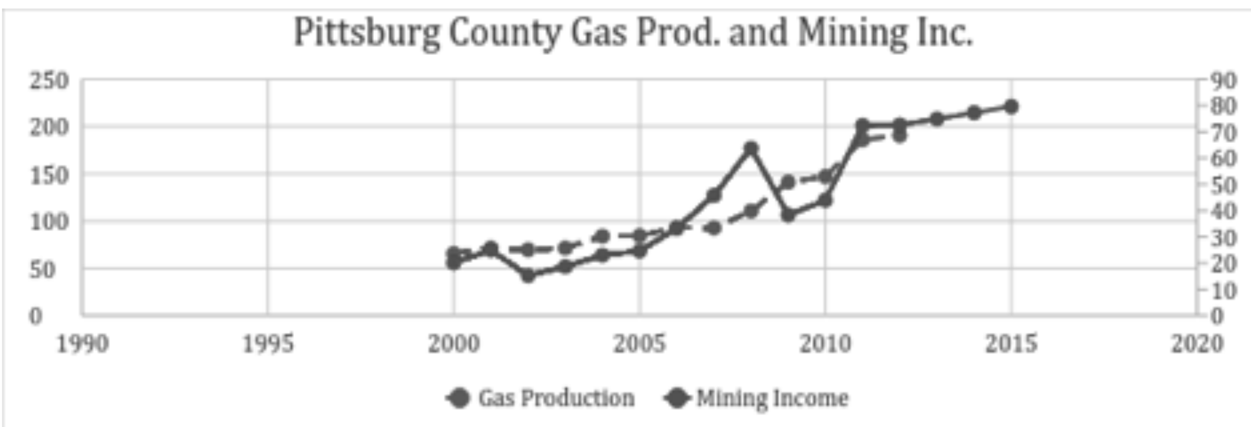


Figure A- 71. Pittsburg County gas production and mining income.

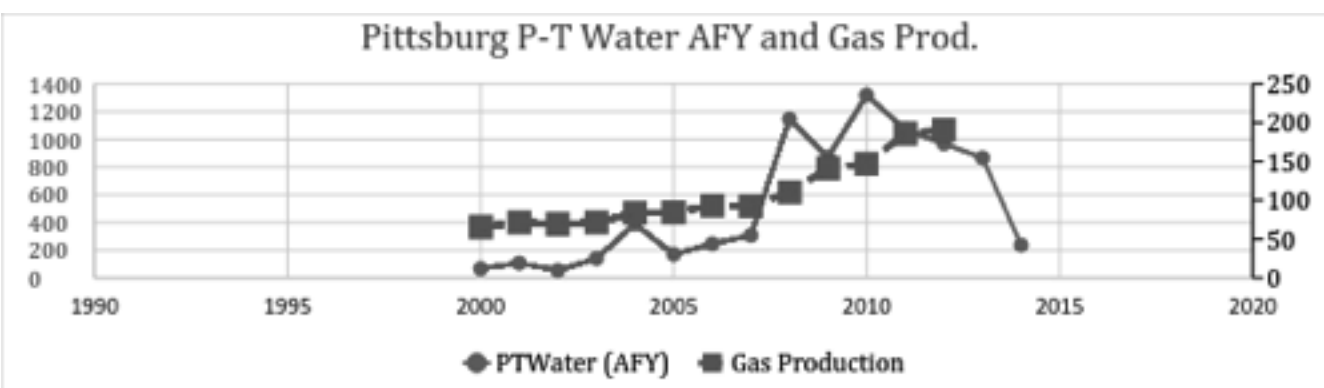


Figure A- 72. Pittsburg County provisional-temporary water and gas production.

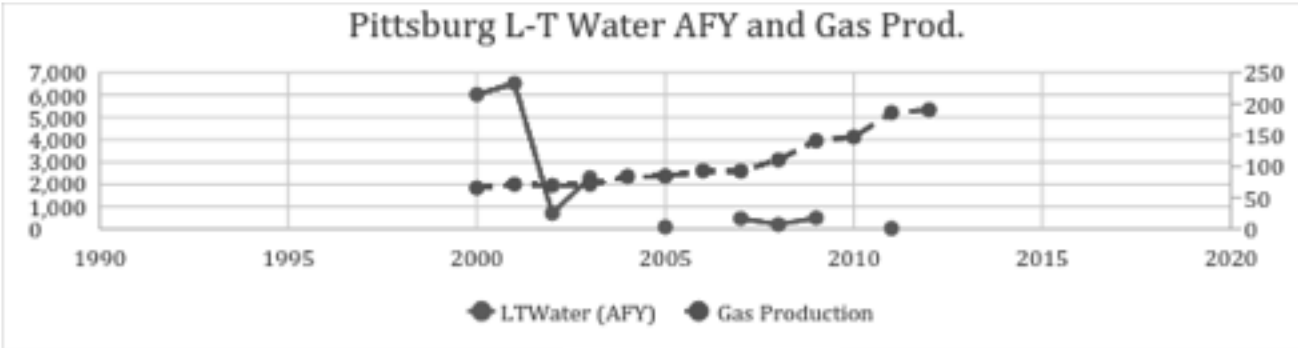


Figure A- 73. Pittsburg County long-term water use (acre feet per year).

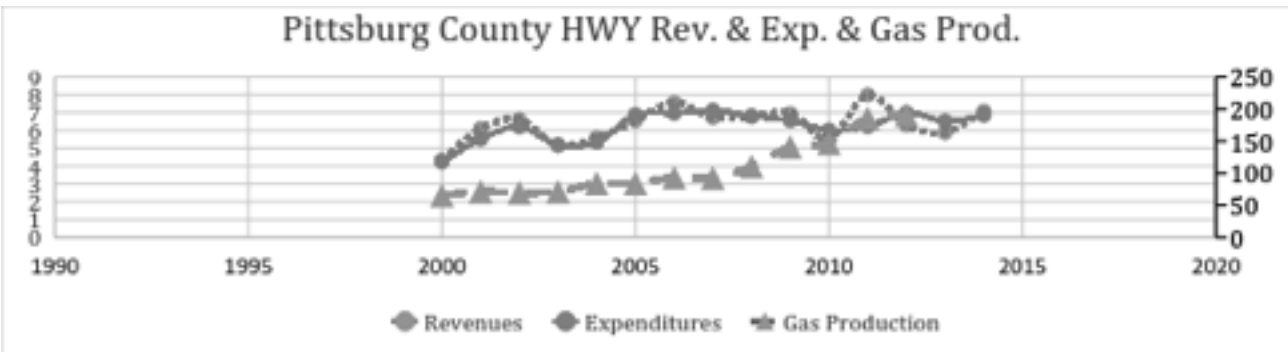


Figure A- 74. Pittsburg County highway revenue and expenditures, and gas production.

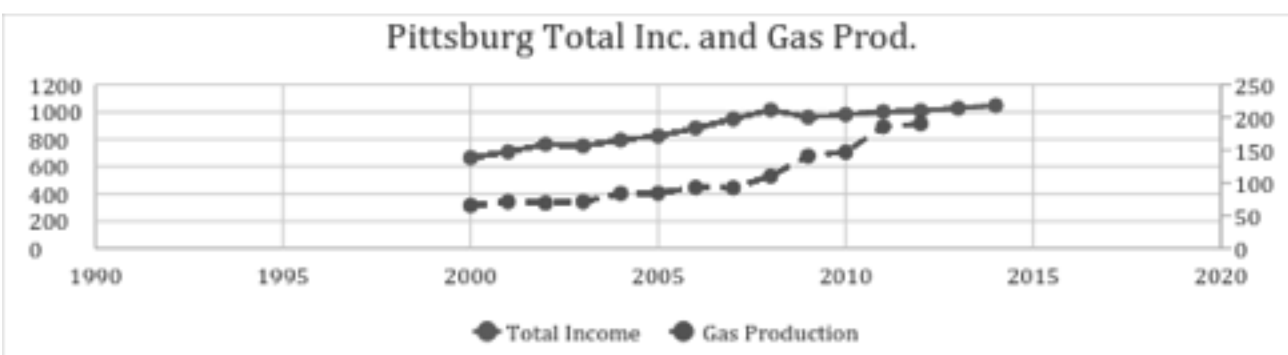


Figure A- 75. Pittsburg County total income and gas production.

Figure A- 76. Pittsburg County total employment and gas production.

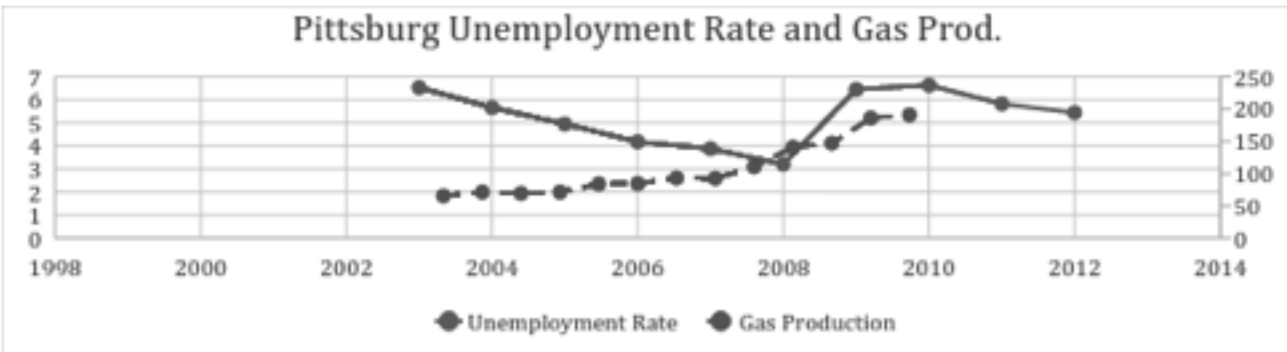


Figure A- 77. Pittsburg County unemployment rate and gas production.

Pottawatomie County

Natural gas production triggered increased county mining income, but that income remained high even with the subsequent decline in gas production. Temporary water use peaked several years after gas production peaked. Highway revenue and expenditures remained relatively stable in spite of the rapid increase and decrease in natural gas production. County total employment increased as gas production increased. The unemployment rate tended to fall as gas production peaked and initially increased as gas production declined, then began to fall as gas production continued to decline.

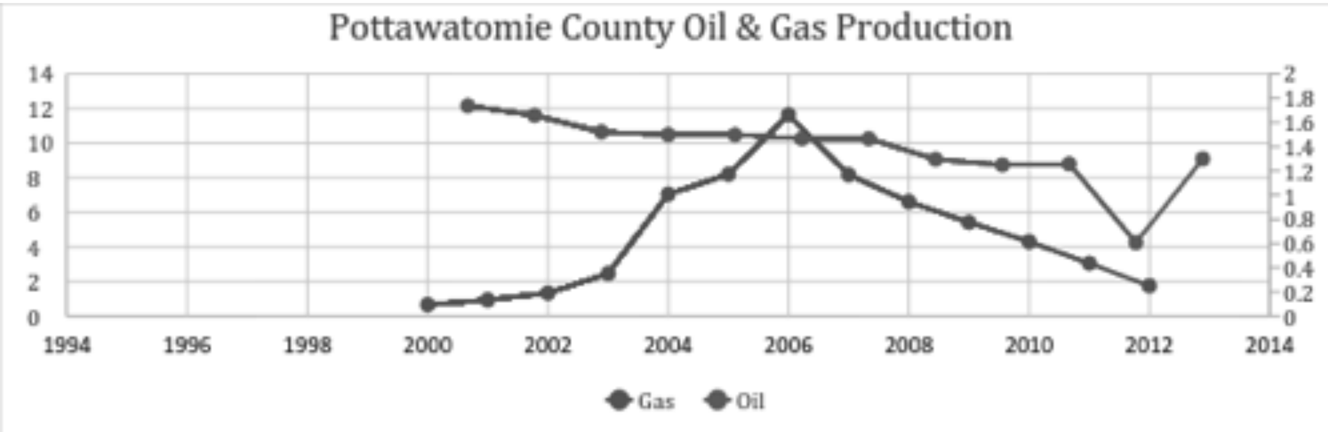


Figure A- 78. Pottawatomie County oil and gas production.

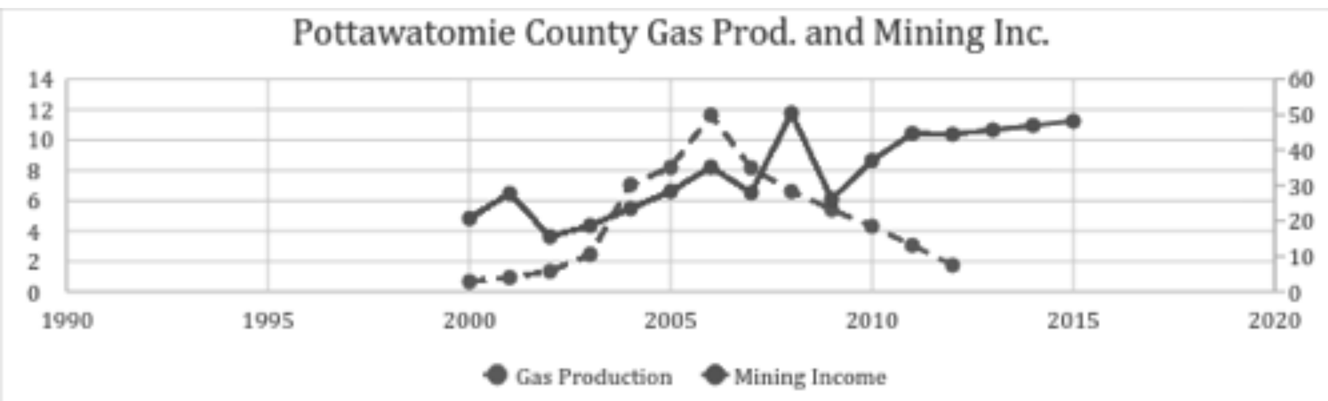


Figure A- 79. Pottawatomie County gas production and mining income.

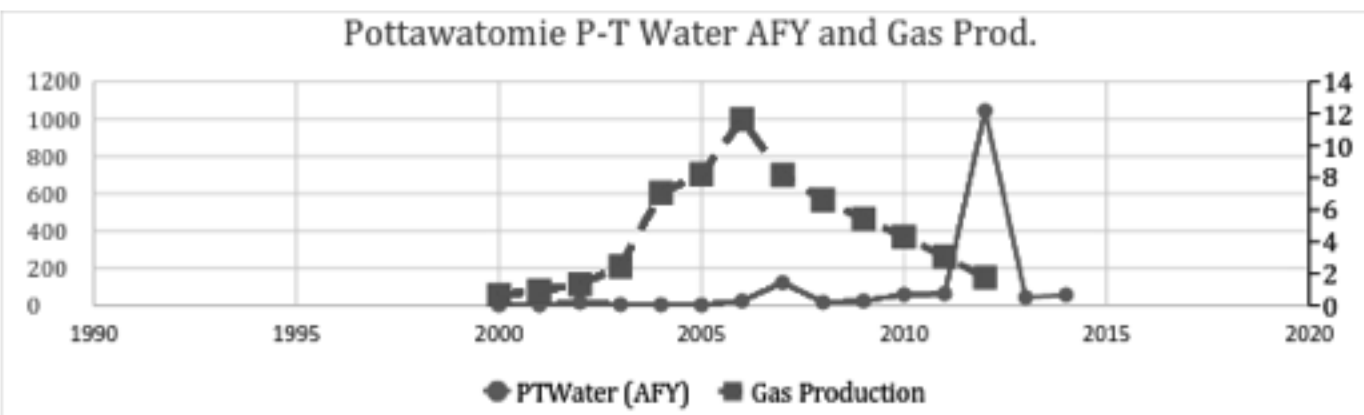


Figure A- 80. Pottawatomie County provisional-temporary water and gas production.

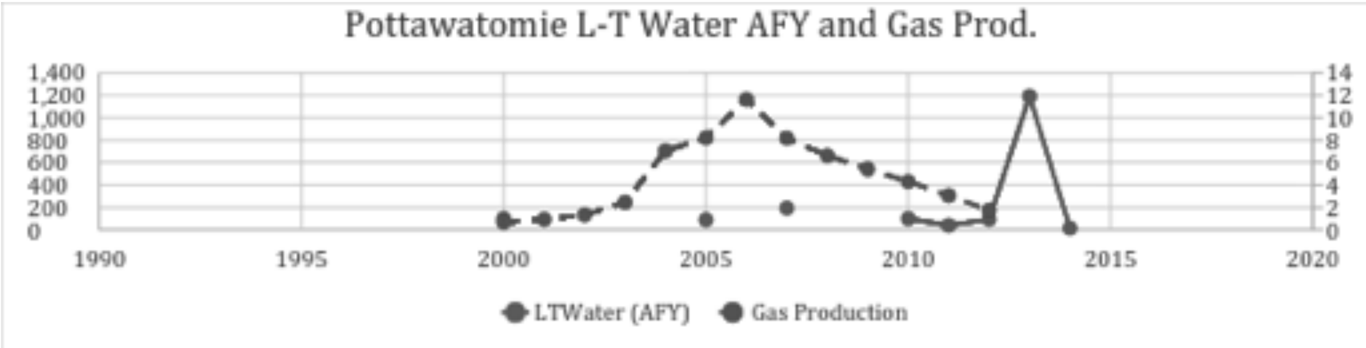


Figure A- 81. Pottawatomie County long-term water use (acre feet per year).

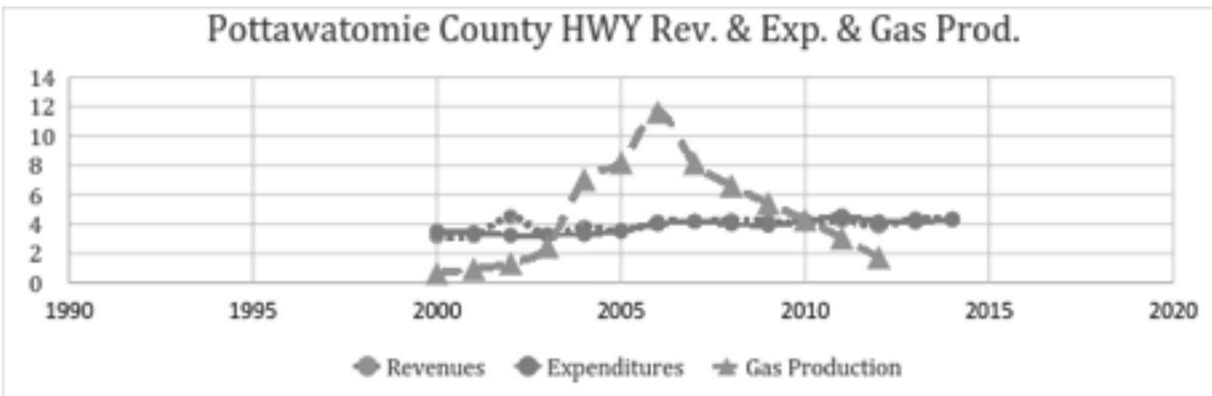


Figure A- 82. Pottawatomie County highway revenue and expenditures, and gas production.

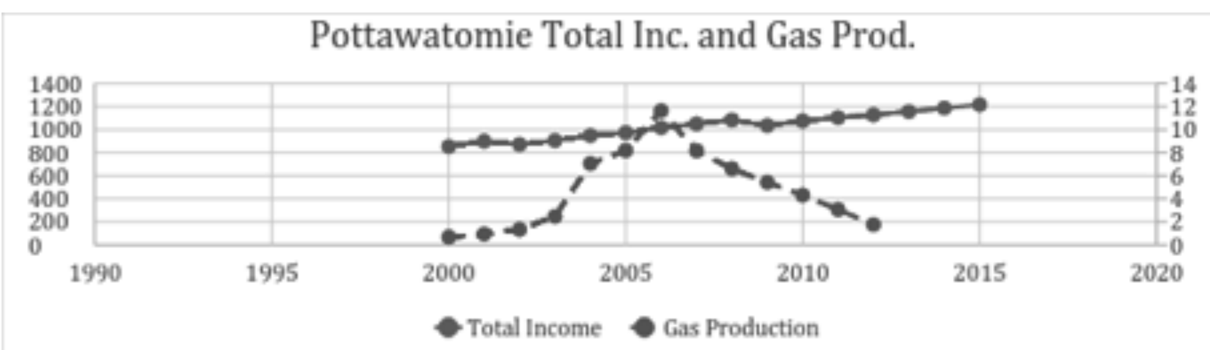


Figure A- 83. Pottawatomie County total income and gas production.

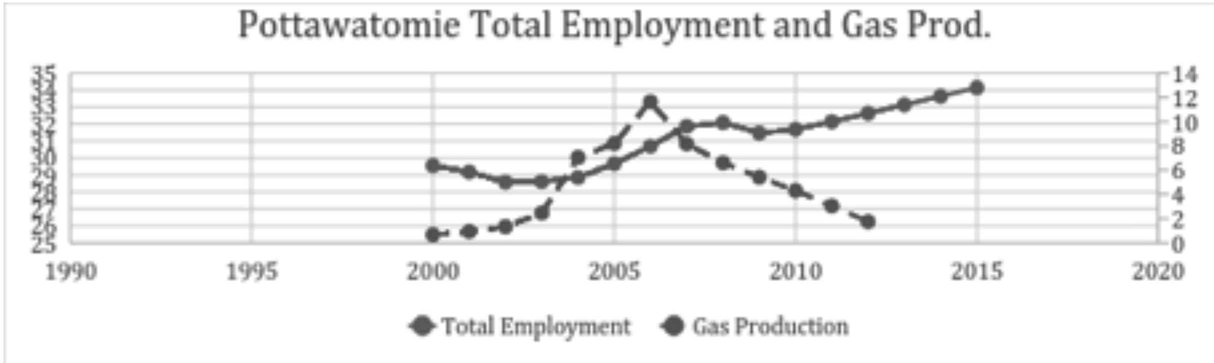


Figure A- 84. Pottawatomie County total employment and gas production.

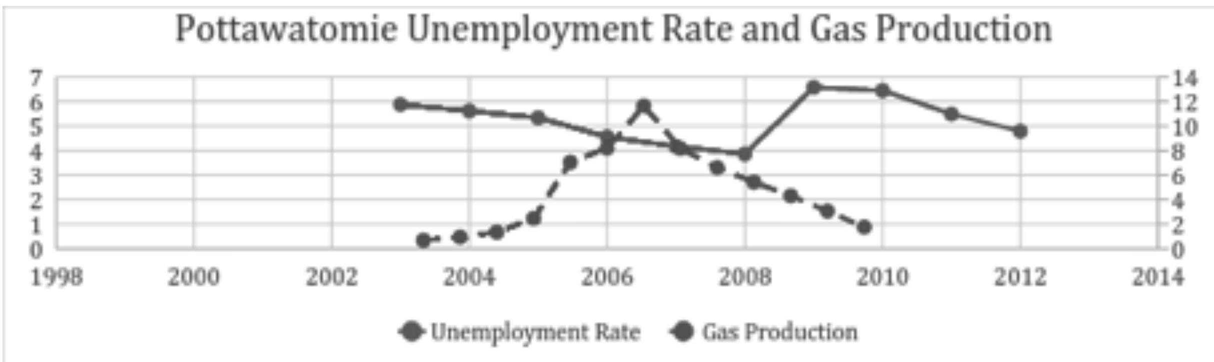


Figure A- 85. Pottawatomie County unemployment rate and gas production.

Roger Mills County

Roger Mills County natural gas production saw some increase in the 2005-2007 period, declining until 2011, then edging up. Mining income has followed that pattern. Temporary water use increased as natural gas peaked in 2006, and then declined until 2009. However, the increase in temporary water use since then has been countercyclical to the declining water use. Long-term water use has been somewhat sporadic. There is an apparent strong relationship between gas production and highway revenue and expenditures. That relationship has not held for total income and employment.

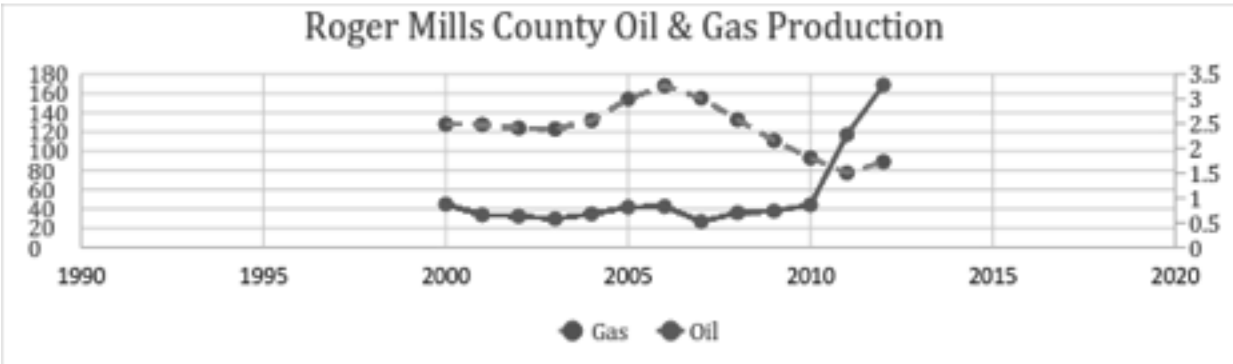


Figure A- 86. Roger Mills County oil and gas production.

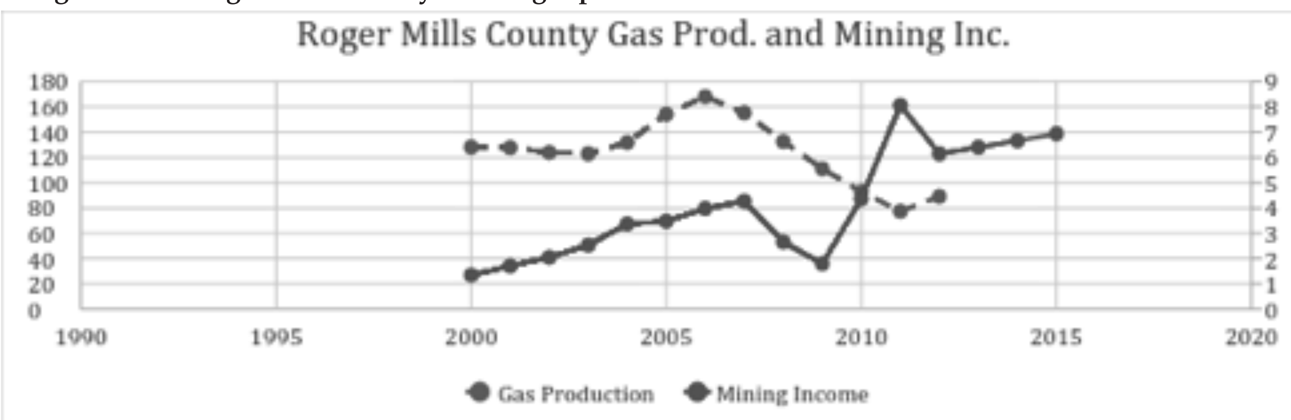


Figure A- 87. Roger Mills County gas production and mining income.

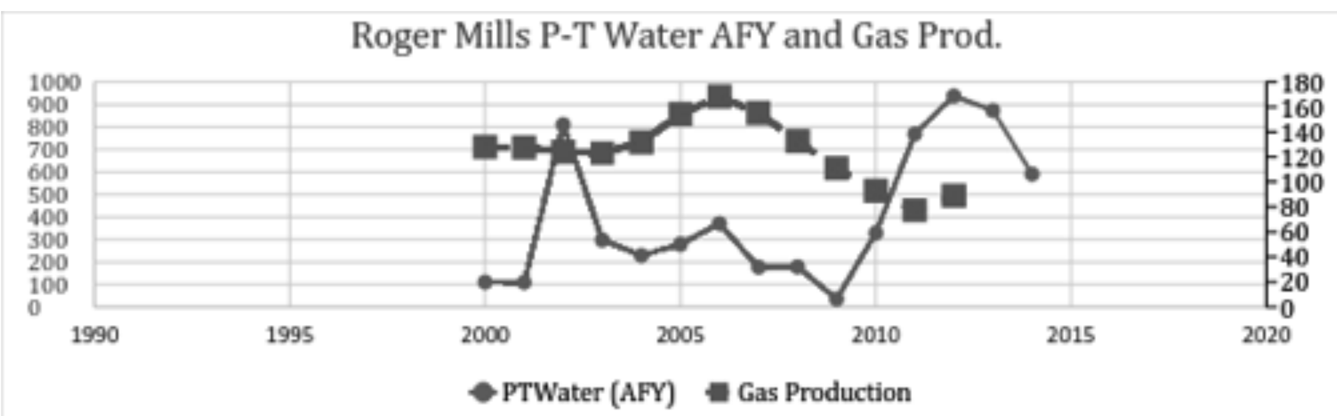


Figure A- 88. Roger Mills County provisional-temporary water and gas production.

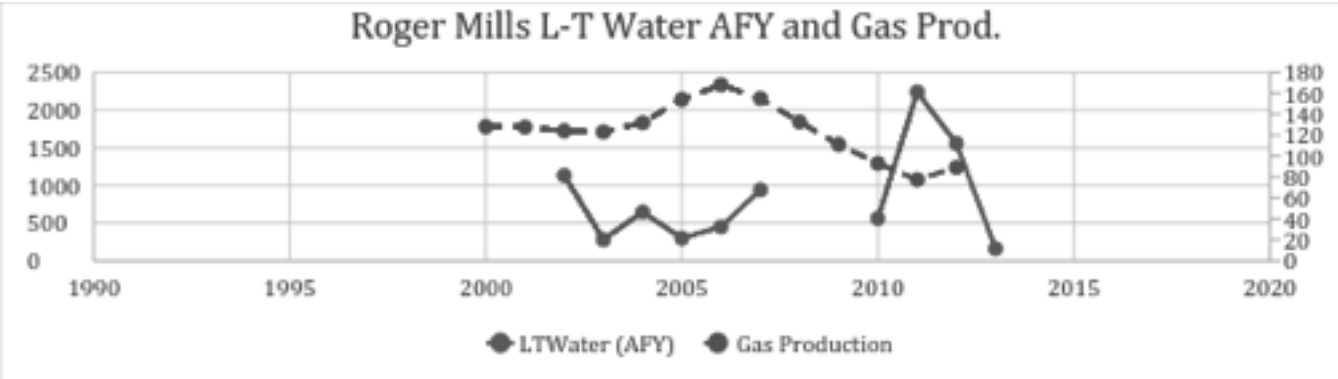


Figure A- 89. Roger Mills County long-term water use (acre feet per year).

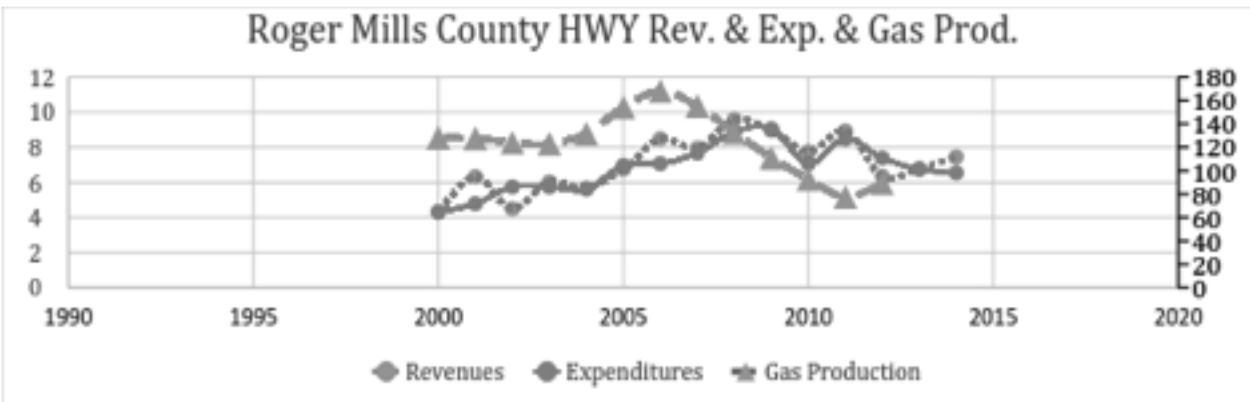


Figure A- 90. Roger Mills County highway revenue and expenditures, and gas production.

Figure A- 91. Roger Mills County total income and gas production.

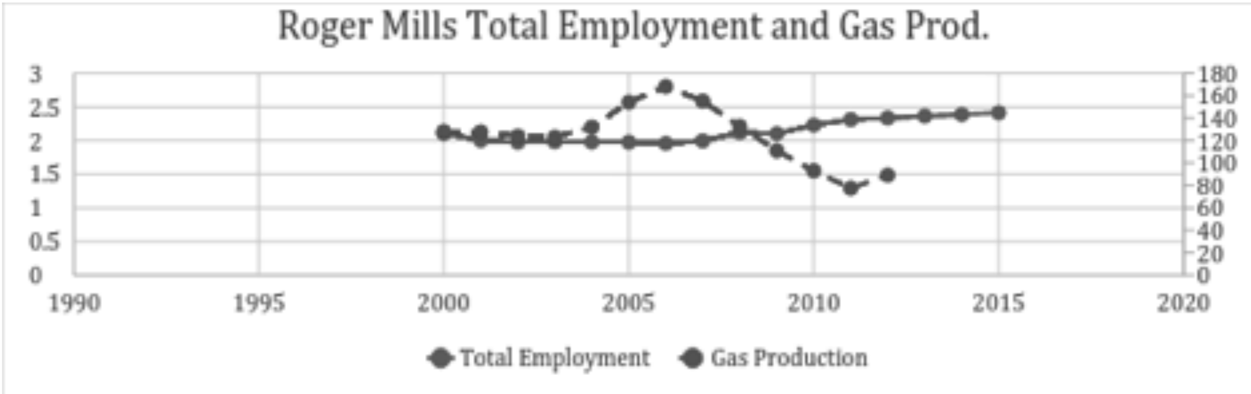


Figure A- 92. Roger Mills County total employment and gas production.

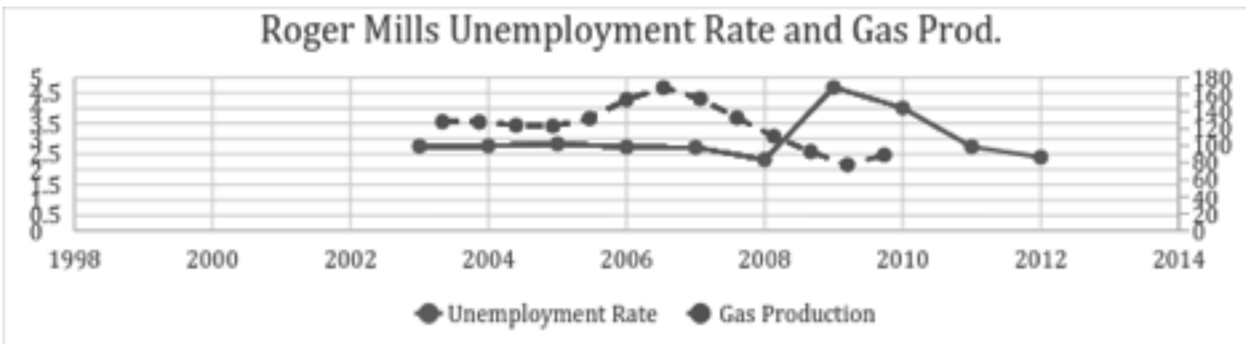


Figure A- 93. Roger Mills County unemployment rate and gas production.

Woods County

Temporary water use rose as fell in sync with gas production in the county. Highway revenue and expenditures increased somewhat after gas production peaked. Total employment increased as gas production increased, but on a pre-gas production increase trend. The unemployment rate declined as gas production increased in the county.

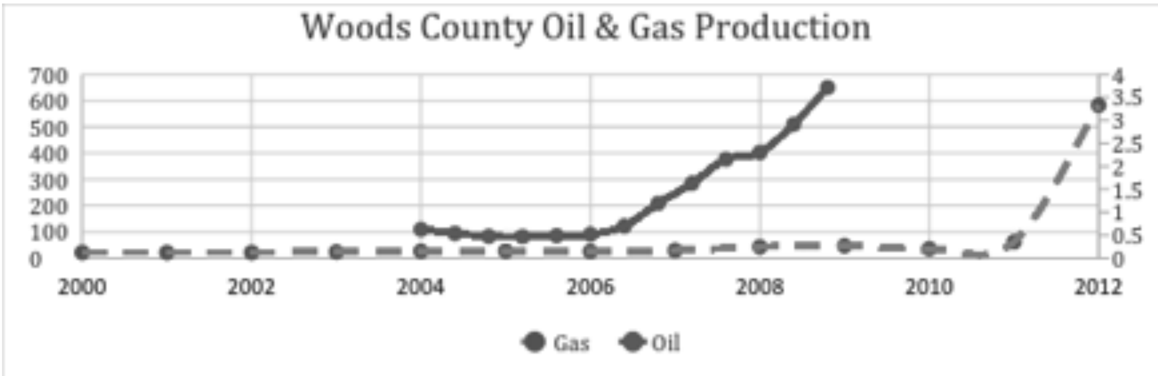


Figure A- 94. Woods County oil and gas production.

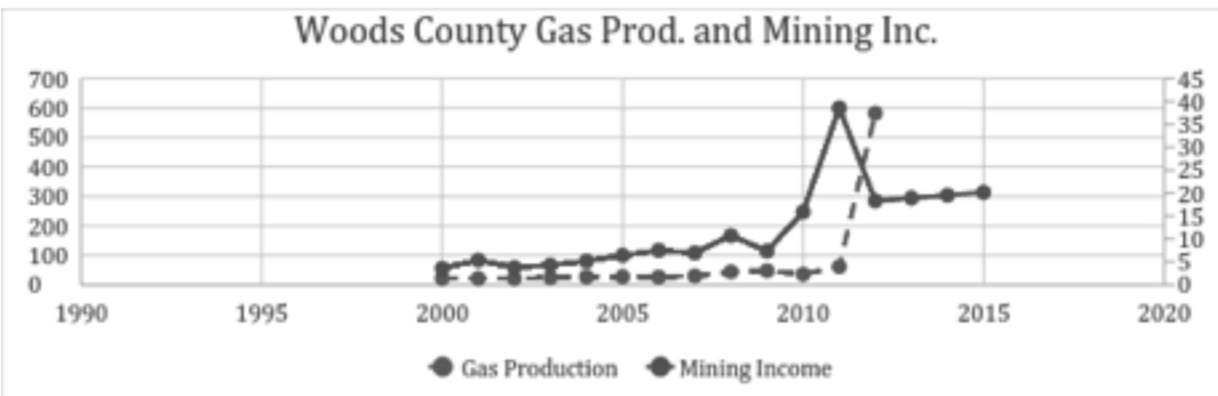


Figure A- 95. Woods County gas production and mining income.

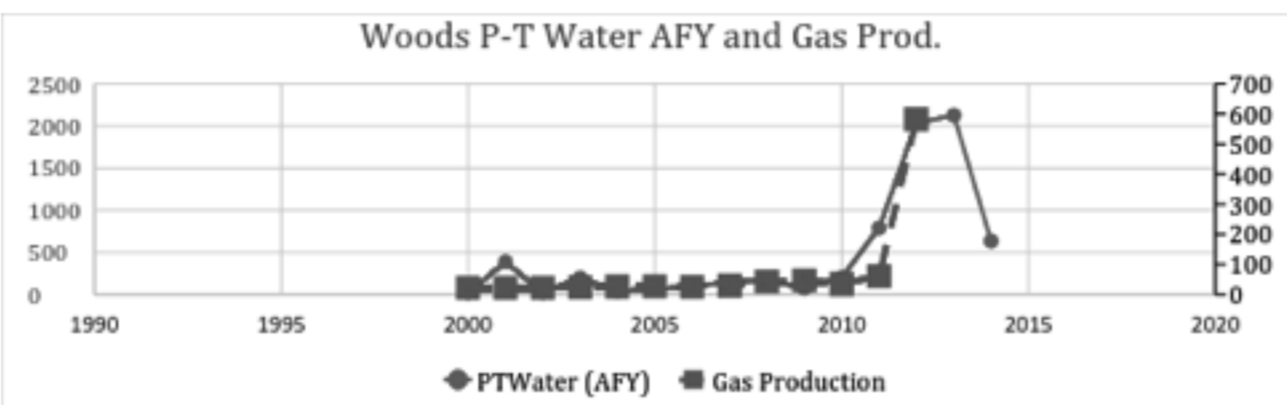


Figure A- 96. Woods County provisional-temporary water and gas production.

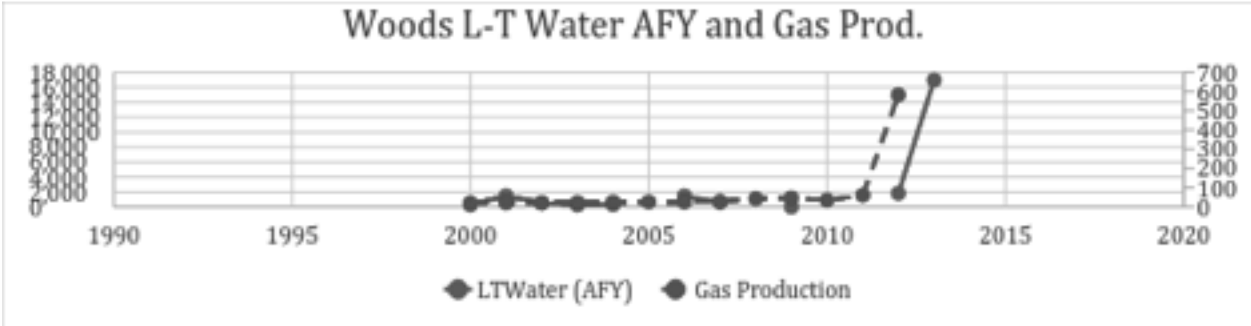


Figure A- 97. Woods County long-term water use (acre feet per year).

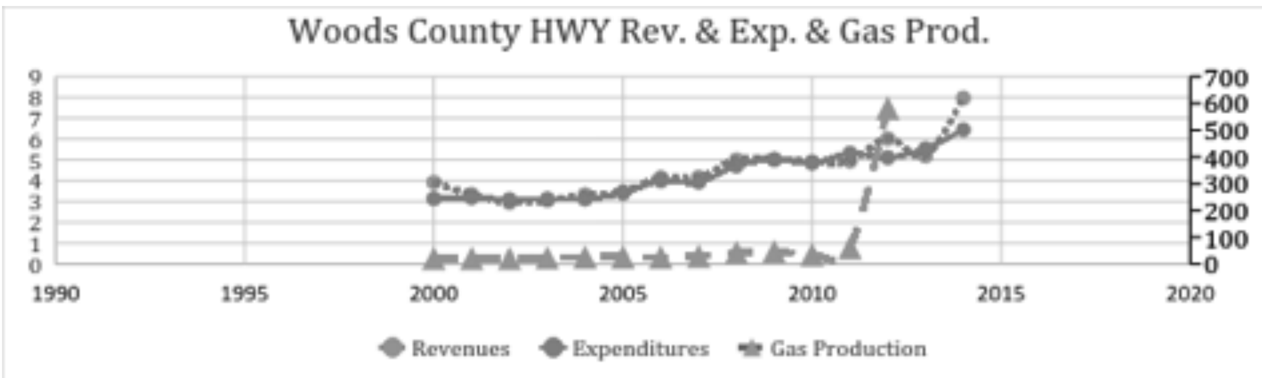


Figure A- 98. Woods County highway revenue and expenditures, and gas production.

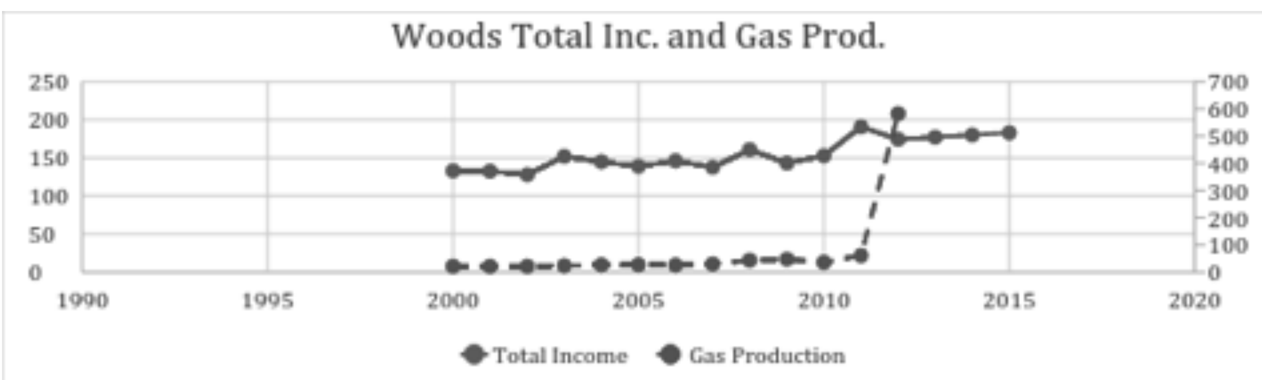


Figure A- 99. Woods County total income and gas production.

Woodward County

Mining income increased with gas production, but settled down after 2011. Both temporary and long-term water use are weakly related to gas production. It is not clear that highway revenues and expenditures have much of a relationship with gas production since 2010. County income and employment do seem to follow gas production.

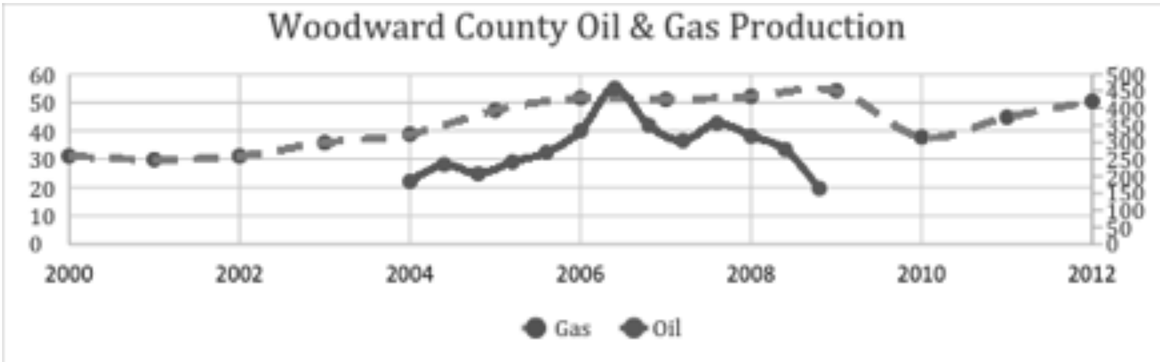


Figure A- 102. Woodward County oil and gas production.

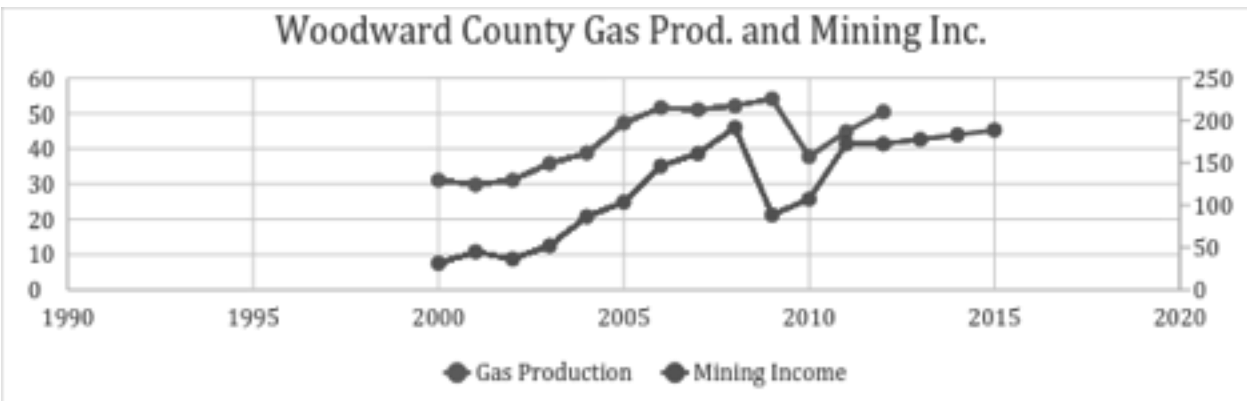


Figure A- 103. Woodward County gas production and mining income.

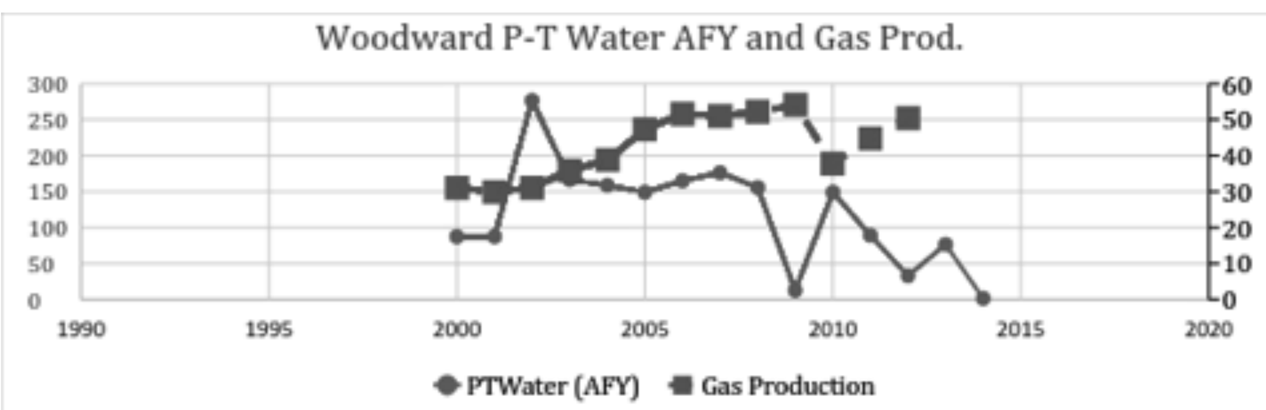


Figure A- 104. Woodward County provisional-temporary water and gas production.

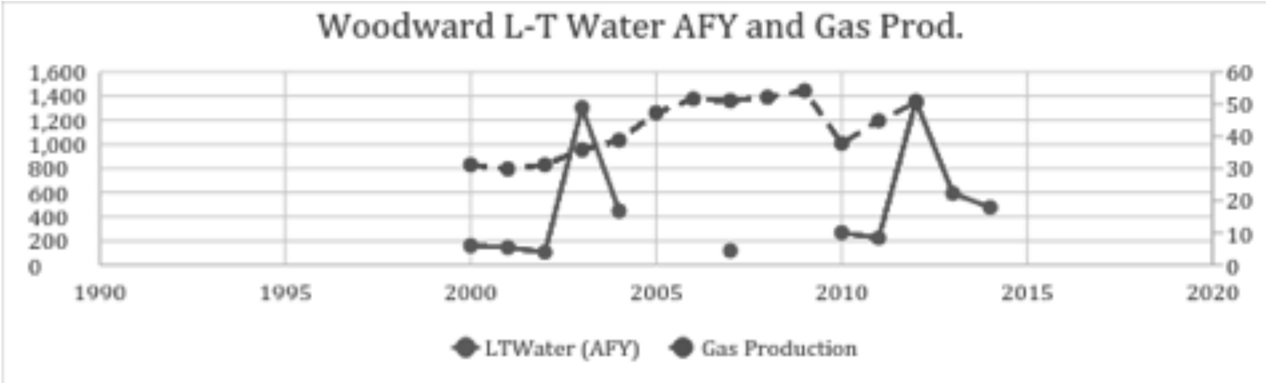


Figure A- 105. Woodward County long-term water use (acre feet per year).

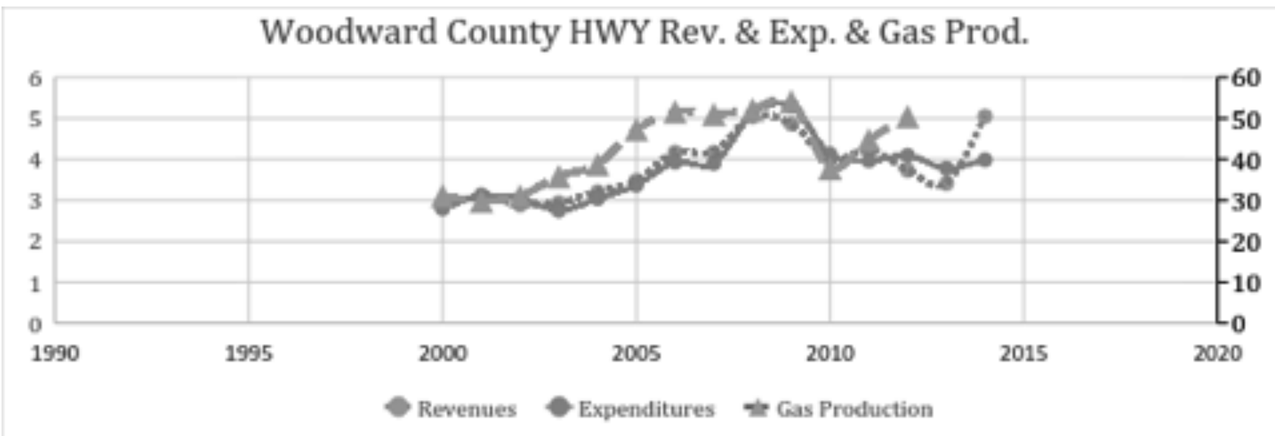


Figure A- 106. Woodward County highway revenue and expenditures, and gas production.

Figure A- 107. Woodward County total income and gas production.

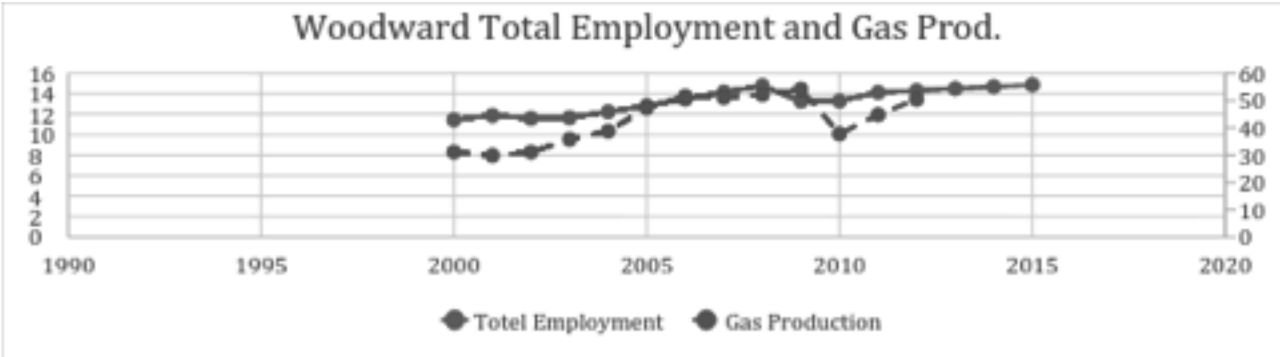


Figure A- 108. Woodward County total employment and gas production.

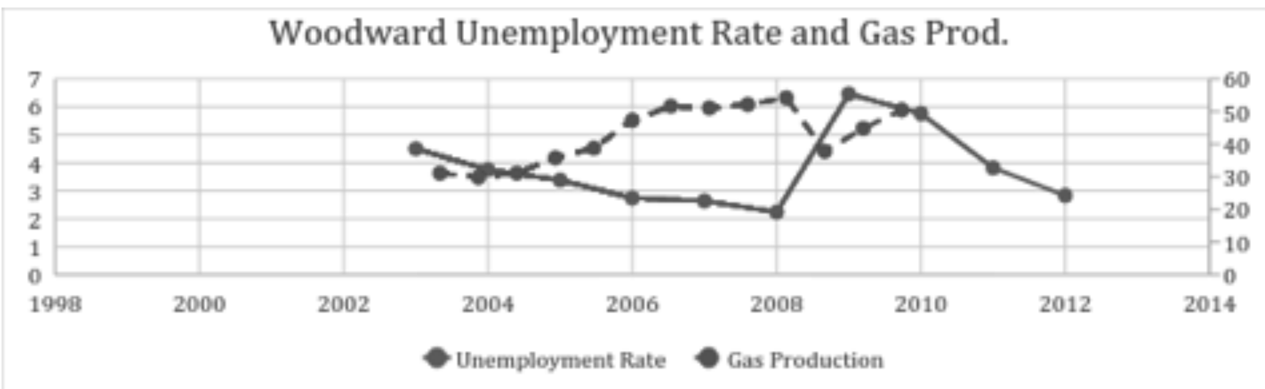


Figure A- 109. Woodward County unemployment rate and gas production.

Oklahoma (state)

State production of both oil and gas peaked in 2012. Mining income has generally been on an upward trend in the state during this period. Temporary water use mirrored gas activity in the state. Highway revenues and expenditures have slowly trended up irrespective of gas production, as have both total income and employment. The unemployment rate generally is inversely related to gas production.

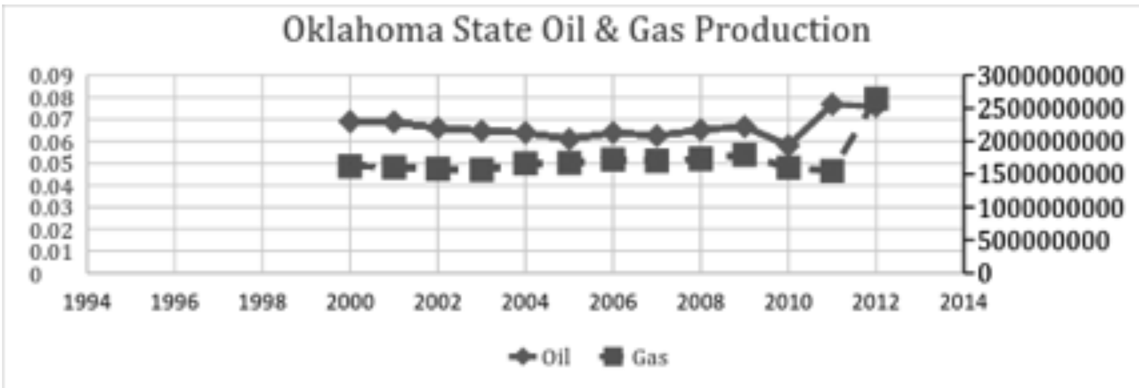


Figure A- 110. Oklahoma state oil and gas production.

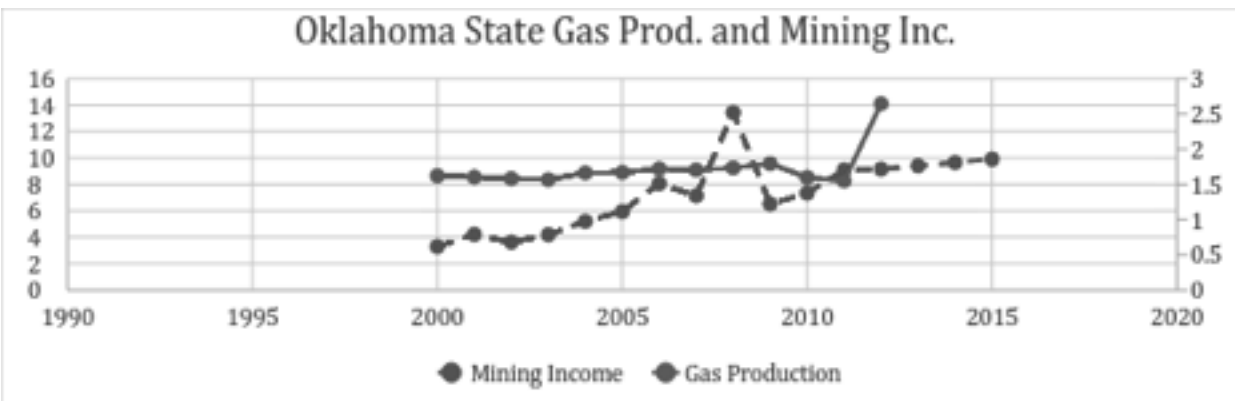


Figure A- 111. Oklahoma state gas production and mining income.

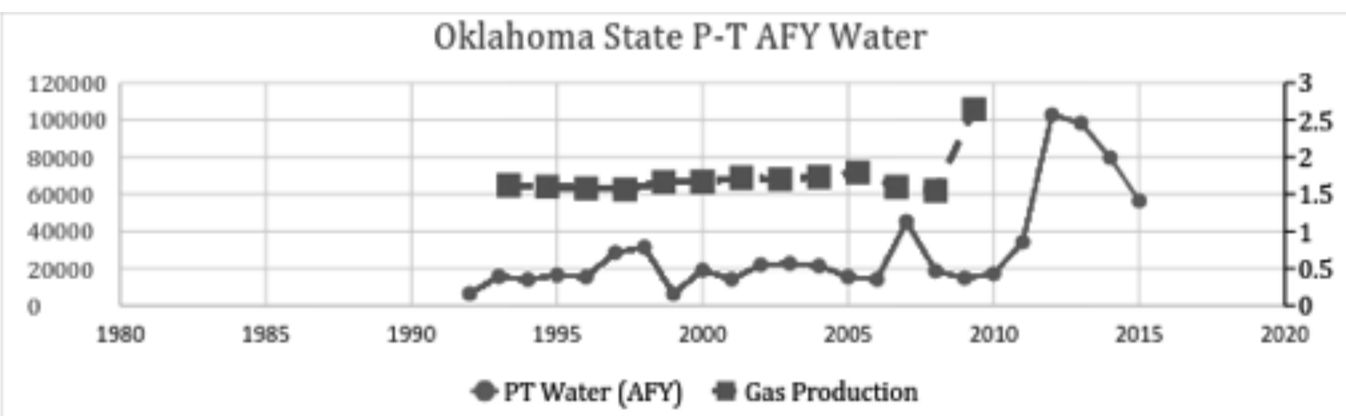


Figure A- 112. Oklahoma state provisional-temporary water and gas production.

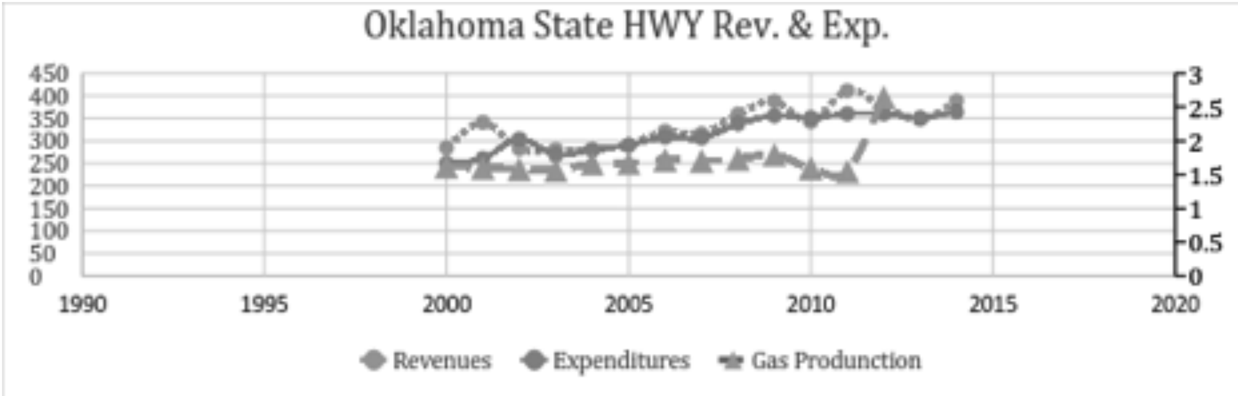


Figure A- 113. Oklahoma state highway revenue and expenditures.

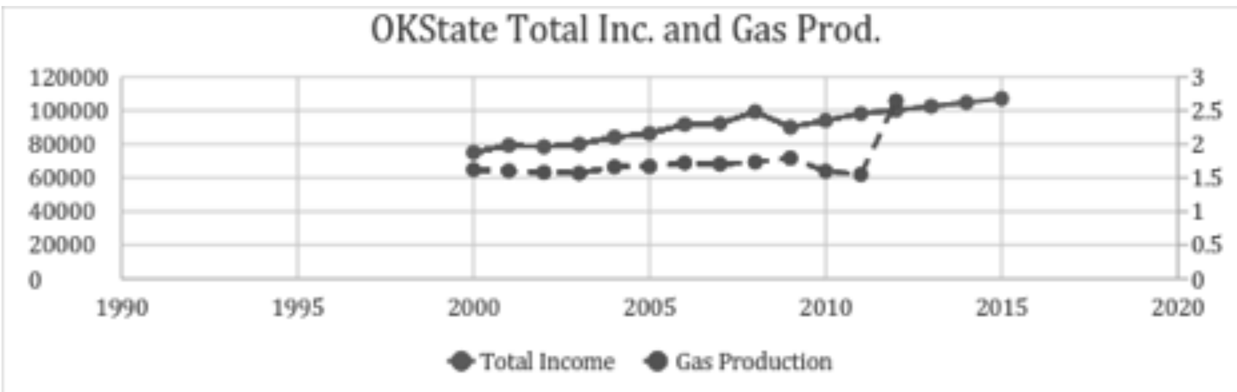


Figure A- 114. Oklahoma state total income and gas production.

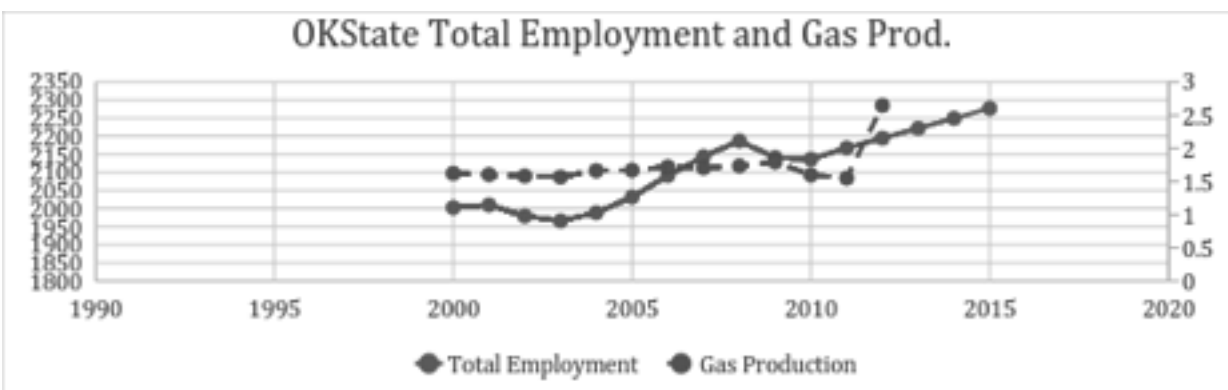


Figure A- 115. Oklahoma state total employment and gas production.

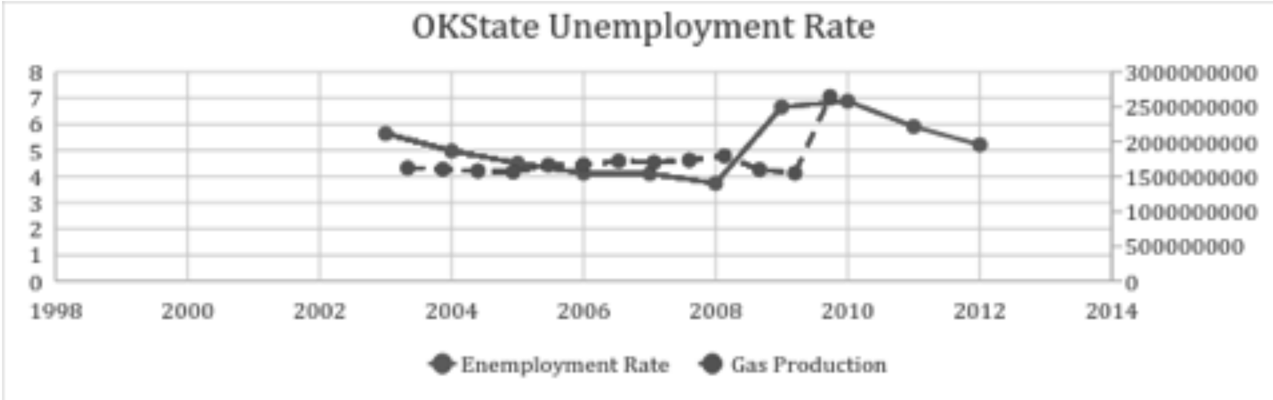


Figure A- 116. Oklahoma state unemployment rate.