

LAND CHANGE AND VULNERABILITY TO
DROUGHT: IMPACT AND GROWTH OF CENTER
PIVOT IRRIGATION IN UNION COUNTY, NM
AND CIMARRON COUNTY, OK

By

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Abstract: Union County, New Mexico and Cimarron County, Oklahoma are a part of the vital ranching and agriculture high plains region in the United States. However, this region experiences extended periods of cyclical drought threatening its agricultural production, thus creating the need for extensive irrigation, particularly by center pivot irrigation systems. Such systems, however, draw, in large part, from the rapidly depleting Ogallala Aquifer. As a result of a combination of these stressors, agriculture's long-term sustainability in the region is questionable. Utilizing an integrated Land Change Science and Political Ecology framework, this study explores the policies and practices that have led to the extensive use of center pivot systems and land change through time (1950s to 2014) and space in Union County, New Mexico and Cimarron County, Oklahoma. Additionally, the study investigates local perspectives on the use of center pivot irrigation systems for drought resilience and livelihood sustainability. The results of this study reveal that since 2005, center pivot irrigation systems have declined in Union County from 54,216 acres to 51,306 acres (5.37%). In Cimarron County on the other hand, center pivot systems have increased from 73,357 to 79,622 (8.54%). Furthermore, results reveal that the driving force of irrigation use is historically due to government programs such as direct payments and insurance subsidies and economic influences such as ethanol and the price of corn and gas. However, more recently since 2005, drought and tighter water regulations appear to be the driving force behind decreased center pivot use in Union County. Conversely, in Cimarron County, high corn prices and fewer water regulations appear to have increased center pivot use since 2005. Local perceptions on the use of center pivot systems uncover increasing concern over the depleting aquifer. Perceptions also show concern over long-term sustainability of irrigated agriculture and their community's economic future. Overall, this study reveals that differences in state policies lead to different water use, and consequently, agricultural practices. This, in turn, has implications for the resilience of local communities, especially in times of drought.

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CHAPTER I

INTRODUCTION

Union County, New Mexico and Cimarron County, Oklahoma are within the Southern High Plains Region of the United States, which has experienced dramatic land-use/land-cover change (LULCC) in the last century. Over the past 65 years, this arid region has transformed from an intermittent producer of dry land crops to an industrial irrigation based agricultural complex (Sophocleous and Merriam 2012). Center pivot irrigation (CPI) systems in particular, are one of the largest drivers of such land change and water decline in the area (Allen et al. 2007). The result of this transformation is that now, agricultural irrigation in the High Plains uses 97% of the groundwater withdrawn from the High Plains/Ogallala aquifer. In turn, the aquifer is being depleted at an unsustainable rate (Allen et al. 2007; Sophocleous 2012). Given the importance of agriculture to the livelihoods of those in the region, the depletion of its main water source is of great concern.

This study explores two counties within the High Plains region that have agriculturally based economies where irrigation has transformed the landscape. Utilizing a combined Land Change Science (LCS) and Political Ecology (PE) framework, this study seeks to better understand the complex nature between LULCC, socio-economic influences and vulnerability.

The research questions include:

- 1) How much land (in acreage) in Union County, NM and Cimarron County, OK is irrigated by Center Pivot Systems and how has this changed over space and time?
- 2) What policies and practices have influenced Center Pivot Irrigation growth and how?
- 3) How do local communities perceive the role of Center Pivot Irrigation use in relation to vulnerability and drought in the region?

These questions seek to assess: LULCC due to CPI systems in the last 60 years, the role of groundwater management institutions and policies in the expansion and extensive use of CPI systems, and local perceptions of these systems in relation to vulnerability and drought resiliency.

This research is part of a larger NSF project (Vadjunec et al. 2012) assessing the role of governance on LULCC and vulnerability and resiliency to drought in the grasslands of the American West. The research is being conducted in Union County, NM and Cimarron County, OK (Figure 1). The study area counties were chosen as especially suitable for a comparison of vulnerability, adaptation and resiliency to long-term drought. Comparison is suitable due to their similar climate geographic locale, and predominately agriculturally-based economies. However, because the two counties are in different states, they have very distinct land and water tenure policies and state administrative practices. This offers a prime case study to compare how different policies result in different land-use practices and in turn, may result in individuals that are more or less resilient to drought. The study area counties are part of the High Plains Region, which is a valuable area in the United States for commercial agriculture including cattle production and farming. The remainder of this chapter will contextualize the research problem and study area. The following sections include background on: the High Plains Region, the Ogallala Aquifer, groundwater policies in the region, and finally specific background on the study area counties.

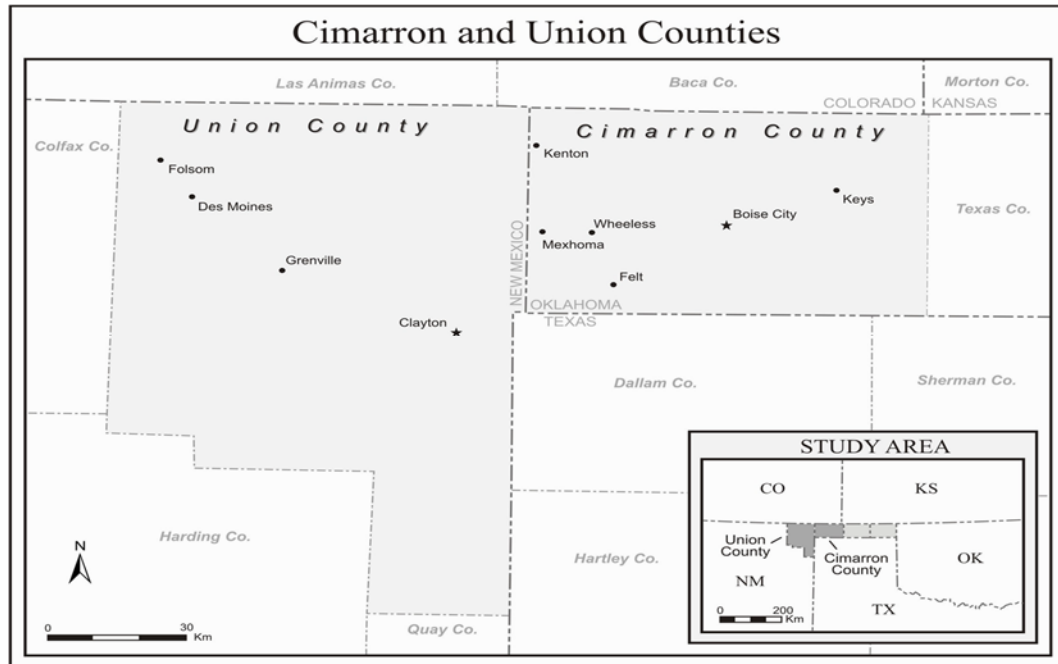


Figure 1: Study Area Counties

(Source: Vadjunec et al. 2012:4)

1.1 United States High Plains

The United States High Plains Region is a sub region of the Great Plains and includes parts of Montana, Wyoming, North Dakota, South Dakota, Nebraska, Colorado, Kansas, Oklahoma, New Mexico and Texas (U.S. Department of the Interior-High Plains Partnership 2004). The dramatic social and environmental transformation of the High Plains over the last century is due to multiple factors (Sophocleous and Merriam 2012). These factors include climatic variables, technological advancements and overall changes in the national agricultural economy.

1.1.1 Climate and Drought Influences on the Transformation of the High Plains Region

Climatic factors have played an important role in the transformation of the region and movement towards irrigated farmland. The High Plains Region has a semi-arid climate where drought is a natural and recurring feature of the area. These drought cycles cause great pressure

on the agricultural practices in the region (Allen et al. 2007). The mean annual precipitation of the High Plains is quite varied throughout the region. Precipitation ranges from only 12 inches in the west, near where the study area is situated, to 33 inches in the east (USGS 2014). The region also has frequent winds, low humidity and a high rate of evaporation, which further exacerbate problems of drought (USGS 2014).

Though the region has had many drought occurrences, the most well known drought took place during the 1930s and is known as “The Dust Bowl” (Worster 2004). The Dust Bowl completely devastated agricultural production, and subsequently the communities, for nearly a decade. Frequent dust storms blew dirt from the ground continuously, due to the lack of moisture in the soil and no natural vegetation to hold it in place. The plowing practices of the farmers stripped all vegetation from the ground leaving no defense against the winds (Worster 2004). This extreme long-term drought event completely changed the communities’ attitudes and agricultural practices in the High Plains. The Dust Bowl also marshaled in new proactive programs to help agriculturalists and communities to cope with and better manage drought related issues. Programs such as the Soil Conservation Agency, now known as the Natural Resources Conservation Service, started educational projects on soil conservation measures amongst other things (NDMC 2014). Programs like this one continued to play an important role in mitigating the effects of the cyclical droughts over the past century.

During the 1950s, 1970s, 1990s and from 2001 to 2014, the area has been presented with episodes of severe drought conditions (US Drought Monitor 2014). During the drought in the 1950s, a larger area was actually affected than during the Dust Bowl. Fortunately, however, with the new programs, educational projects and conservation techniques, the extensive conditions of the 1930s were prevented (Wilhite et al. 1986). While not as extensive, the drought in the 1970s brought new challenges and awareness of water management issues, particularly for irrigated cropland (Greb 1979). The most recent drought from 2001 to 2014, particularly from 2011

through 2014, is quite significant and had conditions dryer and hotter than during The Dust Bowl years (US Drought Monitor 2014). The number of sustained drought years has been longer than previous drought cycles as well. These drought cycles in the region and the entire U.S., combined with the desire for higher production and profit returns, have also encouraged a rapid change in technologies, particularly for irrigation.

1.1.2 Technological Influences on the Transformation of the High Plains Region

Agricultural technology advances began in the 1880s with the advent of the wind pump well, followed by the "pit-less" centrifugal pump in 1910 (Sophocleous and Merriam 2012). Large-scale irrigation methods began to be employed after WWII, following the drought of the 1950s (Worster 2004). During this time, agriculturalists began to have a sense of security in irrigation. One USDA official at the time even said the region had "climate free agriculture" due to the seemingly endless supply of irrigation water (Worster 2004:234). A majority of irrigated land during the 1950s and 1960s was irrigated by a flood (furrow) method. This type of irrigation applies water into long shallow ditches at evenly spaced intervals with specific rates of flow (USDA-SCS 2008). Though useful for maximizing yields and profits over dry land farming, evaporation loss and water waste were substantial problems making this type of irrigation method quite inefficient given the local climate (USDA-SCS 2008). Furrow irrigation is typically only 60 to 75 percent efficient when taking into account water loss (Solomon 1988).

In 1949 the first Center Pivot Irrigation (CPI) System was invented and patented in Texas (USDA-SCS 2008). However, CPI systems did not become widely used for another 20 years. During the 1970s CPI systems began to spread rapidly throughout the area. In the Western states, in just 10 years between 1970 and 1980, CPI area expanded by 686 percent (McKnight 1986). CPI systems were advantageous to flood irrigation due to less evaporation loss and waste, with an increased efficiency of 75-90 percent (Solomon 1988). CPI systems were also advantageous

because they were less labor intensive. Furthermore, CPI systems allowed for irrigation of unlevel or sandy land that was previously unproductive (McKnight 1986). Though these popular CPI systems reduced the amount of evaporation and water waste, the sprinkler systems were still not very efficient for the semiarid climate of the high plains.

During the 1980s and 1990s, higher efficiency sprinklers used by the CPI systems were invented to help reduce evaporation and increase water efficiency to greater than 95 percent (Alliery and Gollehon USDA ERS n.d.). Due to the higher efficiency and cost savings, even more CPI systems began to be installed, putting greater pressure on the Ogallala Aquifer's groundwater resources (Sophocleous and Merriam 2012). These technological advances coincided with an ever-changing American economy, which further facilitated the transformation of the High Plains Region.

1.1.3 Economic Influences on the Transformation of High Plains Region

Today, the High Plains are a vital ranching and agriculture region in the United States, and local economies are highly dependent on agriculture. The region is known as the "grain basket of the United States" (Scanlon et al. 2012:9321). Crops grown in the area provide a considerable proportion of the total crop production in the United States. Current land use by area is 55.6 percent rangeland and 40.9 percent agriculture (USGS 2014a). Of the 40.9 percent for agricultural land, 28 percent of it is irrigated (USGS 2014a). During most years, irrigation is required for economic yields for the cash crops including: alfalfa, corn, cotton, sorghum, soybeans, peanuts, and wheat (USGS 2014a). Due to increasing market demands, corn, in particular, is one of the mostly widely grown irrigated feed grain crops in the High Plains. Additionally, corn is processed into many different food and industrial products. These products include corn oil, sweeteners, beverage and industrial alcohol, and fuel ethanol (USDA-ERS 2015). The United States is currently a major exporter in the global corn trade market, and

exports about 20 percent of its corn (USDA-ERS 2015). This expansion of the market for corn and corn-related products continues to play an enormous part in the transformation of the Great Plains.

In addition to being an important area for crop production, the region also accounts for about 18 percent of cattle production in the United States (USGS 2014a). Cattle production in this region in particular, relies heavily on the vast amount of cereal grains grown in the area such as corn, soybeans, wheat, barley and sorghum. This is especially true during drought when grass is inadequate to support cattle's needs (EPA 2012). During such times, it is necessary for ranchers to supplement the cattle's diet with feed. The most common feed grain is corn, particularly in the high plains region where a majority of the crop is grown. The irrigated corn for feed is essential to sustain the large cattle populations and feedlots (EPA 2012).

The primary source of water for the irrigated crops that support both farming and ranching productions in the region comes from the vast, but rapidly depleting High Plains Aquifer System. The largest aquifer in that aquifer system is the Ogallala Aquifer, which proves to be an invaluable resource for the economy and communities of the region.

1.2 Ogallala Aquifer in the High Plains

The High Plains Aquifer System is commonly referred to as the Ogallala Aquifer, though it actually encompasses multiple aquifers. This High Plains System includes the Ogallala Aquifer (the largest) as well as several other formations including the Morrison, Dakota, Brule and the Arikaree aquifers (Miller and Appel 1997). The High Plains Aquifer is a large underground water reservoir, which underlies a stretch of eight states including: Texas, New Mexico, Oklahoma, Colorado, Kansas, Wyoming, Nebraska, and South Dakota (McGuire 2012) (Figure 2). The aquifer makes the region one of the most productive farming areas in the world. However, such productivity comes at the high cost of a putting the future sustainability of the water resource at

enormous risk (Sophocleous 2012). Aquifers like the Ogallala depend on continuous recharge (water that reaches the water table) from sources like precipitation, surface water (rivers, streams, ponds, etc.) and return flow from irrigation (Steward et al. 2013). For the High Plains Aquifer, recharge comes almost exclusively from precipitation. However, due to the limited amount of precipitation in the region, the net recharge rate for the aquifer is practically zero. Though, there are a few places with a small amount of recharge occurring in Union County, NM (USGS High Plains Water Level Monitoring Study-New Mexico 2014).



Figure 2: U.S. Ogallala Aquifer Boundary

(Source: Adapted by author from USGS High Plains -Water Level Monitoring Study 2014a)

Along with the very minimal recharge that occurs, there is also a vast amount of water being pumped from the aquifer for irrigation, mainly by CPI systems. This depletion of the aquifer is considered to be occurring at an unsustainable rate (Scanlon et al. 2012; Sophocleous 2012; Steward et al. 2013). The USGS's High Plains Aquifer Water-Level Monitoring Study reports that irrigated acreage increased rapidly from the 1940s to the 1980s, with 2.1 million acres irrigated in 1949 and by 1980 13.7 million acres were irrigated (USGS High Plains Water Level Monitoring Study 2014a). By 1997 that number slightly increased to 13.9 million acres but then

declined to 12.7 million acres in 2002 (USGS High Plains Water Level Monitoring Study 2014a). That same monitoring study also reports that groundwater irrigation withdrawals from 1949 to 1974 increased from 4 million acre-feet of groundwater to 19 million acre-feet, and from 1980 to 2000 irrigation withdrawals varied between 2 to 18 percent of 1974 withdrawals (USGS High Plains Water Level Monitoring Study 2014). The variations found in groundwater withdrawals can be closely linked with the groundwater well and pumping policies in place by each state.

1.3 Groundwater Rights and Policies in the High Plains

In the United States, ground water policy creation and assigning groundwater property rights is a responsibility given to individual states (Emel and Roberts 1995; Theesfeld 2010). There are typically three options for governing groundwater. The first is by prior appropriation rights, second is by riparian appropriation rights and the third is correlative rights (SRWP 2014). Prior appropriation rights are rights that are not tied to land ownership. The first to appropriate water for beneficial use has the right to that water (SRWP 2014). However, in order to obtain rights for beneficial use, acquiring a permit is required by each state. This type of doctrine is found in most of the states within the High Plains region including: Oklahoma, New Mexico, Wyoming, Kansas, and Colorado. How each state interprets and enforces this type of appropriation varies greatly. In Oklahoma, the groundwater is considered private property of the overlying surface owner, but groundwater use is also subject to "reasonable regulation" (OWRB 2014) by their Water Resources Board. The Water Resources Board is charged with issuing permits for drilling new wells. However, an additional requirement for obtaining a permit entails posting the application in the local newspaper for it to possibly be contested by others in the area. Oklahoma also has Annual Yields (MAYS) regions. MAYS regions only allow for a maximum amount of water withdrawn from an area based on the amount of available groundwater in the basin (OWRB 2014). In New Mexico, groundwater permits are the responsibility of a State

Engineer. Like in Oklahoma, the applications for rights must be posted in the newspaper and can be contested by others who feel their water rights could be impaired (NCSL 2013).

Riparian appropriation rights are water rights based on the English or common law rule, which give the landowners absolute rights over all water below ground. In this case the landowner can use, transfer or sell all the water they can capture from wells on their land as long as it is for beneficial use (NCSL 2013). There is also a limitation that water may not be taken to maliciously hurt a neighbor or be willfully wasteful (Sophocleous 2012). No state in the region uses this doctrine completely as all have some system of permits and regulations that groundwater users must follow. Correlative rights are similar to riparian rights in that groundwater is tied to the landowner. However, this doctrine considers groundwater a common resource and therefore limits withdrawal to a "reasonable use" (Nebraska Legislature 2014). This system is used by Nebraska to regulate groundwater use. Often though, a dual doctrine system is in place that uses both riparian and prior appropriation rights systems to restrict groundwater use. This dual doctrine is found only in Texas in the High Plains Region (NCSL 2013). In Texas, water rights are tied to the landowners, though the state also has local state water management areas or districts with locally elected board members. These water districts may intervene or set their own regulatory constraints and permitting systems (TWDB 2014).

Regardless of the type of appropriation system used, the ways in which each of these states govern their groundwater resources directly affects how water is withdrawn and how much, particularly for irrigation purposes. Also, due to groundwater's undefined boundaries, each state's groundwater policies may directly affect neighboring states as well. The study counties; Union County, NM and Cimarron County, OK, are part of this High Plains Region and are directly affected by these groundwater policies that have possible implications for agriculture.

1.4 Study Site

1.4.1 Union County, New Mexico

Union County, NM is located in the Northeastern part of the state and shares a border with Texas, Colorado and Cimarron County, OK. The county has a population of 4,370 and a land area of 3,823 sq. miles (US Census 2013b). Union County's population density is very low, with an average of 1.2 people per square mile (US Census 2010b). The climate of Union County is quite dry with an average annual precipitation of 16 inches and with an average of only 61 days per year with precipitation (WRCC 2014). The average annual high temperature is 68 degrees and the average annual low is 37 degrees (WRCC 2014). Currently, the county is in the middle of a long term severe to exceptional drought (US Drought Monitor 2014a), with an average of 13.3 inches of annual precipitation since 2001 (NOAA-Climate Data Center 2015).

New Mexico has a long tradition of ranching and farming (Raish and McSweeney 2011), which continues to this day. Currently, in Union County, 94 percent of agricultural land is in pasture or rangeland and about 6 percent is in cropland, irrigated cropland making up about 38 percent (Vadjunec et al. 2012:3). The county is ranked second in the state for cattle production and in comparison to other counties in New Mexico, it produces almost twice as many cattle. The county also ranks first in corn production with 62 percent of total production in New Mexico. Furthermore, the most important source of employment, with about 22 percent of all households, is from agriculture (Vadjunec et al. 2012:3).

1.4.2 Cimarron County, Oklahoma

Cimarron County, OK is the western-most county in the panhandle region of the state and borders Texas, Colorado, Kansas and Union County, NM. The county has a population of 2,335 and land area of 1,834 sq. miles. Cimarron County's population density is similarly very low with 1.3 people per square mile (US Census 2010a). The climate of Cimarron County is also quite dry

with an average annual precipitation of 17.26 inches and an average of only 55 days a year with precipitation. The average annual high temperature is 71 degrees and the average annual low is 40 degrees (OCS 2010). Currently, the county is in the middle of a severe to exceptional drought (US Drought Monitor 2014b) with an average of 13.9 inches of annual precipitation since 2001 (OCS 2010).

Cimarron County, like Union County, NM, has a strong agricultural and ranching tradition. Presently, Cimarron County has 60 percent of its land dedicated to rangeland and 39 percent in cropland, of which 11 percent is irrigated (Vadjunec et al. 2012:5). Cimarron County is the second largest producer of cattle in Oklahoma (Vadjunec and Sheehan 2010) and in the top two percent for production of cattle in the nation. Employment from agriculture in the county makes up more than 36 percent of total employment (Vadjunec et al. 2012:4).

Table 1: Total amount of land (acres/percent) in irrigated agriculture in Union County, New Mexico and Cimarron County, Oklahoma (1949 to 2012)

Year	Union	Union % of Total	Cimarron	Cimarron % of Total
1949	6,181	0.25%	1,759	0.15%
1954	7,091	0.29%	2,744	0.23%
1964	8,723	0.35%	31,416	2.66%
1969	27,611	1.12%	83,986	7.12%
1978	33,516	1.36%	95,382	8.09%
1987	31,264	1.27%	46,840	3.97%
1992	32,848	1.34%	50,642	4.30%
1997	46,580	1.89%	68,941	5.85%
2002	49,428	2.01%	50,056	4.25%
2007	47,027	1.91%	45,513	3.86%
2012	26,014	1.06%	39,430	3.34%

(Source: Adapted from USDA Ag Census 1949, USDA Ag Census 1964, USDA Ag Census 1969, USDA Ag Census 1978, USDA Ag Census 1987, USDA Ag Census 2002, USDA Ag Census 2007, USDA Ag Census 2012)

As part of the High Plains agricultural region, both counties have seen a dramatic increase in irrigated acreage for ranching and agricultural uses over the past 65 years that have drastically changed the landscape (Table 1). The decline in water levels from the extensive

irrigation and pressures from cyclical climatic changes, technological advances and economic transformations has put great amounts of stress on agriculture in the region. In turn, these stresses have created more vulnerable communities that are reliant on agriculture for their livelihoods (Sophocleous 2012).

The following chapter, chapter two, provides a literature review for background on common property resources, water governance and vulnerability/resiliency. Chapter two then explores the theoretical framework on Land Change Science and Political Ecology that guides this study.

CHAPTER II

LITERATURE REVIEW AND THEORETICAL FRAMEWORK

Introduction

The decline of the High Plains Aquifer is one of the largest water management concerns currently facing the United States (Sophocleous 2012). Within the next 30 years, at the current rate of depletion, 35 percent of the southern high plains will be unable to support irrigation for agriculture (Scanlon et al. 2012:9321). Given the extensive ecological implications of groundwater depletion, research that evaluates current groundwater governance policies and explores possible implications of those policies is expansive (Allen et al. 2007; Scanlon et al. 2012, Sophocleous 2012). More so, the socio-economic implications, such as community and agricultural vulnerability from groundwater depletion have also lead to increasing research on vulnerability, resiliency and the role of water governance and politics (Emel et al. 1992; Theesefeld 2010; Jepson 2012; Vadjunec et al. 2012).

This chapter first assesses the concept of common pool resources and groundwater as a unique case. Next, the chapter explores the idea of groundwater governance as a base for understanding groundwater use and management. Then in section 2.3, the concepts of vulnerability and resiliency and their connection to adaptation, governance and land change are discussed. Lastly, section 2.4 outlines the argument for an integrated Land Change Science and Political Ecology framework to explore this multi-scalar and multi-temporal study.

2.1 Common Pool Resources and Groundwater as a Unique Case

2.1.1 Common Pool Resources

A common pool resource is a natural resource that benefits and is shared by a group of people. Since common pool resources are shared, when one individual pursues their own self-interest to use or collect that resource, it diminishes the availability for others (Ostrom 1990). In other words, with every unit extracted by one user, the resource becomes more limited for use by another. More so, due to two common pool resource characteristics, this extraction is difficult to control. The two main characteristics of common pool resources are: excludability and subtractability. Excludability is the difficulty in excluding or controlling access by users of the resource. Subtractability is the possibility of reaching an upper limit of production of resource units. Essentially, a resource that is not limitless. Together these two characteristics make common pool resource management difficult. Examples of common pool resources include: rangelands, irrigation systems, fisheries, forests, wildlife, and groundwater basins (Ostrom 1990).

Common pool resource management is an important area of research due to the growing population, and, in turn, the growth in demand or pressures on finite resources. These pressures often result in overexploitation of resources when local institutions are unable to regulate resource use due to local instability (Dietz et al. 2003). This overexploitation is commonly referred to as the 'commons dilemma' (Hardin 1968). The 'commons dilemma' presents a choice between an individual's self interest or a collective interest to manage and use resources to ensure long-term sustainability. More specifically, rewards for cooperation are less than the rewards for non-cooperation, making resource extraction more desirable no matter the long-term outcome (Gifford and Hine 1997). Due to this 'commons dilemma', and common overexploitation of resources, actions are often taken to try to govern and limit resource use through policy

interventions. In the case of groundwater, governing and limiting its use is even more difficult due to its unique characteristics.

2.1.2 Groundwater as a Unique Case

Groundwater is considered a common-pool resource having both subtractability and low excludability (Lopez-Gunn 2009; Theesfeld 2010). Subtractability in the case of groundwater is when the water levels drop with every unit of extraction. Excludability in the case of groundwater simply means the difficulty of excluding water users (Ostrom 2010). This excludability factor makes groundwater a particularly difficult resource to manage and restrict usage. Restriction is especially difficult because of groundwater's undefined boundaries. Groundwater boundaries typically cross between many different governmental jurisdictions such as regional, state, county and district levels. Due to this transboundary characteristic, assigning effective property rights is especially challenging (Theesfeld 2010).

The transboundary nature of groundwater also creates regulatory practices and policies that are highly variable from one governmental jurisdiction to another (Lopez-Gunn 2009). Some of these regulations involve the privatization of groundwater, while other governmental institutions have a practice of no regulation at all. Regardless, Lopez-Gunn (2009) contends that for effective aquifer management, collective action needs to take place between each sovereign state. Each state will also have to voluntarily elect to restrict its sovereign rights for the long-term stability of aquifer use. While groundwater shares these same characteristics with other common pool resources, Theesfeld (2010) offers that there are also three other attributes that make it a more unique case. These three attributes are: time lag, irreversibility and information asymmetry.

The time lag of groundwater refers to the effects of groundwater use, intervention, or even pollution possibly being recognized at a much later time period than that of initial contact (Puri and Aureli 2005, Theesfeld 2010). Due to the large spatial distances that aquifers cover,

impacts of depletion or pollution can take decades to recognize. This makes pumping effects on aquifers difficult to recognize as well (Theesfeld 2010). Irreversibility is another more unique attribute to groundwater. This refers to the possibility of doing irreversible damage to storage capacity or even contamination. Groundwater aquifers in certain cases have little to no net recharge; making withdraws from them unable to be replaced. Additionally, because of the hydrologic connectivity of aquifers, once contaminated, it is often difficult to impossible to contain and reverse the effects (Jarvis 2006; Theesfeld 2010).

The third unique attribute of groundwater is what Theesfeld (2010:133) terms, "information asymmetry." This attribute has more to do with the management aspects of groundwater administration. Groundwater management requires significant amounts of information to make informed decisions. However, most information regarding aquifer use is typically held by those who use or provide the water resource. Thus, they control what information is released and who is able to receive it. Users and producers can include everyone from the national, regional to individual level. Due to this, knowledge on groundwater is often misused or misinterpreted by different stakeholders in political or business arenas to pursue their own interests and benefits (Conca 2006; Theesfeld 2010).

With the increasing concern for water resources across the globe, understanding groundwater as a unique common pool resource case becomes increasingly important for studying groundwater use and management. Effective groundwater management and policy interventions to address all of these issues are difficult, and possible implications are quite varied. Therefore, it is of great importance to understand the implications of past policies of groundwater management to make more informed regulatory decisions in the future. A groundwater governance perspective provides an ideal approach to assess and understand these implications.

2.2 Groundwater Governance

While understanding the various ways in which groundwater is managed and regulated is critical, Jepson (2012) argues for the importance of understanding groundwater management issues through a governance lens. This approach differs from simply looking at government or policy. *Governance* encompasses not only the government and policies; but also the range of actors and political practices that shape environmental decision-making (Jepson 2012; Vadjunec et al. 2012). *Water governance* in particular, refers to the "range of organizations, institutions, laws and discourses that coordinate, regulate, or manage water allocation and use" (Jepson 2012:619). Thus, focusing on water governance can help to reveal the implications of policies from multiple levels of actors and institutions to local water users (Lopez-Gunn 2009; Theesfeld 2010; Faysse and Petit 2012).

Jepson (2012) uses this water governance framework to explain how water laws and political discourses are used to exclude a disenfranchised group of water users in Texas. Mexican-Americans in Jepson's study are excluded from not only legal access to potable water, but also from participating in the legal system that creates policies to manage that access. It is through these legal discourses where implications of groundwater regulation materialize. Welsh and colleagues (2013) also use this governance framework to assess how farmers in the Bear River Region in the United States, who have the most legally secure water rights, are somehow also the most vulnerable to severe drought. During times of drought, these farmers are accustomed to having readily available irrigation water. However, when water is no longer available, farmers lack past non-irrigated drought experience or knowledge to adapt accordingly. Welsh and colleagues (2013:3) argue that, "drought vulnerabilities are shaped not only by natural contexts, but social contexts as well." The social contexts of drought vulnerability include: political, institutional, geographic, economic, and social structures (Keenan and Krannich 1997; Wilhite et al. 2005; Lebel et al 2006). Institutions often create reactive policies that may actually

increase vulnerability instead of being proactive to reduce or mitigate impacts due to drought (Welsh et al. 2013).

Both Jepson (2012) and Welsh and colleagues (2013) find that inadequate or misguided groundwater policies may lead to increasingly vulnerable communities or ecological systems (see also Somma 1997; Folke et al. 2005; Agnew 2011; Johnson et al. 2011). Thus, it is important to understand what role governance plays in fostering or hindering more resilient communities and ecological systems. The following section explores the concepts of vulnerability and resiliency as they relate to communities and ecological systems.

2.3 Vulnerability and Resiliency

Vulnerability and resiliency are terms that are relevant to both the biophysical/ecological realm and the social/human realm (Gallopín 2006). *Vulnerability* is defined as "the state of susceptibility to harm from exposure to stresses associated with environmental and social change, and from the absence of capacity to adapt" (Birkenholtz 2011:297). Vulnerability reduces the ability for people or communities to resist and adapt to ecological or social pressures.

Vulnerability is considered a powerful analytical tool that can be used to describe states of susceptibility to harm, marginality and powerlessness of social and biophysical systems (Adger 2006). Adger (2006), in particular, argues that vulnerability does not exist in isolation from "the wider political economy of resource use" (270). Adger (2006) further argues that vulnerability is driven (deliberately or not) by human action, reinforced self-interest, and the distribution of power beyond just interactions between humans with their environments. Thus, vulnerability does not only occur because of humans living in a vulnerable environment but also because of varied social, political and economic factors that influence and guide those interactions.

The key to reducing vulnerability, whether for a person, community or ecosystem, is having or fostering resiliency. "Resilience thinking" originates from ecology and the idea of

systems and ecological resilience (Aldunce et al. 2014:255). However, this idea of ecological resilience has evolved into a resilience perspective beyond just ecological systems. This perspective is now commonly used to understand the dynamics of social and ecological interactions (Folke et al. 2005). Using this combined perspective, *Resiliency* is defined as the “capacity of a system to absorb disturbance, reorganize while undergoing change and still be able to retain the same or similar functionality or state as prior to a disturbance” (Walker et al. 2004:2). These reorganizations and absorptions are often in the form of adaptations, which help communities or systems better cope with and adjust to disturbances. Within the social component of resiliency, systems are able to learn and change or adapt through institutional contexts as in; sharing past knowledge, social capital and strong social connections (Aldunce et al. 2014).

Scholars stress the need to understand and assess vulnerability from a local scale as imperative for learning adaptive lessons from past local knowledge (McLeman et al. 2008; Langridge et al. 2006; Fraser et al. 2011). McLeman and colleagues (2008) suggest that in order to uncover knowledge about vulnerabilities, adaptive behaviors, and processes in agricultural regions, researchers need to look at historically comparable situations. In turn, this will provide important lessons for present day policy makers (McLeman et al. 2008). Langridge and colleagues (2006) also encourage a historical analysis approach for studying processes and relations that create social resilience in order to reveal local insights (Langridge et al. 2006). These scholars illuminate the importance of drawing from local knowledge to inform their research and create better solutions and policies for resilience.

Research that examines the role governance (e.g. institutions, actors and policies) plays in creating vulnerability or fostering resiliency is also stressed (Langridge 2006; Beymer-Farris 2013; Vadjunec et al. 2012). Vulnerability and resilience research often emphasizes a multi-scalar framework to understand what creates vulnerable and/or resilient communities/systems. Such research is also concerned with whether or not communities are able to adapt to certain pressures

from multiple levels of institutions. Beymer-Farris's (2013) research in Tanzania's Mangrove Forests utilizes this multi-scalar resiliency framework. The study assesses the role of human and non-human actors in the production of ecological resilience (Beymer-Farris 2013). Her work focuses on the political and economic structures and power relations over access, control, and management of biodiversity conservation. The study considers how such power relations can result in both successes and failures of ecological resilience (Beymer-Farris 2013).

Research by Vadjunec and colleagues (2012) also assesses the role that various governmental institutions, actors and policies play in vulnerability to drought in the grasslands of the American West. The study explores community resiliency to drought by examining environmental conditions, cultural-historical factors and land-use management, all within a multi-scalar context of governance, power, and politics (Vadjunec et al. 2012). In both of these studies, the impact of political structures and power relations at various scales greatly influence a community's ability to adapt, be resilient and resist vulnerabilities. To best explore socio-ecological resiliency, both studies argue for an integrated Land Change Science and Political Ecology framework.

2.4 Combined Land Change Science and Political Ecology Framework

2.4.1 Land Change Science

Land Change Science (LCS) seeks to understand the dynamics of land-system changes or patterns, such as ecosystems services, land degradation or vulnerabilities from human-environment interactions through the use of modeling (Rindfuss et al. 2004). LCS acknowledges that land cover and land use are a coupled human-environment system where humans and their environment cannot be separated from each other. Models reflect this idea by incorporating not only biophysical attributes but also socio-economic and land-use data as well (Turner et al. 2007; Brannstrom and Vadjunec 2013). LCS models are generally larger in scale, often at the regional

or national levels, and for the most part take a top down approach to understand biophysical land changes through space and time (Turner and Robbins 2008). LCS also encompasses resilience themes from ecology, and addresses and models vulnerability and resilience of coupled human-environment systems. Subsequently, "LCS has adopted land systems vulnerability as a major research component" (Turner and Robbins 2008:298).

Applications of LCS models include issues that remote sensors and physical scientists are concerned with, such as shifts in vegetation cover from agriculture (Walker and Richards 2013). Geographic Information Systems (GIS) and remote sensing (RS) are often used to model these land changes. For example, Kull (2013) uses remote sensing analysis of aerial photographs to study land-use/land-cover change (LULCC) in the central highlands of Madagascar. The aerial photo analysis reveals land-cover change patterns of grassland by a growing population of subsistence small-scale farmers and increased crop fields and farm trees. The analysis also reveals considerable variability between numerous study sites that are a result of government-sponsored agricultural colonization or forestry projects (Kull 2013). Vadjunec and colleagues (2012) also use RS and GIS in order to model land-use management and spatio-temporal environmental and human relationships in the Grasslands of the American West. The GIS analysis maps and analyzes the spatial distribution of private and public lands and associated uses over time, in order to explore adaptations and vulnerabilities to drought (Vadjunec et al. 2012).

In the example by Kull (2013) in Madagascar, the aerial photo analysis shows what land-cover changes have taken place, but does not explain the political-ecological implications of these land-cover changes to the land and land users. In the second example by Vadjunec and colleagues (2012), GIS analysis is being used to show environmental and human relationship changes through space and time. However, solely using a GIS model of social and environmental change does not explain how governance, politics and structural institutions have impacted those relationships. If using only LCS, both examples would, for the most part, lack the structural

explanations and adequate exploration of socio-economic implications of local, regional and national political actions (Robbins 2004). For this reason, both examples also incorporate a Political Ecology perspective to enhance their studies. Political ecology's emphasis on governance, power, and politics offers a theoretical framework from which to explore these structural implications further.

2.4.2 Political Ecology

Blaikie and Brookfield (1987) state that *Political Ecology (PE)* "combines the concerns of ecology and a broadly defined political economy" (Blaikie and Brookfield 1987:17) in order to explain environmental change and the forces that drive such change. PE can be considered, in part, a toolkit of political economy that creates a way of exploring issues of access and control over resources (Peet and Watts 2004). PE researchers seek to identify the broader systems of access and control to explain mismanagement and degradation problems. Ideas of power and control are critical to PE (Robbins 2004). Consequently, land-change patterns that occur are often considered to be a result of uneven power relations, among other things (Brannstrom and Vadjunec 2013).

PE work generally takes a bottom-up approach to analysis, with focuses predominantly at the household level in order to understand individual actions and responses to environmental and social pressures (Robbins 2004). Blaikie (1985:107) states that a PE approach starts with "actual people making actual decisions on how to use the land." Often these local scale land-use and land-cover changes are considered apolitical (nonpolitical) and only consequences of local actors and their actions (Robbins 2004:14). PE examines these changes more critically by starting at the local level and then connecting land-management processes to various levels of institutions and actors (Blaikie and Brookfield 1987). PE seeks to explain these processes within the larger, biological, social and politicized context (Rocheleau et al. 2001; Robbins 2004).

Historically in PE research, the local actors are often disenfranchised or marginalized peoples in the "developing world." Thus, a primary focus of PE work has been predominantly linked to cultural ecology studies on hunter gatherers, rural subsistence farmers, producer communities, peasantries and pastoralists and the institutional processes that impact their land use (Blaikie 1985; Netting 1986; Hecht and Cockburn 1990; Rocheleau et al. 2001; Kull 2004). For example, Blaikie (1985) explores studies on soil erosion in developing countries like Zambia, Thailand and various countries in Africa. Blaikie (1985) argues for research that first focuses at the micro level scale for land and land users, to understand soil erosion. Then, a "move up the scale of concern" enables a connection of land users with larger systems such as markets, laws and political struggles and institutions like transnational companies (Blaikie 1985:107). Blaikie's (1985:107) "bottom up" study finds that the transnational companies actually put pressure on the local communities to produce intensively. This in turn paves the road for more intensive land use and soil erosion. The implications from such pressures and further soil erosion are that land users become more marginalized from the process.

While PE studies still largely focus on developing world groups, more recently, PE research increasingly also focuses on the "developed world" (McCarthy 2002; Robbins 2006). Developed countries also have environmental conflicts that are a result of uneven development due to the relationship between knowledge, policy and power (Robbins 2006). Sheridan's (2007) study on ranchers and urban sprawl in the American West utilizes this "first world" PE framework. Sheridan's (2007) study explores resource control and contested landscapes between traditional land users and more recent developers of the land. The study explores ideological and political conflicts between the two groups, to explain uneven access to the contested landscapes and uneven control over the resources within them (Sheridan 2007). Like in PE research on third world environmental conflicts, the uneven access and control of resources further marginalizes

certain groups, such as small-scale agriculturalists. Further, both third and first world PE studies reveal implications of uneven access that are closely linked with larger institutional structures.

In both third and first world Political Ecologies, vulnerability and resilience of individuals, communities or ecosystems are also intimately linked with local land-change processes and uneven power relations. Often, marginalized peoples are more vulnerable to land changes and environmental degradation due to uneven development, or unequal access to resources. Given this, PE also has considerable focus on vulnerability and resilience of such groups (Langridge et al. 2006; Turner and Robbins 2008; Birkenholtz 2011; Welsh et al. 2013). For instance, work by Birkenholtz (2011) utilizes a PE framework to study vulnerability to climate change in Rajasthan, India. The study explores vulnerability implications and unintended policy effects of social power processes. The study further explores how political and economic constraints inhibit adaptations to climate variability, which further exacerbates vulnerabilities. Birkenholtz (2011) begins with a local-level analysis on how farmers cope with weather variability. Then, the analysis links farmers' coping mechanisms or lack of, to broader social and economic structures to better understand the roles of such structures to farmer's vulnerability. A PE framework enables Birkenholtz (2011) to directly link vulnerability with larger structural institutions.

Though PE work is able to effectively critically examine environmental change problems through a socio-economic lens, in both third and first world regions, it has been criticized for often ignoring the ecological component of political ecology (Walker and Richards 2013). Critics argue that ecosystems are largely ignored and that the focus remains primarily on human systems instead (Beymer-Farris 2013). Land Change Sciences' emphasis on the biophysical answers the "where's the ecology in political ecology" question. Therefore, LCS and PE both answer and ask distinct but complementary questions the other does not. Together LCS and PE provide a more comprehensive framework for studying land changes and implications.

2.4.3 Combined Land Change Science and Political Ecology Framework-

Land Change Science and Political Ecology are "complementary and parallel approaches" for addressing land change through human environment dynamics (Turner and Robbins 2008:296). Both LCS and PE emphasize the complexity of land-change processes and the strong influences of context within a coupled human-environment system (Turner and Robbins 2008). LCS emphasizes biophysical models of land change with a top down approach and gives attention to ecosystem and earth system interactions (Turner and Robbins 2008). In contrast, PE focuses on socio-economic (and political) factors of land change from a bottom up approach. Together they create a more dynamic and multi-scalar study on land change causes and implications. Both LCS and PE tie local problems to global human and environment systems. LCS and PE both also "follow land management practices to their environmental consequences" (Turner and Robbins 2008:300) and are concerned with potential environmental degradation and scarcity linked with land management practices.

Brannstrom and Vadjunec's book (2013:2) "Land Change Science, Political Ecology and Sustainability: Synergies and Divergences" states that, LCS and PE seek explanations of "real world problems relating to livelihoods and resources" and call for a hybrid LCS/PE research approach. Other scholars also use this combined framework to shape studies on land change, agriculture, governance and resilience, among other things (Turner et al. 2007; Vadjunec et al. 2012; Beymer-Farris 2013; Kull 2013; Walker and Richards 2013). For example, Jepson and colleagues (2010) use remote sensing to analyze land-use and land-cover change due to agriculture in the Brazilian Cerrado. The study first uses LCS to examine the land changes from high-input agriculture by modeling. Then, using qualitative and archival data, the study examines the impact of local, regional and national government institutions and actors on land-use and land-cover changes. The role of these institutions "explains the processes that cause patterns of high-input agriculture expansion" (Jepson et al. 2010:87). Beymer-Farris's (2013) work on

ecological resiliency, as presented earlier, is also framed using a combined LCS/PE lens as well. The study begins by using models to explore changes using LCS. Then, to explain structural changes, the study focuses on the political and economic structures and power relations over access, control and management (Beymer-Farris 2013:99; Robbins and Turner 2013). Together LCS and PE provide a multi scalar approach to study the role of these institutions and power relations in land change. Furthermore, LCS and PE are especially useful for understanding how such relations contribute to vulnerability.

Conclusion

This chapter first reviewed the concept of Common Pool Resources and the increasing pressures and overexploitation of such resources. Groundwater however, is an especially unique case of a common pool resource. This is because of three additional attributes: time lag, irreversibility, and information asymmetry. Researchers often use a groundwater governance lens to better understand groundwater management and policy implications that arise from all Common Pool Resources attributes. Such implications often result in more vulnerable or resilient societal and/or ecological systems. Common throughout many LCS and PE studies is the importance of using LCS and PE both to understand resiliency or vulnerability. LCS and PE together, present a way in which to *critically* examine land changes and the driving socio-economic/political or governance forces that create or inhibit resilient systems. The next chapter on methods will explain the techniques used to explore the concepts presented in this theoretical framework.

CHAPTER III

METHODOLOGY

Introduction

This research uses a mixed methods approach to study the relationship between center pivot irrigation growth, institutions and vulnerability in Union County, NM and Cimarron County, OK. The research analysis includes methods that are used by research in Land Change Science (LCS) as well as Political Ecology (PE) in order to create a mixed method, multi-scalar approach. LCS typically takes a top down approach through the use of Remote Sensing (RS) and GIS techniques to explore land change (Turner and Robbins 2008). Conversely, PE typically takes a bottom up approach utilizing methods such as participant observation, key informant interviews and archival research (Turner and Robbins 2008). These methods are used together to first explore land change through the use of GIS and RS. Then, key informant interviews are conducted in order to explore institutional or policy explanations for such growth. Finally, archival and secondary research is used to triangulate the research results by expanding on the explanations provided in the key informant interviews.

In addition to the three primary methodologies, methods from the larger NSF-Funded project (CMMI#1266381) were also utilized, particularly in the initial phase of the research formulation and throughout the research process. Fieldwork in June of 2014 involved participant observation, a focus group, and household surveys. While these methods and results were undertaken for the larger project, they were helpful to this project in many ways.

As a NSF grant funded research assistant, I gained valuable IRB training and field experience at the study site. Also, the fieldwork helped me to gain social capital in the communities, become familiar with the study area and its characteristics, as well as to acquire first hand knowledge of the issues that the area faces. During this fieldwork in June of 2014, I helped to conduct portions of the 120 household surveys that were undertaken. The household surveys typically lasted from two to three hours, and had both open and closed-ended questions. The questions asked during the surveys were quite varied and subjects included issues related to drought, land use, agricultural production, and household and agriculture water use. Furthermore, more specific questions related to my research were asked as well. These questions inquired about center pivot irrigation use and influences that encouraged or discouraged its use. Extensive notes were taken during this process of participant observation. Overall, the responses to these questions helped to frame my own thesis research as well as helped to formulate my research questions.

The specific research components (Table 2) were then chosen in order to best explore the research questions:

- 1) How much land (in acreage) in Union County, NM and Cimarron County, OK is irrigated by Center Pivot Systems and how has this changed over space and time?
- 2) What policies and practices have influenced Center Pivot Irrigation growth and how?
- 3) How do local communities perceive the role of Center Pivot Irrigation use in relation to vulnerability and drought in the region?

Table 2. Research Components: Primary Data Collection and Analysis

Questions	Methodologies	Summary of Analysis
1	GIS/RS	Goal: Calculate and map CPI change from 1950s to present Analysis: Use GIS/RS to digitize CPI growth and calculate change
2 and 3	Key Informant Interviews (n=20)	Goal: a) Explore policies and factors that have influenced the growth of CPI b) Explore the relationship between CPI, drought and community vulnerability Analysis: Open grounded coding used to analyze interview data
3	Archival and Secondary Research	Goal: Explore the policies and factors coded from the key informant interviews that have driven the use of CPI Analysis: Use primary and secondary sources to triangulate data

The mixed methods for the project are presented in three stages below. The first stage is the GIS/RS analysis. Stage 1 involves the data collection, processing, calculation and mapping of CPI change. The years of analysis (1950s to the present) are based on time periods of significant change in either technology or climate. The imagery from the 1950s are used as a baseline for 'pre-development', or before CPI began to be used. The 1980s show the change after the transition from flood irrigation to CPI during the 1970s. The next set of images in the 2000s reveal the shorter increments of change during the most recent long-term drought cycle that has lasted since about 2001 (OCS 2010).

The second stage of the methods is the key informant interviews. Key informant interviews involved ten days in the field in January 2015 interviewing local governmental officials, business owners and community members. The interviews use an open coding method in order to determine common influencing factors on CPI use and vulnerability to drought. As this stage involves human subject research, the IRB approval fell under the domain of the larger NSF Project (Appendix A). IRB training was completed as part of the part the initial fieldwork requirements. The third stage of methods is the archival and secondary research. The archival and secondary research further explores the topics found through the open coding of the interview data. The final stage of archival/secondary research triangulates the data for a more comprehensive understanding of when CPI change took place and what factors influenced that change. The three parts of the methods are detailed below.

3.1 Part 1: GIS/RS Analysis

Part one of the methods involved a GIS/RS analysis where data was first collected. The next step was then to process the data and then finally analyze.

3.1.1 Data and Data Collection

The first part of stage one was data collection. The primary data for the GIS/RS analysis was FSA NAIP aerial imagery taken during peak crop growing conditions (USDA-NRCS 2005). The imagery came from multiple sources and in various forms, some purchased by the larger project and some open source, which are shown below (Table 3). In addition to imagery, a shapefile of county outlines was needed for the GIS analysis.

Table 3. Data, Data Source and Data Description

Data	Data Source	Description
1956 Union County Aerial Imagery Mosaics	Earth Data Analysis Center	2 historical imagery mosaics downloaded from ftp site as tif files Not georeferenced Scale 1:20,000
1959 Cimarron County Aerial Imagery Mosaics	Oklahoma Geological Survey Image Library-Norman, OK	6 historical imagery mosaics scanned and saved as tif files Not georeferenced Scale 1:20,000
1986 Union County Aerial Imagery	USDA-FSA APF Office	99 historical aerial images scanned and saved as tif files Not georeferenced Scale 1:40,000
1985 Cimarron County Aerial Imagery	USDA-FSA APF Office	48 historical aerial images scanned and saved as tif files Not georeferenced Scale: 1:40,000
2005 Union County Aerial Imagery	USDA-NRCS Geospatial Data Gateway	NAIP Digital Orthophoto Quarter-Quadrangle (DOQQ) raster image (tif file) Datum: UTM NAD 83 Zone 13 Resolution: 1 Meter
2005 Cimarron County Aerial Imagery	USDA-NRCS Geospatial Data Gateway	NAIP Digital Orthophoto Quarter-Quadrangle (DOQQ) raster image (tif file) Datum: UTM NAD 83 Zone 13 Resolution: 1 Meter
2009 Union County Aerial Imagery	USDA-NRCS Geospatial Data Gateway	NAIP Digital Orthophoto Quarter-Quadrangle (DOQQ) raster image (tif file) Datum: UTM NAD 83 Zone 13 Resolution: 1 Meter
2008 Cimarron County Aerial Imagery	USDA-NRCS Geospatial Data Gateway	NAIP Digital Orthophoto Quarter-Quadrangle (DOQQ) raster image (tif file) Datum: UTM NAD 83 Zone 13 Resolution: 1 Meter
2011 Union County Aerial Imagery	USDA-NRCS Geospatial Data Gateway	NAIP Digital Orthophoto Quarter-Quadrangle (DOQQ) raster image (tif file) Datum: UTM NAD 83 Zone 13 Resolution: 1 Meter
2010 Cimarron County Aerial Imagery	USDA-NRCS Geospatial Data Gateway	NAIP Digital Orthophoto Quarter-Quadrangle (DOQQ) raster image (tif file) Datum: UTM NAD 83 Zone 13 Resolution: 1 Meter
2014 Union County Aerial Imagery	USDA-NRCS Geospatial Data Gateway	NAIP Digital Orthophoto Quarter-Quadrangle (DOQQ) raster image (tif file) Datum: UTM NAD 83 Zone 13 Resolution: 1 Meter
2013 Cimarron Aerial Imagery	USDA-NRCS Geospatial Data Gateway	NAIP Digital Orthophoto Quarter-Quadrangle (DOQQ) raster image (tif file) Datum: UTM NAD 83 Zone 13 Resolution: 1 Meter
County Outline Shapefile	USDA-NRCS Geospatial Data Gateway	NRCS Counties by state TIGER Line files Vector format Datum: UTM NAD 83

3.1.2 Data Processing

In order for the data to be used for analysis, some of the images needed to be processed first (Figure 3).

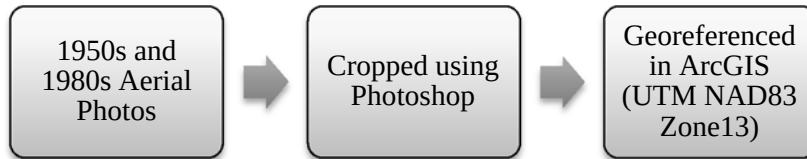


Figure 3: GIS Data Processing Flowchart

The 1956 and 1986 Union County imagery and the 1959 and 1985 Cimarron County imagery all needed to have their borders cropped first using Adobe Photoshop. The borders were cropped to ensure that images would overlap without the image borders obstructing data. Next, the images were georeferenced to the desired coordinate system. Georeferencing was used to scale and rotate the images to match the desired projected coordinate system of UTM NAD 83 Zone 13 using an image already in that coordinate system. The georeferencing was done in ArcMap using the georeferencing toolbar. Each of the images was georeferenced by year in separate ArcMap .mxd files.

In order to georeference the images, each needed to have at least four control points, one in each of the four corners. The points were as spread out as possible to ensure more accurate referencing. The control points were checked for residuals and root mean square (RMS) error. RMS error is the difference between where the points actually ended up, as opposed to the actual location (ESRI 2014). Typically RMS values should be a single pixel or about one meter. In the instance of this analysis issues with the 1950s and 1980s images emerged making RMS values higher than one, though still useful for digitization and analysis. For these images, error was higher at times because the photos were taken at an angle as well as mosaicked together by staples or tape. Due to these issues with the images, the more control points that were tagged the

worse the RMS rate became. The average RMS for the 1950s imagery was around five however, because there were no CPI circles present and no digitization was needed, this did not cause an issue. The average RMS for the 1980s imagery was around two, which was still deemed an acceptable RMS value for this analysis after to a couple of spot checks. The first check was to verify that the average size of the digitized CPI circles in the 1980s were nearly the same size as the CPI circles from subsequent years. Each of the circles in the 1980s were about 2,563 feet in diameter and each of the circles in subsequent years were about 2,561 feet. This ensured that the georeferencing was accurate enough to capture correct CPI size. The second check was to verify that the CPI circles in the 1980s were located within the aquifer and within nearly the same area as the other CPI circles from subsequent years. All of the circles from the 1980s in both Union County and Cimarron County fell within the aquifer boundary. Also, when the layers of all CPI years were overlapped, the CPI circles from the 1980s were also within about 120 feet of what would be the same CPI circles from the subsequent years. After each image was rectified, all of the 1950s and 1980s images were in the same UTM NAD 83 projected coordinate system and ready for analysis.

The 2005 through 2014 images for both counties were already in a form that was ready for analysis in ArcMap. Each year was already in a single image that was already georeferenced to the desired coordinate system. The county shapefile for the entire county also needed to be further processed to only be the outline for Union County and Cimarron County using the query box from layer properties. These new layers were created in order to show the boundaries of each county so that analysis was done in the correct area.

3.1.3 Data Analysis

In order to calculate and map CPI change over time, the CPI circles for each year needed to be digitized. Digitizing the circles created vector data that could then be used to calculate their

area and map change. Images from the 1950s (the project's baseline) were not digitized due to the fact that there were no CPI circles present in that time period. The CPI circles for all other years were digitized using the same process. For Union County the years digitized were: 1986, 2005, 2009, 2011 and 2014 and in Cimarron County the years digitized were: 1985, 2005, 2008, 2010 and 2013. Each year was digitized in its own ArcMap file that was created and saved during the processing stage to keep them well organized (Figure 4).

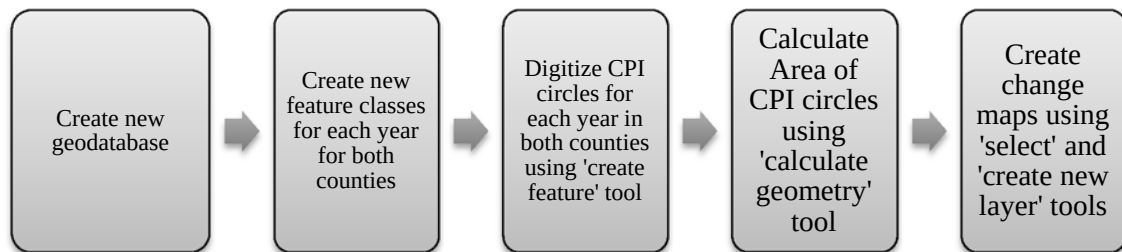


Figure 4: GIS Data Analysis Flowchart

The first step in digitizing the data was to create a new geodatabase in ArcCatalog to store the saved digitized feature classes. Also within ArcCatalog, new feature classes were created within the geodatabase for each year. When the new feature classes were created, each were named according to county and year, the feature types were polygons and the coordinate systems were imported from the NAIP image. The CPI circles were then digitized using the editor 'create feature' with the circle construction tool. As this study is interested in CPI irrigation from the High Plains Aquifer, only CPI circles that were within its boundaries were digitized.

Once all of the CPI circles were digitized for Union County 2014, the areas in acres for each of the circles were calculated. This was done in the attribute table by adding a new field and using the 'calculate geometry' tool. From these values a percent change of either increase or decrease from year to year was calculated in Excel.

The next step was to identify and calculate the number of CPI systems and identify the area of change from year to year. Given that in the 1950s imagery no CPI systems were present, the change from the 1950s to the 1980s was calculated to be zero. As a result, all of the CPI systems digitized in the 1980s were therefore new. Consequently, for both counties change was calculated and mapped starting with the 1980s through the present. Change maps that were created for Union County were: 1986-2005, 2005-2009, 2009-2011 and 2011-2014. In Cimarron County the change maps created were: 1985-2005, 2005-2008, 2008-2010 and 2010-2013.

In order to calculate and map the change over time the 'select' tool was used. The 'select by location' tool could not be used for this analysis due to a couple of problems with the data. The same issues that caused problems with georeferencing the older imagery also caused issues with digitizing as well. Some of the CPI circles did not line up from one year to the next due to the imagery being slightly off. Another issue was with some CPI circles changing sizes and shapes from year to year. Instead the 'select' tool was used to select CPI circles manually.

Union County 1986 to 2005 will be used as an example to explain the process of calculating and mapping change over time and space. First, the vector files of 1986 and 2005 years being analyzed needed to be in the same map file and designated with two different colors. To find the CPI circles that were new in 2005, the 1986 image was layered above the 2005 image in the table of contents. Then using the 'select' tool, all of the CPI circles in 2005 not covered by CPI circles from 1986 were selected (Figure 4). Once all new circles were selected, then the 'create a layer from selection' feature was used. This created a new layer that was renamed "New CPI 2005." Each of the new selection layers were then exported into the geodatabase using the 'feature to polygon' tool.

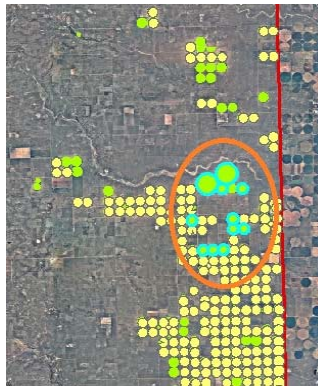


Figure 5: Selection for CPI Change Union County, NM 1986-2005¹

Next the 'select' tool was again used to find any CPI circles that were no longer present in 2005 that were there in 1986. This was done by changing the order of the feature layers in the table of contents moving the 2005 layer above the 1986 layer. Any CPI circles from 1986 that were not covered by CPI circles from 2005 were selected. A new layer was also created from this new selection and named "2005 Lost CPI." Together these two new layers showed areas where new CPI were present as well as areas where CPI systems were no longer present. To calculate the total number of new CPI units, number of CPI units that were no longer present, and total acreage, the 'statistics' feature was used in the attribute table for each of the new layers. This same process was then used to calculate and map the change for each year (incrementally) in both counties.

The previous change maps explored CPI change throughout the analysis years where some CPI circles were actually not in use for all years but were then later used in subsequent years. This was due to some CPI circles going into and out of use over the years. So, in order to analyze the total area of developed irrigated acreage, another change map was created for each county. These new change maps showed the total change over the years for only CPI circles that had never been present before (i.e. an accumulation of all land that was broken out in CPI over

¹ Yellow CPI circles are 1986 and Green CPI circles are 2005 "New" CPI are selected green circles are designated by blue outlines

time). To calculate and map this change the 'select' tool was used similar to the previous change maps. The Union County change analysis will be used as an example to explain the process for both counties.

First, the 1986 CPI circles layer was added to the map and labeled in orange. Next, the 2005 CPI circle layer was added under the 1986 image and those circles present in 2005 and not in 1986 were selected. Once all new locations were selected a new layer was created and colored a rose color. Then, the next layer of 2009 CPI circles was added under both 1986 and the newly created 2005. Only circles present in 2009 and not in 1986 or 2005 were selected and a new layer created and colored yellow. This same process occurred for 2011 (colored purple) and 2014 (colored blue). Once all new layers were created for each year, areas were calculated for each using the 'calculate geometry' tool in the attributes table. These new calculations were only new acres each year and then all together a total amount of new acres. The final product was a map for each county showing the CPI circles that were installed each analysis year.

The next phase in this research includes is key informant interviews. The key informant interviews are used to understand the drivers of the CPI land changes found in the GIS/RS analysis. The methods used in the key informant stage are described below.

3.2 Part 2: Key Informant Interviews

As noted above, questions asked during the key informant interviews were informed by the participant observation and household surveys done with the NSF project in Summer 2014. The prior fieldwork revealed common issues and concerns that helped to guide the initial research topics. Key informant interviews (n=20) were conducted in Union County, NM and Cimarron County, OK from January 9-18, 2015. Key informant interviews were semi-structured having several predetermined questions. The interviews were also conversational and informal in nature. Each interview took between 20 minutes to 60 minutes. While the questions acted as a guide for

the interview, the interviewees were encouraged to talk about other areas they felt were important to the project area and study problem. During all of the interviews, hand-written notes were taken. The key informant interview questions were focused around the following major themes/questions:

- Major water concerns or issues in the area
- Water restrictions or regulations in the community
- Irrigated Agriculture
- Policies or factors that influence use of irrigation
- Concern over irrigated agriculture
- Community reliance on agriculture
- Irrigation and Community Vulnerability
- The future of irrigated agriculture in the region

A stratified snowballing technique was used as the sampling method for choosing interviewees (Trost 1986). This method was used to ensure a balanced group of opinions from a range of officials and residents. In both counties, the interviews started with local officials from relevant agencies and other contacts made from the larger NSF project. At the end of each interview, the interviewees were then asked for names of individuals who could also be interviewed for relevant information. Overall, ten interviews were conducted in each county. Of the ten in each county, five were either government workers or officials, while the other five in each county were local community members. The local community interviewees were a combination of ranchers, farmers, irrigators, non-irrigators, people from in town and people that live in the rural area. The aim was to interview a varied group of people in order to gain diverse perspectives.

As the interviews progressed, an open grounded coding method was employed to start finding common themes in the responses. This coding technique enabled themes to emerge through constant data reduction, comparison and reassessing of notes to then collect more data on any emerging themes and patterns (Corbin and Strauss 1990; Knigge and Cope 2006). The

responses to each question asked to the interviewees first were summarized into a few words. This was done in order to identify common words and responses that emerged throughout the interview. As the interviews progressed further, more questions emerged, which were then used to guide and direct the next interviews and observations (Berg 2007). Assessing the interview responses at the end of each day ensured that new themes were identified and answers to the research questions began to emerge.

After all of the interviews were conducted, a final coding was done using notecards. This coding placed common themes into code groups to answer the research questions. One code group answered how CPI changes have been influenced, and another group answered perceptions on CPI use and vulnerability to drought. The results of the coding had two main objectives. One objective was to understand the community's perceptions on: CPI growth and use, drought and vulnerability. The second objective was to direct the archival and secondary research.

3.3 Part 3: Archival and Secondary Research

Archival and secondary research methods were used in order to obtain information on past policies and practices that led to the extensive use of CPI systems. Particular attention was given to the dates that coincided with the GIS mapping and aerial photograph periods for comparison purposes. In addition to certain periods of time, the archival and secondary research focus was further narrowed by the coded themes from the key informant interviews. The archival/secondary research started at the end of the first day of interviews and coding. Resources were explored to find if the responses to the interviews matched corresponding archival/secondary data. The themes found throughout coding changed the direction of the archival/secondary research from what was originally planned. The interview responses lead to a focus on a more national scale instead of local. Due to the change in scale of causes of CPI change, the types of documents also needed to change in response to the new scale.

A majority of the archival and secondary research was focused at the national scale, such as federal government websites such as EPA, USDA, etc. However, some focus was at the state, regional and county level as well. Typically when the focus was on water policy and practices, relevant documents were at these lower scales of state, region or community. At all of the scale levels, documents were primarily found on official websites as secondary data (Table 4). Archival data included documents such as historical corn prices from the USDA and water rights and policies from the Oklahoma Water Resources Board. Additionally, some data on water rights and policies at the state level were found at the Oklahoma City Archives. Other data predominately included journal articles to further explore what other scholars have found on the topics. The end results of the archival/secondary research were first organized by the research question, then by theme, and then by date. This enabled the results to detail and compare how different drivers of CPI change effected such change at different periods of time.

Table 4: Archival/Secondary Research Data Sources: National vs. State/Regional/County Scales

National Scale Data Sources	State/Regional/County Data Sources
Reports from the USDA Economic Research Service	Oklahoma Water Resources Board (Online and from OKC Archives)
EWG Farm Subsidy Database	New Mexico Office of the State Engineer
USGS High Plains Water Level Monitoring Study	USDA Agricultural Census Union County
USDA Risk Management Agency	USDA Agricultural Census Cimarron County
USDA-Farm Service Agency Conservation Programs	
USDA Economics, Statistics and Market Information System	
USDA Economic Research Service Feed Grains Database	
U.S. Drought Monitor	
U.S. Environmental Protection Agency- Ag 101	
U.S. Department of Energy -Alternative Fuels Data Center	
U.S. Energy Information Administration	
Renewable Fuels Association	

Conclusion

This chapter has described the mixed methodology approach taken for the study. The methods were chosen to best follow an integrated, mixed methods LCS and PE framework. Utilizing more than one method enabled a more comprehensive and multi-scalar understanding to the CPI land change and the drivers of that change. In the next chapter, the results of the GIS/RS analysis explore CPI land change through maps and calculations. The results and discussion of the key informant interviews and archival/secondary research explore the drivers of CPI change as well as the perspectives of the CPI use in relation to drought and vulnerability.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

This chapter explores the results from the mixed method analyses and then discusses those results. Section one of this chapter provides a GIS/RS change analysis of CPI circles from the 1950s to 2014. Section two then explores the coding results of the key informant interviews. Key informant interview coding results were used to investigate first, what policies and practices have influenced CPI growth and second, local perceptions on CPI use in relation to vulnerability and drought. Section three provides the results of archival and secondary research. Archival and secondary research was used to further investigate policies and practices that have influenced CPI change. The final section is a discussion of all results and how they fit into the broader context of the theoretical framework of LCS and PE research discussed in Chapter II.

4.1 GIS/RS Analysis Results

This GIS/RS analysis explores CPI area and change from the predevelopment of CPI (1950s) to the present day. Each of the study area counties are explored separately for a comparative analysis. The analysis of both counties shows that CPI circles are found almost exclusively within the High Plains Aquifer boundary (Figure 6 and 7). A few other CPI circles are found near other sources of water like rivers. However, this analysis was only on CPI from the High Plains Aquifer, so the other circles were not included.

Between the two counties, Cimarron County has a much larger portion of its land lying over the High Plains Aquifer. Cimarron County has 935,209 acres of land lying over the aquifer out of their total 1,178,857 county acres, or 79% (Figure 7). Union County on the other hand, has 995,063 acres of land lying over the aquifer out of their total 2,459,924 county acres, or 40% (Figure 6). However, even though land might lie over the aquifer boundary, this does not necessarily mean that water is available to be pumped. The aquifer's landform characteristics make each area over the aquifer unique, having different depths of water or saturated thickness (USGS 2003). In Union County in particular, much of the western boundary of the aquifer has little to no saturated thickness, making it unsuitable for irrigation (USGS 2003).

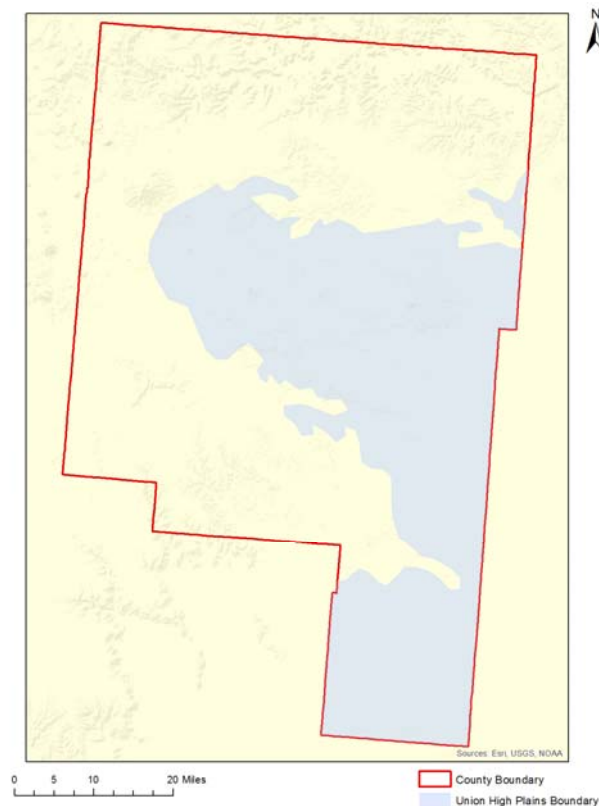


Figure 6: High Plains (HP) Aquifer Boundary in Union County, NM

Created by author (Data Source: USGS 2006)

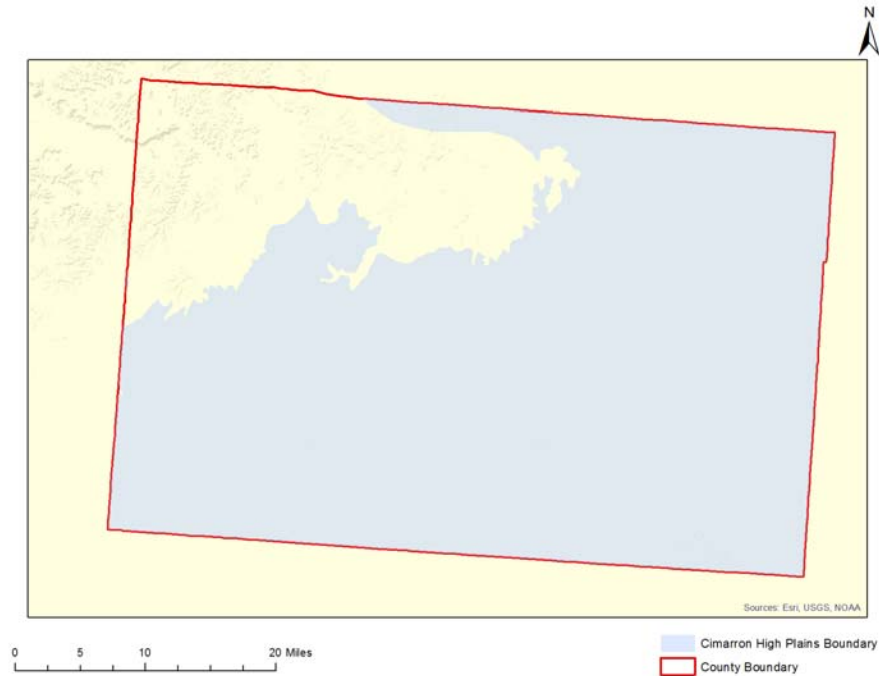


Figure 7: High Plains (HP) Aquifer Boundary in Cimarron County, OK

Created by author (Data Source: USGS 2006)

4.1.1 Center Pivots and Percent Change By Year of Analysis and County

The CPI land area analysis of the two counties revealed that the growth of CPI was initially the same when CPI first emerged. Predevelopment (1950s) imagery showed that zero CPI systems were installed in either county. By the 1980s, 341 CPI circles were present in Union County (Figure 8 and 9) and 342 CPI circles were present in Cimarron County (Table 5, Figure 8 and 10). Though nearly the same numbers of CPI circles were present in the 1980s, a much smaller percentage of Union County (1.71%) became irrigated by center pivot than Cimarron County (3.73%). During this time, the average size of the CPI circle in Union County was 122 acres and 128 acres in Cimarron County.

Table 5: Union County, NM (UC) and Cimarron County, OK (CC) CPI Area and Percent Change

Year	# of CPI		CPI Area in Acres		% of County		% Change in Acreage	
	UC	CC	UC	CC	UC	CC	UC	CC
1956/1959	0	0	0	0	0%	0%	---	---
1986/1985	341	342	41,889	44,089	1.71%	3.73%	---	---
2005/2005	427	577	54,216	73,357	2.21%	6.22%	29.43%	66.3%
2009/2008	443	572	56,953	72,751	2.32%	6.17%	5.05%	-.83%
2011/2010	450	597	57,788	75,993	2.36%	6.45%	1.47%	4.46%
2014/2013	400	628	51,306	79,622	2.1%	6.75%	-11.22%	4.7%

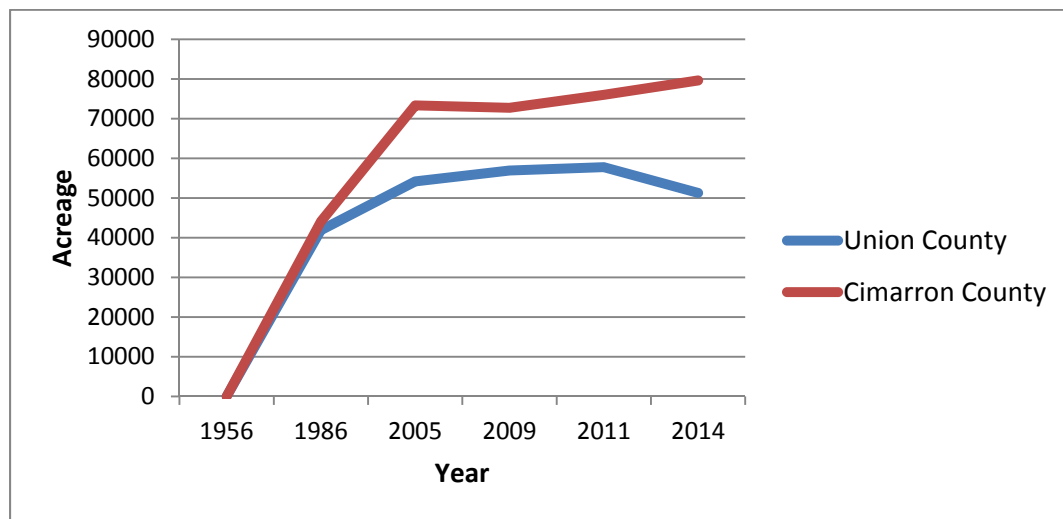


Figure 8: Total CPI in Acres in Union County, NM and Cimarron County, OK

In 2005, CPI area increased in Union County from 41,889 acres to 54,216 acres with a change of 29.43% from 1986 (Table 5, Figure 9). In Union County after 2005, CPI area was never greater than 57,788 acres and began to decrease after 2011 (Table 5, Figure 9) (See Appendix B for the remaining mapped CPI results). In 2014, Union County had its most dramatic decrease in CPI acreage with a more than 11% decline. The CPI area from 2011 to 2014 went from 57,788 acres to 51,306 acres. From 2005-2014 the average size of CPI circles stayed relatively the same at around 128 acres. Overall, within the last 30+ years, Union County had an

increase in CPI area of 22.48% (Table 6). However, more recently, within the last 10 years, since the height of the most recent drought, Union County had an overall decrease of 5.37% (Table 6).

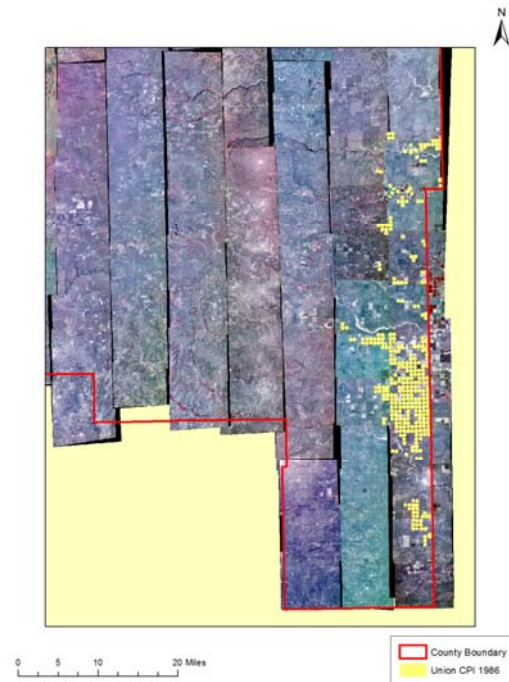


Figure 9: 1986 Union County, NM Center Pivots

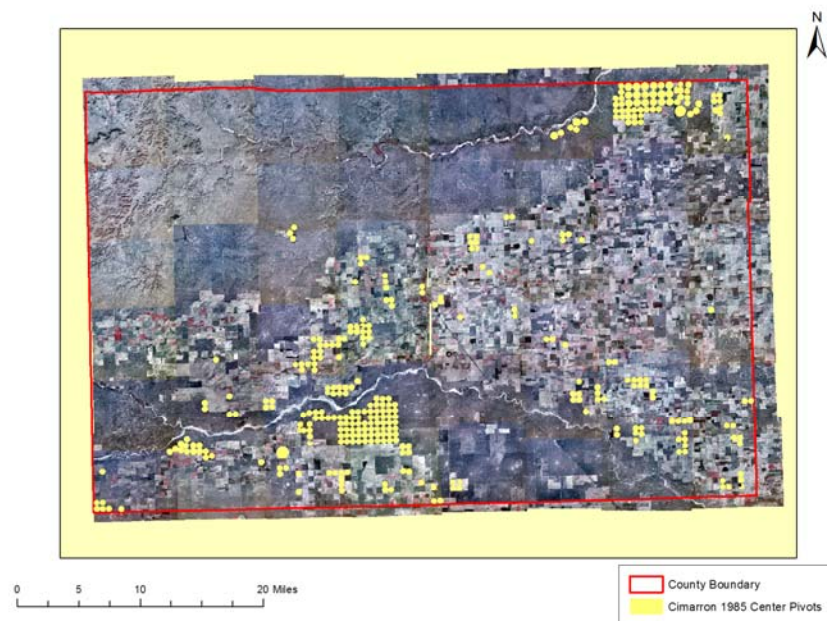


Figure 10: 1985 Cimarron County, OK Center Pivots

Similar to Union County, in 2005, Cimarron County had another large increase in CPI acreage. The area in CPI grew from 44,089 acres to 73,357 acres with a 66.3% change from 1985 to 2005 (Table 5, Figure 10). After 2005, Cimarron County had a slight decrease to 72,751 acres in 2008. After 2008, the county increased about 4% each analysis year, with an increase of 75,993 acres in 2010 and 79,622 acres in 2013 (Table 5). As in Union County, from 2005- 2013 the average size of CPI circles stayed relatively the same at around 127 acres. Overall, Cimarron County had a much larger increase than Union County over the past 30 years with 80.5% growth (Table 6). Just within the last drought period (10 years) CPI acreage in Cimarron County had increased by 8.54% (Table 6). The following sections (1.2 and 1.3) explore specific areas and acreages of CPI change throughout the years of analysis for each county.

Table 6: 30 Year (1985-2015) and 10 Year (2005-2014) Percent Change in Total CPI Acreage

	Union County, NM	Cimarron County, OK
~30 year % Change in CPI	22.48%	80.5%
~10 Year % Change in CPI	-5.37%	8.54%

4.1.2 Union County, NM Center Pivot Areas of Growth by Analysis Year

The CPI change map analysis explored specific areas of change in Union County throughout the years of analysis from 1985/1986 through 2013/2014 (Figures 11-14). More specifically, the maps show where new CPI were located, as well as places where CPI were present before but were no longer present the following analysis year. The CPI change maps designate new CPI circles as orange and CPI circles that were no longer present, as green.



Figure 11: CPI Change in Union County, NM 1986-2005



Figure 12: CPI Change in Union County, NM 2005-2009



Figure 13: CPI Change in Union County, NM 2009-2011

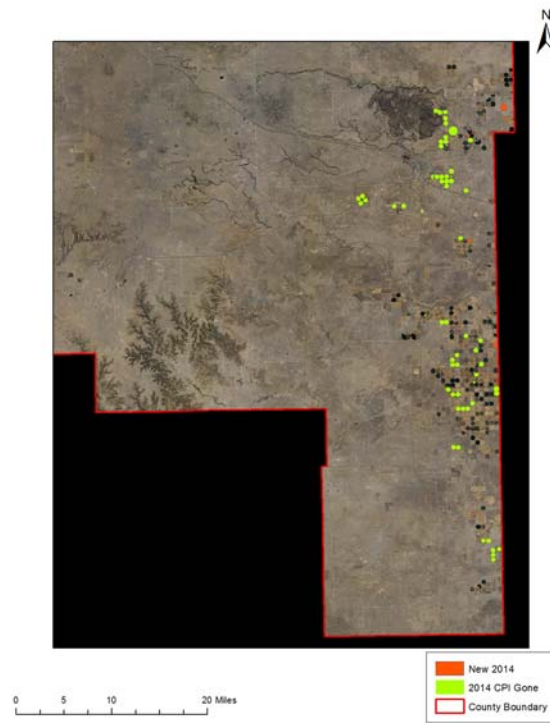


Figure 14: CPI Change in Union County, NM 2011-2014

In 1956 (predevelopment) in Union County, no CPI systems were installed and therefore all circles present by 1986 were considered 'new'. However, from 1956 to 1986 CPI area had grown to 41,889 acres. As a result, all CPI circles in 1986 were considered new and, therefore, 1956-1986 was not mapped for change. From 1986 to 2005 Union County had increased the number of CPI circles by 86 and had a net increase in CPI acreage of 12,327 (Table 7). Of those 86 CPIs present, all of the new CPIs were located throughout the entire available aquifer irrigation area (Figure 11). There were no areas that had high concentrations of new CPI circles; instead they were spread throughout the irrigated area. In addition to new circles being present, there were also circles that were no longer present in 2005 (Figure 14). The systems that were no longer present were also dispersed throughout the irrigated area and showed no pattern of concentrated CPI growth.

The years of 2005 to 2009 had a decrease in number of CPI units present with only 20 installed and only a net increase of 2,737 CPI acres (Table 7). Most of the new circles present from 2005-2009 were located on the outer edges of the irrigated area. Many smaller partial circles were also present in the north (Figure 12). In addition to few newly present CPI circles; few circles remained present in 2009 as well (four CPIs). The circles that were gone showed no pattern and were scattered throughout the irrigated area.

In Union County, between the years of 2009 to 2011, CPI acreage showed little change with a net increase of only 835 acres (Table 7). A majority of the 19 new CPI circles present were grouped to the north and the south along the eastern border of the county (Figure 13). A few other circles were also installed in scattered places throughout. The years from 2009 to 2011 also revealed a slight pattern in the 12 CPI circles that were no longer present. There was a small cluster of units in the center of the irrigated area on the eastern border of the county.

From 2011 to 2014 Union County had a dramatic decrease in CPI acreage. Many CPI circles were no longer present (59 CPIs) in 2014, and only 9 CPIs were new. Union County had a net decrease of 6,482 irrigated acres by 2014 (Table 7). The few new circles that were present were located further north near the eastern county border (Figure 14). The circles that were no longer present also showed a small pattern being located mostly on the western edge of the irrigated area sprawling from the north to the south.

Table 7: Union County, NM (UC) and Cimarron County, OK (CC)

New and No Longer Present CPI Acreage 1954-2014

Years	# of New CPI		New CPI Acreage		# of CPI No Longer Present		CPI No Longer Present Acreage		# of CPI Net Change		Acreage Net Change	
	UC	CC	UC	CC	UC	CC	UC	CC	UC	CC	UC	CC
1956-1986/ 1954-1985	341	342	41,889	44,089	---	---	---	---	341	342	41,889	44,089
1986-2005/ 1985-2005	105	282	14,741	34,732	19	47	2,414	5,464	86	235	12,327	29,268
2005-2009/ 2005-2008	20	38	3,110	4,522	4	43	373	5,128	16	-5	2,737	-606
2009-2011/ 2008-2010	19	52	2,186	7,017	12	27	1,351	3,775	7	25	835	3,242
2011- 2014/2010- 2013	9	60	785	7,368	59	29	7,267	3,739	-50	31	-6,482	3,629

4.1.3 Union County, NM Center Pivot Areas of Cumulative Growth 1986-2014

The previous change analysis explored areas of CPI that were either present or no longer present. However, even though a CPI circle was no longer present, did not necessarily mean that

it would never be used again for irrigation. Therefore, a second type of change was analyzed (Figure 15). The second change analysis explored only new or cumulative irrigated ('broken out') land from the 1986 to 2014 analysis years. This analysis was done in order to measure the total amount of land over time had been turned into CPI irrigated land. In other words, this also helped to better capture the extent and growth of agricultural irrigation wells within the counties. In Union County, a similar pattern emerged from this analysis as the previous change analysis. In general, the new irrigated acreage was found mostly in the north and along the western border of the irrigated area. However, a majority of the newer CPI circles that were present were in the north. After the initial jumps in acreage in 1986 (41,889) and 2005 (56,647), newly irrigated acreage decreased greatly (59,477 acres in 2009, 60,656 acres in 2011 and 61,147 acres in 2014 (Table 8 and Figure 15).

Table 8: Cumulative CPI Acreage 1986-2014,
Union County, NM and Cimarron County, OK

Years	# New CPI		New CPI Acreage	
	UC	CC	UC	CC
1986/1985	341	342	41,889	44,089
2005/2005	447	629	56,647	80,049
2009/2008	463	660	59,477	83,711
2011/2010	473	689	60,656	88,490
2014/2013	477	730	61,147	93,633

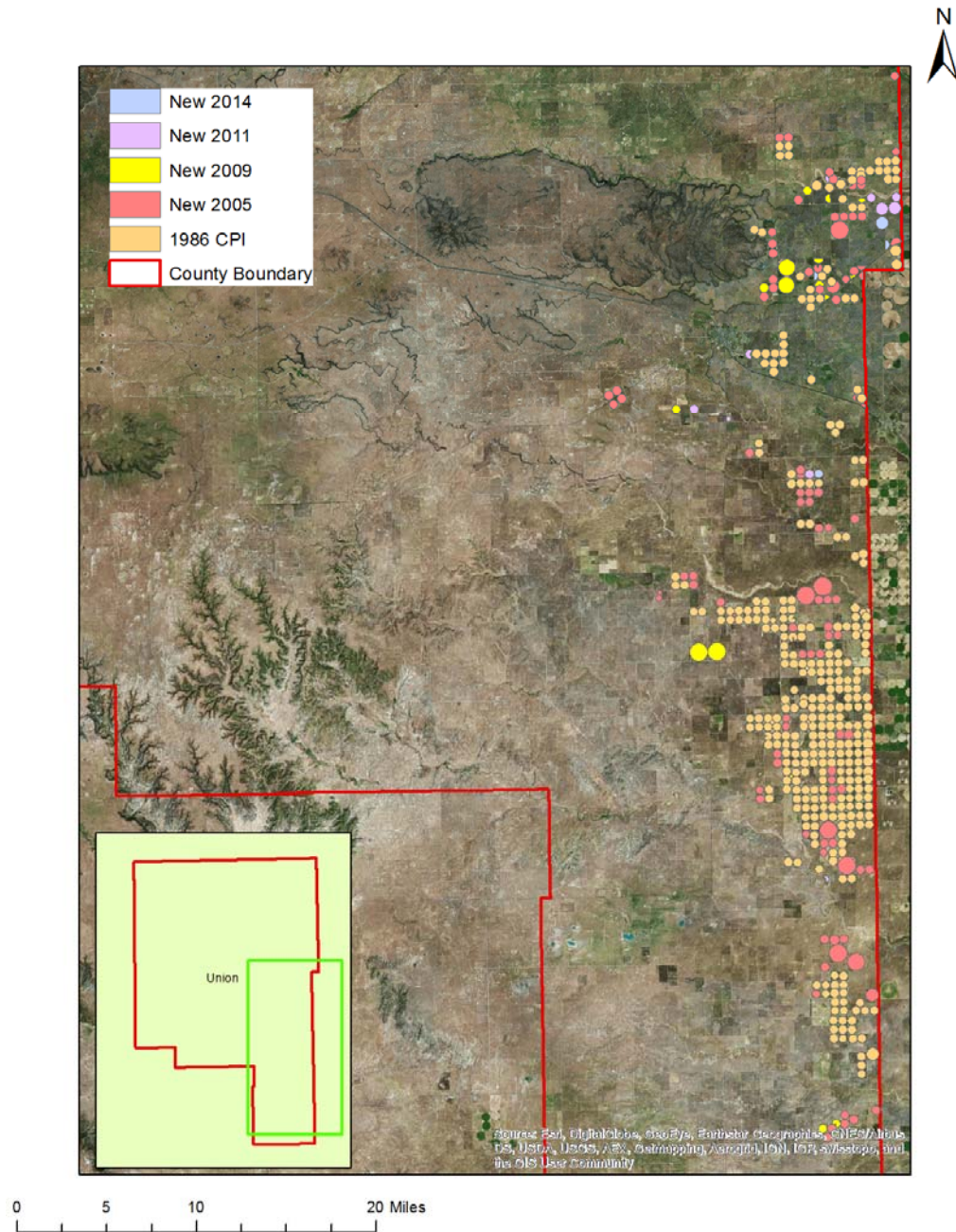


Figure 15: Cumulative CPI Growth in Union County, NM 1986-2014

The overall trend from both analyses in Union County reveals that after the substantial increase in number of systems in 2005, the slight growth of irrigated acreage remained relatively steady. The newer systems that were installed tended to be near the eastern border of the county, while the systems that were no longer present tended to be on the western border of the irrigated

area. However, by 2014 total CPI acreage dropped considerably, particularly in areas to the west. The following subsection explores CPI change in Cimarron County.

4.1.4 Cimarron County, OK Center Pivot Irrigation Areas of Growth By Analysis Year

The CPI change maps of Cimarron County also explore specific areas of change as in Union County (Figures 16-19). Orange circles represent new CPI areas and green represents CPI circles no longer present.

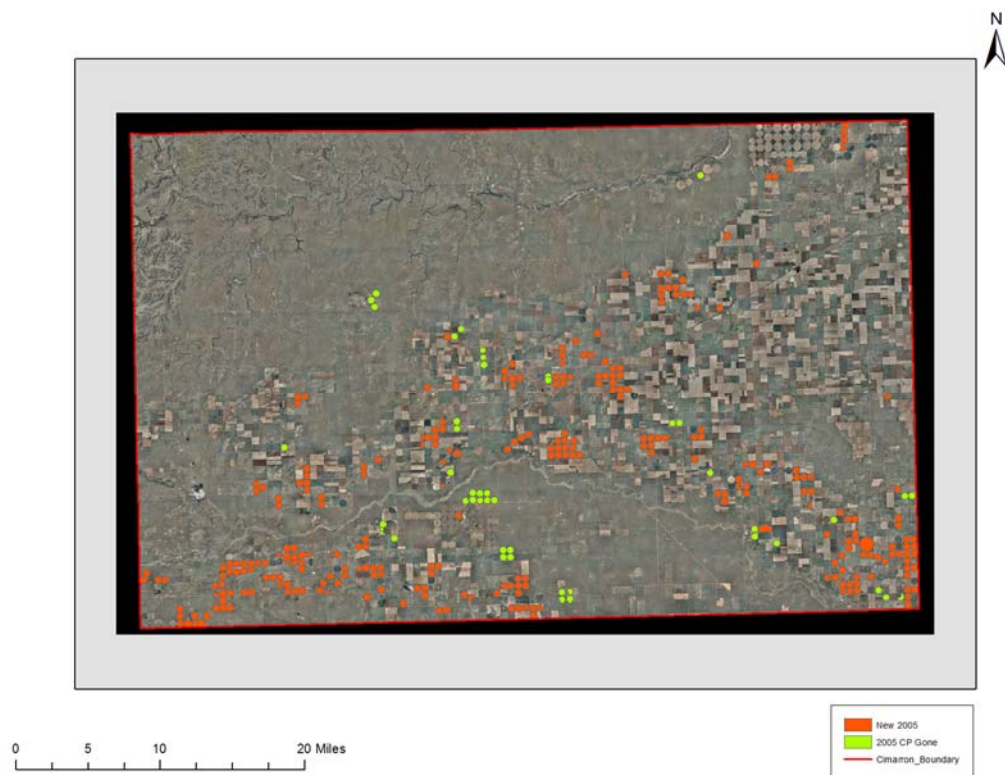


Figure 16: CPI Change in Cimarron County, OK 1985-2005

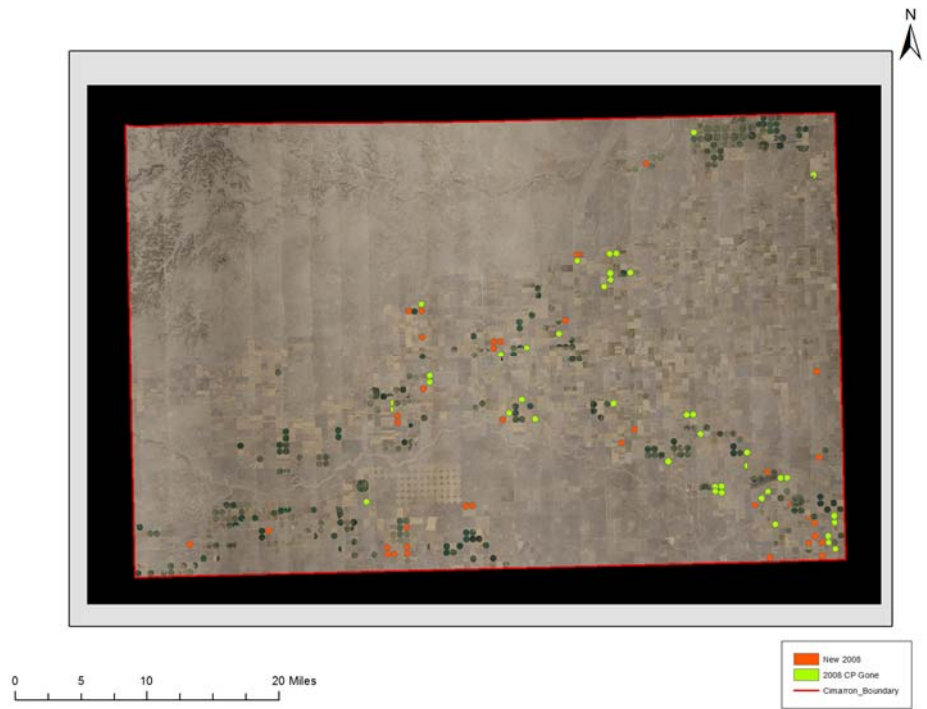


Figure 17: CPI Change in Cimarron County, OK 2005-2008

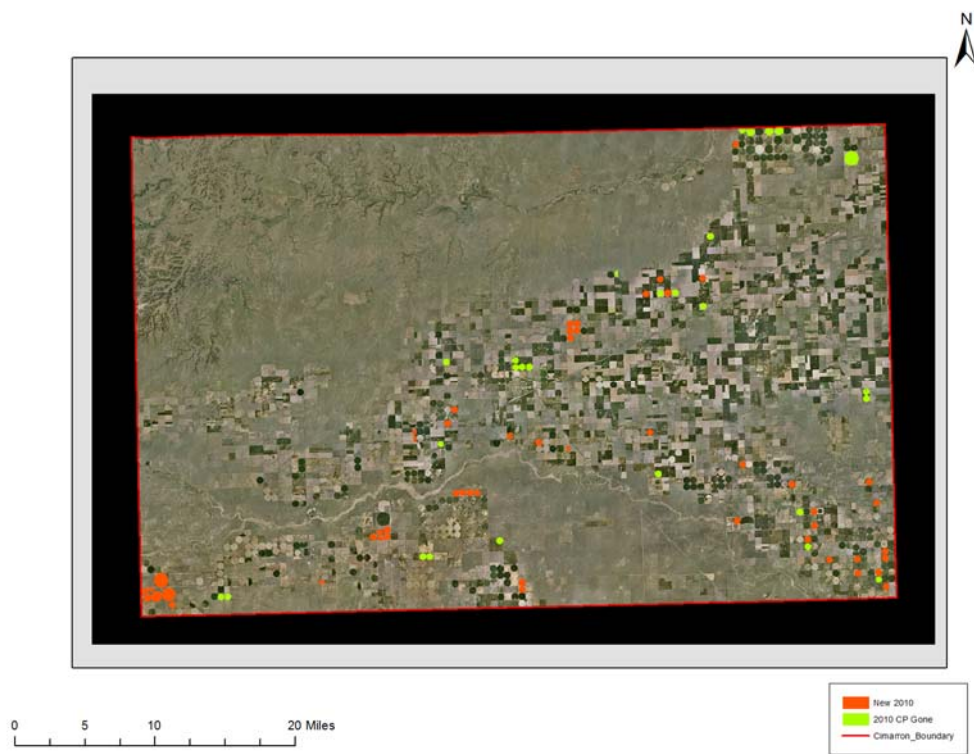


Figure 18: CPI Change in Cimarron County, OK 2008-2010



Figure 19: CPI Change in Cimarron County, OK 2010-2013

Like in Union County, in Cimarron County the predevelopment analysis year of 1959 had no CPI systems installed. Then by 1985, CPI area had grown to 44,089 irrigated acres. So, similar to Union County in 1985, all CPI circles in 1986 were considered new and not mapped for change from 1959 to 1985. Another large increase in CPI circles occurred from 1985 to 2005 in Cimarron County. CPI circles increased by 235 units and had a net increase in acreage of 29,268 (Table 7). All of the new circles were located throughout the entire irrigated area, though a large number of new circles were located in SE, SW, and Central portions of the county (Figure 16). In addition to new circles being installed, Cimarron County also had circles that were no longer present in 2005 (Figure 16). A majority of the circles that were no longer present were located closer to the center of the county, with others scattered throughout as well.

Between the years of 2005 and 2008 Cimarron County actually showed a decrease of 606 acres in CPI area (Table 7). While not a substantial decrease, the locations of the 43 circles that were no longer present had a distinct pattern. The majority of the circles that were no longer

present in 2008 were in the central to SE portions of the county (Figure 17). The new circles (38 CPIs) were located in similar areas, though more new systems were located in the SW portion as well.

Between 2008 and 2010 CPI acreage increased once again in Cimarron County by 3,242 acres (Table 7). Like in the previous years, a majority of the 52 new circles were located in the SW (Figure 18). Other new circles were also located across the entire irrigated region as well. Circles that were no longer present (27 CPIs) showed no obvious pattern of concentration, though a somewhat larger proportion were in central to NE portions of the county. Within the central portion of the county there were some areas where in 2005 the CPI circle was no longer present but then returned to use in 2010.

The increasing trend in CPI acreage in Cimarron County continued in 2010 to 2013, with a net increase of 3,629 acres (Table 7). The 60 new and reestablished circles showed no real pattern of concentration as they were scattered throughout the irrigated region (Figure 19). However, some larger clusters of newer CPI circles were in the NE and SW. The 29 circles that were no longer present showed little pattern and were located in the central, SE and NE portions of the county. Like in previous years some circles in central Cimarron County were those that returned to use or were reestablished in 2013 after being gone in previous analysis years.

4.1.5 Cimarron County, OK Center Pivot Areas of Cumulative Growth 1985-2013

An analysis of areas of cumulative acreage was also undertaken for Cimarron County. In the previous change maps some areas had been used for irrigation off and on throughout the years. The change map in figure 20 shows the cumulative total of only new irrigated land from each analysis year. In Cimarron County, no distinct pattern of new CPI area emerged. New irrigated acreage was found throughout the irrigated area. However, a majority of the newer larger CPI circles were installed in the NE and SW corners of the county, historic dryland

agricultural areas of the county. After an initial jump in acreage between 1985 (44,089 acres) and 2005 (80,049 acres), the growth of newly 'broken out' irrigated acreage slowed considerably (Table 8 and Figure 20). However, the cumulative amount of irrigated acreage was still increasing steadily each subsequent analysis year (83,711 in 2008, 88,490 in 2010 and 93,633 in 2013).

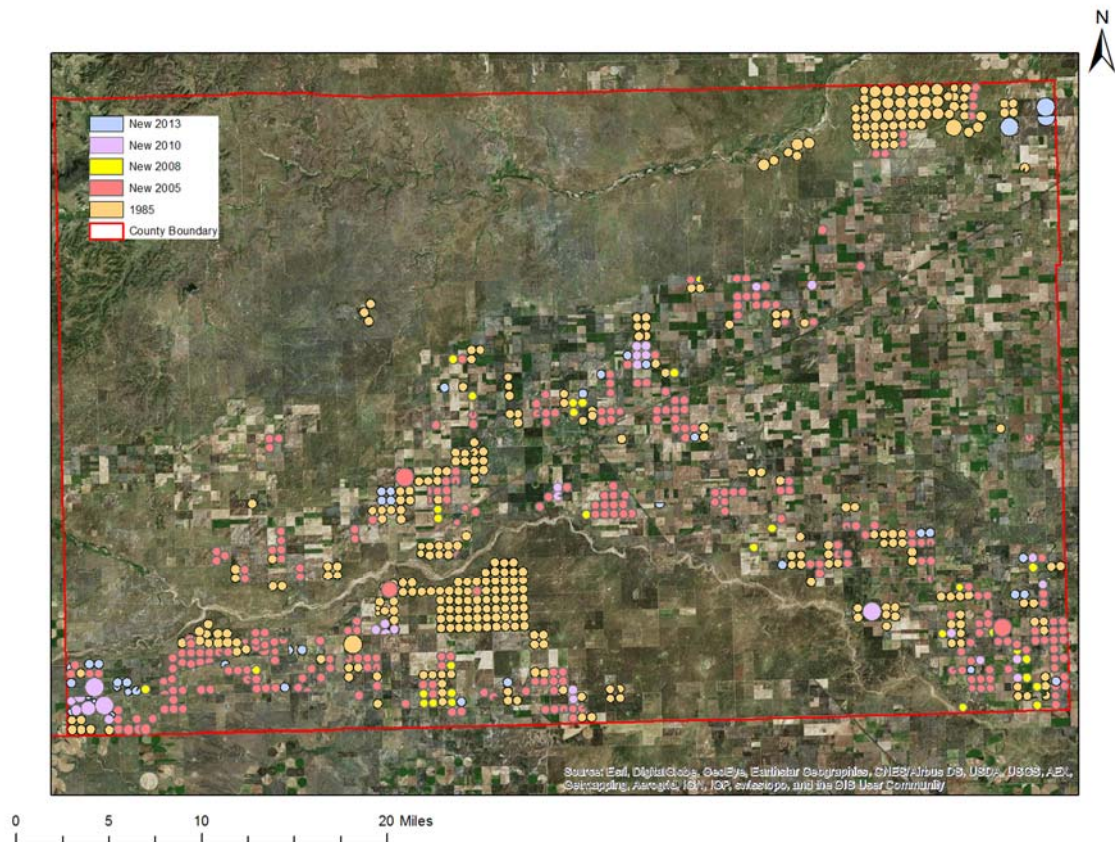


Figure 20: Cumulative CPI Growth in Cimarron County, OK 1985-2013

Between the years of the 1950's to 2013 the overall trend in Cimarron County has been an increase in CPI acreage. However, after 2005, the rate of increase in CPI circles was lower than years prior. The majority of the new circles that were installed were located more towards the NE, SE and SW corner borders of the county. Though, many newer CPI circles in 2013 were in the center of the county as well. In general, the CPI circles that were no longer present tended

to be more towards the central and SE portions of the county, but were also located in other various parts of the county as well.

4.1.6 Union County, NM and Cimarron County, OK CPI Change and Growth Comparison

In general, Union County and Cimarron County have been trending differently in CPIs installed or total acreage. Union County is decreasing in acres, while Cimarron County is increasing. Initially between predevelopment in the 1950s to the mid 1980s both Union County and Cimarron County increased in CPI acreage by nearly the same amount to just over 40,000 acres. However, by 2005 Cimarron County had increased by more than 66 percent of land irrigated by CPI to over 70,000 acres. Union County however, only increased by about 30 percent to about 55,000 acres (Table 7). Since 2005, Union County only slightly increased in acreage, then by 2010 started to decrease dramatically back down to about 50,000 irrigated acres. In Cimarron County, since 2005, acreage has been increasing at a steady rate and has most recently almost reached 80,000 acres of irrigated land (Table 7).

The change map analyses for both counties explored when and where CPI circles were either installed or no longer in use from the 1950s to 2014. However, understanding why these changes took place require a more in depth inquiry. The next section explores the coded analysis from the key informant interviews. The coded analysis is used to understand what appear to be the primary drivers of CPI changes from year to year and between the two counties.

4.2 Coding Results from Key Informant Interviews

Key informant interviews are used to explore research questions number two and three. Therefore, key informant interview questions and subsequent response categories are organized into two subsections. Subsection 4.2.1 answers: what policies and practices have influenced center pivot irrigation growth and how (question 2). Subsection 4.2.2 answers: how do the local communities perceive the role of CPI use in relation to vulnerability and drought (question 3).

4.2.1 Policies and Practices that have Influenced CPI Growth and How

The key informant interviews revealed many policies and practices as influencing CPI growth. These policies and practices fit into three main coded categories. These categories are economic influences, aquifer availability/water level influences, and water rights/policy influences (Table 9). Each of these main categories contains subcategories of further coded common responses to interview questions. The responses to key informant questions in each of the two counties are in general similar, except for in the third main category (water rights and policy influences). These differences in response are due to their state's differing water rights and policies.

Table 9. Primary Coded Categories From Key Informant Interview Responses in Union County, NM and Cimarron County, OK (n=20)

	Main Categories of Coded Responses to Practices and Policies that Influence CPI Growth		
	Economic Influences	Aquifer Availability/ Water Level Influences	Water Rights and Policy Influences
Subcategories of Coded Responses	• Corn prices/Grain prices • Gas Prices/ Costs to irrigate • Ethanol plants • Beef industry/ • Feed/Feedlots • Loan/Insurance programs • Drought influences	• Changes in CPI irrigation practices	• Well drilling permits • Union County, NM: Closed basin with leniency/loopholes • Cimarron County, OK: No restrictions beyond permits, self-regulation

4.2.1.1 Economic Influences in CPI Growth and Use

Economic influences by far were offered as the greatest influence on CPI growth and use in both of the counties. Ninety-three percent of the respondents that were asked what influenced the use of irrigation mentioned an economic incentive. The productivity and return that farmers and ranchers get out of an irrigated circle far exceeds the profits from non-irrigated land. Various

interviewees² argued that as long as the economic incentive was there to irrigate, then CPI irrigation would continue. Furthermore, one interviewee said that the productivity from irrigated farmland actually helped the entire community, as residents are "all connected to agriculture in one way or another."

The price of corn specifically was the top economic response with nearly 77% of respondents mentioning its importance, particularly for current CPI use. The price of corn over the past seven or eight years has been quite high, making the profits from growing it appealing. Of those 77% percent who mentioned the role of corn, about half also mentioned the role of gas prices in influencing CPI use as well. Weak gas prices make irrigation costs much lower and high prices make costs higher. Interview responses stated that the price of corn together with the price of gas greatly influence economic return. Selling corn for high prices combined with lower operating costs creates greater profit margins, thus further incentivizing CPI irrigation. If the two are reversed, this discourages irrigation. One farmer stated that irrigation had "always pretty much been economics driven" for instance in the 1990s when gas prices were higher and grain prices were lower. The respondent said that this "reduced the use of irrigation greatly."

A few respondents offered that the growth of ethanol and ethanol plants was another influence in CPI growth. This influence is also connected to corn and corn prices and as one interviewee stated the "massive subsidies" given to produce corn for ethanol. Ethanol plants require corn and other grains for their production and therefore put more demand on the corn and grain markets. The ranching economy is also closely linked to corn production and CPI irrigation as well. Corn and grains are used as feed to supplement cattle diets when grass is not abundant enough. Feedlots in particular, as stated by one rancher, were said to use a "great amount of feed to support their operations" and influenced the market for corn. Additionally, some ranchers or

² Results are presented anonymously to protect human subjects

feedlots actually irrigated their pasturelands in order to grow enough grass to support their businesses.

Federal subsidy and conservation programs were mentioned by 54% of respondents as influential in CPI use. These programs were offered as influences that both encourage and discourage irrigation. These include federal programs such as EQIP, CRP and crop insurance. Some of the programs help to encourage conservation efforts by putting land out of production. For instance in Union County one official stated that "more land was actually going into CRP" than being used for irrigation. Different programs help to subsidize the irrigation system costs of the towers or high efficiency sprinklers. Other programs influence market structure through insurance guarantees if crops fail. However, a few respondents claimed that the incentives offered for conservation by some programs were not enough to discourage irrigation. One farmer argued that, "the payments were little compared to the profits from irrigating."

Drought also appears to have influence on CPI growth and use. Drought exacerbates water problems of water and creates the need for more irrigation. Increased irrigation must be used in times of lower than average precipitation. Although no respondents directly stated that drought influenced CPI use, indirectly 75% of respondents did. For instance, many respondents instead directly stated that during times of drought CPI systems are never turned off because there is no supplemental rainfall. One farmer stated that during drought they "pump all they can" to keep up production. Drought also increases the use of feed in the ranching industry by decreasing the available grassland for grazing herds. This in turn, makes supplemental food all the more necessary. In addition to these many economic influences, key informant interviews also revealed that CPI growth and use was influenced by aquifer availability/water levels as well.

4.2.1.2 Aquifer Availability and Water Level Influences on CPI Growth and Use

Key informant interviews revealed that more recent changes in CPI occurred due to varying water levels from the aquifer. Several respondents said that water level drops started to become very noticeable in the 1990s. Though they also argued that just within the last 10-15 years many wells across the two counties have declined even more substantially. Many respondents offered that numerous irrigators had to either drill deeper to reach water or drill new wells because of these decreases. In addition to dropping, well pumping pressure had decreased considerably as well. One farmer explained that his original wells drilled in 1972 were originally "pumping 1200-1300 gallons per minute" and now they were "down to 600 gallons per minute." A rancher offered a similar story that his wells were drilled in 1964 and were pumping at 3000 gallons per minute. Then in 2000, he put in a new pump to get only 600 gallons per minute. However, most recently, in 2015, he was only pumping 400 gallons a minute. Many others interviewed from both counties told a similar story.

In order to adjust to dropping water levels and pressures, irrigators have had to adjust their irrigation methods. These methods directly impact the increases or decreases in CPI use. A common adjustment that many farmers and ranchers have used is to reduce their full circles to half or even a fourth of the original size. This reduction in circle size decreases the amount of water needed but also reduces the CPI acreage. An irrigating farmer stated that another reduction method irrigators are using "is removing one to three or more towers from the ends of their CPI systems." This reduces the diameter of the circle and therefore requires less pressure and water. That same farmer and a few others also mentioned that some irrigators were using three to four or more pumping wells to irrigate one circle. While this does not necessarily decrease CPI acreage, it may cause an increase in wells drilled. However, a decrease in area can also occur due to multiple pumps being needed for one circle instead of each well irrigating its own circle.

4.2.1.3 Water Use Policies and Restriction Influences on CPI Growth and Use

The first two influences on CPI growth showed little variation in responses between the two counties. However, in the third group the responses differed by county. While both counties' responses involved well drilling permits, the ways in which they were enforced differed widely. The water use policies also differed by county based on the different policies of each state.

Union County residents often noted that the area was declared a closed basin around 2005. A government official stated that this meant that, "no new permits could be issued, but older wells could be drilled deeper or smaller supplemental wells for cattle or homes could be drilled." However, it was also noted by some that this was not strictly enforced and that loopholes existed. One loophole mentioned involved the drilling of supplemental wells designated for home or cattle use. Respondents argued that these types of wells were actually being used for irrigation instead of their approved purpose. Though there were arguments for loopholes, others felt that that no new permits were given out anymore and as one government official put it, "the area actually had more wells going out than in." Overall, however, responses indicate that the policies of New Mexico have created a more restrictive environment for drilling and subsequent CPI growth in Union County.

On the other hand, Cimarron County responses noted that while applying for a permit to drill wells was required, this was not very restrictive at all. The only other restrictions offered were posting an announcement in the paper to be challenged and self-reporting of irrigation numbers. Although these restrictions were in place, many respondents stated that new large wells were even still going in. Additionally, one farmer claimed that it was a "race to the bottom" and another farmer described it as "a race to the last drop." These few regulations in Oklahoma created an unrestrictive environment for drilling new irrigation wells and encouraged subsequent CPI growth in Cimarron County.

Whether in Union County or in Cimarron County the level of restrictiveness in permit and water use policies no doubt directly impacted CPI growth. In Union County, the overall feel was that while loopholes existed, in general, no new wells were going in and this was preventing any further CPI growth in the county. In Cimarron County on the other hand, even though drilling required a permit, these had few restrictions and in general new large wells were still being drilled. The next subsection further utilizes the key informant interview responses to explore the perceptions of the local community on the use of CPI systems as they relate to vulnerability and drought.

4.2.2: How Locals Perceive the Role of CPI Use in Relation to Vulnerability and Drought

The coded responses intended to explore research question number three were placed into four main categories. The four categories include: concern for water levels and the community, agriculture that was reliant on irrigation, drought exacerbated issues and the future of irrigated agriculture in the region (Table 10). Each of these main categories had subcategories of further coded common responses to interview questions. Many of the responses in each of the main category were the same for both counties, especially in regard to concern over water issues and drought. However, the two counties did differ slightly, particularly in how reliant they felt their county was on irrigated agriculture.

Table 10. Coded Categories from Key Informant Interview Responses on Perceptions in Union County, NM and Cimarron County, OK (n=20)

	Main Categories of Coded Responses to Perceptions of CPI Use in Relation to Vulnerability and Drought			
	Concern for Water Levels and the Community	Agriculture Reliant on Irrigation	Drought Exacerbates Issues	Future of Irrigated Agriculture in the Region
Subcategories of Coded Responses	• Depleting Aquifer/ wells dropping • Cimarron- New wells still going in • Groundwater is the only water they really have for the entire community • Entire community reliant on agriculture for their economy	• Irrigation is necessary to sustain agriculture /corn production • Cimarron- Entire community connected to irrigation in some way • Union- Not a lot of farming but rely on irrigated hay and feed	• Increase in irrigation during drought • Increase in supplemental cattle feed	• Decreased amount of irrigated crops • Change in crop type to more drought resilient types • Shift to dryland • Shift to rangeland • Will affect the entire community negatively • Shift needed but optimistic

4.2.2.1 Concern for Water Levels and the Community

In both counties, 100% of the respondents said that water depletion and wells dropping was the number one concern in the area. Everyone knew that water levels were dropping and that their water supply was not infinite. However, there were various levels of concern about aquifer depletion. In Union County, a common concern for many ranchers was for their cattle and house wells. This was a concern because many ranches were located near farms with large irrigation wells. The large wells had pumped so much water that it caused the rancher's wells to decrease considerably or even dry up. In Cimarron County, a major concern was for new large wells that were still going in and no regulations to try and prevent more from going in. One farmer stated that others were "putting in a lot more large pumping wells within the last 4-5 years." In both counties, many respondents were very concerned about depleting wells and argued something needed to be done now. One rancher argued that they "need to stop drilling wells" although the

state should still "honor the rights of those that already have them and realize this is their livelihood." Others in both Cimarron and Union County agreed something should be done but adaptations could be made when necessary.

A top concern for 57% of respondents from both counties was that their entire communities (both rural and urban areas) would be affected by the loss of aquifer water. Residents rely on groundwater for their homes and businesses and few other sources of water exist. One local resident stated that this is "the single important issue they all face" and that if "they don't have drinking water, they don't have a community." Additionally, everyone in both communities were connected to agriculture in some way and relied on ranching and farming as their main economic source. A loss of agricultural production and revenues would be a major upset to the entire community. One farmer argued that a loss of irrigation and agriculture "would be an economic hit to all businesses in the area because they are all connected in some way." Given that everyone in their communities were connected to agriculture and rely on it, the next subsection discusses whether or not the respondents felt irrigation was necessary to sustain the agriculture that their communities relied on.

4.2.2.2 Agriculture That is Reliant on Irrigation

When asked about the areas' reliance on irrigation for agriculture, the responses from each county were somewhat different. In Union County a few ranchers felt that they were not very vulnerable to aquifer depletion because they did not irrigate. Many of them stated that the area did not have much farming, so they were not very concerned about having enough water. Other ranchers though were very concerned for their ranching operations. Much of the water sources for their cattle were pumped from the aquifer with little other water available. One rancher stated that his ranchland adjoins irrigated land and that his "windmills have dried up and has had to move them and drill deeper." A loss of irrigation water would also affect the irrigated

cattle feed areas that they sometimes rely on to supplement their herd's diet. Additionally, the feedlots that ranchers sell their cattle to would also be affected with less irrigated feed, reducing the amount of cattle they purchase.

In Cimarron County, responses were a bit different as the county is more directly connected to irrigated farming. Not only were farmers connected to irrigation, but also 100% of respondents from the Cimarron community said they were connected in some way. One farmer stated that a loss of irrigation "would change the economics of the area." More specifically, industries that support irrigation would leave and industries that support them, creating a domino affect on the economy. Given the entire communities' connection to irrigation, respondents felt that the area was very reliant on irrigated agriculture. Reliance on irrigation was especially true for corn production, which was the top cash crop in the county.

In both counties, issues from a depleting aquifer and agricultural economies reliant on irrigation were only worsened by excessive long-term drought conditions. The following subsection discusses how drought exacerbates such issues.

4.2.2.3 Drought Exacerbates Issues

For both counties, drought worsened the issues of water depletion and reliance on irrigation for agriculture. This was especially true for farming operations. Though corn production in the area always required irrigation regardless of drought, supplemental rainfall reduced the use of irrigation. However, with excessive drought, it was necessary for farmers to increase the use of irrigation. For ranching operations, drought created issues with food supply for cattle herds. Ranchers had to increase supplemental feed and hay to make up for the lack of grass. In both counties drought created more concern over issues that were already prevalent. Overall, respondents in both counties were concerned and in some instances felt vulnerable to depleting wells, the potential impacts to the agricultural economy, and drought worsening these problems.

The respondents argued there would be a shift needed in agricultural practices and potentially the economies as well. Even so, many were optimistic for the future of agriculture in the region and felt as though adjustments could be made.

4.2.2.4 Future of Agriculture in the Region

While everyone that was interviewed was concerned about water issues and the depleting aquifer, 81% were still optimistic about the future of agriculture. In Union County, some ranchers stated that a decrease in irrigation was already occurring and this trend would continue. In Cimarron County, some farmers were already trying to grow crops that were less water intensive as well as other conservation practices such as sprinkler and GPS technology changes. Though some shifts were already taking place in both counties, respondents knew that more shifts in practices needed to occur. In Union County, most often respondents offered that the land would need to return to rangeland or go into CRP land. One resident even argued that the community "needs to look into an economy that is not so much reliant on agriculture." In Cimarron County, more changes in crop types as well as a return to dry land farming were offered as future options. More so, a local resident hoped that "science will move fast enough" by creating things such as drought resilient GMO crops, to address the issue. Regardless of the types of change, the major concern over the effect of such changes on the entire community was still at the forefront.

Though many of the respondents did not directly say that they were vulnerable to CPI use and irrigated agriculture, their concerns revealed increasing vulnerabilities. The concerns of water depletion and community connection to irrigated agriculture offer that both communities would be affected greatly. However, many were optimistic that adjustments could be made to maintain agricultural operations, which may reduce such vulnerabilities.

The next section of results from archival and secondary research further explores the practices and policies that influence CPI growth and use provided in section 2.1.

4.3 Archival and Secondary Research Results

The results of the archival and secondary research further explore the three main categorical influences found from the coding results. Archival/secondary data is used to expand on each of the subcategories to better understand their complex influences on CPI growth and use.

4.3.1 Economic Influences

The top economic influences as coded from the key informant interviews were corn, grain and gas prices. More specifically the high prices of corn combined with lower prices of gas are driving the use of irrigation. Other economic influences revealed were: ethanol, ethanol plants, feedlots, corn feed, federal programs and drought. The archival and secondary data below were found from national and county data from the USDA, EPA, US-IEA, RFA and the AFDC.

4.3.1.1 Corn, Grain and Gas Prices

Throughout the years the price of energy has been an important factor in increasing or decreasing CPI use. CPI irrigation in the high plains in particular is energy intensive (Report of Progress 611 KSU, 1990). When coupled with high or low commodity prices of corn and other grains, farmer's net incomes are greatly impacted through increased pumping costs and decreased return on investments (Sands and Westcott 2011).

When corn, grain and natural gas prices are compared to the amount of irrigated acres in both Union and Cimarron Counties, some trends appear that correspond with information found in the key informant interviews regarding this relationship. The mid 1980s had higher gas prices (\$5.50/thousand cubic feet) (US-EIA 2015) with lower prices for corn (\$1.48/bushel) and sorghum (\$1.48/bushel) but higher prices for wheat (\$2.94/bushel) (USDA-ERS 2015) (Figure 21). In turn, for both counties wheat had the largest amount of irrigated acres with 9,551 acres in

Union County and 20,088 acres in Cimarron County (USDA 1987) (Figures 22 and 23) (Report of Progress 611 KSU, 1990). Then, in the mid 1990s prices of gas fell considerably to \$3.14/thousand cubic feet (US-EIA 2015) and prices of corn and sorghum rose slightly (\$3.01/bushel and \$2.68/bushel) (USDA-ERS 2015). The price of wheat jumped higher (\$5.21/bushel) (USDA-ERS 2015) and in Cimarron County the number of irrigated wheat acres grew to its highest level of 27,162 acres of irrigated wheat (USDA 2002). However, in Union County irrigated acres of wheat stayed relatively steady (10,451 acres), while the amount of acres in irrigated corn grew higher than wheat acres to 16,037 acres (USDA 2002).

In 2005, the prices of gas jumped higher once again to \$8.56/thousand cubic feet (US-EIA 2015) and the prices of all grains fell. The prices of wheat (\$3.10/bushel) remained relatively higher than corn (\$1.80/bushel) and sorghum (\$1.80/bushel) (USDA-ERS 2015). In Union County after 2005, these changes seemed to have little effect on irrigated acres as irrigated corn still rose slightly to 28,680 acres and irrigated wheat and sorghum acreage remained steady at 11,889 acres of irrigated wheat and 200 acres of irrigated sorghum (USDA 2002). In Cimarron County however, corn acreage fell to 13,018 acres while wheat acreage surpassed corn acreage to 16,550 acres (USDA 2007). After 2005, the prices of corn increased every year until 2012 except in 2009 when the prices fell to \$3.62/bushel (USDA-ERS 2015). In 2012, after the extensive drought in 2011 (US Drought Monitor 2014a), the price of all grains dropped including corn to \$4.82/bushel, wheat to \$7.18/bushel and sorghum to \$4.50/bushel (USDA-ERS 2015).

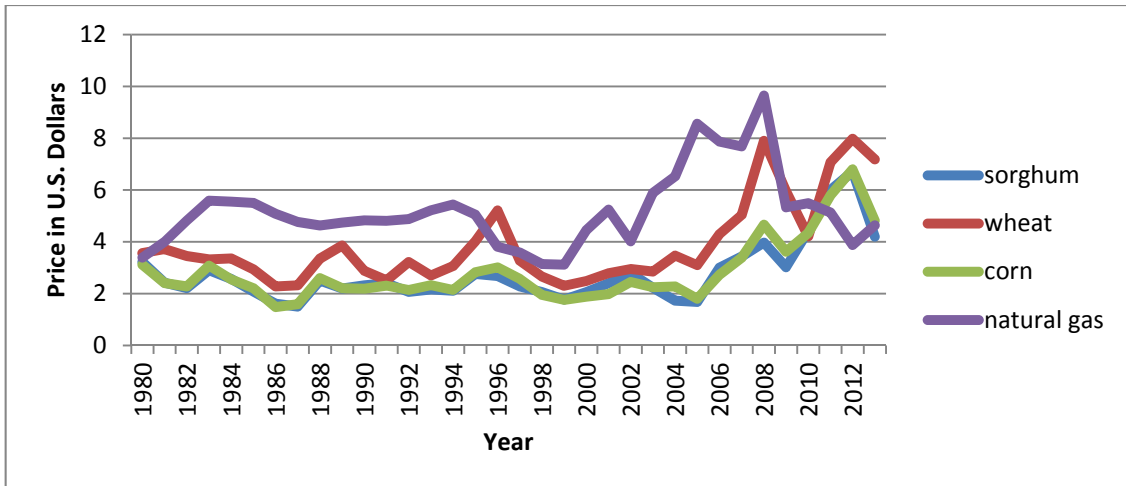


Figure 21: Inflation Adjusted Prices: Grains and Natural Gas- Great Plains Region 1980-2014

(Grain in US Dollars/bushel, Gas is US Dollars/thousand cubic feet) Data Source: Grain Prices- USDA Economic Research Service 2015 Natural Gas prices- U.S. Energy Information Administration 2015

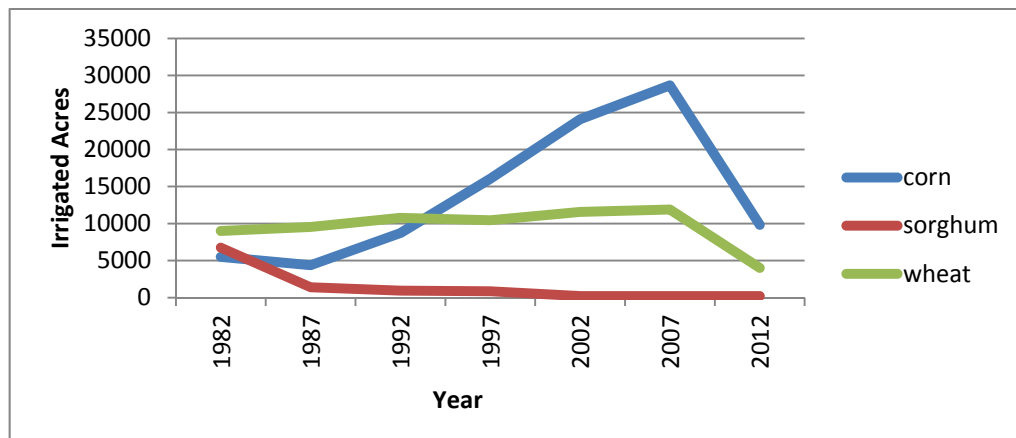


Figure 22: Amount of Irrigated Acres by Grain Type in Union County, NM 1982-2012

Data Source: USDADANew Mexico 1982-2012

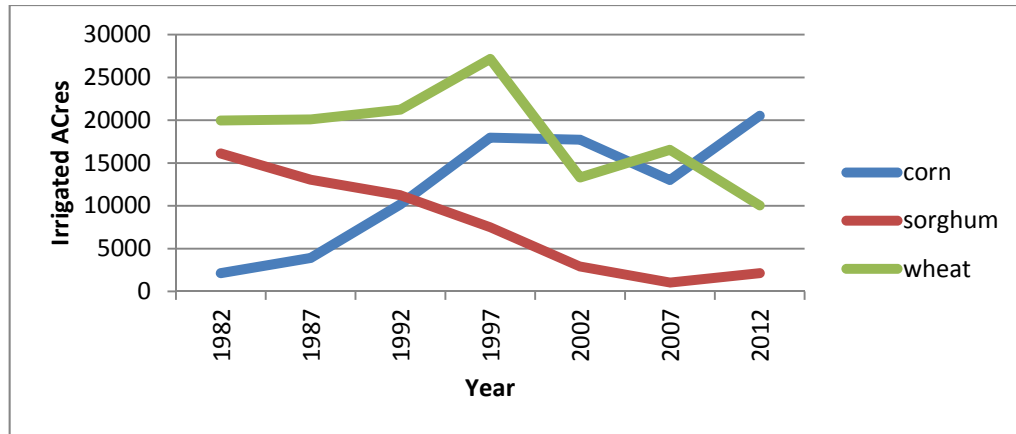


Figure 23: Amount of Irrigated Acres by Grain Type in Cimarron County, OK
1982-2012

Data Source: USDA Oklahoma 1982-2012

Overall, the price of corn and gas as the determining factor of irrigation seemed to hold true in both counties until the mid 1990s. This trend continued in Cimarron County, particularly after 2000. Union County though, showed much less variation in irrigated acres regardless of corn or gas prices after 1995. Wheat and sorghum irrigated acres stayed relatively steady while corn continued to rise until 2007 when the amount of irrigated corn acres fell significantly.

Furthermore, some influences on irrigated corn acres remained unexplained by just the rise and fall of grain prices. Most often the price of wheat remained higher than the price of corn, however, irrigated corn acres in both counties were continually growing. This can be explained in part by corn being easier to grow and having higher yields/profits. Though other factors including higher demand by the ethanol and feed markets, as well as having the support of the government through subsidy programs have strongly influenced growth in the production of corn (Angelo 2010).

4.3.1.2 Ethanol and Ethanol Plants

The growth of ethanol production had an enormous impact on the U.S. agricultural sector particularly for corn prices and subsequent expansion of irrigated corn acreage (Westcott 2007a). Ethanol plants began a rapid expansion around 2005 when dozens of plants were opened (Baker and Zahniser 2007). This expansion of the ethanol market and boosted demand for ethanol caused an increase in corn prices, which in turn created incentive to increase corn acreage (Westcott 2007b). Furthermore, the demand for ethanol encouraged farmers to increase acreage through the shifting of land to cropland that was not previously so. Increased acreage was gained through transforming former pasturelands, fallow lands, expiring CRP contracted lands, and lands previously used for other crops (Westcott 2007a).

A rapid spike in ethanol production in the United States occurred almost immediately after the opening of the ethanol plants around 2005. At this time ethanol production increased more than three hundred percent (from 3,904-13,298 million gallons) in just five years (RFA 2015) (Figure 24). At the same time, corn production for ethanol grew rapidly in response increasing by more than three hundred percent (from 1,603 to 5,018 million bushels) in those same years as well (AFDC 2014) (Figure 24). The effects of this expansion were reflected in Figures 21, 22 and 23 whereas corn prices and irrigated corn acres in Union and Cimarron Counties increased in that same time period, though did not continue at an increase in Union County. Overall, the role of ethanol in the growth of irrigation was a more recent influence, in turn causing the more recent influence of high corn prices on irrigated acreage.

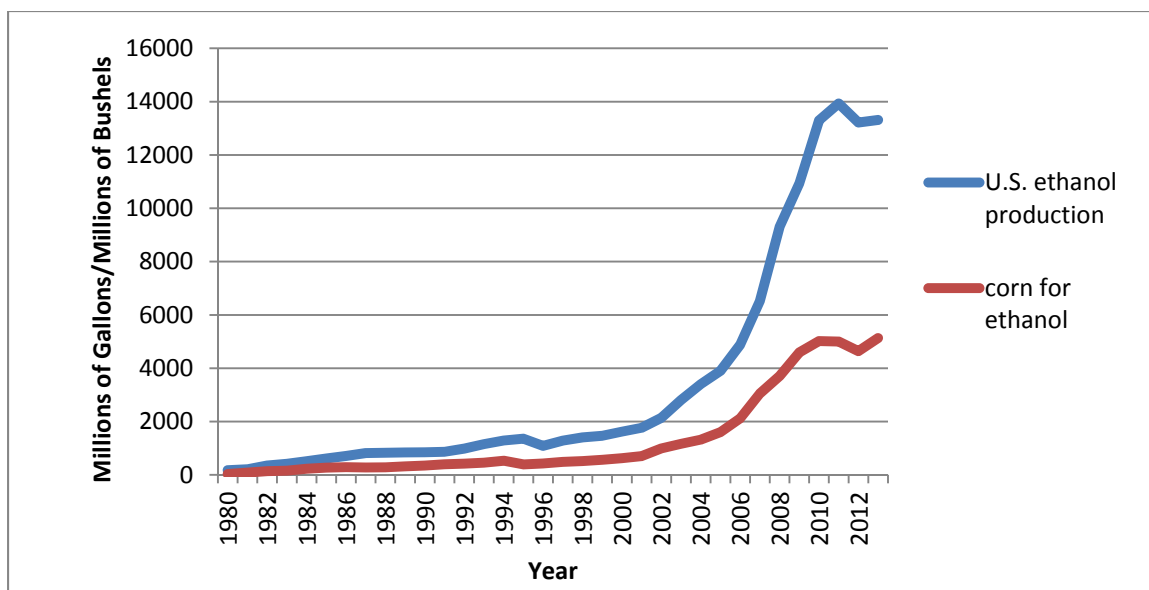


Figure 24: U.S. Ethanol Production in Millions of Gallons and
U.S. Corn Production for Ethanol in Millions of Bushels 1980-2014

Data Sources: Renewable Fuels Association 2015 and AFDC.energy.gov 2015

In addition to ethanol production changing the market for corn production and prices, it has also had an impact on the cattle industry as well. The cattle industry had for many years driven the demand for corn for feed, however, with the shift towards ethanol, this changed.

4.3.1.3 Feed and Feedlots

Since the 1950s, the United States beef industry grew and changed dramatically. A major influence in this change was the emergence of large-scale feedlots. The calf feeding industry became the dominant way of beef production, as an ever-increasing percentage of total cattle weight was gained through a grain diet (Corah 2008). Thus, feedlots used an increasingly substantial amount of feed particularly from irrigated corn. Additionally, cattle not produced on feedlots were also increasingly given diets subsidized with grain, particularly in years of inadequate grass (Corah 2008).

Until the ethanol expansion in 2005, feed and feedlots for cattle contributed to the demand for corn production and, in turn, irrigated corn acreage. However, after 2005, all corn produced just for feed dropped from 6,000 bushels to a low of 4,000 bushels in 2012 (Figure 25), while the number of total U.S. cattle on feed grew (Figure 25). Although there was a reduced amount of corn produced just for feed, coproducts (i.e solubles left over from its production) of ethanol could be used for feed. The ability to make both ethanol and coproducts increased the revenues in the industry, further driving the price of corn and its demand (USDA ERS 2015).

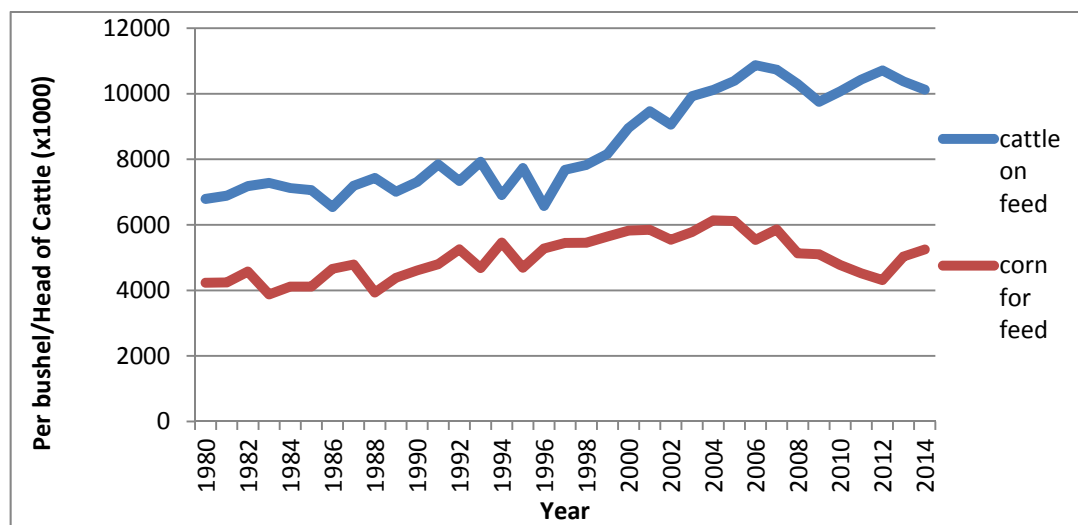


Figure 25: U.S. Corn Production for Feed and U.S Cattle on Feed 1980-2014

Data Sources: USDA Economic Research Service Feed Grains Database (1,000 metric ton) and USDA Economics, Statistics and Market Information System 2015 (x1000 head)

4.3.1.4 Federal Agricultural Programs and Policies

Federal agricultural programs and policies have long influenced crop production and subsequent prices. Planted acreage typically reflects producer net returns per acre for a given commodity, however, government policies and programs initially intervened in such market price forces. Between 1970 and 1986 government price support and commodity storage programs, as well as public stockholding by the government influenced wheat and corn prices (Westcott and

Hoffman 1999). During this time many commodity subsidies were tied to production levels with a fixed payment per bushel (Angelo 2010). For instance, commodity price support programs for corn and wheat enabled producers to obtain loans from the government at a certain loan rate per unit of production. In addition to price support programs, crop-planting choices were influenced by government program rules and crop specific acreage requirements for eligibility to receive benefits. More specifically, the government had a mandated minimum amount of planted acreage for different crop types, instead of plantings being based solely on farmer's decisions from market prices (Westcott and Hoffman 2010).

Changes made to the 1985 Farm Bill reduced the influence of these price support programs on crop production and price. These changes were a reflection of the change in U.S. agricultural policies that shifted towards more market based pricing and a sharp reduction in loan interest rates (Westcott and Hoffman 2010). This change in federal policy seems to be reflected in irrigated crop acreage type in both Union and Cimarron Counties (Figures 22 and 23). In both counties after 1987, corn production began to increase along with the increased price for corn and lower prices of gas.

The 1985 Farm Bill also marked a shift towards efforts to influence production in other ways. Influences included agricultural policies that encouraged conservation practices through acreage reduction programs, paid land diversions and other voluntary long-term programs. The Conservation Reserve Program (CRP) for instance encouraged all three. The CRP program provided payments to take highly erodible and environmentally sensitive land out of production as well as resource sustaining practices for ten years or more (Stubbs 2014). After implementation of the CRP program, initial enrollment in Union County and Cimarron County was quite strong (Figure 26), especially in Cimarron County. Just two years after its implementation, Union County had 26,465 acres enrolled and Cimarron County had 147,109 acres enrolled (USDA-FSA 2015). The amount of acres enrolled in both counties stayed

relatively steady throughout the years until around 2007. In Cimarron County in 2007, the amount of land enrolled in CRP dropped from the historic maximum of 159,142 acres to current enrollment of 116,549 acres (a 26.7% decrease) (USDA-FSA 2015). This drop further reiterates the concern that former CRP land was being transferred to cropland for irrigated corn due to high corn prices after the 2005 expansion of ethanol (Stubbs 2014). In Union County though, acreage only dropped slightly in from 25,212 acres in 2004 to 18,512 enrolled acres in 2012. Enrolled acreage began to increase again to current enrollment around 21,674 acres (a 17% increase) (USDA-FSA 2015). Unlike Cimarron County, this trend in Union County did not follow the increased corn prices and corn acreage trend.

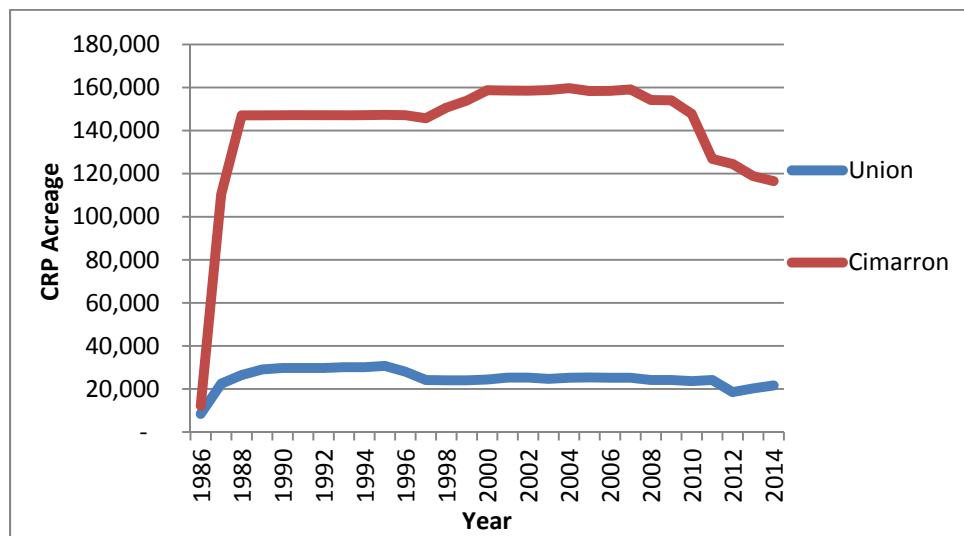


Figure 26: CRP Cumulative Enrollment Acres in Union County, NM and Cimarron County, OK by Fiscal Year 1986-2014

Data Source: USDA FSA Conservation Programs 2015

The 1996 Farm Bill made additional changes by eliminating the influence of supply control programs entirely. This further enabled farmers to make their own planting decisions based on the crop that provided the best market prices or profitability (Westcott and Hoffman 2010). Due to this, corn acreage in the United States increased significantly (Capehart et al.

2015). Though the influences of supply control programs were eliminated, a new program of Direct Payments was implemented with the 1996 Farm Bill. Direct payments were initially designed as transition payments. In this program farmers would receive a reduced direct payment each year until 2002. The payments were based on historic specific crop yields and prices (Effland et al. 2014). Direct Payments were implemented to help farmers adjust to the new market priced agriculture (Keeney 2013).

After 2000, U.S. farmers were already becoming less dependent on federal direct payments to help their operations. Instead, due to a bill that increased government paid premium subsidies, more farmers were increasingly relying on crop insurance for revenue guarantees (EWG Farm Subsidy Database 2012). Crop insurance ensured farmers had something to fall back on in case of crop failure. So with increased grain prices over the following years and less monetary risk, corn production was able to increase (USDA-RMA 2015). Like crop insurance, federal disaster insurance was relied on a great deal as well. Even though the federal government has encouraged crop insurance over disaster insurance, both are still important for providing a safety net for crop production (Dismukes and Glauber 2005).

Eventually the 2014 Farm Bill eliminated the direct payments program completely. After the elimination of direct payments, crop and disaster insurance programs had become even more important to agriculturalists (EWG Farm Subsidy Database 2012). However, the new policies reversed the ideas of the 1996 Farm Bill that aimed to eliminate the influence of the federal government on production decisions. Instead, the new premium subsidies created the need for farmers to understand and follow payment guidelines and production requirements (Keeney 2013). However, the impact of this reversal of policies for both production and irrigation is still too early to know.

The next subsection explores how drought creates additional pressures and strains on these economic and production systems, possibly changing their influence on irrigated acreage.

4.3.1.5 Drought

Across the United States drought is the leading cause of production losses to crop farms (USDA-ERS 2013). The High Plains region in particular has had major drought events in the 1890s, 1930s, mid 1950s, late 1970s, late 1980s and early 1990s and 2001-2014 that have substantially affected their crop production (U.S. Drought Monitor 2014). Farmers in drought prone regions must therefore factor drought risks into their farming decisions (Wallander et al. 2013). Most often these decisions involve steps for reducing vulnerability. Such steps include using more irrigation to sustain crop production in times of drought, utilizing USDA conservation programs, or even the abandonment of unproductive land when dry land farming is not an option (Wallander et al. 2013).

With the first option, maintaining crop production requires more irrigation in times of drought. Farmers must decide whether crop yields and prices are enough to offset the pumping costs of more irrigation (Jekanowski and Vocke 2013). The second option of using USDA conservation programs like CRP for risk management, are often used to offset the loss from unproductive land. The CRP program, though not intended for drought risk management, has often been used to lessen drought losses through CRP rental payments (Wallander et al. 2013). The third option of abandonment is the least desirable and least profitable option, though if a crop fails, farmers usually have safety nets in crop insurance and disaster payments (USDA ERS 2013).

The management decisions each farmer or rancher makes directly affect how much land does or does not go into production and, therefore, how much irrigated acreage there will be from year to year. Consequently, drought can encourage an increase in irrigated acreage if a farmer

decides irrigating is more profitable, especially if a particular crop such as corn is markedly high. However, drought can also lead to less irrigated acreage if the operation costs are too high, especially when combined with low crop prices. When typically market prices or government programs influence these production decisions, drought interrupts this system. Another factor that interrupts or influences irrigation decisions is water levels and water availability. The following section explores these water level influences.

4.3.2 Aquifer Availability/Water Level Influences

Irrigated acreage in the United States reached its peak in the 1970s and with it an awareness of water level declines of groundwater aquifers (USGS 2014a). With this depletion came a decrease in irrigated acreage due to increased energy pumping costs, lower farm profits and government conservation programs (Musick et al. 1990). The major water level declines in Union County from predevelopment (1950s) to 2013 occurred near the eastern border of the county near Texas (USGS High Plains Aquifer Water Level Change 2015) (Figure 27). In the GIS/RS analysis in section one, this is also where a majority of the CPI circles were no longer present in years after 2005. This shows water level decline likely contributing to the decrease in irrigated acreage. In Cimarron County, the major water level declines from predevelopment to 2013, were located in the central to Northeast portions of the county (USGS High Plains Aquifer Water Level Change 2015) (Figure 27). Like in Union County, this is where much of the CPI circles that were no longer present in the GIS/RS analysis were located.

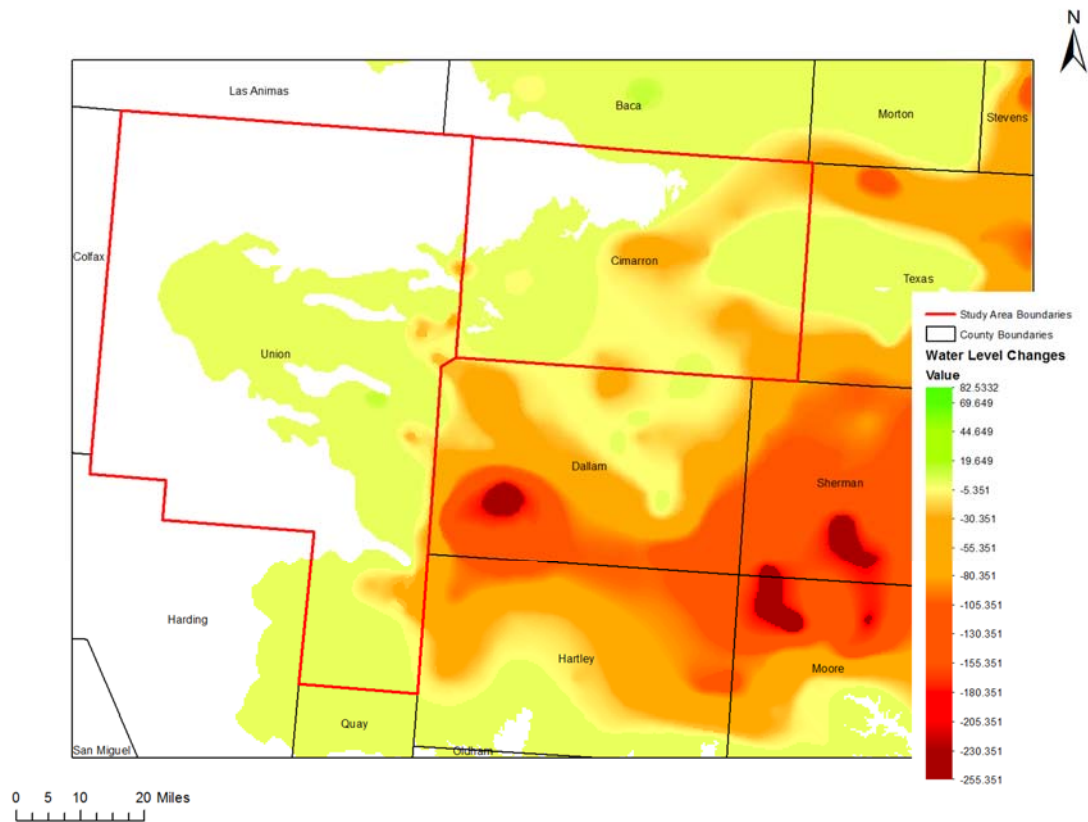


Figure 27: High Plains Aquifer Water Level Changes 1950-2013

Created by the Author from USGS High Plains Aquifer Water Level Change Data (2014b)

The most common way to combat these issues of water level declines over the years was to conserve groundwater and reduce energy costs through higher efficiency technologies (Upendram and Peterson 2007). The following subsection discusses changes in irrigation technologies that influenced changes in irrigated acreage.

4.3.2.1 Changes in Irrigation Practices

Lower levels of water and subsequent increases in pumping costs created the need for higher efficiency techniques to conserve water as well as energy. At both the Federal and State levels, programs like the Environmental Quality Incentives Program (EQIP) were created in order

to help offset the costs of technology upgrades for farmers. The EQIP program initiated by the 1996 Farm Bill included cost share contracts that provided subsidized technology improvements in order to conserve water. Among these upgrades were low-pressure sprinklers systems (LEPA) (Peterson and Ding 2005). The LEPA sprinklers replaced the much less efficient gun sprinklers for CPI systems. Though the LEPA sprinklers were intended to conserve water, the sprinklers also reduced energy pumping costs for the farmer (Upendram and Peterson 2007). This reduction in pumping costs actually caused an unintended consequence of increased irrigated acreage in some areas. This was in part due to shifting crop patterns, mainly towards more water intensive corn production (Pfeiffer and Lin 2013). More recently water levels have become extremely low in some areas and are to a point where pumping costs are so high that irrigation is often not worth the production even with higher efficiency technologies. With ever decreasing levels of water, pumping costs will continue to rise higher, in turn putting pressure on farmers to decide whether to drill a new well or no longer irrigate.

Over the years, water level declines not only influenced changes in technology and subsequent irrigated acreage but also water use regulations and policies. In the United States, water regulations vary by state and directly influence a farmer's ability to irrigate their land. The following section explores the influences of water regulations on irrigated acreage.

4.3.3 Water Rights and Policy Influences

After the expansion of irrigation to peak acreage in the 1970s and noticeable water level declines, some states began to address issues of water rights and regulations. With each state having the authority to delegate regulations for their water resources, stark differences emerged. The difference in water resource control involved either public ownership of water rights or private (Massey and Sloggett 1984). Public ownership regarded groundwater as a public resource and the authority to regulate its use is given to the state. Private ownership considers groundwater

the property of the overlying landowner and authority to regulate its use lies with them (OWRB 2014). In the states where groundwater was privately owned the degree of state or local groundwater management was far less intervening than publicly owned (Massey and Sloggett 1984). As a result, expansion of irrigated acreage could be hindered through restrictive drilling rules if the state's policies were more limiting. The following subsection discusses how these differing water regulations have emerged from New Mexico regarding groundwater as a public resource and Oklahoma regarding groundwater as a private resource.

4.3.3.1 New Mexico Water Policies vs. Oklahoma Water Policies

The most common regulations in the High Plains/Ogallala Aquifer region that influenced irrigated acres include permitting, well spacing and quantity restrictions (Massey and Sloggett 1984; OWRB 2014). Permitting can restrict the amount of wells installed through application and approval requirements. Well spacing also restricts the number of wells installed by requiring a minimum distance between them. Controls on the quantity of water are also used to regulate wells; this, however, may not be as effective in influencing irrigated acreage.

In New Mexico, the state engineer is charged with the task of issuing permits in areas with declared water basins (NMOSE 2015). Declared basins place water resources under the control of the state and gives regulatory rights to the state engineer. In the 1980s the state engineer had only declared twelve basins, which did not include Union County (NMOSE 2015). With no declared basin new wells could be installed on the basis of prior appropriation rights. Union County was not part of a declared basin until 2005. Once declared, permits were required to drill new wells for irrigation, as well as well spacing and restrictions on the amount of water that could be withdrawn. Well spacing and amount restrictions are carried out and vary by local districts (Nebraska Legislature 2014).

In Oklahoma, in the 1980s, the state's Water Resource Board created a state water plan to establish a reliable supply of water for the state. As part of the state plan, Maximum Annual Yields (MAYs) for each basin and sub basin were to be created in order to ensure enough water for the next 20 years (OCWP 2012). During that same time, Oklahoma also started requiring permits to drill new irrigation wells. In 2012 the Panhandle basin's MAYs were established and were set at two acre-feet per year (AFY) per acre in the three Panhandle counties. Additionally, rules required that new wells being installed had to be at least 1,320 feet apart from any other authorized well (OWRB 2014). Though Oklahoma requires permits to drill new wells and has set well distance and quantity regulations, the regulations are otherwise not very restrictive.

Next, the discussion explores the relationships between the GIS/RS, coded groups and archival and secondary research results. Furthermore, Section 4.4 explains the relevance of these results within a combined LCS/PE framework.

4.4 Discussion

The first section of the results revealed a stark difference between CPI use in Union County, NM and Cimarron County, OK, particularly since 2011. In both counties initial CPI growth occurred rapidly and nearly the same number of circles were present in 1985/1986. However, after this initial jump, Union County CPI growth was much lower than that of Cimarron County. CPI use stayed relatively steady in Union County until 2011 when use dropped drastically. Cimarron County on the other hand, dropped slightly in 2008 then grew steadily in the following analysis years. This difference in initial growth between the two counties might have been in part due to the difference in availability of the High Plains Aquifer under each county. The High Plains Aquifer does not lie under as much of Union County as Cimarron County, thus preventing the further spread of irrigation beyond the initially developed land.

However, results from sections two and three revealed other causes for the more recent differences in CPI growth and use.

The key informant interview results from sections two and three revealed the policies and practices that influenced CPI growth and use. Primarily, residents indicated that the prices of corn and gas were the largest influence in the use of CPI for irrigation. Respondents all agreed that high prices for corn and lower prices for gas were creating much higher profits and encouraging the use of irrigation to grow corn. Additional influences mentioned were the demand for grain for feed and more recently ethanol. Other influences from water level declines, drought, and water regulations also contributed to CPI growth (or decline) and use. Though all of these were important influences, archival/secondary research revealed that such influences tended to have more recent (since 2005) effects on the increased or decreased use of irrigation.

Through archival and secondary research, governmental policies and programs proved important influences throughout all analysis years. Programs and policies such as the farm bills, crop insurance premium subsidies, and ethanol production requirements in particular impacted what types of crop were grown, how much and their prices. Not only did these governmental programs influence irrigation in the past but they also were closely linked to the more current trends mentioned in the key informant interviews. In particular, the prices of corn, gas and demand for ethanol. So while the prices of corn and gas were encouraging agriculturalists to irrigate, governmental programs were influencing the demand for ethanol and in turn the prices of corn. These policies and programs however did not influence both counties the same.

The high price of corn and governmental influences proved to greatly influence Cimarron County irrigation. Though, this same trend did not occur in Union County. This is particularly true after 2005. In 2005 ethanol plants and demand for ethanol increased greatly and with it demand for corn. Subsequently in Cimarron County irrigation of corn increased, while irrigation

of corn in Union County decreased. However, these changes occurred at the same time as excessive drought from 2001-2014, as well as after the water basin was closed and more restrictions were placed on well drilling in Union County. While both counties had excessive drought since 2001, the counties seemed to have responded in different ways. Union County overall decreased use of CPI systems, while many more CPIs were installed in Cimarron County. This could indicate that Union County responded to drought and water level declines by reducing irrigation given they were unable to drill new wells. Conversely, those in Cimarron County responded to drought conditions by increased irrigation and drilling more wells to ensure they were able to produce corn crops.

The key informant interviews from section two also revealed how the local communities of Union County and Cimarron County perceived the use of CPI with regard to drought and vulnerability. The overall trend of concern in both counties was for the water level declines. However, the level of concern differed within and between the two counties. The main difference seemed to be between those that ranched and those that farmed and irrigated. Many ranchers were concerned especially because their wells were drying up. However, many felt they were not very vulnerable because they did not irrigate, so they knew how to get by without it. Conversely, farmers knew that they had to irrigate to grow corn and during drought needed to irrigate to grow other crops as well. Beyond just the ranchers and farmers the rest of the local community was concerned because everyone relied on agriculture for their economy in some way. So not only would the loss of irrigation affect the farmers and ranchers but would affect everyone connected to them.

While agriculture is important to the local economies of both Union and Cimarron Counties, their production is also an important part of the agriculture production across the United States. Thus, a loss in irrigation and decline in production in these areas would likely have a big impact across the entire nation. Not only would production of corn and other grains be

impacted, but cattle production as well. Given that Union County is second in the state for cattle production and first in the state for corn production, and Cimarron County is the second largest producer in the state of cattle and corn (Vadjunec et al. 2012:3), both contribute extensively to both their state's and U.S. economy. Losing agricultural production from this region could create some food security issues across the nation. Additionally, this issue of water level declines and potential impacts on U.S. agriculture is occurring in other parts of the country as well, particularly in California. Similar to the study area counties, drought in California is requiring more irrigation and water levels are dropping drastically with potential to impact the U.S. food supply extensively (Schoups et al. 2005). Therefore, this study's results can be used to help identify drivers of irrigation use and identify potential practices and policies to be changed in the study areas as well as across the U.S.

The combined Land Change Science and Political Ecology framework presented in Chapter Three helps to reveal some important links in this study. The framework helps to reveal links between land changes and the political and socio-economic factors that influence such change in the ground. Land Change Science, and related remote sensing technologies enabled a top down approach to mapping land change. Political Ecology facilitated a more bottom up approach to understanding the drivers behind that land change. More specifically, PE facilitated the various structural levels of political, governmental and social drivers that influence such land change (Blaikie and Brookfield 1987). In this study, those drivers tend to be from national and state level governmental institutions and policies. The national policies impact the type of crop the farmers grow, the crop price and help to reduce the risk of growing those crops through direct payments and subsidies. The state level policies affect water use and the farmers' ability to irrigate. In this study, the national and state policies affect land use and land change in different ways. The national policies seemingly encourage the production of irrigated crops, while the state

water policies either encourage irrigation by limited restrictions as in Oklahoma or by more restrictions as in New Mexico.

National and state policies not only affect land change, but they also affect ecological and social vulnerability and resilience of communities (Langridge et al. 2006). Due to the increased use of irrigation not only are water levels declining at an unsustainable rate, but the possibility of land degradation is occurring as well. With the increased incentive to grow corn and irrigate, many in Cimarron County decided not to renew their CRP land and instead transfer it to irrigated land. Conversely, in Union County more land went into CRP. These changes could result in more land that is vulnerable to degradation in Cimarron County than in Union County due to more use. Furthermore, with increased irrigation over the years the communities have become more reliant on irrigated agriculture. This is especially true during years of drought, which are predicted to become more frequent (US Drought Monitor 2014a). Thus, adaptations to non-irrigation agriculture might be more difficult and impact the community's resilience to drought.

The following chapter will summarize the previous four chapters and discuss the scope and limitations of this study. Furthermore, the chapter will provide possible recommendations for additional research.

CHAPTER V

CONCLUSION

As cyclical drought and groundwater depletion continue to worsen and threaten the agricultural lifestyle and economy of the High Plains Region (Allen et al. 2007), understanding the dynamics between land-use and land-cover change, drought and vulnerability will become increasingly important. More so, it will become increasingly important to understand how various institutions and actors influence these changes and affect the resiliency or vulnerability of local communities. Utilizing a combined Land Change Science (LCS) and Political Ecology (PE) framework facilitated a comparative analysis between two counties within the High Plains Region to help better understand such complex interactions. More specifically, this study analyzed how center pivot irrigation (CPI) in Union County, NM and Cimarron County, OK changed over space and time, what policies and practices have lead to these changes and finally how the local communities perceived the use of center pivot systems in relation to vulnerability and drought.

Chapter one of this study introduced the research problem and background on the study area. Background included information on the High Plains Region, the High Plains Aquifer, and local groundwater rights as well as specific background on the two study area counties. Chapter two reviewed relevant literature on common pool resources, groundwater as a unique common pool resource, groundwater governance and vulnerability and resiliency. Chapter two also discussed the combined LCS and PE theoretical framework from which this study was shaped.

Chapter three presented the mixed methods used such as: GIS/RS, key informant interviews and archival and secondary research. Finally, Chapter four presented the results of this study followed by a discussion on results and how those findings relate to the integrated LCS/PE framework.

The results of this research indicated that in both counties CPI grew quickly after the 1950s until around 2005 when Union County started to decrease while in Cimarron County the acreage increased. In Union County, NM, by 1986, CPI acreage was 41,889 then in 2005 that acreage grew to 54,216. After which, acreage began to decrease and was 51,306 in 2014. In Cimarron County on the other hand, CPI acreage was 44,089 in 1985 and grew to 73,357 by 2005. Then in 2013 CPI acreage had grown once again to 79,622. So over the last ten years, since about 2005 during the most recent drought, center pivot irrigation systems have declined in Union County, NM, by 5.37%, while in Cimarron County, OK, center pivot systems have increased by 8.54%.

While the CPI results from this study showed that CPI acreage in Union County, NM had declined since 2005 and Cimarron County, OK had increased, these results differ from the USDA Agricultural Census data presented in chapter one (Table 1). The statistics from the census data revealed a slightly different story. Census data reported that actual irrigated acreage was declining in both counties. The decline in acreage started around the same time period (~2002-2005) in Union County, NM for both the census and this study's data; however, this is not true in Cimarron County. In Cimarron County, OK the census data reported that irrigated acreage started declining in 1997 and subsequently continued to drop. Additionally, the census data presented much lower amounts of irrigated acreage than found in this study. The differences in the results of this study and the USDA Agricultural Census data are likely due to actual irrigated acreage being reported, instead of just accounting for the presence of an irrigated circle or not. This issue is discussed further in the scope and limitations sections below.

Additional results suggest that the driving force of irrigation use was historically due to national government programs such as direct payments and insurance subsidies and economic influences such as ethanol and the price of corn and gas. Though, more recently since 2005, drought, state water regulations, and declining water levels appeared to be the driving force of decreased center pivot use in Union County. Conversely, in Cimarron County, high corn prices and fewer state water regulations encouraged an increase in center pivot use since 2005.

Utilizing a LCS/PE framework help to reveal findings that national and state policies not only affect land change, but they also affect ecological and social vulnerability and resilience (Langridge et al. 2006). Due to the increased use of irrigation, not only are water levels declining at an unsustainable rate, but also the possibility of changes in land degradation are occurring as well. With the increased incentive to grow corn and irrigate, many in Cimarron County decided not to renew their CRP land and instead transfer it to irrigated land. Conversely, in Union County more land went into CRP. These changes could result in more land that is vulnerable to degradation in Cimarron County than in Union County due to more use. The results of this study find that differences in state policies lead to different land and water use practices and in turn have implications for the sustainability of local agricultural communities. This study and its findings are possibly transferable to other agricultural communities that are reliant on irrigation for their economies. This study's methods and results could be used to help identify drivers of irrigation use and potential practices and policies to be changed across the U.S. Such potential practices and policies to be changed include encouraging corn growth for ethanol production or more restrictions on drilling new wells for irrigation.

Scope and Limitations

A major purpose of this study was to map and analyze land change over time and space due to CPI change. While this study was able to map this change throughout the analysis years,

there were limitations to identifying center pivot circles for mapping. For this study CPI circles were mapped if they were either present or not. This method did not account for whether or not the circle was actually in use for a specific year or not. Doing this would have demanded a much more detailed remote sensing analysis to assess for circles that were in use. Additionally, mapping for CPI circles going into and out of use does not reveal how much water is being used and why the wells went out of use. Circles can go out of use due to water levels that are too low and/or cost too much to pump or because the drought is so bad. Such interpretations were too complex for this study. However, the method used was able to correctly and accurately identify areas of change and cumulative growth. Additionally, the method used in this study helped to reveal land that might have been completely changed from a CPI irrigated circle to dry land or other land cover like CRP, that no longer utilized/needed an agriculture circle

Another limitation to this study was due to obtaining older aerial imagery. Older imagery was either far too expensive to obtain or, if free or cheaper, was not ideal. Therefore, some of the imagery was poorer quality and created issues with georeferencing. There was also a limitation to the amount of years that could be analyzed due to either high prices for older aerial imagery or newer year availability. Had more years of imagery been cheaper or free then more analysis years would have been possible and likely able to link changes in CPI use more closely with influential factors.

Limited funding was also a limiting factor for this research, specifically fieldwork, as well. Though a field research grant was obtained, the amount limited the last phase of fieldwork to ~2 weeks. This, combined with a shorter time frame for being in the field, limited the amount of interviews that could be done. It is possible that more interviews, asking different or more questions, could have revealed more information on CPI use and growth. However, the household surveys and participant observation that were undertaken for the larger NFS project prior to this

research helped to lessen this issue through increased field experience and community interaction (~4 weeks).

Directions for Future Research

As a smaller research project/thesis associated with a larger NSF research project, this study aimed to add additional insight into the research area to help further understand the dynamics of the region and its drought resiliency and vulnerability. The results of this project will be included in future publications in professional journals and contribute to the NSF Project's results. Those results will also be presented and distributed to the local communities of the study areas for them to utilize as well.

In addition to contributing to the larger NSF project, there are additional areas of possible future research on this study topic. One area that could contribute more to this research would be to expand the study area to include other counties nearby that also use CPI. Nearby counties such as Dallam County, Texas and Morton County KS, would also be ideal additional study areas. Both of these counties border either Union County, NM or Cimarron County, OK and would be ideal for comparison of the effects of state and national policies on CPI use. Each county is in a different state and could possibly have different trends in CPI growth and use throughout the years that could vary with implemented policies. Furthermore, the possible counties mentioned all irrigate using center pivots much more than the study area counties and could potentially reveal different trends in growth and use when larger areas of the county are able to be irrigated.

Possible future research similar to this study could also be done in other areas in the country as well. The issues of depleting aquifers, drought and agricultural uncertainty are also occurring in other places in the United States. One place in particular, as mentioned in the discussion earlier, is California. Their agricultural areas have a rapidly depleting aquifer and long-term extensive drought. This type of research could help to map extensive land change areas

due to CPI and or possibly other irrigation methods and identify the main contributing policies and practices that have influenced that growth. Once identified it might be possible to change or implement new policies that help to sustain agriculture and communities in those areas.

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APPENDICES

Appendix A: Internal Review Board Approval Letter

Oklahoma State University Institutional Review Board

Date: Wednesday, January 07, 2015 Protocol Expires: 4/15/2017

IRB Application No: AS1260

Proposal Title: Experiencing Drought in the Grasslands of the American West

Reviewed and
Processed as: Exempt
Modification

Status Recommended by Reviewer(s) **Approved**

Principal
Investigator(s):

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Norman, OK 73019

The requested modification to this IRB protocol has been approved. Please note that the original expiration date of the protocol has not changed. The IRB office MUST be notified in writing when a project is complete. All approved projects are subject to monitoring by the IRB.

- ☒ The final versions of any printed recruitment, consent and assent documents bearing the IRB approval stamp are attached to this letter. These are the versions that must be used during the study.

The reviewer(s) had these comments:

Modification to add a questions to the interview guidelines.

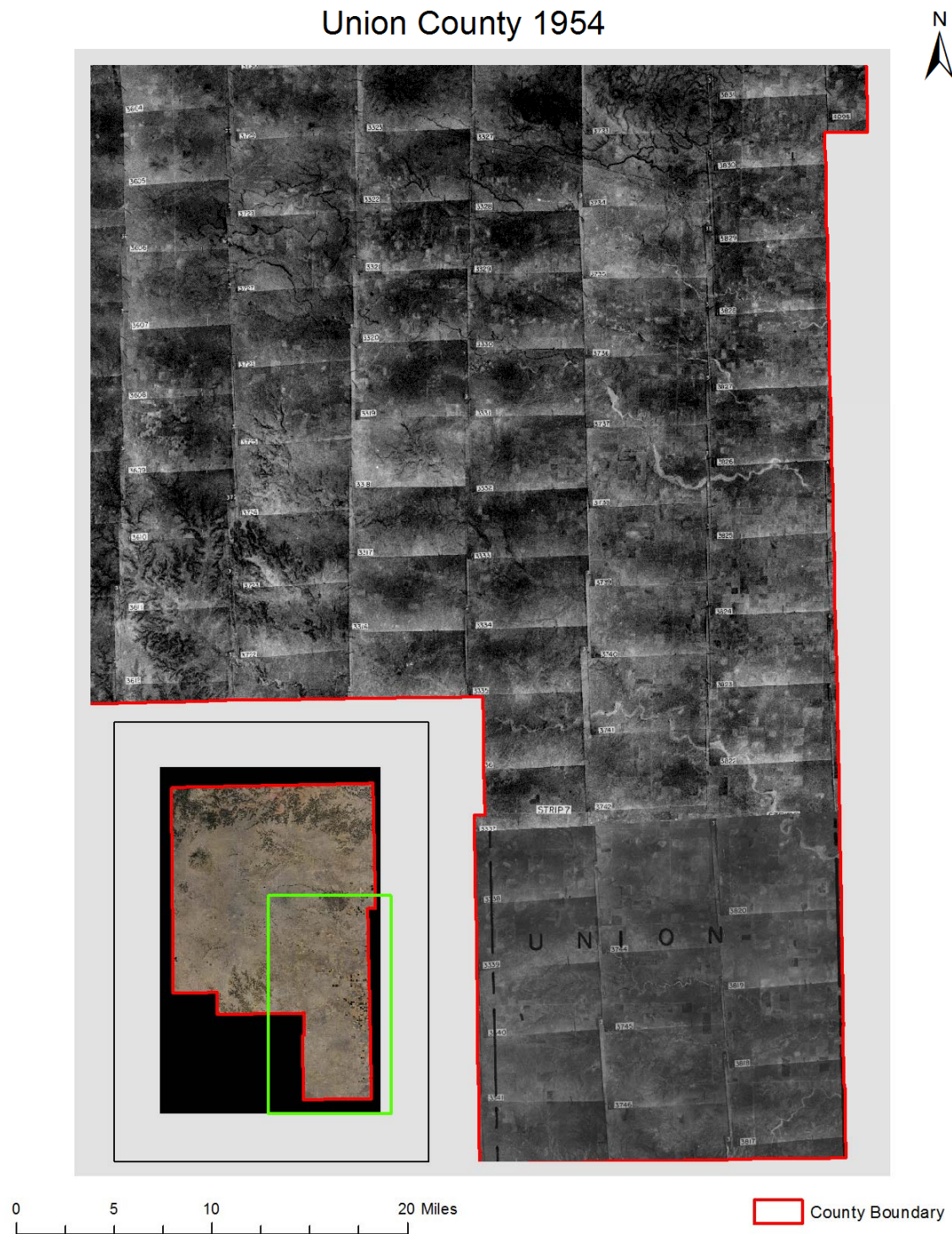
Signature :



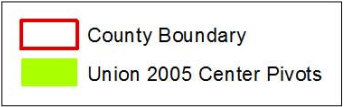
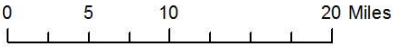
Hugh Crethar, Chair, Institutional Review Board

Wednesday, January 07, 2015
Date

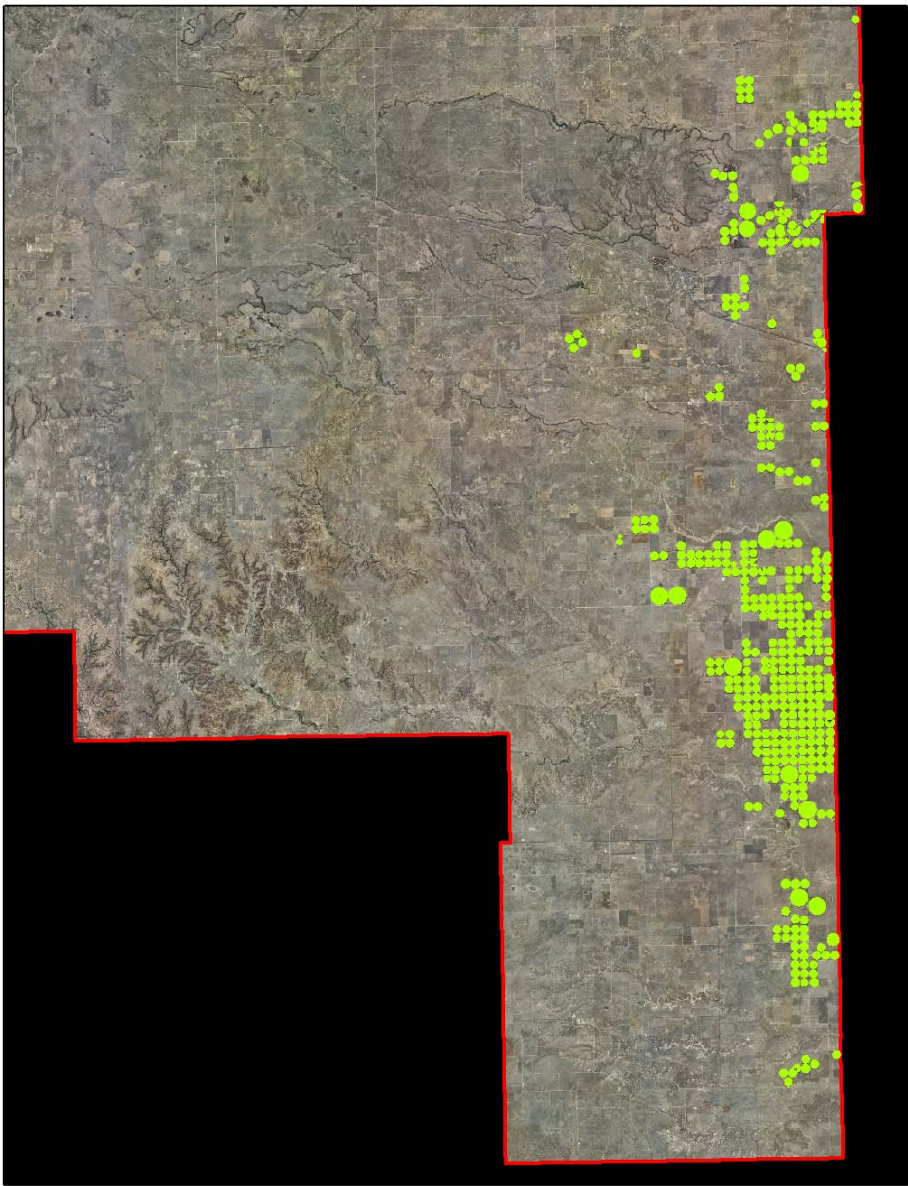
Appendix B: Additional Maps of Predevelopment Imagery and Digitized CPI



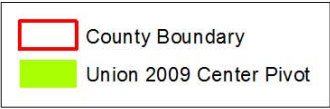
2005 Union County Center Pivots



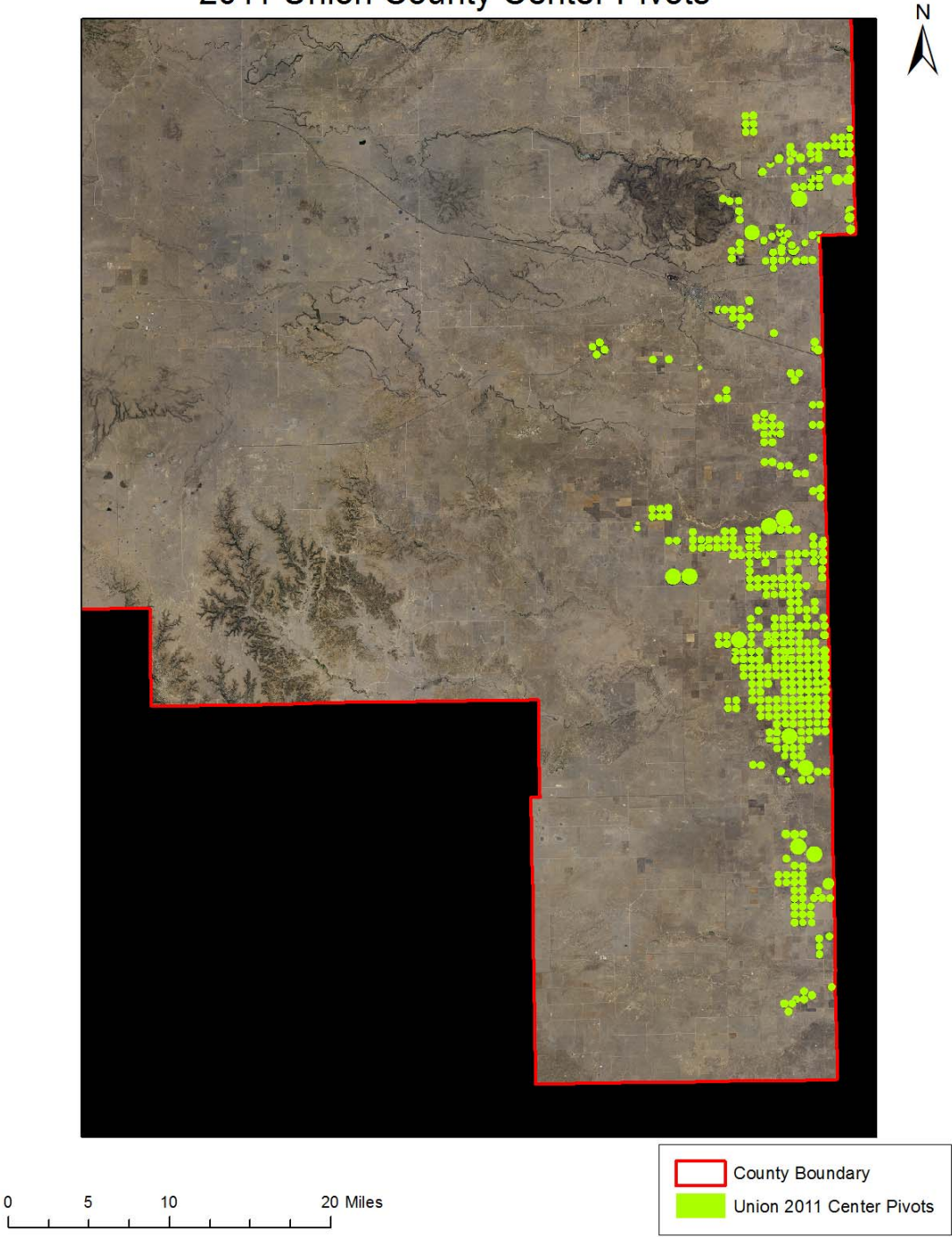
2009 Union County Center Pivots



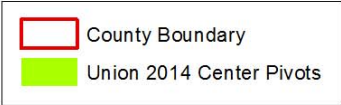
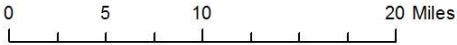
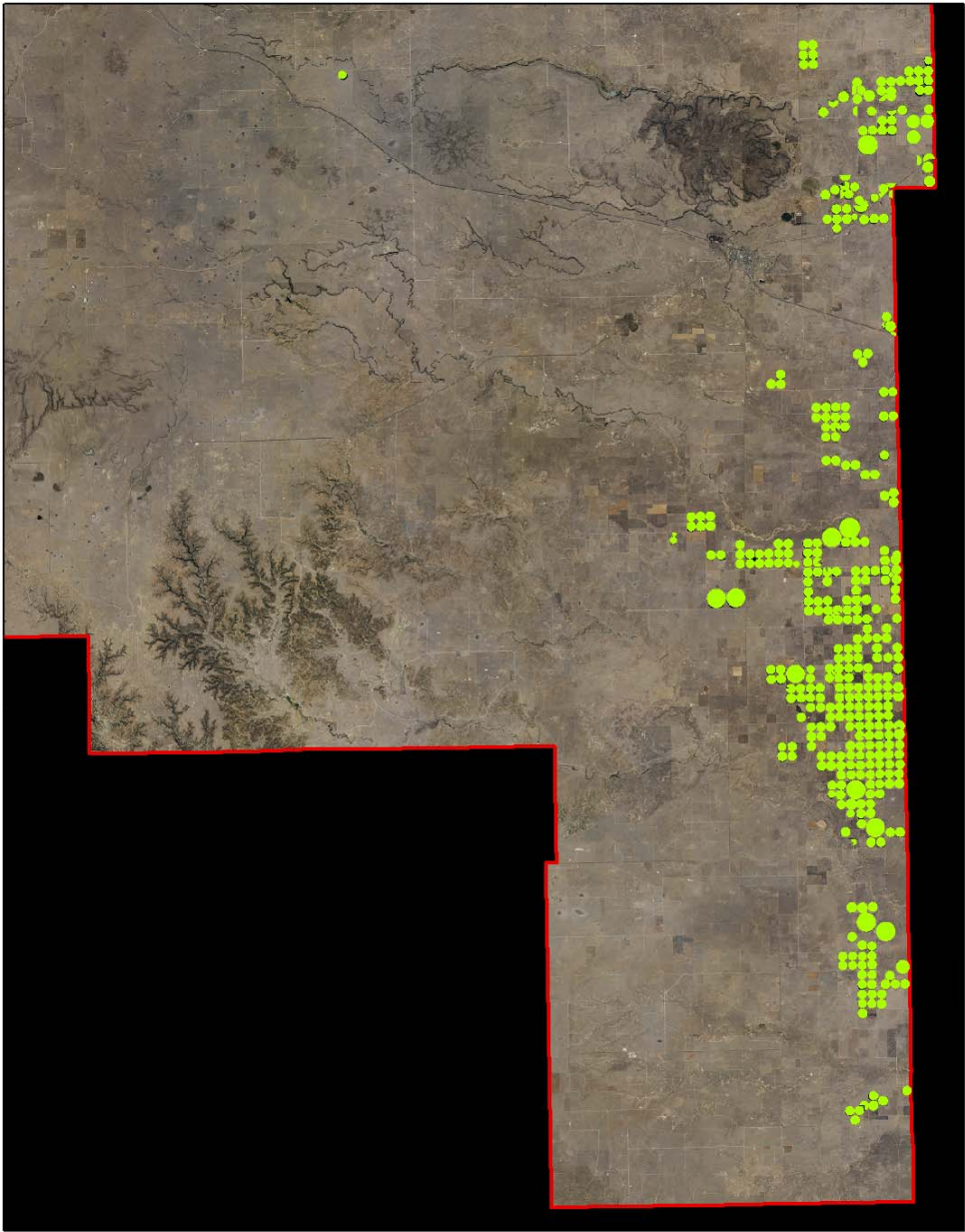
0 5 10 20 Miles



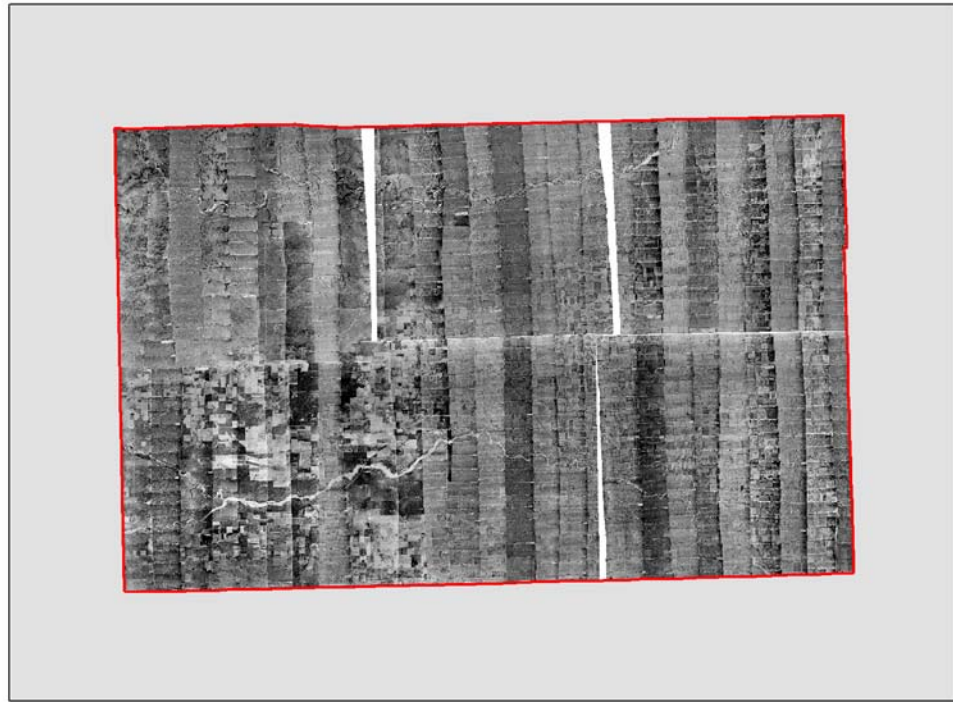
2011 Union County Center Pivots



2014 Union County Center Pivots



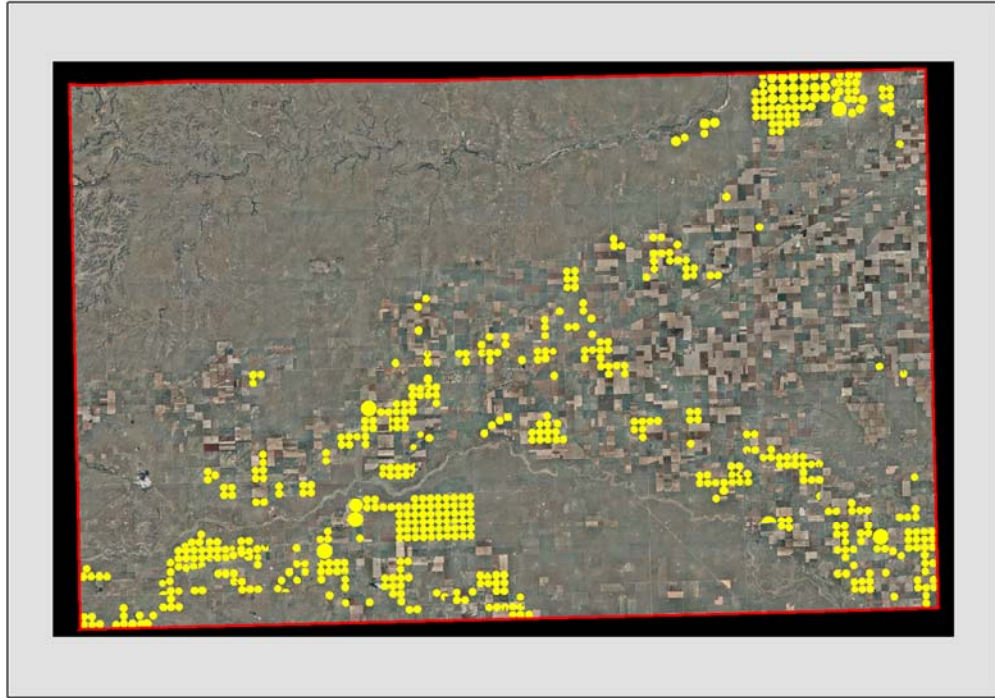
Cimarron County 1959



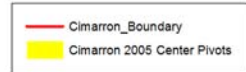
0 5 10 20 Miles

 County Boundaries

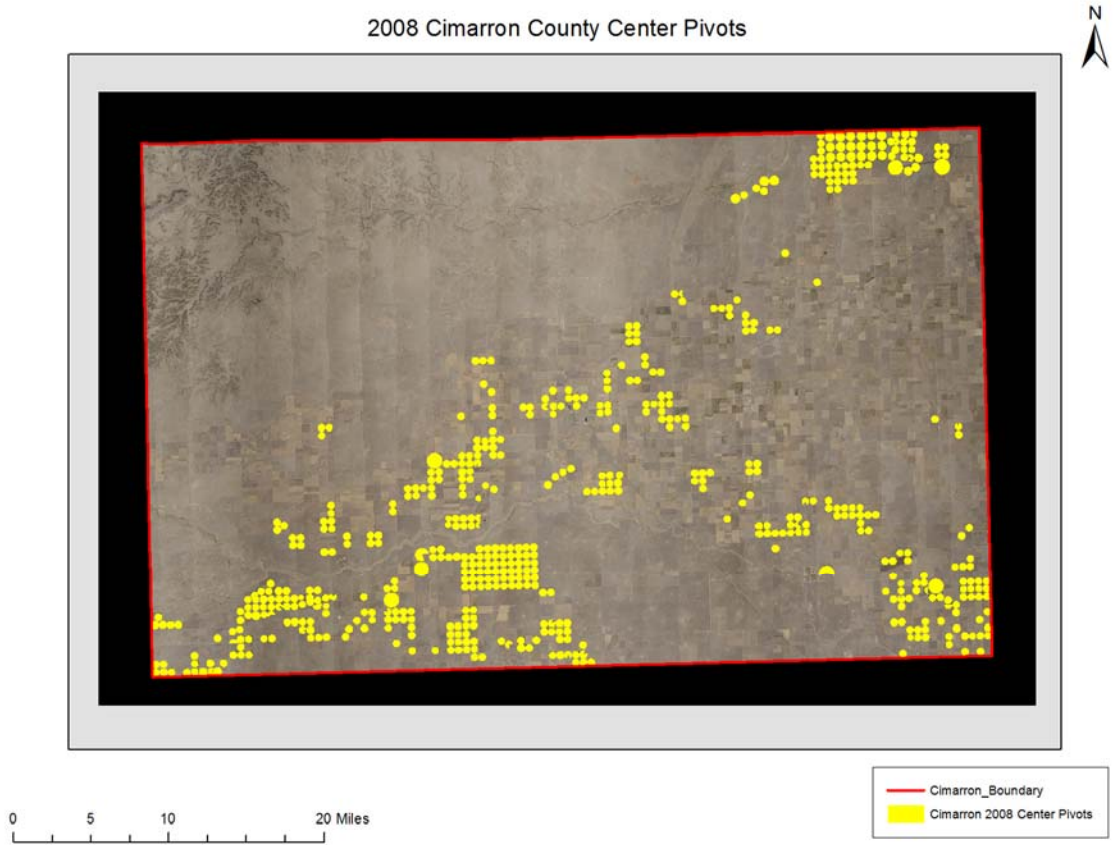
2005 Cimarron County Center Pivots



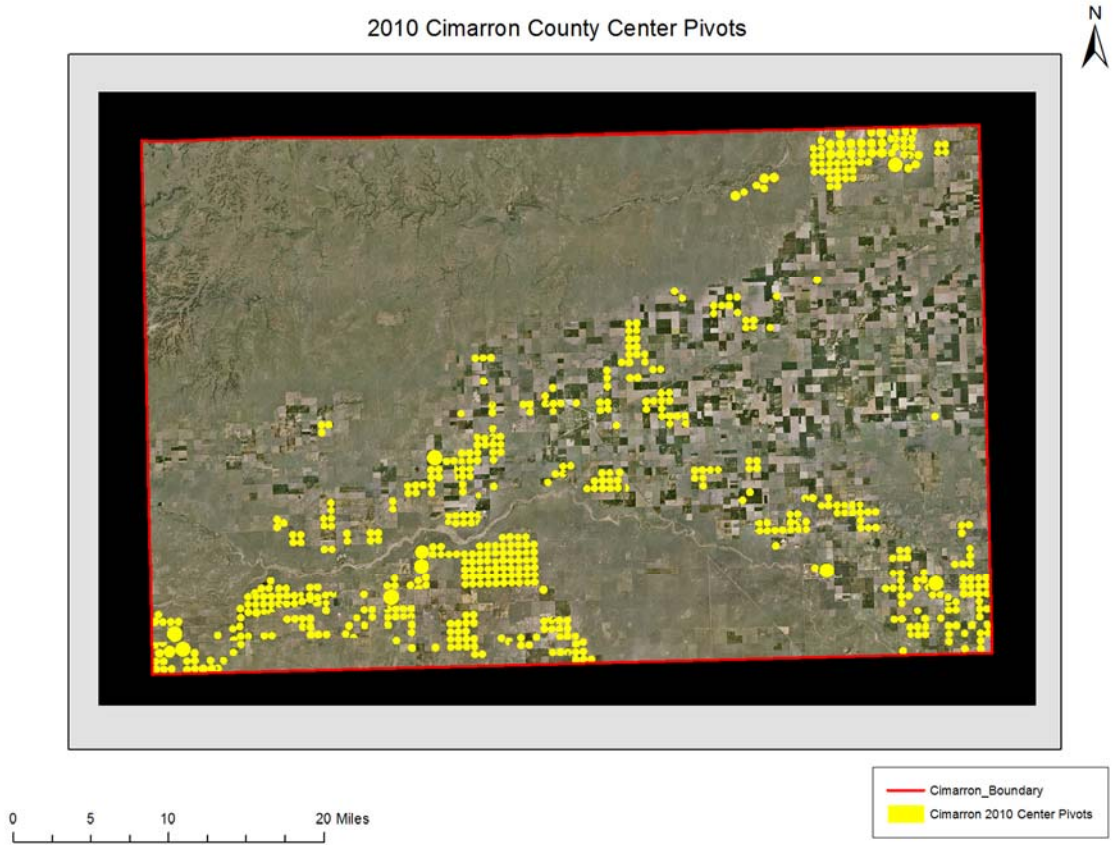
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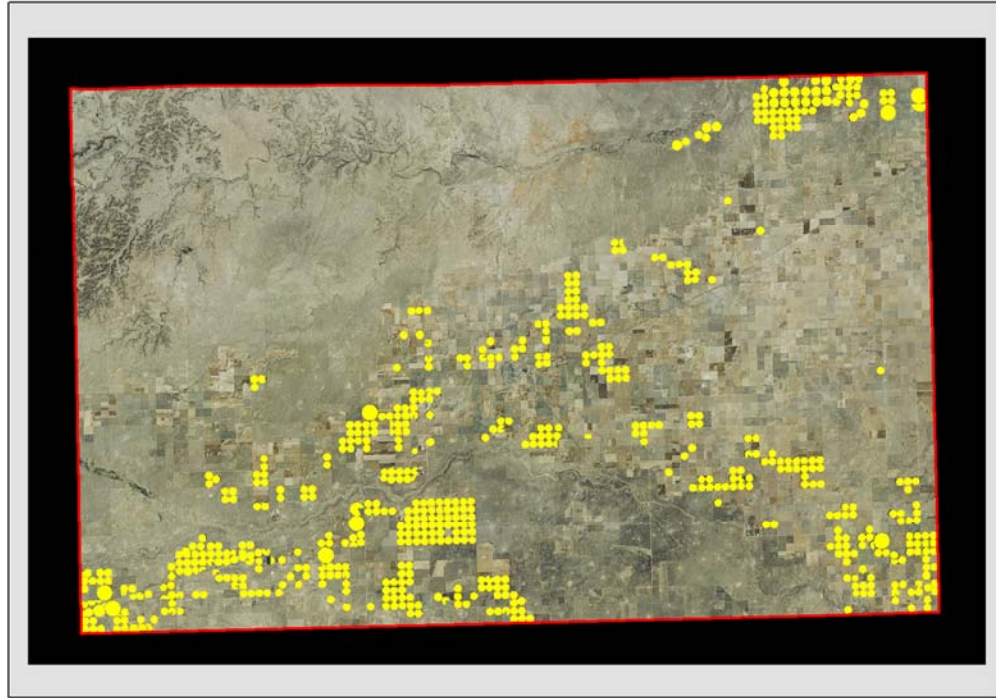
2008 Cimarron County Center Pivots



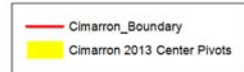
2010 Cimarron County Center Pivots



2013 Cimarron County Center Pivots



0 5 10 20 Miles



VITA

Kathryn Wenger

Candidate for the Degree of

Master of Science

Thesis: KATHRYN WENGER

Major Field: Geography

Biographical:

Education:

Completed the requirements for the Master of Science in Geography at Oklahoma State University, Stillwater, Oklahoma in July 2015.

Completed the requirements for the Bachelor of Science in Geography at James Madison University, Harrisonburg, VA in 2011.

Experience: Research Assistant/Teaching Assistant, Oklahoma State University, Department of Geography (August 2013-July 2015)

Data Operations Analyst- Geospatial Team, CACI International. Inc., Charlottesville, VA (June 2010-June2012)

Teaching Assistant, James Madison University, Department of Geography, (August 2009-December 2010)

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