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ANALYSIS OF HIGH PLAINS RESOURCE RISK AND ECONOMIC IMPACTS

Vincent C. Tidwell, Vanessa N. Vargas, Shannon M. Jones, Bern C. Dealy, Calvin Shaneyfelt, Braeton J. Smith, and Barbara D. Moreland

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Vincent C. Tidwell, Shannon M. Jones, and Barbara D. Moreland
Earth Systems Analysis

Vanessa N. Vargas, Bern C. Dealy, Calvin Shaneyfelt, and Braeton Smith
Resilience and Regulatory Effects

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Abstract

The importance of the High Plains Aquifer is broadly recognized as is its vulnerability to continued overuse. This study explores how continued depletions of the High Plains Aquifer might impact both critical infrastructure and the economy at the local, regional, and national scale. This analysis is conducted at the county level over a broad geographic region within the states of Kansas and Nebraska. In total, 140 counties that overlie the High Plains Aquifer in these two states are analyzed. The analysis utilizes future climate projections to estimate crop production. Current water use and management practices are projected into the future to explore their related impact on the High Plains Aquifer, barring any changes in water management practices, regulation, or policy. Finally, the impact of declining water levels and even exhaustion of groundwater resources are projected for specific sectors of the economy as well as particular elements of the region's critical infrastructure.

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EXECUTIVE SUMMARY

The area overlying the High Plains Aquifer[1] is one of the most prolific agricultural regions in the Nation, covering 111.8 million acres (175,000 square miles) in parts of eight states—Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. Following World War II, improved pumps and center pivot irrigation technology made High Plains' groundwater available for large-scale irrigated agriculture. Since this time, the High Plains has become one of the most intensively irrigated areas in the United States, accounting for about 30% of all groundwater withdrawn for irrigation. As of 2007, there were 50 million acres of cropland, of which 15.4 million acres were irrigated, in the High Plains. The High Plains region supplies approximately one-fourth of the Nation's agricultural production. Associated crops provide the Midwest cattle operations with enormous amounts of feed that account for 40% of the feedlot beef output in the United States. The aquifer also provides drinking water to 82% of the people who live within its boundaries, totaling 2.3 million according to the 2000 census. This growing reliance on the High Plains aquifer quickly exceeded groundwater recharge rates signaled by water-level declines that began in parts of the High Plains Aquifer soon after the onset of substantial irrigation around 1950, and by 1980, water levels in parts of Texas, Oklahoma, and southwestern Kansas had declined by more than 100 ft.[2]

The importance of the High Plains Aquifer is broadly recognized as is its vulnerability to continued overuse. The purpose of this study is to explore how continued depletions of the High Plains Aquifer might impact both critical infrastructure and the economy at the local, regional and national scale. This analysis is conducted at the county level over a broad geographic region within the states of Kansas and Nebraska. In total, 140 counties that overlie the High Plains Aquifer in these two states are analyzed. The analysis utilizes climate projections to estimate crop production into the future. Current water use and management practices are projected into the future to explore their related impact on the High Plains Aquifer barring any changes in water management practices, regulation, or policy. Finally, the impact of declining water levels and even exhaustion of groundwater resources are projected for specific sectors of the economy as well as particular elements of the region's critical infrastructure.

Together, the results of the crop modeling experiments represent a range of possible outcomes that could arise from future variations in groundwater availability, climate, and agricultural innovation. In the absence of any other changes, future climate projections were found to impose a small downward trend in dryland yields for corn, sorghum, soy, and winter wheat across the region. Historically, irrigation has been used to offset the impacts of variations in temperature and precipitation on crop yields; however, declining water levels are likely to limit such adjustments in the future. Improvements to farm operations and technology could overcome the impacts of climate variability and declining groundwater levels if future trends are consistent with that of the recent past.

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[1] The High Plains Aquifer is comprised of several water-bearing units with the Ogallala formation as its principal member.

[2] Luckey, R.R., Gutentag, E.D., and Weeks, J.B. (1981). Waterlevel and saturated-thickness changes, predevelopment to 1980, in the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Hydrologic Investigations Atlas HA–652, 2 sheets, scale 1: 2,500,000. (Also available at https://pubs.er.usgs.gov/publication/%20ha652.)

Although efforts have been made to reduce groundwater depletions, groundwater pumping in most regions of the High Plains Aquifer still exceeds sustainable groundwater recharge rates. Projecting current pumping rates forward in time, the time at which the aquifer is unlikely to be able to sustain continued pumping was calculated. Eighteen counties in Kansas were projected to have 25 or fewer years of available groundwater, while another 12 had an estimated aquifer life of less than 50 years. Thirty counties in Kansas and seven in Nebraska have a projected aquifer life of less than 100 years. These vulnerable counties are largely associated with extensive irrigated acreage and/or zones at the margin of the High Plains Aquifer where the formation thins.

The associated economic analysis utilizes information from numerous sources, including previous NISAC and agricultural economic reports and input from key stakeholders. Information from these various sources are combined in order to derive the assumptions for the economic model, and to bound the parameters and variables necessary to translate the scenario text into a quantitative economic model. The economic analysis is a two-pronged approach that includes three steps for estimating the economic consequences of resource risk in the High Plains. The two-pronged approach involves (1) starting at the national level and drilling down to identify major industries at the state and county level while also categorizing industries as water intensive and therefore vulnerable to resource risk, and (2) translating microeconomic impacts to the macroeconomic level.

The analysis focuses on industries deemed economically dominant and high water intensive. Industries falling into both categories were selected for microeconomic impacts because of their likely sensitivity to increasing prices for pumping groundwater. Our qualitative analysis confirmed that agriculture by output (volume and dollars), wages, employment, and water use is the industry most susceptible to increasing resource risk in the High Plains region. The Agriculture Industry is the focus of Step 3, which is a combined microeconomic and macroeconomic consequences analysis to capture both the regional and national impacts associated with resource risk in the High Plains. Follow-on effects to other industries and critical infrastructure are the result of the physical-based relationships between industries represented through dollar relationships in the economic modeling.

ACRONYMS AND ABBREVIATIONS

AMRC	Agricultural Marketing Resource Center
ASM	Annual Survey of Manufacturers
BCCA	bias-correction constructed analogs
BEA	Bureau of Economic Analysis
BLS	Bureau of Labor Statistics
CBP	County Business Patterns
C-BT	Colorado-Big Thompson Project
CFS	Commodity Flow Survey
CMIP5	Coupled Model Intercomparison Project (fifth in series)
DHS	Department of Homeland Security
EISA	Energy Independence and Security Act
EPAct	Energy Policy Act
EPIC	Environmental Policy Integrated Climate (model)
GDP	gross domestic product
GFDL-CM3	Geophysical Fluid Dynamics Laboratory Coupled Model 3
HSIP	Homeland Security Infrastructure Program
KGS	Kansas Geological Survey
NAICS	North American Industrial Classification System
NASS	National Agricultural Statistics Service
NCDC	National Climatic Data Center
NDNR	Nebraska Department of Natural Resources
NISAC	National Infrastructure Simulation and Analysis Center
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
PPI	producer price index
RCP	Representative Concentration Pathway
REMI	Regional Economic Models, Inc.
RFS	Renewable Fuel Standard
SCTG	Standard Classification of Transported Goods
SPLC	Standard Point Location Code
SSURGO	Soil Survey Geographic (database)
STB	Surface Transportation Board
STCC	Standard Transportation Commodity Code
USACE	U.S. Army Corps of Engineers
USA PATRIOT	Uniting and Strengthening America by Providing Appropriate Tools Required to Intercept and Obstruct Terrorism (Act)
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

KEY FINDINGS

- Climate projections impose a small downward trend on dryland crop yields. While climate-related impacts on agriculture have been overcome by improvements to farm operations (including irrigation) in the past, declining water levels are likely to limit such adjustments in the future.
- If current water use practices are continued into the future, sixty counties in Kansas and seven in Nebraska are projected to face exhaustion of groundwater supplies in 100 years or fewer. Nebraska has begun water metering and other actions to limit groundwater withdrawals in some districts.
- Declining water levels mean increased farm operations costs. Every $1,000 increase in utility expenditures corresponds to a 2.6% increase in the probability of a farm operation exiting the industry.
    - In Nebraska, where declining water levels are the issue of concern with respect to water resources, there will be an increase in utility costs for irrigation using groundwater.
    - A 25% increase in utility costs over 50 years results in approximately a 0.4% decrease in Nebraska gross domestic product (GDP).
- Exhaustion of groundwater supplies could also cause some farmers to switch to dryland farming. A modest shift from irrigated to dryland farming slightly impacts projected state GDP growth:
    - In Kansas, where 30 counties face groundwater depletion within the next 50 years, a 25% decrease in irrigated acres over 50 years results in approximately a 0.2% decrease in Kansas GDP.
    - Reductions in irrigated acreages will affect follow-on industries such as agriculture support activities and consumer demand categories for disposable income.
- The critical infrastructure sectors most affected by resource risk and economic impacts are Food and Agriculture, Water and Wastewater Systems, Chemical (ethanol production), and Energy (ethanol as a transportation fuel).

1 INTRODUCTION

This report documents the analysis methodology and results for a study by the National Infrastructure Simulation and Analysis Center (NISAC) examining the potential impacts of groundwater resource constraints in Nebraska and Kansas on critical infrastructures in the region.[3] This analysis provides insight into the extent to which future climate variability might impact crop production, sectors of the economy and critical infrastructures. Insights gained from this study will help to inform future resource management and planning exercises. These analyses will also help identify and prioritize measures aimed at adapting to an uncertain and variable water resource future.

1.1 Background

The area overlying the High Plains Aquifer is one of the most prolific agricultural regions in the Nation.[4] This is in large part due to the extent, quality and accessibility of this groundwater resource. In terms of size, the High Plains Aquifer is one of the world's largest underground freshwater sources, underlying 111.8 million acres (175,000 square miles) in parts of eight states—Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming (see Table 1 and Figure 1). The water-saturated thickness ranges from a few feet to more than 1000 feet, generally greatest in the northern plains. In terms of quality, the High Plains Aquifer is characterized by high water yields owing to its origin as ancient runoff from the Rocky Mountains that deposited high permeability sands, gravel, clay, and silt across this region. Groundwater of the High Plains Aquifer is also accessible with water depth ranging from 400 feet in parts of the north to between 100 and 200 feet throughout much of the south.

The High Plains Aquifer was first discovered by the United States Geological Survey in the 1890s, but was considered of limited agricultural importance.[5] [6] Windmill pumps could only provide small quantities of water—approximately enough to irrigate 5 acres or provide for 30 cattle.[7] In a 1928 bulletin, the Nebraska Agricultural Extension Service highlighted the need for improved irrigation methods to supplement scarce rainfall and streams; while the underground water supply is abundant, “there are insufficient means of lifting it to the surface and applying it

[3] The term “critical infrastructure” has the meaning provided in section 1016(e) of the USA PATRIOT Act of 2001 (42 U.S.C. 5195c (e)): “…systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health or safety, or any combination of those matters.” Public Law 107-56-OCT. 26, 2011, Uniting and Strengthening America by Providing Appropriate Tools Required to Intercept and Obstruct Terrorism (USA PATRIOT) Act of 2001.

[4] The High Plains Aquifer is comprised of several water-bearing units with the Ogallala formation as its principal member.

[5] Webb, W.P. (1931). *The Great Plains*, New York, NY: Grosset & Dunlap.

[6] U.S. Department of Commerce (1937), The Future of the Great Plains: Report of the Great Plains Committee to the House of Representatives, 75th Cong., 1st session, doc. 144.

[7] Cunfer, G. (2005). *On the Great Plains: Agriculture and Environment*, College Station: Texas A&M University Press.

to the land."[8] Groundwater irrigation was thought to be of great potential value, particularly in raising corn yields, but pumps were small and expensive.[9] [10] [11]

Figure 1—Extent of High Plains Aquifer

[8] Weakly, H. E. and Zook, L.L. (1928). Pump Irrigation Results. Agricultural Experiment Station, University of Nebraska College of Agriculture, Lincoln, Bulletin 227 (June).
[9] Weakly, H.E. (1932). Pump Irrigation and Water Table Studies. Agricultural Experiment Station, University of Nebraska College of Agriculture, Lincoln, Bulletin 271 (May).
[10] Weakly, H.E. (1936). Pump Irrigation at the North Platte Experimental Substation. Agricultural Experiment Station, University of Nebraska College of Agriculture, Lincoln, Bulletin 301 (June).
[11] Brackett, E.E. and Lewis, E.B (1933). Pump Irrigation Investigations in Nebraska. Agricultural Experiment Station, University of Nebraska College of Agriculture, Lincoln, Bulletin 282 (July).

Following World War II, improved pumps and center pivot irrigation technology made High Plains' groundwater available for large-scale irrigated agriculture. Since this time, the High Plains has become one of the most intensively irrigated areas in the United States, accounting for about 30% of all groundwater withdrawn for irrigation in the United States.[12] More than 90% of the water pumped from the High Plains irrigates at least one-fifth of all U.S. cropland. As of 2007, there were 50 million acres of cropland nationwide, of which 15.4 million acres were irrigated in the High Plains.[13] Crops that benefit from irrigation provided by the aquifer are cotton, corn, alfalfa, soybeans, and wheat. Expansion of irrigated agriculture over the past 60 years has helped make the High Plains one of the most productive agricultural regions in the Nation. The High Plains region supplies approximately one-fourth of the Nation's agricultural production.[14] Associated crops provide the Midwest cattle operations with enormous amounts of feed that account for 40% of the feedlot beef output in the United States.[15] The aquifer also provides drinking water to 82% of the people who live within its boundaries, totaling 2.3 million according to the 2000 census.[16]

Table 1—Characteristics of the High Plains Aquifer. Source: USGS, 1997[17]

Characteristic	Unit	Total	CO	KS	NE	NM	OK	SD	TX	WY
Area underlain by aquifer	mi^2	174050	14900	30500	63650	9450	7350	4750	35450	800
% of total aquifer area	%	100	8.6	17.5	36.6	5.4	4.2	2.7	20.4	4
% of each state underlain by aquifer	%	--	14	38	83	8	11	7	13	8
Avg. area weighted saturated thickness in 1980	ft.	190	79	101	342	51	130	207	110	182
Volume of drainable water in storage in 1980	MAF	3250	120	320	2130	50	110	60	390	70

[12] Maupin, M.A., Kenny, J.F., Hutson, S.S., Lovelace, J.K., Barber, N.L., and Linsey, K.S. (2014). Estimated use of water in the United States in 2010: U.S. Geological Survey Circular 1405, 56 p., http://dx.doi.org/10.3133/cir1405.
[13] U.S. Department of Agriculture. Census of Agriculture for 2007: Washington, D.C., National Agricultural Statistics Service. http://www.agcensus.usda.gov/.
[14] McMahon, P.B., Dennehey, K.F., Bruce, B.W., Gurdak, J.J., Qi, S.L. (2007). Water-Quality Assessment of the High Plains Aquifer, 1999–2004 (US Geological Survey, Reston, VA), Professional Paper 1749.
[15] *Aquifer Close Up*. Center for Biological Computing, Indiana State University, Department of Life Sciences. http://mama.indstate.edu/users/johannes/aquifer/htm
[16] Maupin, M.A., Kenny, J.F., Hutson, S.S., Lovelace, J.K., Barber, N.L., and Linsey, K.S. (2014). Estimated use of water in the United States in 2010: U.S. Geological Survey Circular 1405, 56 p., http://dx.doi.org/10.3133/cir1405.
[17] USGS (1997). Characteristics of the High Plains Aquifer. http://www.ne.cr.usgs.gov/highplains/hpchar.html.

The High Plains Aquifer originally filled with groundwater thousands of years ago during the last ice age. As the aquifer now receives less than an inch of annual recharge due to minimal rainfall, high evaporation, and low infiltration of surface water, this "fossil" groundwater resource is essentially nonrenewable.[18] [19] [20] Water level declines began in parts of the High Plains Aquifer soon after the onset of substantial irrigation—around 1950.[21] By 1980, water levels in the High Plains Aquifer in parts of Texas, Oklahoma, and southwestern Kansas had declined by more than 100 ft.[22] In response to water-level declines, Congress, under the authority of Title III to the Water Resources Research Act (U.S. Public Law 98-242, 99-662), directed the U.S. Geological Survey (USGS), in collaboration with numerous federal, state, and local water-resources entities, to access and track water level changes in the aquifer. Using thousands of groundwater wells in this assessment the following results were noted:

- Area-weighted, average water-level changes in the aquifer were an overall decline of 14.2 feet from predevelopment to 2011, and a decline of 0.1 foot from 2009–11.
- Total water in storage in the aquifer in 2011 was about 2.96 billion acre-feet.
- Changes in water in storage, predevelopment to 2011, involved an overall decline of about 246 million acre-feet (a depletion of approximately 8%).
- Changes in water in storage, 2009-11, involved an overall decline of 2.8 million acre-feet.[23]

However, these depletions are not evenly distributed over the aquifer area; rather, depletion varies by location due to differences in aquifer characteristics and the distribution of irrigation. Measured declines in groundwater levels from predevelopment to the present, as measured by the USGS, are shown in Figure 2. Groundwater declines of over 100 feet are not uncommon, with some of the most significant declines registered in Kansas and to a lesser extent in Nebraska.[24]

[18] Zwingle, E. (1993). Wellspring of the High Plains. *National Geographic*, March, 80-109.
[19] Opie, J. (1993). *Ogallala: Water for a Dry Land*. Lincoln: University of Nebraska Press.
[20] McGuire, V.L., Johnson, M.R., Schieffer, R.L., Stanton, J.S., Sebree, S.K., and Verstraeten, I.M. (2003). Water in storage and approaches to ground-water management, High Plains aquifer, 2000: U.S. Geological Survey Circular 1243.
[21] Gutentag, E.D., Heimes, F.J., Krothe, N.C., Luckey, R.R., and Weeks, J.B. (1984). Geohydrology of the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Professional Paper 1400–B, 63 p. (Also available at http://pubs.usgs.gov/pp/1400b/report.pdf.)
[22] Luckey, R.R., Gutentag, E.D., and Weeks, J.B. (1981). Waterlevel and saturated-thickness changes, predevelopment to 1980, in the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Hydrologic Investigations Atlas HA–652, 2 sheets, scale 1: 2,500,000. (Also available at https://pubs.er.usgs.gov/publication/%20ha652.)
[23] McGuire, V.L. (2013). Water-level and storage changes in the High Plains aquifer, predevelopment to 2011 and 2009–11: U.S. Geological Survey Scientific Investigations Report 2012–5291, 15 p. (Also available at http://pubs.usgs.gov/sir/2012/5291/.)
[24] McGuire, V.L., Lund, K.D., and Densmore, B.K. (2012). Saturated thickness and water in storage in the High Plains aquifer, 2009, and water-level changes and changes in water in storage in the High Plains aquifer, 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009: U.S. Geological Survey Scientific Investigations Report 2012–5177, 28 p.

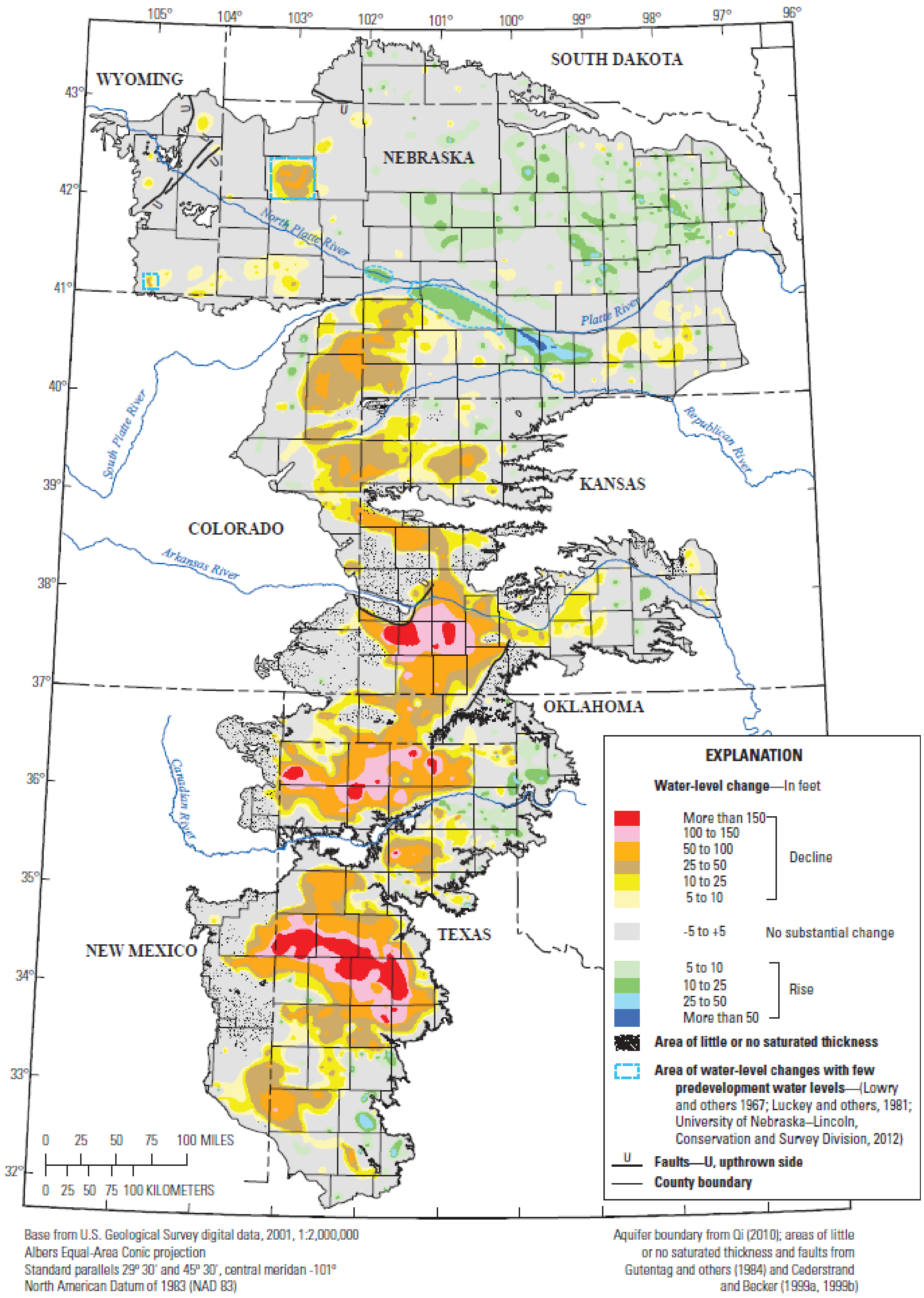

Figure 2—Water Level Declines for the High Plains Aquifer from Predevelopment to 2011[25]

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[25] Source: McGuire et al. 2012.

Despite rapid water table drawdown and near depletion of some portions of the aquifer, irrigated acreage continues to expand.[26] Underlying natural and socioeconomic drivers of this expansion are numerous and complicated.[27] For example, farmers' water extraction draws from broader areas such that, over time, there is little marginal effect on farmers' own water levels. The High Plains, therefore, represents a classic "common pool" problem in which individual water users do not pay the social cost of water extraction.[28] Although a range of management and policy actions could help move this region toward sustainability, such efforts are complicated by a diverse range of state laws and regulations, economic drivers, and agricultural production systems.[29] [30] In fact, there has been little strict regulation of water use, though some states and local water-management districts have increasingly limited new wells, restricted "wastage," and explored well-metering.[31]

Growing concern and economic importance coupled with the complicated physical and social dynamics of the High Plains Aquifer have made it the subject of numerous studies. Hornbeck and Pinar compared counties with access to High Plains Aquifer groundwater to those without, finding those with access improved crop drought-resistance in the short run and enabled the production of higher-value crops in the long run. [32] Intensifying groundwater depletions, however, have been met with declining land values and rising revenues consistent with expectations that many areas will lose their current access to groundwater. Das and Willis tested the effectiveness of two water conservation policies—extraction tax and extraction quotas—in the Texas High Plains. [33] Almas projected income and hydrological changes in Texas Panhandle region over a 60-year time horizon, finding a significant decline in water use and transition from irrigated agriculture to dryland farming. [34] A study of water policy alternatives for the southern High Plains Aquifer by Wheeler, et al. indicated that blanket water conservation policies for the region as a whole are likely to be inefficient given the significant differences in hydrological

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[26] USDA (2013, 2007, 2002, 1997). National Agricultural Statistics Service. www.nass.usda.gov

[27] Peterson, J. and Bernardo, D. (2003). High Plains Regional Aquifer Study Revisited: A 20-Year Retrospective for Western Kansas. *Great Plains Research: A Journal of Natural and Social Sciences*. Paper 662. http://digitalcommons.unl.edu/greatplainsresearch/662.

[28] Hornbeck, R. and Pinar, K. (2012) The Historically Evolving Impact of the Ogallala Aquifer: Agricultural Adaptation to Groundwater and Drought, Discussion Paper 2012-39, Cambridge, Mass: Harvard Environmental Economics Program, September 2012.

[29] McGuire, V.L., Johnson, M.R., Schieffer, R.L., Stanton, J.S., Sebree, S.K., and Verstraeten, I.M. (2003). Water in storage and approaches to ground-water management, High Plains aquifer, 2000: U.S. Geological Survey Circular 1243, 51 p. (Also available at http://pubs.usgs.gov/circ/2003/circ1243/.)

[30] Sophocleous, M. (2010). Review: groundwater management practices, challenges, and innovations in the High Plains aquifer, USA—lessons and recommended actions. *Hydrogeology Journal*, 2010

[31] McGuire, V.L., Johnson, M.R., Schieffer, R.L., Stanton, J.S., Sebree, S.K., and Verstraeten, I.M. (2003). Water in storage and approaches to ground-water management, High Plains aquifer, 2000: U.S. Geological Survey Circular 1243.

[32] Hornbeck, R. and Pinar, K. (2012) The Historically Evolving Impact of the Ogallala Aquifer: Agricultural Adaptation to Groundwater and Drought, Discussion Paper 2012-39, Cambridge, Mass: Harvard Environmental Economics Program, September 2012.

[33] Das Biswaranjan and Willis, D. B. (2005). The Effectiveness of a Groundwater Extraction Tax Versus a Quota Policy to Achieve Groundwater Conservation in the Texas High Plains. Presented at the Western Agricultural Economics Association Annual Meeting, July 68, 2005, San Francisco, California.

[34] Almas, L.K. (2008). Economic Optimization Models to Project Income and Hydrological Changes: A Case of Groundwater Management in Texas. Selected Paper prepared for presentation at the International Conference on Policy Modeling (EconMod 2008) Berlin, Germany, July 2-4, 2008.

characteristics and current irrigation levels across the region. [35] Stewart and others assessed groundwater declines for a portion of the High Plains Aquifer in Kansas, finding that approximately 30% of the groundwater has been pumped to date, while another 39% will be depleted over the next 50 years if current trends are maintained. [36] They also found that water use reductions of 20% today, which would cut agricultural production to the levels of 15–20 years ago, would actually result in increased net production over the long term due to projected future increases in crop water use efficiencies (e.g., improved irrigation efficiency and farm management practices).

From this discussion, the importance of the High Plains Aquifer is apparent. It is also evident that this valuable groundwater resource is being threatened by overuse. The purpose of this study is to explore how continued depletions of the High Plains Aquifer might impact both critical infrastructure and the economy at the local, regional and national scale. This analysis is conducted at the county level over a broad geographic region within the states of Kansas and Nebraska. In total, 140 counties that overlie the High Plains Aquifer in these two states are analyzed. The analysis utilizes climate projections to estimate crop production into the future. Current water use and management practices are projected into the future to explore their related impact on the High Plains Aquifer. Finally, the impact of declining water levels and even exhaustion of groundwater resources are projected for specific sectors of the economy as well as particular elements of the region's critical infrastructure.

1.2 Analysis Questions

The purpose of this study is to explore how continued depletions of the High Plains Aquifer might impact both critical infrastructure and the economy at the local, regional, and national scale and provide decisionmakers with an assessment of how continued depletions of the High Plains Aquifer might impact both critical infrastructure and the economy at the local, regional and national scale. Research, modeling, and analysis focused on five overarching questions:

> *How will climate variability impact agricultural production?*
>
> *How might groundwater depletions evolve in the future?*
>
> *Which economic sectors are most vulnerable to groundwater depletion?*
>
> *When are declining groundwater levels and aquifer depletion likely to begin impacting the economy and critical infrastructure?*
>
> *How do impacts at the local level aggregate to affect the economy at a regional and national level?*

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[35] Wheeler, E.A., Segarra, E., Johnson, P.N., Johnson, J.W., and Willis, D.B. (2006). Policy Alternatives for the Southern Ogallala Aquifer. Selected Paper prepared for presentation at the Southern Agricultural Economics Association Meetings Orlando, Florida, February 5-8, 2006.
[36] Steward, D.R., Bruss, P.J., Yang, X., Staggenborg, S.A., Welch, S.M. and Apley, M.D. (2014). Tapping unsustainable groundwater stores for agricultural production in the High Plains Aquifer of Kansas, projections to 2110. PNAS Plus, doi/10.1073/pnas.1220351110

1.3 Assumptions

Given the complexity of this problem, assumptions are necessary to make the analysis tractable. This section reviews the most important assumptions underpinning this research along with their potential implications on the findings of this work.

One key assumption of this work relates to the scale of analysis. Here, the county represents the finest scale of resolution for model simulation. This is driven largely by the availability of data over the broad geographic regions of Kansas and Nebraska. This county-level view necessarily aggregates important variability occurring below the county scale. The analysis will not capture the detailed aquifer response at a particular location or simulate the behavior of a particular farmer or small co-op. Instead, this analysis will help identify broad system vulnerabilities and the potential implications of these vulnerabilities.

Another important assumption is associated with the economic modeling. Although the Agricultural Industry is capable of withstanding negative economic shocks, it is assumed that if individual farm operations face increasing input costs (energy for groundwater pumping) for a sustained period of time, the continued successful operation of some irrigated farms in the region may not be possible. This paper presents an analytical and practical approach for estimating whether farm operations will exit the market or reduce production. It is recognized that farm operations have other options; for example, they could sell the farm, be absorbed into a larger farm operation, reduce irrigated acreage, adopt crop rotation or crop-switching practices, introduce genetically modified GMO water-saving crops or new irrigation technologies, and sell or rent water rights.

This full set of options is extensive and complex and beyond the resources of this analysis. Limiting options in this way allows the analyst to roll up the full set of responses into two representative categories. Limiting options to exiting the market or reducing production also captures the impetus for a tipping point. That is, the decision will either be of the type that farm operation continues, although in a different manner as before, or it does not continue and proceeds with available market options; either way, it represents a tipping point. It is these tipping points that are of concern here as they have the potential for regional and national macroeconomic impacts.

It is not the role of NISAC to endorse, promote, or enforce a particular set of policy options or regulations; therefore, this analysis does not address potentially offsetting policies or regulation.

A number of other subordinate assumptions have been made in each phase of our modeling and analysis. While not addressed here, each assumption is noted and discussed in the context of its related modeling and analysis exercise.

2 METHODS

This section summarizes the data gathered from stakeholders and formulation of models to assess potential climate impacts on crop productivity, aquifer depletions, the economy, and infrastructure.

2.1 Crop Modeling

2.1.1 Background and Methodology

This analysis provides a range of impacts to agriculture in the High Plains region that could arise from future variations in groundwater availability, climate, and agricultural innovation. To accomplish this, two crop models are used to simulate corn, soy, sorghum, and winter wheat crop yields using downscaled weather inputs generated by the Geophysical Fluid Dynamics Laboratory Coupled Model 3 (GFDL-CM3). They include the Environmental Policy Integrated Climate (EPIC) model and an econometric model of stochastic production functions. The EPIC model is used to analyze the impacts of climate variability on crop yield independently from other factors and represents the lower bound of this range. The econometric crop model is used to show the impacts of climate variability on crop yield if historical trends in agricultural innovation continue to impact agricultural production in the future and represents the upper bound of this range.

Simulations for both the EPIC and econometric crop models were performed at the county level for one county per climate division overlying the High Plains Aquifer within Kansas and Nebraska (14 counties total), as shown in Figure 3. This approach assumes that the outcome of crop yield simulations performed in one county represents the likely outcome for all counties within the same climate division. The National Climatic Data Center (NCDC) defines the U.S. climate division boundaries according to areas that share similar climatology with consideration to state, county, and drainage basins boundaries as well as the distribution of major crops. This method of defining climate division boundaries has proven useful for research applications in economics, water resources, and agriculture.[37]

Annual yields were simulated for corn, soy, sorghum, and winter wheat over the period 1960-2089. The distribution of these crops across Kansas and Nebraska are shown along with the 14 representative High Plains counties in Figure 4 through Figure 7. To determine which crops to include in this analysis, preliminary research was done to identify which crops are most vulnerable to climate variability and groundwater depletion and could potentially contribute to changes in the economic profile of the High Plains areas of Kansas and Nebraska. Of the crops that were identified through this research, complete data sets to be used for model calibration and validation were available for corn, soy, sorghum, and winter wheat crops only.

[37] Guttman and Quayle, 1996.

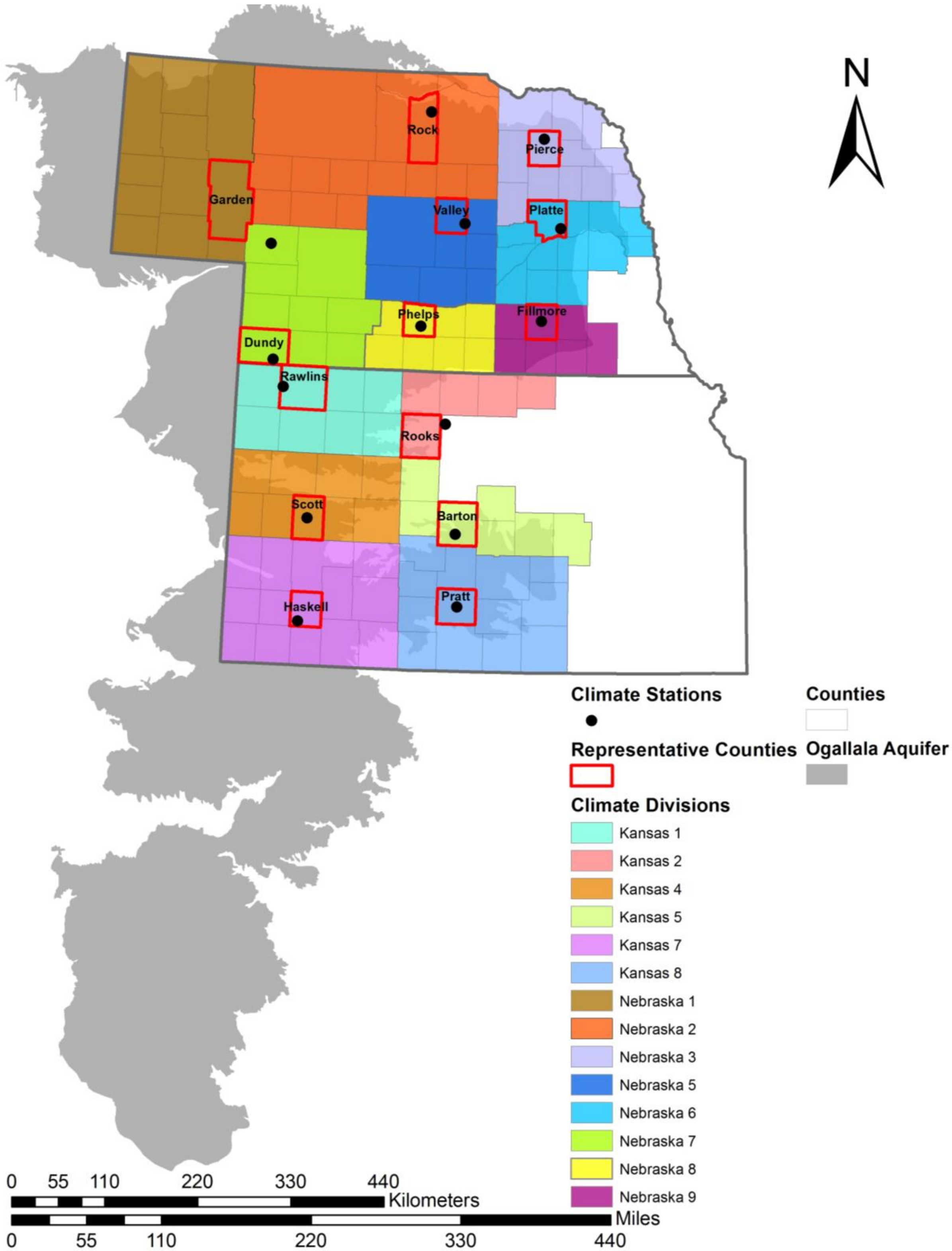

Figure 3—Spatial Extent of the Agricultural Modeling Experiments

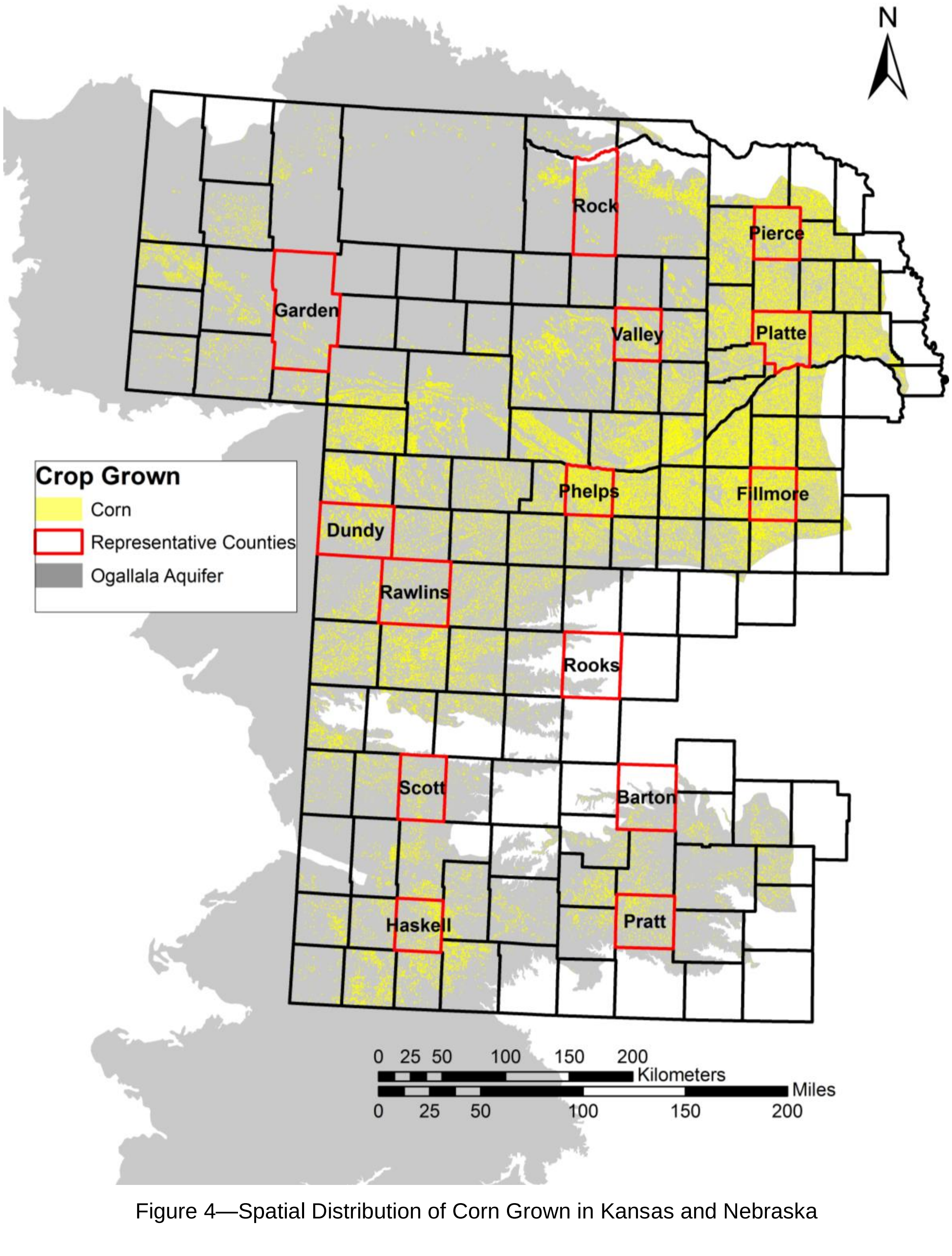

Figure 4—Spatial Distribution of Corn Grown in Kansas and Nebraska

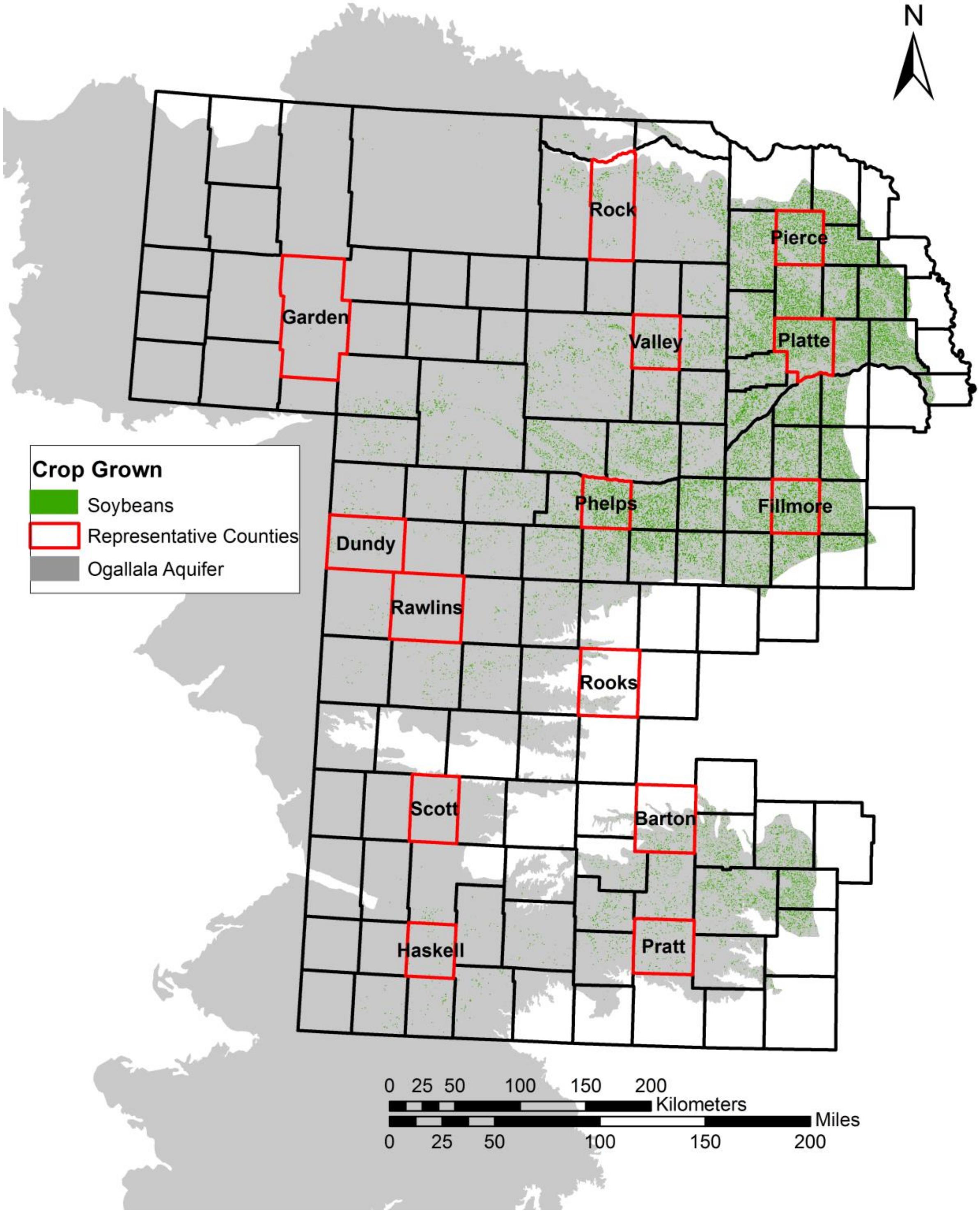

Figure 5—Spatial Distribution of Soy Grown in Kansas and Nebraska

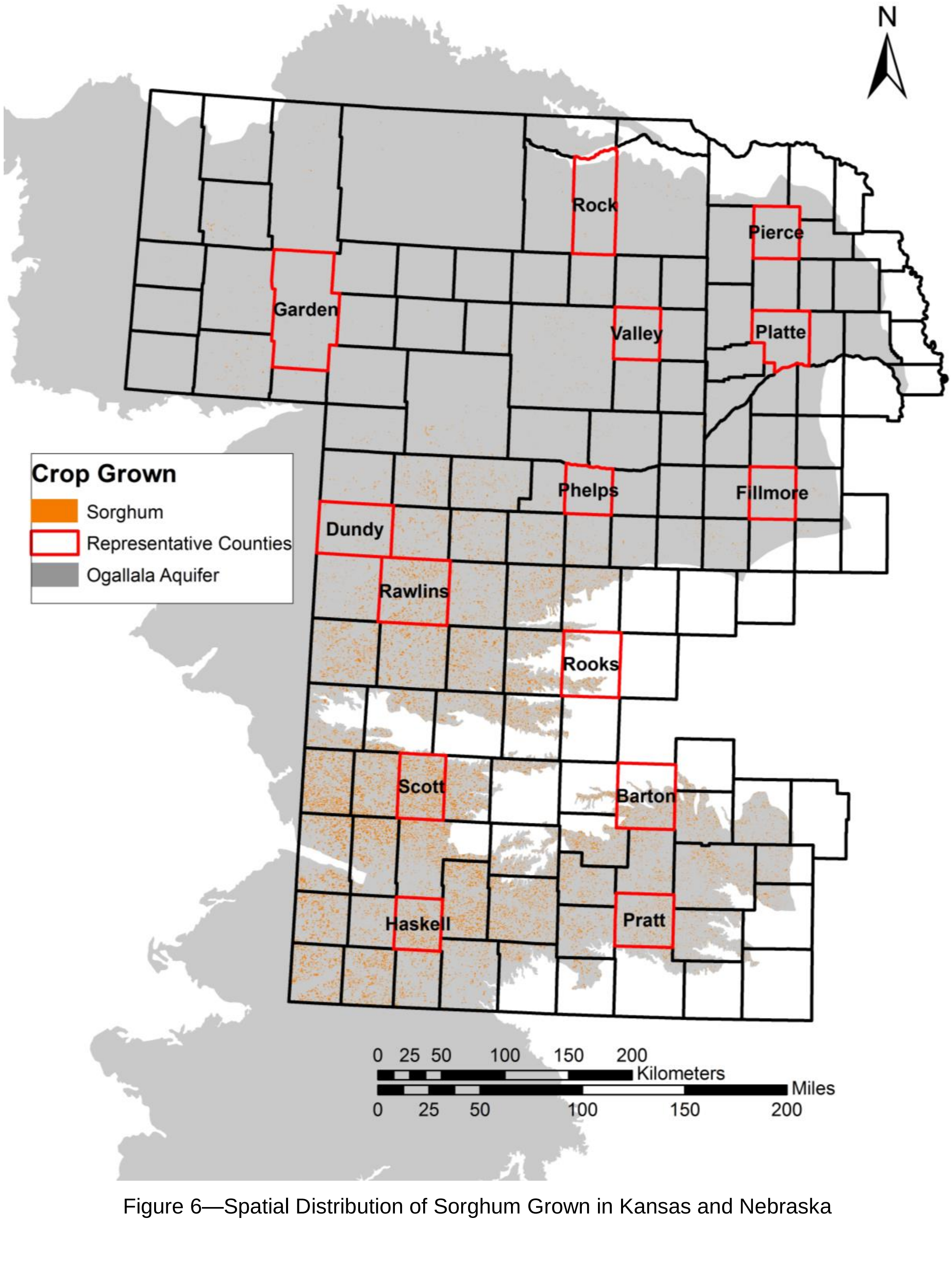

Figure 6—Spatial Distribution of Sorghum Grown in Kansas and Nebraska

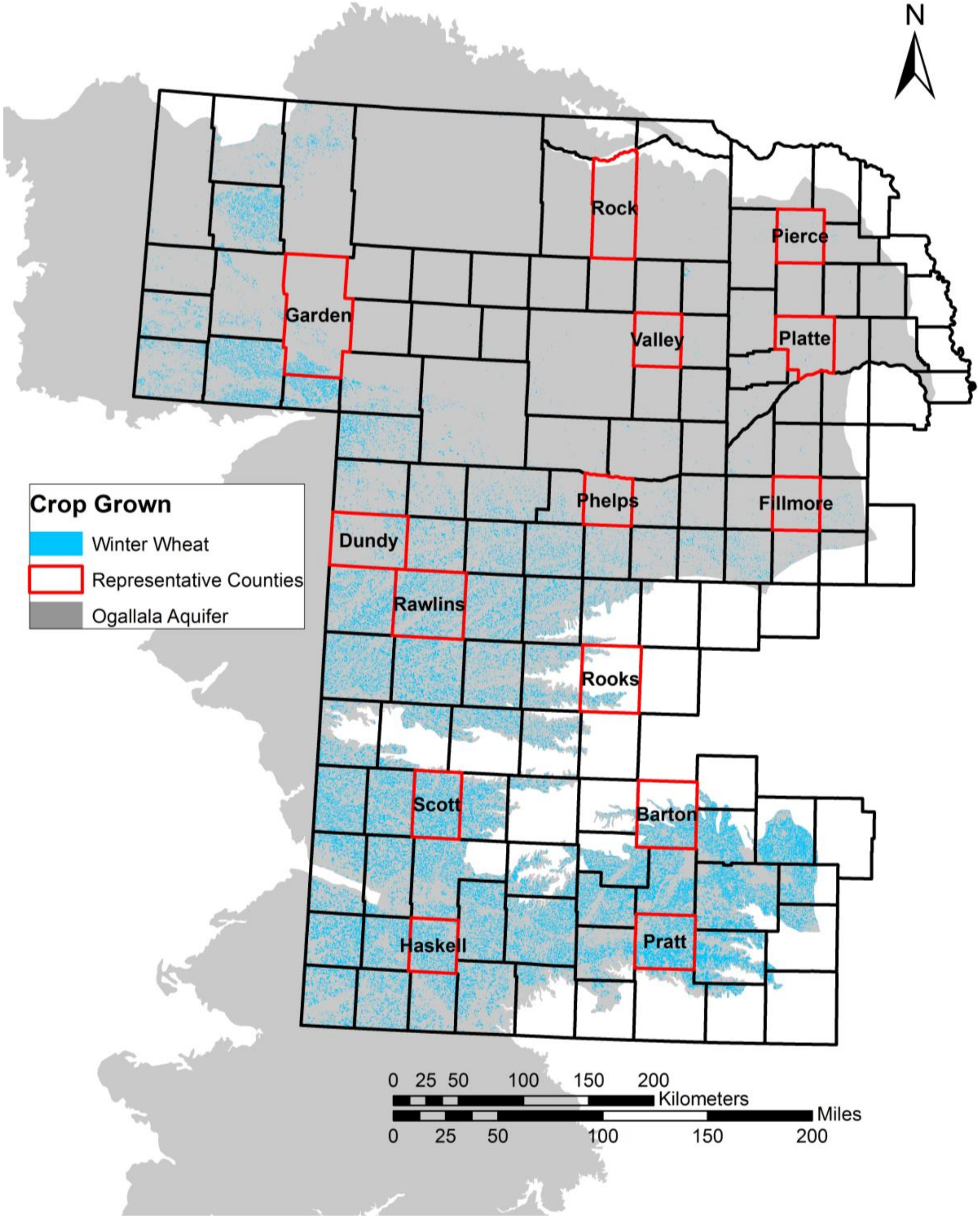

Figure 7—Spatial Distribution of Winter Wheat Grown in Kansas and Nebraska, from the Environmental Policy Integrated Climate (EPIC) Model

2.1.2 The Environmental Policy Integrated Climate (EPIC) Model

The Environmental Policy Integrated Climate (EPIC) model is a physical process-based cropping system model that operates on a daily time-step to simulate the relationship between weather, erosion, nutrient cycling, hydrology, farm management practices, and plant growth through a series of algorithms described by Williams, et al. (1995).[38] EPIC has been used extensively to analyze the impacts of climate variability on crop yields.[39] Such analyses typically use EPIC to simulate yield as a function of daily weather inputs with respect to a variety of crop-specific growth parameters (e.g., temperature thresholds, crop water requirements) while holding all other variables (e.g., technology, farm management practices) constant over time. EPIC has been shown to reliably simulate crop yields in the High Plains region.[40]

For the present analysis, the EPIC model was applied at the county level to remain consistent with the resolution of the available input data. Simulation of crop yields at the county level assumes homogeneity in cropping system, weather, soil properties, tillage, and irrigation methods and requires that a single input value for each parameter be selected to characterize an entire county. Efforts were made in this research to select input values that represent the most common environmental aspects and farm operation behaviors within each county.

Model calibration was performed using county-level historical yield data from the National Agricultural Statistics Service (NASS).[41] EPIC model input parameters were adjusted within the ranges prescribed by expert recommendation so that simulated yields generated by EPIC using historical weather inputs would align as closely with historical yields as possible. Model validation was performed by testing the statistical significance of correlations between modeled and actual yields, and is described in the EPIC Model Calibration and Validation section below. Through the model validation procedure, it was determined that the EPIC model performed well at reproducing dryland (non-irrigated) yields and could therefore be used to estimate crop yields in the High Plains region under the climate conditions projected by the GFDL-CM3 climate model. The EPIC model did not show the same level of skill at reproducing irrigated crops, and it was therefore determined that the econometric model would be used to simulate irrigated crop yields for this analysis.

2.1.3 Econometric Crop Model

Crop yields are also estimated using an econometric model of stochastic production functions. The production function parameter estimates are used to forecast future yields, accounting for changes in climate variables projected by the GFDL-CM3 climate model. The specific econometric model used is based on previous studies exploring the impact of climatic variation on crop yield.[42] The analysis by Isik and Devadoss used a stochastic production function specification introduced by Just and Pope.[43]

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[38] Williams, 1995.
[39] Gassman, 2011.
[40] Rosenberg et al. 1992; Easterling et al. 1993; Easterling et al. 1997; Niu et al. 2008.
[41] NASS, Quick Stats. http: //quickstats.nass.usda.gov/, accessed February 18, 2015.
[42] Isik and Devadoss, 2006.
[43] Just, R. E., and Pope, R. D. (1978). Stochastic specification of production functions and economic implications. *Journal of Econometrics*, 67-86.

Within the Just-Pope framework, production uncertainty is equivalent to heteroscedasticity in an econometric model.[44] The general form of the Just-Pope production function is specified as:

$$y_{it} = f(\boldsymbol{x}_{it}; \boldsymbol{\beta}) + \omega_{it} h(\boldsymbol{x}_{it}; \boldsymbol{\delta})^{1/2} \quad (1)$$

Where $f(\cdot)$ is the mean function, $h(\cdot)$ is the variance function, and $\boldsymbol{x}$ is an input vector (with $\boldsymbol{\beta}$ and $\boldsymbol{\delta}$ representing the input vector parameters for the mean and variance function, respectively). There is also a stochastic term (ω_{it}) with zero mean and variance σ_{ω}^2. Mean output is given by

$$\mathrm{E}[y] = f(\boldsymbol{x}_{it}; \boldsymbol{\beta}) \quad (2)$$

while the variance of the output is given by

$$\mathrm{var}(y) = [h(\boldsymbol{x}_{it}; \boldsymbol{\delta})]^2 \sigma_{\omega}^2 \quad (3)$$

Estimation of the Just-Pope production function involves estimating both $f(\cdot)$ and $h(\cdot)$. In the context of this analysis, however, we are only interested in the mean function ($f(\cdot)$). Within the Just-Pope framework, production risk is analogous to heteroskedasticity. Thus, efficient estimation of the mean production function requires accounting for the production risk. Ordinary least squares (OLS) estimation would yield a consistent, but inefficient estimate of the parameters.[45] Therefore we choose an alternative estimation method for the production function. Although this study does not explicitly estimate the variance function, valid inference still requires the use of a heteroscedasticity-consistent estimator.[46] The empirical approach used in this study includes a fixed-effects estimator with heteroscedasticity-consistent covariance.[47]

Three separate production functions are estimated (linear, quadratic, and linear-quadratic) for each crop type. Each production function specifies that yield is a function of a linear time-trend, as well as climate variables (temperature and precipitation).

$$y_{it} = f(TREND, T_{it}, P_{it}) \quad (4)$$

Where $TREND$ is a categorical year variable, T represents the mean of the daily high temperature during the specific crop-growing season, and P represents annual precipitation. Temperature is specified in degrees Fahrenheit. Annual precipitation (in inches), P, is calculated for each crop from the end of the previous growing season to the end of the current growing season. The subscripts i and t represent a specific county at a specific point in time, respectively. The alternative production functions estimated differ only in how the independent variables interact to produce the dependent variable, y_{it}.

[44] Asche and Tveterås, 1999.
[45] Asche and Tveterås, 1999.
[46] Saha, Havenner, and Talpaz, 1997.
[47] White, 1980.

2.2 Crop Modeling Data

2.2.1 Historical Weather

Historical weather data from the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC) online database were used to calibrate and validate the EPIC and econometric crop models.[48] The historical weather data include daily observations of precipitation, minimum temperatures, and maximum temperatures recorded at weather stations located within or close to each of the 14 High Plains counties included in this analysis (Figure 3).

2.2.2 Simulated Weather

Crop yields were simulated using daily precipitation and temperature values generated by the GFDL-CM3 model.[49] GFDL-CM3 is one of several global climate models that contributed to the fifth Coupled Model Intercomparison Project (CMIP5) archive.[50] The GFDL-CM3 data used as input to the crop models were generated from the CMIP5 historical and Representative Concentration Pathway 8.5 (RCP8.5) experiments and were linked to form continuous time series from 1960 to 2089.[51] The simulation over the historical period (1960-2005) is forced with estimated solar radiation, natural and anthropogenic aerosols, and historical greenhouse gas concentration. The simulations over the RCP period (2006-2089) are forced with prescribed future solar radiation and aerosols, and greenhouse gas concentration derived from an emissions pathway that increases the anthropogenic radiative forcing by 8.5 W/m^2 relative to preindustrial conditions by the year 2100.[52]

To perform this analysis at the county level, a statistically downscaled version of the GFDL-CM3 daily precipitation and temperature output was downloaded from the "Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections" website.[53] The DCHP dataset converts precipitation and temperature values simulated by the GFDL-CM3 model at a 2° by 2.5° resolution to a 0.125° resolution using daily bias-correction constructed analogs (BCCA) statistical downscaling technique.[54] The BCCA statistical downscaling technique produces a set of daily precipitation and temperature time series that are organized spatially. One value for each weather variable is assigned to each 0.125° grid cell in daily increments. To remain spatially consistent with the NCDC historical weather station locations, a spatially weighted daily average of each weather variable was calculated over the grid cells located within a 17-kilometer radius of the 14 representative climate stations shown earlier in Figure 3.

2.2.3 Historical Crop Yields

Historical crop yield data for corn, soy, sorghum, and winter wheat were derived from survey data available on the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) Quick Stats 2.0 online database.[55] For each crop, the area harvested (acres) and

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[48] National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center, 2015.
[49] Donner et al., 2011.
[50] Taylor et al., 2012.
[51] Moss et al. 2010.
[52] Moss et al. 2010; Meinshausen et al. 2011; IPCC 2013.
[53] DCHP, 2013.
[54] Maurer et al. 2010.
[55] NASS, 2015.

quantity harvested (bushels) were downloaded at the county level in yearly increments for as many years as were available from 1960 to 2010. Data for irrigated and non-irrigated farmland were processed separately. Annual yields in tons per hectare were then calculated for irrigated and non-irrigated crops by converting acres to hectares and bushels to tons using the approximate net weight per bushel values provided in the 1997 Census of Agriculture report (USDA, 1997).

2.2.4 EPIC Model Inputs

The following data sources were leveraged to meet the minimum EPIC model input requirements:

- Location: The latitude, longitude, and elevation of the center of each county were obtained using ArcGIS.
- Crop Management: The sprinkler irrigation method was selected for all irrigated simulations based on the number of acres irrigated by sprinkler systems compared to other systems (USDA, 2012). The maximum annual irrigation water amount for each crop was specified in the model based on the 2013 state average estimated quantity of water applied per crop and held constant throughout the simulation period.[56] County-level tillage information by crop was not readily available so the optimal tillage selection was determined through model calibration.
- Soil: The Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database was used to determine the representative soil type for each county.[57] The representative soil was defined as the most extensive soil type classified as farmland within each county. The SSURGO soil types are associated with a unit name, texture, and percent slope which match the EPIC soil options.
- Weather: The USDA NCDC historical daily weather data (1960-2010) were used for model calibration and validation.[58] The GFDL-CM3 downscaled daily weather inputs (1960-2089) were used in the crop yield projections.[59]
- Other: The EPIC default inputs were used for all other parameters, including farm management practices and equipment, which are held constant throughout the simulation period.

2.3 Groundwater Modeling

2.3.1 Background and Methodology

To evaluate the economic implications of High Plains Aquifer depletions on Kansas and Nebraska, an estimation of changing groundwater levels is necessary. Estimating change in groundwater level allows a calculation of depth-to-groundwater, which further allows a prediction of the cost to pump that water to the surface for crop irrigation or other use. Simulation of depth-to-groundwater also provides insight as to how soon the groundwater

[56] USDA 2012.
[57] NRCS, 2015.
[58] NCDC, 2015.
[59] DCHP, 2013.

resource may become exhausted. The increasing cost to lift water and the time-to-resource-exhaustion are the key pieces of information passed to the economic analysis.

This analysis utilizes a simple water-budget approach implemented at a county level. Available resources, availability of data, and the needs of the project (economic analysis limited to the county level) all favored adoption of the water-budget approach over the development of a more sophisticated and spatially resolved groundwater model. This county-level perspective provides conservative, county-level aggregate impacts to groundwater depletions and water levels, which are well tuned to the needs of the economic analysis.

The water budget is formulated as a simple balance of groundwater inflows and outflows with a corresponding change in aquifer storage.

An individual balance is calculated for each of the 140 counties in Kansas and Nebraska that overlie the High Plains Aquifer. Elements of groundwater inflow include the ambient recharge rate and recharge induced by large-scale agricultural irrigation. Elements of groundwater outflow are dominated by pumping for irrigation and other water uses.

Changes to the depth to groundwater are calculated by dividing aquifer storage by the area of High Plains Aquifer in a given county and the porosity (or more accurately, the specific yield) of the formation. The energy to pump water to ground surface was estimated by multiplying the depth to groundwater by the weight of the water and dividing by the pump efficiency (taken to be 0.5).[60] Finally, the time to depletion of the aquifer was calculated as the time when the groundwater level falls below 20% of the predevelopment saturated thickness.

To implement this model, a variety of data were required. Most of the necessary data were acquired from the U.S. Geological Survey (USGS), with supporting information collected from the Kansas Geological Survey (KGS), and the Nebraska Department of Natural Resources (NDNR). Data supporting the groundwater inflow component of the model included ambient recharge data taken from Gutentag and others,[61] while agricultural recharge was taken as the product of agricultural pumping (see below) and the agricultural recharge rate (estimated at 15% of the agricultural pumping).[62] [63]The outflow element of the model required information on groundwater pumping. Groundwater pumping rates by county for both total groundwater pumping and agricultural irrigation were taken from the USGS water use reports for the years 1985, 1990, 1995, 2000, 2005 and 2010.[64] Calculation of the depth to groundwater of the High Plains Aquifer required information on the aquifer area in each county, which was taken from the

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[60] *California Agricultural Water Electrical Energy Requirements*; California Energy Commission ITRC Report No. R 03-006; prepared by the Irrigation Training and Research Center, California Polytechnic State University, San Luis Obispo, CA, 2003.

[61] Gutentag, E. Heimes, F.J, Krothe, N.C., Luckry, R.R., and Weeks, J.B. (1984). Geohydrology of the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey, Professional Paper ; 1400-B, 63P.

[62] USGS. Ground Water Atlas of the United States; Kansas, Missouri, and Nebraska. World Wide Web, http://capp.water.usgs.gov/gwa/ch_d/D-text2.html.

[63] Kansas Geological Survey, 2003. Study Measures Recharge in the Ogallala Aquifer. http://www.kgs.ku.edu/General/News/2003/ogallala.html

[64] USGS, Water Use in the United States. http: //water.usgs.gov/watuse/data/index.html. April 12, 2015.

USGS, and the specific yield, estimated from USGS data.[65] [66] Initial saturated thickness (Figure 8) and depth to groundwater for each county were also taken from USGS databases.[67] [68]

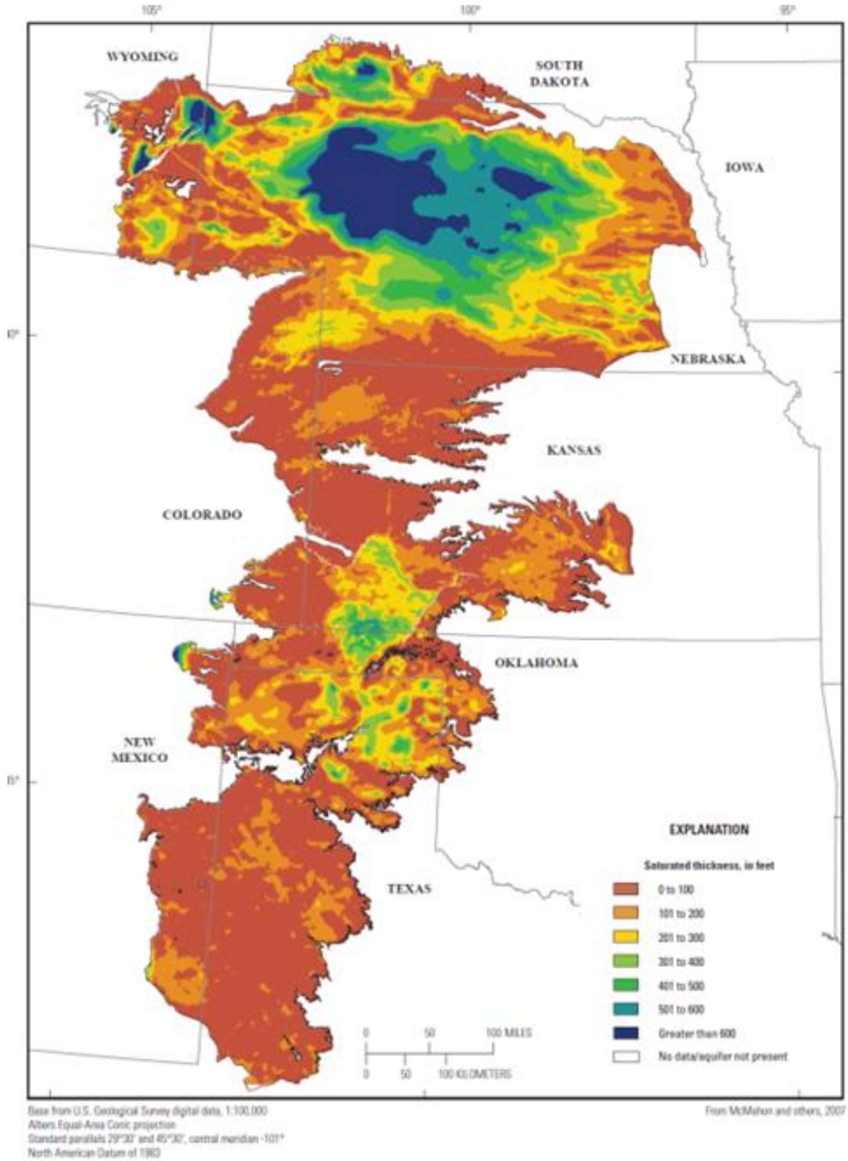

Figure 8—High Plains Aquifer Saturated Thickness Measured in 2009[69]

[65] Digital map of aquifer boundary for the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming. https://ogallala/GIS/Ogallala_Aquifer/hp_bound2010.shp.xml.
[66] USGS. Specific yield, High Plains aquifer. http: //water.usgs.gov/GIS/metadata/usgswrd/XML/sir12-5177_hp_sp_yield.xml, accessed March 5, 2015.
[67] USGS. Saturated thickness, High Plains aquifer, 2009, High Plains Aquifer. http://water.usgs.gov/GIS/metadata/usgswrd/XML/sir12-5177_hp_satthk09.xml, accessed March 5, 2015.
[68] USGS. Water-level change, High Plains aquifer, 2005 to 2009. http://water.usgs.gov/GIS/metadata/usgswrd/XML/sir12-5177_hp_wlc0509.xml, accessed March 6, 2015.
[69] Source: McGuire et al. 2012.

It is recognized that this simple water budget does not address all the important factors influencing groundwater level declines in the High Plains Aquifer. The budget does not consider groundwater-surface water interactions with the region's rivers, and the model fails to consider complications of aquifer geometry. Model calibration was performed to address these shortcomings of the water budget. Calibration was performed using measured data tracking changes in groundwater level, aggregated by county, available at 5-year intervals from 1985 to 2010.[70] Measured changes in groundwater level were calibrated to the estimated groundwater budget for the same 5-year intervals. The calibrated model was developed by performing linear regression using the multiple sets of data collected over the 5-year intervals from 1985-2010. The calibrated model was then used to estimate changes in groundwater level, time to aquifer depletion, and energy to pump the water—all at a county level.

2.3.2 Water Use and Intensity by Industry

Water usage in the Midwest is composed of a host of consumptive and non-consumptive industries, the largest of which is agriculture at approximately 80%.[71] Kansas and Nebraska each use groundwater for the majority of all water use, which may be because agriculture is vastly more water intensive than the next highest industry user, which is publicly supplied water. Agriculture, defined exclusively as the production of crops, covers huge geographic scales and sees spatiotemporal-heterogeneity in water use, both between individual farms and between years for one farm. Groundwater offers easy access to a personalized water source, especially at locations removed from surface water access. Water use intensity reflects the amount of water each industry uses relative to other industries, providing insight into industry water reliance, efficiency, and scale. Public use refers to regional or municipally supplied water, while domestic use refers to residential use not covered under public supply. Public supply numbers may be misleading because publicly supplied water has a variety of users across the state and does not necessarily reflect residential and commercial users alone. Although the data is not specific, public water use includes free metered water and unaccounted for and unsold water. Free metered water is considered water used for public services and water treatment processes.[72] Per the USGS, "unaccounted for water in the distribution system is the result of leaks, unauthorized use, or inaccurate meters" while unsold water may be in transit or in treatment.[73] Thermoelectric power supply is water provided to power plants that use heat to convert liquid water into steam to power turbines. Examples of thermoelectric power generators include coal, natural gas, and nuclear power plants. Most power plants sit near surface water, are not dependent on the High Plains Aquifer, and are not considered to be consumptive use. Consumptive use is the term for water taken from a water supply without the return of that water back to a water supply.

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70 USGS. Water-level change, High Plains aquifer, 2000 to 2005. http://water.usgs.gov/GIS/metadata/usgswrd/XML/sir12-5177_hp_wlc0005.xml, March 6, 2015.

71 USDA ERS. Irrigation & Water Use. http: //www.ers.usda.gov/topics/farm-practices-management/irrigation-water-use.aspx, accessed July 20, 2015.

72 USGS Kansas Water Science Center. Public Water-Supply Use in Kansas, 1987-1997. http://ks.water.usgs.gov/pubs/fact-sheets/fs.187-99.html, accessed July 20, 2015.

73 USGS. Chapter 11, National Handbook of Recommended Methods for Water Data Acquisition. http://pubs.usgs.gov/chapter11/chapter11A.html, accessed July 20, 2015.

2.3.3 Kansas Water Use and Intensity by Industry

Kansas water withdrawals totaled 4997.99 million gallons per day (Mgal/day) in 2010 through various types of water uses. The average publicly supplied water withdrawals in the state are 182 gallons per person per day, with outlier counties using as little as 27 gallons per person per day in Johnson County to 477 gallons per person per day in Harvey County. Johnson County is highly urban and contains the Kansas City suburbs of Overland Park and Olathe. Residents who supply their own water for domestic purposes in Johnson County use an average of 67 gallons per person per day and do so entirely from groundwater sources. Total groundwater withdrawals, which make up the entirety of the Harvey County public water supply, are high but similar to neighboring Sedgewick County, which contains the city of Wichita, the largest city in Kansas. Industry water use intensity, the amount of water use by industry sector, is defined using the average water use per day by industry type. Irrigation (agriculture), hydroelectric power generation, and public suppliers make up the top three water users by industry type (shown in Figure 9). However, including hydroelectric power generators in an index of water users is misleading. Hydroelectric power generation does not "use" water under the consumptive use definition; the water that passes through a hydroelectric dam continues to flow down river and is available for further use in other industries. Therefore, while Douglas County has a recorded water use of 1001.11 Mgal per day (compared to the Kansas average of 47.6 Mgal per day), 98.1% of Douglas County's water withdrawals were for hydroelectric power generation. Therefore, the more accurate estimate of consumptive use for Douglas County would be 19.06 Mgal per day, which does not take into account hydroelectric power generation.

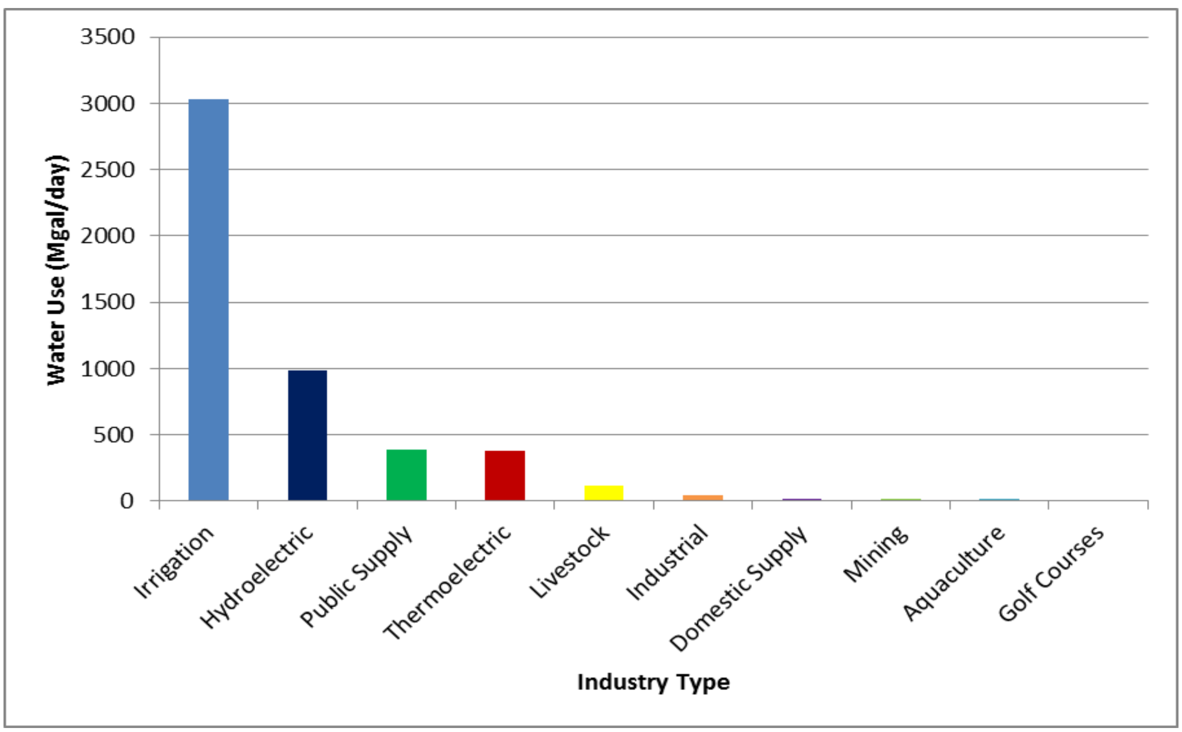

Figure 9—Kansas Water Use Intensity by Industry Sector

Groundwater and surface water contribute to different industry sector supplies in varying amounts. There is no distinction in the available data between commercial use and residential use, presumably because both are users of the public water supply. In Kansas, 60% of publicly supplied water comes from surface water, while 40% comes from groundwater. Only thermoelectric power generation and aquaculture use more surface water than groundwater. Irrigation relies almost entirely on groundwater (95%), while livestock and mining get over 75% of their water supply from groundwater. Overall, Kansas gets 80% of its water supply from groundwater, when excluding hydroelectric water use. When surface water withdrawals include water used for hydroelectric power production, 64% of water use is supplied by groundwater (as shown in Figure 10).

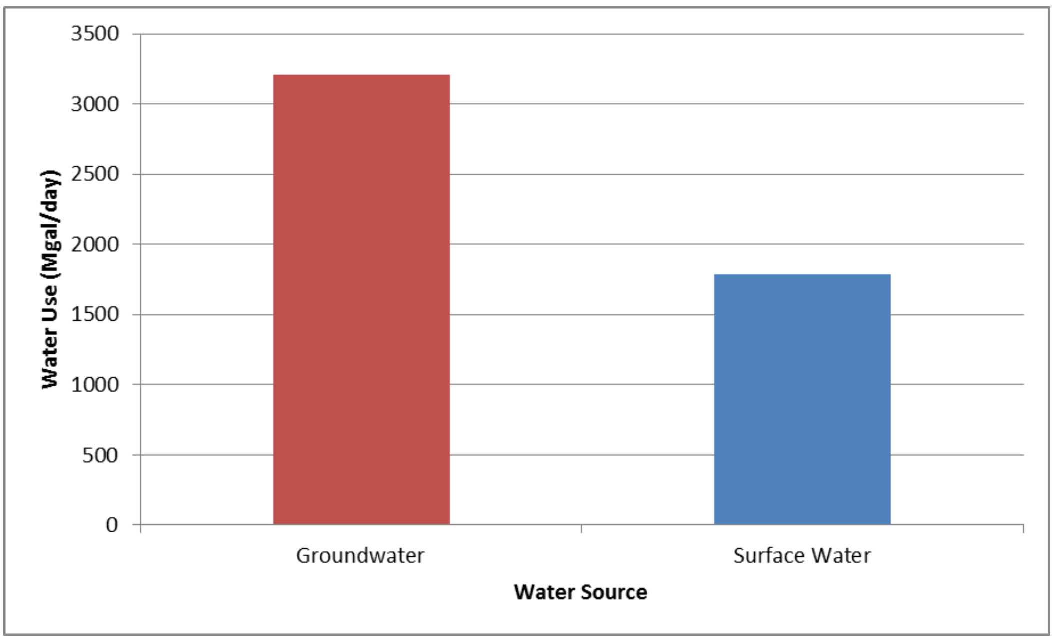

Figure 10—Kansas Water Source

Consumptive water use provides more useful information, specifically because thermoelectric power generation takes a much smaller share of water use by industry as most of the water it withdraws can be consumed by other users. The change in largest consumptive water users is shown in Figure 11.

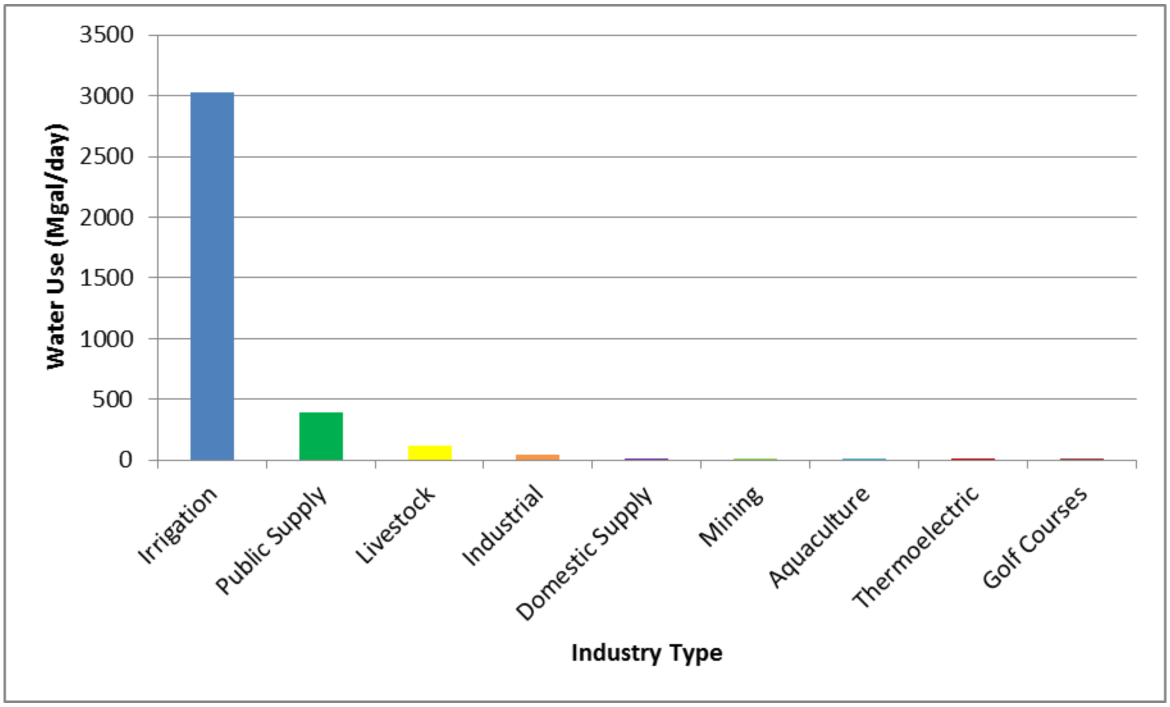

Figure 11—Kansas Consumptive Water Use Intensity by Industry Sector

This changes the profile for source of water as well, as shown in Figure 12, because surface water use for thermoelectric power generation is largely non-consumptive. Groundwater is the source for 88% of consumptive water use when accounting for these differences.

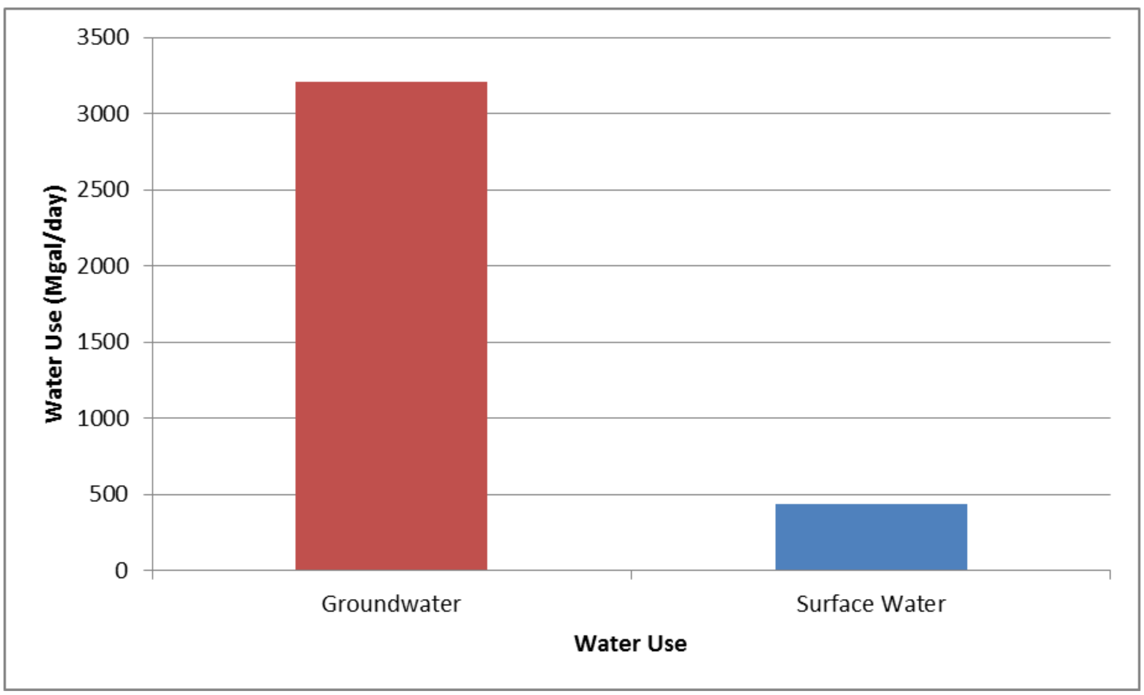

Figure 12—Kansas Water Source (Consumptive)

2.3.4 Nebraska Water Use and Intensity by Industry

Nebraska used an average of 8036.33 million gallons per day (Mgal/day) in 2010 across all industries. Despite having roughly 65% of the population of Kansas, Nebraska uses 61% more water. This is due to more irrigation and more water-intensive thermoelectric power generation in Nebraska than in Kansas. The average publicly supplied water withdrawals in Nebraska are 271.3 gallons per person per day, varying from no publicly supplied users in several counties to 4056 gallons per person per day in Saunders County. This disparity represents the many kinds of recipients of public water and the increased reliance on domestic groundwater well use in many parts of the state. 44 Mgal per day of groundwater are used for domestic consumption in Nebraska in contrast 14.88 Mgal per day in Kansas.

The top three industries with the highest water use intensity (Figure 13) are irrigation for crops, thermoelectric power generation, and public supply. Water use ranges significantly between counties with the largest user, Nemaha County, using an average of 727 Mgal per day and the smallest user, Thomas County, using an average of 1.39 Mgal per day. In Nemaha County, 99% of water withdrawn is for thermoelectric power generation, indicating a much smaller consumptive use of around 5 Mgal per day. Nemaha County is the site of Cooper Nuclear Station, the largest single unit electrical generator in the state.[74] Nemaha County is also in the far eastern portion of the state and therefore receives far more rain than counties further west. Higher rainfall reduces the county's reliance on irrigation for agriculture when compared to western counties.

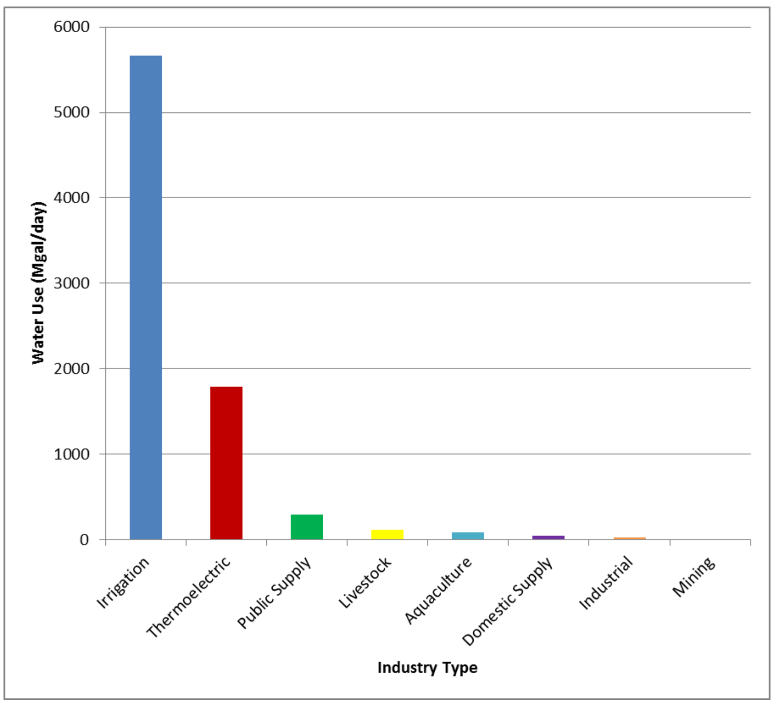

Figure 13—Nebraska Water Use Intensity by Industry Sector

[74] EIA Nuclear & Uranium. Nebraska Nuclear Profile. http: //www.eia.gov/nuclear/state/2008/nebraska/ne.html, accessed July 20, 2015.

In Nebraska, publicly supplied water comes primarily from groundwater (80%) while the rest comes from surface water. Thermoelectric, mining, and aquaculture all rely heavily on surface water over groundwater, but these are the exceptions. Irrigation predominantly uses groundwater (76%), as does public supply, domestic supply, industrial, and livestock. Overall, Nebraska gets 59% of its water supply from groundwater with thermoelectric power generation comprising over half of all surface water withdrawal, as shown in Figure 14. All other industries rely on groundwater for over 75% of water supply.

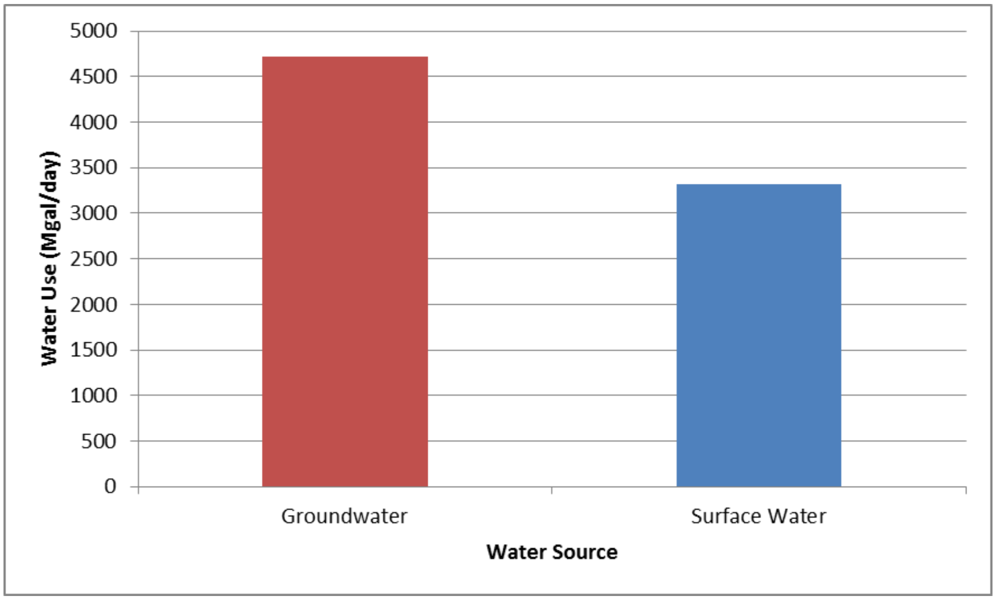

Figure 14—Nebraska Water Source

Nebraska relies heavily on irrigation for water-intensive crops, which helps explain Nebraska's larger daily water use when compared with Kansas. Kansas withdraws almost 100 Mgal per day more on public water, but over 1400 Mgal per day fewer on thermoelectric and nearly 2000 Mgal per day fewer on irrigation. Irrigation demand, based on the number of irrigated acres, is much higher in Nebraska than in Kansas. Nebraska accounts for 15.1% of the country's total irrigated acres, while Kansas accounts for 4.9% of total irrigated acres.[75] Nebraska has 187% more irrigated acres than Kansas, of which corn makes up 64.3% of all Nebraska irrigated acres.[76] Corn requires between 20-25 inches of water for high-yield varieties, but may produce at lower yields with 15-16 inches of water. For Nebraskan farmers, corn water requirements dictate irrigating between 6 inches in the wetter southeastern corner of the state to 14 inches in the dry steps of western Nebraska. Other crops, such as wheat, are grown most commonly as dryland (non-irrigated) crops; when wheat is irrigated, it uses less water than corn because of its shorter growth time to maturity. In addition, nuclear energy requires more water per unit of electricity produced than coal plants; although, the amount of heat, and therefore energy, produced by nuclear plants is also very high compared to coal plants. Therefore, Nebraska water demand is larger than Kansas because water-intensive industries are more predominant in Nebraska.

[75] USDA. Irrigated acres are concentrated in relatively few States. http: //www.ers.usda.gov/data-products/chart-gallery/detail.aspx?chartId=33213&ref=collection, accessed July 20, 2015.
[76] U.S. Department of Agriculture, Census of Agriculture for 2007: Washington, D.C., National Agricultural Statistics Service. http: //www.agcensus.usda.gov/.

Again, when taking into account actual consumptive water use, as opposed to recorded water withdrawal, thermoelectric power generation takes a much smaller share of water use by industry because most of the water it withdraws is recycled by other users, as shown in Figure 15.

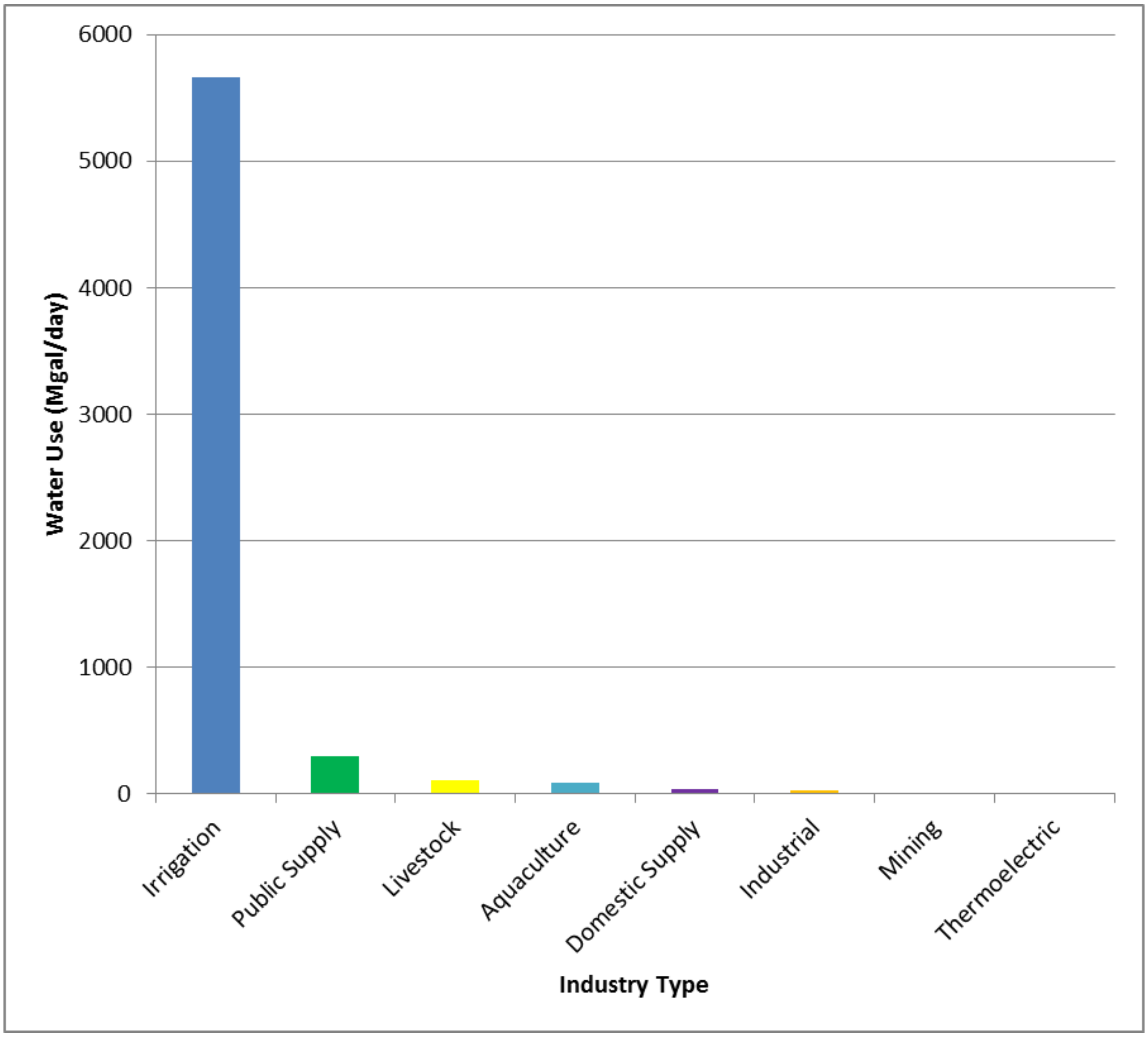

Figure 15—Nebraska Consumptive Water Use Intensity by Industry Sector

This changes the profile for source of water as well, as shown in Figure 16, since surface water use is largely non-consumptive. Groundwater is the source for 75% of consumptive water use when accounting for these differences.

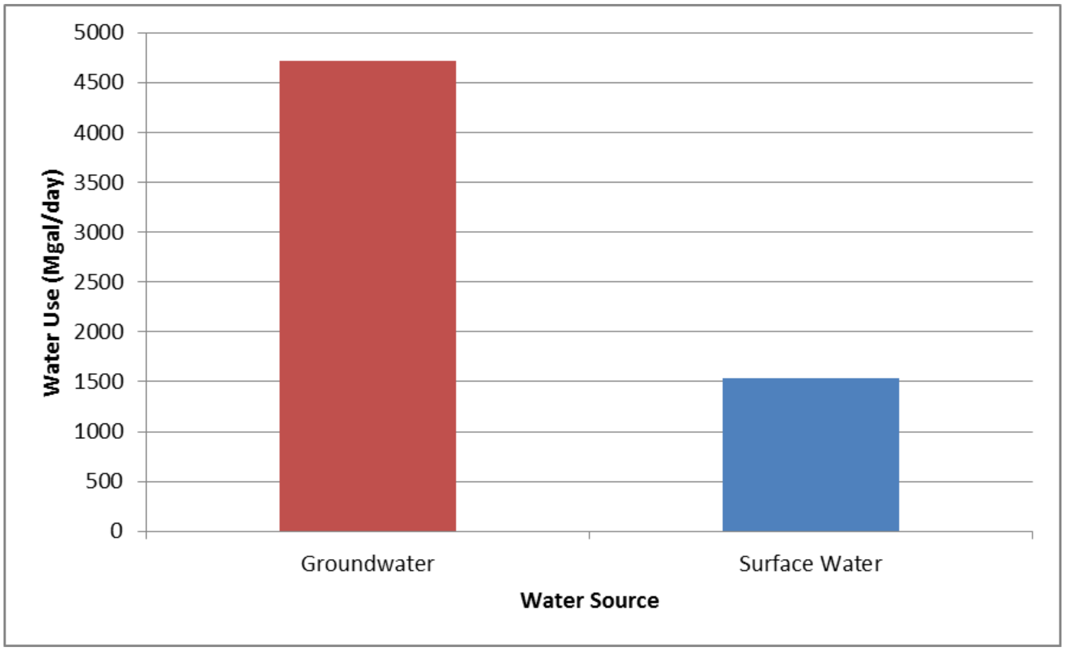

Figure 16—Nebraska Water Source (Consumptive)

For both Kansas and Nebraska, little quantifiable information on commercial use exists to determine which companies are categorized as commercial or industrial. This is especially important for newer industries such as data centers which use vast amounts of water directly and indirectly (because of high power use). Water use by sub-industry, such as hospitality, hospitals, recreation (i.e., water parks, theme parks, botanic gardens, golf courses), and public spaces, such as parks, are included in public supply information. Water use among these sub-groups is relatively very low compared to larger water users (such as irrigators), but may also be relatively high among municipal and county water users.

2.4 Electric Power Generation

An important consideration when evaluating thermoelectric power water use is the type of thermoelectric power being generated. The two prevalent types of thermoelectric power generation in Kansas use either the once-through cooling process or the closed-loop cooling process with dramatic differences in water-use efficiency. All thermoelectric power boils water to create steam, which causes turbines to spin and generate electricity. That steam must be cooled once it passes through the system, although to different degrees. Once-through cooling systems in thermoelectric power plants typically use surface water for this process and eject the wastewater back into the surface water source. Because this process causes ecosystem disruptions due to the warmer water, few new power plants are built with this design. Closed-loop thermoelectric systems are more efficient in that the system reuses water at least once before discharging it back to the water source, effectively halving water use. Kansas once-through thermoelectric power plant use is nearly 5 times the water compared to their closed-loop thermoelectric plant counterparts. Figure 17 shows the location of power generators in Nebraska, while Figure 18 shows the location of thermoelectric power plants that use groundwater. Figure 19 and Figure 20 show the location of power plants and of thermoelectric power plants using groundwater, respectively, for Kansas.

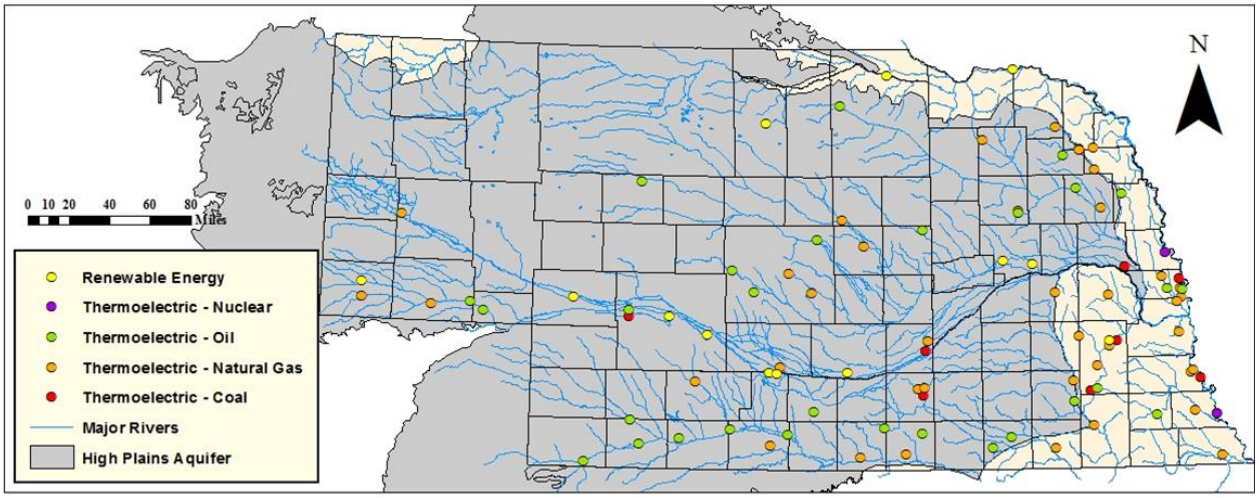

Figure 17—Nebraska Power Generators

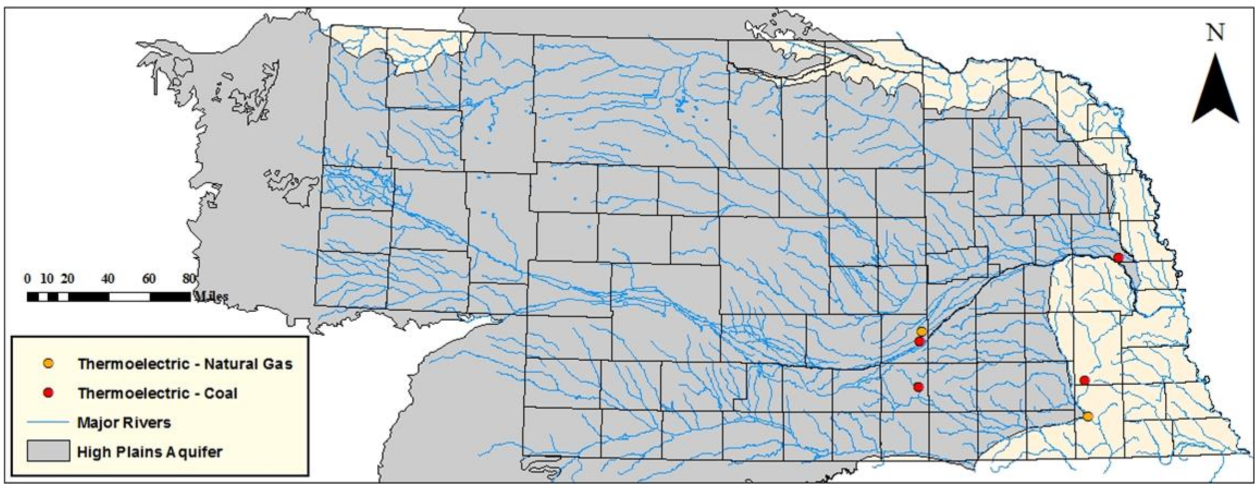

Figure 18—Nebraska Thermoelectric Power Generators Using Groundwater

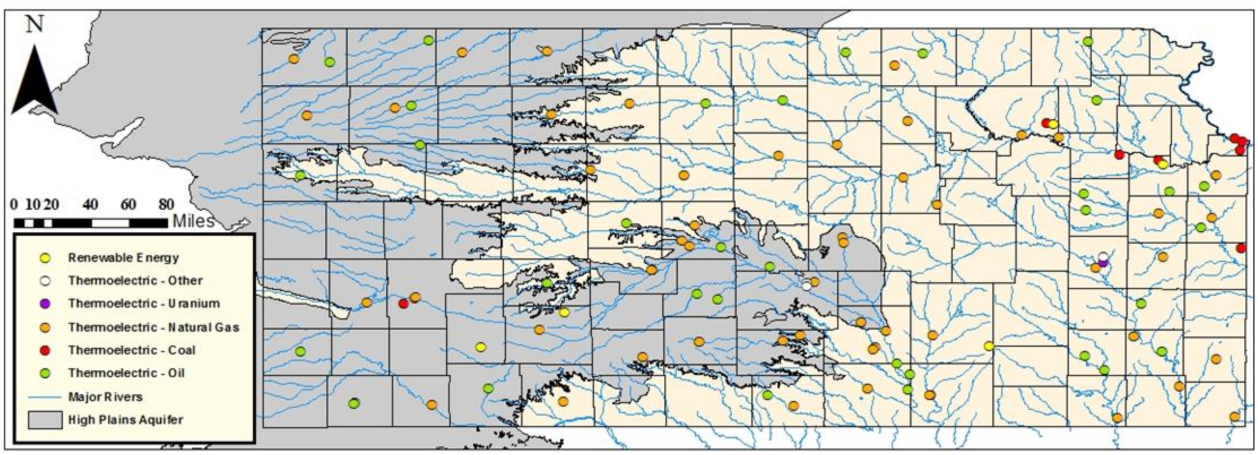

Figure 19—Kansas Power Generators[77]

[77] Renewable energy is limited to commercial wind turbine electric power generation.

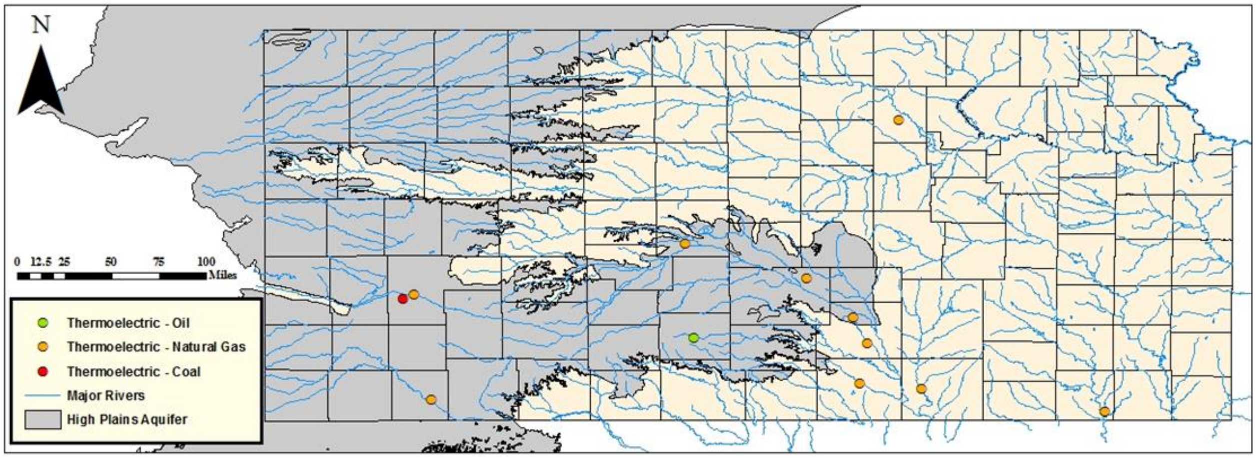

Figure 20—Kansas Thermoelectric Power Generators Using Groundwater

Thermoelectric water use, whether ground or surface withdrawal, is not true consumptive use because thermoelectric plants release most of their water back into streams. Because consumptive use requires water to become unavailable for another consumer, groundwater released into a stream is not considered consumptive use; groundwater can be used instead by a downstream consumer. Kansas thermoelectric power generation receives less than 3% of its water from groundwater sources and therefore plays little role in groundwater depletion. Nebraska uses even less with 0.03% of its water coming from groundwater sources. In Kansas, total consumptive water use is reduced from 4997.99 Mgal per day to 3649.95 Mgal per day, and the largest water users are irrigation for crops, publicly supplied water, and water for livestock. In Nebraska, total consumptive water use is reduced from 8041.81 Mgal per day to 6247.56 Mgal per day with irrigation for crops, publicly supplied water, and water for livestock comprising the largest water users.

2.4.1.1 Ethanol Production

Ethanol production is an increasingly important downstream user of corn and corn-residual products (the stalks, leaves, and cobs that remain after harvest). Increased ethanol usage in the last decade stems primarily from federal quotas for ethanol production, as outlined in the Renewable Fuel Standard (RFS) program under the Energy Policy Act (EPAct) of 2005 and expanded in the Energy Independence and Security Act (EISA) of 2007. The 2007 act mandates that renewable fuel (ethanol) be blended into traditional transportation fuel in increasing increments from 2008 to 2022. The EISA requires 36 billion gallons of renewable fuel to be blended into the transportation fuel supply by 2022, which is an increase of 400% with respect to 2008 levels. The EISA has two primary goals: to increase domestic energy supplies and decrease greenhouse gas emissions.[78]

Corn prices have seen several shifts since the early 20th Century. The most recent shift in corn prices occurred in 2007 when corn first sustained a price of over $4.00 per bushel until the end of 2013. Corn reached its highest price ($7.63 per bushel) in 2012 when the Corn Belt was besieged

[78] Hunter-Pirtle, A.K., Economic Impact of Increased Corporate Average Fuel Economy (CAFÉ) Standards. http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1022&context=agecondiss, May, 10, 2015

by severe drought during the growing season, limiting supply. Corn prices have largely fallen since the end of 2014 and are back under $4.00 per bushel, partly due to increased supply. According to the Agricultural Marketing Resource Center (AMRC), ethanol producers became the second highest market for corn behind the domestic feed market. This has lead economists with the AMRC to identify that post-2007 corn and crude oil prices follow similar patterns (Figure 21).[79] The influence of the U.S. ethanol industry, in terms of its percentage of market demand for corn, is cited as the reason corn prices closely trend with gasoline prices. The location of ethanol and biodiesel plants in Nebraska and Kansas are shown in Figure 22.

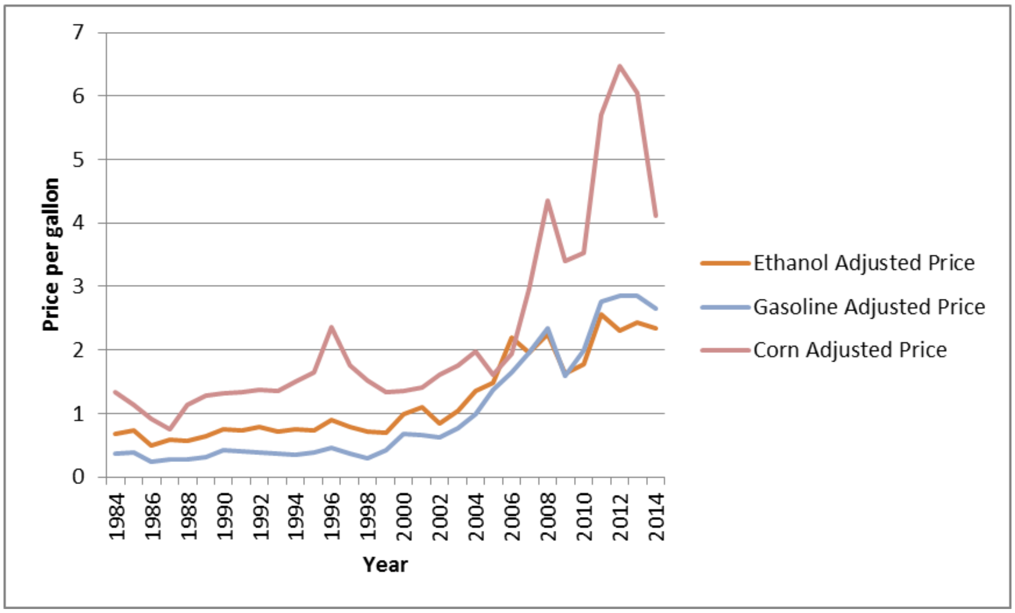

Figure 21—Corn, Ethanol, and Gasoline Prices

Irrigation is pervasive in crop production, both in Nebraska and Kansas. Since the advent of irrigation and subsequent irrigation technologies, such as the center pivot, farm operators have increasingly turned to irrigation to hedge against climate volatility and grow high-yield, water-intensive crops. Between 1984 and 2006, according to the NASS farm census data, the average number of irrigated acres in Nebraska and Kansas was 6,544,697 and 2,638,535, respectively.[80] Nebraska grew corn on 66% of those 6.5 million acres, while Kansas grew corn on 42% of those irrigated acres. Irrigation as a function of time in the Census of Agriculture for Nebraska and Kansas are shown in Figures 23 and 24, respectively.

[79] Wisner, R. Corn, Ethanol and Crude Oil Price Relationships – Implications for the Biofuels Industry. http://www.agmrc.org/renewable_energy/ethanol/corn-ethanol-and-crude-oil-prices-relationships-implications-for-the-biofuels-industry/, May 10, 2015.

[80] USDA Census of Agriculture. 2012 Census Volume 1, Chapter 1: State Level. http://agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_1_State_Level, May 10, 2015.

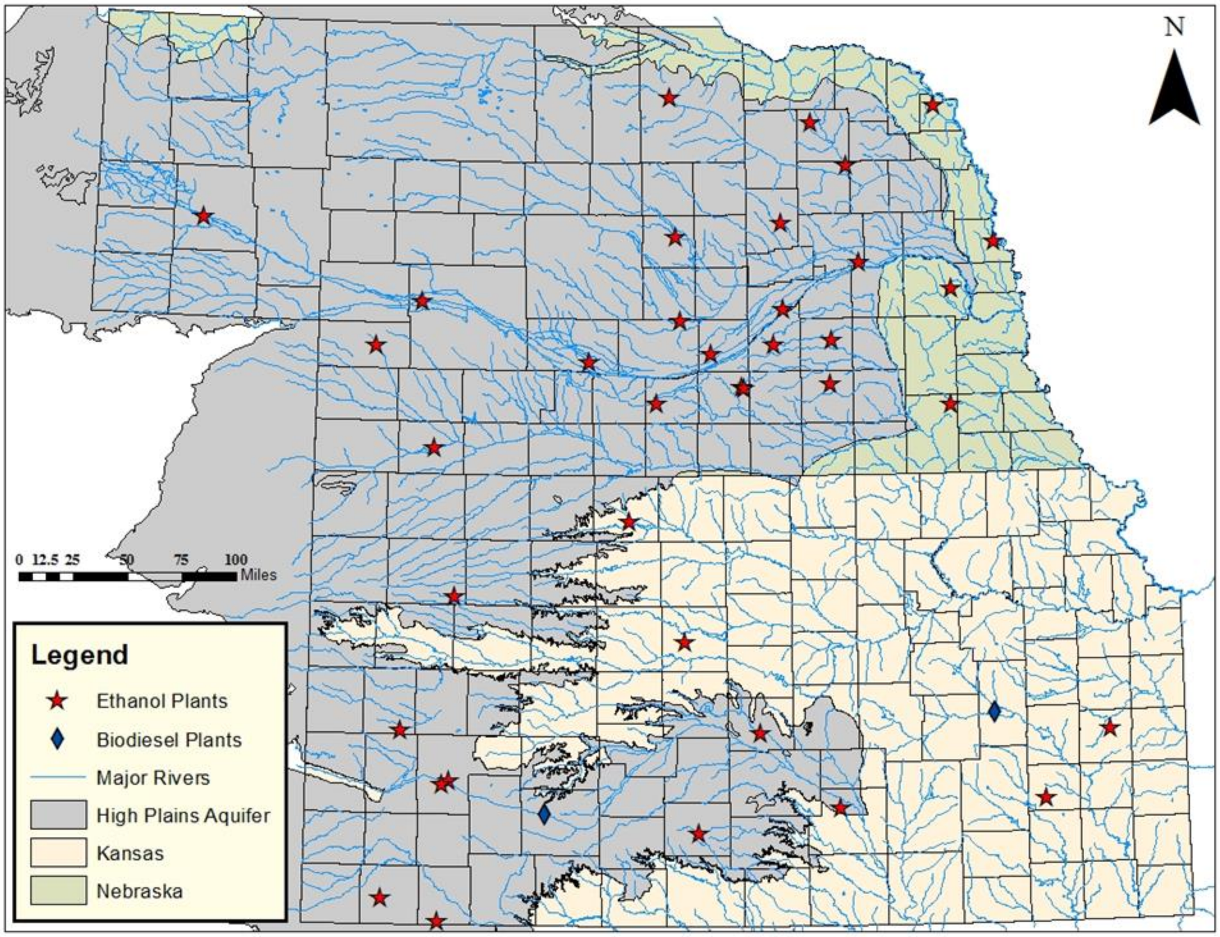

Figure 22—Spatial Distribution of Ethanol and Biofuel Plant Locations

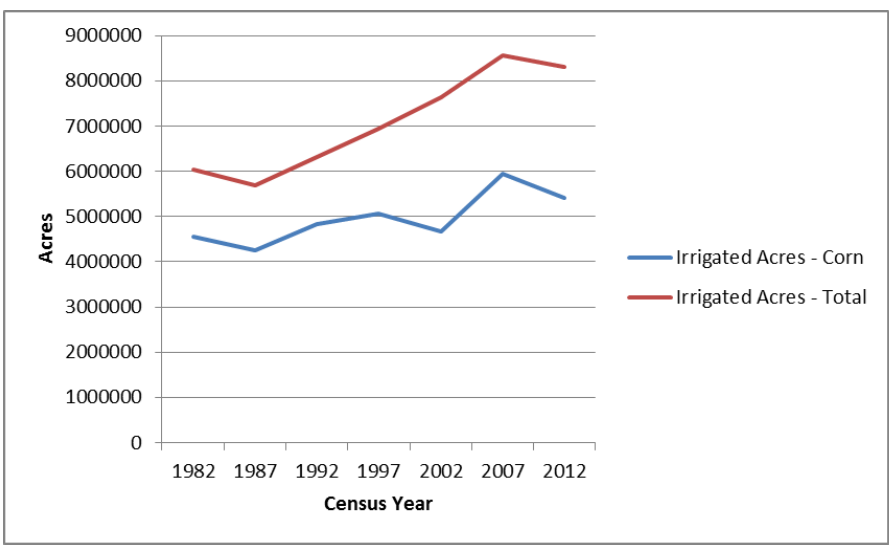

Figure 23—Nebraska Irrigated Acres

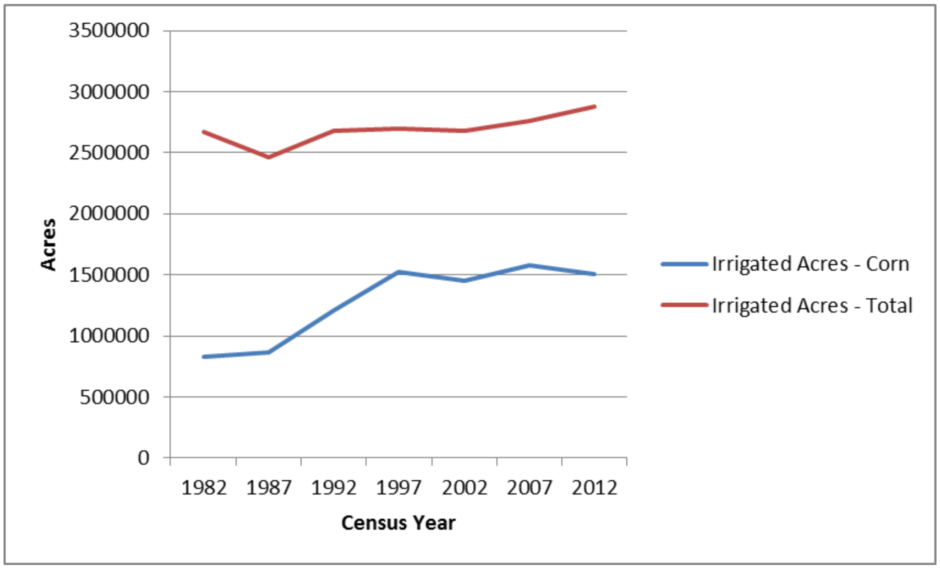

Figure 24—Kansas Irrigated Acres

From 2007 to 2012, the most recent year with agricultural census data, irrigated acres increase to their highest levels in both Nebraska and Kansas. The average number of irrigated acres after 2007 was 8.43 million and 2.82 million for Nebraska and Kansas, respectively. Between census years 1982 and 2002, there was an average of 6.5 million acres and 2.6 million acres for Kansas and Nebraska, respectively. Between the pre-2006 and post-2006 periods, an additional estimated 1.91 million acres were added to Nebraska with 1.1 million acres of that increase dedicated to corn. Kansas saw a larger jump between pre-2006 and post-2006 in terms of percent change (Figure 25), although much smaller nominally with 183,484 irrigated acres added in total. The 2007 and 2012 census periods report that Kansas has, on average, irrigated 1.5 million acres of corn from an average of 1.1 million acres between 1982 and 2002.

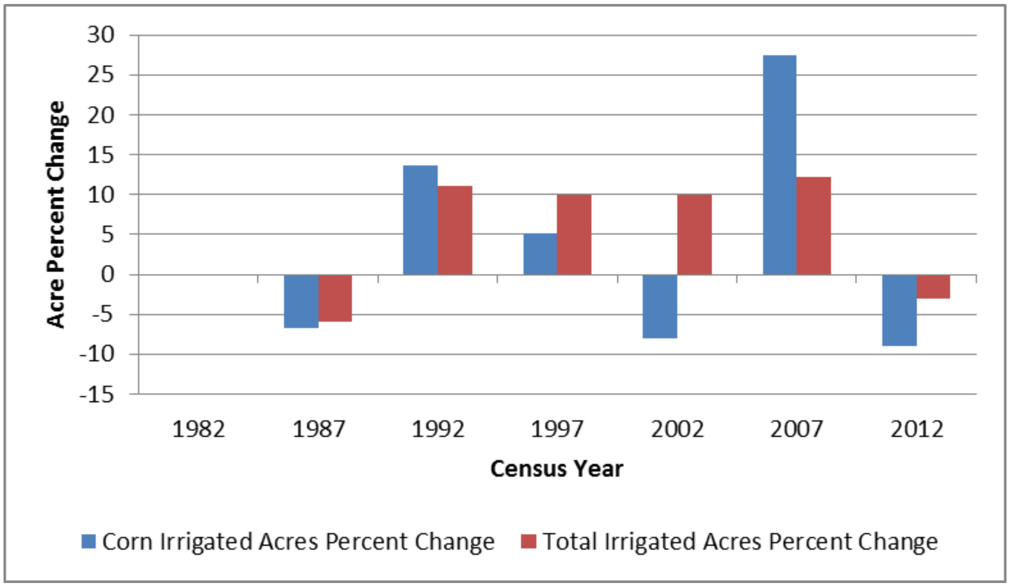

Figure 25—Kansas Percent Change in Irrigated Acres

During the last census on farm operations for Nebraska, irrigated acres for corn fell by 9% and total irrigated acres fell by 3% from the 2007 census level (Figure 26). Kansas irrigated acres for corn fell by 4%, while total irrigated acres rose by 5% from the 2007 census levels. In total, the change in land allocation for irrigated corn can be attributable to many factors, some of which are economic conditions or changes in the demand for ethanol.

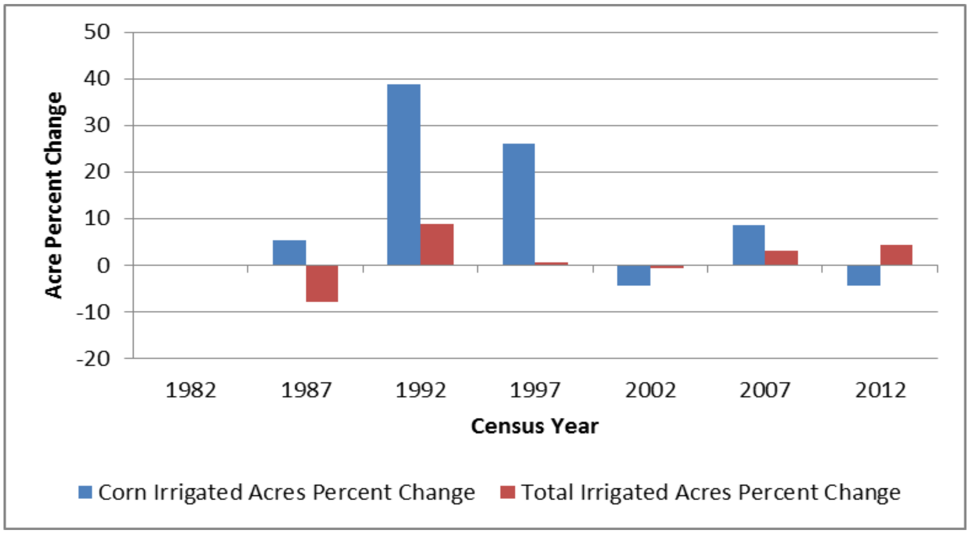

Figure 26—Nebraska Percent Change in Irrigated Acres

Nebraska and Kansas rank first and second in irrigated acres for corn production, which constitutes 80.6% of irrigated acres in the Corn Belt. Nebraska alone accounts for 60% of all irrigated acres of corn. The processing of corn for ethanol production has its own set of water requirements. Corn ethanol uses water for 5 processes of production: grinding, liquefaction, fermentation, separation, and drying. In all, the USDA estimates a modern ethanol-processing mill consumes 3 gallons of water for every gallon of ethanol produced; previous generations of processing mills can use much more water.[81] This is significant because Nebraska ethanol mills can produce over 1.9 billion gallons of ethanol per year; Kansas ethanol facility capacity is over 500 million gallons per year.[82] According to the University of Illinois, an average ethanol plant producing 40 million gallons of ethanol per year can use up to 330,000 gallons of water per day, or 120 million gallons of water per year.[83]

2.4.1.2 Livestock Feedlots and Processing

The livestock industry is an amalgamation of various producers and processors of animal products. Livestock farm operations primarily produce cattle and calves, hogs and pigs, poultry, and dairy cattle; processing operations may also include feedlots. The locations of livestock producers in Nebraska and Kansas are shown in Figures 27 and 28. Livestock is measured by head or by live weight, the weight of the living animal before slaughter, which is used to price the animal.

[81] Argonne National Laboratory. Consumptive Water Use in the Production of Ethanol and Petroleum Gasoline. http://www.transportation.anl.gov/pdfs/AF/557.pdf, accessed May 11, 2015.

[82] Nebraska Energy Office. Fuel Ethanol Facilities Capacity by State and by Plant. http://www.neo.ne.gov/statshtml/122.htm, accessed May 8, 2015.

[83] University of Illinois Extension. Water Use for Ethanol Production. http://web.extension.illinois.edu/ethanol/wateruse.cfm, accessed May 8, 2015.

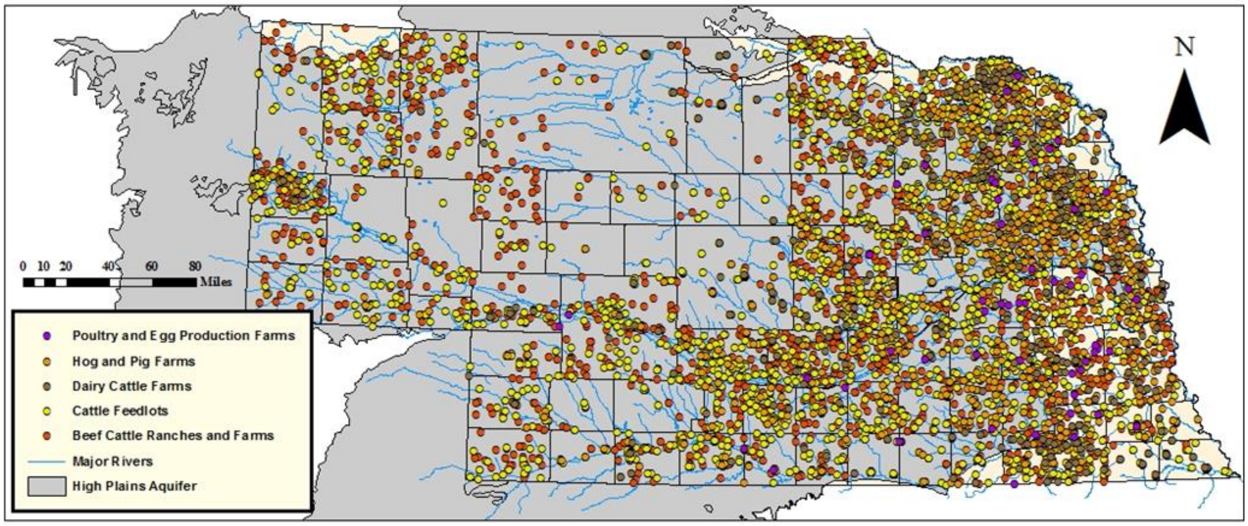

Figure 27—Locations of Livestock Producers in Nebraska: Cattle, Hog, and Poultry

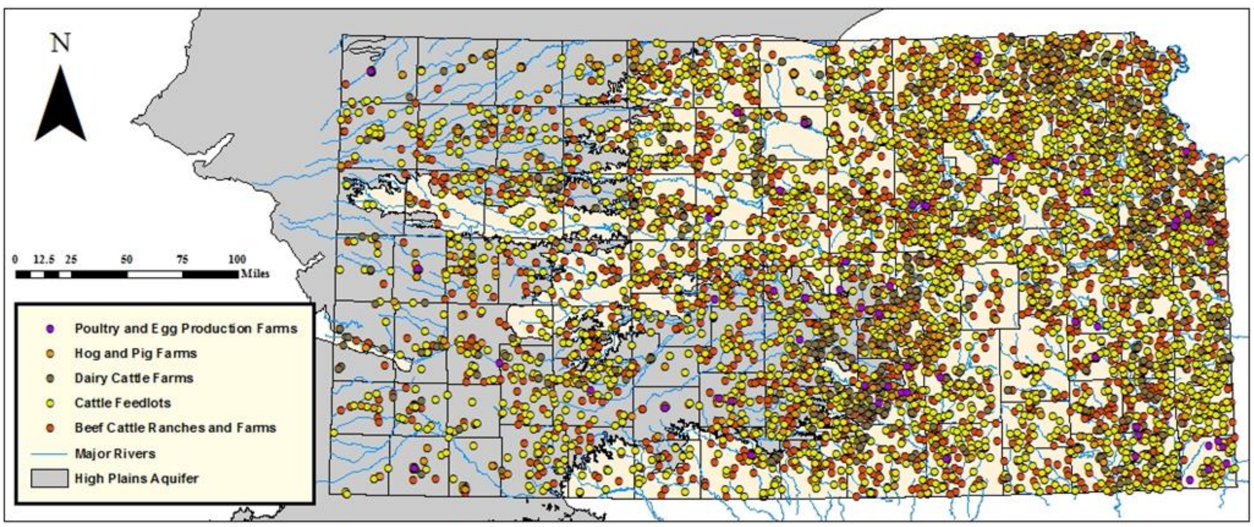

Figure 28—Locations of Livestock Producers in Kansas: Cattle, Poultry, and Hog

Other sectors of the livestock industry include value-added processing facilities such as slaughter, processing, packaging, and distribution operations for animal products. The location of these facilities in Nebraska and Kansas are shown in Figure 29 and Figure 30. These facilities prepare meat, milk, and eggs. Additional output includes animal fats and oils, tallow rendering, and all associated warehousing and cold storage for meat products. Animal processing plants produce a large variety of other animal products for market such as sausage, calf's foot jelly, jerky, tanned hides, smoked meats, and luncheon meat, among others.[84]

[84] NISAC data.

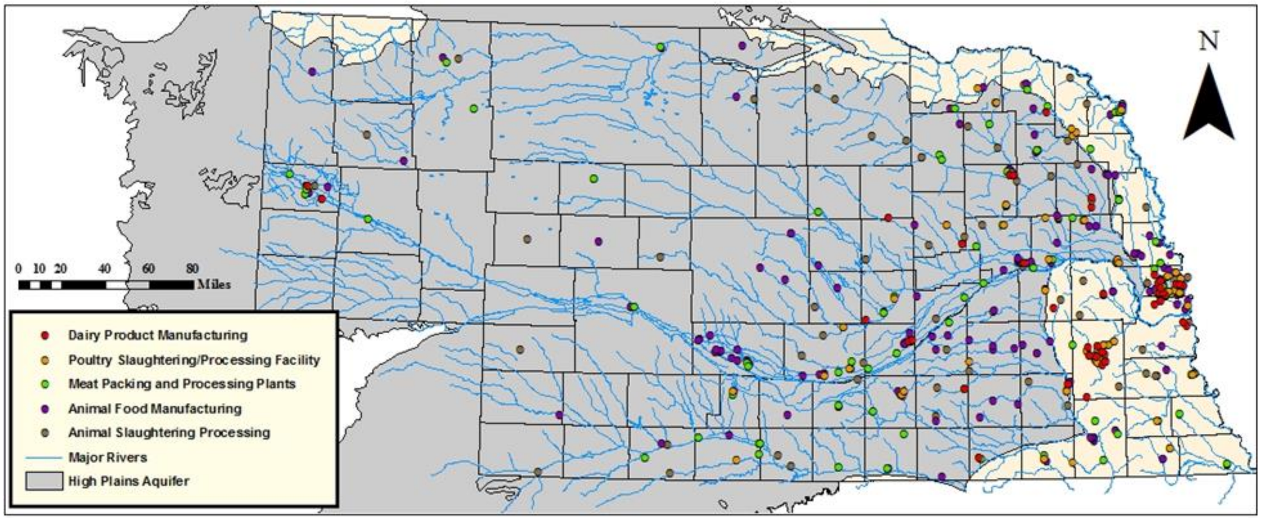

Figure 29— Locations of Meat Processing Facilities in Nebraska, All Livestock

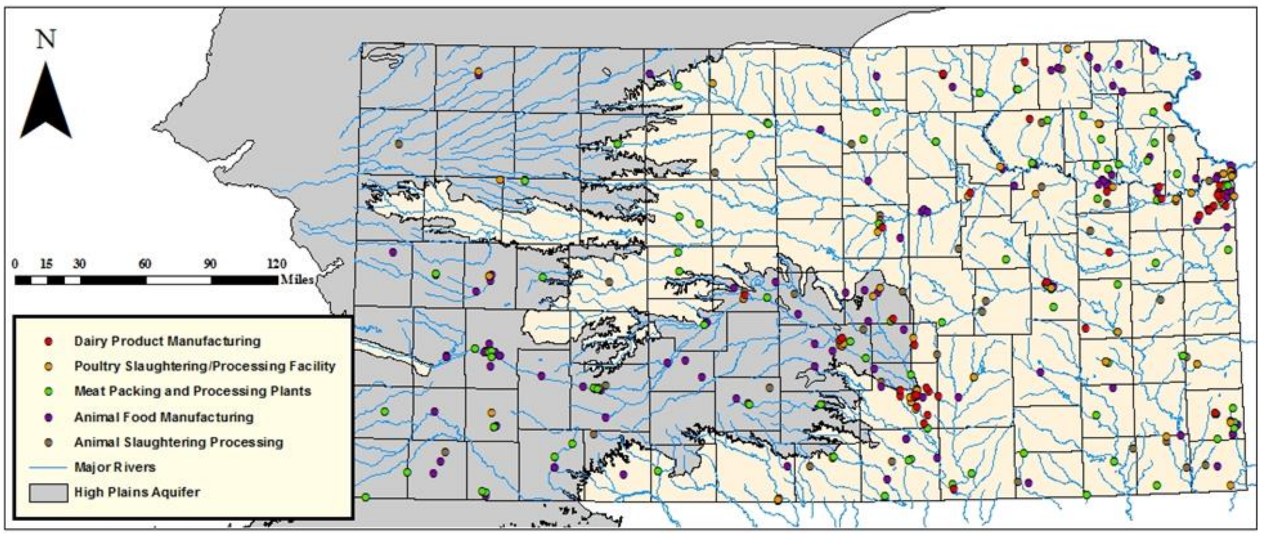

Figure 30—Locations of Meat Processing Facilities in Kansas, All Livestock

A large share of Nebraska's agricultural production, by value, comes from livestock. Locations of livestock producers in Nebraska are shown in Figure 31 through Figure 34. Cattle and calves were the top Nebraska commodity in terms of value, followed by corn, soy, hogs, and wheat. Nebraska ranks first in the Nation for commercial red meat production, commercial cattle slaughter, and beef and veal exports. The beef cattle industry in Nebraska is the single largest industry in the state. Non-cattle livestock produced in the state are also significant to the State. Nebraska ranks 6th in all hogs and pigs and 7th in commercial hog slaughter nationally.[85]

[85] USDA NASS Nebraska Field Office. Nebraska Agricultural Factcard. http: //www.nda.nebraska.gov/facts.pdf, accessed April 27, 2015.

Livestock production made up 45% of total agricultural cash receipts in Nebraska as of 2012.[86] For value-added cattle production, Nebraska has had the largest quantity feed cattle slaughtered since 2003, which represents a robust livestock-related manufacturing sector.[87]
Nebraska ranks behind only Texas in terms of the number of cattle and calves in inventory with Kansas a close third. Nebraska's roughly 6.2 million cattle produce 4.5 billion pounds of live weight. Despite the fact that Texas has over double the number of cattle, Nebraska leads the Nation in commercial cattle slaughter capacity.[88] Water at a slaughtering facility is necessary for washing the carcass, cleaning the plant, and employee use. For cattle, water use is estimated at 0.09 gallons per pound of live weight,[89] which is approximately 405 million gallons of water for all Nebraska cattle produced. A neighboring state, Iowa, leads the nation in hog production. Nebraska, however, produces over 1.3 billion pounds of hog and pig products by live weight with over 2 billion pounds annually in commercial hog and pig slaughter.[90] Nebraska livestock roam over 23 million acres of rangeland and pastureland with cow and calf operations typically ranging in size between 20 head to over 1,000 head in the largest feedlots.[91]

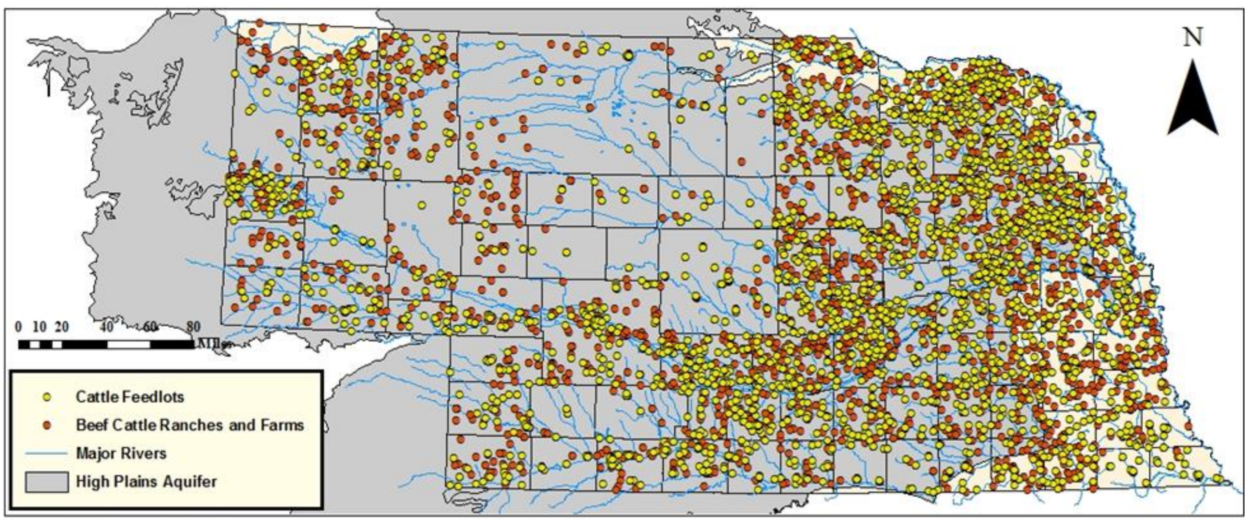

Figure 31—Locations of Cattle Feedlots, Ranches, and Farms in Nebraska

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[86]University of Nebraska-Lincoln Department of Agricultural Economics. Nebraska Livestock Expansion White Paper.
http://agecon.unl.edu/documents/2369805/4129310/Nebraska+Livestock+Expansion+White+Paper.pdf/b968304d-f016-4a50-b119-b856560fa82d, accessed pril 27, 2015.
[87]University of Nebraska-Lincoln Department of Agricultural Economics. Nebraska Livestock Expansion White Paper.
http://agecon.unl.edu/documents/2369805/4129310/Nebraska+Livestock+Expansion+White+Paper.pdf/b968304d-f016-4a50-b119-b856560fa82d, accessed April 27, 2015.
[88] U.S. Census Bureau. Statistical Abstract of the United States: 2012.
http://www.census.gov/compendia/statab/2012/tables/12s0873.pdf, accessed May 1, 2015.
[89] Wulff, S. M. et al. (1985) Feasibility of Establishing Small Livestock Slaughter Plants in North Dakota. North Dakota State University Department of Agriculture and Applied Science,
http://ageconsearch.umn.edu/bitstream/23174/1/aer208.pdf, accessed July 21, 2015.
[90]U.S. Census Bureau. Statistical Abstract of the United States: 2012.
http://www.census.gov/compendia/statab/2012/tables/12s0873.pdf, accessed May 1, 2015.
[91]Nebraska Department of Agriculture. Nebraska Agriculture.
http://www.nda.nebraska.gov/publications/ne_ag_facts_brochure.pdf, accessed April 25, 2015.

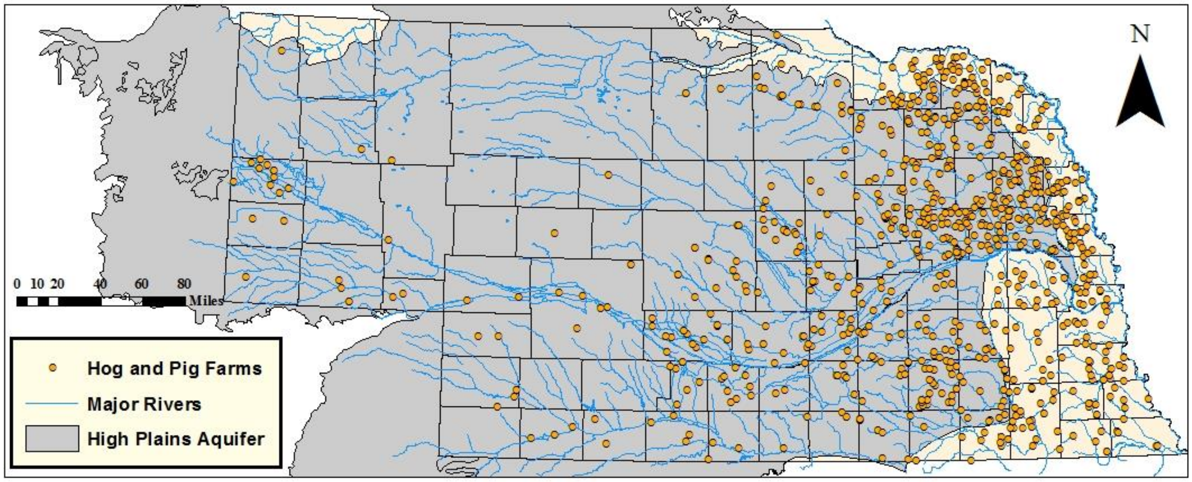

Figure 32—Locations of Hog and Pig Farms in Nebraska

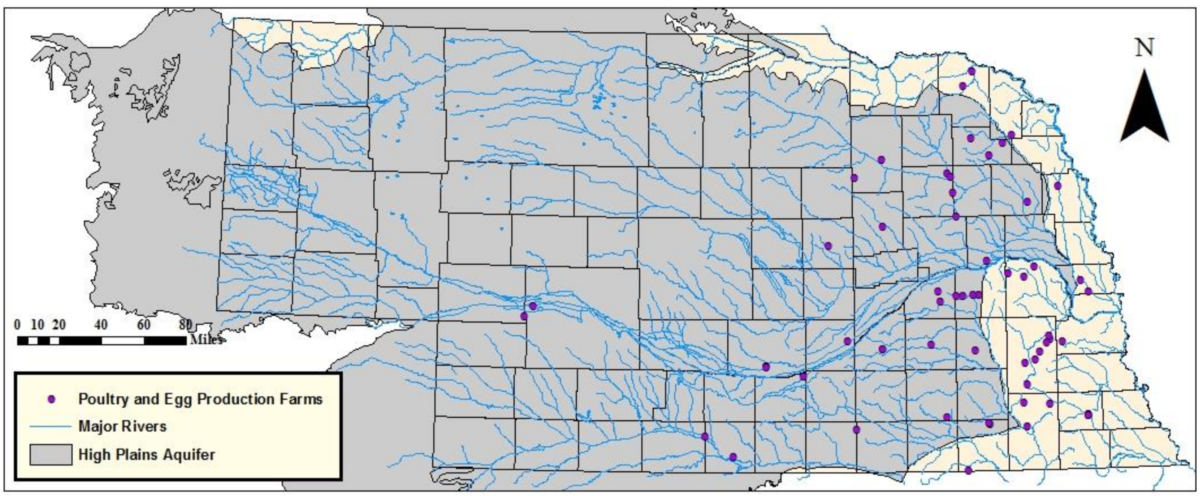

Figure 33—Locations of Poultry and Egg Farms in Nebraska

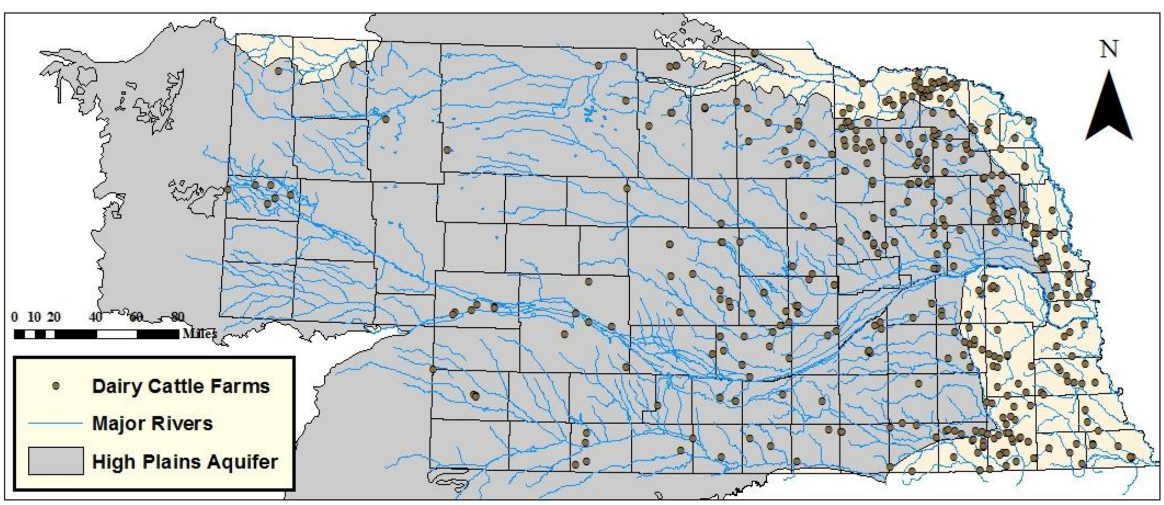

Figure 34—Locations of Dairy Farms in Nebraska

In total, Kansas livestock, which includes cattle and calves, hogs and pigs, sheep and lambs, and wool and milk, produced $5.5 billion in 2013. Nearly 80% of this value came from cattle and calves.[92]

Kansas has nearly 6 million cattle and 1.9 million hogs and pigs in the state. Kansas produces 4 billion pounds of live weight cattle, and according to the most recent data, Kansas has also surpassed Texas in terms of commercial slaughter capacity at 8.3 billion pounds of cattle slaughtered in the state. Kansas also has a wide range in the size of cow and calf operations, ranging in size between just a few animals to over 1,000 in a single operation.[93] The locations of livestock production facilities in Kansas are shown in Figure 34 through Figure 37.

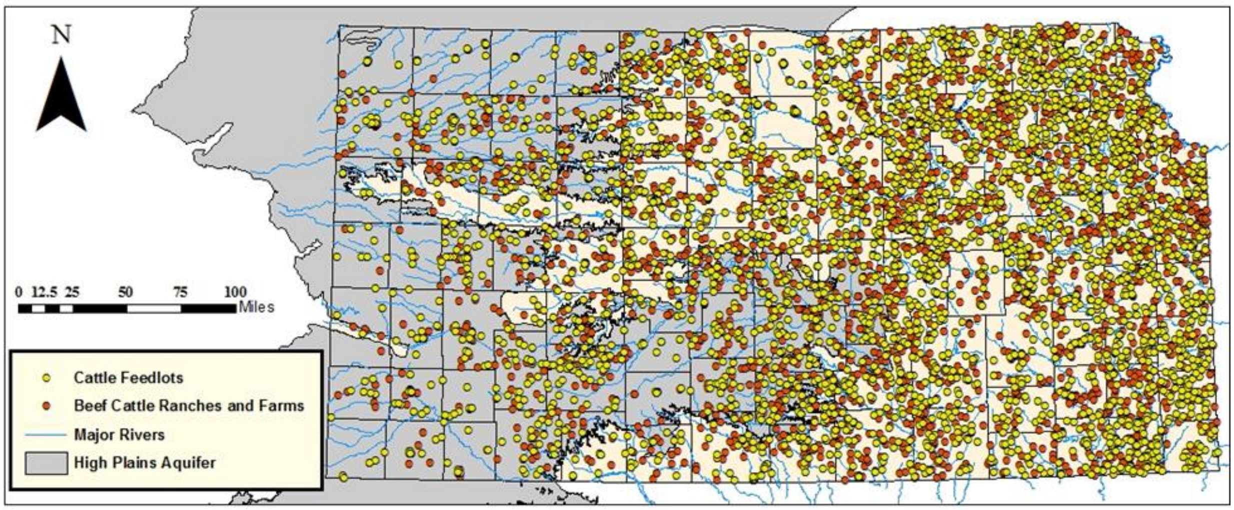

Figure 35—Locations of Cattle Feedlots, Ranches, and Farms in Kansas

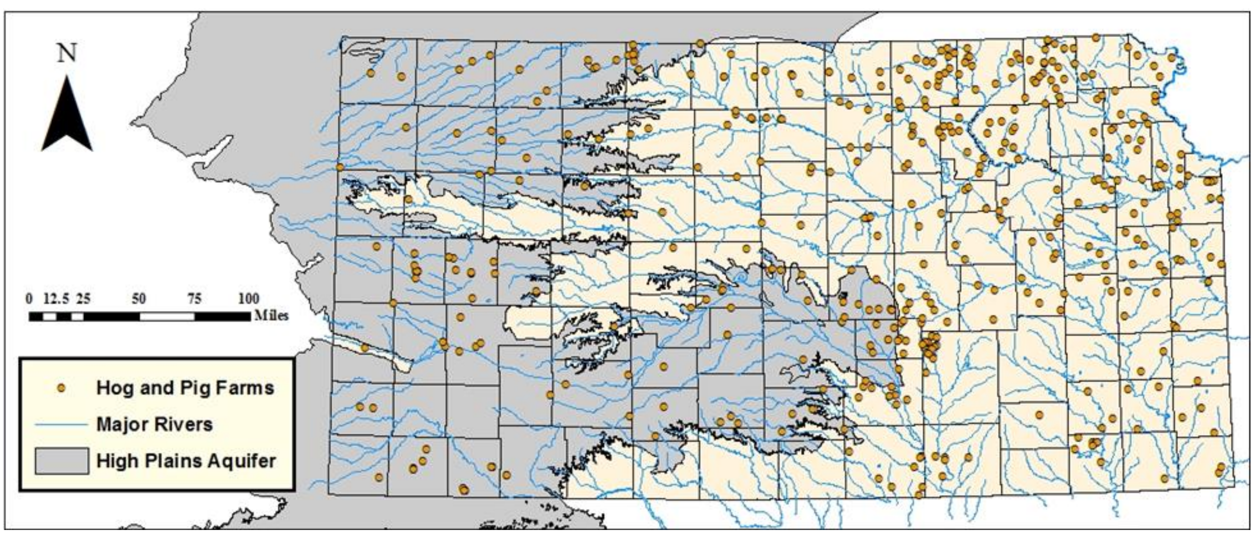

Figure 36—Locations of Hog and Pig Farms in Kansas

[92] Kansas Farm Facts. Farm Value of Livestock Production in Kansas. http://www.ipsr.ku.edu/ksdata/ksah/ag/16ag9.pdf, accessed April 6, 2015.
[93] U.S. Census Bureau. Statistical Abstract of the United States: 2012. http://www.census.gov/compendia/statab/2012/tables/12s0871.pdf, accessed May 1, 2015.

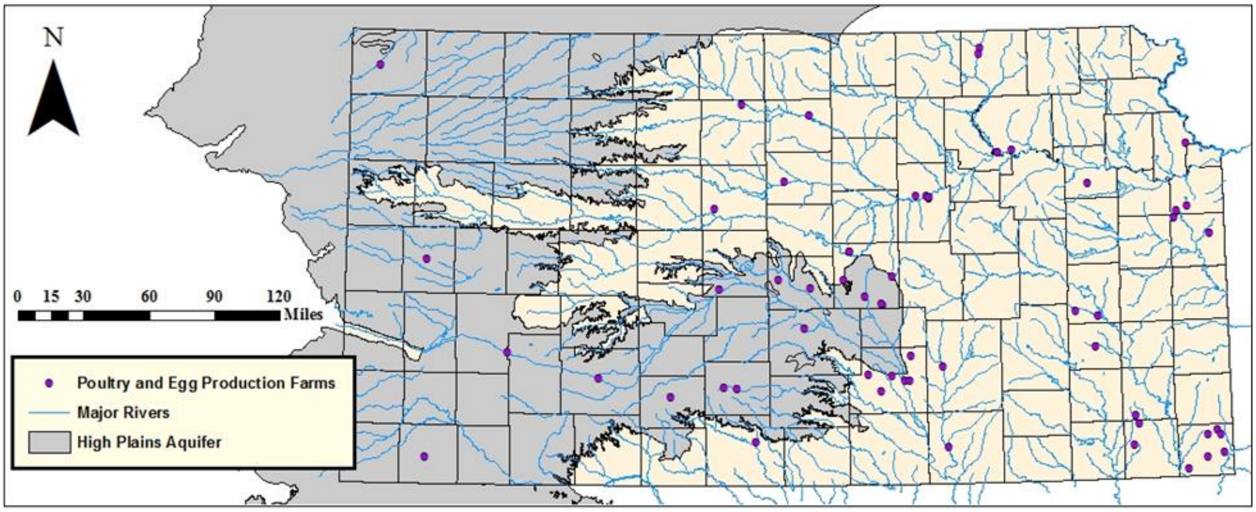

Figure 37—Locations of Poultry and Egg Farms in Kansas

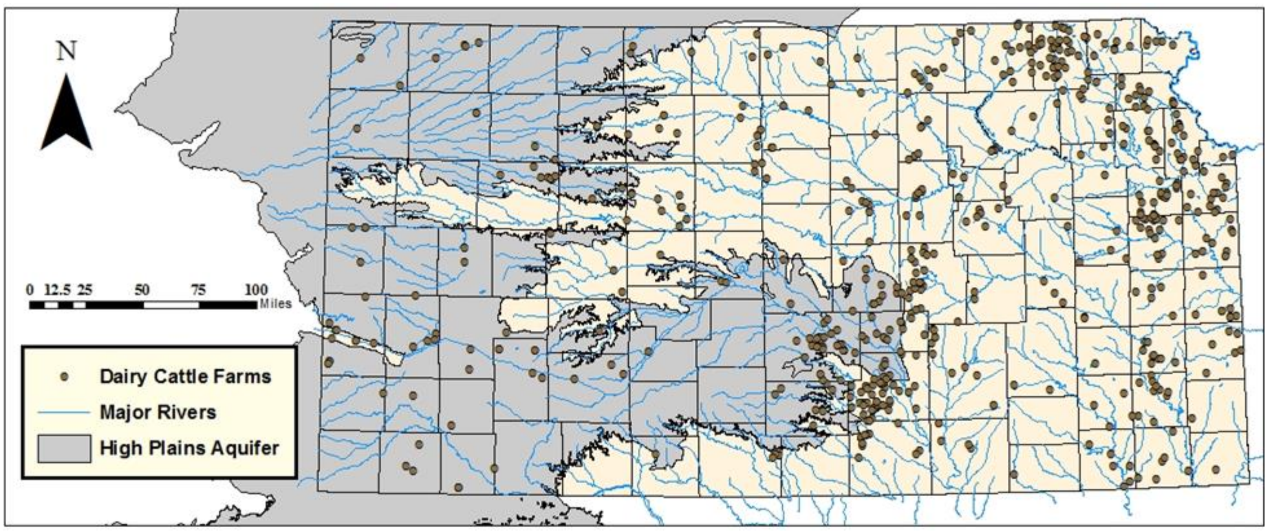

Figure 38—Locations of Dairy Farms in Kansas

Livestock production, such as cattle, requires inputs such as carbohydrates, minerals, and nutrients. Water is a critical direct input for cattle and, just as much as any combination of nutrients, water intake directly affects cattle performance. Livestock use water for body growth, excretion of waste, and sweat. There are a number of environmental factors that further influence livestock water requirements. Temperature, along with physical activity and feed type, augments the water requirements for livestock significantly. For example, cattle need on average an additional 0.68-1.45 gallons of water per day for every ten-degree increase in ambient temperature above 40° F.[94] These water requirements depend heavily on the size and type of the cattle, such as growing heifers, steers, or bulls, compared to mature or finishing cattle (Table 2). This requirement changes after ambient temperature rises above 80°F; cattle need 2.86 additional

[94] University of Nebraska-Lincoln Extension, Institute of Agriculture and Natural Resources. Water Requirements for Beef Cattle. http: //www.ianrpubs.unl.edu/live/g2060/build/g2060.pdf, accessed May 18, 2015.

gallons of water per day at 90°F. At this temperature, a mature bull or finishing cattle will require over 20 gallons of water per day. For every day with daily temperatures exceeding 90°F, the current cattle population requires 60-124 million gallons of water.[95]

Table 2—Average Cattle Water Requirements in 10° Fahrenheit Increments[96]

	Water Requirement (Gallons per Day)						
Temperature (°F)	400-600 lb. Growing Heifers, Steers, Bulls	600-1,000 lb. Finishing Cattle	900-1,000 lb. Wintering Beef Cows	900 lb. Lactating Cows	1,400-1,600+ lb. Mature Bulls	Avg. Cattle Water Intake	Avg. % Change
40	5.20	7.33	6.35	11.40	8.35	7.73	
50	5.63	7.93	6.85	12.60	9.00	8.40	8.76%
60	6.50	9.10	7.85	14.50	10.35	9.66	14.95%
70	7.60	10.67	9.20	16.90	12.15	11.30	17.01%
80	8.73	12.27		17.90	13.95	13.21	16.89%
90	12.40	17.43		18.20	19.80	16.96	28.35%

2.5 Economic Analysis

2.5.1 Introduction

This section describes the analytical approach used to estimate the economic consequences of the resource risk to the High Plains Aquifer without mitigating policies and other external shocks to agriculture in Nebraska and Kansas. The framework combines microeconometric empirical models with macroeconomic simulation to capture firm- and industry-level consequences of a groundwater resource risk that potentially translates to macroeconomic consequences. The first section describes the approach used to bound the analysis. Next is discussion of the process for identifying relevant industries, filtering for water intensive use, and then estimating the economic consequences.

The economic analysis is a two-pronged approach with three steps for estimating the economic consequences of resource risk in the High Plains region. The two-pronged approach consists of two processes (see Figure 39): (1) start at the national level and drill down to identify major industries at the state and county level while also categorizing industries as water intensive and therefore vulnerable to resource risk; (2) translate microeconomic impacts to the macroeconomic level.

[95] University of Nebraska-Lincoln Extension, Institute of Agriculture and Natural Resources. Water Requirements for Beef Cattle. http: //www.ianrpubs.unl.edu/live/g2060/build/g2060.pdf, accessed May 18, 2015.
[96] Adapted from: University of Nebraska-Lincoln Extension, Institute of Agriculture and Natural Resources. Water Requirements for Beef Cattle. http: //www.ianrpubs.unl.edu/live/g2060/build/g2060.pdf, accessed May 18, 2015.

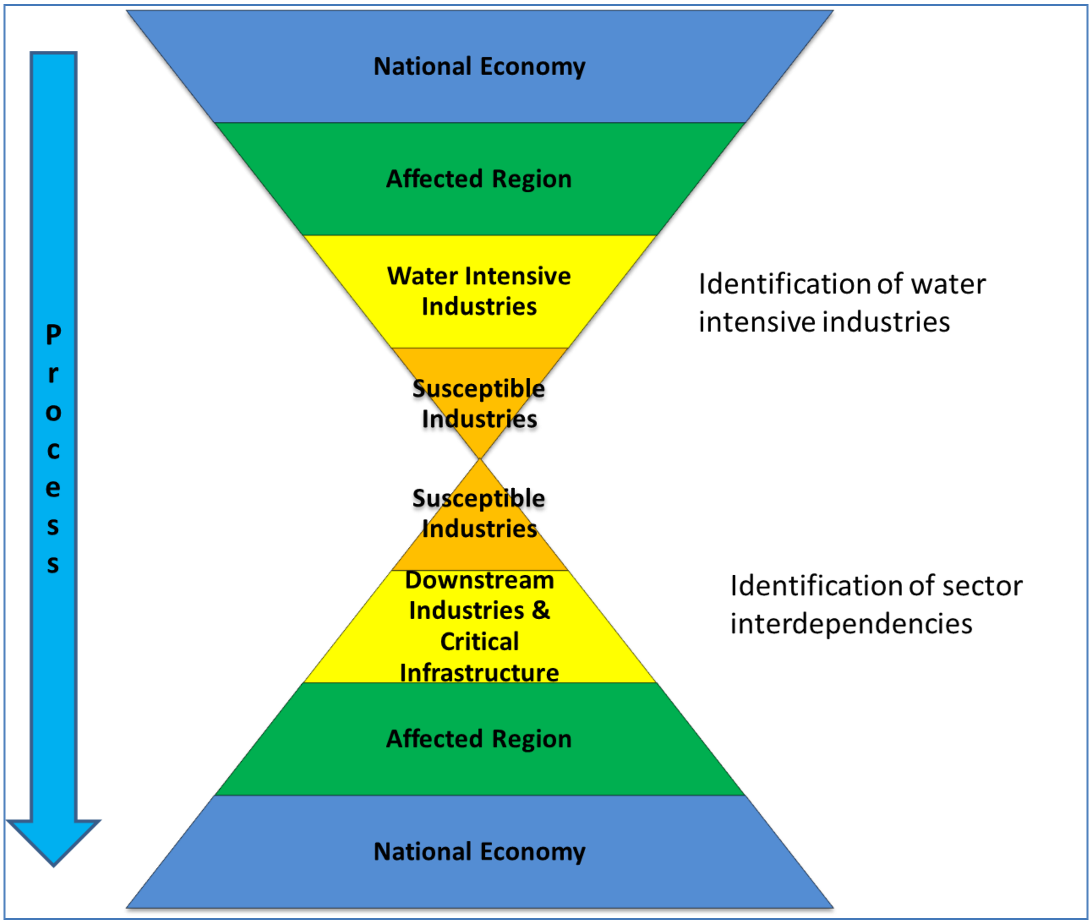

Figure 39—Abstraction of Economic Methodology

The economic methodology first drills down from the macro to the micro level and then back out from the micro to the macro level. The methodology is informed by multiple types of firm and industry data as well as critical infrastructure databases. Figure 40 is an abstraction of the three-step process for achieving estimation of economic consequences. Step 1 is achieved by applying state and county-level data to identify and determine the dominant industries in the affected counties in Kansas and Nebraska. We look at the data from four perspectives determined by two methods of analysis and two criteria. First, we look at how frequently particular industries are dominant in each county for a given state; industries are dominant if they occupy the greatest share either of employment or of productivity, which we measure via wages paid and dollar contribution to output. Next, we look at the industries' employment and wages shares across the entire affected area. Together, these analyses measure industries' centrality and universality by two intuitive criteria. The conclusions that follow may be useful in determining the future impacts of the resource risk or of other acute or chronic hazards.

The industries deemed economically dominant were compared against the analysis on water intensity and use. If an industry falls into both categories, it is then selected for microeconomic impacts because it is likely sensitive to increasing prices to pump groundwater. Step 3 is actually a combined microeconomic and macroeconomic consequences analysis to capture both the regional and national impacts associated with resource risk in the High Plains.

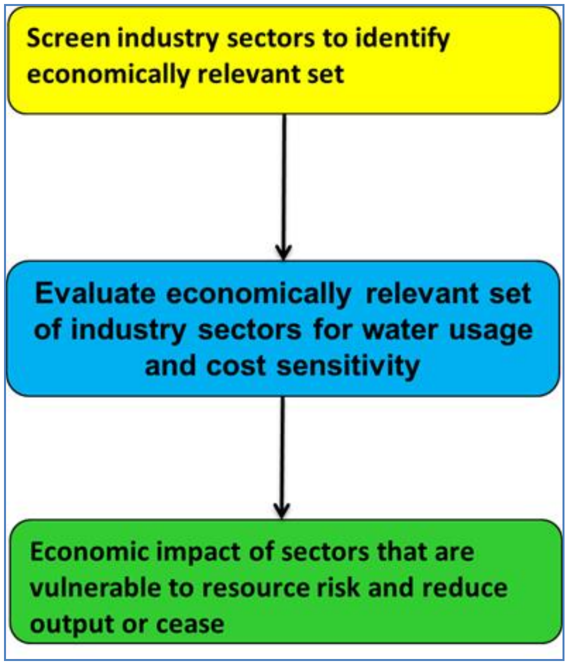

Figure 40—Three-Step Process for Identifying Economic Impacts of Resource Risk

Water use efficiency and profit maximization are at the center of the microeconomic analysis. Barring any mitigating water management policy, how will the agricultural industry be affected by the need for deeper wells? Irrigation is essential to maintain current levels of agricultural productivity, and it is assumed farmers will continue to drill deeper wells until it is no longer profit-maximizing to do so. Howitt, et al. (2010) state that farmers may allow land to go fallow under severe drought circumstances rather than drill deeper, more expensive wells. Profits can be made by selling water rights compared to producing comparatively low-value agricultural products. Farm operations in any part of the U.S. may face similar choices when water resources are constrained. It is important that the microeconomic analysis is carefully framed and conducted because, in reality, industry changes can have potentially severe and far-reaching effects. The results of the microeconomic analysis will be largely assumptions driven and sensitive to data selection/availability. In this paper, we are not strictly modeling potential water management policies or the response behavior of farmers; we are modeling the economic consequences at all levels given worst-case scenarios in the absence of mitigating policies, or the core assumption is business as usual (no policy, farm management, or regulatory change) in the resource risk of the High Plains region.

Our analysis leverages techniques widely applied in the agriculture economics literature while selecting a methodology that best accommodates our requirements—an analysis that can capture the local, regional, and national economic consequences over a decades-long period of time. The main difference between our analysis and what is found throughout the literature is the modeling scope. NISAC analyses are critical for two reasons: these studies not only inform stakeholders at the national level, but they are also valuable for their usefulness to local and regional stakeholders likely to be the most affected by a chronic event similar to the resource risk in the High Plains region.

Our approach is aimed at identifying catalysts that cause farm operations to reach a tipping point where they will then need to implement a change in managed practices or technology.

2.5.2 General Economic Analysis Data

The data in this report are sourced from the Bureau of Economic Analysis (BEA), U.S. Census Bureau, USDA NASS, Homeland Security Infrastructure Program (HSIP) Gold, and publicly available reports. Each dataset spans several years with year-to-year coverage varying. The dataset selection is representative of the vast scope of the study with some data representative of individual firms, others covering industries and regions, and some data national in type. Only the BEA and Census Bureau data is publicly available free data. Both HSIP Gold and USDA NASS datasets are restricted, with the HSIP Gold available to particular government and quasi-government organizations, and the NASS data only available under strict protocols. Appendix B describes each particular dataset, its purpose, and how it was used in this study.

2.5.3 Data—Farm Operation Observations

Data for the microeconomic analysis are extracted from the Census of Agriculture for the years 1982 to 2012. The NASS conducts the survey that makes up the census on a five-year schedule (1982, 1987, 1992, 1997, 2002, 2007, and 2012). The longitudinal dataset is comprised of 308,126 observations representing 76,057 unique farm operations and 26 variables tracked at different points in time. The farm operations of interest are those in counties in Nebraska and Kansas that sit atop the High Plains Aquifer because it can be assumed that these operations have drawn and will continue to draw on the High Plains Aquifer as a source of irrigation.

The Census of Agriculture data are collected every five years from individual farms in the United States. The statistics on individual farm observations are produced by USDA-NASS, which conducts surveys and prepares reports covering every aspect of U.S. agriculture. Observations at the individual farm operation level are highly restricted and protected data. The highly-protected nature of the data is the result of the guarantee by the USDA that if a farm operation participates in the survey the information collected will never be used to regulate, reveal "trade secrets," provide competitive advantage, or result in legal proceedings. "Safeguard the privacy of farmers, ranchers, and other data providers, with a guarantee that confidentiality and data security continue to be our top priorities," (USDA-NASS).

When a particular farm operation's characteristics are tracked at multiple points in time, the data collected are a longitudinal dataset, which measure change. For our purposes, the various factors on farm proprietor response to changing inputs can be estimated. Access to individual farm operation observations or longitudinal data allows for the tracking of individual farm operations at different points in time (every five years), which is necessary to understand which factors may affect a farmer's operation and decisions regarding market participation, for example, to examine if increasing pumping costs will lead to decreased farm production through farm exits, selling farms, crop switching, or increasing fallow crop acreage.

2.5.4 General Economic Conditions: Kansas and Nebraska

Kansas is home to nearly 2.9 million people with a median household income around $51,332. There is significant disparity per median household income between Woodson County ($30,852), Johnson County ($75,139), and Woodson County ($30,852). Nonfarm employment in the state is around 1.4 million jobs compared to around 1.0 million jobs in agriculture. Kansas unemployment rates range from 2.6% in Sheridan County to 11.2% in Linn County. There are approximately 1.88 million people in Nebraska with a median household income of $45,338, ranging from $32,292 in Banner County to $65,803 in Washington County. Overall, Nebraska's unemployment rates range between 1.5% in southwestern Perkins County to 5.3% in northeastern Dakota County. County contributions to GDP are shown in Figure 41.

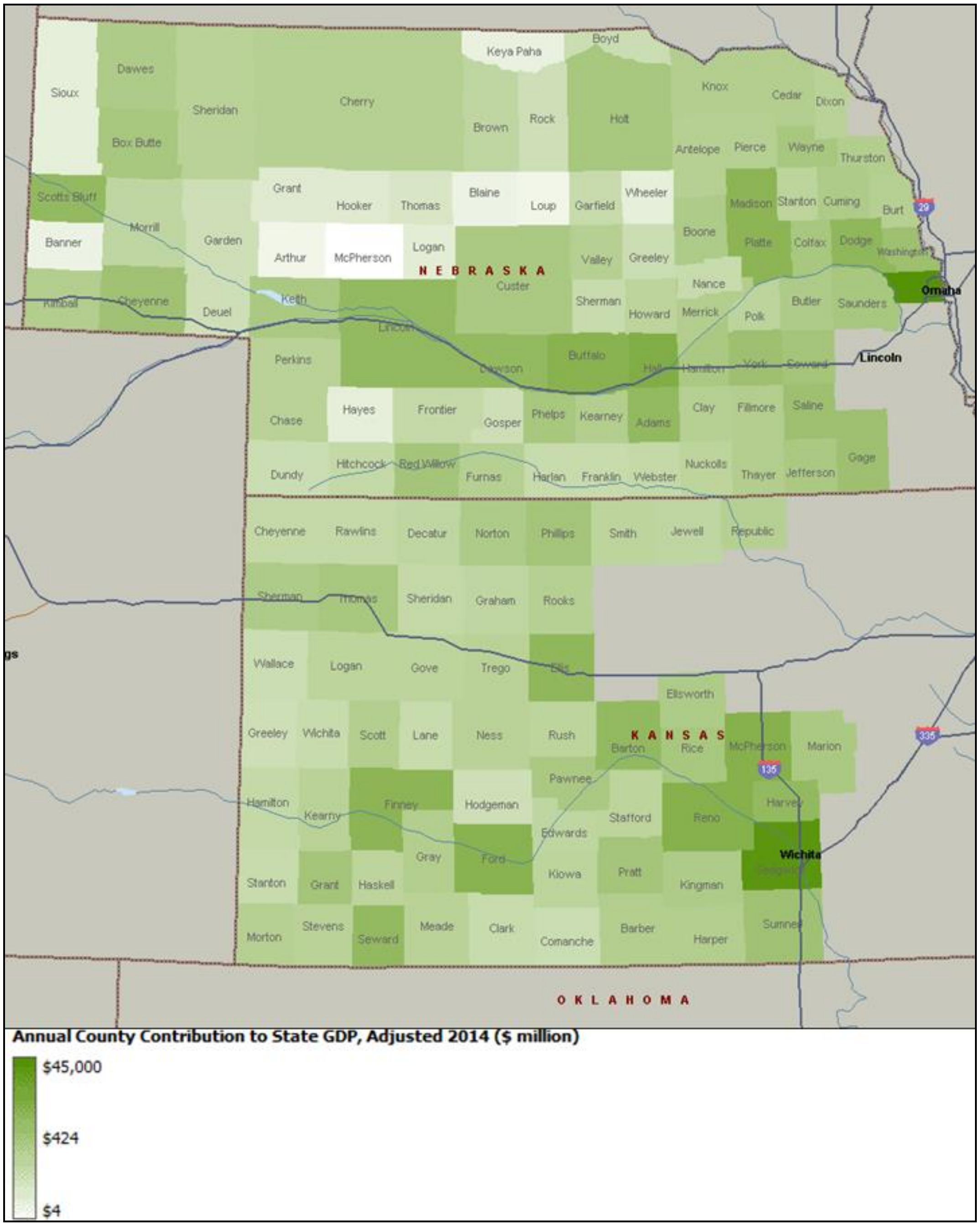

Figure 41—County Contribution to 2014 State Gross Domestic Product (GDP)

2013 GDP for Kansas was $144.1 billion with an average unemployment rate of 4.9% as of July 2014, which is an improvement from 7.5% in the summer of 2009.[97] Overall, as shown in Figure 42, the economy appears to be improving from the downturn of 2007 to 2009. The five largest industries by output at the two-digit North American Industrial Classification System (NAICS) level are: Wholesale Trade, Healthcare and Social Assistance, Real Estate and Rental Leasing, Manufacturing, and Government (local and Federal). Each of the five industries displays a positive growth trend with Manufacturing slightly more volatile or susceptible to negative growth. Manufacturing across the country is fairly anemic, and Kansas has seen similar trends.

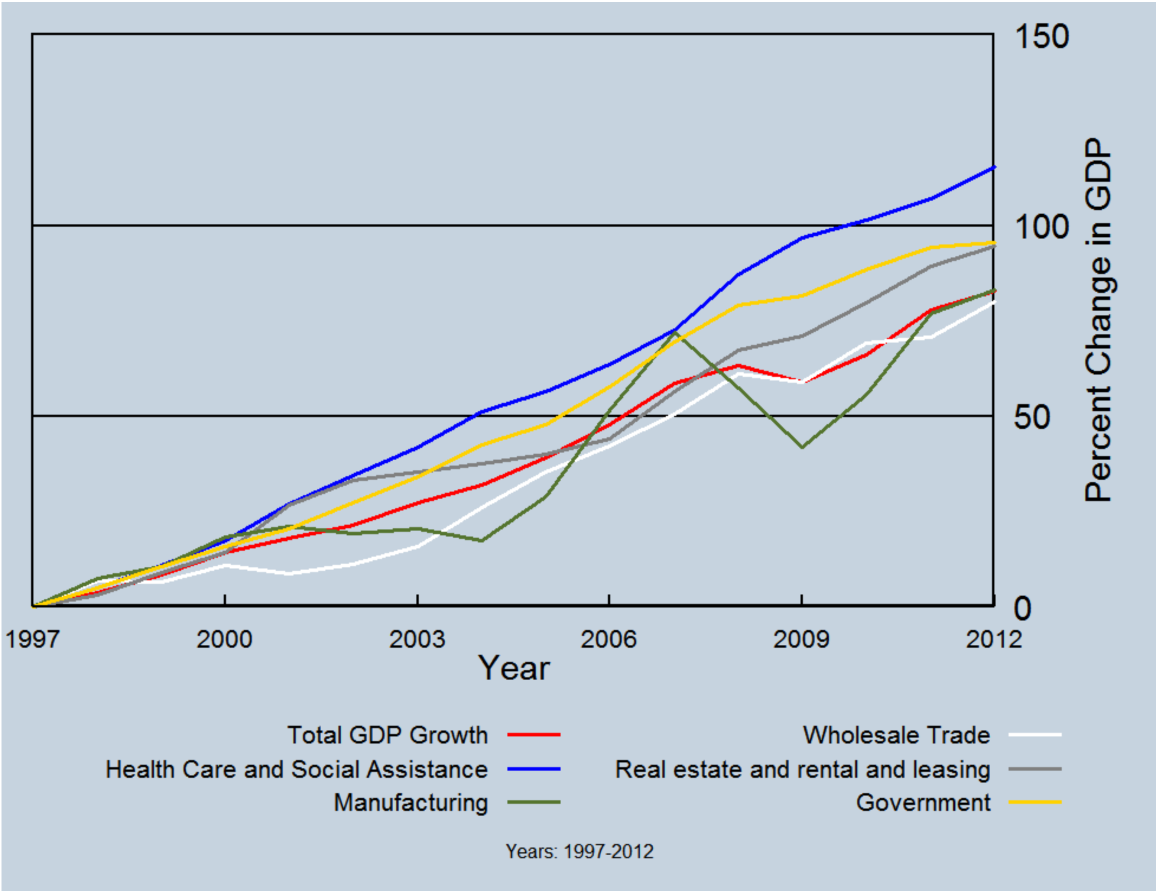

Figure 42—Leading Industry Output Trends in Kansas

Agriculture does not appear in the top five industries by output. This is to be expected given agricultural volumes are small in dollar value compared to other industries. Agriculture makes up less than 0.04% of state economic output, which can primarily be attributed to the low-dollar-value crops characteristic of Kansas farms. These crops include wheat, corn, sorghum, and soybeans. High-dollar-value crops include nut, citrus, and vegetable crops typically grown in locations such as California, Oregon, and Washington among others. Agricultural and farm output trends in Kansas are shown in Figure 43.

[97] Bureau of Labor Statistics. Kansas Economy at a Glance. http://www.bls.gov/eag/eag.ks.htm, October 1, 2014.

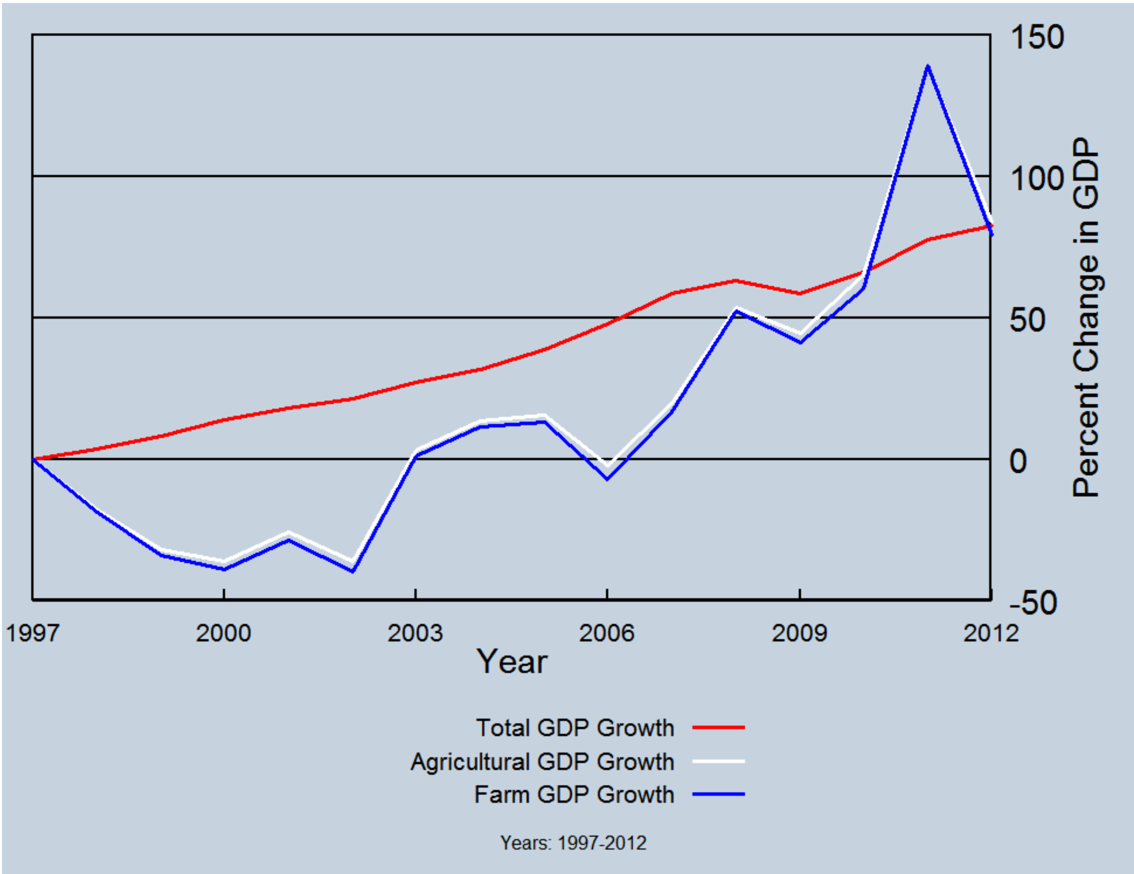

Figure 43—Agricultural and Farm Output Trends in Kansas

2013 GDP for Nebraska was $109.6 billion.[98] Output in Nebraska has been growing at a rate exceeding the national average.[99] As of July 2014, Nebraska's unemployment rate was 3.6%. During the most recent recession (18 months spanning December 2007 to September 2009),[100] Nebraska only experienced a minor bump in unemployment, reaching 4.9% in late 2009. Overall, during the recessionary period, the agricultural sector outperformed the broader state economy in terms of industry output (see Figure 44). The five largest industries in Nebraska (in terms of output) are Government (local and Federal), Manufacturing, Agriculture, Real Estate and Rental Leasing, and Finance. The Agricultural industry has grown by 256% since 2004, with less substantial gains in all other industries for that time. In all, Nebraska's GDP grew 216% since 1997, averaging 5% growth per year.

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[98] Bureau of Economic Analysis. Industry Data. http://www.bea.gov/iTable/iTable.cfm?ReqID=51&step=1#reqid=51&step=2&isuri=1, October 1, 2014.
[99] JPMorgan Chase & Co., 2013
[100] NBER. Business Cycle Dating Committee of the National Bureau of Economic Research. http://www.nber.org/cycles/sept2010.pdf, accessed March 18, 2015.

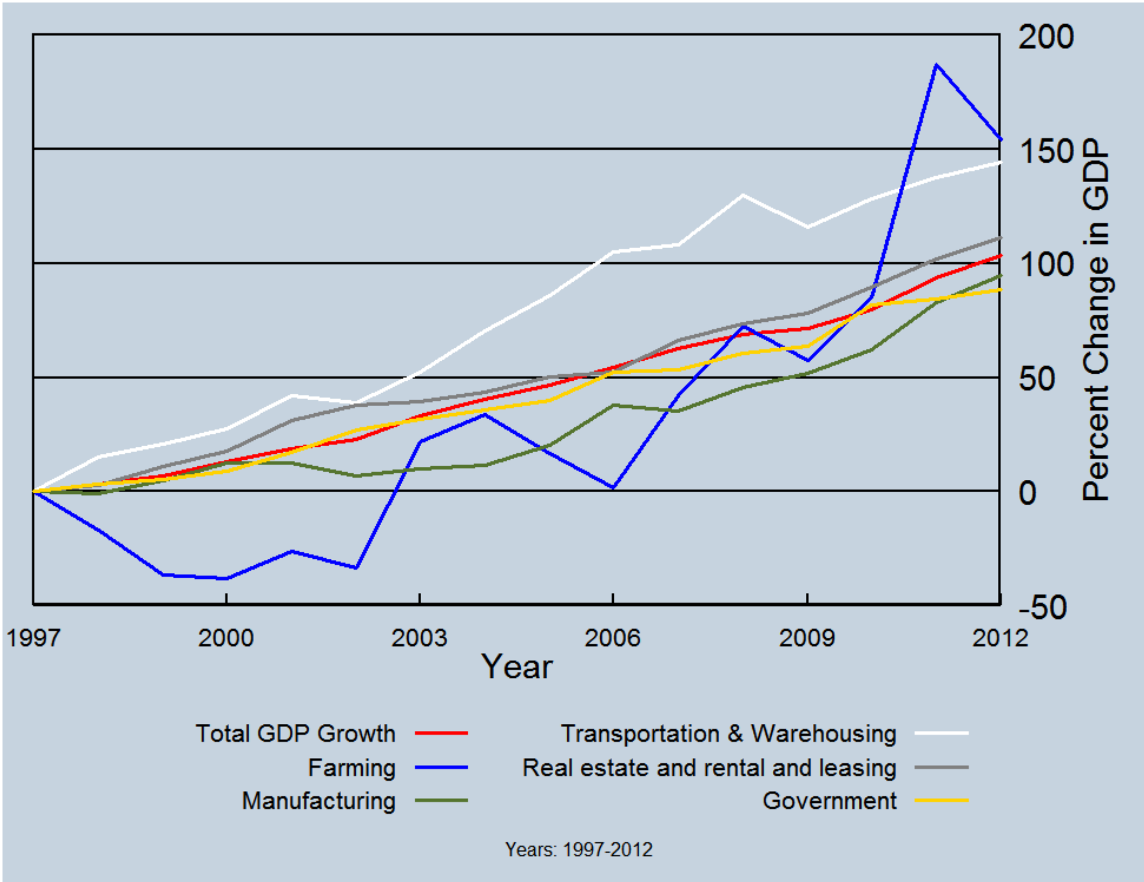

Figure 44—Leading Industry Output Trends in Nebraska

Nebraska agriculture is robust, but accounts for only 1.8% of employment. The rest of Nebraska's economy is service oriented with 848,000 service-industry jobs (86%) compared to 138,000 manufacturing positions (14%). Despite historic employment growth in agriculture, the Nebraska Department of Labor expects crop and animal production employment to decrease by 11-15% by 2022, while services and manufacturing employment is expected to grow. Agricultural and farm output trends in Nebraska are shown in Figure 45.

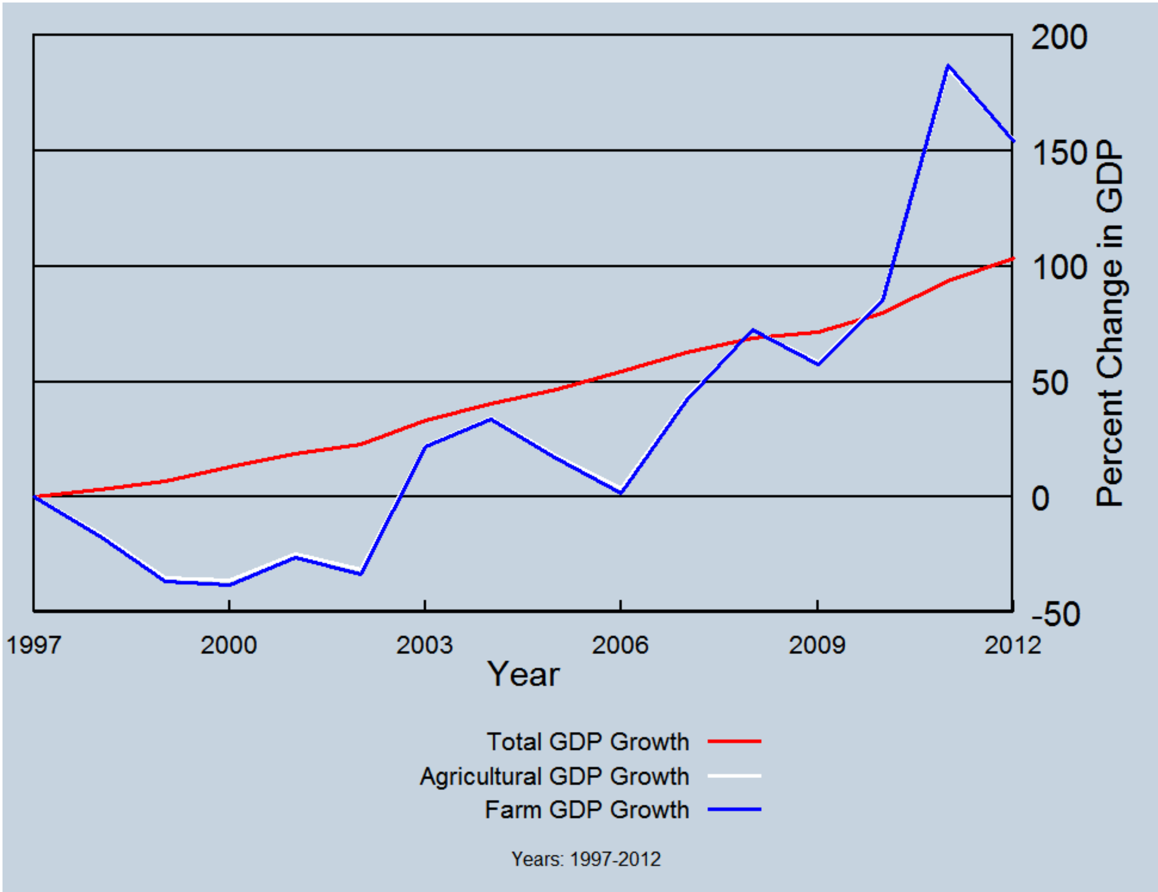

Figure 45—Agricultural and Farm Output Trends in Nebraska

Agricultural industry in Kansas and Nebraska is labeled the "Primary Leading Industry" since many of the other industries growing over the 1997 to 2012 timeframe can be linked to the Agricultural industry. Wholesale Trade and Manufacturing (includes food processing) in Kansas, and Transportation and Warehousing, and Manufacturing in Nebraska, which are related to the selling, storing and transportation, and manufacturing of agriculturally produced goods.

2.5.4.1 Industry Exposure to Resource Risk

We use state and county-level data to determine the dominant industries over the affected counties in Kansas and Nebraska. We look at the data from four perspectives determined by two methods of analysis and two criteria. First, we look at how frequently particular industries are dominant in each county for a given state; industries are dominant if they occupy the greatest share either of employment or of productivity, which we measure via wages paid. Next, we look at the industries' employment and wages shares across the entire affected area. Together, these analyses measure industries' centrality and universality by two intuitive criteria. The conclusions that follow may be useful in determining the future impacts of the resource risk or of other hazards, acute or chronic. The following section provides a more detailed look at the economic foundations of counties by state that rely on the High Plains Aquifer. Figure 46 shows the dominant industry for each county in the analysis area within Kansas while Figure 47 shows the same data with Government excluded. Figure 48 and Figure 49 show the same values for Nebraska.

When state and local government are excluded as a category from the Dominant Industry Maps, the importance of Agriculture and other industries connected to agriculture is immediately apparent. These industries include Chemical Products, Wholesale Trade, Retail Trade, Food and Beverage and Tobacco, and Manufacturing Sectors. The related figure captures the highest value-added contributor to state GDP within each county, but do not control for the intensity of leading industry dominance. In other words, the sum of each county's leading industry should not be considered to be representative of the entire state.

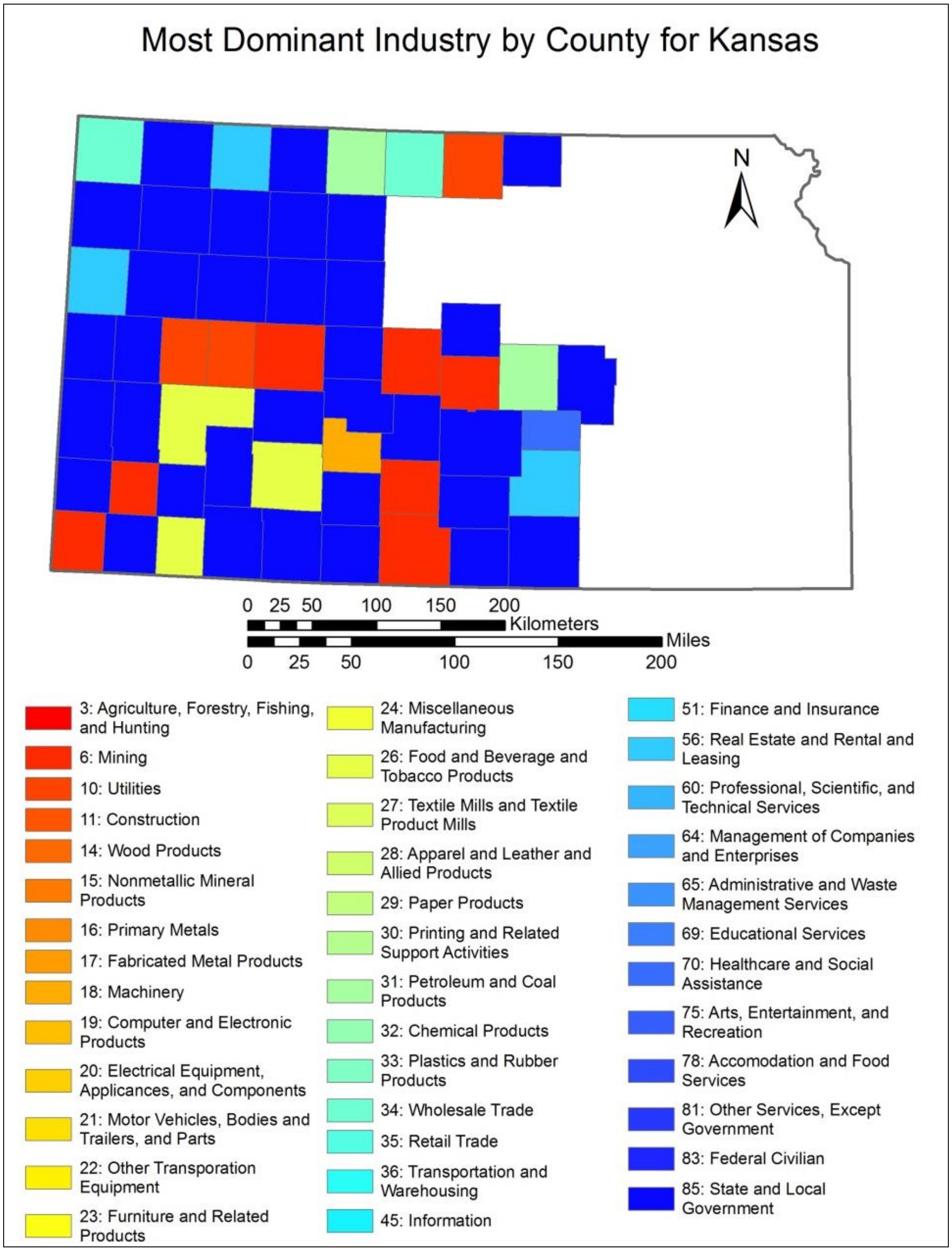

Figure 46—Kansas Counties by Dominant Industry

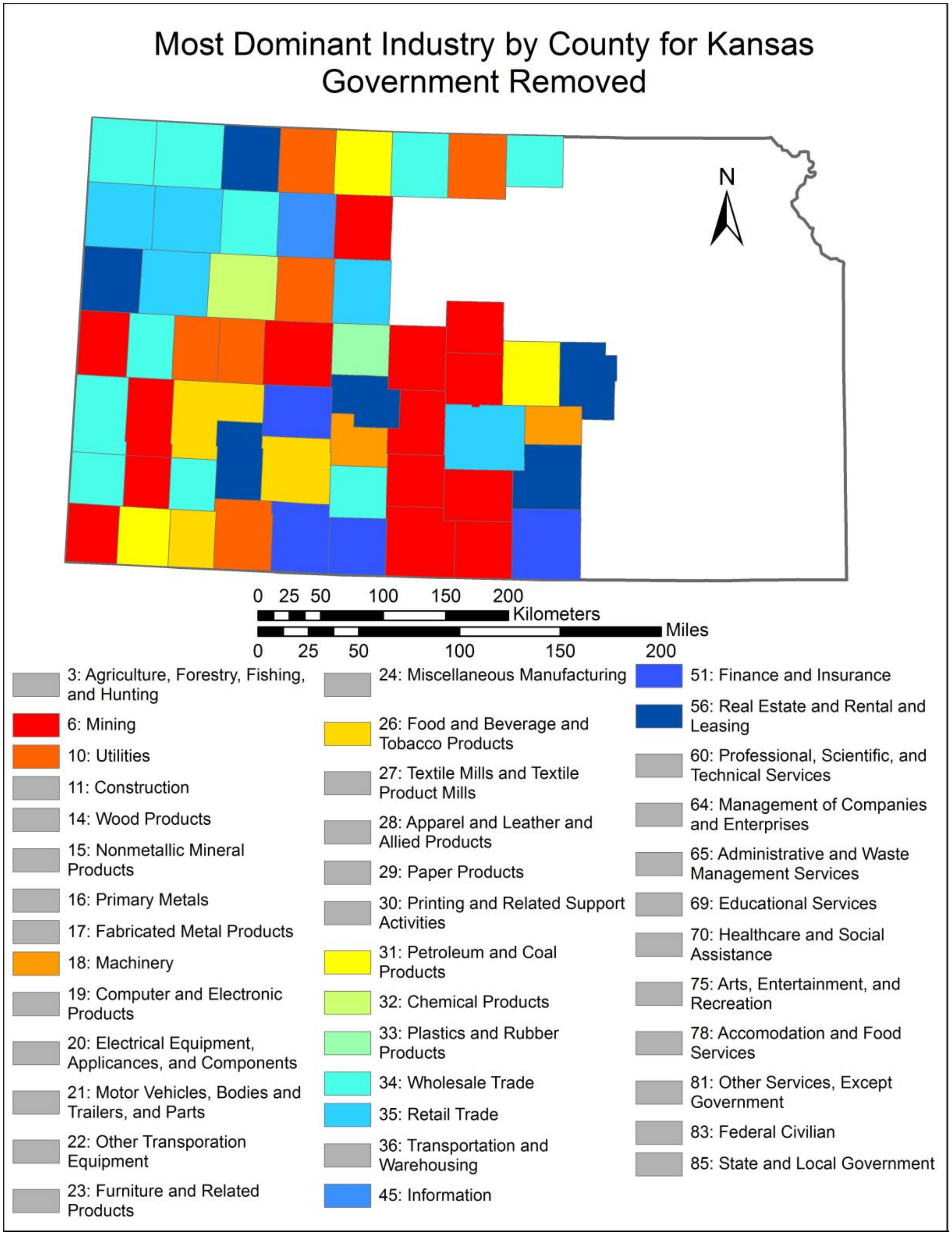

Figure 47—Kansas Counties by Dominant Industry, Excluding Government

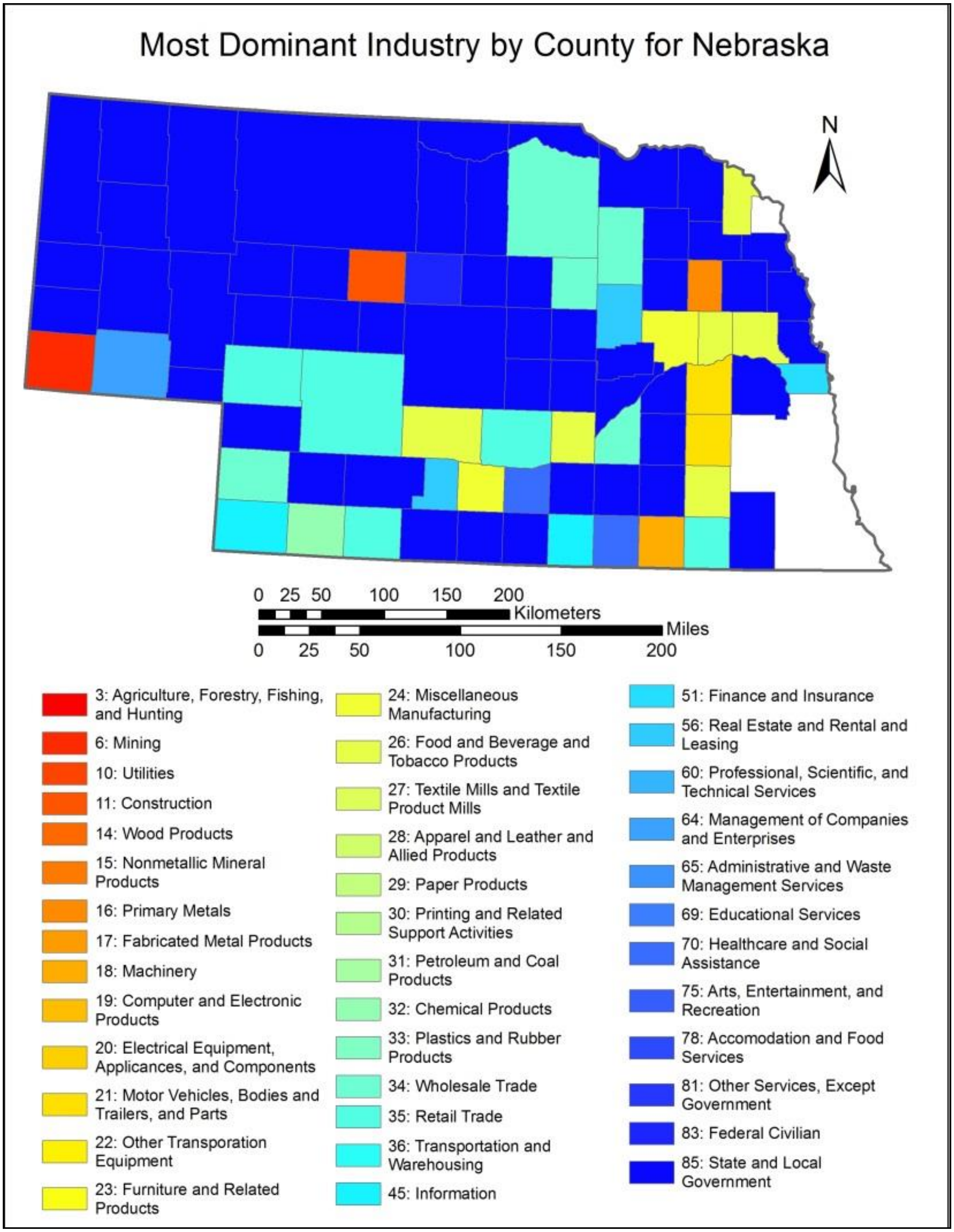

Figure 48—Nebraska Counties by Dominant Industry

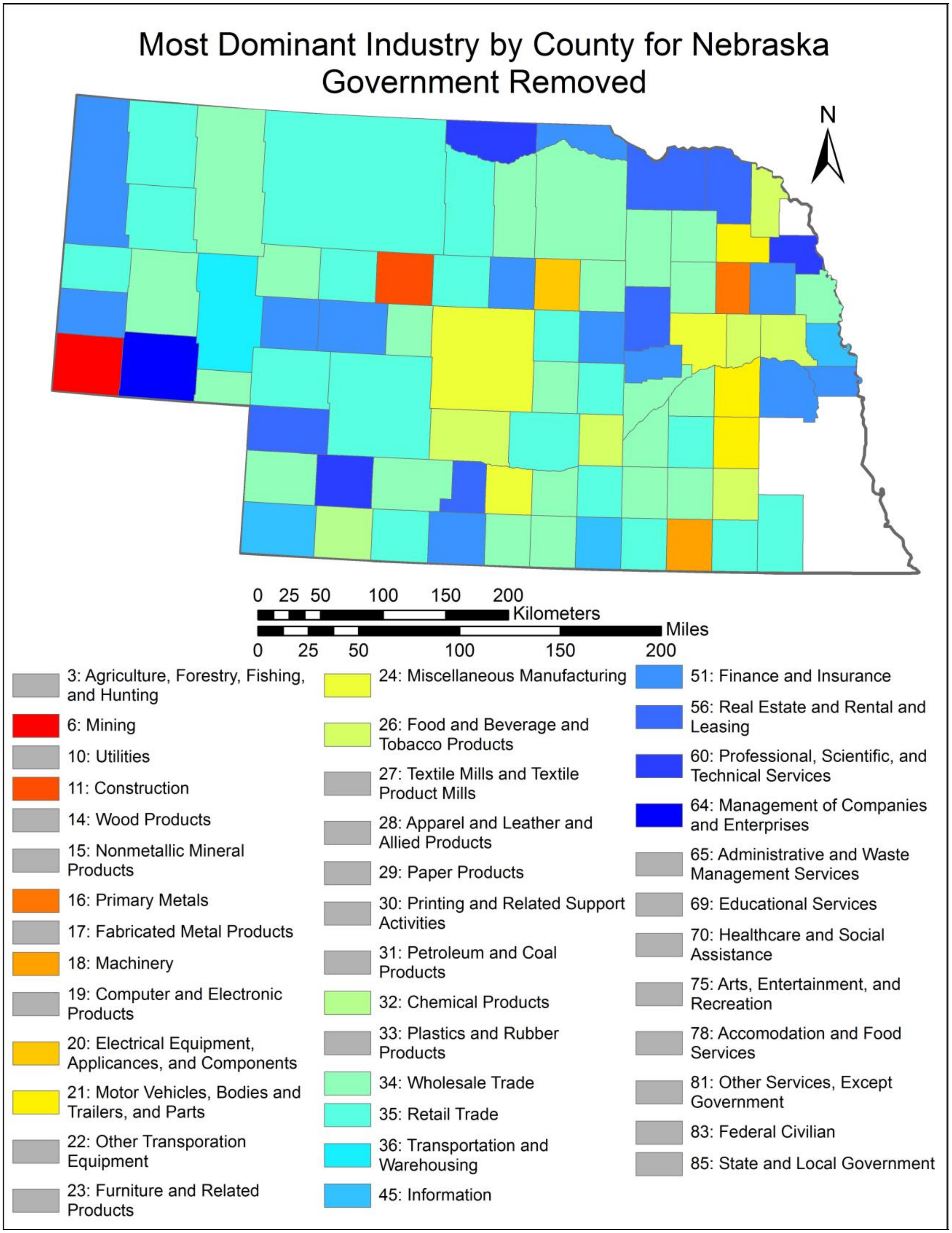

Figure 49—Nebraska Counties by Dominant Industry Sectors, Excluding Government

2.5.4.2 Commodities by Origin and Destination

The commodities originating in Kansas are approximated from the 2007 Commodity Flow Survey (CFS). All commodities are presented in dollars (adjusted 2014). The destinations for commodities listed in Figure 50 and Figure 58 are states, but destinations can be cities or metropolitan statistical areas within the United States. Commodities with the largest contributions by dollar value are Transportation Equipment; Meat, Fish, Seafood and their Preparations; and Mixed Freight. Leading commodities by volume are Cereal Grains, Gravel and Crushed Stone, and Natural Sands.

According to the CFS conducted in 2007, Kansas shipped commodities approximately valuing $104 billion to all U.S. States, with Kansas internalizing approximately 43% of the valued commodities.[101] Excluding Kansas, commodities valued at approximately $59 billion are destined for all U.S. States.[102] The distribution of shipped commodities is mapped for the 48 contiguous states and Washington D.C. in Figure 51 to Figure 58. The graphics below are meant to provide a high-level understanding of the various destinations of all commodities originating in Kansas, with the lowest values associated with darker shades of green and, as value increases, the colors on the map go from green to red. Comparing across heat maps, it is clear that Kansas (often shaded the darkest red on many maps) is routinely a receiver of their own commodities, meaning these goods are either consumed in-state or receive further processing to become final goods for sale.

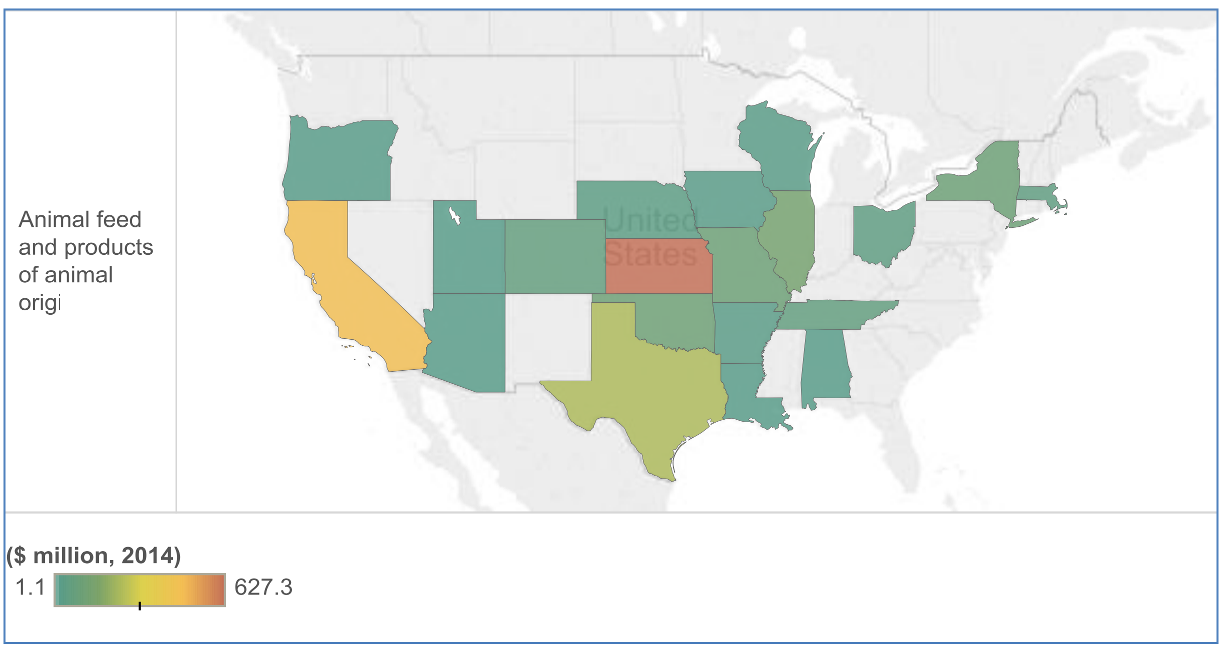

Figure 50—Commodity Shipments Originating in Kansas to All States: Animal Feed and Products of Animal Origin, 2007 CFS ($Million, Adjusted 2014)[103]

[101] Adjusted 2014 dollars.
[102] Adjusted 2014 dollars.
[103] Source: 2007 Commodity Flow Survey; Shipment Characteristics by Two-Digit SCTG (Standard Classification of Transported Goods) Commodity for Geographic Area of Origin by Destination: 2007; Estimates are based on data from the 2007 Commodity Flow Survey.

Animal Feed and Products of Animal Origin, by value, are mostly destined for other industry sectors within Kansas ($627 million) for either consumption or further processing. The next three destinations by value are: California ($470 million), Texas ($239 million), and Illinois ($126 million).

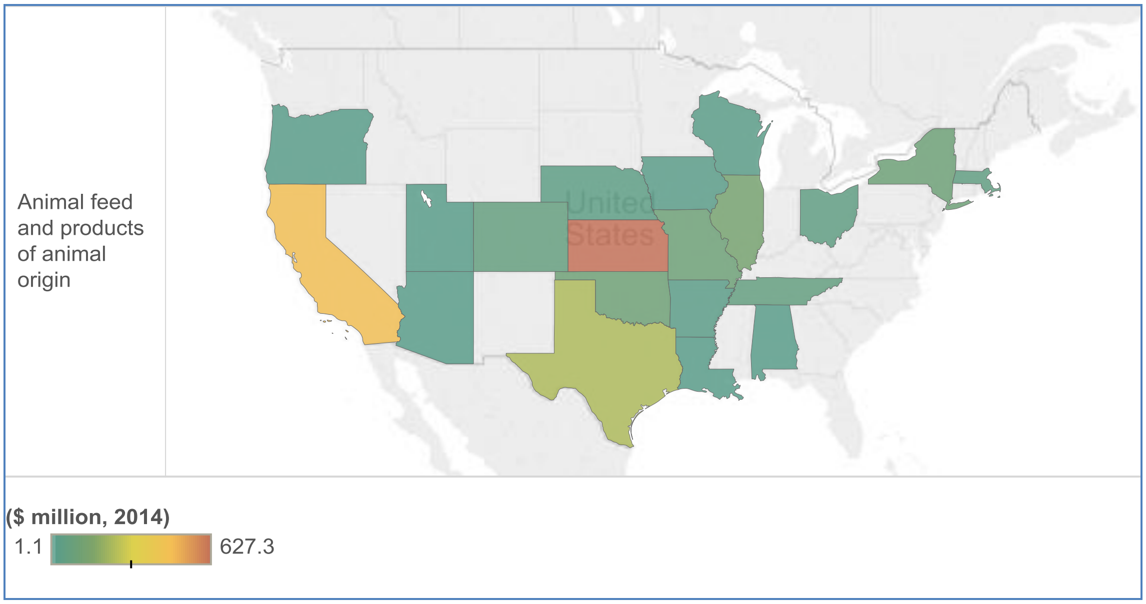

Figure 51—Commodity Shipments Originating in Kansas to All States: Animal Feed and Products of Animal Origin, 2007 CFS ($Million, Adjusted 2014)[104]

According the 2012 CFS data, Animal Feed and Products of Animal Origin are currently shipped to more states than in 2007. As shown in 2007, Animal Feed and Products of Animal Origin, by value, for 2012 again mostly stay within Kansas ($1.3 billion) for either consumption or further processing. The next three destinations by value are: California ($140 million), Indiana ($136 million), and Florida ($117 million). Shown in Figure 52, with expanded geographical territory for commodity shipments, the value by dollar is less concentrated in just a few states as shown in Figure 53. When comparing 2007 to 2012, it is of interest to note the amount of Animal Feed and Products of Animal Origin, by dollar value, that now remain within Kansas.

[104] Source: 2007 Commodity Flow Survey; Shipment Characteristics by Two-Digit SCTG Commodity for Geographic Area of Origin by Destination: 2007; Estimates are based on data from the 2007 Commodity Flow Survey.

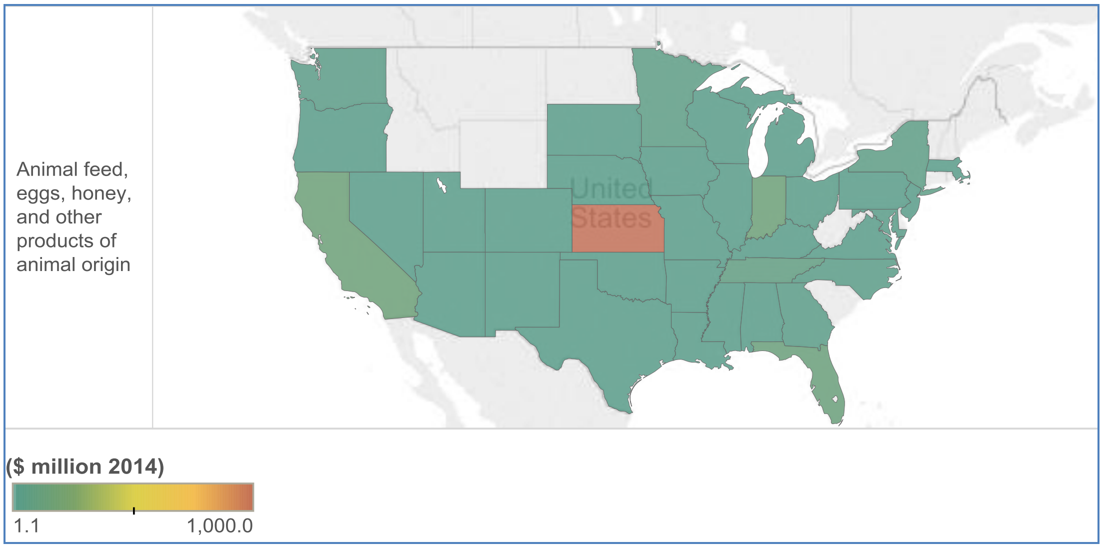

Figure 52—Commodity Shipments Originating in Kansas to All States: Animal Feed and Products of Animal Origin, 2012 CFS ($Million, Adjusted 2014)[105]

Articles of Base Metal reported for the 2007 CFS, shown in Figure 53, and Machinery, shown in Figure 54, have a more extensive geographical footprint than most other commodities, although not the highest value. Articles of Base Metal commodity shipment values ranges from approximately $1 million (South Dakota) to $360 million (Texas), excluding Kansas, which is the single largest receiver by value.

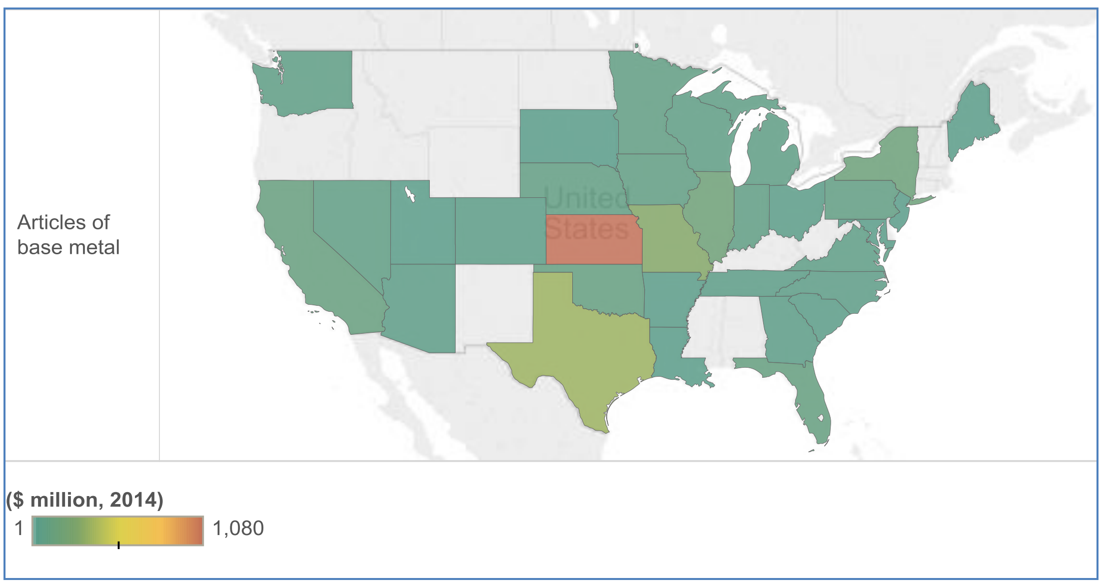

Figure 53—Commodity Shipments Originating in Kansas to All States: Articles of Base Metal, 2007 CFS ($Million, Adjusted 2014)[106]

[105] Source: 2007 Commodity Flow Survey; Shipment Characteristics by Two-Digit SCTG Commodity for Geographic Area of Origin by Destination: 2007; Estimates are based on data from the 2007 Commodity Flow Survey.
[106] Source: 2007 Commodity Flow Survey; Shipment Characteristics by Two-Digit SCTG Commodity for Geographic Area of Origin by Destination: 2007; Estimates are based on data from the 2007 Commodity Flow Survey.

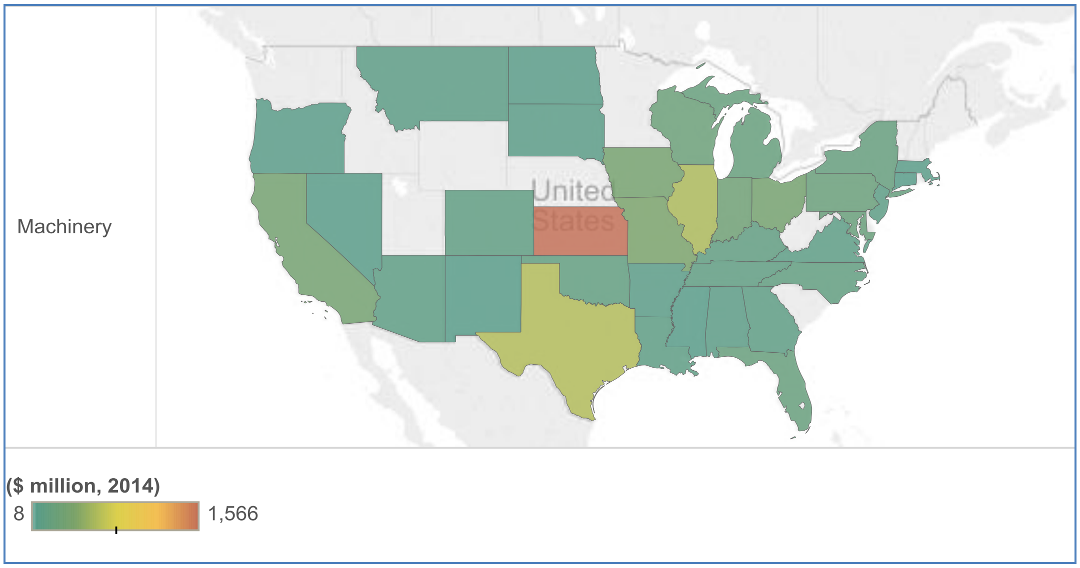

Figure 54—Commodity Shipments Originating in Kansas to All States: Machinery, 2007 CFS ($Million, Adjusted 2014)[107]

Between the 2007 and 2012 CFS reporting period, Kansas dramatically increased shipment of Articles of Base Metal to all States (Figure 55), and Machinery (Figure 56) has a more extensive geographical footprint than most other commodities, although still not the highest value of all commodities for the 2012 CFS. Articles of Base Metal commodity shipment values from Kansas range from approximately $2 billion (within Kansas) to approximately $3 million (to South Carolina). Nationally, the value of shipments for Machinery from Kansas range from approximately $1.7 billion (to Texas) to approximately $ 28 million (to Oregon). Kansas retains approximately $6.6 billion in valued shipments of Machinery.

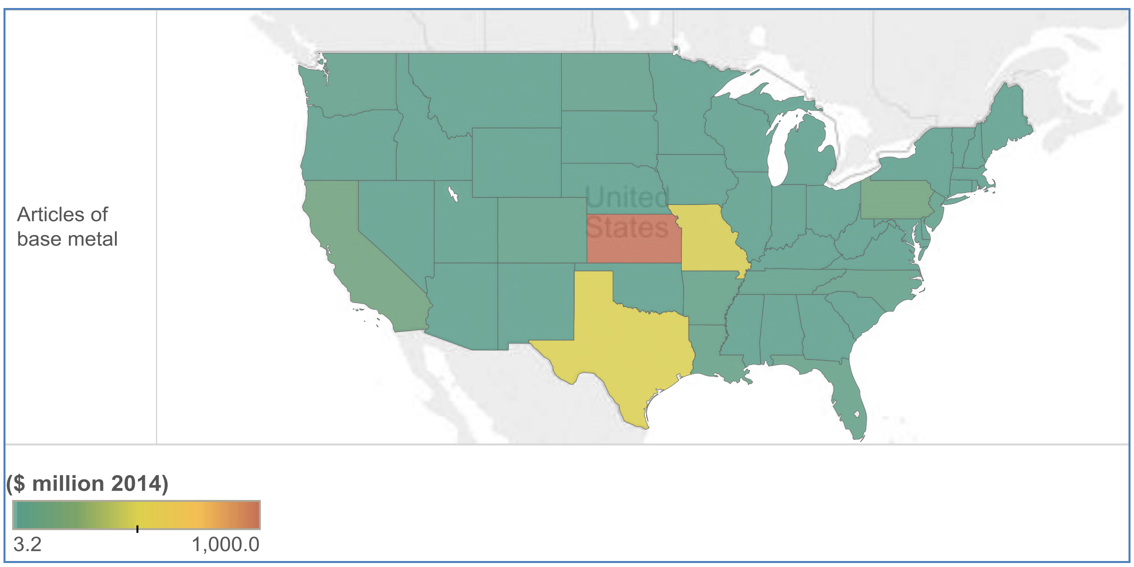

Figure 55—Commodity Shipments Originating in Kansas to All States: Articles of Base Metal, 2012 CFS ($Million, Adjusted 2014)[108]

[107] Source: 2007 Commodity Flow Survey; Shipment Characteristics by Two-Digit SCTG Commodity for Geographic Area of Origin by Destination: 2007; Estimates are based on data from the 2007 Commodity Flow Survey.

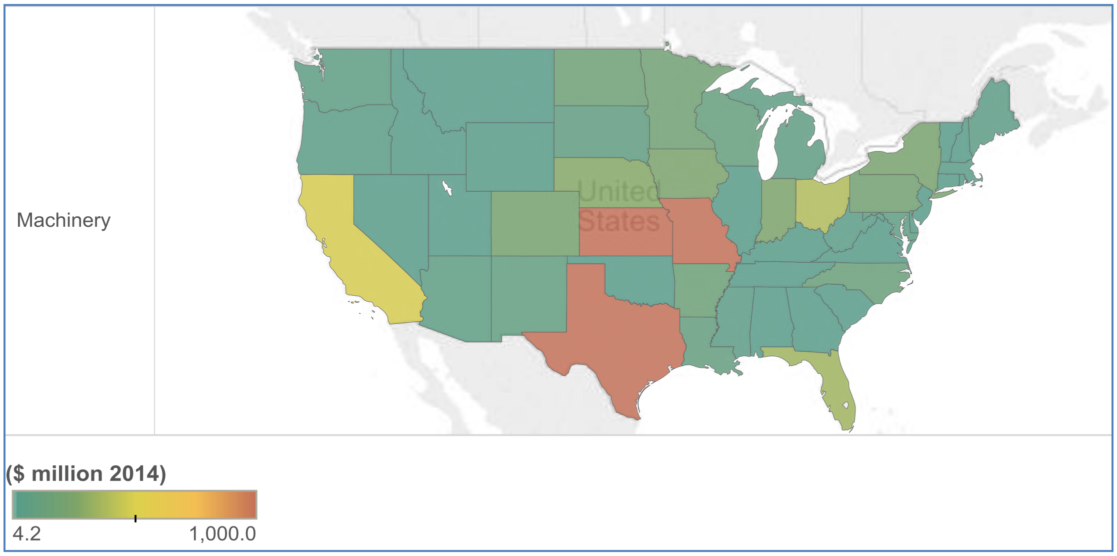

Figure 56—Commodity Shipments Originating in Kansas to All States: Machinery, 2012 CFS ($Million, Adjusted 2014)[109]

A consistently high value of shipped commodities is Meat, Fish, Seafood and their Preparations (Figure 57) to all U.S. states with values ranging from approximately $2 million to $1.3 billion. Excluding Kansas the largest recipients of Kansas Meat, Fish, Seafood and their Preparations are: California ($1.2 billion), Texas ($1.1 billion), and Illinois ($897 million).

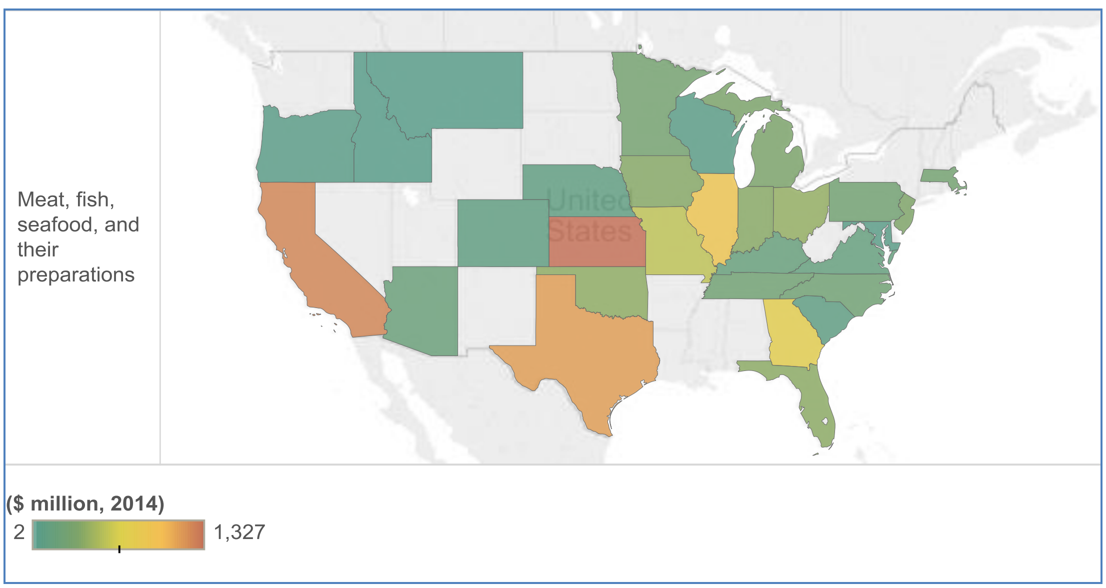

Figure 57—Commodity Shipments Originating in Kansas to All States: Meat, Fish, Seafood, and their Preparations, 2007 CFS ($Million)[110]

[108] Source: 2007 Commodity Flow Survey; Shipment Characteristics by Two-Digit SCTG Commodity for Geographic Area of Origin by Destination: 2007; Estimates are based on data from the 2007 Commodity Flow Survey.
[109] Source: 2007 Commodity Flow Survey; Shipment Characteristics by Two-Digit SCTG Commodity for Geographic Area of Origin by Destination: 2007; Estimates are based on data from the 2007 Commodity Flow Survey.

In 2012, CFS Meat, Fish, Seafood and their Preparations (Figure 58) remained a high-value commodity with extensive geographic coverage. Shipped values from Kansas ranged from approximately $2 million (to Montana) to $2 billion (to Texas). In the 2012 CFS, Kansas was no longer the largest recipient of its own Meat, Fish, Seafood and their Preparations; the largest recipient by dollar value was Texas (Figure 58).

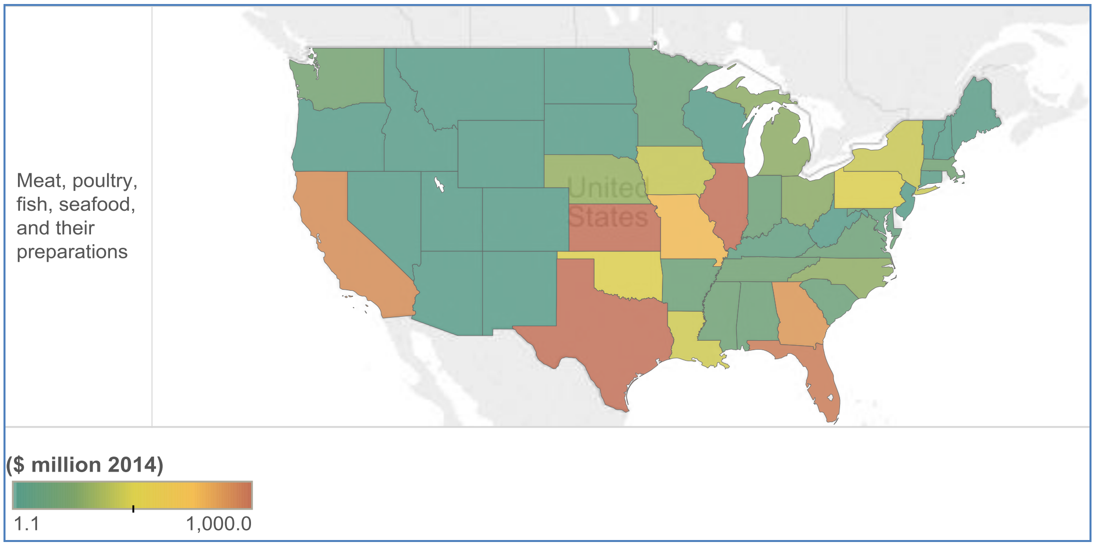

Figure 58—Commodity Shipments Originating in Kansas to All States: Meat, Fish, Seafood, and their Preparations, 2012 CFS ($Million, adjusted 2014)[111]

The commodities originating in Nebraska and shipped to all states approximated, by value, from the 2007 and 2012 CFS are shown in Figures 59 through 65). All commodities values are adjusted for 2014 dollars. By dollar value for the year 2007, the largest commodity shipments are: Meat, Fish, Seafood and their Preparations; Other Prepared Foodstuffs; and Cereal Grains. For the year 2012, the largest value commodity shipments were: Meat, Fish, Seafood and their Preparations, Cereal Grains, and Machinery. Between the years 2007 and 2012, the value of all commodity shipments increased by approximately $34 billion. For all commodities originating in Nebraska, the dollar values increased.

A closer look at a select set of agriculture-related commodities further supports the trend of increasing agriculture and farm production in Nebraska. By dollar value, “meat” has dramatically increased since 2002 (all dollars adjusted to 2014). Overall, this is signally increasing economic reliance on the agriculture industry.

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[110] Source: 2007 Commodity Flow Survey; Shipment Characteristics by Two-Digit SCTG Commodity for Geographic Area of Origin by Destination: 2007; Estimates are based on data from the 2007 Commodity Flow Survey.
[111] Source: 2007 Commodity Flow Survey; Shipment Characteristics by Two-Digit SCTG Commodity for Geographic Area of Origin by Destination: 2007; Estimates are based on data from the 2007 Commodity Flow Survey

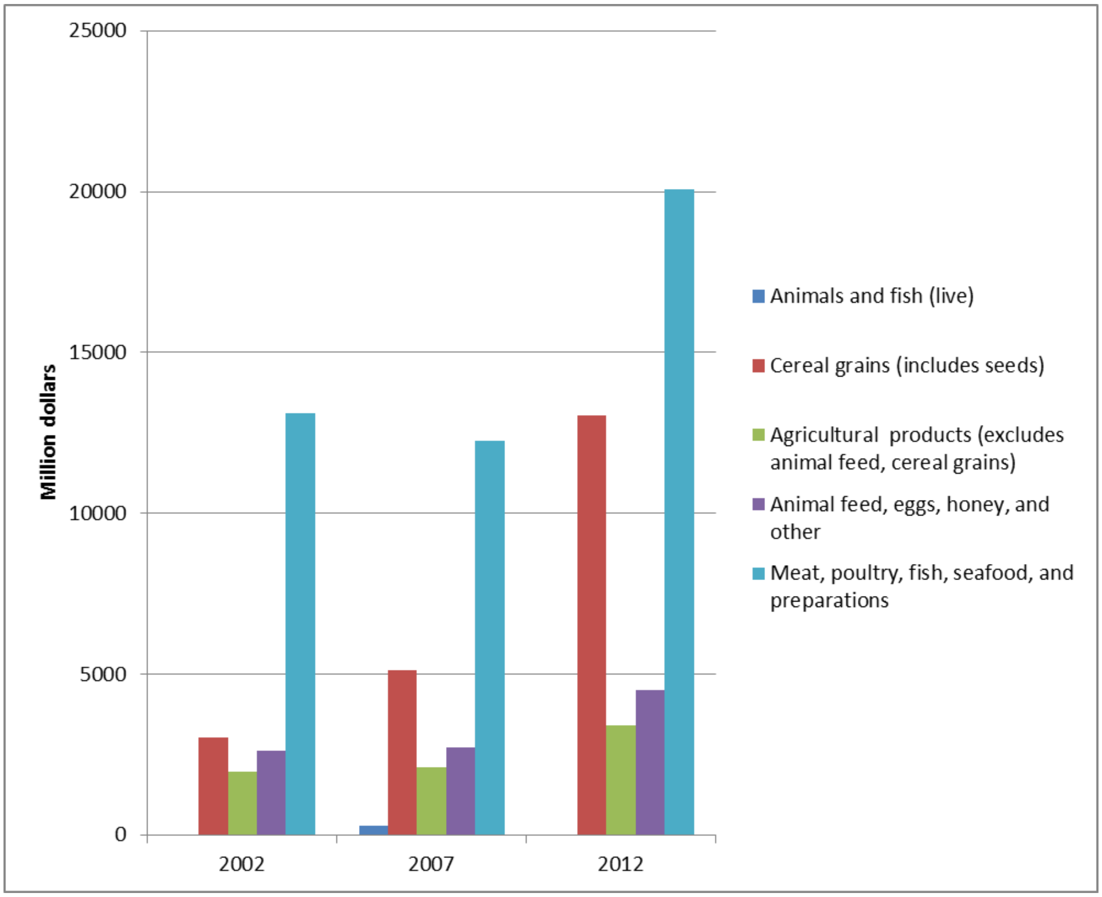

Figure 59—Value of Select Agriculture-Related Commodities Originating in Nebraska, 2002 to 2012 CFS

Nebraska shipped approximately $132 billion for the goods mapped in Figure 64 and Figure 65, removing Nebraska value of shipped commodities is approximately $89 billion.[112] [113] Nebraska itself is a destination for Nebraska commodities (shipments originating in Nebraska and staying in Nebraska). States that are routinely in receipt of Nebraska commodities are: California, Florida, Texas, and Washington, (California appears in nearly every heat map in Figure 59 to Figure 64). Although variant in population, these states are home to major U.S. shipping ports: Port of Long Beach, Port of Los Angeles, Port of Oakland, Port of Houston, and Port of Seattle. It can be assumed that not only are these states consuming commodity shipments, they also likely facilitate export of Nebraska commodities. For example, many grains exit the United States through the ports of Seattle and Tacoma on their way to Asian markets.

According to the 2007 CFS, the commodities with the most extensive geographical footprint are Animal Feed and Products of Animal Origin, as shown in Figure 60. Animal Feed and Products of Animal Origin value of shipments range from approximately $10 million to $831 million, with Nebraska itself the primary destination. Shipments to destinations outside of Nebraska include California ($1.1 billion), Illinois ($1.3 billion), Texas ($1.5 billion), and Washington ($728 million). The states listed also house some of the largest seaports in the Nation, and it can be inferred that some portion of these commodity shipments are destined for export.

[112] Adjusted for 2014 dollars.
[113] Adjusted for 2014 dollars.

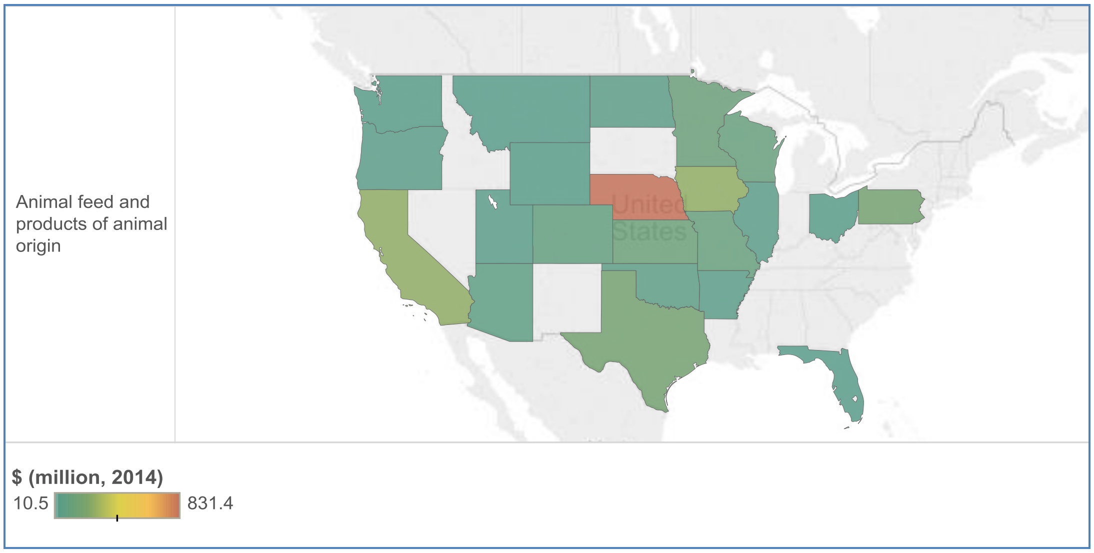

Figure 60—Commodities Shipments Originating in Nebraska to All States: Animal Feed and Products of Animal Origin, 2007 CFS ($Million)[114]

According to the 2012 CFS, shipments of Animal Feed and Products of Animal Origin (Figure 61) increased by value and geographic extent. Animal Feed and Products of Animal Origin value of shipments range from approximately $4 million shipped to North Carolina (additional receiving states have values too low to report) to approximately $418 million shipped to Texas. Nebraska is the primary destination of commodity shipments by dollar value at approximately $1.7 billion.

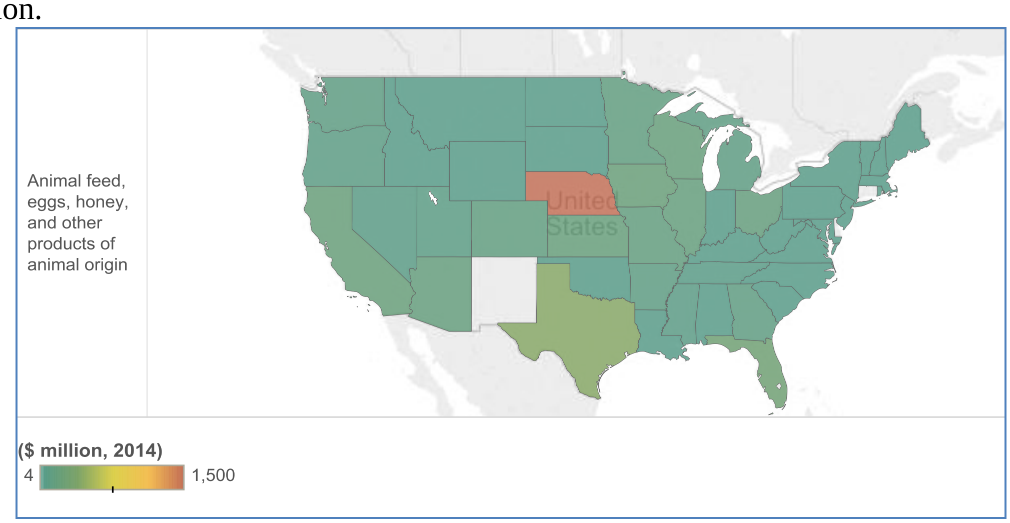

Figure 61—Commodities Shipments Originating in Nebraska to All States: Animal Feed and Products of Animal Origin, 2012 CFS ($Million, Adjusted 2012)[115]

[114] Source: 2007 Commodity Flow Survey; Shipment Characteristics by Two-Digit SCTG Commodity for Geographic Area of Origin by Destination: 2007; Estimates are based on data from the 2007 Commodity Flow Survey.

[115] Source: 2007 Commodity Flow Survey; Shipment Characteristics by Two-Digit SCTG Commodity for Geographic Area of Origin by Destination: 2007; Estimates are based on data from the 2007 Commodity Flow Survey.

For Meat, Fish, Seafood, and their Preparations (Figure 62), commodity shipments recorded in the 2007 CFS to destinations outside of Nebraska include California ($1.1 billion), Illinois ($1.3 billion), Texas ($1.5 billion), and Washington ($728 million).

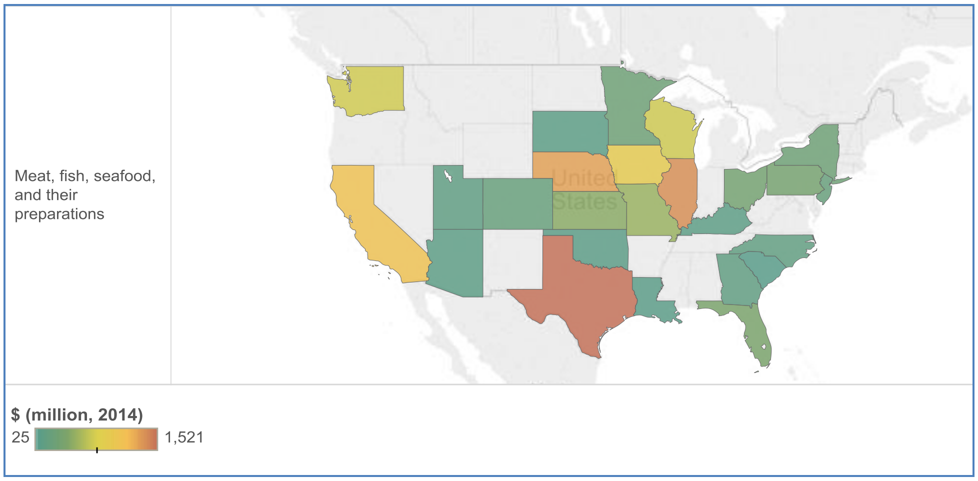

Figure 62—Commodities Shipments Originating in Kansas to All States: Meat, Fish, Seafood, and their Preparations, 2007 CFS ($Million)[116]

Reporting for the 2012 CFS shows increased geographical distribution for Meat, Fish, Seafood, and their Preparations commodity shipments (Figure 63). For commodity shipments with destinations outside of Nebraska, values ranged from approximately $15 million for Arkansas (with some values too low to be reported by state) to approximately $2.8 billion for Illinois. Nebraska itself retains approximately $2.9 billion of Meat, Fish, Seafood, and their Preparations commodity shipments.

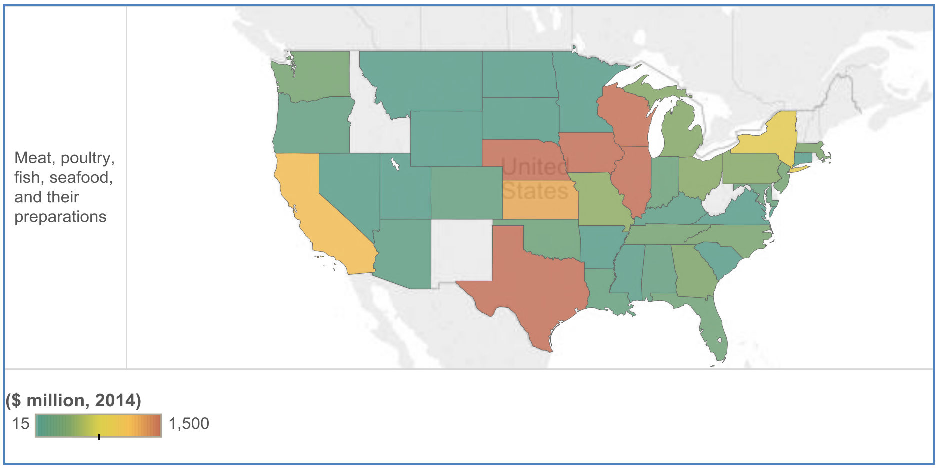

Figure 63—Commodities Shipments Originating in Kansas to All States: Meat, Fish, Seafood, and their Preparations, 2012 CFS ($Million, Adjusted 2014)[117]

[116] Source: 2007 Commodity Flow Survey; Shipment Characteristics by Two-Digit SCTG Commodity for Geographic Area of Origin by Destination: 2007; Estimates are based on data from the 2007 Commodity Flow Survey.

[117] Source: 2007 Commodity Flow Survey; Shipment Characteristics by Two-Digit SCTG Commodity for Geographic Area of Origin by Destination: 2007; Estimates are based on data from the 2007 Commodity Flow Survey.

Another commodity group with an extensive geographical footprint for the 2007 CFS is Plastics and Rubbers, as seen in Figure 64. The value of external shipments range from approximately $8 million (Mississippi) to $92 million (California), and similar to Meat, Fish, Seafood, and their Preparations, Nebraska itself receives the largest value of Plastics and Rubbers shipments ($1.1 billion). At the time of the 2012 CFS (Figure 65) reporting, these goods were now shipped to all states, although with some values were too small to report. For the 2012 CFS, the value of commodity shipments range from approximately $1 million (Nevada) to approximately $143 million (Iowa).

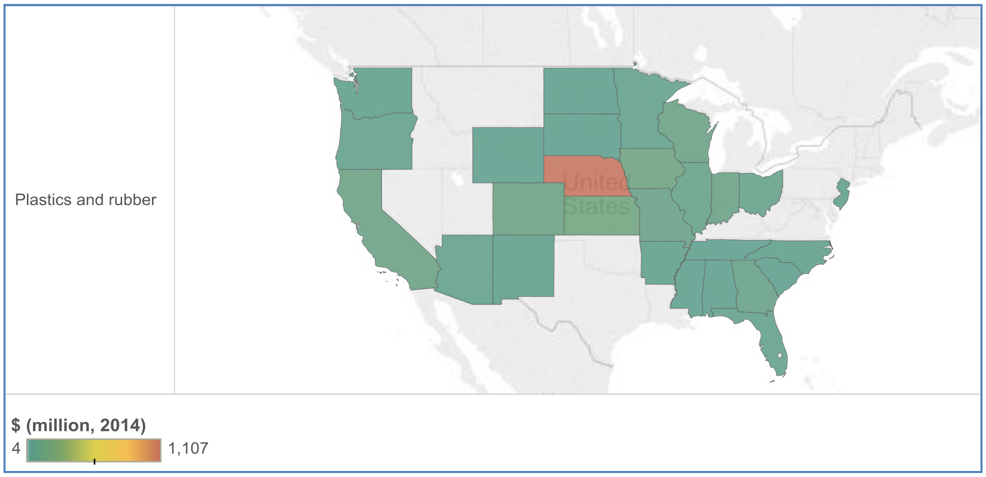

Figure 64—Commodities Shipments Originating in Nebraska to All States: Plastics and Rubber, 2007 CFS ($Million)[118]

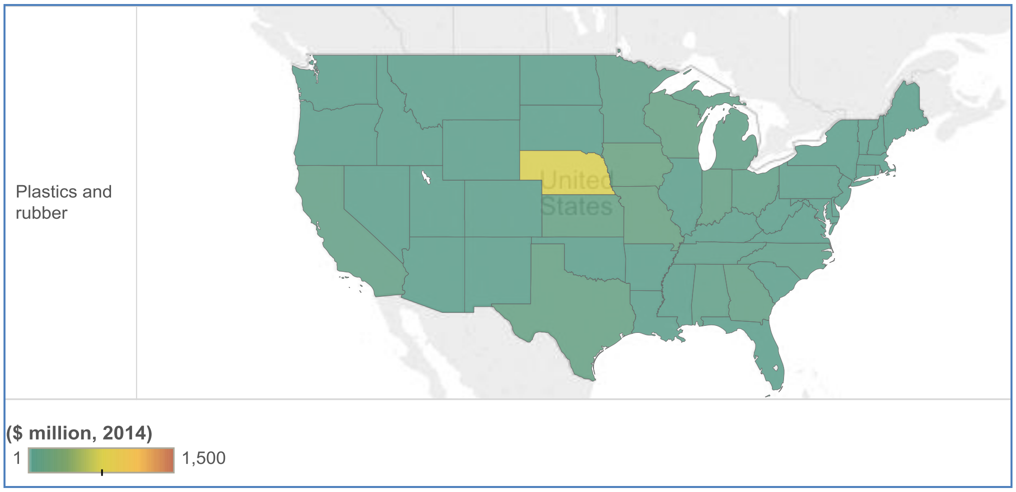

Figure 65—Commodities Shipments Originating in Nebraska to All States: Plastics and Rubber, 2012 CFS ($Million, adjusted 2014)[119]

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[118] Source: 2007 Commodity Flow Survey; Shipment Characteristics by Two-Digit SCTG Commodity for Geographic Area of Origin by Destination: 2007; Estimates are based on data from the 2007 Commodity Flow Survey.

[119] Source: 2007 Commodity Flow Survey; Shipment Characteristics by Two-Digit SCTG Commodity for Geographic Area of Origin by Destination: 2007; Estimates are based on data from the 2007 Commodity Flow Survey.

Overall, between the 2007 and 2012 CFS reporting period, commodity shipments by value and volume from Kansas and Nebraska increased. Both states increased the geographical reach of their commodity shipments. The value of shipments in the 2012 CFS was less concentrated in states with international seaports, and the dollar value of commodity shipments were not more uniformly distributed across many states. The commodities supplied by Kansas and Nebraska are delivered across the country with assumed downstream economic influence.

2.5.4.3 Farm and Non-Farm Employment by Industry Sector

Farming shows a trend of increasing employment for all years for both Kansas and Nebraska, has displayed the overall largest gains in Kansas, and is the second leading (in terms of employment growth) industry in Nebraska. As of 2011, the Retail Trade industry had yet to recover the employment losses experienced during the 2007 to 2009 recession (refer to Figure 66 and Figure 68).

Table 3 and Table 4 compare employment within the counties dependent on the High Plains Aquifer to their respective states. Manufacturing is the greatest contributor to Kansas GDP, and employment within manufacturing is also largely concentrated within counties that are dependent on the High Plains Aquifer (approximately 46%). Similarly, Farming is a substantial employer within Kansas, and is also concentrated within the area under study. This highlights two separate ways (employment and GDP) in which the economic wellbeing of Kansas is subject to the availability of the High Plains Aquifer.

Table 3—Output and Employment: State Total versus Areas Dependent on High Plains Aquifer, Kansas

Industry	GDP	State Employment	Employment within Drought Boundary	
	$B (2015)	Thousands	Thousands	Percent
Accommodation and food services	3	110,666	36,506	33
Administrative and waste management services	4	99,547	29,941	30
Arts, entertainment, and recreation	1	28,336	9,096	32
Construction	4	82,906	29,575	36
Educational services	1	27,078	7,372	27
Federal civilian	3	27,356	7,935	29
Finance and insurance	6	96,569	23,230	24
Forestry, fishing, and related activities	0	9,037	1,606	18
Health care and social assistance	10	192,116	55,229	29
Information	5	31,927	7,760	24
Management of companies and enterprises	2	15,282	4,623	30
Manufacturing	22	167,217	76,148	46
Federal military	4	37,988	7,117	19
Mining	2	40,466	16,704	41
Professional, scientific, and technical services	6	93,624	21,868	23
Real estate and rental and leasing	14	60,946	17,489	29
Retail trade	9	179,262	64,344	36

Industry	GDP	State Employment	Employment within Drought Boundary	
	$B (2015)	Thousands	Thousands	Percent
State and local	14	234,601	77,119	33
Transportation and warehousing	5	57,253	11,947	21
Utilities	3	8,223	1,469	18
Wholesale trade	9	64,557	22,152	34
Government	20	299,945	92,220	31
Farming	6	187,970	86,356	46

According to the Quarterly Census of Employment and Wages program run by the U.S. Bureau of Labor Statistics, the industries that employ the greatest number of full-time equivalent workers include Federal and State Government (320,049), Healthcare and Social Assistance (132,432), Retail Trade (129,436), and Manufacturing (96,605). Overall, the largest employment growth of the major industries previously listed is expected to be in Healthcare and Social Assistance due to demographic trends. Manufacturing and Government currently contribute equally to Nebraska's GDP output, tying for first place. Manufacturing has seen a consistent decline in employment since 2008 despite the predominance of Nebraska's manufacturing sector in total economic output. Employment and GDP figures by sector in Nebraska are shown in Table 4.

Table 4—State Output and Employment and Drought County Employment: Nebraska

Industry	GDP	State Employment	Employment within Drought Boundary	
	$B (2015)	Thousands	Thousands	Percent
Accommodation and food services	2	75,402	50,358	67
Administrative and waste management services	2	58,749	41,968	71
Arts, entertainment, and recreation	0.5	22,053	14,367	65
Construction	4	62,415	43,902	70
Educational services	1	23,545	14,100	60
Federal civilian	2	16,691	10,242	61
Finance and insurance	7	78,973	54,654	69
Forestry, fishing, and related activities	0.3	9,954	2,842	29
Health care and social assistance	7	132,432	85,071	64
Information	2	19,424	14,560	75
Management of companies and enterprises	2	17,294	10,869	63
Manufacturing	13	96,605	69,665	72
Federal military	1	13,346	5,403	40
Mining	0.3	3,234	1,414	44
Professional, scientific, and technical services	4	61,574	40,365	66
Real estate and rental and leasing	9	39,880	28,245	71
Retail trade	5	129,436	94,992	73
State and local	10	145,006	101,530	70

Industry	GDP	State Employment	Employment within Drought Boundary	
	$B (2015)	Thousands	Thousands	Percent
Transportation and warehousing	7	61,371	27,763	45
Utilities	2	1,788	1,011	57
Wholesale trade	5	43,743	34,473	79
Government	13	175,043	117,317	67
Farming	9	141,196	125,235	89

The Agriculture Industry, specifically Farming, is the largest employer in the state of Kansas. Agriculture has proven to be a resilient industry during unstable economic times, providing consistent employment growth and accruing increasing share of GDP. Domestically, the promotion of ethanol targets adds an additional market for corn and, to a lesser extent, sorghum. Distillers' grains, a coproduct of ethanol manufacturing, are highly valued as fodder for commercial livestock production because they are high in protein and act as a more efficient nutrient source.

Farm and non-farm employment by industry sector for Kansas is shown in Figure 66. Employment is presented at the two-digit NAICS level. The top five industries in Kansas include Manufacturing, Retail Trade, Farming, Healthcare and Social Assistance, and Government (local and Federal). Kansas has over 6,000 farm employees whose ranks have seen tremendous growth since 2008, as much as 20-25% in a year (refer to Figure 66 and Figure 67). In Kansas, the healthcare sector continued to add jobs at a consistent rate, even during the financial downturn in 2008, performing better than the economy as a whole.
The government sector (state and Federal combined) also added jobs since 2005, albeit more slowly. Government jobs include schools, universities, military installation, public services, and public administration.

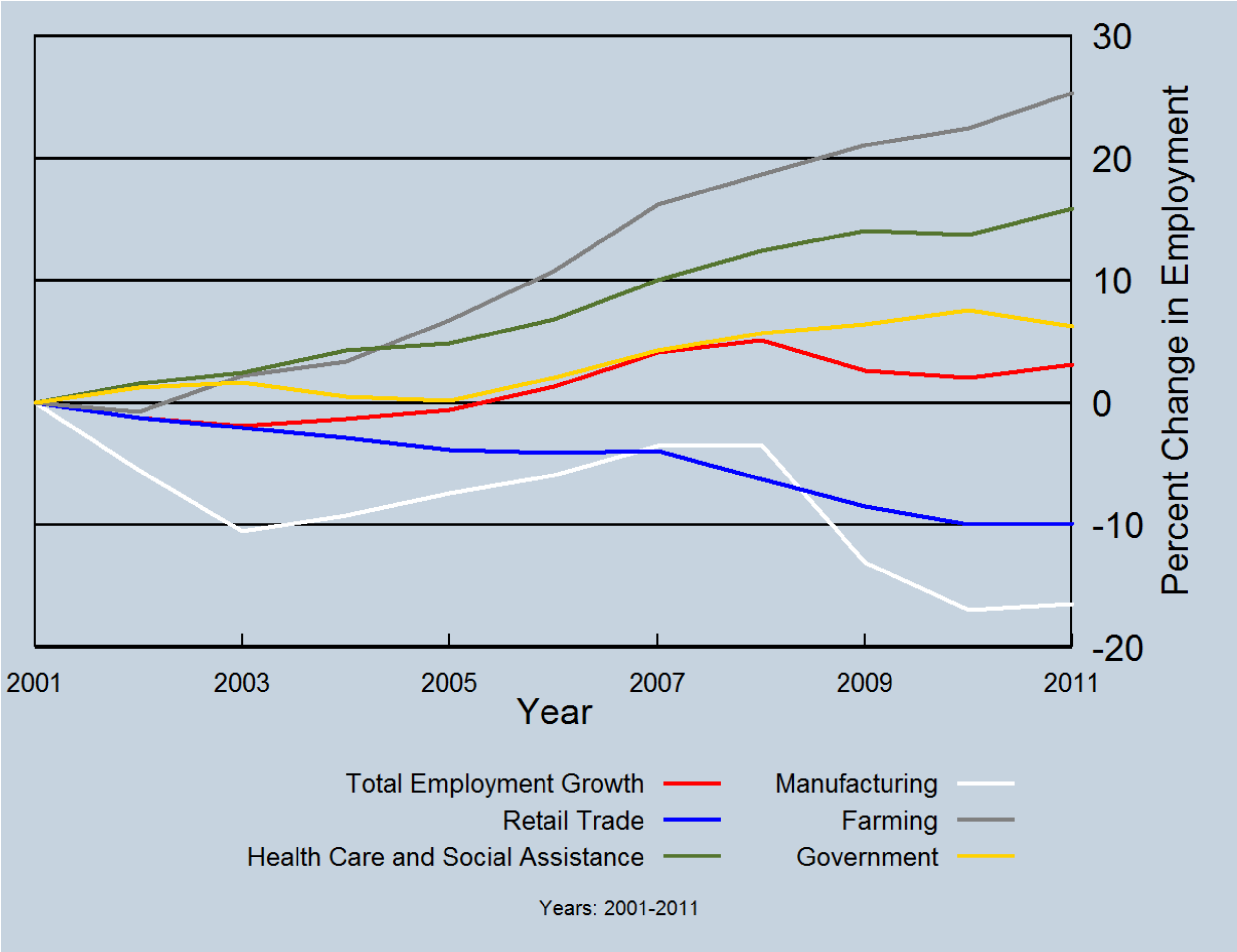

Figure 66—Leading Industry Employment Trends: Kansas

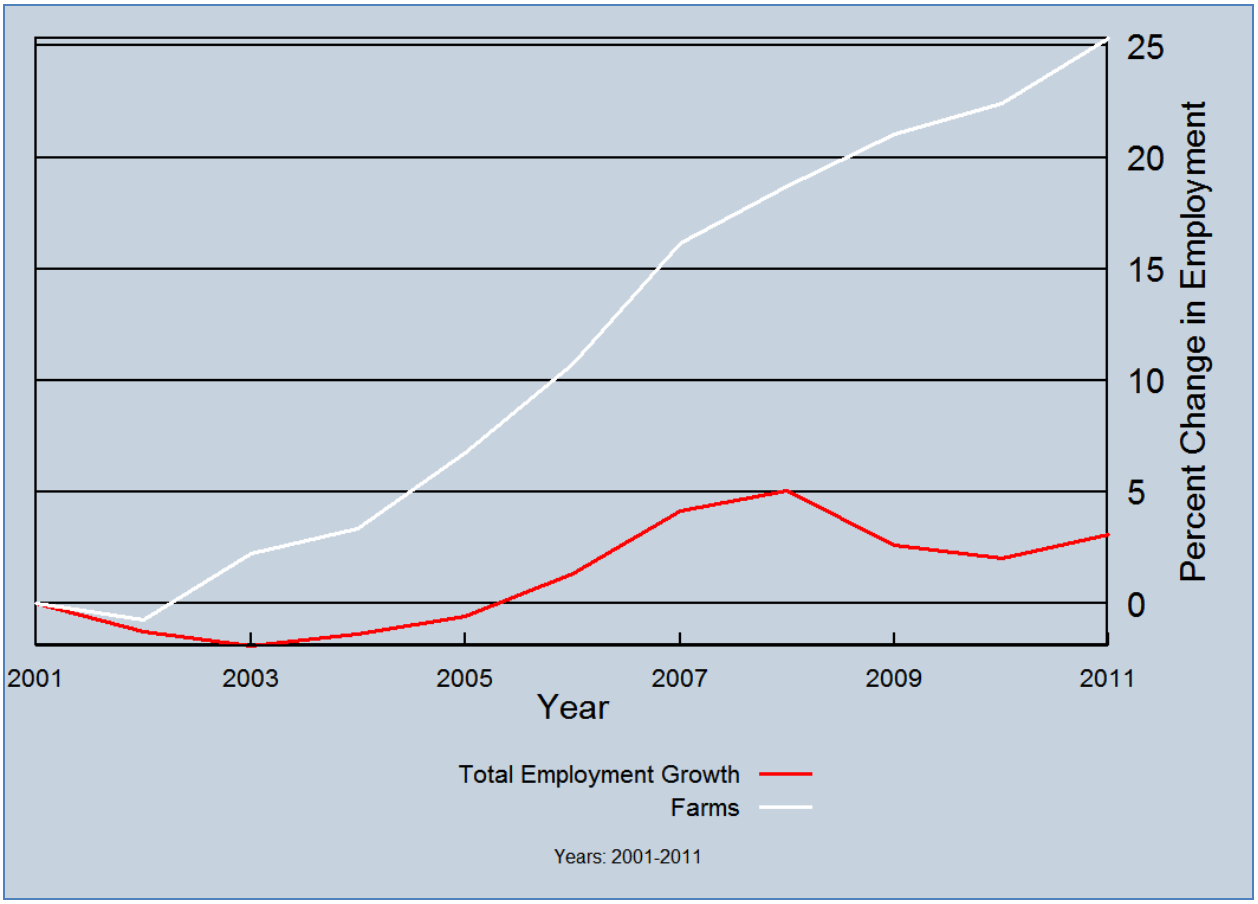

Figure 67—Kansas Farm Employment Trends

Farm-related occupations (which do not count farm proprietors) in Kansas provide relatively high pay (as shown in Table 3), especially for agricultural science teachers and first-line supervisors, along with buyers and purchasing agents. These jobs, which pay on average more than $41,000 a year, make up less than 30% of all agricultural jobs in the state. These jobs are well above the per capita income of $26,929 and slightly below the median household income of $51,332.[120]

Table 3 provides a detailed breakdown of farm employment and farm-related occupational data alongside hourly and annual wages. Many of the listed occupations are above minimum wage. Compared to wages in manufacturing or tertiary service positions, three of the occupations are at or above the average per capita annual income of metropolitan Kansas residents; the remaining seven occupations have earnings that are 25-50% fewer than metropolitan Kansas incomes. Farm-related occupations (downstream from agriculture production) are focused on livestock and crop processing and play an important role in Kansas' agricultural employment. Meat cutters and meat packers have more employees than all on-farm employment. Prepared foods, which require processing raw food products, have over 1,000 employees in the state. These wages are on average less than the wages of on-farm employees and employ a greater number of people.

[120] U.S. Census Bureau. State & County Quick Facts. http://quickfacts.census.gov/qfd/states/20000.html, accessed April 24, 2015.

Table 5—Farm-Related Occupation by Type, Kansas, May 2013 (BLS)

Farm Related Occupation	Employment	Average Wage	
		Hourly	Annual
Farmers, Ranchers, and Other Agricultural Managers	N/A	N/A	N/A
First-Line Supervisors of Farming, Fishing, and Forestry Workers	260	$24.10	$50,140
Agricultural Inspectors	290	$20.03	$41,650
Graders and Sorters, Agricultural Products	130	$14.03	$29,180
Agricultural Equipment Operators	1,240	$14.17	$29,460
Farmworkers and Laborers, Crop, Nursery, and Greenhouse	490	$11.10	$23,100
Farmworkers, Farm, Ranch, and Aqua-cultural Animals	850	$11.51	$23,930
Buyers and Purchasing Agents, Farm Products	860	$32.67	$67,950
Purchasing Agents, Except Wholesale, Retail, and Farm Products	1,600	$10.20	$21,210
Agricultural Sciences Teachers, Postsecondary	370	N/A	$84,580

Table 6—Production and Manufacturing Occupations, Kansas, May 2013

Production and Manufacturing Occupation	Employment	Average Wage	
		Hourly	Annual
Meat, Poultry, and Fish Cutters and Trimmers	5,280	$13.16	$27,370
Slaughterers and Meat Packers	2,130	$12.51	$26,020
Food and Tobacco Roasting, Baking, and Drying Machine Operators and Tenders	100	$14.03	$29,180
Food Batch-makers	810	$13.94	$29,000
Food Cooking Machine Operators and Tenders	350	$13.08	$27,200
Food Processing Workers, All Other	N/A	N/A	N/A

Non-farm employment by industry sector for Nebraska is shown in Figure 68; employment is presented at the two-digit NAICS level. The top five industries in Nebraska include: Retail Trade, Farming, Manufacturing, Healthcare and Social Assistance, and Government (local and Federal). In Nebraska, the number of jobs in manufacturing declined during 2009, losing approximately 11% of the workforce that year and approximately 4% in the following year. Healthcare employment continues to grow as the country's population ages. During the same years, retail and manufacturing sectors in Nebraska have experienced increases in contribution to state GDP. The percent change in employment for industries at the two-digit NAICS level is also shown in Figure 68.

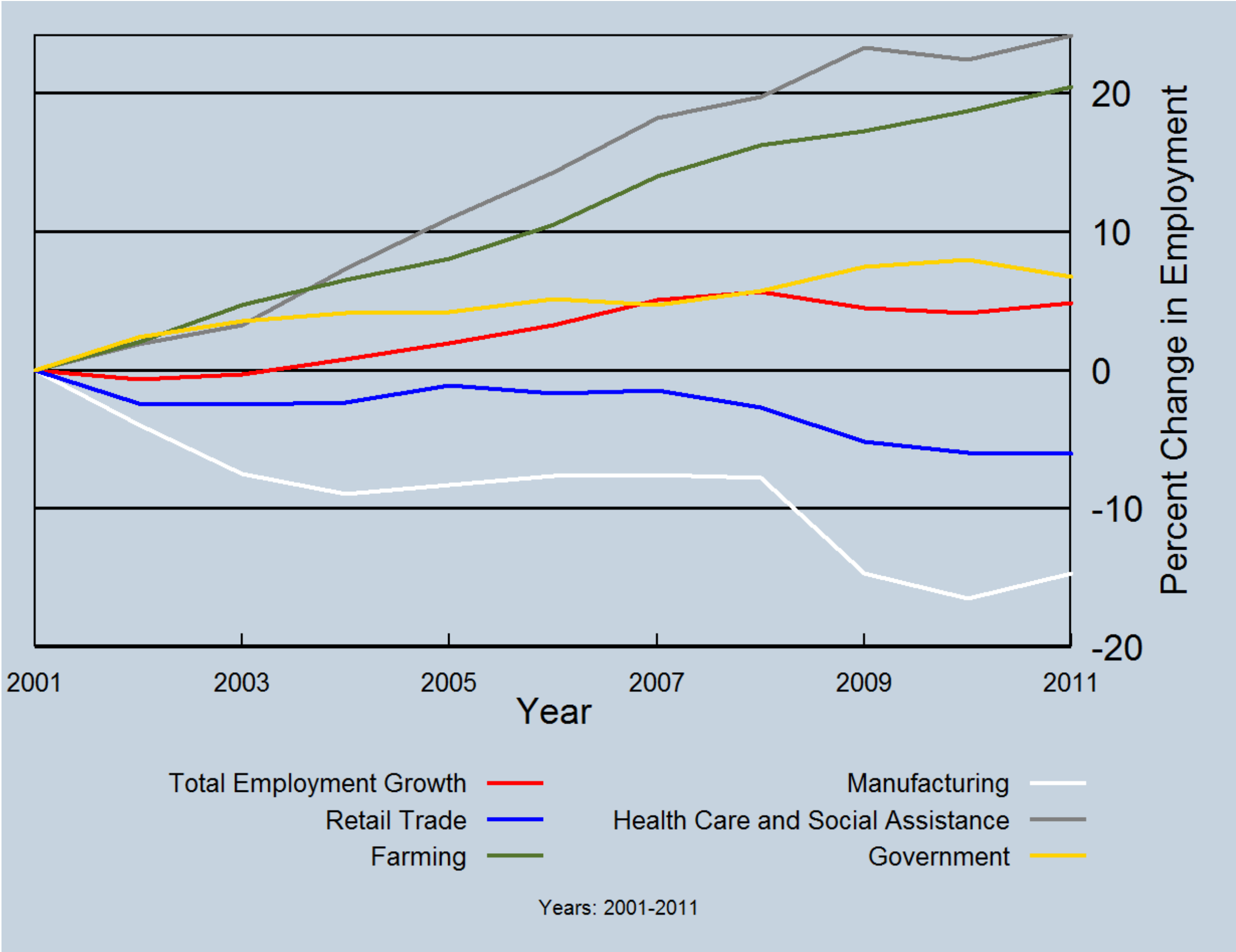

Figure 68—Leading Industry Employment Trends: Nebraska

Nebraska Agriculture GDP contribution has doubled since 1997, with a large portion of this growth attributable to Farming (see Figure 68). At the same time, Farm employment has increased 25%. The agricultural sector and its related industries have experienced higher growth rates post-2008 than pre-2008, as value-added products like beef and ethanol retained strong demand.

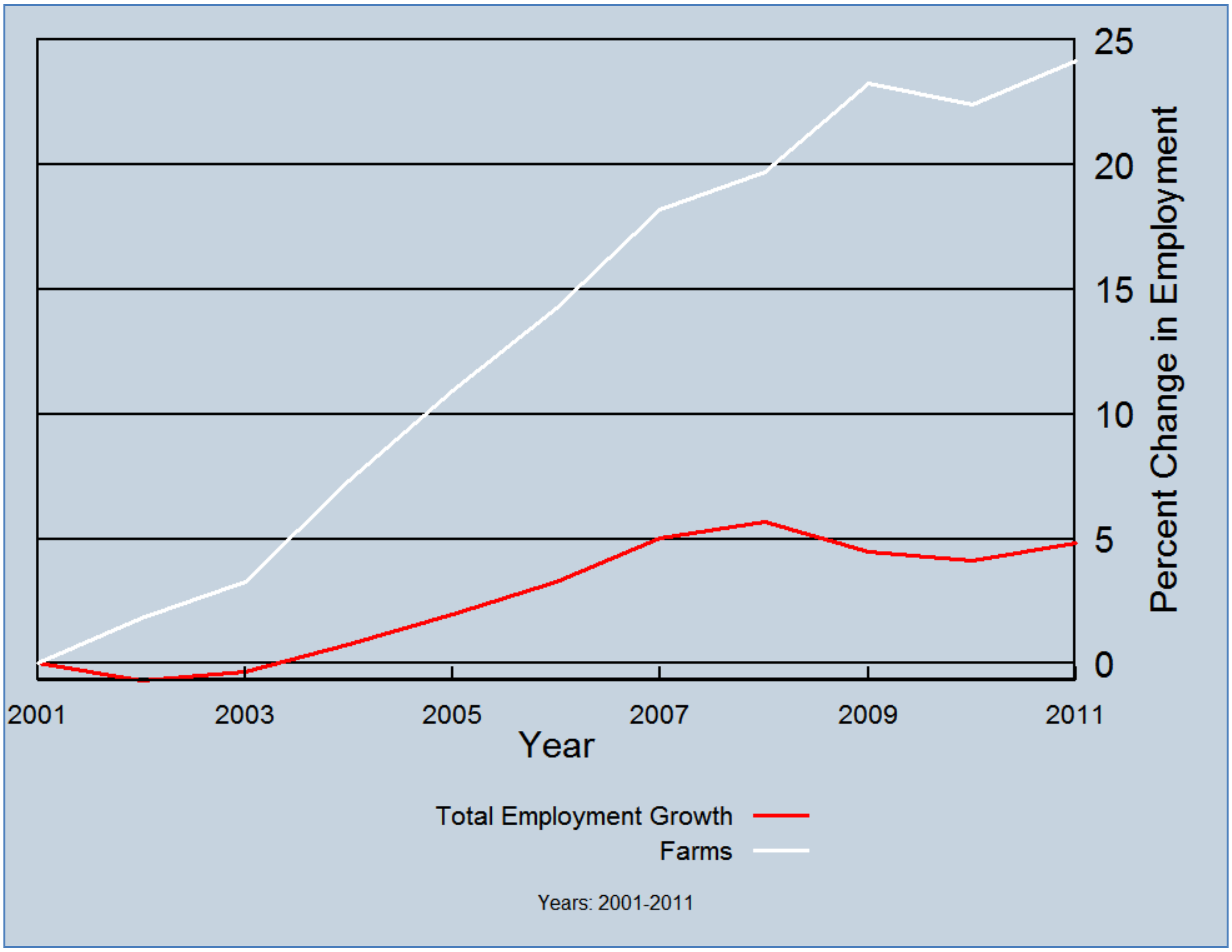

Figure 69— Nebraska Farm Employment Trends

Farm-related occupations (which do not count farm proprietors) in Nebraska provide relatively high pay, especially for managers and first-line supervisors, along with buyers and purchasing agents. These jobs, which pay on average more than $44,000 a year, make up over half of all agricultural jobs in the state (refer to Table 7). This is well above the per capita income of $26,899 and slightly below the median household income of $51,672.[121] Farm-related occupations centered on livestock and crop processing also play a substantial role in Nebraska's agricultural employment, as seen in Table 8. Meat cutters alone account for more than all on-farm employment combined, which is representative of Nebraska's central role in cattle and other livestock production.

[121] U.S. Census Bureau. State & County Quick Facts. http: //quickfacts.census.gov/qfd/states/31000.html, accessed April 24, 2015.

Table 7—Farm Occupation by Type, Nebraska, May 2013 (BLS)

Farm Related Occupation	Employment	Average Wage	
		Hourly	Annual
Farmers, Ranchers, and Other Agricultural Managers	100	$29.87	$62, 120
First-Line Supervisors of Farming, Fishing, and Forestry Workers	190	$21.40	$44,510
Agricultural Inspectors	N/A	N/A	N/A
Graders and Sorters, Agricultural Products	190	$10.95	$22,780
Agricultural Equipment Operators	820	$15.29	$31,800
Farmworkers and Laborers, Crop, Nursery, and Greenhouse	940	$12.48	$25,950
Farmworkers, Farm, Ranch, and Aqua-cultural Animals	850	$11.51	$23,930
Buyers and Purchasing Agents, Farm Products	610	$32.67	$67,950
Purchasing Agents, Except Wholesale, Retail, and Farm Products	1,600	$26.31	$54,720
Agricultural Sciences Teachers, Postsecondary	180	N/A	94,300

Table 8—Production and Manufacturing Occupations, Farm Related, Nebraska, May 2013 (BLS)

Production and Manufacturing Occupations	Employment	Average Wage	
		Hourly	Annual
Meat, Poultry, and Fish Cutters and Trimmers	11,620	$13.43	$27,940
Slaughterers and Meat Packers	2,440	$21.40	$44,510
Food and Tobacco Roasting, Baking, and Drying Machine Operators and Tenders	240	$15.81	$32,890
Food Batch-makers	1,250	$15.48	$32,200
Food Cooking Machine Operators and Tenders	270	$13.75	$28,610
Food Processing Workers, All Other	160	$10.08	$20,970

2.5.5 Economic Modeling Assumptions

2.5.5.1 Policy and Regulation Actions

It is not the role of OCIA NISAC to endorse, promote, or enforce a particular set of policy options or regulations. Therefore, this study does not explicitly account for potentially offsetting policy or regulation. In essence, this is a consequence analysis that assumes no intervening action by Government or market forces will offset the impacts.

2.5.5.2 Supply Shocks

Generally, a supply shock is modelled as a discrete event that generates a transitory, but substantial, negative impact on an economic system. This study, however, considers the consequences of a persistent and intensifying impact on a natural resource that is an input to substantial economic activities within a system. As water resource risk intensifies, availability of water will decrease and the cost of extracting water will increase. This is due to aquifer drawdown, lack of sufficient aquifer recharge, and evaporative conditions from increasing temperatures. The substantial decline in groundwater available for irrigation coupled with the increase in the amount of energy required and the associated costs to extract groundwater, as given in the scenario, could have significant economic consequences. The economic consequences of such a resource risk include regional impacts such as reduced output and income in the affected region, and national impacts such as reduced quantity of goods and services available outside the region. Reduced agricultural output will likely affect critical infrastructure industries, especially infrastructures that involve heavy water use or are dependent on the Agriculture Industry.

2.5.6 Impact of Increased water scarcity

As discussed previously, Agriculture is the largest user of water in both Kansas and Nebraska and is also a substantial source of employment. The Agriculture Industry, therefore, requires in-depth, careful, and substantial analysis to fully understand the consequences of resource risk. Although agriculture in general is capable of withstanding substantial negative economic shocks, increased water scarcity and costs associated with extraction over a sustained period of time could make it difficult for firms in agriculture to remain competitive with firms outside the region not facing the same challenges. While firms in the Agriculture Industry may respond to water scarcity in a number of ways, we consider two specific options. First, we consider how increased pumping costs impact the likelihood that a farm operation exits the industry. Next, we consider how increased scarcity may result in reduced irrigation, which would translate to lower yields and reduced output in the Agriculture Industry.

While the direct impacts of a water resource risk are primarily concentrated in the Agriculture Industry, the impact is not limited solely to farm operations and other firms in agriculture. Farm operations utilize inputs provided by other local firms, farm operations provide employment to local residents, and the personal income of farm operators is often spent in the community where they farm. Thus, the regional economic impacts are important to consider in addition to the impacts to the Agriculture Industry. A macroeconomic simulation model is utilized to estimate the wider regional economic impacts.

2.5.7 Macroeconomic Model

The regional macroeconomic consequences of water resource risk are estimated using NISAC's PI+ model from Regional Economic Models, Inc. (REMI). The specific version used for the analysis is a state-level model with 67 industry sectors. The REMI model is an empirically validated model that combines aspects of input-output modelling and computable general equilibrium. A REMI analysis is carried out in two steps: first, a baseline forecast is computed, in which there is no change to the economy, and second, an alternative forecast is generated based on a specific scenario. The economic impact of the change in the economy is measured as the differences between the baseline and alternative forecasts. This study calculates the regional economic impacts of two separate scenarios at varying levels of severity.

2.5.7.1 Scenario 1

First, we estimate how changes in farm operation market participation decisions induced by increased extraction costs propagate through the regional economy. For this scenario, the change in market participation is based on an empirically estimated relationship between extraction costs and farm operation exit decisions. The empirical model used for this study follows previous work exploring the factors that determine farm operation exit (Hoppe and Korb, 2006). A more detailed discussion of the empirical model is presented in Appendix E: The Econometric Model. The empirical model provides us with an estimate of the marginal impacts of increased extraction costs. However, we must impose the change in extraction costs exogenously. Farm operation utility costs are used as a proxy for extraction costs. Table 9 presents the average utility costs of farm operations in Kansas and Nebraska in 2012. On average, Kansas farm operation expenditures on utilities were approximately $5,282. Nebraska farm operation utility expenditures were on average $9,861, which is substantially higher than the average for Kansas. However, the initial difference in expenditures may simply reflect differences in the states' respective crop portfolio or a difference in average farm operation size. It should not be inferred from these data alone that farm operations in Nebraska pay more per unit.

Table 9—Utility (Energy) Expenditures in Kansas and Nebraska ($1,000): 2012 Average and Hypothetical Increases of 25, 50, and 75%

	Kansas	Nebraska
2012 Average	5.282	9.861
2012 Average plus 25%	6.603	12.326
Difference	+1.321	+2.465
2012 Average plus 50%	7.924	14.791
Difference	+2.641	+4.930
2012 Average plus 75%	9.244	17.256
Difference	+3.962	+7.395

Increasing extraction costs may increase the likelihood that a farm operation exits the industry. However, this is a marginal increase in the likelihood of exit. The number of farm operations in Kansas and Nebraska has been trending downward in recent years. Table 10 presents the number of farm operations responding to the Census of Agriculture in Kansas and Nebraska for each Census-year from 1982 to 2012. Between 1982 and 2012, both states experienced declining numbers in farm operations. Annually, Kansas has lost approximately 0.5% of farm operators. Since 1982, cumulative decline in farm operations in Kansas are approximately 16%. Annual percent decline for farm operations in Nebraska is approximately 0.6%. Cumulatively, this amounts to approximately a 17% decline in Nebraska farm operations between 1982 and 2012.

Table 10—Farm Operation Count in Kansas and Nebraska (1982-2012)

	Farms	
	Kansas	Nebraska
1982	73,315	60,243
1987	68,579	60,502
1992	63,278	52,923
1997	65,476	54,539
2002	64,414	49,365

	Farms	
	Kansas	Nebraska
2007	65,531	47,712
2012	61,773	49,969
Percent Change in Farms (1982-2012)	-15.743%	-17.054%
Annualized Percent Change in Farms (1982-2012)	-0.525%	-0.568%

The annualized percent change in farms between 1982 and 2012 for each state is assumed for the baseline REMI model. Increases in farm exit over the historical average are calculated using the marginal effect of increased utility costs on exit probability, estimated by the empirical model, combined with hypothetical increases in utility expenditures presented in Appendix E: The Econometric Model. This impact is modelled within the REMI model as a decrease in farm proprietor's income. This is calculated by reducing farm proprietor income by the percentage difference in the number of farms estimated following historical trends and the number of farms estimated when utility costs are increased by 25, 50, and 75%. It should be noted that the increase in utility costs are not modelled as an instantaneous change; the increase is applied uniformly over the REMI entire simulation period (2015-2060). This was intentional. The depletion of the High Plains Aquifer is not expected to be instantaneous, but rather a gradual decline.

2.5.7.2 Scenario 2

Next, we estimate a separate regional economic model to model the impacts of decreased irrigation. Given that in general the historical yield of a given irrigated crop is much higher than the yield for the same crop in the absence of irrigation, this impact is modelled as a decrease in farm output. We calculate the expected change in Agricultural Industry output associated with a reduction in the percentage of irrigated acreage for four crops: corn, soybeans, winter wheat, and sorghum. The per-acre difference in yield associated with switching from irrigation to dryland farming is calculated as the difference in the yield estimated by the econometric model presented above and the yield estimated by the EPIC model for dryland. The change in total yield for each crop in each county associated with an exogenous decrease in irrigated acreage is calculated by reducing the number of irrigated acres by 25, 50, and 75%, and then increasing the number of non-irrigated acres by the same amount. The impact to the entire Agriculture Industry within each county must be weighted by each crop's contribution to Agriculture Industry output.

3 RESULTS

3.1 Crop Modeling Results

Time series (1960-2089) of annual crop yields (tons per hectare) from the EPIC model dryland simulation (light blue line), econometric model crop dryland simulation (green line), and the econometric model irrigated crop simulation (dark blue line) are plotted for corn (A), winter wheat (B), sorghum (C), and soy (D) for each of the 14 representative High Plains counties (Appendix C, Figures 105-118). Each crop yield time series has been normalized to its 1960 value to facilitate comparison between results. Trends are quantified via linear regression and appear alongside the corresponding crop yield time series. The linear regression coefficients for each crop simulation and county are summarized in Appendix C. Examples of the crop modeling results for Dundy County, Nebraska, and Barton County, Kansas, are shown below in Figure 70 through Figure 77.

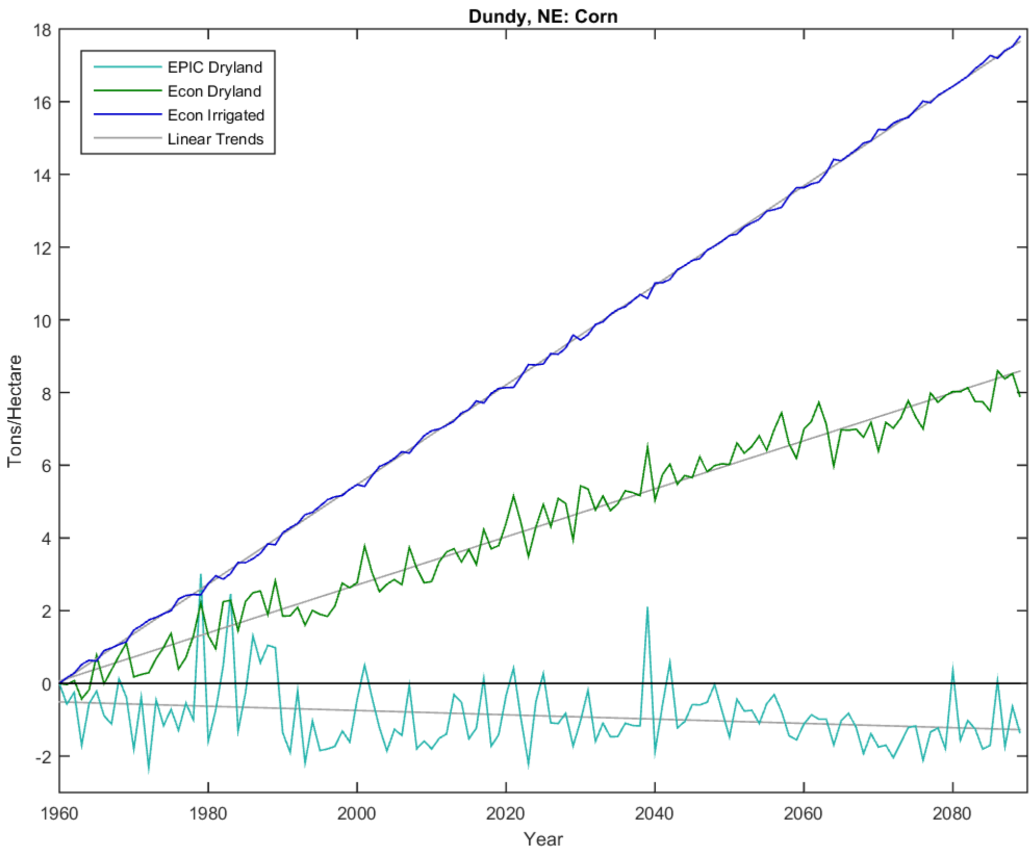

Figure 70—Results from the Crop Modeling Simulations for Corn in Dundy County, Nebraska

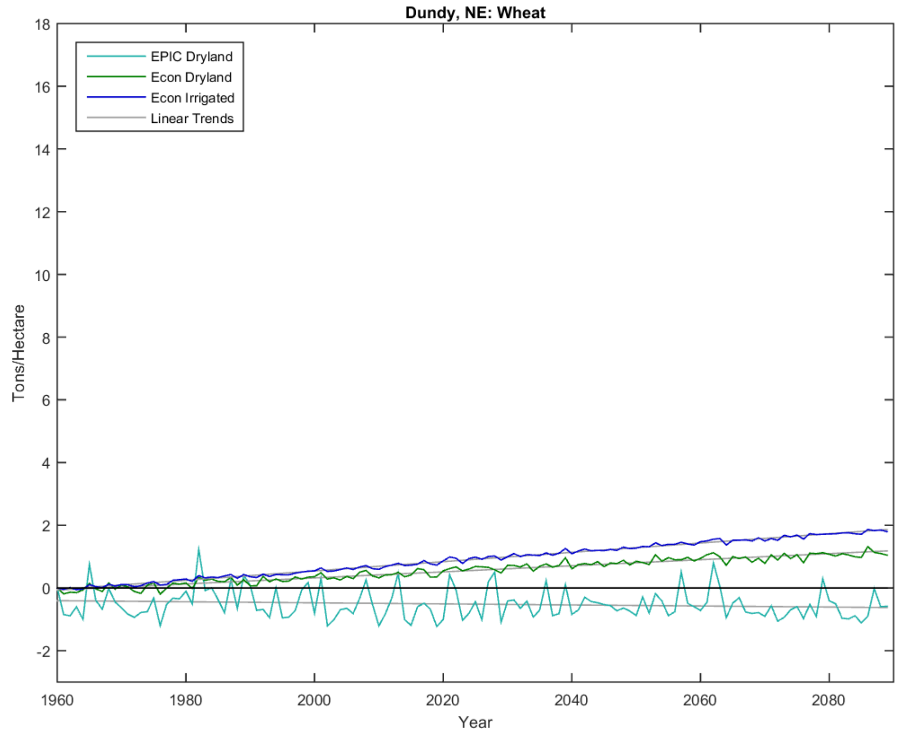

Figure 71—Results from the Crop Modeling Simulations for Wheat in Dundy County, Nebraska

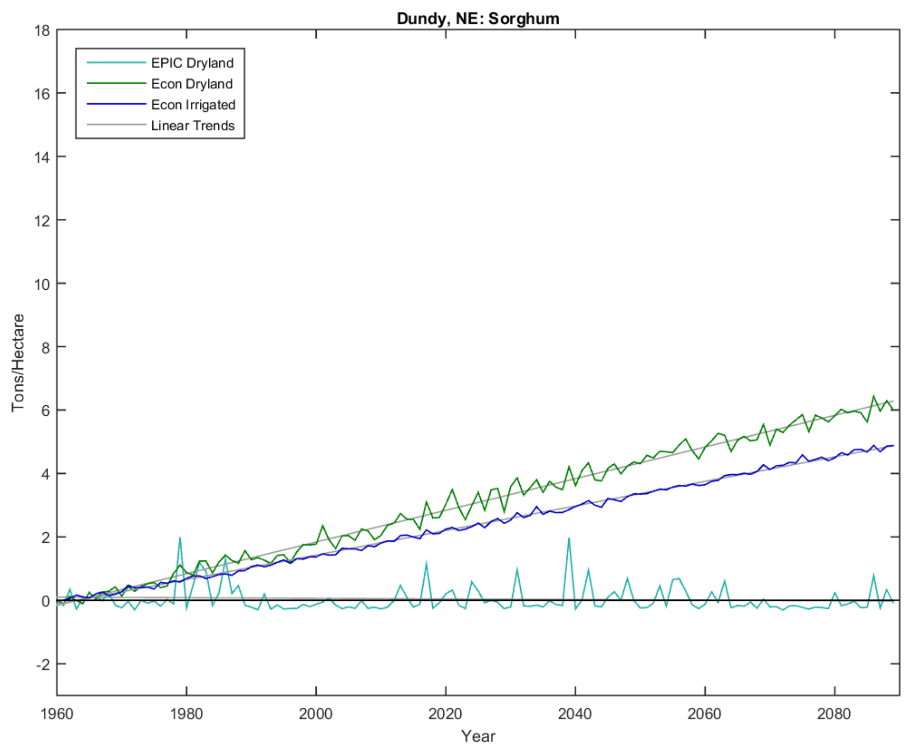

Figure 72—Results from the Crop Modeling Simulations for Sorghum in Dundy County, Nebraska

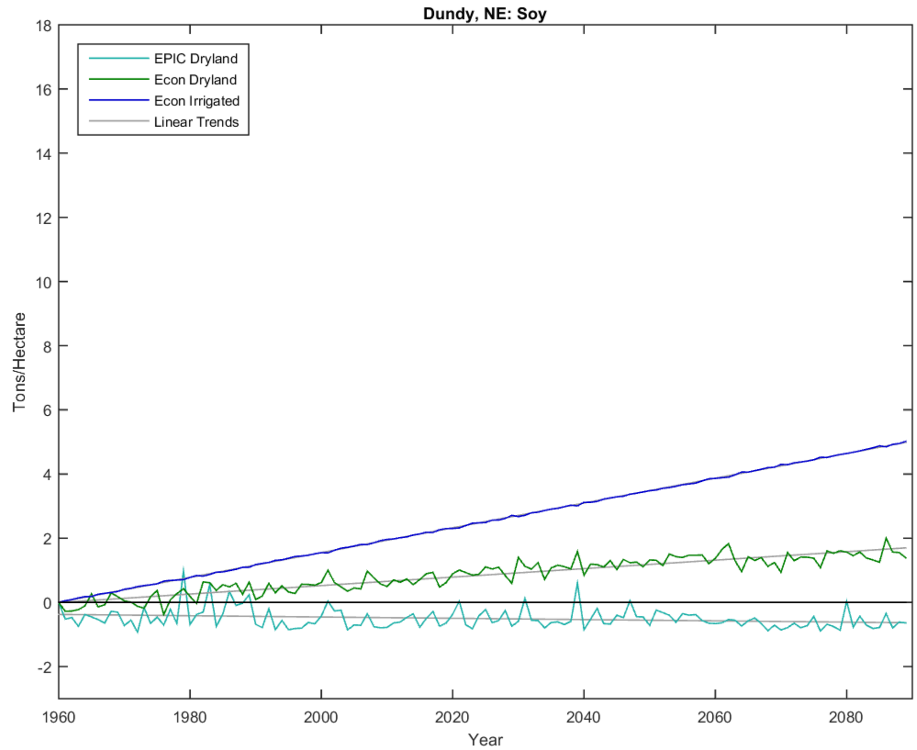

Figure 73—Results from the Crop Modeling Simulations for Soy in Dundy County, Nebraska

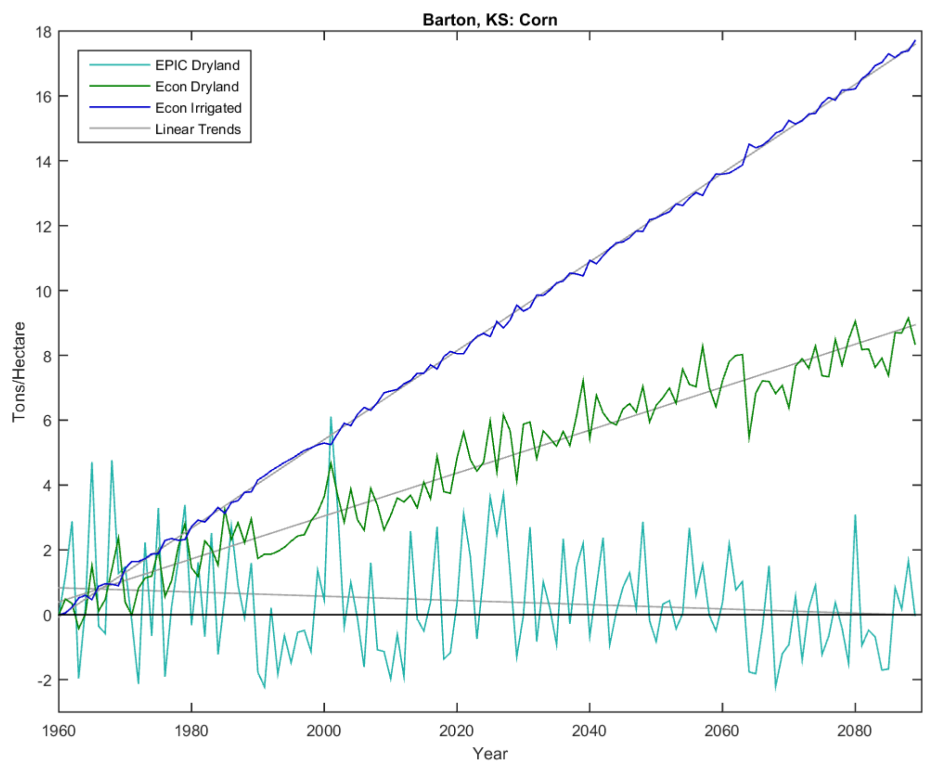

Figure 74—Results from the Crop Modeling Simulations for Corn in Barton County, Kansas

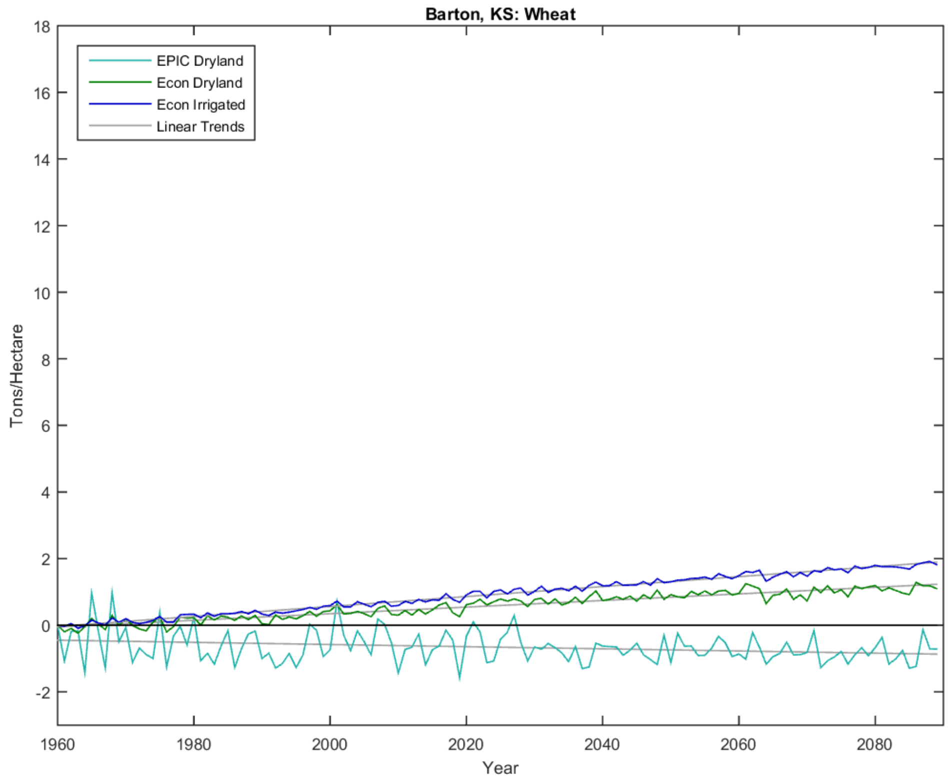

Figure 75—Results from the Crop Modeling Simulations for Wheat in Barton County, Kansas

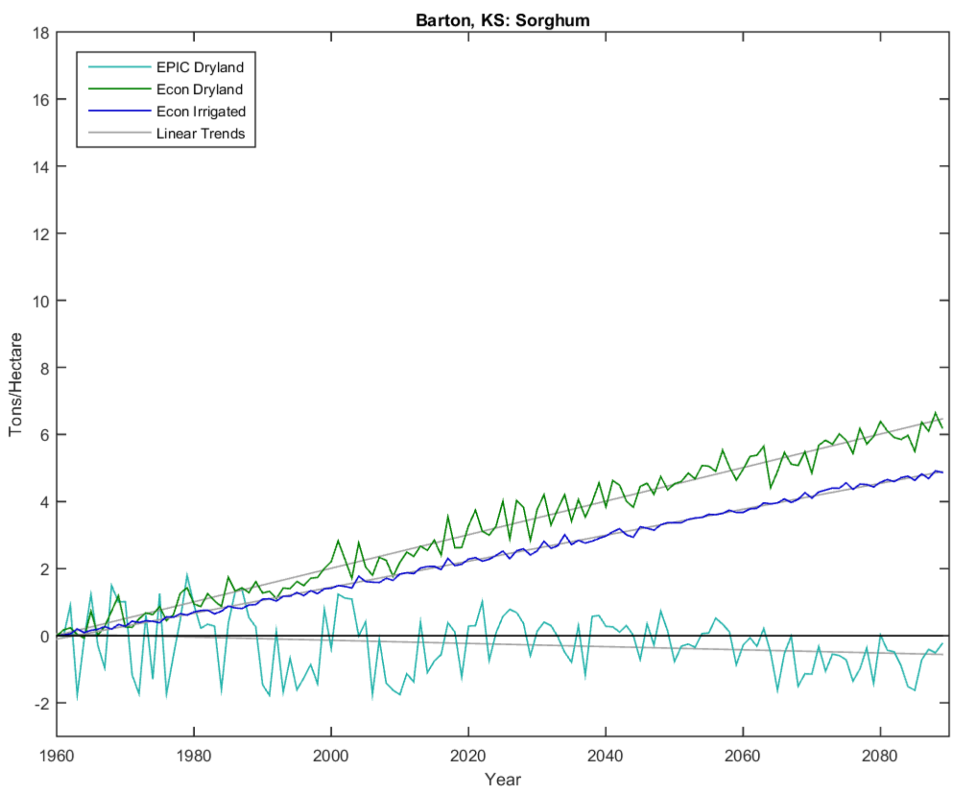

Figure 76—Results from the Crop Modeling Simulations for Sorghum in Barton County, Kansas

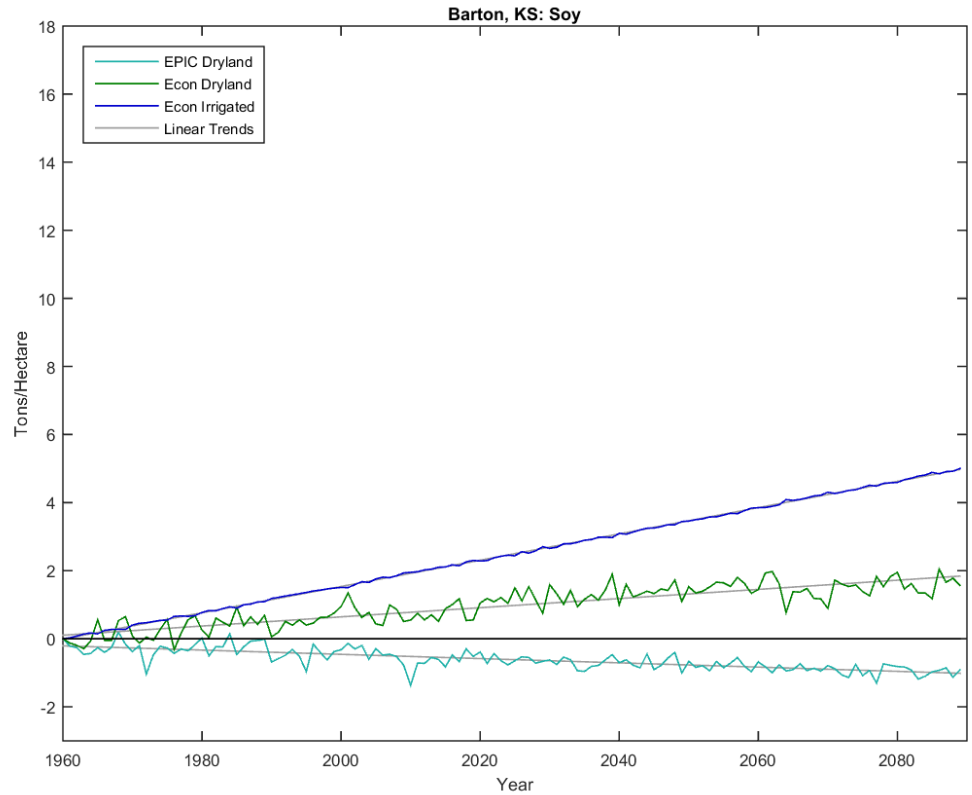

Figure 77—Results from the Crop Modeling Simulations for Soy in Barton County, Kansas

Together, the results of the crop modeling experiments represent a range of possible outcomes that could arise from future variations in groundwater availability, climate, and agricultural innovation. The results of the EPIC dryland simulations illustrate the impact that climate variability alone would have on crop yields under the climate conditions projected by the GFDL-CM3 model using the RCP 8.5 emissions scenario. The EPIC dryland results show a downward trend in yields for corn, sorghum, soy, and winter wheat in all 14 representative High Plains counties. Dryland yields simulated by EPIC show average decreases of -0.006 tons/hectare per year for corn, -0.002 tons/hectare per year for winter wheat, -0.003 tons/hectare per year for sorghum, and -0.004 tons/hectare per year for soy (see Appendix C: Summary Statistics).

Irrigation has, historically, been used to offset the impacts of variations in temperature and precipitation on crop yields. For example, farmers can increase the amount of irrigation water applied to their crops during times of drought in order to mitigate losses in yield. In the High Plains, farmers have utilized water from the High Plains Aquifer to maintain the production levels that have strengthened the agricultural sector throughout the region. Projections of temperature associated with the RCP 8.5 emissions scenario are expected to increase evaporation in places where moisture is available.[122] As evaporation rates increase, more water will be required to maintain the soil moisture levels needed for crops to grow, increasing water demands on the High Plains Aquifer.

[122] IPCC 2013.

The results of the EPIC dryland experiments show that the impacts of climate variability alone will likely reduce crop yields in the future. It is possible, however, that farm operation behavior and technology can be adapted to offset these impacts, as illustrated by the econometric crop model results. Whereas farmers might normally use groundwater to offset the impacts of climate variability on crops during dry years, the depletion of the High Plains Aquifer could hinder their ability to do so in the future. As groundwater availability decreases over time, it is possible that more agricultural land will be converted from irrigated to dryland fields. The potential losses in yield that result from this conversion can be interpreted as the difference in net yield between the econometric crop model irrigated (using the linear production function for irrigated crops) and the EPIC model dryland projections at any point along the 1960-2089 time series.

3.2 Confidence and Uncertainty

Model calibration is a process by which model input parameters are adjusted so that the model output is as similar to observed values as possible. We calibrated the EPIC model for the corn, sorghum, soy, and winter wheat crops using NASS historical yield data from Hayes and Holt counties in Nebraska and Finney and Jewell counties in Kansas (Figure 78). First, the most influential parameters affecting the simulated crop yields and their reasonable limits were identified through a literature review and expert recommendation from members of the EPIC modeling team at the Blackland Research and Extension Center.[123] The model parameters included in the model calibration were: tillage type, crop stress irrigation trigger, potential heat units, and harvest index.

[123] Wang et al., 2012; personal communication, December 2014 to present.

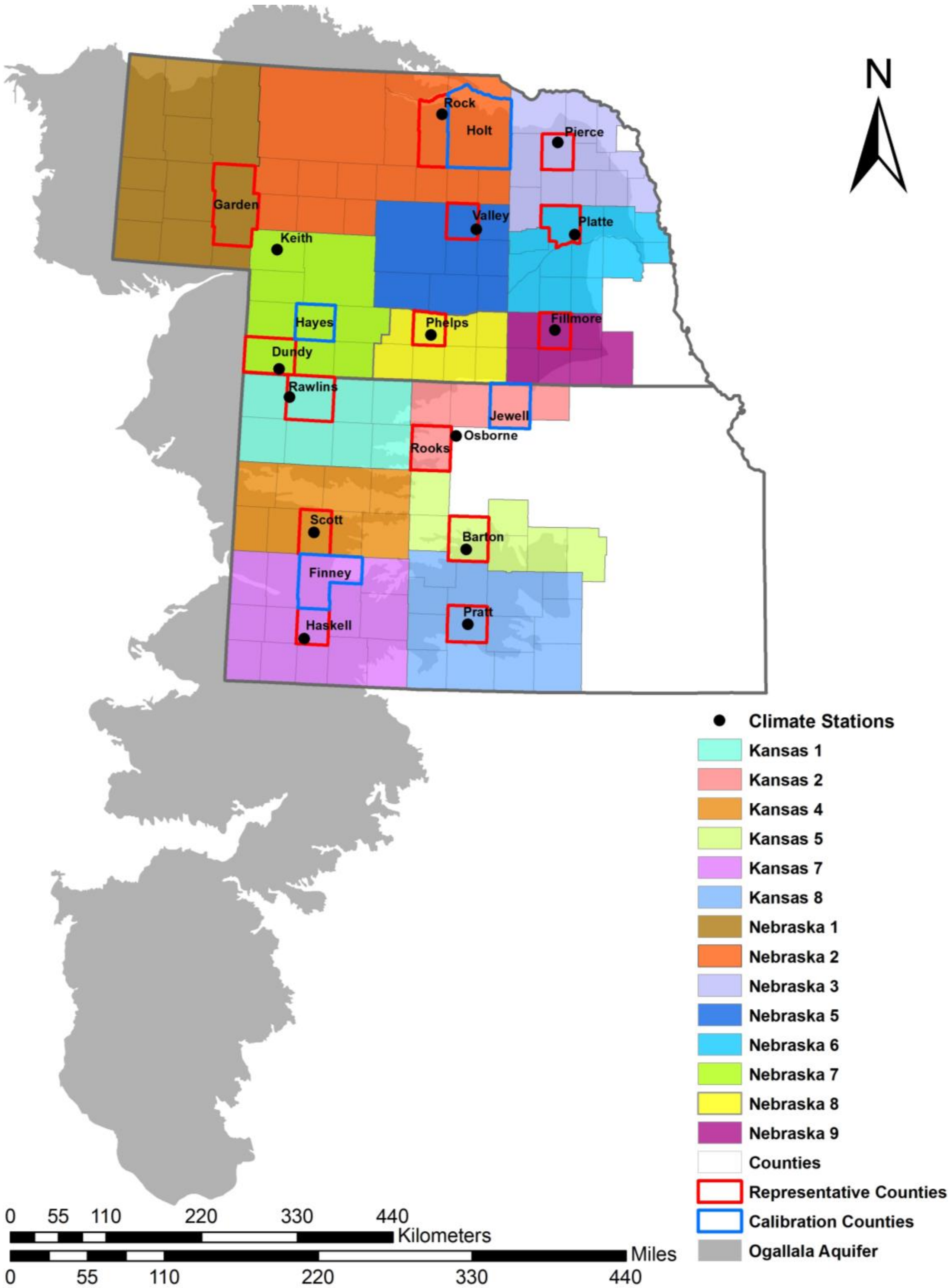

Figure 78—Spatial Extent of the Agricultural Modeling Experiments: Counties Used in Model Calibration Outlined in Blue; Counties Used in Model Validation and Crop Yield Projections Outlined in Red

Model simulations for each crop were made with various input values for each calibration parameter. Correlation coefficients between simulated and actual yields were calculated for each calibration run. The input value that produced the highest correlation coefficient between the simulated and actual yield was selected and then used to calibrate the next parameter. Through this procedure, the optimal configurations of input parameters were identified for each crop. EPIC model validation was performed for each crop and county using the optimal input configurations identified in the calibration phase. For each validation simulation, the correlation coefficient between the simulated and actual yield was calculated and tested for statistical significance at the 90-95% confidence interval ($0.05 \leq \alpha \leq 0.1$) using a two-tailed t-test. Model performance was assessed according to the percentage of counties (out of 14 total) that were statistically significant for each crop and were considered acceptable if significant correlations were found in ≥50% of the High Plains counties.

Table 11—Percentage of Representative High Plains Counties (of 14 total) Where the Validation Simulations were Significantly Correlated ($0.05 \leq \alpha \leq 0.1$) with Historical Yields

EPIC Validation Results Summary		
Crop	Non-Irrigated Yield	Irrigated Yield
Corn	86%	14%
Sorghum	64%	29%
Soy	57%	0%
Winter Wheat	71%	14%

The EPIC model showed acceptable performance in simulating dryland (non-irrigated) crop yields for corn, soybeans, sorghum, and winter wheat, which were significantly correlated with actual yield data in 57% or more of the 14 representative High Plains counties (Table 11). The actual and simulated dryland yields tend to be strongly correlated with precipitation. An example of this is shown for corn yields in Dundy County, Nebraska (Figure 79 and Figure 80), where the proportion of variance in corn yield accounted for by the linear relationship with precipitation is 24% for historical yield and 42% in simulated yield. Given a set of historical precipitation data, EPIC is shown to reproduce the inter-annual fluctuations in historical crop yields related to variations in precipitation with reasonable accuracy.

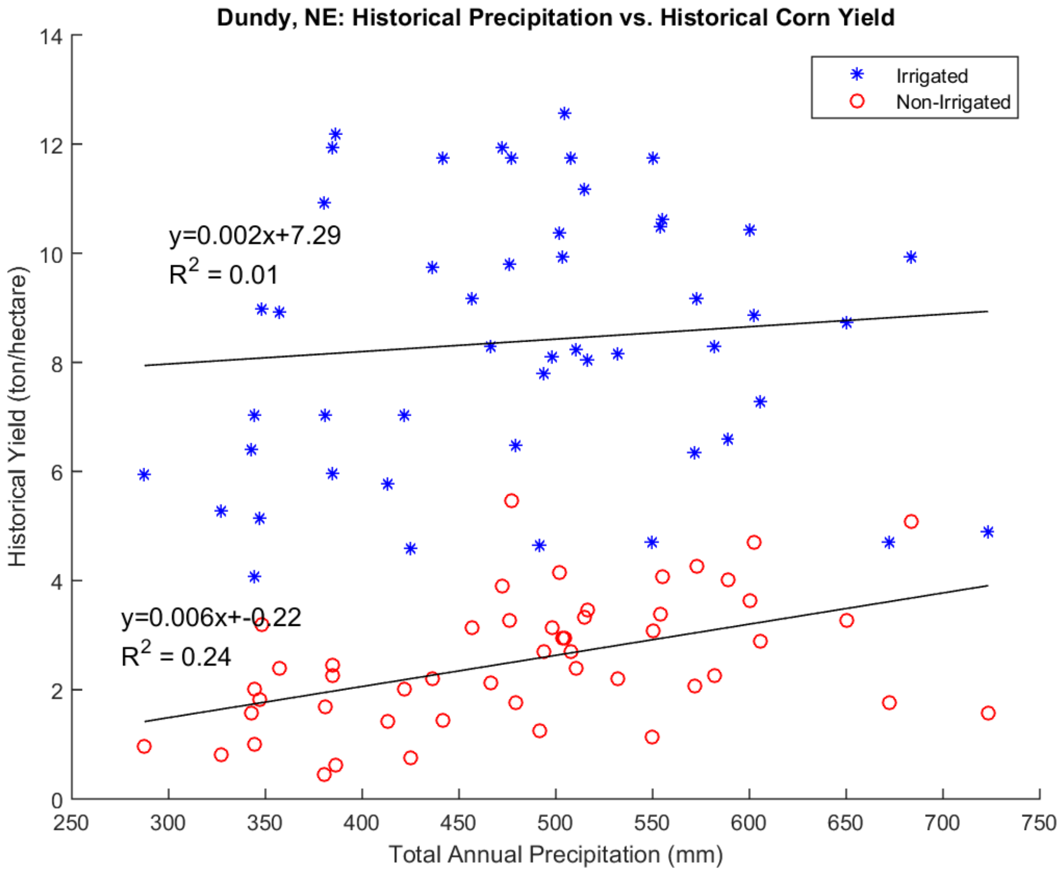

Figure 79—Comparison of Relationship between Historical Yield and Historical Precipitation: Dundy County, Nebraska

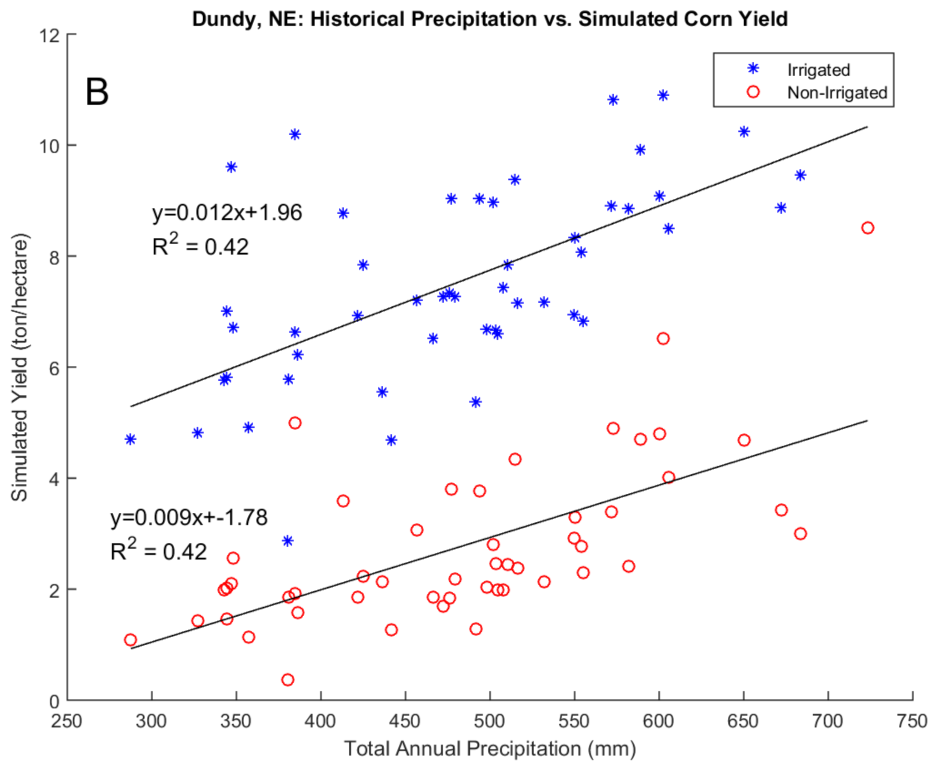

Figure 80—Comparison of Relationship between Simulated Yield and Historical Precipitation: Dundy County, Nebraska

The percentage of counties where *r* (actual, simulated) was significant (0.05≤α≤0.1) for irrigated crops was found to be less than 50% for corn, sorghum, soybeans, and winter wheat (Table 11). EPIC did not show acceptable performance in simulating irrigated yields. One explanation for EPIC's shortcoming in reproducing irrigated yields is that the correlation between EPIC simulated yield and precipitation remains strong in EPIC simulations, while this correlation tends to weaken in the historical record. An example of this is shown for corn yields in Dundy County (Figure 80), where the proportion of variance in corn yield accounted for by the linear relationship with precipitation is 1% for historical yield and 42% for simulated yield. This suggests that variations in historical yields were strongly influenced by non-weather related factors that EPIC is not designed to model. Therefore, the EPIC model was not used to simulate irrigated yields for this analysis. Instead, the econometric crop model, which is based on historical data and reproduces the historical yield trends with reasonable accuracy, was used to simulate irrigated yields.

The econometric model estimates the parameters β and δ representing the input vector parameters for the mean and variance function. The model parameters, estimated from historical climate data, are used to forecast future yields to explore the impact of climate variation on crop yield. Calibration is unnecessary in the econometric model because parameters are endogenously derived based on exogenous variables. The R^2, which is a measure of goodness of fit, performed adequately, especially in irrigated crops, in part because the model is able to capture changes in productivity independent of climate variables, which irrigation naturally mitigates against.

3.3 Groundwater Modeling Results

Concern over the High Plains Aquifer has been expressed due to the significant groundwater declines registered across the entire region (as previously noted and illustrated by Figure 2). These declines are largely the result of groundwater pumping to support irrigated agriculture. Although efforts have been made to reduce groundwater depletions, groundwater pumping in most regions still exceeds sustainable groundwater recharge rates. Projecting current pumping rates forward in time, we have calculated the time to aquifer exhaustion. Figure 81 shows when the aquifer is likely to no longer be able to sustain continued pumping in the High Plains Aquifer counties of Kansas and Nebraska.

Counties of highest concern are those with 25 or fewer years of sustainable groundwater use. These vulnerable counties are largely associated with areas with extensive irrigated agriculture and zones at the margin of the High Plains Aquifer where the formation thins. In total, 18 counties in Kansas are at the highest level of risk. In addition, there are 12 counties in Kansas with projected aquifer life of 25-50 years. Thirty counties in Kansas and seven in Nebraska are of concern with aquifer life projected between 50 and 100 years.

Falling groundwater levels means additional energy is required to lift water for irrigation, resulting in higher cost to the water user. To explore this effect, the times when the cost to pump (lift) groundwater for irrigation or other uses increases by 25%, 50% and 75% over current rates were calculated. These calculations assumed current pumping rates and associated groundwater level declines projected into the future. Time to 25%, 50%, and 75% increased pumping costs on a county level basis for Kansas and Nebraska are mapped in Figure 82 through Figure 84. The pattern of timing of groundwater decline and timing of groundwater exhaustion (Figure 81) is consistent across these maps. Counties with relatively short times to groundwater exhaustion also tend to be the counties with the shortest time to 25% (or greater) increase in pumping costs. For many counties, the aquifer becomes exhausted before a 50% or 75% increase in pumping costs is realized (i.e., timing does not change between the maps for the 50% and 75% increase in cost).

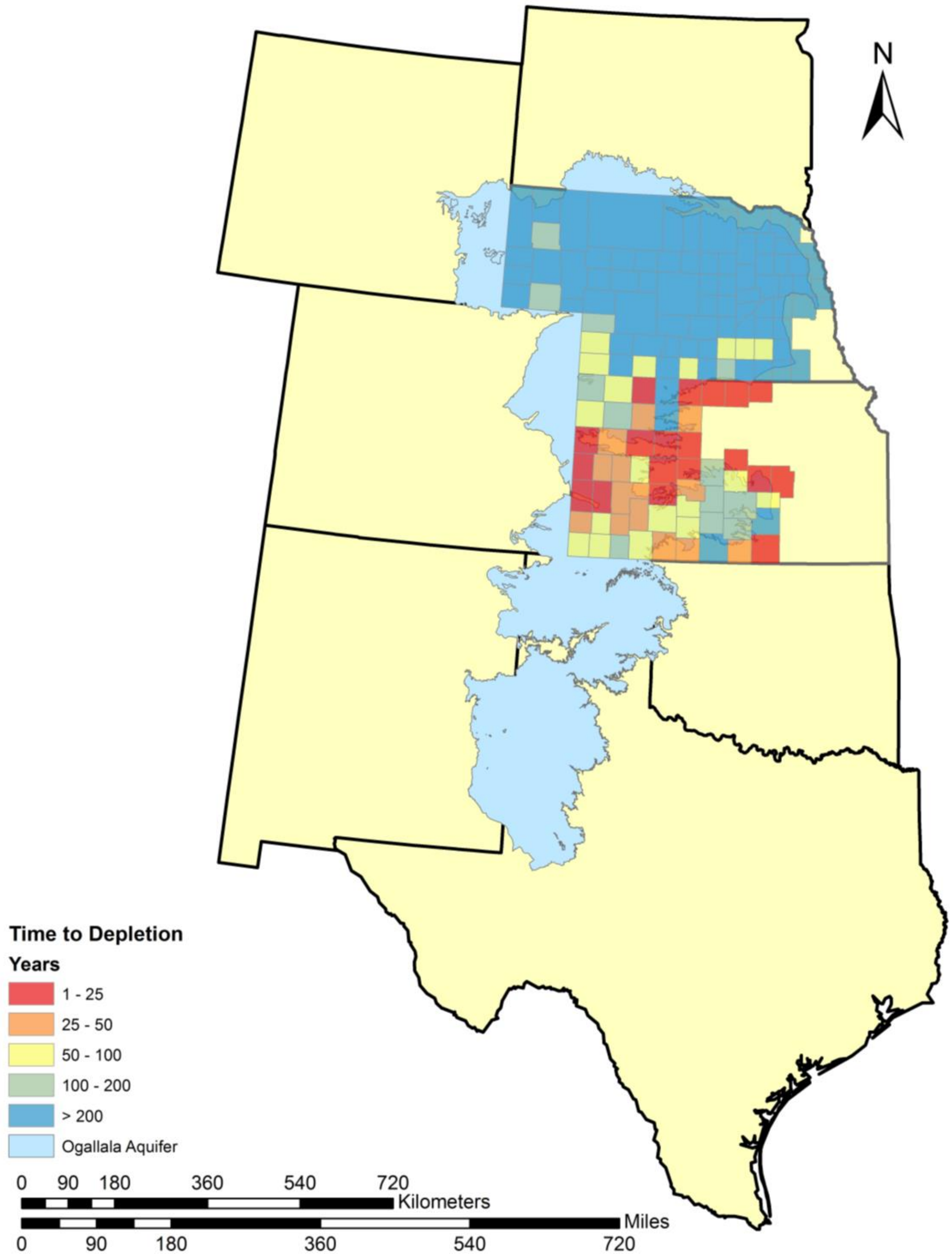

Figure 81—Time at Which Continued Pumping of the High Plain Aquifer is likely to Become Unsustainable

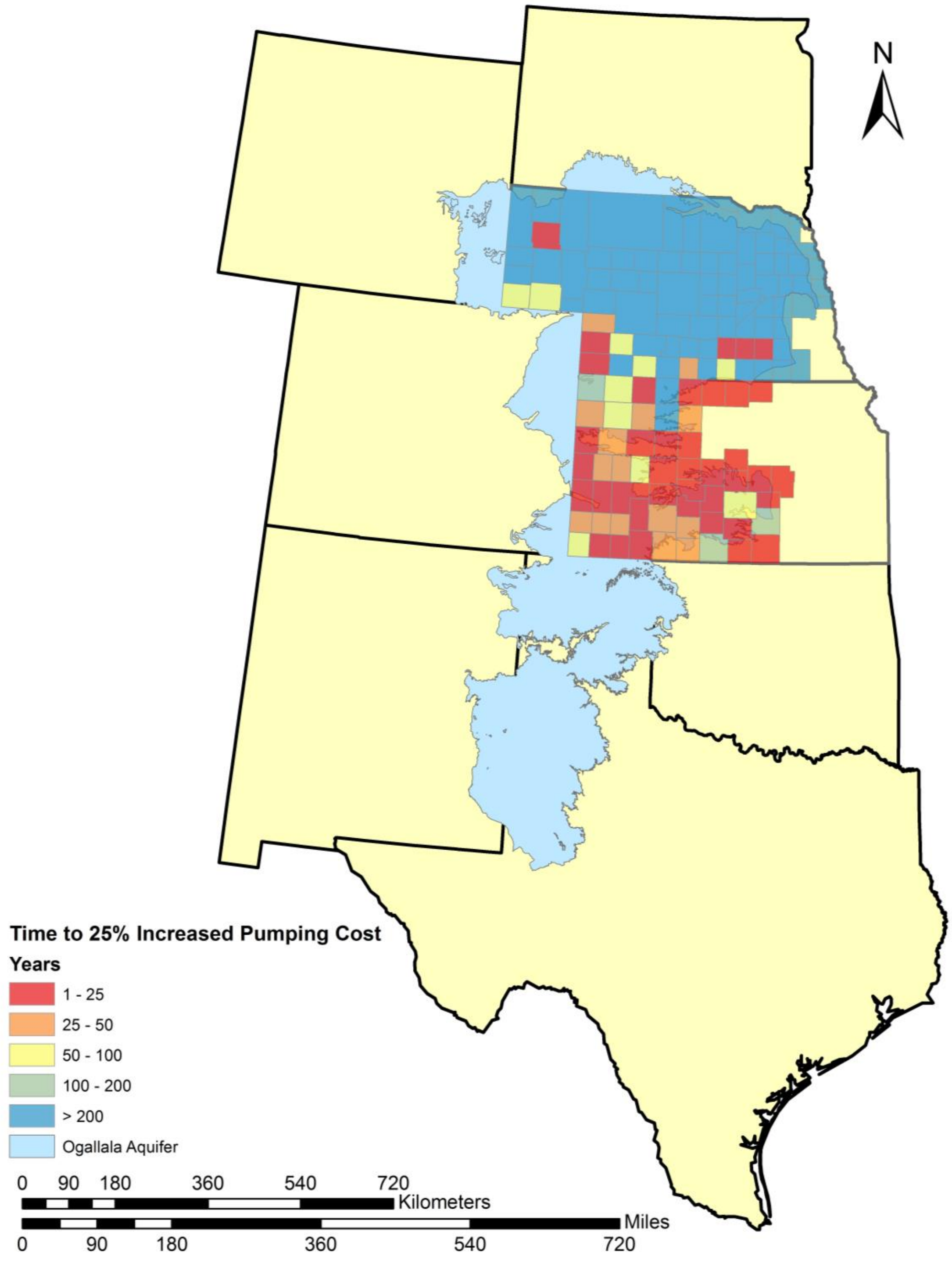

Figure 82—Time When the Cost to Pump (Lift) Groundwater for Irrigation or Other Uses Increases by 25% over Current Rates

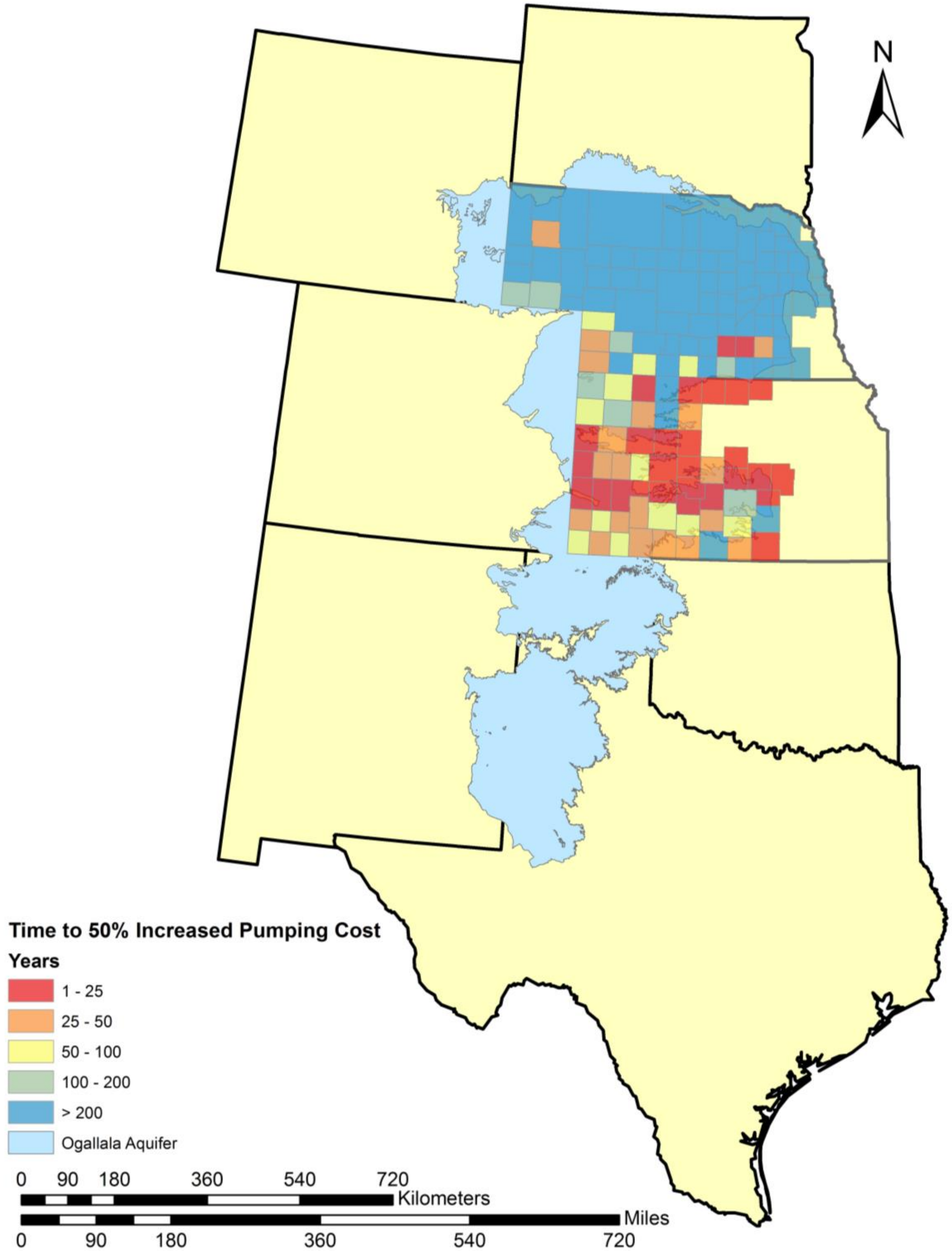

Figure 83—Time When the Cost to Pump (Lift) Groundwater for Irrigation or Other Uses Increases by 50% over Current Rates

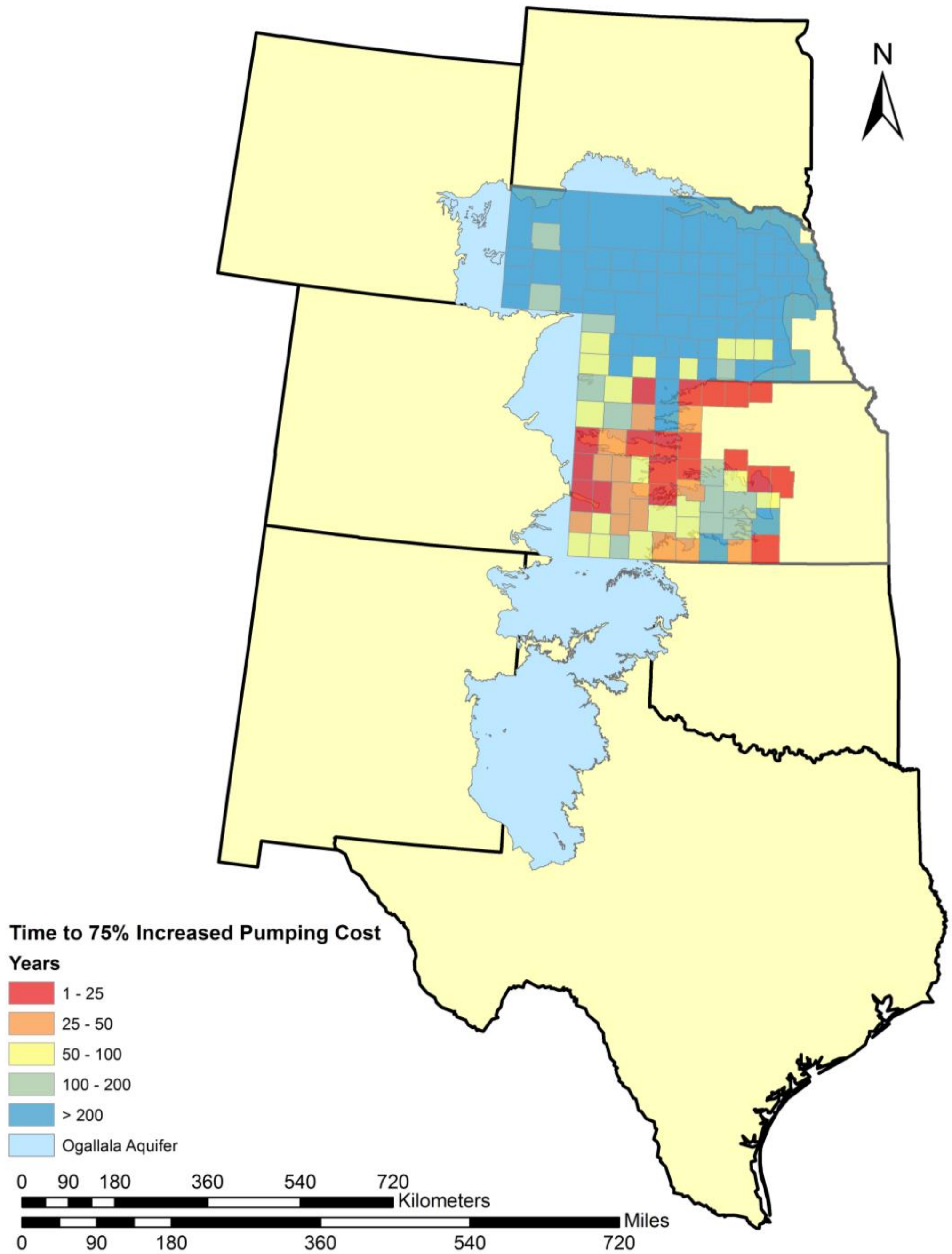

Figure 84—Time When the Cost to Pump (LIFT) Groundwater for Irrigation or Other Uses Increases by 75% Over Current Rates

3.4 Economic Analysis Results

3.4.1 Empirical Regional Results

The data used in the estimation are compiled from the 1982 through 2012 Census of Agriculture, maintained by the USDA. Exit probability was estimated using data from all states located on the High Plains Aquifer (Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming, from here on referred to collectively as High Plains States). Due to the number of observations, this data set was limited to farm operations that had responded to at least there censuses $(n = 234{,}142)$. Table 12 presents the results from logit model predicting farm exit. Note that there are two specifications of the logit model, which vary only in detail regarding irrigation. Specifically, the model presented in Column 1 does not account for whether the specific use of irrigation corresponds to farm operation specialty. The model presented in Column 2 includes interactions between farm specialty and irrigation use. These interactions were included to account for farms where land is irrigated for uses other than their specialty. It is likely that extraction costs are a much more salient concern to farm operators whose irrigation decisions relate directly to their specialty.

First, for both models, the coefficient on $OGALLALA\ COUNTY$ is negative and highly significant (beyond the 1% level). From this, we can infer that farm operations across the High Plains States are less likely to exit if they are operating within a county that is over the aquifer. Next, for both models, the coefficient on $IRRIGATED\ CROPS$ is negative and highly significant (beyond the 1% level). Likewise, the coefficient on $IRRIGATED\ PASTURE$ is also negative and highly significant (beyond the 1% level) for both model specifications. For model #1, the coefficient for $BEEF$ is positive and highly significant (beyond the 1% level). For the model presented in Column 2, the coefficient on $BEEF$ is negative and highly significant (beyond the 1% level). The interaction between $BEEF$ and $IRRIGATED\ PASTURE$ is positive and highly significant (beyond the 1% level). This suggests that although farms that specialize in beef are less likely to exit, this effect is limited to those that do not rely on irrigated pasture lands.

For both models, specialization in $CASHCROPS$ is associated with a decrease in probability of exit (both models significant beyond the 1% level). When PS, however, is interacted with $IRRIGATED\ CROPS$, the probability of exit increases by a highly significant amount (beyond the 1% level).

The variable of interest in the logit model is the coefficient on the $UTILITY\ EXPENDITURES$ variables. For both models, coefficient on $UTILITY\ EXPENDITURES$ is positive and highly significant. However, the coefficient on $UTILITY\ EXPENDITURES$ for the model presented in Column 2 is roughly double the size of the coefficient on $UTILITY\ EXPENDITURES$ seen in Column 1. Given the non-linearity of the logit model, however, it should not necessarily be interpreted that the model in Column 2 is predicting an impact twice as high as that of the model predicted in Column 1.

Table 12—Logit Model Predicting Farm Exit (All High Plains States)

Variable	1	2
OGALLALA COUNTY (Reference: Not Located on aquifer)	-0.1212*** (0.0273)	-0.3413*** (0.0379)
IRRIGATED CROPS	-0.5668*** (0.0350)	-1.5625*** (0.0374)
IRRIGATED PASTURE	-0.4128*** (0.0318)	-0.1656*** (0.0427)
IRRIGATED CROPS × *CASHCROPS SPECIALTY*		1.5138*** (0.0168)
IRRIGATED PASTURE × *BEEF SPECIALTY*		0.1790*** (0.0174)
IRRIGATED PASTURE × *DAIRY SPECIALTY*		-0.5654*** (0.0353)
UTILITY EXPENDITURES ($1,000s)	0.0012*** (0.0003)	0.00245*** (0.00028)
FUEL and OIL EXPENDITURES ($1,000s)	-0.0009*** (0.0003)	-0.00357*** (0.00035)
SALESCLASS (Reference: Less than $1,000)		
$1,000 to $9,999	-0.2060*** (0.0268)	-0.1710*** (0.0277)
$10,000 to $49,999	-0.2881*** (0.0280)	-0.3401*** (0.0290)
$50,000 to $99,999	-0.6188*** (0.0324)	-0.7746*** (0.0335)
$100,000 to $249,999	-0.8580*** (0.0306)	-1.0882*** (0.0317)
More than $250,000	-0.8346*** (0.0296)	-0.8573*** (0.0309)
AGE (Reference: Age under 45)		
≥ 45 *and* < 55	-0.0332* (0.0177)	-0.0522*** (0.0183)
≥ 55 *and* < 65	-0.2117*** (0.0171)	-0.2514*** (0.0177)
≥ 65	0.0767*** (0.0168)	0.0218 (0.0175)
GENDER (Reference: Male)	0.4090*** (0.0208)	0.4451*** (0.0215)
RACE (Reference: Other)		
WHITE	-0.4159** (0.1882)	-0.2612 (0.1931)
BLACK	0.0166 (0.1969)	0.0955 (0.2021)
AMERICAN INDIAN	0.1686 (0.2054)	0.2384 (0.2107)
DAYS WORKED OFF − *FARM* (Reference: 0 to 199)		
200 DAYS OR MORE	-0.4434*** (0.0263)	-0.4217*** (0.0272)

Variable	1	2
SPECIALTY		
BEEF	0.1251***	-0.3839***
	(0.0437)	(0.0489)
HOGS	-1.2363***	-1.5115***
	(0.0433)	(0.0516)
CASH CROPS	-0.5932***	-1.4573***
	(0.0666)	(0.0691)
DAIRY	-1.7336***	-1.8377***
	(0.0599)	(0.0671)
YEAR (Reference: 2012)		
1987	5.6906***	6.5521***
	(0.1340)	(0.2143)
1992	4.9921***	5.8703***
	(0.0292)	(0.0315)
1997	4.5424***	5.4544***
	(0.0293)	(0.0315)
2002	3.8844***	4.4959***
	(0.0274)	(0.0292)
2007	5.0851***	5.1644***
	(0.0252)	(0.0252)
CONSTANT	-1.4448***	-1.2885***
	(0.1941)	(0.2004)
OBSERVATIONS	234,142	234,142

Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Marginal effects of an increase in utility expenditure are calculated for the model presented in Column 2 of Table . The marginal effects were calculated, holding all other independent variables at their sample average. The standard error of the marginal effect was calculated using the Delta-method. The marginal effect of an increase in utility expenditures is 0.0262 (delta-method standard error was 0.00527, corresponding to a significance level beyond the 1% level).

3.4.2 Simulated State and National Economic Impacts

3.4.2.1 Scenario 1–Farm Proprietor Income

Results for Scenario 1, losses to farm proprietor income, Figure 85 to Figure 87, shows the GDP losses for each exit scenario of energy (utility) cost increases of 25% (baseline), 50% (medium), and 75% (extreme) with the scenarios ranked top to bottom in descending order of total GDP losses for the forecast period of 46 years. Scenario 1 depicts farm exits as decreases to farm proprietor income because this is representative of overall shrinking of the farm market. Notice that for the forecast of farm exits in all possible energy future costs baseline, medium, and extreme, the most significant contributors to GDP losses is the extreme case of energy cost increases to pump groundwater. This is an expected result given the energy needs associated with greater groundwater pumping depths. Total employment for the United States, Kansas, and Nebraska follows a similar pattern; refer to Appendix D for graphical depictions.

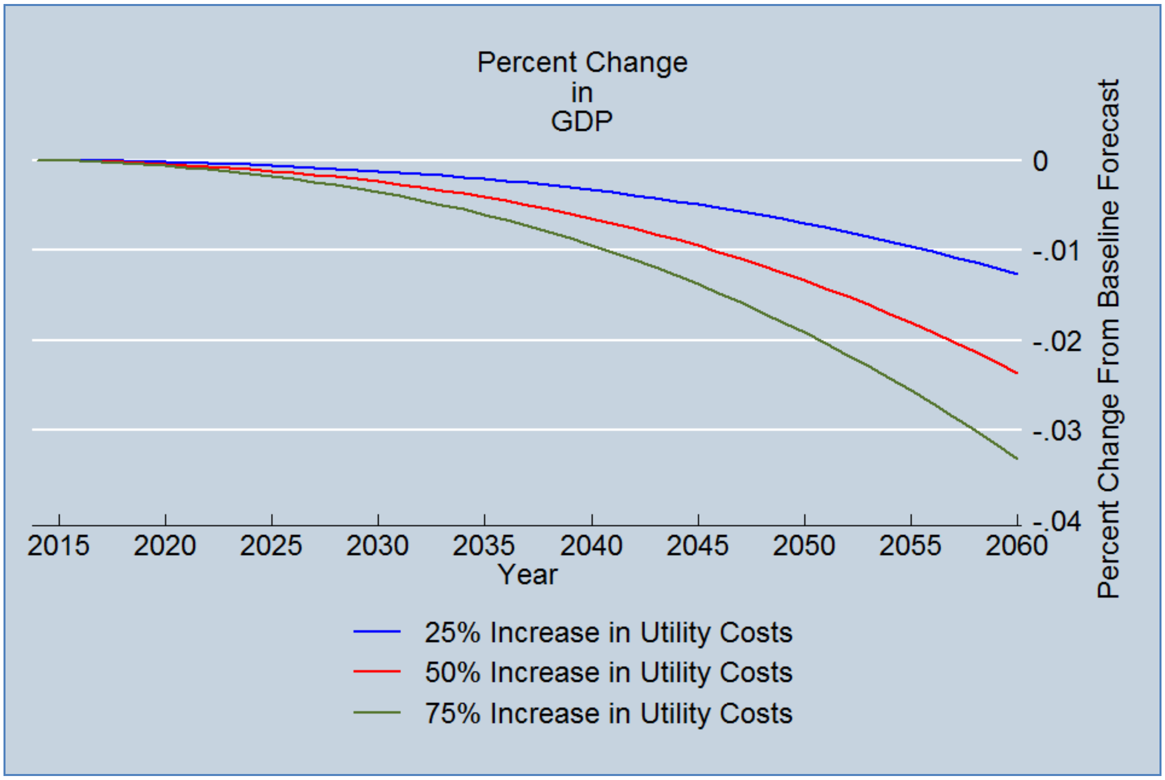

Figure 85—National: Annual Percent Change in GDP, Scenario 1 in the Affected Region

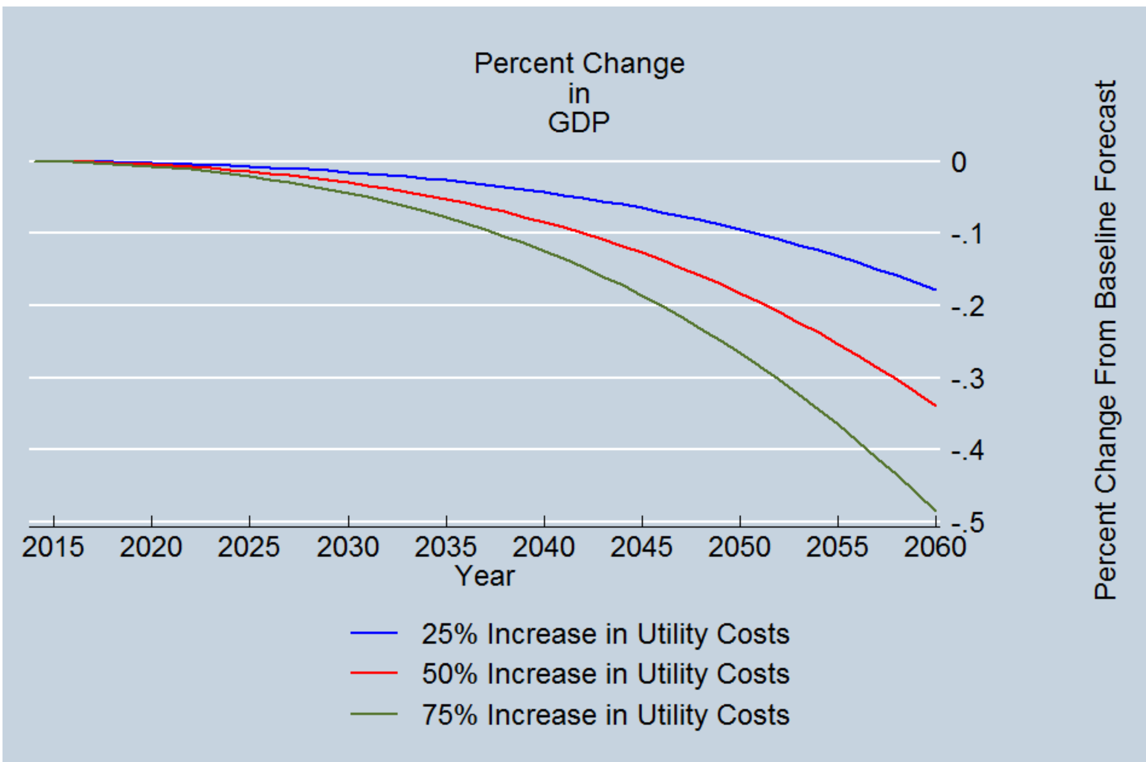

Figure 86—Kansas: Annual Percent Change in GDP, Scenario 1 in the Affected Region

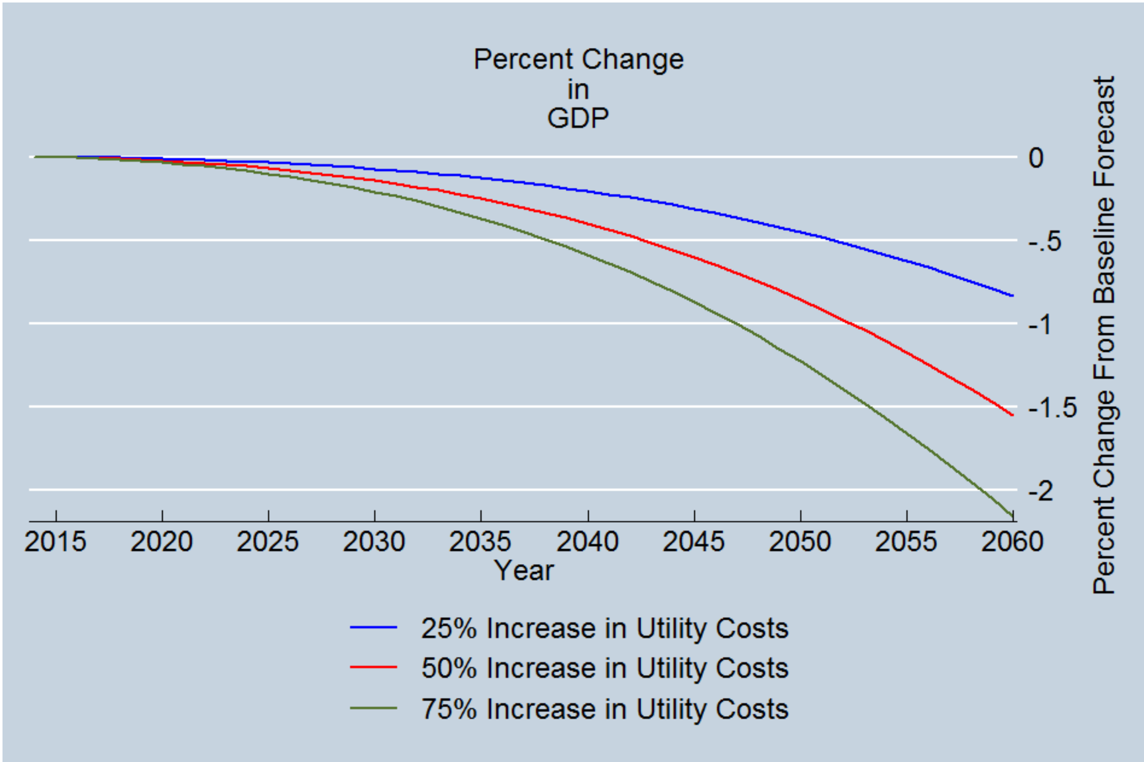

Figure 87—Nebraska: Annual Percent Change in GDP, Scenario 1 in the Affected Region

For losses to personal income and real disposable income, the percent change follows a similar pattern to GDP losses for Kansas, Nebraska, and the United States, with Nebraska showing the larger percent changes. Energy cost increase can directly affect proprietor income of those involved with agriculture production. As farm operations exit, proprietor income continues to fall. Recall from assumptions that farm operations can exit, and in real-world terms this can mean: farm is sold, farm becomes part of a larger operation, or some other farm operation can make up the lost production.

The primary function of farm exit is to show that a farm operation that once made income and produced agricultural goods is no longer doing so, but the main effect is that farm operation is no longer generating income. The farm production can, in a sense, "live on," but the overall number of farm operations is reduced. At the two-digit NAICS code level shown in Figure 88 and Figure 89, we have displayed the effects of the loss of proprietor income on all industries for Scenario 1 (75%). The largest dollar losses secondary to farm loss are for the Construction, Retail Trade, Health Care and Social Services, Real Estate and Rental Leasing, and Finance and Insurance. This is an expected effect because these industries are related to personal income spending or changes in population (Health Care and Social Services). Explicit analysis of changes in population and demographics are outside the scope of the analysis.

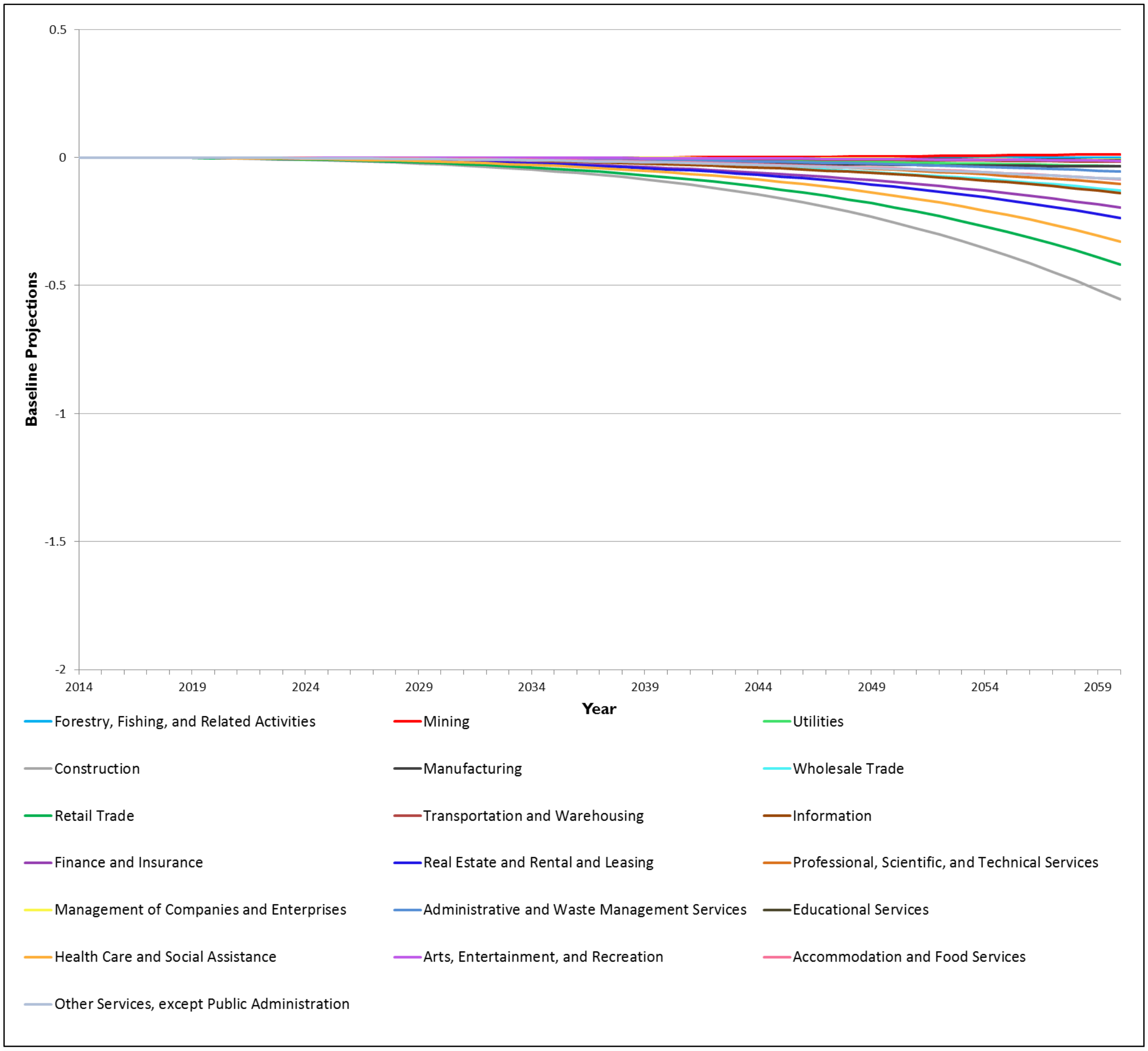

Figure 88—Kansas: Percent Change from Baseline Output, Scenario 1 (75%)

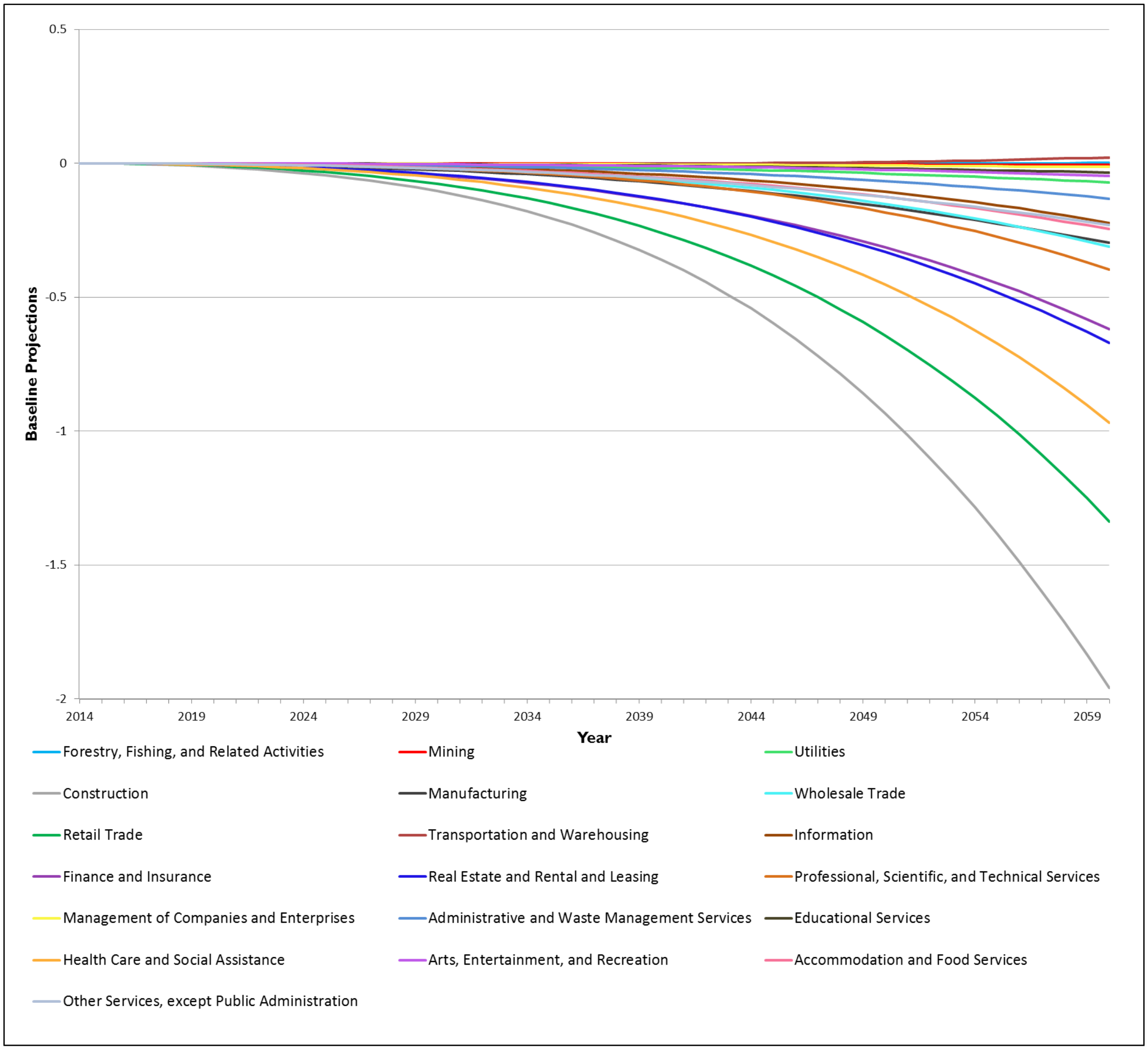

Figure 89—Nebraska: Percent Change from Baseline Output, Scenario 1 (75%)

With a decline in proprietor's income, another expected effect is declining levels of consumption (or demand), as shown in Figure 90 and Figure 91. REMI results provide changes in demand for 67 industry sectors. For Scenario 1, the greatest (and increasing) percent change in the demand for goods and services over time accrues to industry categories known as "luxury" because they are not explicitly necessary for everyday life. Kansas and Nebraska show similar trends with the same "luxury" categories affected with differences in the percent change from baseline and the ranking of affected industries.

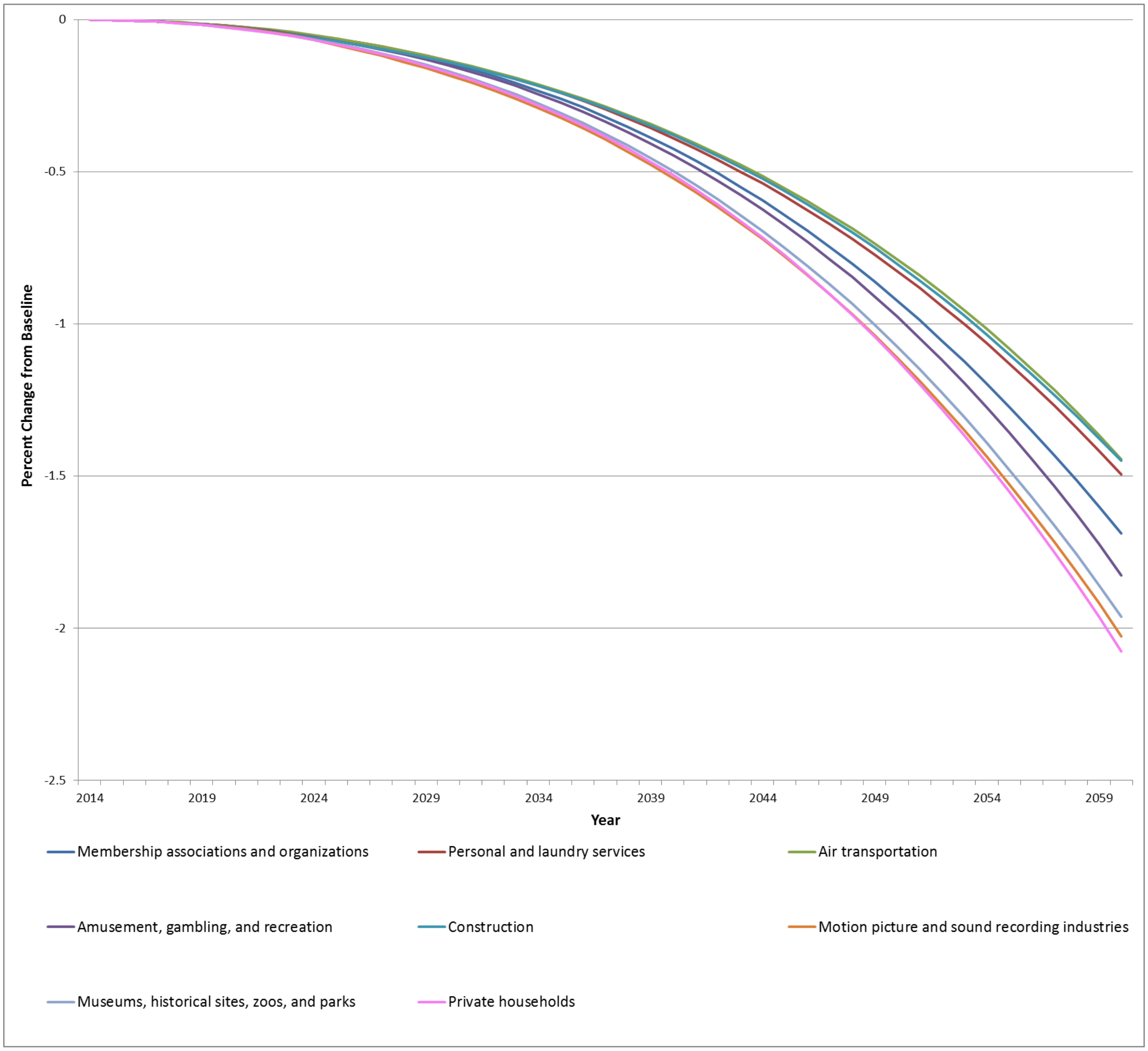

Figure 90—Kansas: Percent Change in Demand for Goods and Services, Scenario 1 (75%)

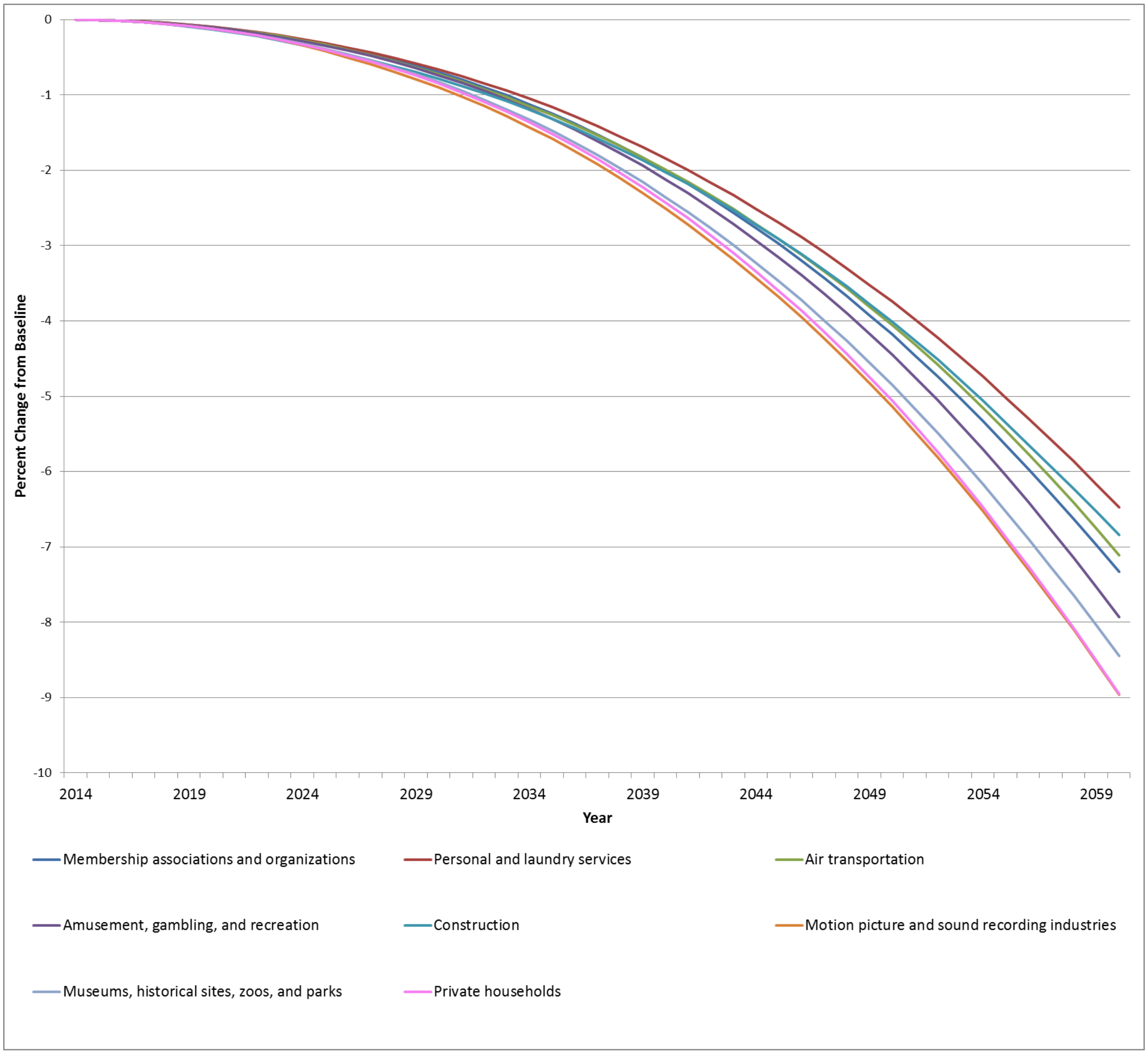

Figure 91—Nebraska: Percent Change in Demand for Goods and Services, Scenario 1 (75%)

As a result, there are follow-on impacts for sectors related to disposable income categories considered "luxury" goods and services; however, they do not have an equal effect on agriculture output. This outcome is not surprising for two reasons related to substitution. First, as farm operations exit, it can be assumed that larger operations within the state can and will make up the lost production. Second, affecting proprietor's income affects all goods and services that are part of the national consumer basket of goods used for analytical comparison.

Figure 92 through Figure 99 highlight changes in GDP and demand for goods and services under Scenario 1 for the 25% and 50% utility cost increases.

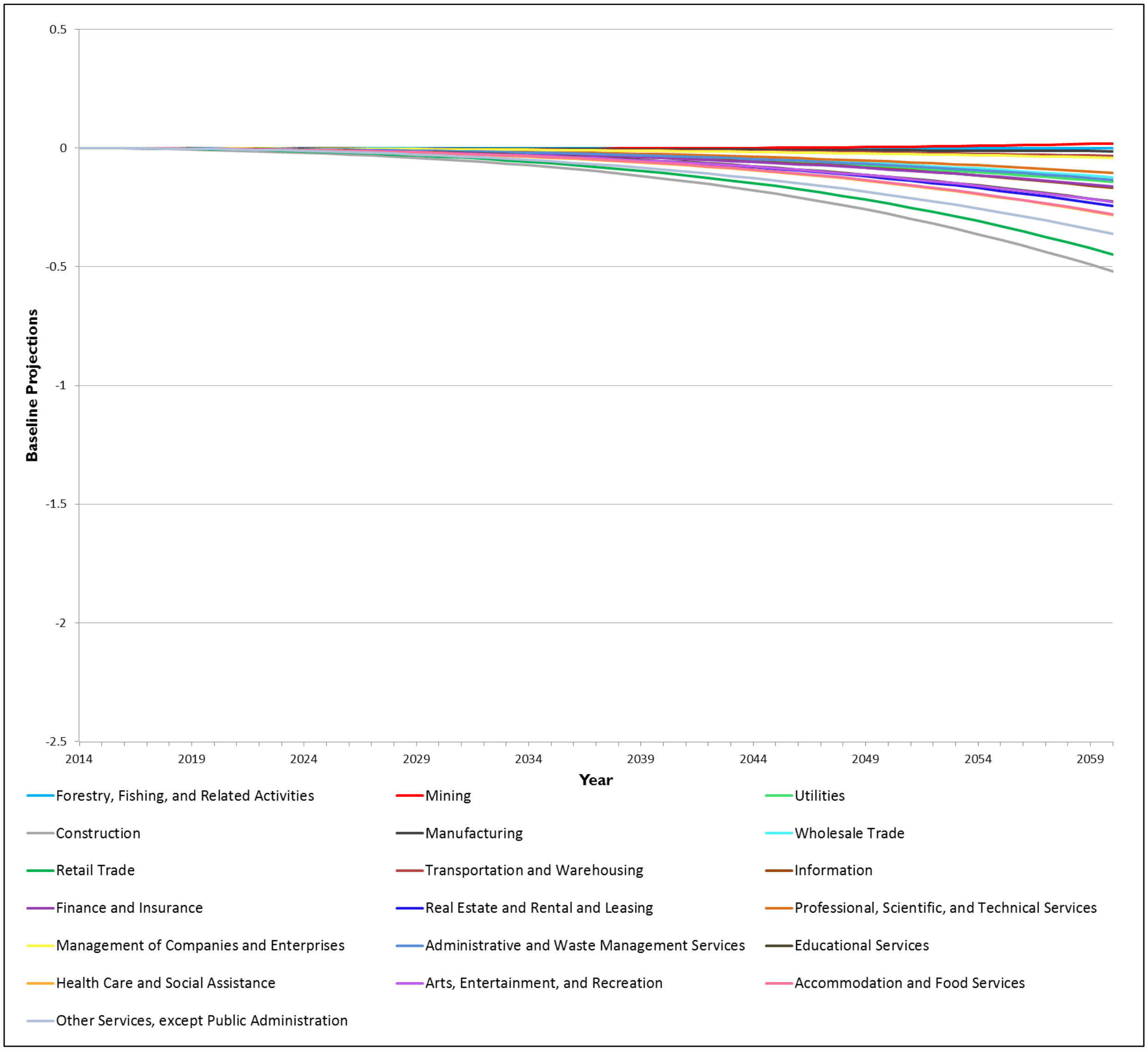

Figure 92—Kansas: Percent Change from Baseline Output, Scenario 1 (25%)

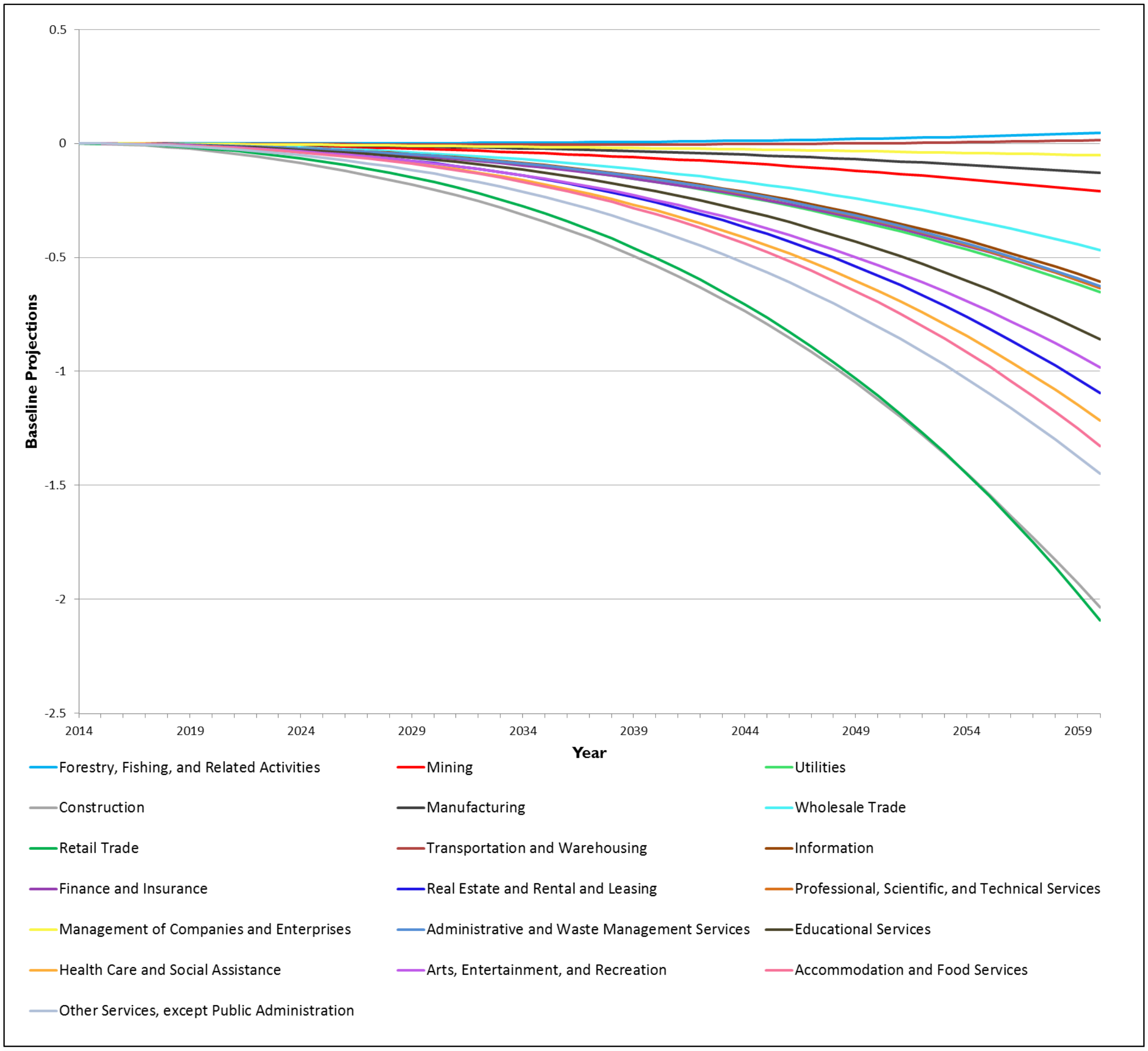

Figure 93—Nebraska: Percent Change from Baseline Output, Scenario 1 (25%)

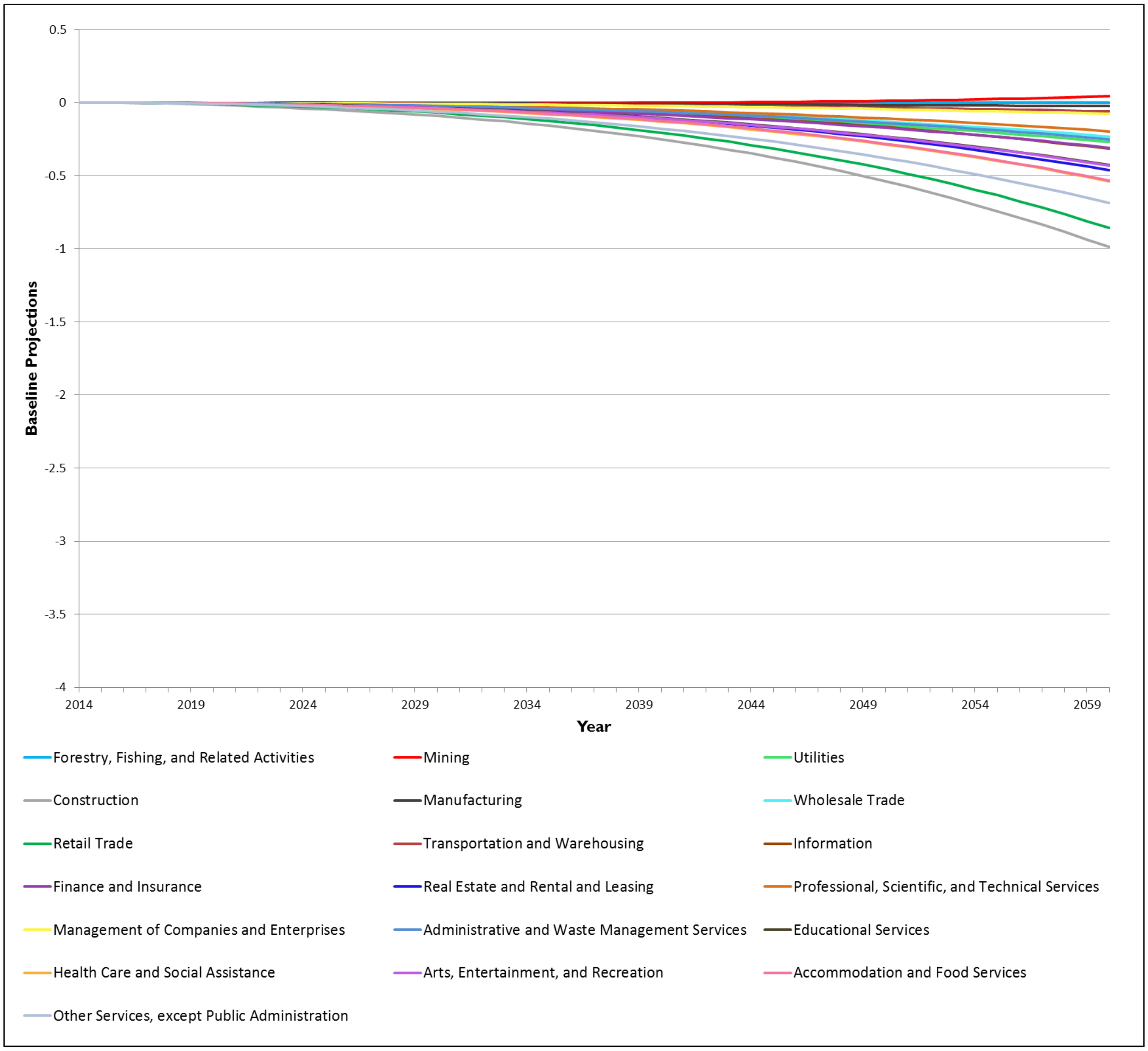

Figure 94—Kansas: Percent Change from Baseline Output, Scenario 1 (50%)

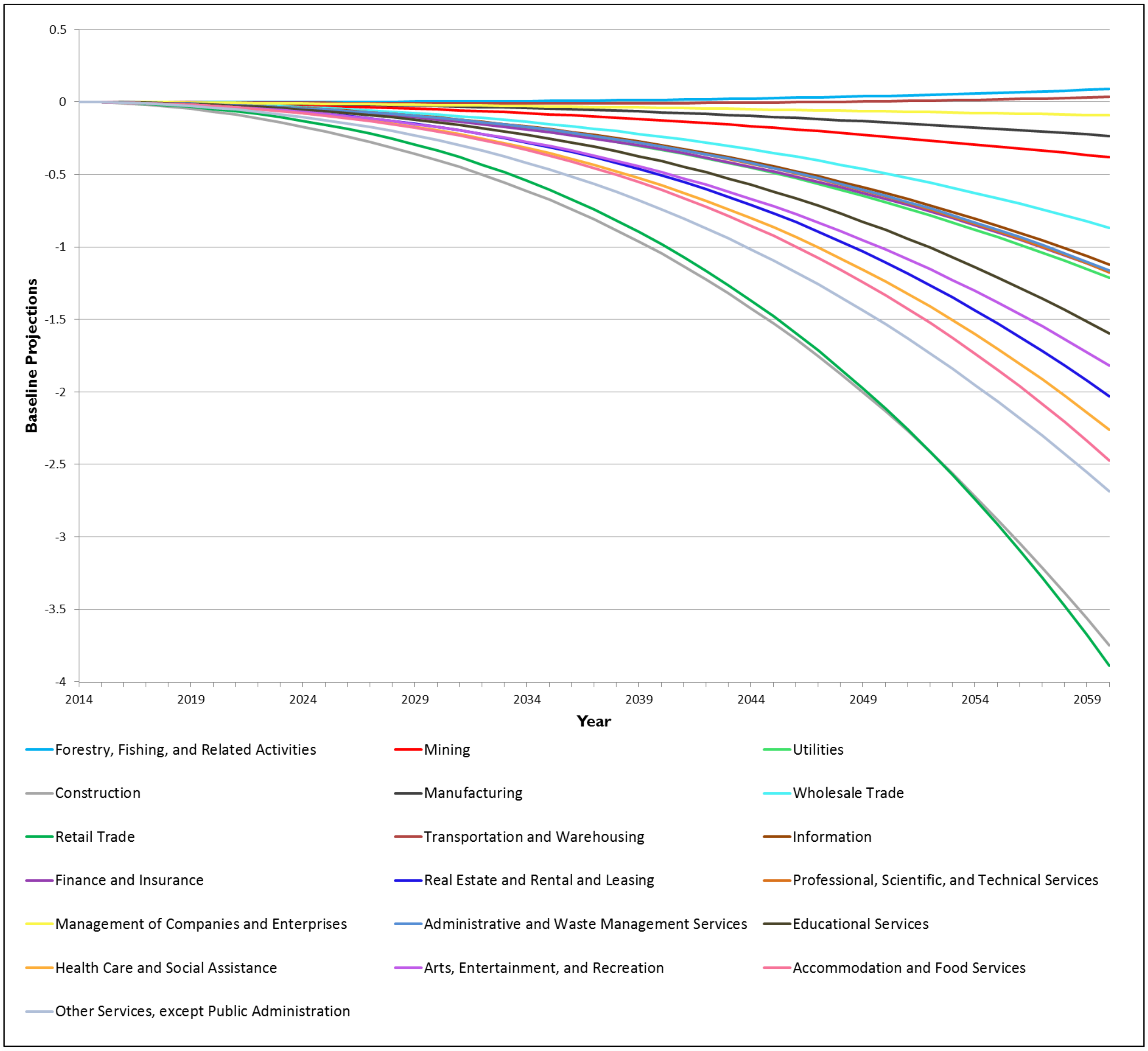

Figure 95—Nebraska: Percent Change from Baseline Output, Scenario 1 (50%)

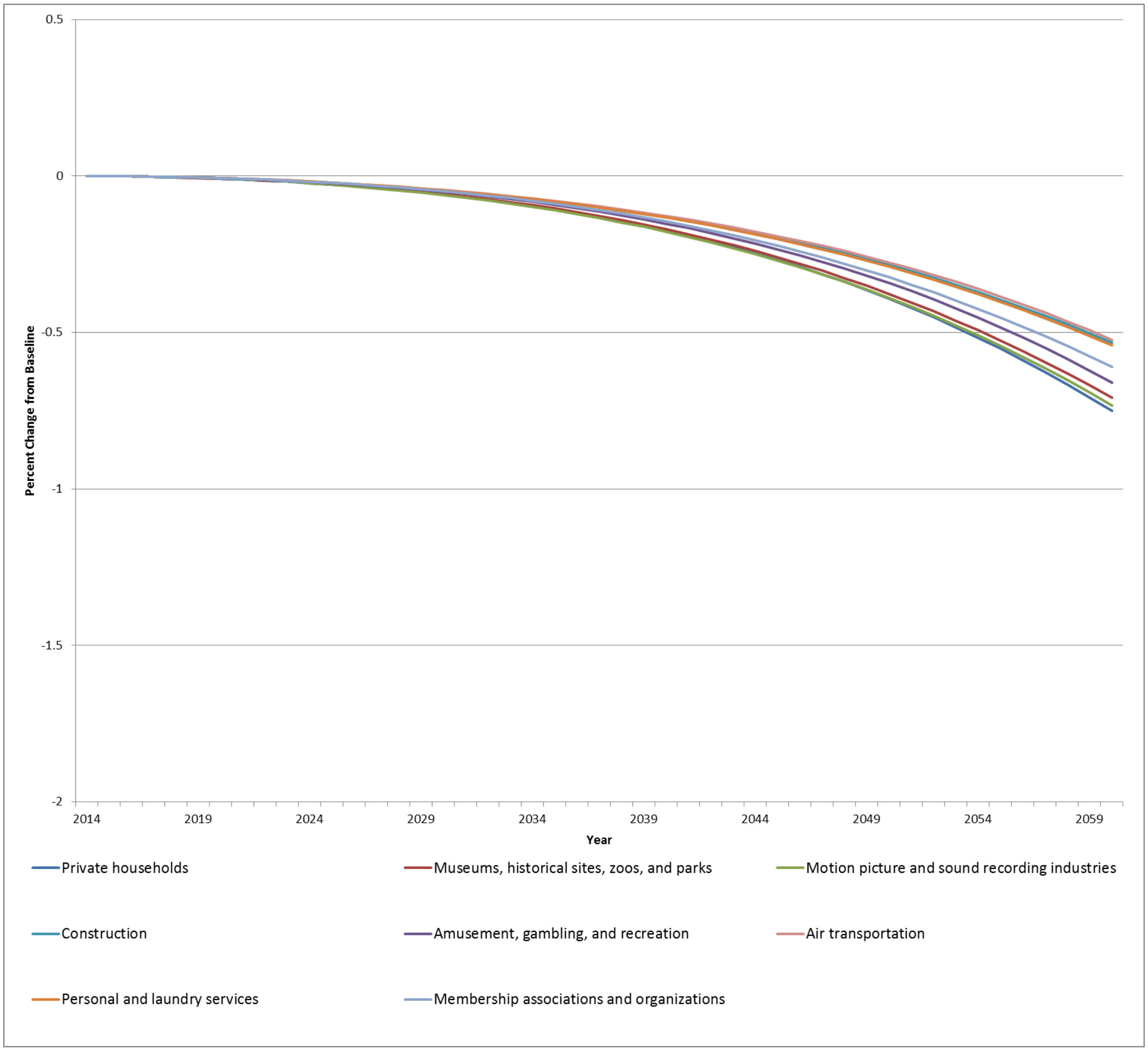

Figure 96—Kansas: Percent Change in Demand for Goods and Services, Scenario 1 (25%)

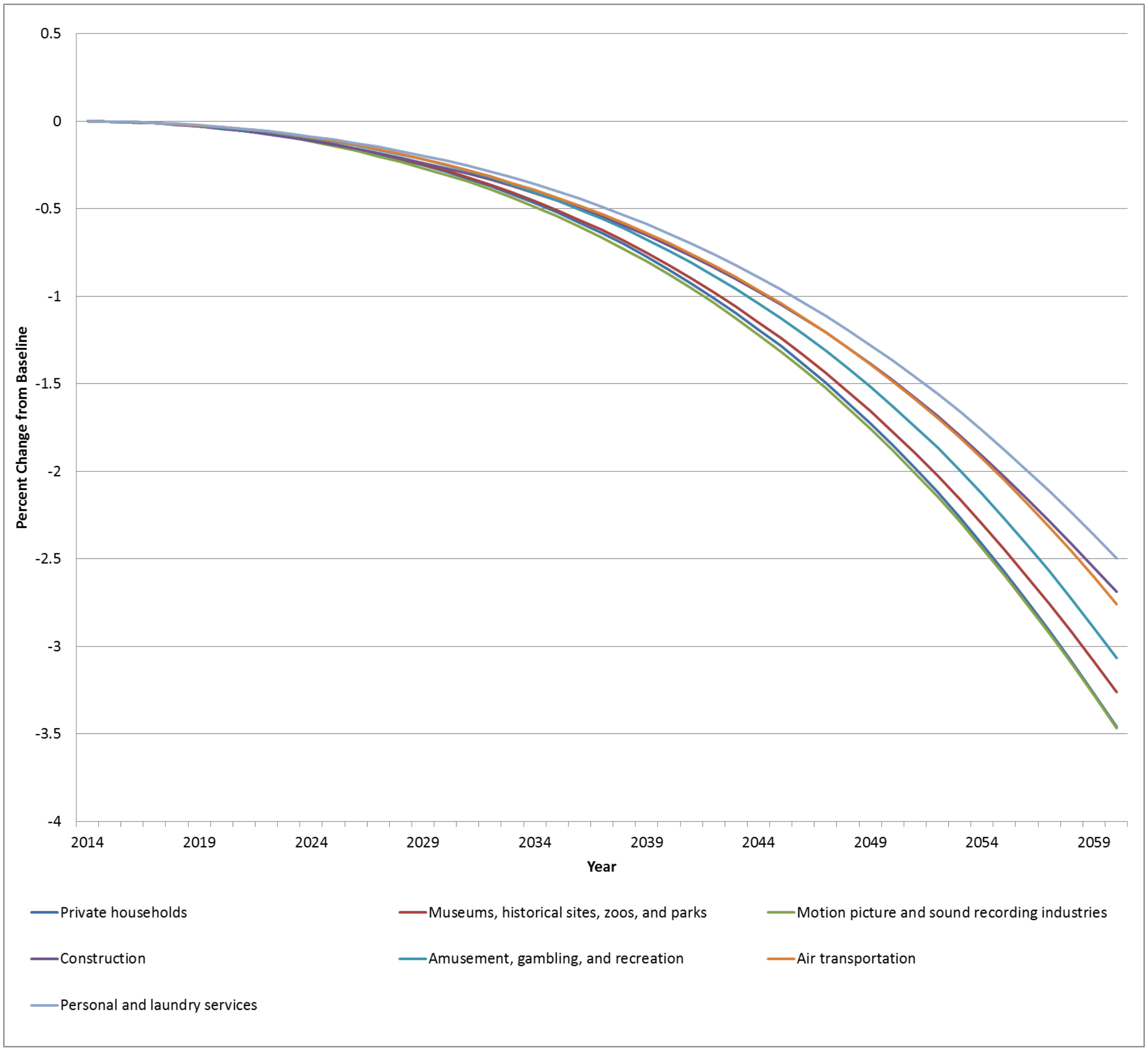

Figure 97—Nebraska: Percent Change in Demand for Goods and Services, Scenario 1 (25%)

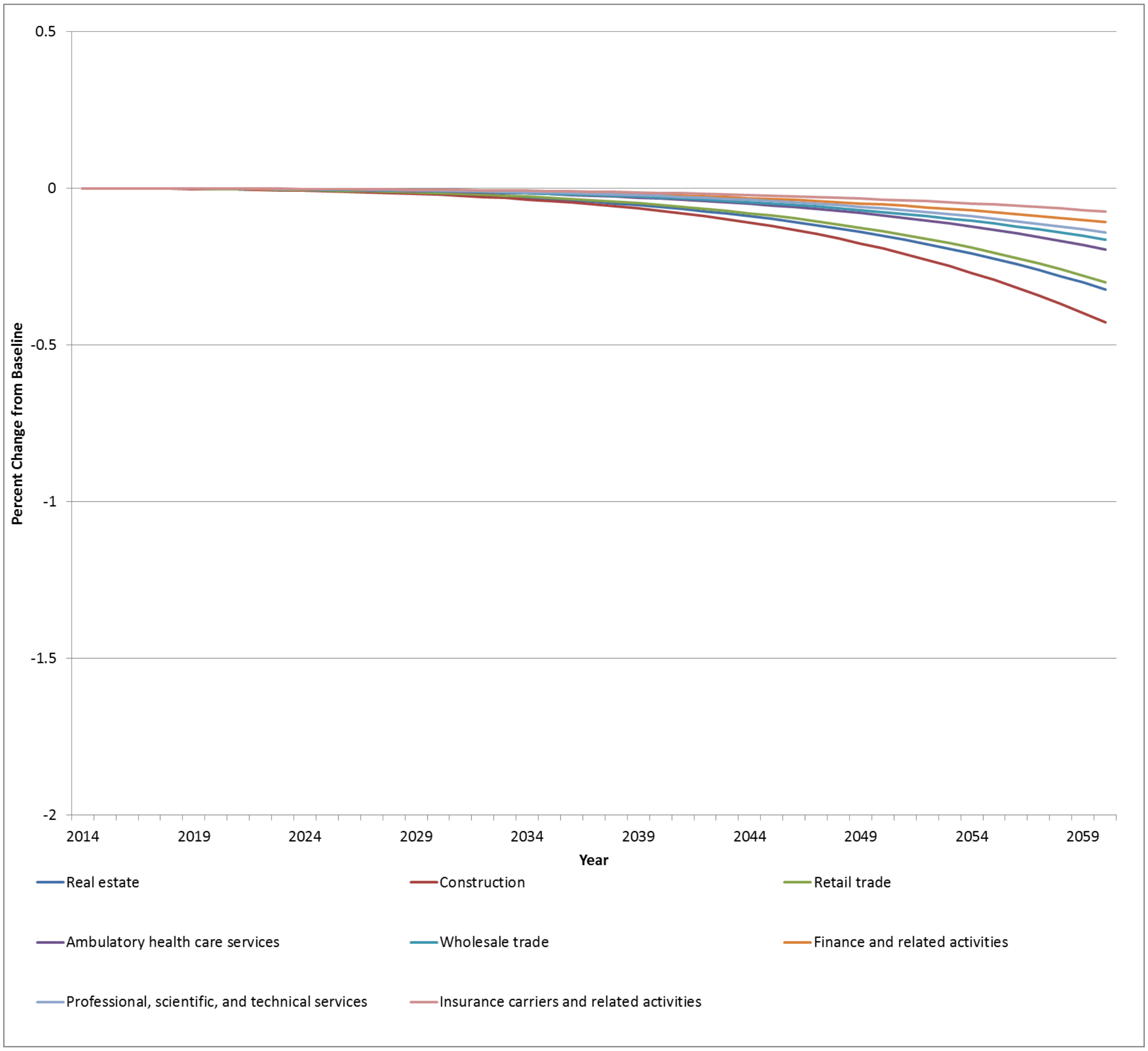

Figure 98—Kansas: Percent Change in Demand for Goods and Services, Scenario 1 (50%)

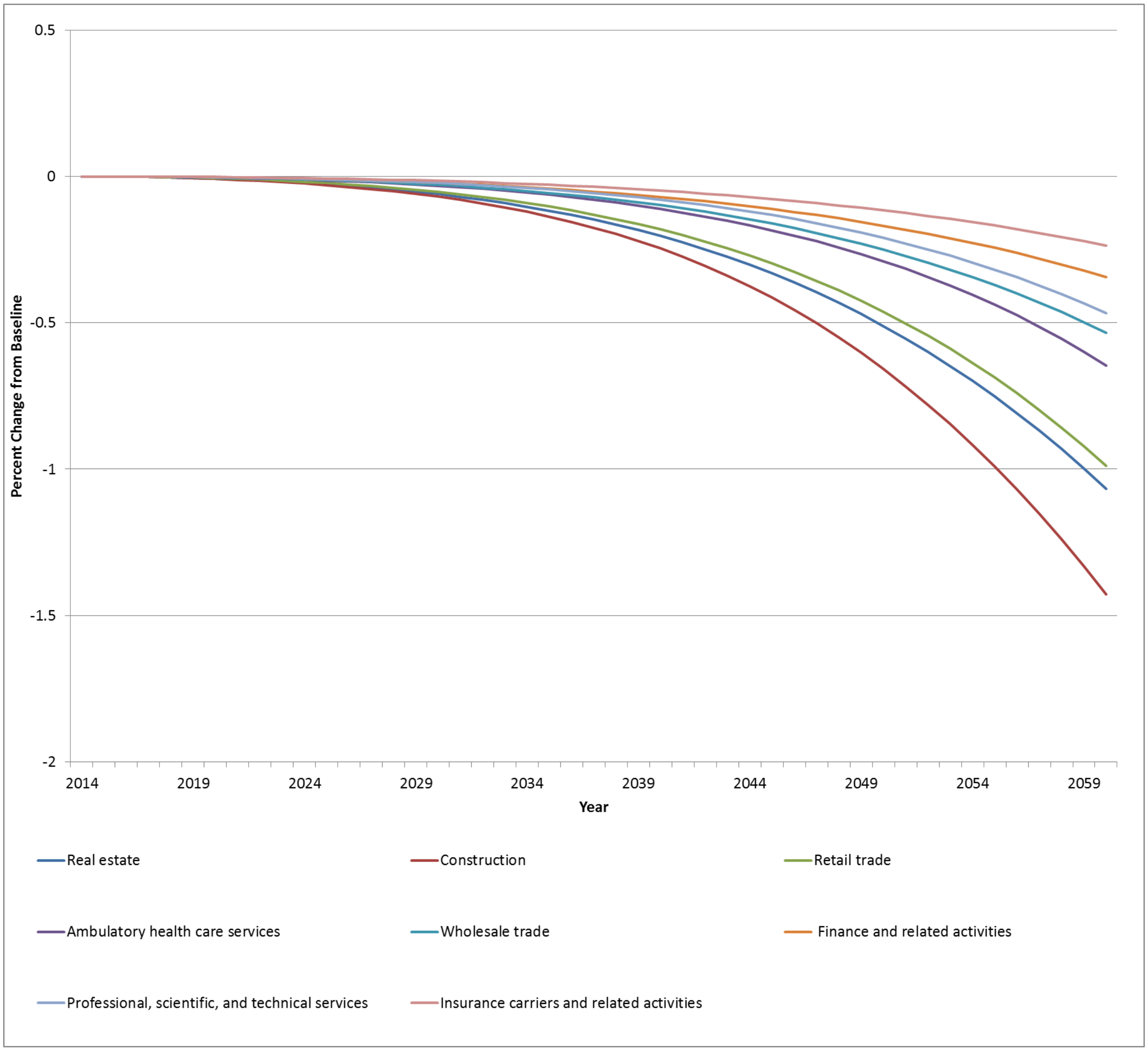

Figure 99—Nebraska: Percent Change in Demand for Goods and Services, Scenario 1 (50%)

3.4.2.2 Scenario 2–Reduced Irrigated Crop Acreage Results

Results for each bounded decrease in the cost to use energy to extract groundwater follow a similar annual pattern for the percent change from baseline; nationally, the impact is small. The effects on annual state GDP for Kansas and Nebraska represent a greater percentage change from baseline, as seen in Figure 101 and Figure 102. Nebraska is more reliant on agriculture as a foundational economic industry and, as a result, has greater negative economic outcomes. Negative outcomes extend to real disposable personal income, which is small for the United States (Figure 103) and Kansas (Figure 104) but more substantial for Nebraska (Figure 105), and employment, as shown in Figure 106, Figure 107, and Figure 108.

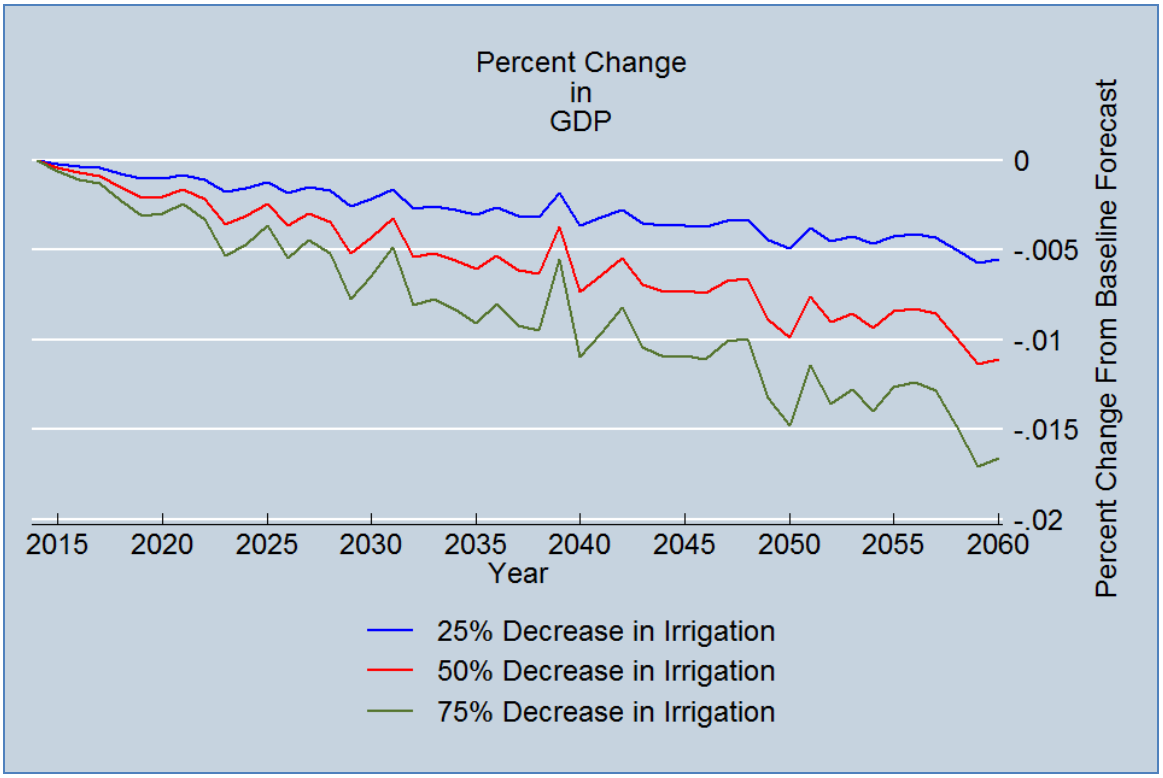

Figure 100—National: Annual Percent Change in GDP, Scenario 2, All Crops in the Affected Region

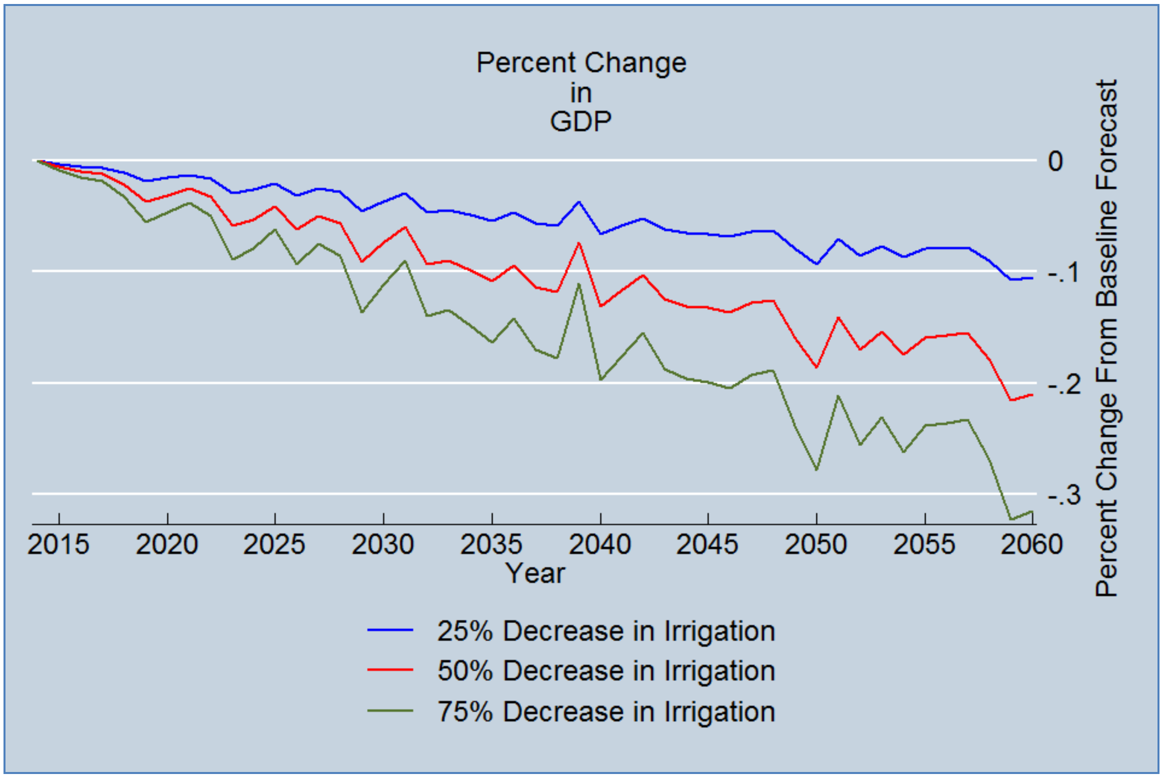

Figure 101—Kansas: Annual Percent Change in GDP, Scenario 2, All Crops in the Affected Region

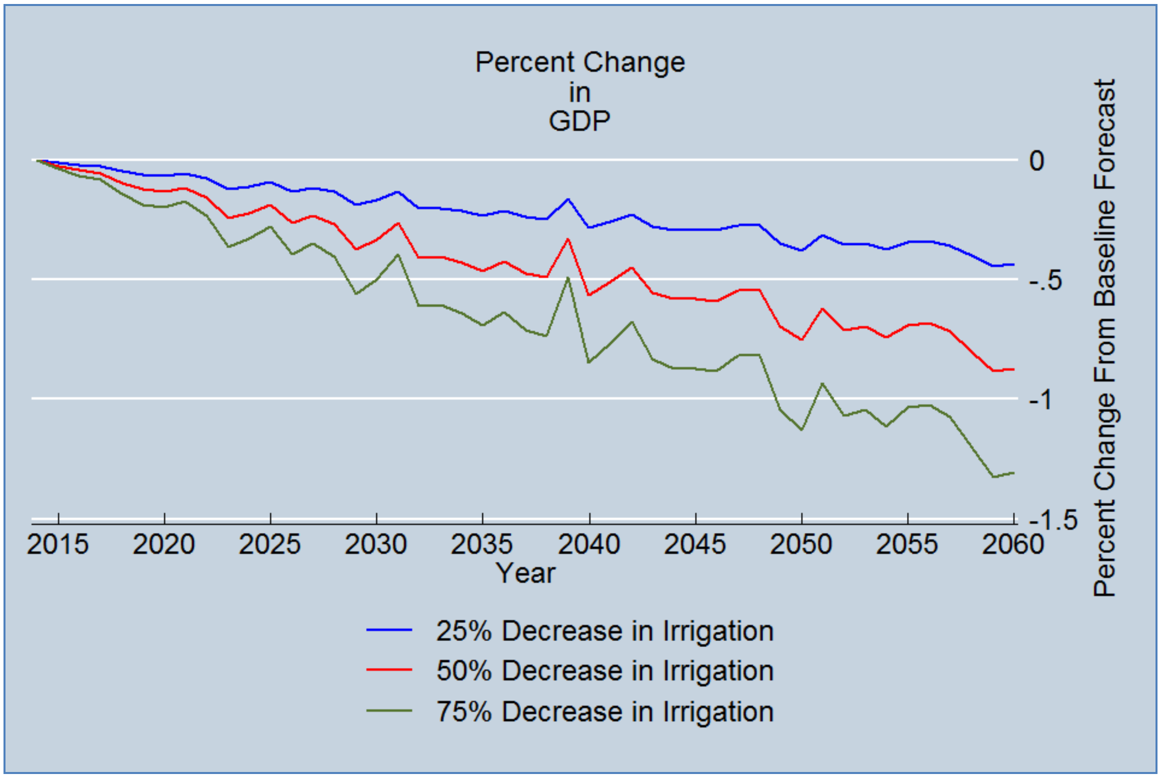

Figure 102—Nebraska: Annual Percent Change in GDP, Scenario 2, All Crops in the Affected Region

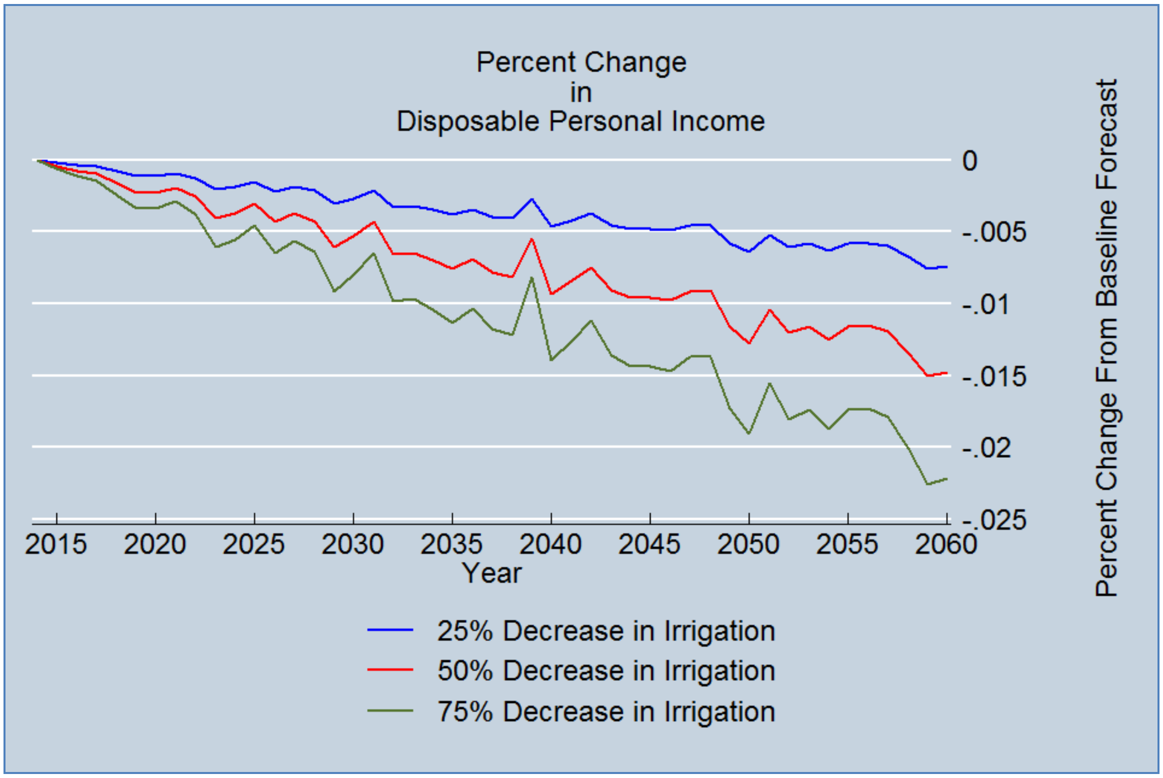

Figure 103—National: Percent Change in Real Disposable Income, Scenario 2, All Crops in the Affected Region

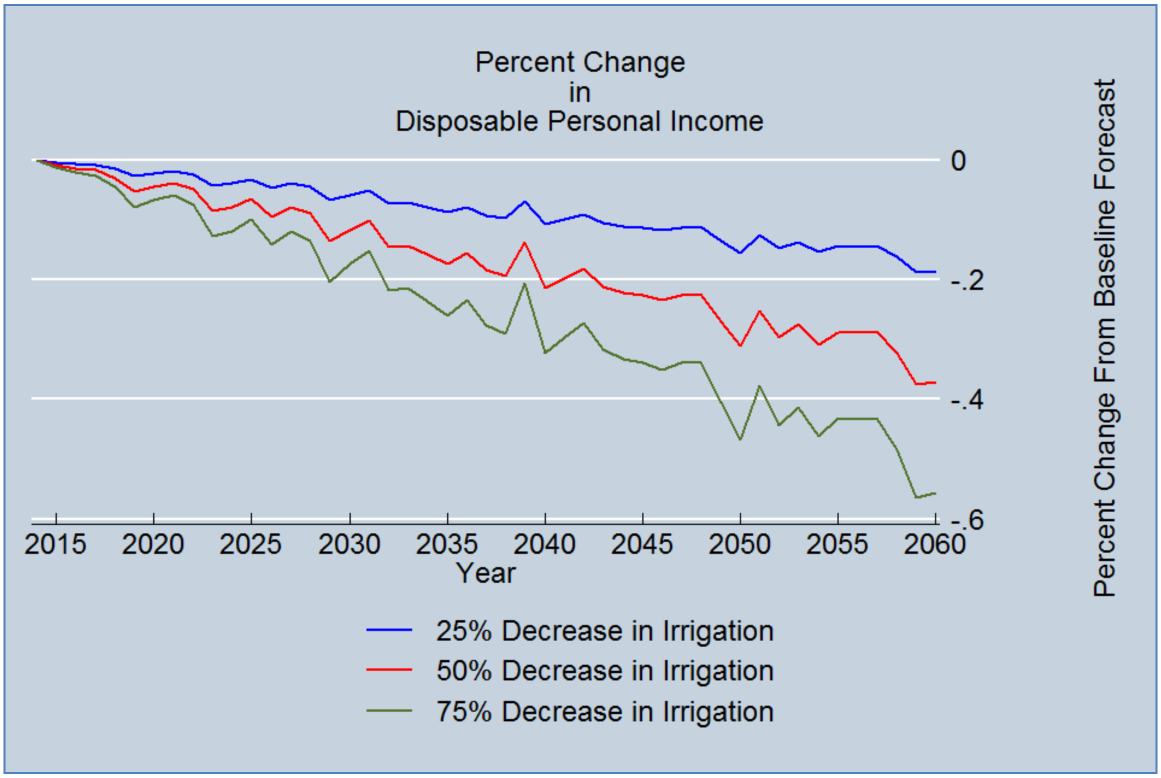

Figure 104—Kansas: Percent Change in Real Disposable Income, Scenario 2, All Crops in the Affected Region

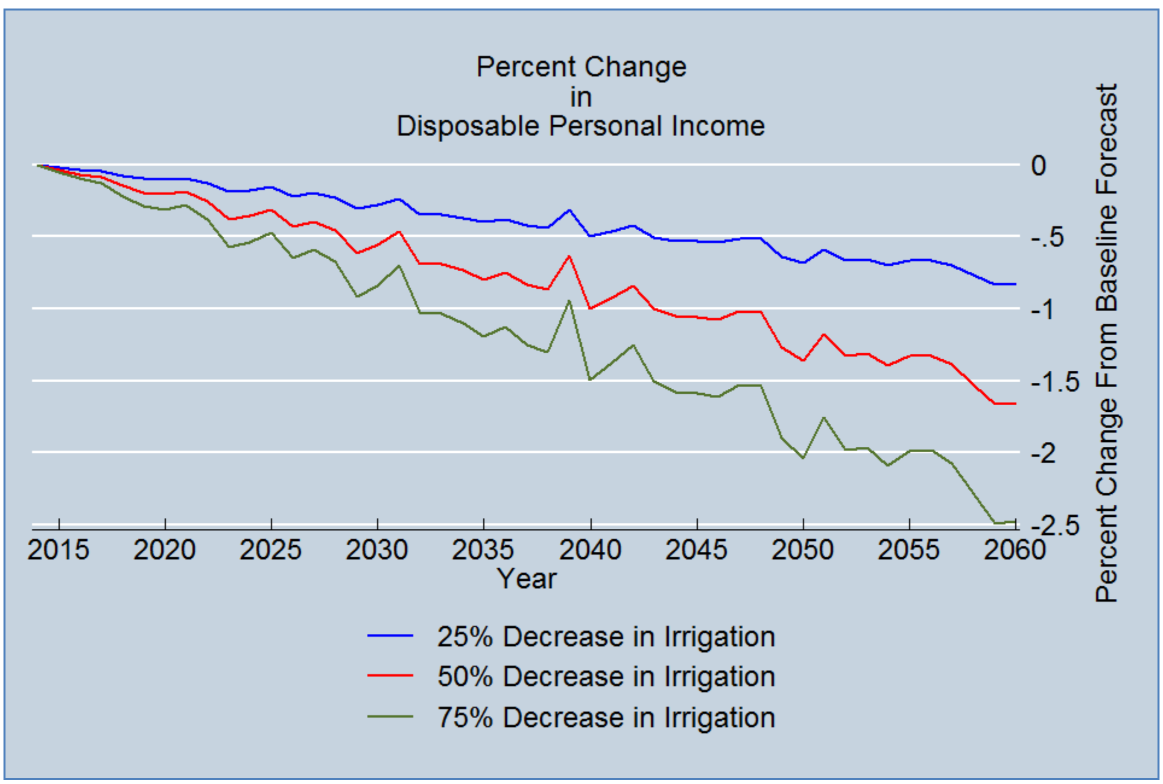

Figure 105—Nebraska: Percent Change in Real Disposable Income, Scenario 2, All Crops in the Affected Region

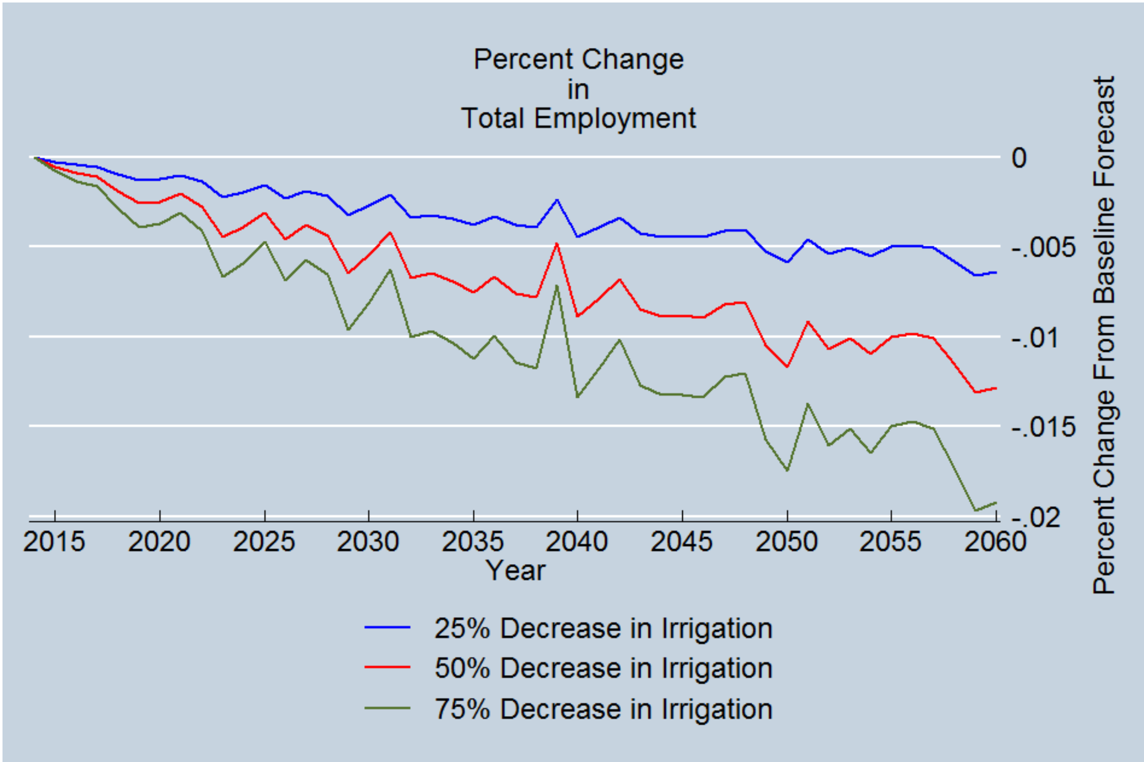

Figure 106—National: Percent Change in Total Employment, Scenario 2, All Crops in the Affected Region

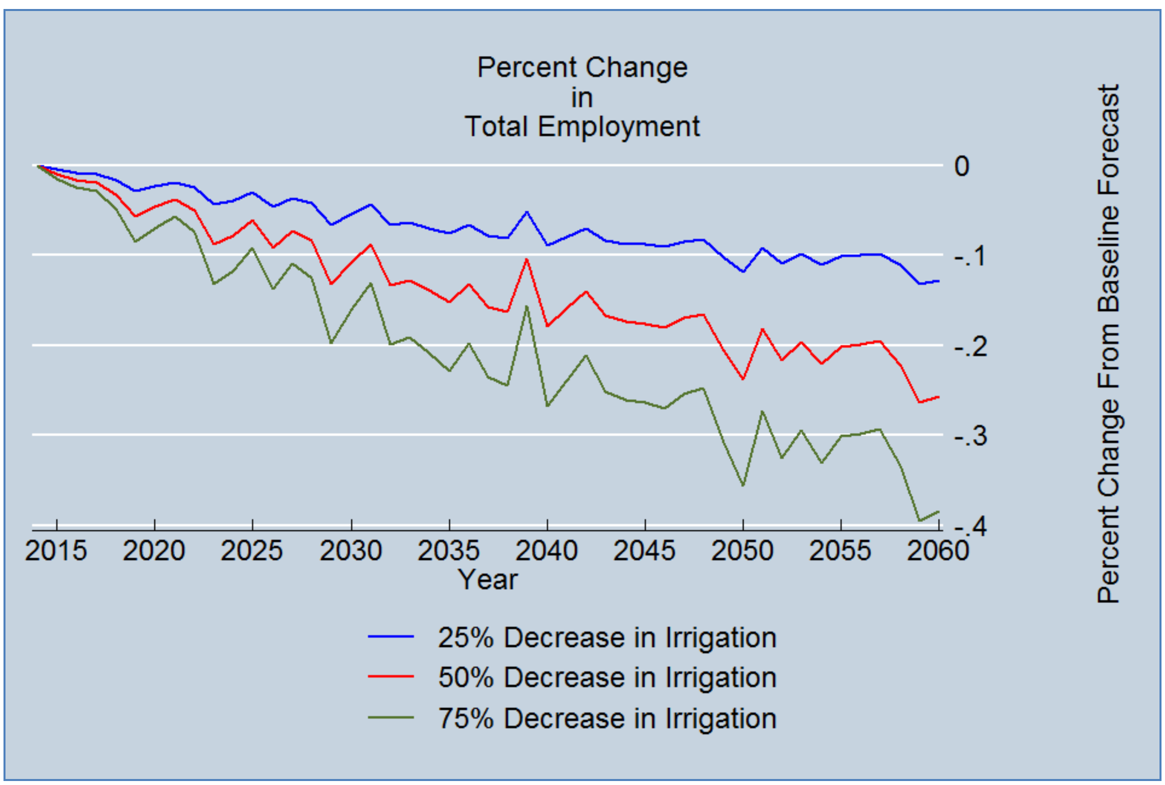

Figure 107—Kansas: Percent Change in Total Employment, Scenario 2, All Crops in the Affected Region

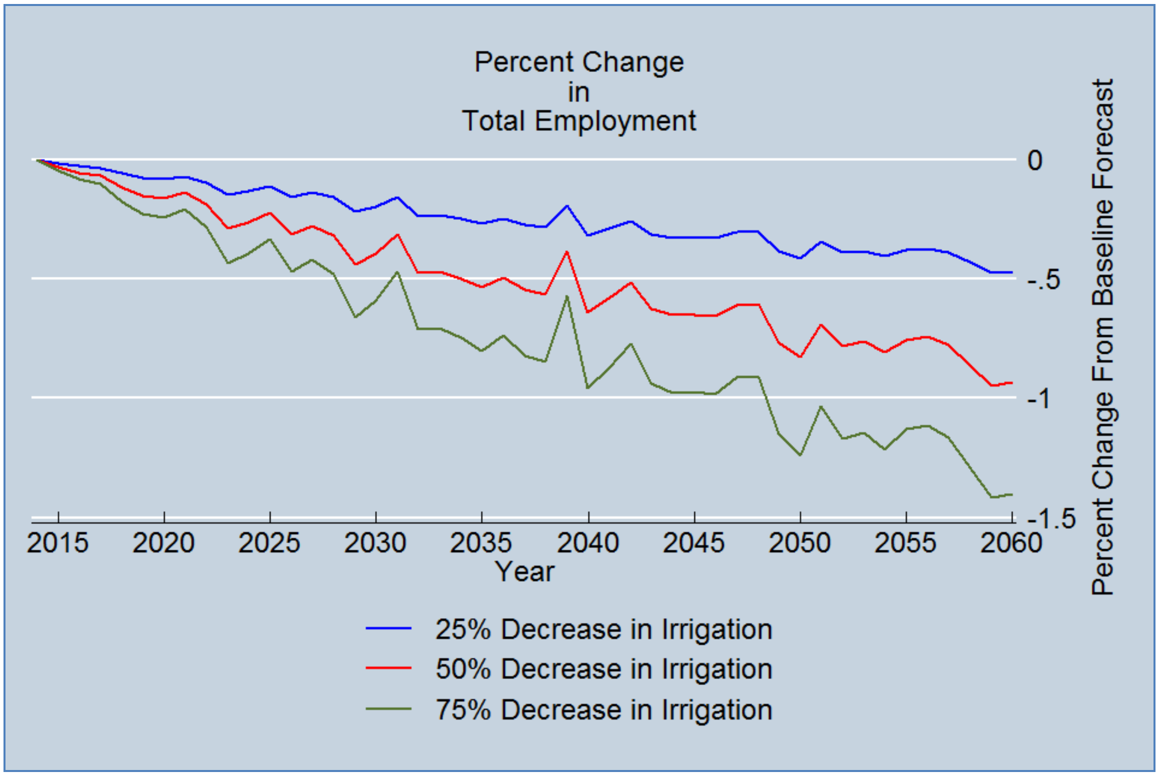

Figure 108—Nebraska: Percent Change in Total Employment, Scenario 2, All Crops in the Affected Region

At the industry sector level, all results for Kansas and Nebraska are dominated by agriculture and forestry support activities, which can be seen in Figure 109 and Figure 110. Food manufacturing and chemical manufacturing in Nebraska are also affected in significant amounts, but when compared against agriculture support, the effect is difficult to discern. Kansas follows a same pattern; however, again all other percentage changes from baseline are subordinate to agriculture and forestry support activities. Future efforts would benefit from treating agriculture support activities as an outlier, allowing for a more detailed analysis on other industry sectors of interest.

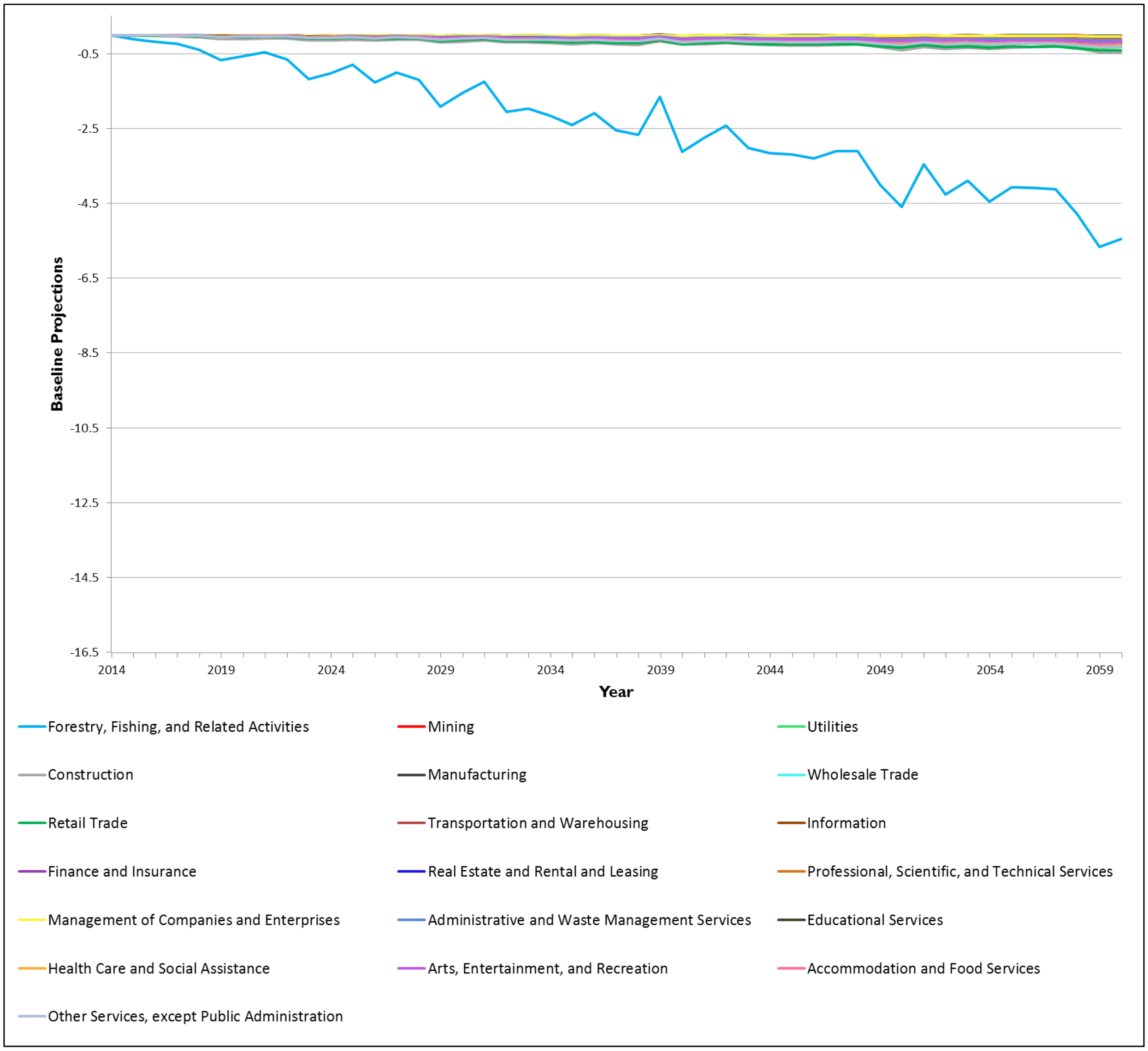

Figure 109—Kansas: Percent Change in Annual GDP Output, Scenario 2 (75%), All Crops in the Affected Region

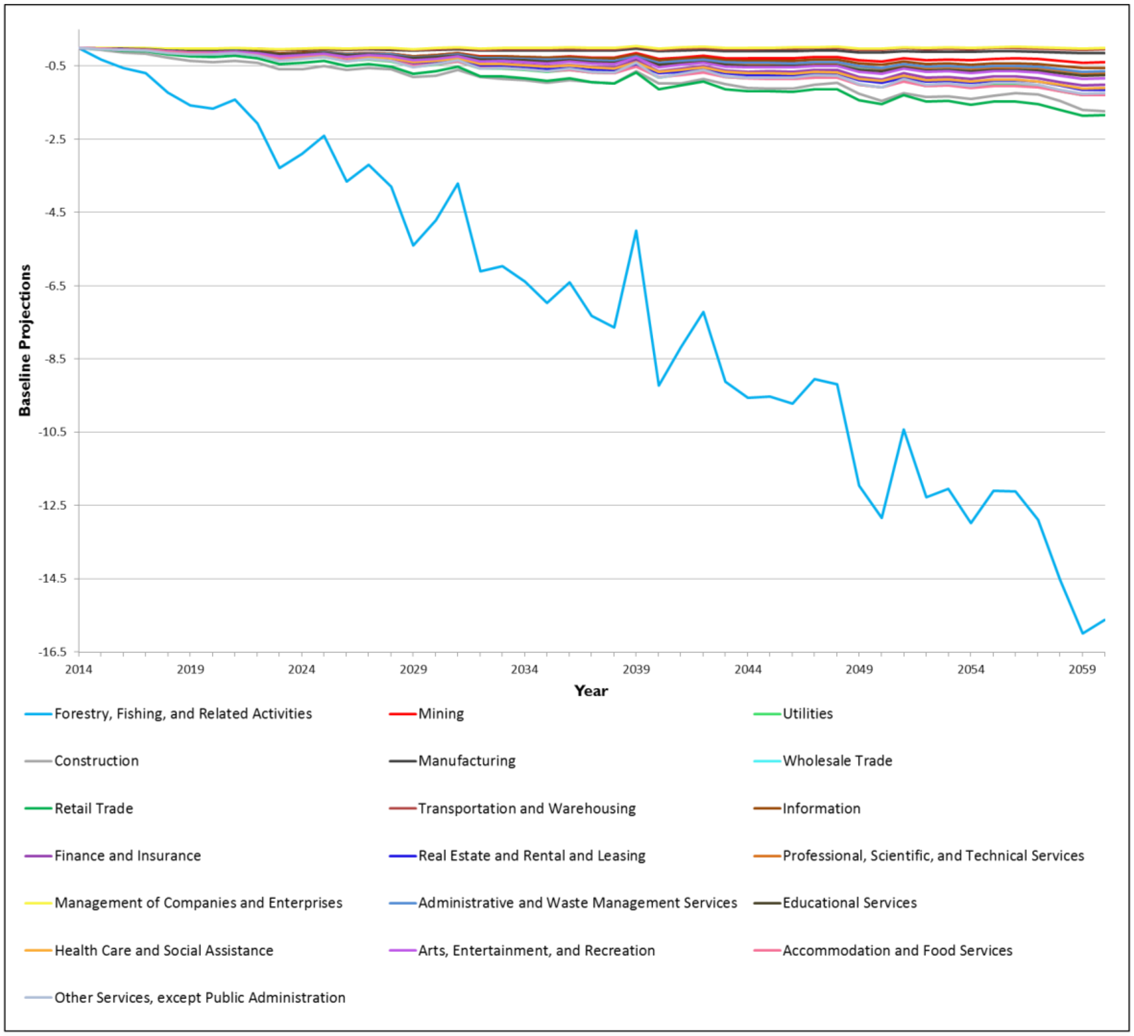

Figure 110—Nebraska: Percent Change in Annual GDP Output, Scenario 2 (75%), All Crops in the Affected Region

3.4.3 Confidence and Sensitivity Analysis of Macroeconomic Model

Individual REMI model runs were completed for each individual crop in the region of analysis. This was accomplished by determining what percentage of each crop is part of total agriculture production for Kansas and Nebraska. Each crop was modeled individually and reduced by the amount associated with the reduction in irrigated acreage determined by the microeconomic empirical analysis. The purpose of the factor analysis is to determine the individual magnitude of effect each crop could have within the model and, in turn, the model results. This is done to determine if there are any apparent anomalies or sensitives not previously identified. Overall, for the factor analysis, the removal of agricultural production is sensitive to the proportion removed and which state is affected. The specific crop type did not provide traceable variable impacts; however, removal of agriculture production in Nebraska had noticeable follow-on effects on chemical manufacturing. This is likely representative of the relationship between corn production and ethanol (classified as chemical production), which is a physical relationship translated into dollars and multiplier effects.

In addition to factor analysis, analysts conducted sensitivity runs to explore the impact of some input assumptions. Sensitivity Analysis is used to determine how "sensitive" a model is to changes in the value of the parameters of the mode and to the structure of the model. For this analysis, the focus is on parameter sensitivity. Parameter sensitivity is usually performed as a series of tests in which the analyst sets different parameter values to see how a change in the parameter causes a change in the dynamic behavior of the stocks. By showing how the model behavior responds to changes in parameter values, sensitivity analysis is a useful tool in model building and model evaluation.

Sensitivity tests help the modeler to understand dynamics of a system. Experimenting with a wide range of values can offer insights into behavior of a system in extreme situations, such as the economic impacts of disasters. Discovering that the system behavior greatly changes for a change in a parameter value can identify a leverage point in the model: a parameter whose specific value can significantly influence the behavior of the system.

3.4.3.1 Parameters

The first exploration examines parameters at the state and national levels. Changes were made to the parameters listed in Table 13, which were selected based on assumptions of which parameters are expected to have to most influence in the REMI Model. For example, Farm Proprietor Income and Agriculture Production are selected because they most closely relate to our empirical model output; increases of 1, 5, and 15% were implemented. Chemical Manufacturing was chosen because it is connected to a number of other industries, as represented by its industry multipliers. For example, ethanol is classified as chemical production. The industry sector for Food Manufacturing was selected as the general representative of all food processing and manufacturing industries.

Table 13—National and State Parameters by Sector

Parameter	1st Run	2nd Run	3rd Run
Farm Proprietor Income	1	5	15
Chemical Manufacturing	-1	-5	-15
Agriculture Production	-1	-5	-15
Food Manufacturing	-1	-5	-15

As the magnitude of the shocks increased, so did the percent of the change in GDP. For each shock (Small, Medium, and Large), Food Manufacturing had the smallest effect, Chemical Manufacturing was second in impact, and Agriculture Production had the most substantial effect on GDP.

In one test, analysts included more digits in the input file to test for sensitivity to rounding or to determine the benefit of additional resolution. This had very little effect on the results, indicating that the additional level of detail does not add much resolution to the findings. Analysts conducted another test to examine the importance of variation in input costs across industries, holding input costs constant at the industry averages. These results support the conclusion that the differences in input costs, by industry, smoothed over a year, are not large and do not add to the overall and industry-level results.

4 ANALYSIS LIMITATIONS

The econometric approach works well at reproducing observed yields because it empirically derives results based on historic farm operation behavior. There are, however, limitations to consider with the econometric model for this same reason. Advancement in crop practices, farm technology, genetically modified crop strains, and agricultural education have grown dramatically over the last 40 years. These factors have historically translated to increased yields. For example, smart irrigation technology is equipped with soil moisture sensors, equipping center pivot sprinklers with the means to adjust water output as needed by the crop. This reduces water stress and increases the resources crops need to produce. The econometric model assumes the historical trend will continue. While agricultural technology may well continue to progress and improve yields in the future, it also may slow or stop crop yield advances altogether.

Moreover, changes in resource availability that have not been problematic historically may become scarce, which is another issue the econometric model cannot address. This matters if that resource is vital in producing yields, such as groundwater for irrigation, because the model relies on continued resource availability for all producing regions. Groundwater availability is difficult to predict, short of using complex hydrogeology and economic models, because it is subject to many variables. These models rely on a host of assumptions about future behavior. However, within the scope of the econometric model, if irrigation water becomes unavailable, it can be used to predict the economic consequences of such a loss at any year of production.

The findings from the econometric model and the EPIC model in tandem show the range of possibilities under the future climate scenarios. Given the limitations of both the upper and lower bounds, it is reasonable to assume future yields may not follow historic gains. Corn, although water and resource intensive, currently maintains a tremendous share of crop market value because high-value downstream industries rely on corn as an input; specifically, ethanol production and cattle production, in addition to being water-intensive industries, depend on corn as an efficient grain for feed and distillation. As water becomes prohibitive to extract, as demonstrated in the three water decline scenarios, the economic losses compound compared to a baseline, no-impact projection. The severity of the extraction costs corresponds with the severity of the losses and the likelihood of farm exit increases.

If pumping costs increase over time as groundwater drawdown increases, then farm operations will hit a tipping point where decisions about the future of the farm operation will have to be made. Specificity on sets of decisions by farm operation is outside the scope of this analysis because these will largely be driven by regulation, policy, and technology. We do know, however, from the agriculture economics literature, that farm operations do face an “exit decision,” and this decision can be attributed to multiple factors. In fact, there can be too little variation among farms at the county level to have meaningful analysis results.

At the county level, for example, 717,100 farms went out of business or exited between 1992 and 1997, but 703,700 new farms entered during the same time period. In addition, there was a change of either ownership or consolidation for 13,400 farms over five years across all 3,144 counties and county equivalents in the United States (~-0.85 farms per county, per year). Lastly, there are too many alternative explanations for the relatively small variation we actually observe.

County aggregates will mask potentially important determinants of firm exit, like age of farm and age of proprietor(s). For observations of this type, there is not enough variation at the county level. For example, the mean age of proprietors in 2012 was 55.75 (standard deviation = 1.999). Importantly, age can be the result of a transfer instead of an exit. Transfers of ownership cannot be observed at the county level. Farm sales or sales class are also unobservable at the county level; a single large farm could skew the county averages. In other words, 95% of all counties had an average age between 51.75 and 59.75. Farm specialization, or a single crop or animal, could skew the county reported observations.

Water use efficiency and profit maximization are the center of the microeconomic analysis. Barring any mitigating water management policy, how will the agricultural industry be affected by the need for deeper wells? Irrigation is essential to maintain agricultural productivity; it is assumed farmers will continue to drill deeper wells until this is no longer profit maximizing.

Farming operations susceptible to exiting agricultural production, due to declining net farm income, will be deemed sensitive to increasing resource risk. Farm operators will face many choices, some of which may be to conserve current supply through reducing output, barring new policy or new technology. Exits among farm operations will also be distributed unevenly across counties and are also likely to be uneven over time. Because of the High Plains Aquifer's differing declines among counties, more counties in Kansas will see the effects of groundwater decline first while Nebraska counties may never see declines drastic enough for farm operations to consider exiting.

Additional heterogeneity will persist in determining the kind of farm operation considering an exit from the market. Cattle and beef operations seem less likely to exit the market, for example, except when they depend heavily on irrigated acres. The more integrated and reliant an operation is to irrigated acres, the more susceptible to exit they may be. Industries outside of agriculture and forestry support may also be affected by declining aquifer levels, but by much smaller orders of magnitude. Mining is the second most susceptible industry, and public utilities are the third most susceptible industry. These are good examples of industry sectors that rely heavily on water for their operations but use much less water than agriculture. Within the constraints of the model, employment will also be negatively affected by declining aquifer levels, which reflects the declines in industry performance.

NISAC conducted this analysis without considering the costs of formulation, implementation, or enforcement of policy or regulatory action to combat or offset the effects of a chronic disruption (resource risk). The economic consequence estimates is likely directly related to the number of provisions involved with the scenario. For example, the anticipated intervention and policy options, such as crop switching, selling or renting of water rights, other use of agriculture land, or technology, is not postulated for this analysis—the sum of which is likely to be costly or perhaps offsetting to the economic consequence estimates. Future studies could investigate these costs, compute cost-benefit ratios, and evaluate the cost effectiveness of the policy and regulatory scenarios.

A typical disruption analysis of a specific, affected geographic area is usually of an acute nature where a disruption occurs for a period of days or several weeks to several months.

5 CONCLUSIONS

Expansion of irrigated agriculture over the past 60 years has helped make the High Plains one of the most productive agricultural regions in the Nation, accounting for one-fourth of U.S. agricultural production. This expansion in productivity, however, has come at a cost, as the High Plains Aquifer, central to groundwater supply in the plains, is drawn on at a rate far exceeding its recharge. If current water use and management practices are continued, 60 counties in Kansas and seven in Nebraska have less than 100 years of aquifer life remaining.

Shrinking groundwater supplies and changing climatic conditions could pose risks to the region's agricultural production. In the absence of any other changes, future climate projections were found to impose a small downward trend in dryland yields for corn, sorghum, soy, and winter wheat across the region. Historically, irrigation has been used to offset the impacts of variations in temperature and precipitation on crop yields; however, declining water levels are likely to limit such adjustments in the future.

Having modeled groundwater use and farm production in these two states, this analysis identified several potential impacts to the economy and the region's critical infrastructure:

- Kansas and Nebraska provide significant amounts of commodities by dollar and volume to nearly all contiguous 48 states.
- Economic impacts will scale with energy costs to extract groundwater. For this analysis, the economic impacts are primarily contained to Kansas and Nebraska.
- Empirical economic analyses were central to understanding whether resource risk can affect farm operations. The effects of increases in the cost to extract groundwater (represented through increasing energy costs) can influence whether a farm operation will exit or reduce irrigated acreage.
- Farm exits, as modeled through reductions in farm proprietor income, will affect disposable income and reduce demand for consumer goods. This effect is confined to Kansas and Nebraska.
- Reductions in irrigated acreage will affect follow-on industries, such as agricultural support activities, and consumer demand.
- Reductions in irrigated acreage have major implications for critical infrastructures in the region. Infrastructures affected through economic impacts include both the Agriculture and Food sectors (farms, farm products) and Chemical Manufacturing (ethanol production). The exact implications for the Energy critical infrastructure would depend on the centrality of ethanol to the overall transportation fuels portfolio.
- Variations in climate may lead to reductions in crop yields. Whereas farmers have been able to mitigate climate-related losses through irrigation in the past, the decreasing groundwater supply of the High Plains Aquifer could limit their ability to do so in the future.

Detailed effects beyond those captured in this analysis would require higher resolution analysis of detailed sub-sector data and existing modeling output.

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APPENDIX A: WATER ALLOCATION TRANSFERS

Water trading moves water from low-value areas of use to high-value areas of use, in theory to the benefit of both the buyer and seller. Several structural and economic issues impede on truly free water markets, however, which limits their prevalence to areas of very high demand and limited supply. The first limitation is embedded in the legal framework in which water is regulated. Laws that govern groundwater are not the same laws that govern surface water. This archaic legal fragmentation persists from the settlement period when the two water systems were thought to be independent. Although trading may ultimately benefit water users, the legal framework dividing surface water and groundwater can make trading illogical and prohibitive.

For surface water, reasonable use or natural flow rights and the principle of “first in time, first in right” are the primary legal tools in allocating water. In reasonable or natural flow rights, all water users with land abutting a watercourse have the right to use the water as long as they do not harm any other water user. The “first in time, first in right” doctrine mitigates water scarcity disputes by allocating water to those chronologically senior rights holders first until the allocations run out. For groundwater users, seniority holds no overarching legal precedent unless conjunctively managed with surface water rights. Groundwater is commonly treated like a mineral under the absolute ownership doctrine, which holds that a landowner owns everything above or below his or her land. Since groundwater experiences subterranean flow and is affected by withdrawals outside of an owner’s land, it tends to succumb to overuse without additional regulation; if a user does choose to conserve the resource, the user’s rival (i.e., a neighboring landowner) may take the opportunity to use more and benefit from the user’s austerity.

The second impediment to trade is that few efficient market platforms exist in which to cost-effectively trade water. While some companies have begun marketing an algorithm-based platform to reduce transaction costs (e.g., Mammoth Trading), most buyers and sellers of water allocation rights must first hire a water broker to search for an interested party. This imposes a search cost, both in terms of the money for a broker and the time in which it takes to find a buyer or seller. Legal rules often impede this search, like limiting the distance to which buyers and sellers can make trades. Other legal rules impose additional costs. For example, a Kansas user wishing to change his or her water allocation must first file an application along with an application fee and receive subsequent approval to do so.

Despite these impediments, water allocation transfers do occur, indicating a desire for market participation. In the Nebraska’s Upper Republican Natural Resource District, 35 transfers involving 100 fields have occurred between 2006 and 2010. Records of trades only exist when water is monitored and water use is enforced, such as in Nebraska. If no restrictions exist on groundwater use, then no trade is necessary. Federal and state projects that distribute water, though, are monitored, especially if they feed urban and nonagricultural users. For example, the Colorado-Big Thompson Project (C-BT) is a trans-basin distribution system that feeds irrigation, towns, and industry. The C-BT consolidates surface water supply into an easily tradable allocation framework with low transaction costs. The success of the C-BT is in the flexibility it provides to users, both in price and in timing, and in its singular regulatory structure.

APPENDIX B: ADDITIONAL DATA

Macroeconomic Data—Regional and National

The economic data are compiled at the two- or three-digit North American Industrial Classification System (NAICS) code levels, depending on how the sources of data align. Economic data are sourced from publicly available data sources. These include the Bureau of Labor Statistics (BLS), Bureau of Economic Analysis (BEA), and the U.S. Census Bureau County Business Patterns (CBP), which includes data for 39 industries at the two- or three-digit NAICS level and the Annual Survey of Manufacturers (ASM). Table B- 1lists specific data used, source, time-period covered, and application, all of which illustrate the regional, national, and industrial scope of the data.

The BEA regional economic data informs the analyst about the geographic distribution of U.S. economic activity and growth. The estimates of GDP by state, and by state and local area personal income and other economic characteristics, are based on a consistent framework and provide consistent metrics for analyzing and comparing individual state and local economies.

The CBP is an annual series estimated by the U.S. Census Bureau that provides county-level economic data by industry. The dataset includes "the number of establishments, employment during the week of March 12, first quarter payroll, and annual payroll." These data have, and continues to be, useful for studying the economic activity of sub-state regions. In general, the dataset serves as a benchmark for other statistical series, surveys, and databases between economic censuses.

The ASM is prepared by the U.S. Census Bureau and provides estimates of sample statistics for all manufacturing establishments in the U.S. with one or more paid employees. The survey is conducted annually, excluding years ending in 2 and 7, at which time ASM statistics are included in the manufacturing sector of the Economic Census.

Commodity Flow Survey Data

For the Commodity Flow Survey (CFS), the U.S. Census Bureau collects survey information about specific commodities for a particular set of industries. The CFS covers business establishments in these industries: mining, manufacturing, wholesale trade, and select retail services. The survey also covers selected secondary establishments deemed in-scope, multi-unit, and retail companies. Excluded industries are: transportation, construction, most retail and services industries, farms, fisheries, foreign establishments, and most U.S. Government-owned establishments. The U.S. Census Bureau collects data on shipments originating from the selected industries, including exports. Imports are not included until the point that they leave the importer's initial domestic location for shipment to another location. The survey does not cover business establishments located in Puerto Rico and other U.S. territories.

CFS data informs the section on discussion commodity shipments from Kansas and Nebraska. Commodities are classified by the Standard Classification of Transported Goods (SCTG) codes as designated by the U.S. Department of Transportation, and data are reported in dollars and volume. Commodity groupings are similar to NAICS industries; they can cross reference with

NAICS codes. Commodities groups start at two-digit assignments with up to five-digit subgroupings. Commodities listings and codes are prevalent in the reporting of goods in transit such as commodity shipments, exports, and imports. Lastly, value of shipments is not the only metric for commodities within the surveys, and volume of shipments are reported alongside the report dollar values for commodities.

Producer Price Index

The BLS estimated producer price index (PPI) is used to adjust other economic time series for price changes and to translate those series into inflation-free dollars because the longitudinal dataset spans multiple decades. For example, constant-dollar GDP data are estimated using deflators based on PPI data. While both the PPI and CPI measure price change over time for a fixed set of goods and services, the CPI and PPI differ for three main areas: the basket set of goods and services, types of price information collected for the set of goods and services, and the service sectors covered. The set of goods and services included in the PPI is the entire marketed output of U.S. producers. This set of goods and services includes: construction products purchased by other producers as inputs to their operations; goods and services purchased by consumers, either directly from the service producer or indirectly from a retailer; and products sold as exports and to the U.S. Government. A primary use of the PPI is to deflate revenue streams to measure real growth in output.

Table B- 1—Data Used in Economic Modeling and Analysis at the Firm and Industry Levels, Regional and National in Scope

Data Type	Source	Annual	Relevance
Industry (39) Employment by County	BEA County Business Patterns	2001-2011	Informs analysis, identify key industries
GDP at State Level	BEA	1997-2012	Informs analysis
Employment by Industry by State	BEA	2001-2011	Informs analysis
Multipliers by Industry by State	BEA	2012	Industry interdependencies
Quarterly Economic Data by Industry by County	BEA	2013	Minimal usefulness given the timeframe of analysis
GDP by Industry by County	Estimated	2001-2011	Can assist in identifying key industries
Sales by Industry by County	Economic Census	2001-2011	Can assist in identifying key industries, market concentration
Locally Generated Industry Reports	Various	2008-2012	Intended to avoid oversights
Individual Farms	Census of Agriculture	1982-2012	Individual farm observations for microeconomic models
Individual non-farm operation locations	HSIP Gold	2012	Location to High Plains Aquifer and water use intensity estimation
Farm and Non-farm operation approximations	Survey of Manufacturers	2005-2013	Microeconomic estimations, value of product shipments

APPENDIX C: SUMMARY STATISTICS

Econometric Crop Model

Table C- 1—Just-Pope Estimation of Corn

	Linear-Quadratic		**Quadratic**		**Linear**	
	Irrigated	Non-Irrigated	Irrigated	Non-Irrigated	Irrigated	Non-Irrigated
Variables	(1)	(2)	(3)	(4)	(5)	(6)
$TREND$	0.067	0.268***	0.137***	0.074***	0.136***	0.074***
	(0.059)	(0.048)	(0.004)	(0.008)	(0.004)	(0.007)
P	1.969	-8.145***	-0.382	0.265	-0.020**	0.101***
	(1.192)	(1.130)	(0.235)	(0.257)	(0.008)	(0.012)
T	-3.039*	8.608***	0.070	-0.064	0.015	-0.096**
	(1.688)	(1.424)	(0.197)	(0.279)	(0.022)	(0.032)
$\frac{1}{2}(P*T)$	0.014**	-0.003				
	(0.006)	(0.004)				
$TREND*P$	-0.001*	0.004***				
	(0.001)	(0.001)				
$TREND*T$	0.001	-0.004***				
	(0.001)	(0.001)				
P^2			-0.004***	-0.003***		
			(0.001)	(0.001)		
T^2			-0.002	-0.000		
			(0.002)	(0.002)		
$P*T$			0.008**	0.000		
			(0.003)	(0.003)		
$CONSTANT$	-115.714	-528.356***	-261.493***	-142.805***	-261.750***	-139.895***
	(119.578)	(96.767)	(8.714)	(17.473)	(7.913)	(15.243)
R^2	0.809	0.591	0.819	0.552	0.802	0.535
Observations	566	566	566	566	566	566
Counties	14	14	14	14	14	14

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table C- 2—Just-Pope Estimation of Sorghum

	Linear-Quadratic		Quadratic		Linear	
	Irrigated	Non-Irrigated	Irrigated	Non-Irrigated	Irrigated	Non-Irrigated
Variables	(1)	(2)	(3)	(4)	(5)	(6)
$TREND$	-0.175*	-0.174*	0.034***	0.046***	0.033***	0.044***
	(0.098)	(0.091)	(0.006)	(0.006)	(0.006)	(0.006)
P	-2.005	-2.010*	0.039	0.026	0.008	0.059***
	(1.495)	(1.102)	(0.235)	(0.139)	(0.008)	(0.008)
T	-5.257*	-5.720**	0.141	0.044	0.040***	0.024*
	(2.771)	(2.456)	(0.111)	(0.103)	(0.013)	(0.012)
$\frac{1}{2}(P*T)$	0.001	0.008**				
	(0.006)	(0.003)				
$TREND*P$	0.001	0.001				
	(0.001)	(0.001)				
$TREND*T$	0.003*	0.003**				
	(0.001)	(0.001)				
P^2			-0.002**	-0.003***		
			(0.001)	(0.001)		
T^2			-0.001	-0.001		
			(0.001)	(0.001)		
$P*T$			0.001	0.003		
			(0.003)	(0.002)		
$CONSTANT$	348.951*	350.248*	-68.295***	-91.661***	-63.794***	-88.298***
	(194.511)	(180.038)	(10.908)	(11.562)	(12.029)	(10.736)
R^2	0.217	0.378	0.219	0.410	0.204	0.363
Observations	428	428	428	428	428	428
Counties	14	14	14	14	14	14

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C- 3—Just-Pope Estimation of Soybeans

	Linear-Quadratic		Quadratic		Linear	
	Irrigated	Non-Irrigated	Irrigated	Non-Irrigated	Irrigated	Non-Irrigated
	(1)	(2)	(3)	(4)	(5)	(6)
$TREND$	0.003	0.057*	0.039***	0.023***	0.038***	0.022***
	(0.026)	(0.027)	(0.003)	(0.002)	(0.003)	(0.002)
P	-0.010	-3.111***	-0.034	0.110	-0.005*	0.038***
	(0.280)	(0.477)	(0.065)	(0.111)	(0.003)	(0.004)
T	-1.097	2.285**	0.065	0.061	0.001	-0.041**
	(0.729)	(0.921)	(0.058)	(0.055)	(0.008)	(0.015)
$\frac{1}{2}(P*T)$	0.002	-0.004				
	(0.001)	(0.002)				
$TREND*P$	-0.000	0.002***				
	(0.000)	(0.000)				
$TREND*T$	0.001	-0.001**				
	(0.000)	(0.000)				
P^2			-0.001*	-0.001***		
			(0.000)	(0.000)		
T^2			-0.001	-0.001		
			(0.001)	(0.001)		
$P*T$			0.001	0.000		
			(0.001)	(0.002)		
$CONSTANT$	-1.457	-112.157*	-75.938***	-45.599***	-73.812***	-40.963***
	(51.630)	(55.206)	(6.059)	(4.679)	(6.110)	(4.206)
R^2	0.729	0.553	0.734	0.518	0.727	0.496
Observations	370	353	370	353	370	353
Counties	14	13	14	13	14	13

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table C- 4—Just-Pope Estimation of Winter Wheat

	Linear-Quadratic		**Quadratic**		**Linear**	
	Irrigated	Non-Irrigated	Irrigated	Non-Irrigated	Irrigated	Non-Irrigated
Variables	(1)	(2)	(3)	(4)	(5)	(6)
$TREND$	0.031	0.088**	0.015	0.015***	0.015	0.014***
	(0.058)	(0.035)	(0.011)	(0.002)	(0.011)	(0.002)
P	3.267	-1.193**	0.186	0.030	0.015	0.020***
	(3.535)	(0.507)	(0.143)	(0.070)	(0.015)	(0.006)
T	-0.924	3.580**	0.477	0.518**	-0.008	-0.048**
	(3.604)	(1.398)	(0.535)	(0.208)	(0.028)	(0.019)
$\frac{1}{2}(P*T)$	0.001	0.006				
	(0.005)	(0.005)				
$TREND*P$	-0.002	0.001**				
	(0.002)	(0.000)				
$TREND*T$	0.000	-0.002**				
	(0.002)	(0.001)				
P^2			-0.001***	-0.002***		
			(0.000)	(0.000)		
T^2			-0.005	-0.007***		
			(0.005)	(0.002)		
$P*T$			-0.002	0.002		
			(0.003)	(0.001)		
$CONSTANT$	-58.752	-166.926**	-40.756**	-39.340***	-26.705	-23.252***
	(112.179)	(68.349)	(14.277)	(4.355)	(20.354)	(4.212)
R^2	0.047	0.202	0.041	0.242	0.033	0.172
Observations	438	438	438	438	438	438
Counties	14	14	14	14	14	14

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C- 5—Corn Production Summary Statistics

Irrigated (N=566)	Mean	Std. Dev	Minimum	Maximum
Yield (tons per hectare)	8.55	2.20	3.77	13.57
P	23.98	6.55	11.58	53.74
T	67.90	2.90	41.58	75.40
½(P * T)	814.16	224.51	290.67	1,785.77
TREND * P	47,635.51	13,023.78	22,949.70	107,104.19
TREND * T	134,892.69	5,944.05	83,496.23	150,637.07
P2	617.71	350.56	134.16	2,888.01
T2	4,619.08	375.58	1,729.05	5,685.38
P * T	1,628.31	449.02	581.35	3,571.53
Non-Irrigated (N=566)	Mean	Std. Dev	Minimum	Maximum
Yield (tons per hectare)	3.77	1.89	0.44	10.67
P	23.98	6.55	11.58	53.74
T	67.90	2.90	41.58	75.40
½(P * T)	814.16	224.51	290.67	1,785.77
TREND * P	47,635.51	13,023.78	22,949.70	107,104.19
TREND * T	134,892.69	5,944.05	83,496.23	150,637.07
P2	617.71	350.56	134.16	2,888.01
T2	4,619.08	375.58	1,729.05	5,685.38
P * T	1,628.31	449.02	581.35	3,571.53

Table C- 6—Sorghum Production Summary Statistics

Irrigated (N=428)	Mean	Std. Dev	Minimum	Maximum
Yield (tons per hectare)	5.06	1.80	0.00	8.77
P	23.95	6.52	10.87	53.74
T	68.92	2.75	41.61	76.46
½(P*T)	824.62	222.54	286.70	1,794.41
TREND * P	47,523.03	12,947.27	21,501.03	107,104.19
TREND * T	136,748.23	5,630.12	82,516.60	151,381.30
P2	616.25	357.51	118.16	2,888.01
T2	4,758.15	364.59	1,731.56	5,845.40
P * T	1,649.23	445.08	573.39	3,588.81
Non-Irrigated (N=428)	Mean	Std. Dev	Minimum	Maximum
Yield (tons per hectare)	3.07	1.50	0.00	6.75
P	23.95	6.52	10.87	53.74
T	68.92	2.75	41.61	76.46
½(P * T)	824.62	222.54	286.70	1,794.41
TREND * P	47,523.03	12,947.27	21,501.03	107,104.19
TREND * T	136,748.23	5,630.12	82,516.60	151,381.30
P2	616.25	357.51	118.16	2,888.01
T2	4,758.15	364.59	1,731.56	5,845.40
P * T	1,649.23	445.08	573.39	3,588.81

Table C- 7—Soybean Production Summary Statistics

Irrigated (N=370)	Mean	Std. Dev	Minimum	Maximum
Yield (tons per hectare)	2.65	0.72	0.12	4.33
P	25.32	6.27	12.80	47.17
T	67.57	2.82	39.76	74.79
½(P * T)	855.21	212.33	278.05	1,552.59
TREND * P	50,351.88	12,483.42	25,091.55	94,008.45
TREND * T	134,353.40	5,807.19	79,828.83	149,423.84
P2	680.51	342.23	163.72	2,224.94
T2	4,573.41	362.07	1,580.49	5,593.05
P * T	1,710.43	424.66	556.11	3,105.18
Non-Irrigated (N=353)	**Mean**	**Std. Dev**	**Minimum**	**Maximum**
Yield (tons per hectare)	1.70	0.61	0.54	3.45
P	25.64	6.20	12.80	47.17
T	67.61	2.86	39.76	74.79
½(P * T)	866.36	209.56	278.05	1,552.59
TREND * P	50,975.13	12,346.57	25,091.55	94,008.45
TREND * T	134,422.79	5,890.98	79,828.83	149,423.84
P2	695.72	341.84	163.72	2,224.94
T2	4,579.74	366.75	1,580.49	5,593.05
P * T	1,732.71	419.11	556.11	3,105.18

Table C- 8—Winter Wheat Production Summary Statistics

Irrigated (N=438)	Mean	Std. Dev	Minimum	Maximum
Yield (tons per hectare)	3.15	1.34	0.63	15.82
P	23.17	6.33	5.17	48.69
T	46.00	2.82	38.62	53.25
½(P * T)	531.76	146.10	124.34	1,230.98
TREND * P	46,008.78	12,577.74	10,379.94	97,718.83
TREND * T	91,381.78	5,736.60	75,688.92	106,811.47
P2	576.55	329.10	26.72	2,370.62
T2	2,124.35	260.60	1,491.26	2,835.14
P * T	1,063.52	292.19	248.69	2,461.97
Non-Irrigated (N=438)	**Mean**	**Std. Dev**	**Minimum**	**Maximum**
Yield (tons per hectare)	2.17	0.56	0.55	3.80
P	23.17	6.33	5.17	48.69
T	46.00	2.82	38.62	53.25
½(P * T)	531.76	146.10	124.34	1,230.98
TREND * P	46,008.78	12,577.74	10,379.94	97,718.83
TREND * T	91,381.78	5,736.60	75,688.92	106,811.47
P2	576.55	329.10	26.72	2,370.62
T2	2,124.35	260.60	1,491.26	2,835.14
P * T	1,063.52	292.19	248.69	2,461.97

EPIC Crop Modeling Results

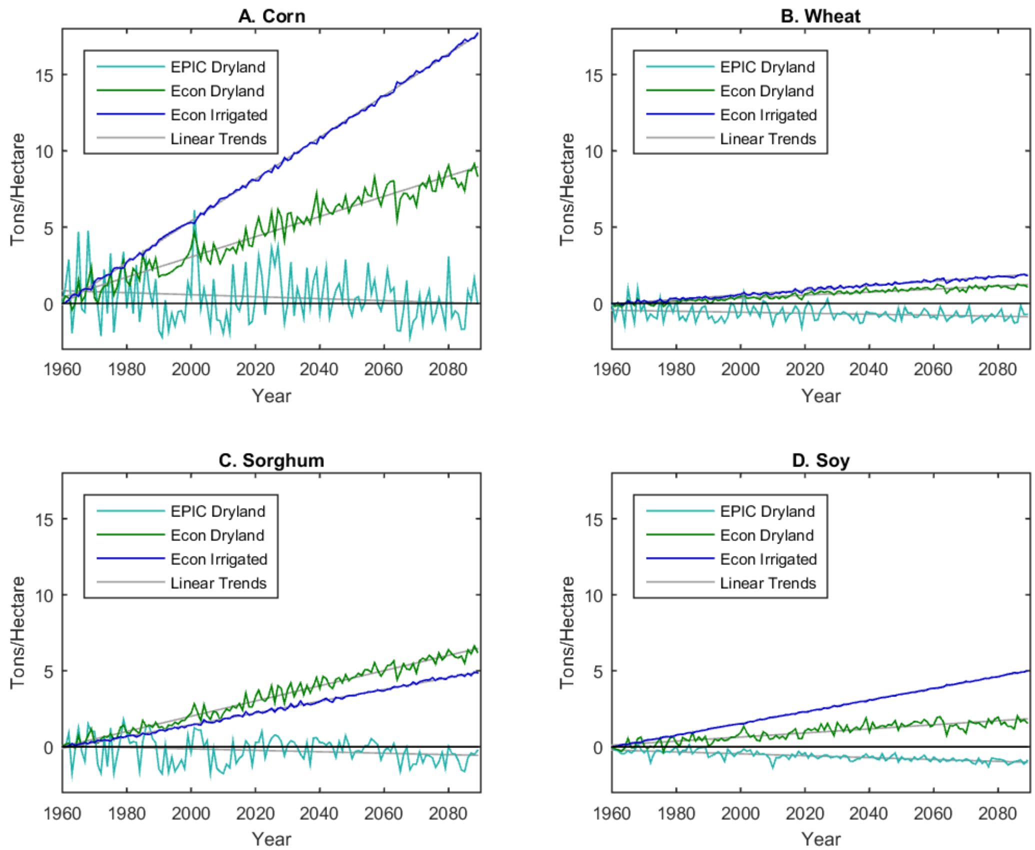

Figure C- 1—Barton, Kansas

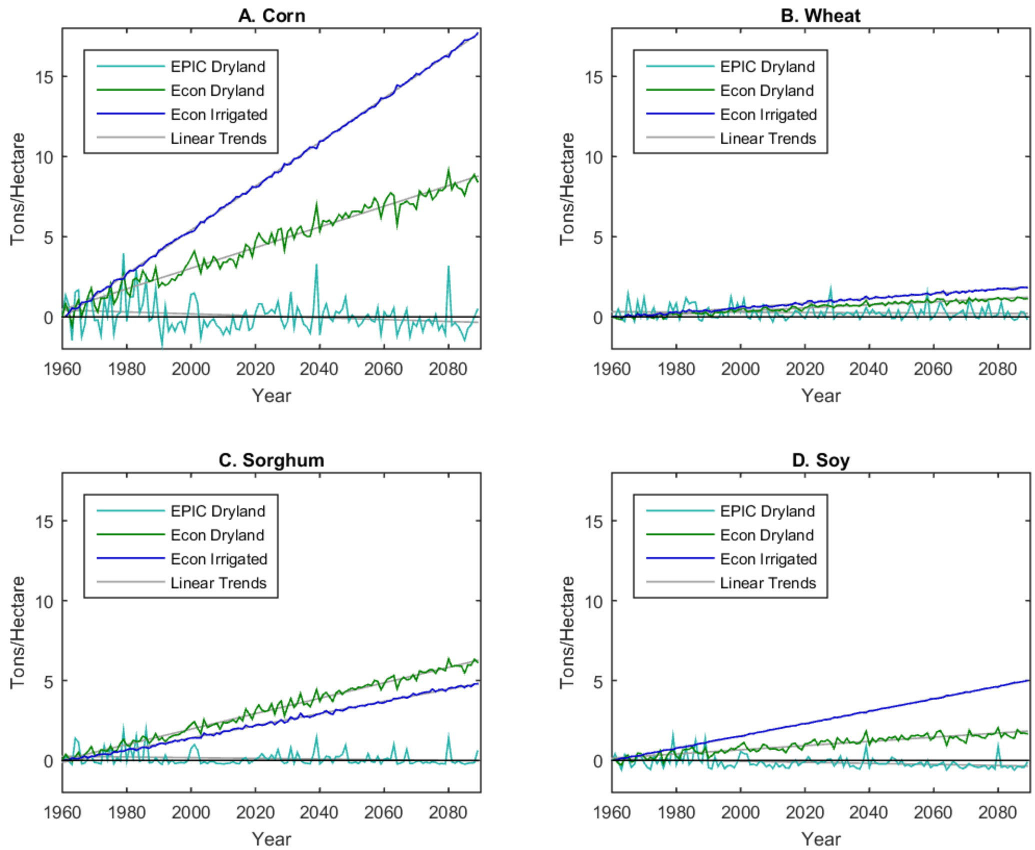

Figure C- 2—Haskell, Kansas

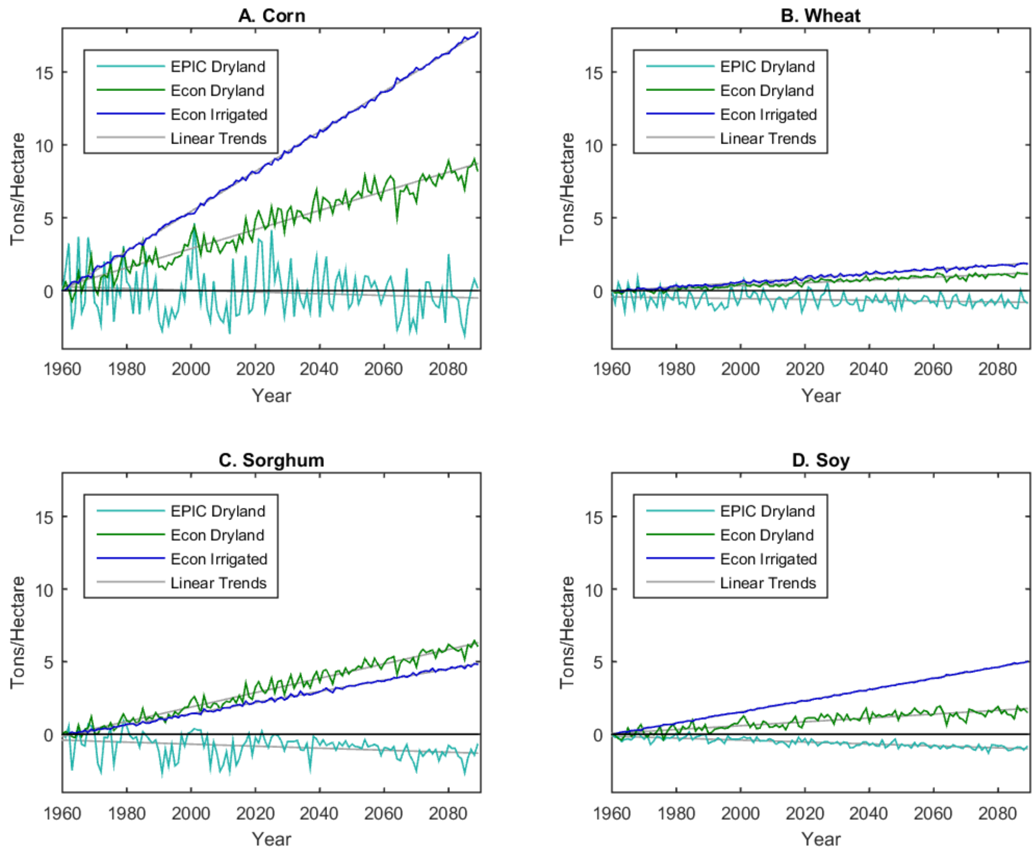

Figure C- 3—Pratt, Kansas

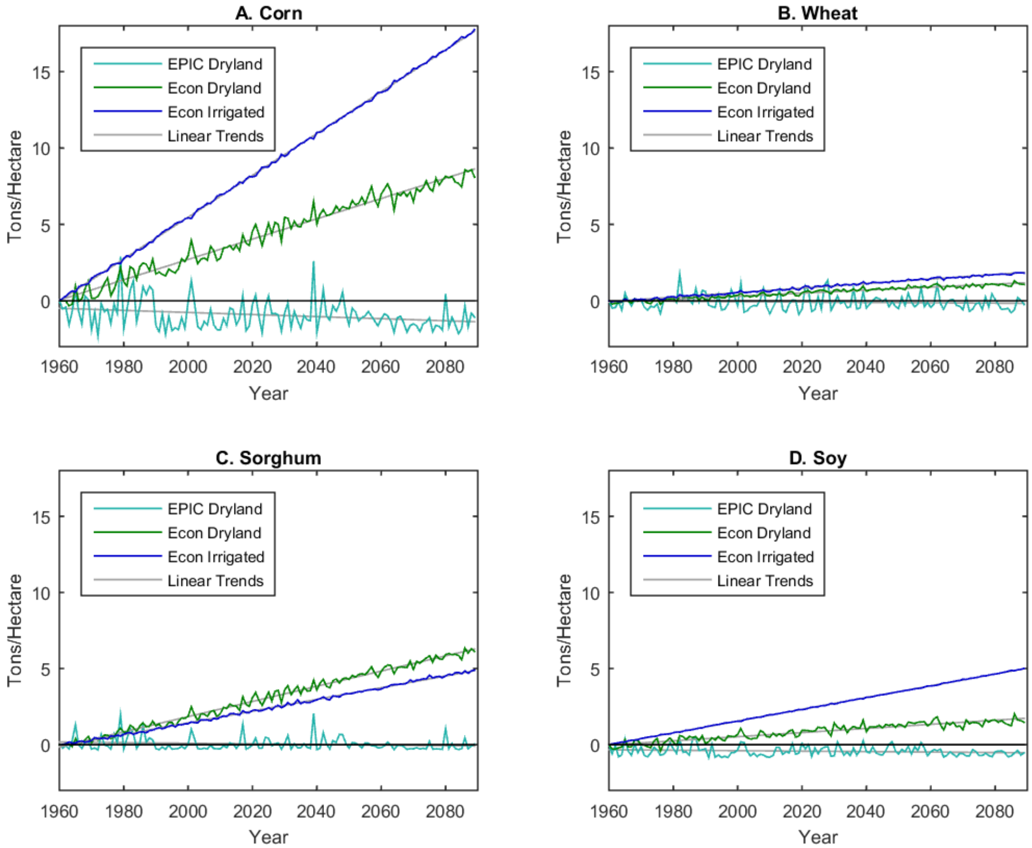

Figure C- 4—Rawlins, Kansas

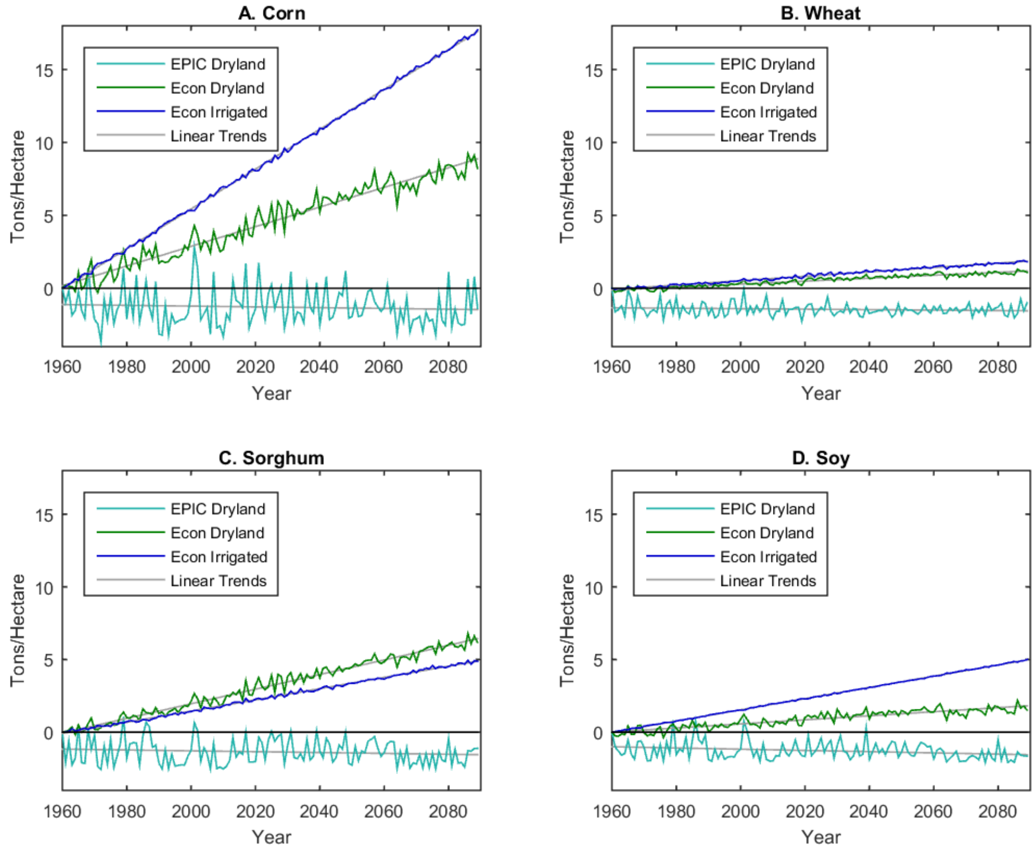

Figure C- 5—Rooks, Kansas

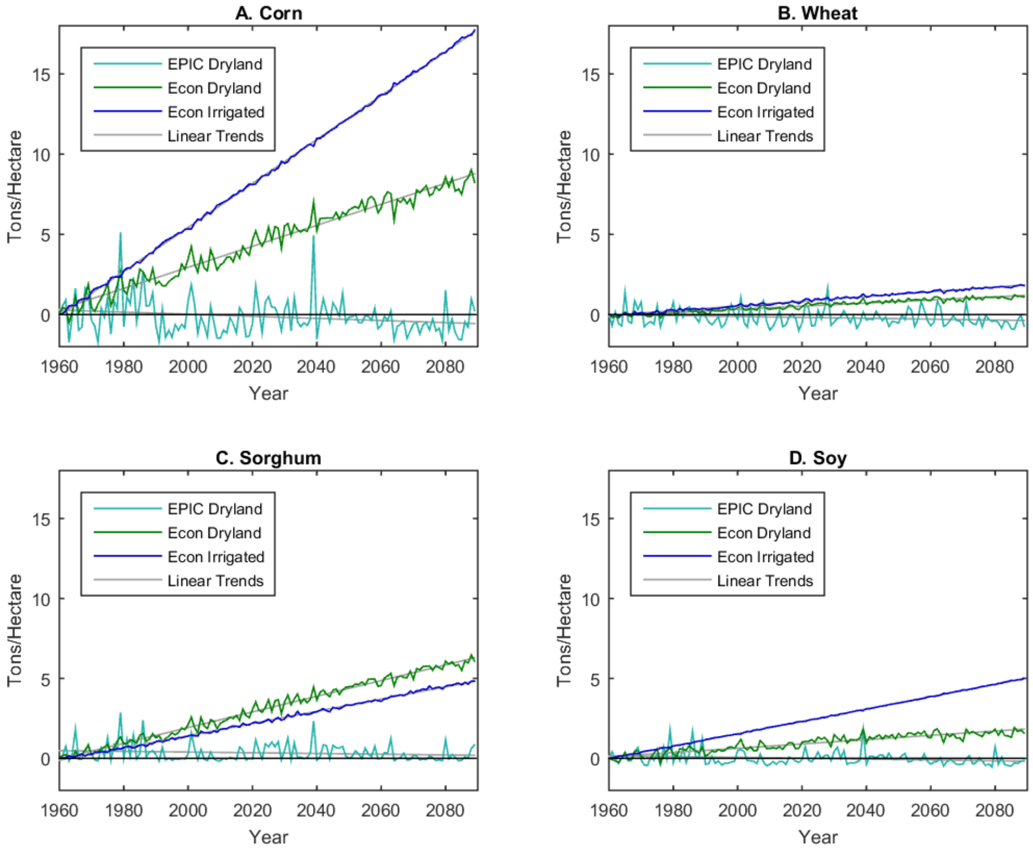

Figure C- 6—Scott, Kansas

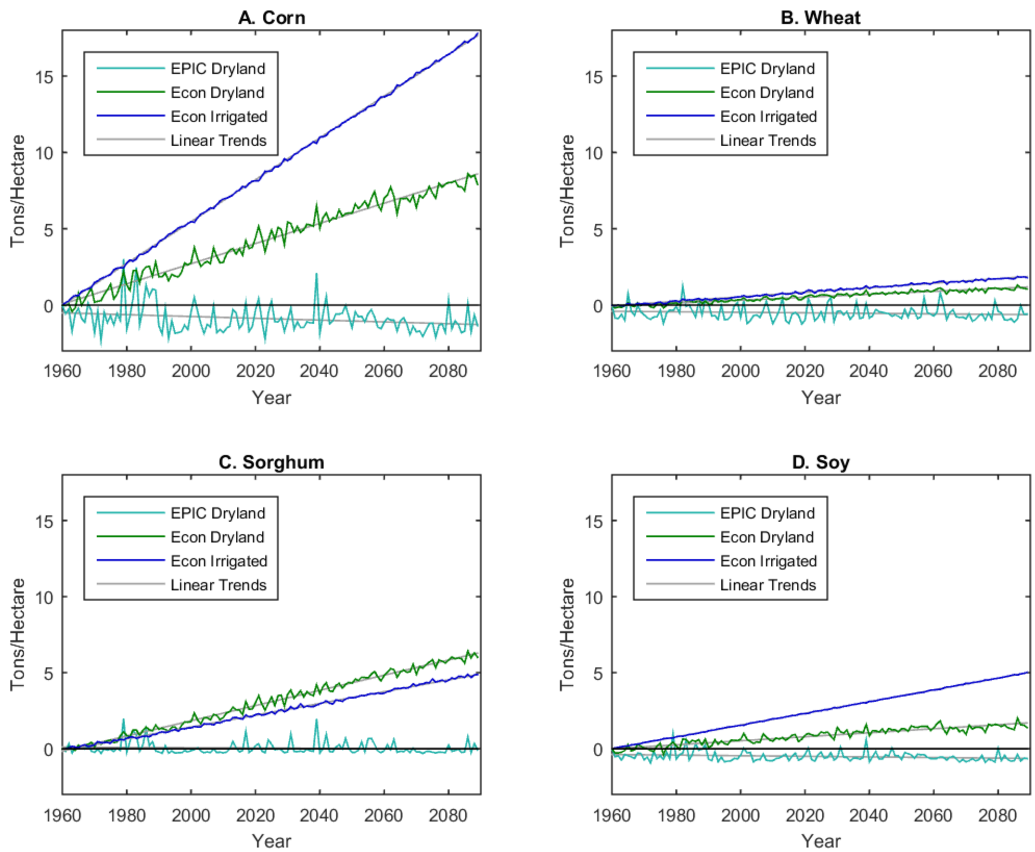

Figure C- 7—Dundy, Nebraska

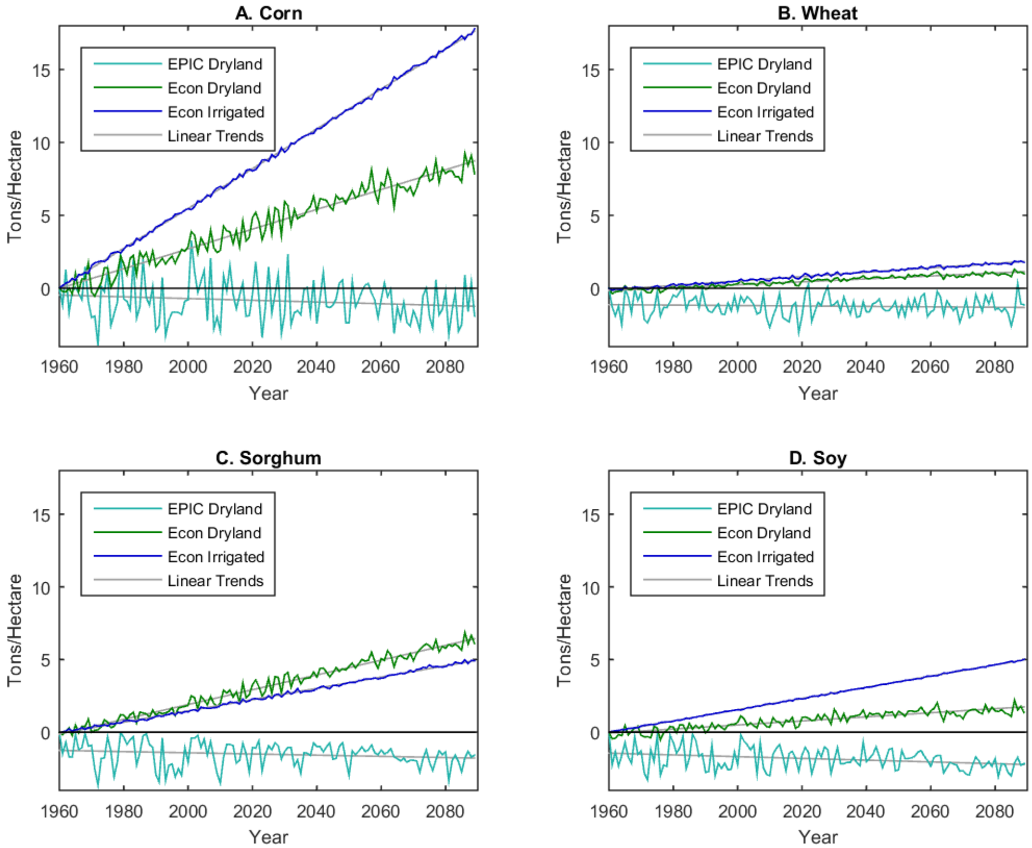

Figure C- 8—Fillmore, Nebraska

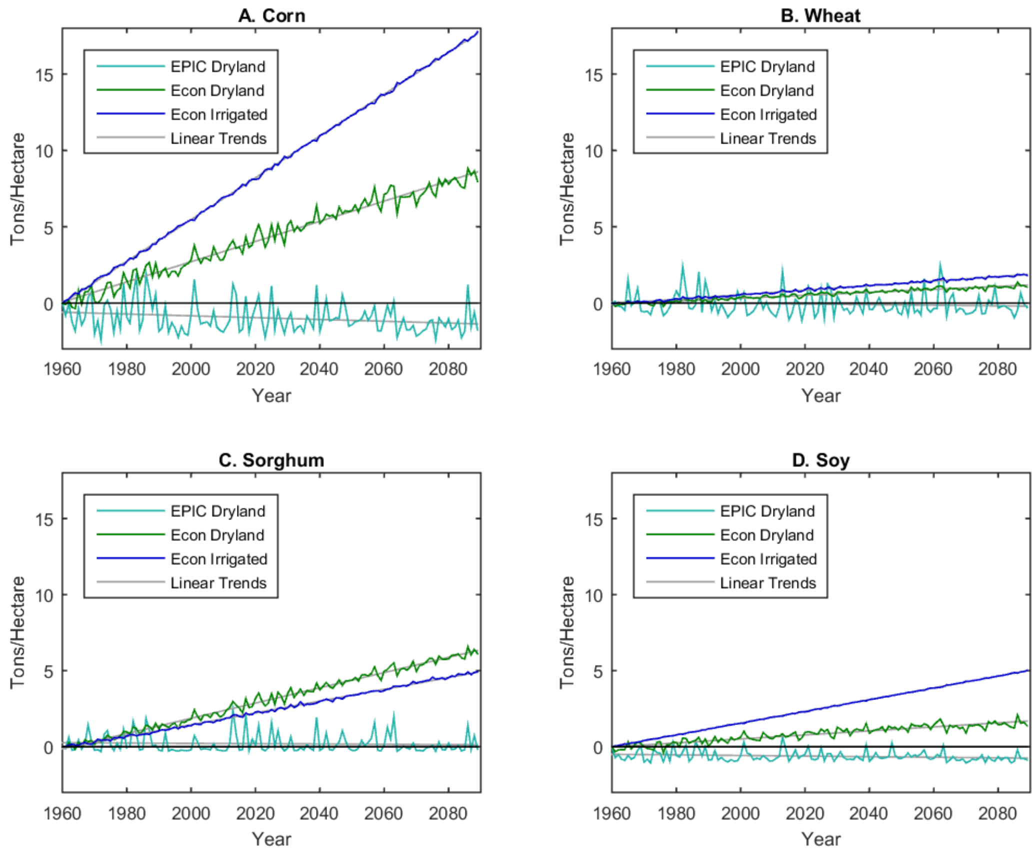

Figure C- 9—Garden, Nebraska

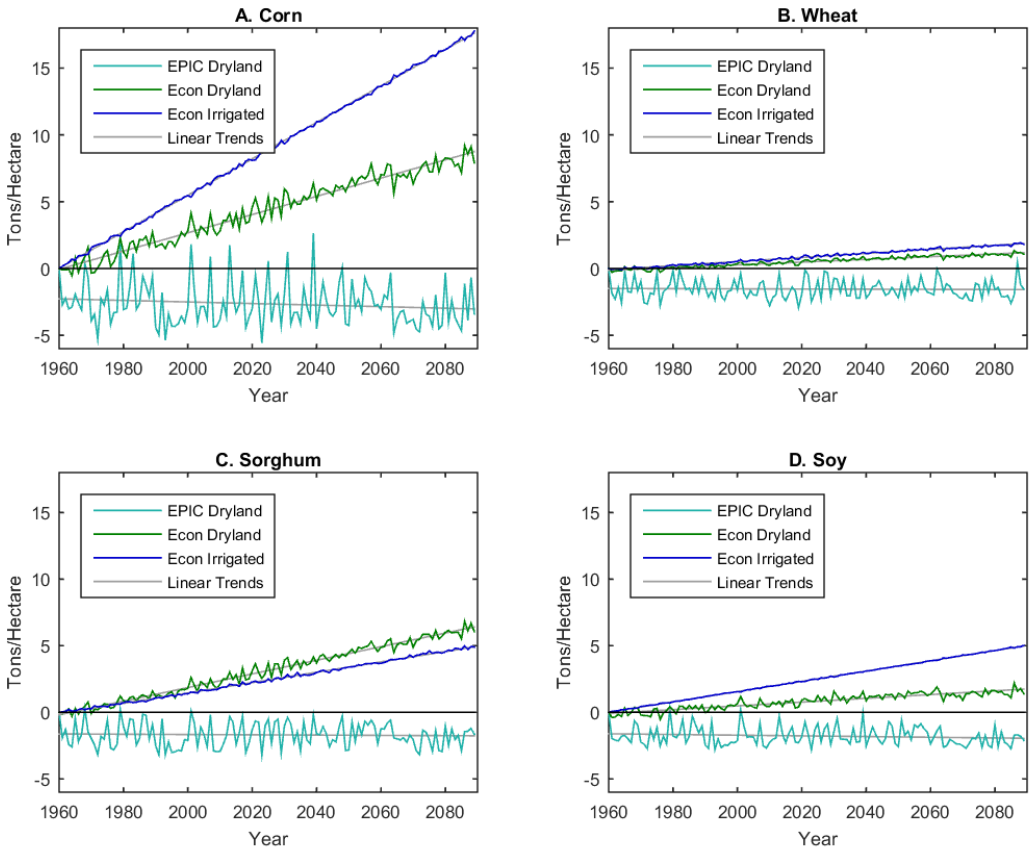

Figure C- 10—Phelps, Nebraska

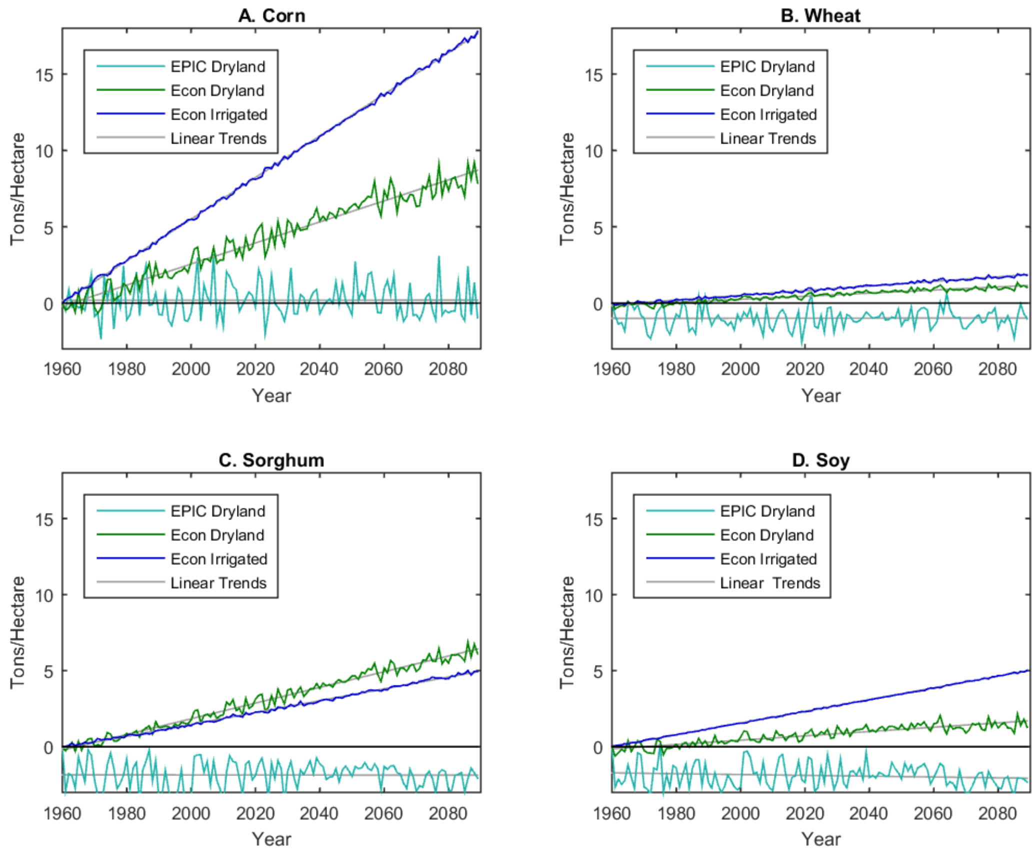

Figure C- 11—Pierce, Nebraska

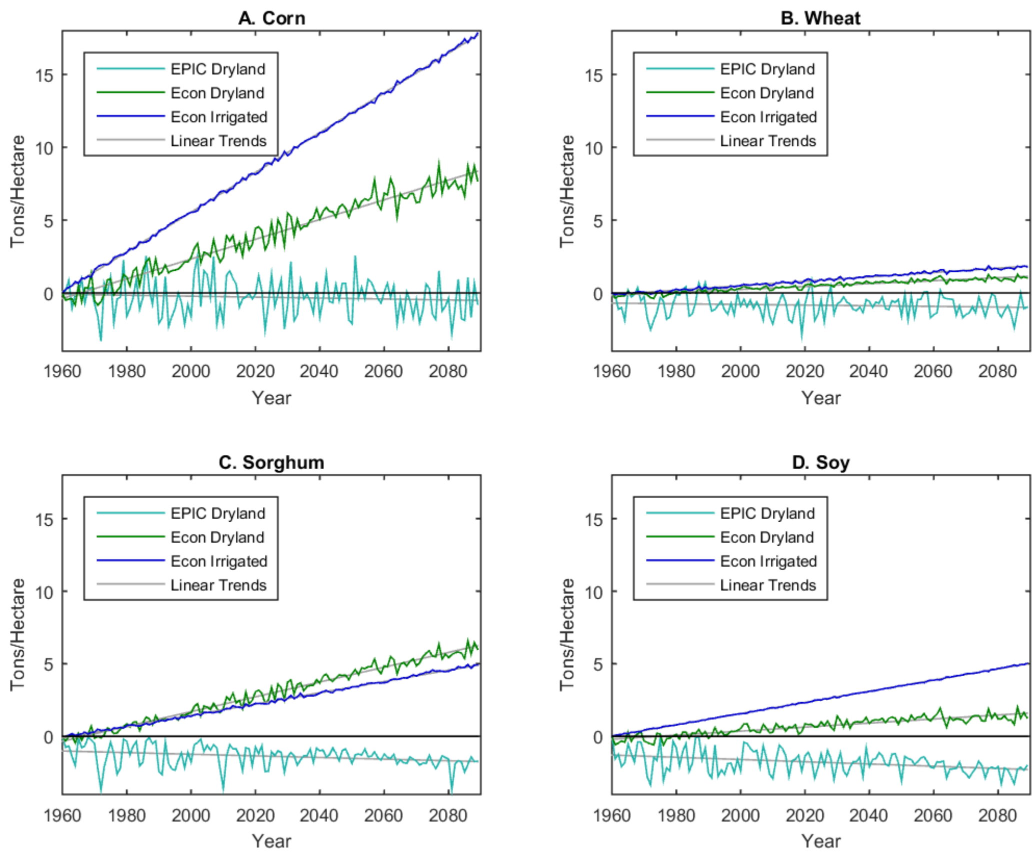

Figure C- 12—Platte, Nebraska

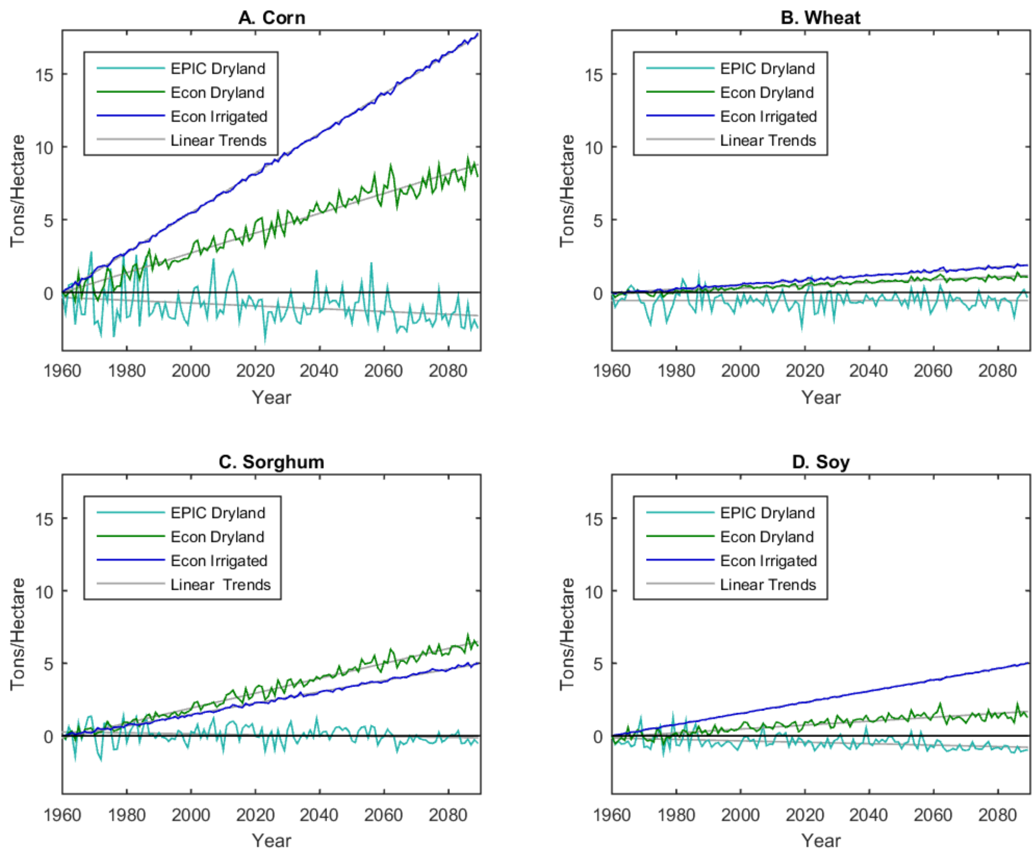

Figure C- 13—Rock, Nebraska

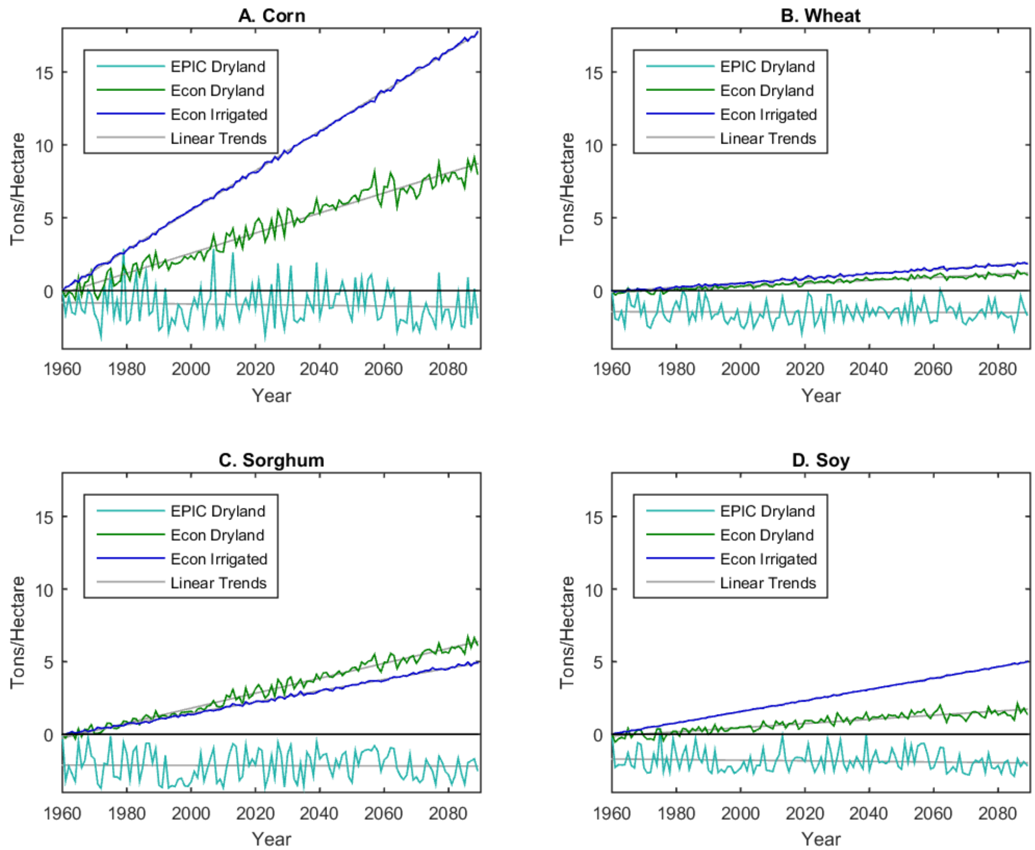

Figure C- 14—Valley, Nebraska

Table C- 9—Summary of Linear Trends

Corn					Winter Wheat				
State	County	EPICDry	EconDry	EconIrr	State	County	EPICDry	EconDry	EconIrr
KS	Barton	-0.007	0.066	0.137	KS	Barton	-0.003	0.010	0.015
	Haskell	-0.006	0.064	0.137		Haskell	-0.001	0.010	0.015
	Pratt	-0.006	0.066	0.137		Pratt	-0.003	0.010	0.015
	Rawlins	-0.007	0.066	0.137		Rawlins	-0.001	0.010	0.015
	Rooks	-0.003	0.067	0.137		Rooks	-0.002	0.010	0.015
	Scott	-0.007	0.066	0.137		Scott	-0.003	0.010	0.015
	Mean	-0.006	0.066	0.137		**Mean**	-0.002	0.010	0.015
	Minimum	-0.007	0.064	0.137		**Minimum**	-0.003	0.010	0.015
	Maximum	-0.003	0.067	0.137		**Maximum**	-0.001	0.010	0.015
NE	Dundy	-0.006	0.066	0.137	NE	Dundy	-0.002	0.010	0.015
	Fillmore	-0.006	0.068	0.137		Fillmore	-0.001	0.010	0.015
	Garden	-0.006	0.066	0.137		Garden	-0.002	0.010	0.015
	Phelps	-0.006	0.068	0.136		Phelps	-0.001	0.010	0.015
	Pierce	-0.010	0.069	0.136		Pierce	-0.001	0.010	0.015
	Platte	-0.003	0.068	0.137		Platte	-0.002	0.010	0.015
	Rock	-0.010	0.068	0.136		Rock	-0.001	0.010	0.015
	Valley	-0.002	0.069	0.136		Valley	-0.001	0.010	0.015
	Mean	-0.006	0.068	0.137		**Mean**	-0.001	0.010	0.015
	Minimum	-0.010	0.066	0.136		**Minimum**	-0.002	0.010	0.015
	Maximum	-0.002	0.069	0.137		**Maximum**	-0.001	0.010	0.015

Sorghum					Soy				
State	County	EPICDry	EconDry	EconIrr	State	County	EPICDry	EconDry	EconIrr
KS	Barton	-0.005	0.050	0.039	KS	Barton	-0.006	0.013	0.039
	Haskell	-0.002	0.048	0.038		Haskell	-0.003	0.013	0.039
	Pratt	-0.007	0.050	0.039		Pratt	-0.007	0.013	0.039
	Rawlins	-0.002	0.050	0.039		Rawlins	-0.001	0.014	0.039
	Rooks	-0.003	0.050	0.039		Rooks	-0.004	0.014	0.039
	Scott	-0.002	0.049	0.038		Scott	-0.003	0.013	0.039
	Mean	-0.004	0.050	0.039		**Mean**	-0.004	0.013	0.039
	Minimum	-0.007	0.048	0.038		**Minimum**	-0.007	0.013	0.039
	Maximum	-0.002	0.050	0.039		**Maximum**	-0.001	0.014	0.039
NE	Dundy	-0.001	0.050	0.039	NE	Dundy	-0.002	0.013	0.039
	Fillmore	-0.004	0.051	0.039		Fillmore	-0.006	0.014	0.039
	Garden	-0.001	0.050	0.039		Garden	-0.002	0.013	0.039
	Phelps	-0.001	0.051	0.039		Phelps	-0.003	0.014	0.039
	Pierce	-0.001	0.052	0.039		Pierce	-0.003	0.014	0.038
	Platte	-0.006	0.051	0.039		Platte	-0.008	0.014	0.039
	Rock	-0.003	0.051	0.039		Rock	-0.005	0.014	0.039
	Valley	-0.001	0.051	0.039		Valley	-0.002	0.014	0.038
	Mean	-0.002	0.051	0.039		**Mean**	-0.004	0.014	0.039
	Minimum	-0.006	0.050	0.039		**Minimum**	-0.008	0.013	0.038
	Maximum	-0.001	0.052	0.039		**Maximum**	-0.002	0.014	0.039

APPENDIX D: ADDITIONAL ECONOMICS FIGURES

Scenario 1—Reduction in Farm Proprietor Income

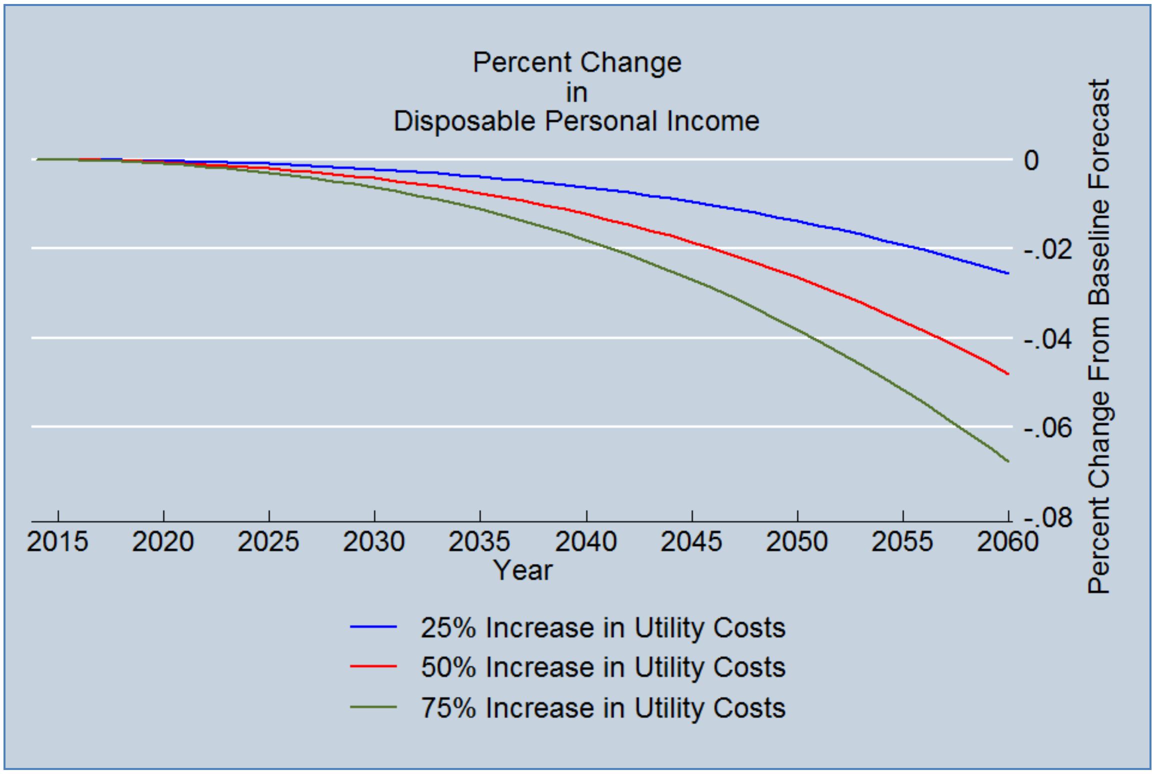

Figure D- 1—Percent Change in Disposable Personal Income, All Regions

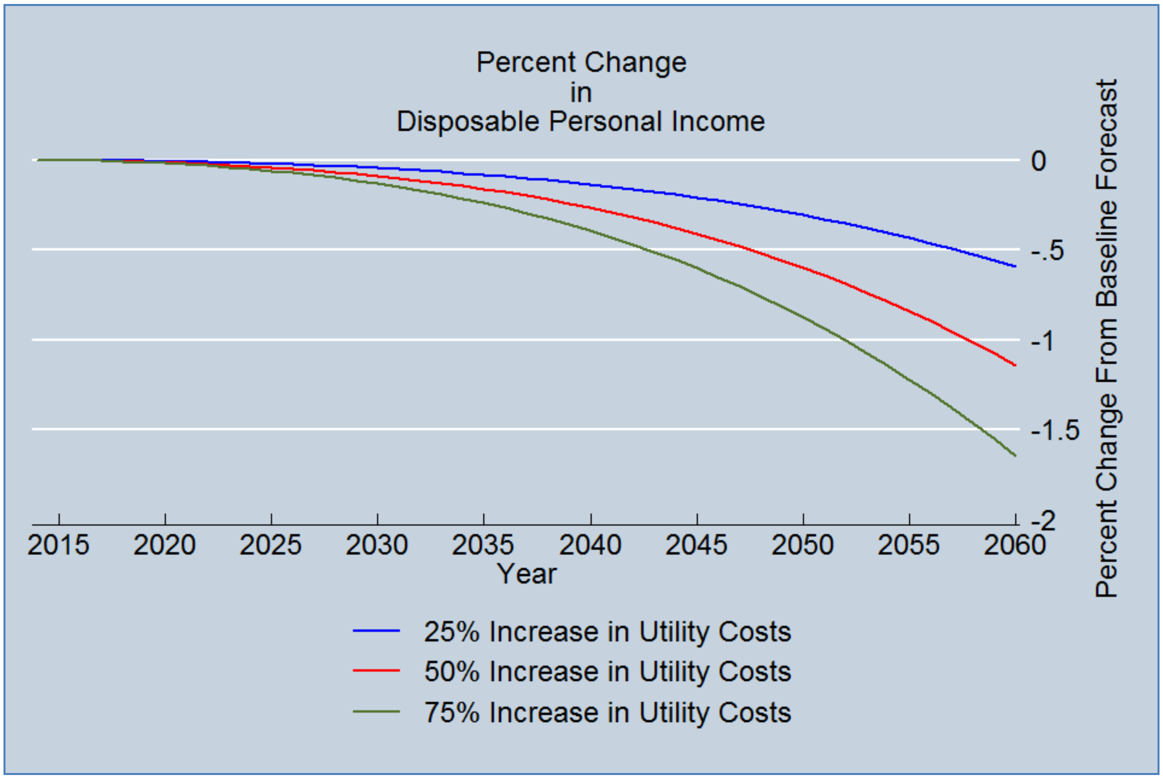

Figure D- 2—Percent Change in Disposable Personal Income, Kansas

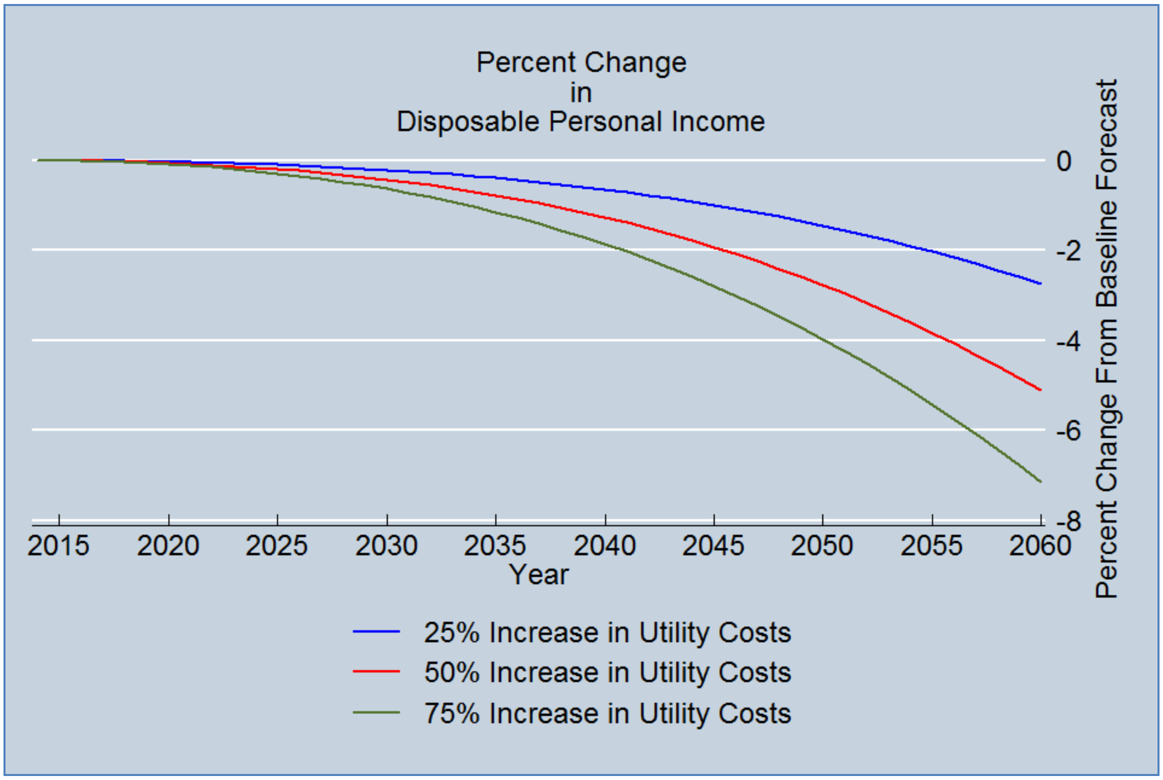

Figure D- 3—Percent Change in Disposable Personal Income, Nebraska

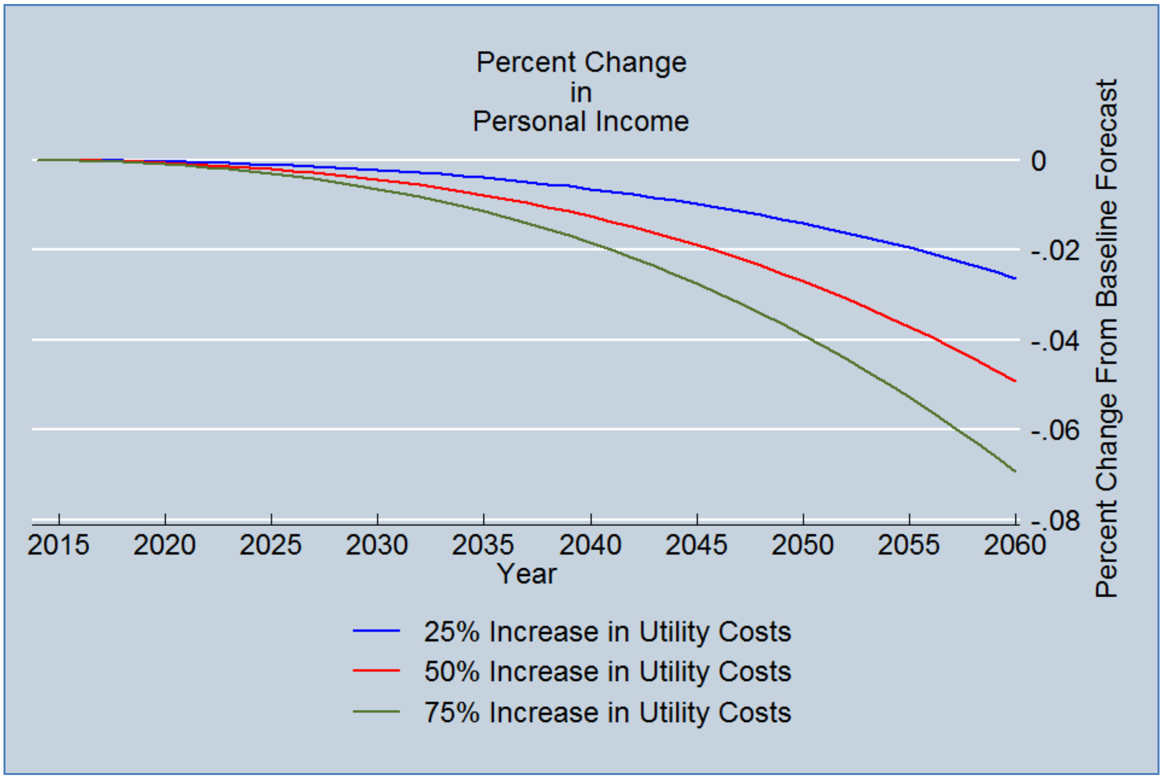

Figure D- 4—Percent Change in Personal Income, All U.S. Regions

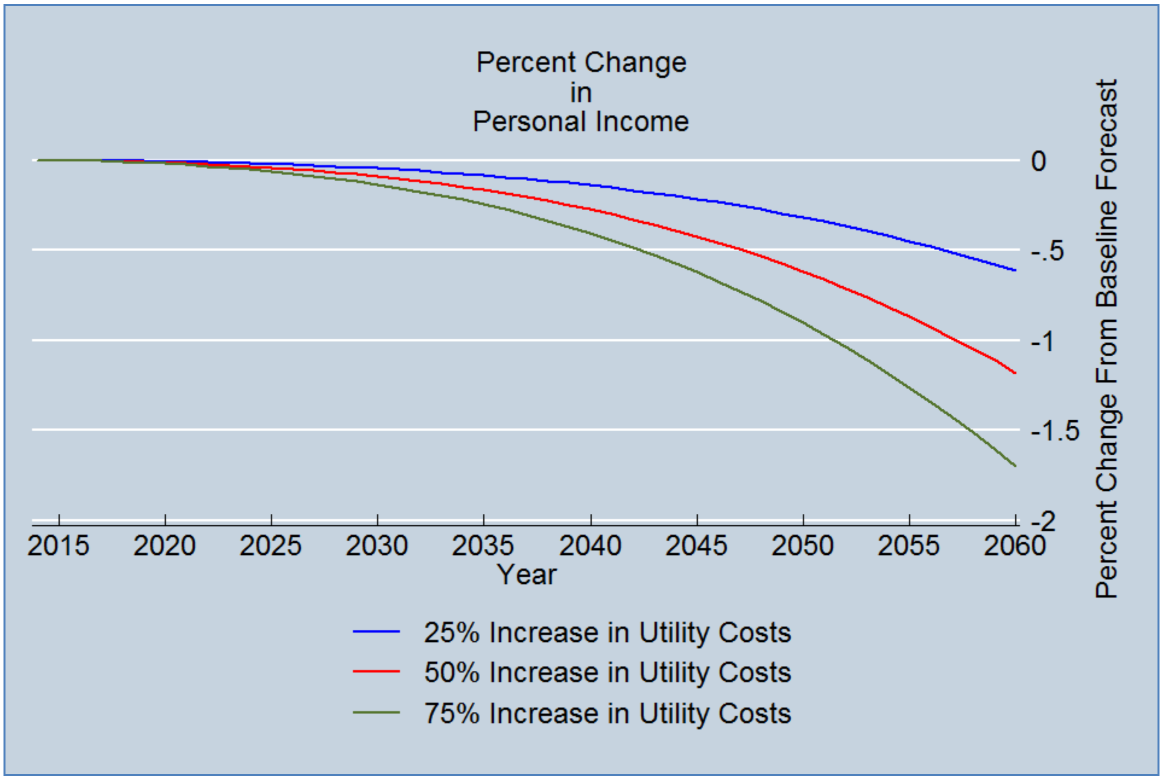

Figure D- 5—Percent Change in Personal Income, Kansas

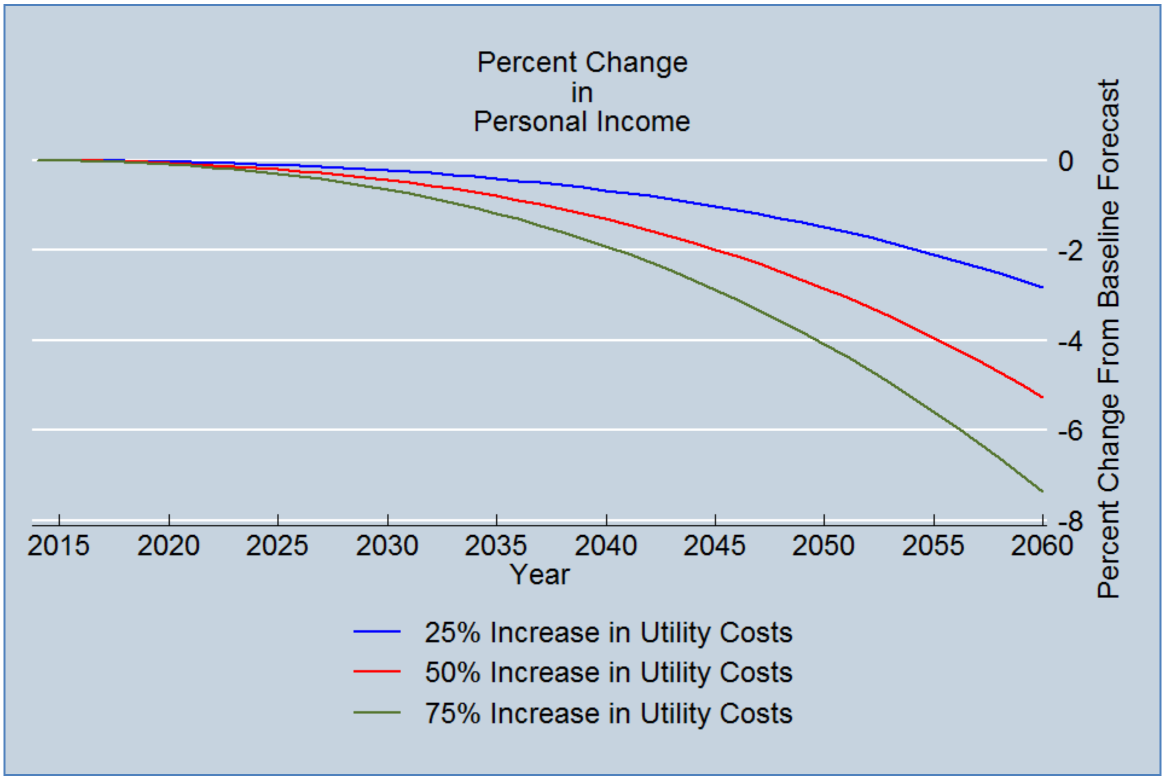

Figure D- 6—Percent Change in Personal Income, Nebraska

APPENDIX E: THE ECONOMETRIC MODEL

In addition to informing the regional economic consequence model, estimating how change in water extraction costs affects the likelihood of farm exits and operations going out of business is an important sub-analysis for the overall economic consequence modeling effort.

Previous studies of the factors influencing firm exit have determined that, although farm exits are influenced by economic factors, the decision to exit is often influenced considerably by factors unique to the family farm operators (Hoppe and Korb). It is necessary to control for operator heterogeneity in the analysis (e.g., age, gender, and race). The study uses a logistic-regression panel data model in order to predict the influence of water extraction costs on an operators' decision to exit the market while explicitly controlling for operator heterogeneity.

Following previous studies, we estimate the probability of farm exit using a logistic regression model:

$$\ln\left(\frac{P_{it}}{1-P_{it}}\right) = Y = X'_{it}\beta + W'_{it}\delta + \varepsilon_{it}$$

where P_{it} is the probability of firm i's exit during period t, and W_{it} is a vector of farm- and time-specific water costs.[124] X_{it} is a vector of farm operation and farm-operator characteristics, including operator age, farm sales, and farm specialization. A random-effects error term, ε_{it}, is specified to mitigate the bias that arises when subjects are observed more than once. The random-effects error term (ε_{it}) includes an individual-specific error component.

[124] Extraction costs may vary at the county level.

APPENDIX F: GLOSSARY

Acre: A unit of land area defined as 4,046.86 square meters in the metric system of measurement.

Ambient groundwater recharge: The groundwater recharge rate that occurs under predevelopment conditions. Recharge is the deep drainage or percolation of water from ground surface to a groundwater aquifer.

Bias-correction constructed analogs (BCCA) (in-depth): The BCCA is a statistical downscaling technique used to refine the spatial and temporal resolution of climate model output. The BCCA downscaling is performed in two steps. First, wet, dry, cool, and/or warm model biases are identified by comparing simulated and observed climate from 1961-1999. Second, biases are then removed from the climate model output using a quantile mapping technique (Wood et al., 2004). [125] The coarser-resolution, bias-corrected output is then translated to a finer resolution using the SYMAP algorithm (Shepard, 1984).[126]

Binary variable: A variable with only two possible values, often 0 or 1.

Center pivot: A method of irrigation that involves a long sprinkler arm that rotates around a central point, creating circular irrigated fields.

Downscaled: Such models adapt high-level information to a local or regional level based on the concept that local conditions are some function of the overarching conditions, but are also shaped by regional geographic characteristics. These models are useful during high-resolution analyses because they offer statistical tools to generate locally relevant data.

Downstream: The economic term for the consumers of a firm's goods or services, including value-added intermediaries.

Endogenous: Designates variables in an econometric model that are explained or predicted by that model.

Exogenous: Designates variables that appear in an econometric model, but are not explained by that model.

Hectare: A unit of land area defined as 10,000 square meters in the metric system of measurement.

Heterogeneity: Constituting dissimilar or diverse elements.

Heteroscedasticity: A statistical term that describes when a variable's variability is not uniform.

Live weight: The weight of an animal before slaughter and processing; used to determine pricing.

Macroeconomic: The branch of economics that deals with whole economies as a set of aggregated markets to evaluate their structure and performance. Macroeconomics typically involves national or supranational scales.

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[125] Wood, A.W., Maurer, E.P., Kumar, A., and Lettenmaier, D.P. (2002). Long-Range Experimental Hydrologic Forecasting for the Eastern United States. *J. Geophysical Research-Atmospheres*, 107(D20), 4429.

[126] Shepard, D.S. (1984). Computer Mapping: The SYMAP Interpolation Algorithm. *Spatial Statistics and Models*, (G.L. Gaile and C.J. Willmott, eds.), 133-145, D. Reidel, Norwell, Massachusetts.

Marginal land: Land that is relatively less productive or desirable because it retains undesirable characteristics.

Microeconomic: The branch of economics that deals with the behavior of individuals or firms in allocating scarce resources to determine the quantity supplied and demanded for a good or service at a particular price.

Porosity: Volume of pores to the total volume of a porous material (e.g., aquifer).

Profit maximization: The assumption in economics that an individual or firm sets target prices and output that result in the greatest profit, defined as total revenue minus total cost.

Pump efficiency: The ratio of work obtained by the pump versus the amount of work required to operate the pump.

Random-effects model: In econometrics, a random effects model assumes variation across entities is correlated to the independent variables in the model, which is especially useful with time-invariant variables—contrasted to a fixed-effects model that assumes variation within an entity is correlated with the independent variable.

RCP8.5: Representative Concentration Pathway 8.5.

Spatiotemporal: A variable defined over both space and time.

Specific yield: Volume of water released from groundwater storage per unit decline of the water table (roughly equivalent to the porosity of the formation).

Water use efficiency: The measure of consumptive to non-consumptive water use for a particular application.

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