ANALYSIS OF HIGH PLAINS RESOURCE RISK AND ECONOMIC IMPACTS

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NATIONAL PROTECTION AND PROGRAMS DIRECTORATE

OFFICE OF CYBER AND INFRASTRUCTURE ANALYSIS

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EXECUTIVE SUMMARY

The Department of Homeland Security (DHS) Office of Cyber and Infrastructure Analysis (OCIA) produced this report on High Plains Aquifer risk and associated economic impacts. The area overlying the High Plains Aquifer 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.[1] Following World War II, improved pumps and center pivot irrigation technology made High Plains groundwater available for large-scale irrigated agriculture. The High Plains has since become one of the most intensively irrigated areas in the United States, accounting for about 30 percent of all groundwater withdrawn for irrigation. As of 2007, the High Plains supported 50 million acres of cropland, 15.4 million acres of which were irrigated. The High Plains supplies approximately one-fourth of the Nation's agricultural production. Associated crops provide significant amounts of feed to the Midwest cattle operations that account for 40 percent of U.S. feedlot beef output. The aquifer also provides drinking water to 82 percent of the people who live within its boundaries.[2] Increasing reliance on the High Plains aquifer has exceeded groundwater recharge rates. Water-level declines began in parts of the High Plains Aquifer soon after the onset of substantial irrigation, around 1950; by 1980, water levels had declined by more than 100 feet in parts of Texas, Oklahoma, and southwestern Kansas.[3]

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 levels. County-level analysis examined 140 counties that overlie the High Plains Aquifer in the States of Kansas and Nebraska to estimate time to depletion of the groundwater resource at current pumping rates. The analysis uses climate projections to estimate future crop production. Current water use and management practices are projected to explore their related impact on the High Plains Aquifer, specifically in the region defined by Kansas and Nebraska together. Finally, the impacts of declining water levels and changes in crop production, including exhaustion of groundwater resources, are projected for specific economic industries and critical infrastructure.

The results of the crop modeling analyses 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 Kansas and Nebraska. Irrigation use, historically, has offset the impacts of variations in temperature and precipitation on crop yields; however, declining water levels are likely to limit offsets in the future. Improvements to farm operations (for example, changing crops to more drought-resist strains) and technology could overcome the impacts of climate variability, if future trends are consistent with recent developments such as improved tilling practices, advanced fertilizers and genetically modified crops.

Despite efforts to reduce groundwater depletions, groundwater pumping in some areas within the High Plains region still exceeds sustainable groundwater recharge rates. To calculate when the aquifer is unlikely to be able to sustain continued pumping, the study projected current pumping rates into the future. Eighteen counties in Kansas were projected to have 25 or less 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. Vulnerable counties are largely associated with extensive irrigated acreage or zones at the margin of the High Plains Aquifer where the formation thins.

The associated economic analysis relies on information from numerous sources including previous National Infrastructure and Analysis Center (NISAC) and agricultural economic reports, and input from key stakeholders to derive its assumptions and to limit the parameters and variables necessary to translate the scenario text into a quantitative economic model. To estimate the economic consequences of resource risk in the High Plains, the economic analysis employed a two-pronged approach: (1) starting at the national level and drilling down to identify

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

[2] 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,

[3] Luckey, R.R., Gutentag, E.D., and Weeks, J.B., 1981, Water-level 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 http: //pubs.er.usgs.gov/publication/ ha652.)

major industries at the State and county levels while also categorizing industries as water intensive and therefore vulnerable to resource risk, and (2) translating microeconomic impacts to the macroeconomic level.

Industries deemed both economically dominant and characterized by high water intensity and use were selected for microeconomic impacts because of their likely sensitivity to higher prices for pumping groundwater. Qualitative analysis confirmed that of all those studied, the agriculture industry by output (volume and dollars), wages, employment, and water use is the most susceptible to increasing resource risk in the High Plains region. OCIA-NISAC completed a combined microeconomic and macroeconomic consequence analysis that focused on the agriculture industry to capture both the regional and national impacts associated with resource risk in the High Plains. Follow-on effects on other industries and critical infrastructure are the result of the physical-based relationships between industries represented through dollar relationships in the economic modeling.

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 highlight the need to continue technological innovations.**
- **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 less.**
- **Declining water levels mean increased farm operations costs. Every $1,000 increase in utility expenditures corresponds to a 2.62 percent increase in the probability of a farm operation exiting the industry.**
    - **A 25 percent increase in utility costs over 50 years results in approximately a 0.1 percent decrease in Kansas State GDP.**
    - **A 25 percent increase in utility costs over 50 years results in approximately a 0.4 percent decrease in Nebraska State 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 percent decrease in irrigated acres over 50 years results in approximately a 0.19 percent decrease in Kansas State 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).**

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INTRODUCTION

The Department of Homeland Security's Office of Cyber and Infrastructure and Analysis (DHS/OCIA) manages the advanced modeling, simulation, and analysis capabilities of the National Infrastructure Simulation and Analysis Center (NISAC) in support of the DHS critical infrastructure protection mission. The National Infrastructure Simulation and Analysis Center (NISAC) analyzed the potential effects of aquifer depletion and increased pumping costs on the High Plains region of the United States, specifically the States of Kansas and Nebraska. NISAC collaborated with local DHS Protective Security Advisors (PSAs), state and local officials, and other DHS personnel to define the scope of this analysis.

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 (Figure 1). The water-saturated thickness ranges from a few feet to more than 1,000 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. 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 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]

Following World War II, improved pumps and center pivot irrigation technology made High Plains groundwater available for large-scale irrigated agriculture. The High Plains has become one of the nation's most intensively irrigated areas, accounting for about 30 percent of all groundwater withdrawn for irrigation in the United States.[12] More than 90 percent 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 include cotton, corn, alfalfa, sorghum, 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

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4 The High Plains aquifer is composed 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. Texas A&M University Press, College Station.
8 Weakly, H. E. and L.L. Zook. 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 E.B. Lewis. 1933. "Pump Irrigation Investigations in Nebraska." Agricultural Experiment Station, University of Nebraska College of Agriculture, Lincoln, Bulletin 282 (July).
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, at http: //www.agcensus.usda.gov/. At the time of reporting, the 2012 data was yet to be released.

the Nation's agricultural production.[14] Associated crops provide the Midwest cattle operations with enormous amounts of feed that account for 40 percent of the feedlot beef output in the United States.[15]

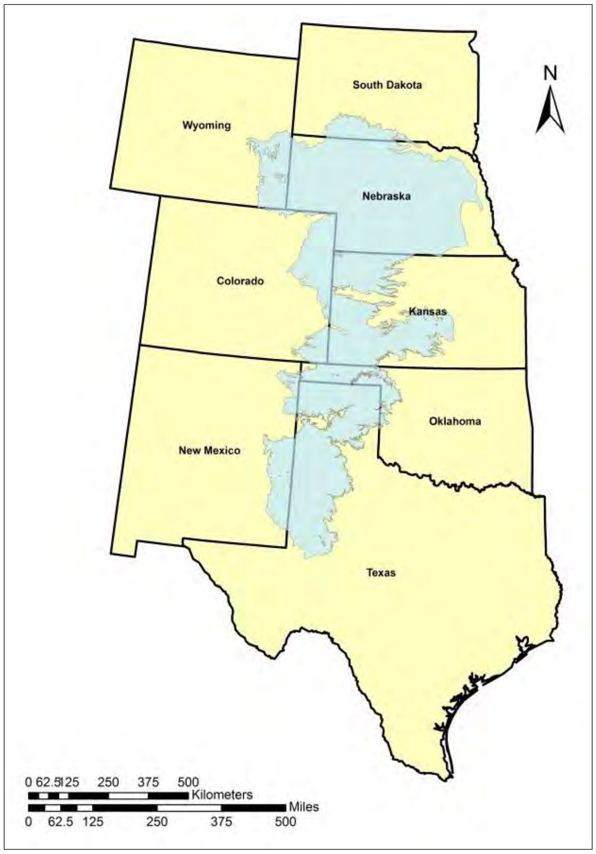

FIGURE 1—EXTENT OF HIGH PLAINS AQUIFER

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.[16,17,18] Water-level declines began in parts of the High Plains Aquifer soon after the onset of substantial irrigation—around 1950.[19] By 1980, water levels in the High Plains Aquifer in parts of Texas, Oklahoma, and southwestern Kansas had declined by more than 100 feet.[20] In response to water-level declines, Congress, under the authority of Title III to the 1984 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:

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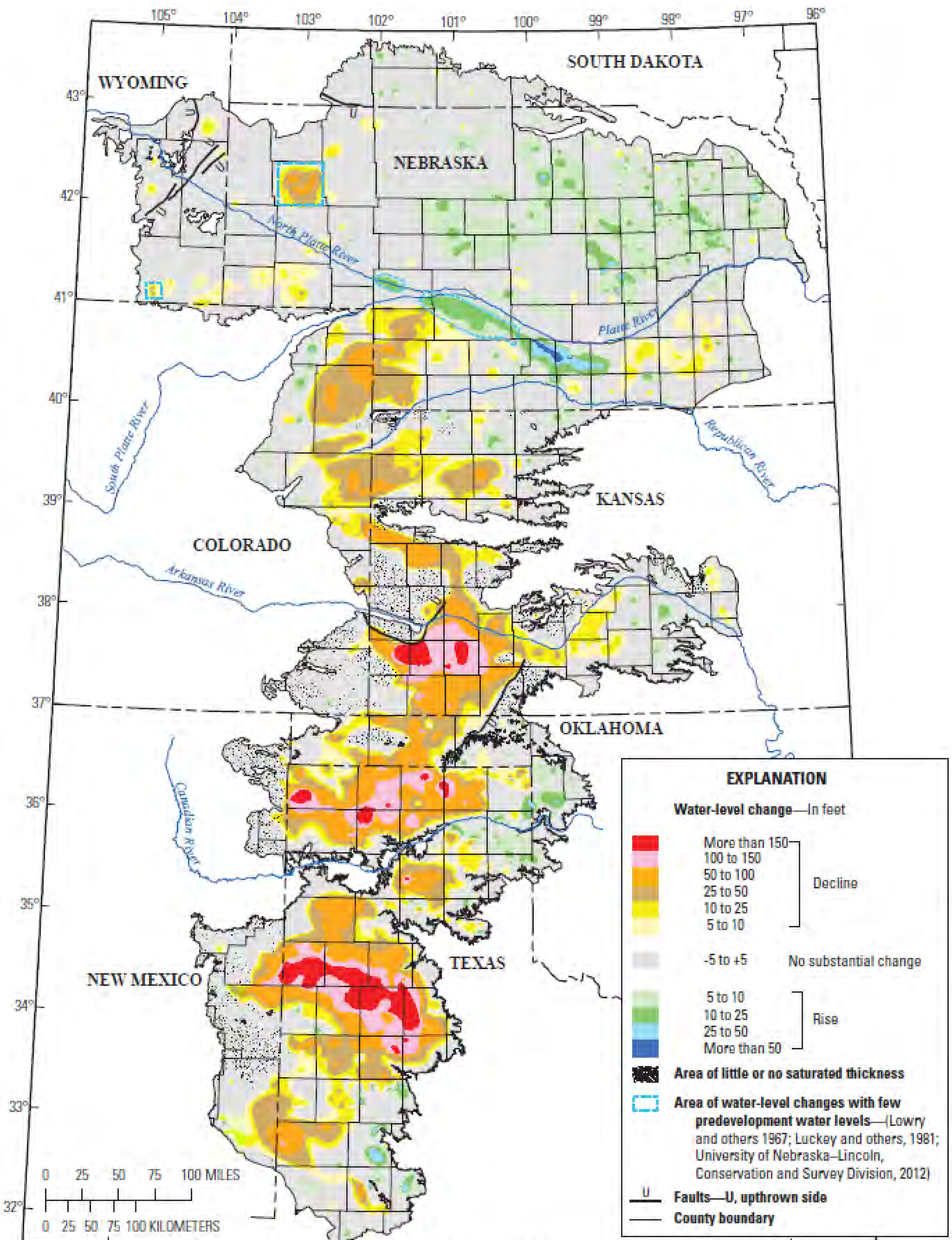
[14] McMahon PB, Dennehey KF, Bruce BW, Gurdak JJ, Qi SL (2007) Water-Quality Assessment of the High Plains Aquifer, 1999–2004 (US Geological Survey, Reston, VA), Professional Paper 1749.
[15] Aquifer Close Up. Published by Center for Biological Computing, Indiana State University, Department of Life Sciences. http: //mama.indstate.edu/users/johannes/aquifer/htm
[16] Zwingle, E. 1993. "Wellspring of the High Plains," National Geographic, March, 80-109.
[17] Opie, J. 1993. Ogallala: Water for a Dry Land. Lincoln: University of Nebraska Press.
[18] 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.
[19] 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.)
[20] Luckey, R.R., Gutentag, E.D., and Weeks, J.B., 1981, Water level 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 http: //pubs.er.usgs.gov/publication/ ha652.)

- 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 percent); and
- Changes in water in storage, 2009-11, involved overall decline of 2.8 million acre-feet.[21]

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 (Figure 2). Measured declines in groundwater of over 100 feet are not uncommon, with some of the most significant declines registered in Texas, Oklahoma, Kansas, and to a lesser extent in Nebraska.[22]

[21] 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/.)

[22] 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, p. 28.



Base from U.S. Geological Survey digital data, 2001, 1:2,000,000
Albers Equal-Area Conic projection
Standard parallels 29° 30′ and 45° 30′, central meridan -101°
North American Datum of 1983 (NAD 83)

Aquifer boundary from Qi (2010); areas of little or no saturated thickness and faults from Gutentag and others (1984) and Cederstrand and Becker (1999a, 1999b)

FIGURE 2—WATER LEVEL DECLINES FOR THE HIGH PLAINS AQUIFER FROM PRE-DEVELOPMENT TO 2011[23]

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23 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, p. 28.

QUESTIONS

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 OCIA NISAC study focused its research, modeling, and analysis on five overarching questions:

1. How might groundwater depletions evolve in the future?
2. How will variations in climate impact agricultural production in the future?
3. Which economic sectors are most vulnerable to groundwater depletion?
4. How might declining groundwater levels, aquifer depletion, and changes in agriculture production impact the economy and critical infrastructure?
5. How do impacts at the local level aggregate to affect the economy at a regional and national level?

ASSUMPTIONS

Given the complexity of aquifer depletion impacts, certain assumptions make the analysis tractable. This section reviews the most important research assumptions and their potential implications.

One key assumption of this work relates to the scale of analysis. Driven largely by the availability of data over the broad geographic region of Kansas and Nebraska, the county represents the finest scale of resolution for model simulation. 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 system vulnerabilities and their potential implications.

Another important assumption is associated with the economic modeling. Although the agricultural industry in the High Plains region 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, then the continued successful operation of some of those irrigated farms may not be possible. This paper presents a predictive analytical approach for estimating whether farm operations will exit the market or reduce production. It is recognized that farm operations have other options. For example, an operator could sell the farm; an individual farm could be absorbed into a larger farm operation; a farmer could reduce irrigated acreage, adopt crop rotation or crop switching practices, or introduce genetically modified water-saving crops or new irrigation technologies; finally, a farmer could sell or rent water rights. The full set of options is extensive and complex and beyond the resources of this analysis. Limiting options to exiting the market or reducing production allows for a full set of responses in two representative categories and captures the impetus for a tipping point. Whether or not the farm operation continues in a different manner or does not continue and proceeds with available market options, either way represents a tipping point with the potential for regional and national macroeconomic impacts. The purpose of the study, therefore, is to inform resource management and planning exercises.

It is not the role of OCIA 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.

DECISION SUPPORT

The intent of this study is to provide decision makers with an assessment of how continued depletions of the High Plains Aquifer as one variable used to inform the economic assessment, might impact both critical infrastructure and the economy at the local, regional, and national scale. The analysis provides insight into the extent to which future climate variability might impact crop production. Analyses also project how changing water demands will impact the rate of depletion of the High Plains Aquifer. From this context, the sectors of the economy and critical infrastructure that are most vulnerable to continued aquifer depletion are identified. The analysis also explores the relationship of these vulnerable infrastructure and economic sectors to the broader economy to estimate the full effect of continued aquifer depletion. 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.

RESULTS

GROUNDWATER MODELING RESULTS

The importance of the High Plains Aquifer coupled with its declining groundwater levels has made this aquifer the subject of numerous studies. Over-pumping (pumping that exceeds groundwater recharge rates) is widely recognized as the cause of the depletions.[24] Given the existing body of work and the limited resources of this project, groundwater modeling efforts were focused solely on providing information tuned to the specific needs of the economic analysis. Thus, the groundwater results are not unique; rather, they are aimed at being consistent with other studies of the aquifer. Key to this analysis was groundwater data produced at a coarse spatial resolution (county level) distributed over a broad geographic region (Kansas and Nebraska).

Two sets of results are discussed that provide the necessary context for the economic analysis. The first set explores how groundwater is currently used by Kansas and Nebraska. The second set projects future changes in groundwater levels assuming that current groundwater pumping and management practices are sustained.

WATER USE AND INTENSITY BY INDUSTRY

Kansas freshwater withdrawals totaled 4,000 million gallons per day (MGD) in 2010 (Figure 3).[25]

- Irrigated agriculture accounted for 3,040 MGD (76 percent) of the freshwater withdrawals.
- Public supply accounted for 391 MGD (9.7 percent).
- Thermoelectric power generation used 377 MGD (9.4 percent).
- Livestock required 144 MGD (3.6 percent).

The ratio of groundwater to surface water withdrawals varied across these sectors. Ninety-four percent of all irrigated agriculture and 80 percent of livestock water demands were met with groundwater. In contrast, only 3 percent of thermoelectric water demand was met by groundwater. Total groundwater pumping in 2010 was 3,200 MGD.

Nebraska freshwater withdrawals in 2010 were 8,040 MGD (Figure 4).[26]

- Irrigated agriculture accounted for 5,660 MGD (70 percent) of the freshwater withdrawals.
- Thermoelectric generation was responsible for using 1,790 MGD (22 percent).
- Public supply accounted for 296 MGD (36 percent).
- Livestock required 114 MGD (1.4 percent).
- Aquaculture, the controlled cultivation of aquatic organisms, used 88.3 MGD (1.1 percent)
- All other sectors combined were responsible for only about 1 percent of the freshwater withdrawals.

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[24] 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/*.)
[25] 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.
[26] Ibid.

Irrigation relied heavily on groundwater at 76 percent, as did public supply, 99 percent; livestock, 82 percent; and industry, 93 percent. In contrast, thermoelectric generation withdrew only 0.3 percent from groundwater, and aquaculture, 7 percent. Total groundwater pumping in 2010 was 4,710 MGD.

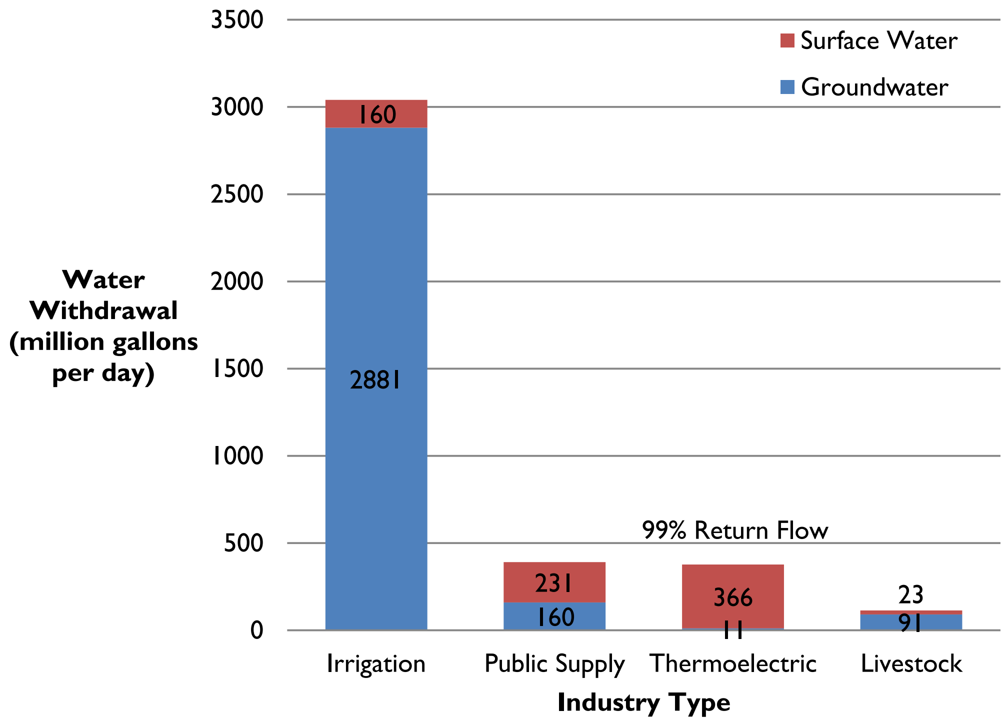

FIGURE 3—FRESHWATER WITHDRAWALS BY KANSAS IN 2010 BY SECTOR AND SOURCE

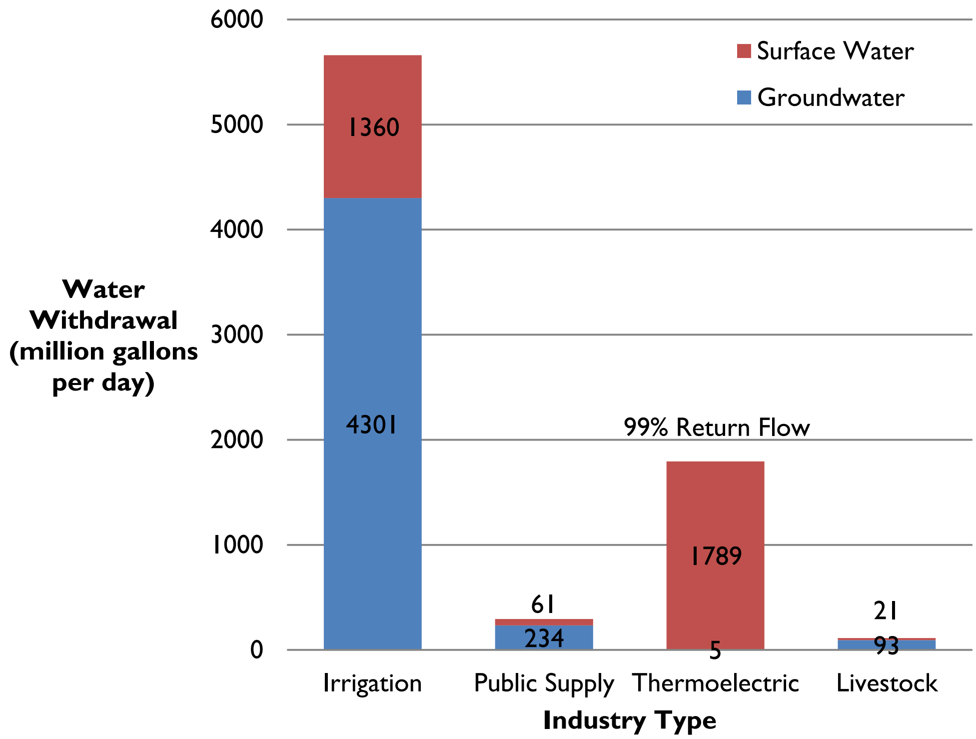

FIGURE 4—FRESHWATER WITHDRAWALS BY NEBRASKA IN 2010 BY SECTOR AND SOURCE

Beyond these state-level water withdrawal statistics, NISAC also considered water use by key industries. Irrigated agriculture is the largest user of water, most of which is sourced from groundwater. Nebraska accounts for 15.1 percent of the country's total irrigated acres, while Kansas accounts for 4.9 percent of total irrigated acres.[27] Nebraska has 187 percent more irrigated acres than Kansas, and corn makes up 64.3 percent of all Nebraska irrigated acres.[28] Corn requires between 20 and 25 inches of water for high-yield varieties, but may produce at lower yields with 15 to 16 inches of water. 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. It is also important to note that irrigation is not uniformly distributed over the two states. Figure 5 shows the relative distribution (percent by county) of irrigated acres for each county that overlies the High Plains Aquifer.

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

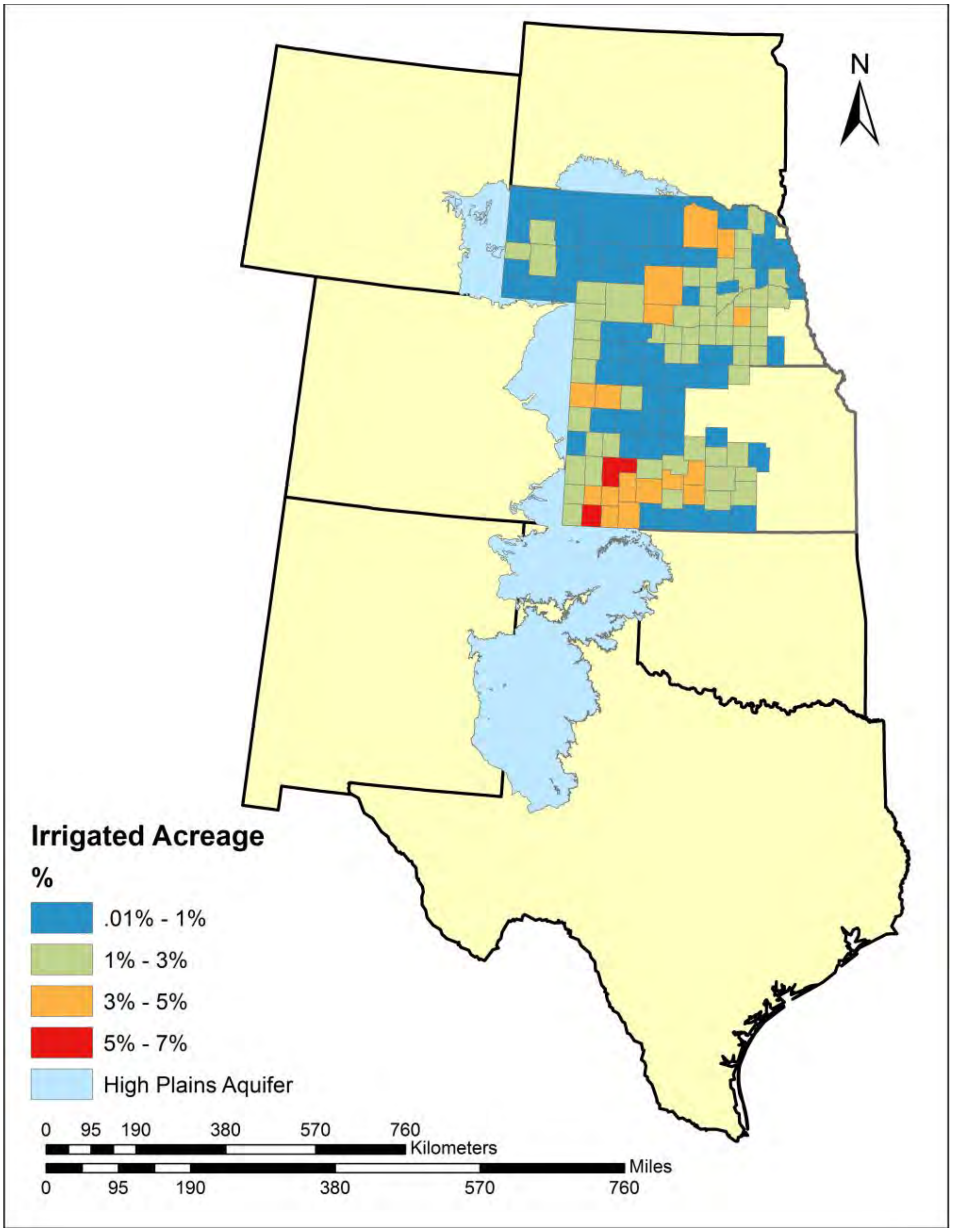

FIGURE 5—PERCENT OF IRRIGATED ACREAGE BY COUNTY (CALCULATED BY STATE)

Ethanol production is an increasingly important downstream user of corn and corn residual products (the stalks, leaves, and cobs that remain after harvest). According to the Agricultural Marketing Resource Center, ethanol producers became the second highest market for corn, behind only the domestic feed market. Strong demand for corn has helped maintain a strong demand for irrigation. In fact, Nebraska and Kansas rank first and second in irrigated acres for corn production. The processing of corn for ethanol production has its own set of water requirements. Corn ethanol uses water for five production processes: grinding, liquefaction, fermentation, separation, and drying. The U.S. Department of Agriculture estimates that a modern ethanol processing mill consumes three gallons of water for every gallon of ethanol produced; previous generations of processing mills can use much more water.[29] Significantly, 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.[30]

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. Nebraska ranks behind only Texas in terms of the number of cattle and calves in inventory, with Kansas a close third. Water requirements for growing cattle can range from 5 to 20 gallons per day depending on such factors as cattle weight and ambient temperature. Other sectors of the livestock industry include value-added processing facilities such as slaughter, processing, packaging, and distribution operations for animal products. 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.[31]

Thermoelectric power generation is important to both states.[32] Freshwater withdrawals are greater for Nebraska supplying 11 power plants totaling 4,918 megawatts (MW) of capacity fueled by coal, natural gas and nuclear. While withdrawals are relatively large, little of this water is consumed but rather is returned to its original source (albeit at a slightly higher temperature). Kansas has 16 thermoelectric power plants with 9,268 MW of capacity which are also powered by a mix of coal, natural gas, and nuclear. Water withdrawals associated with each plant depend on the capacity of the plant, its operation, the plant's fuel type and cooling type. Water use estimates for each of the thermoelectric power plants in the United States is available through the USGS.[33]

CHANGES IN GROUNDWATER LEVELS

Although efforts have been made to reduce groundwater depletions, groundwater pumping in many counties still exceeds sustainable groundwater recharge rates. Projecting current pumping rates forward in time, we have calculated the time to aquifer exhaustion.[34] Figure 6 shows when the aquifer is likely to no longer be able to sustain continued pumping at the current rate in counties of Kansas and Nebraska.

Counties of highest concern are those with 25 or less years of sustainable groundwater utilization. These vulnerable counties are largely associated with areas with extensive irrigated agriculture (Figure 5) and zones at the outer edges of the High Plains Aquifer where the geologic 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 depletion years of 25 to 50 years. Thirty counties in Kansas and 7 in Nebraska are of concern with aquifer depletion years projected for between 50 and 100 years.

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[29] Argonne National Laboratory, "Consumptive Water Use in the Production of Ethanol and Petroleum Gasoline," http: //www.transportation.anl.gov/pdfs/AF/557.pdf, May 11, 2015.
[30] Nebraska Energy Office, "Fuel Ethanol Facilities Capacity by State and by Plant," http: //www.neo.ne.gov/statshtml/122.htm, May 8, 2015.
[31] Wulff, Scott M. et al., "Feasibility of Establishing Small Livestock Slaughter Plants in North Dakota," 1985, North Dakota State University Department of Agriculture and Applied Science, http: //ageconsearch.umn.edu/bitstream/23174/1/aer208.pdf, July 21, 2015.
[32] Thermoelectric generation uses water for cooling. Examples of thermoelectric generators include nuclear, natural gas, coal-fired and oil-fired plants.
[33] Diehl, T.H. and Harris, M.A., 2014. Withdrawal and Consumption of Water by Thermoelectric Plants in the United States, 2010. SIR2014-5184, U.S. Geological Survey. Available at: http://pubs.er.usgs.gov/publication/sir20145184
[34] Current pumping rates are based on the most recent county-level estimates available from the USGS (http://water.usgs.gov/watuse/data/2010) and do not reflect more recent changes in groundwater withdrawals.

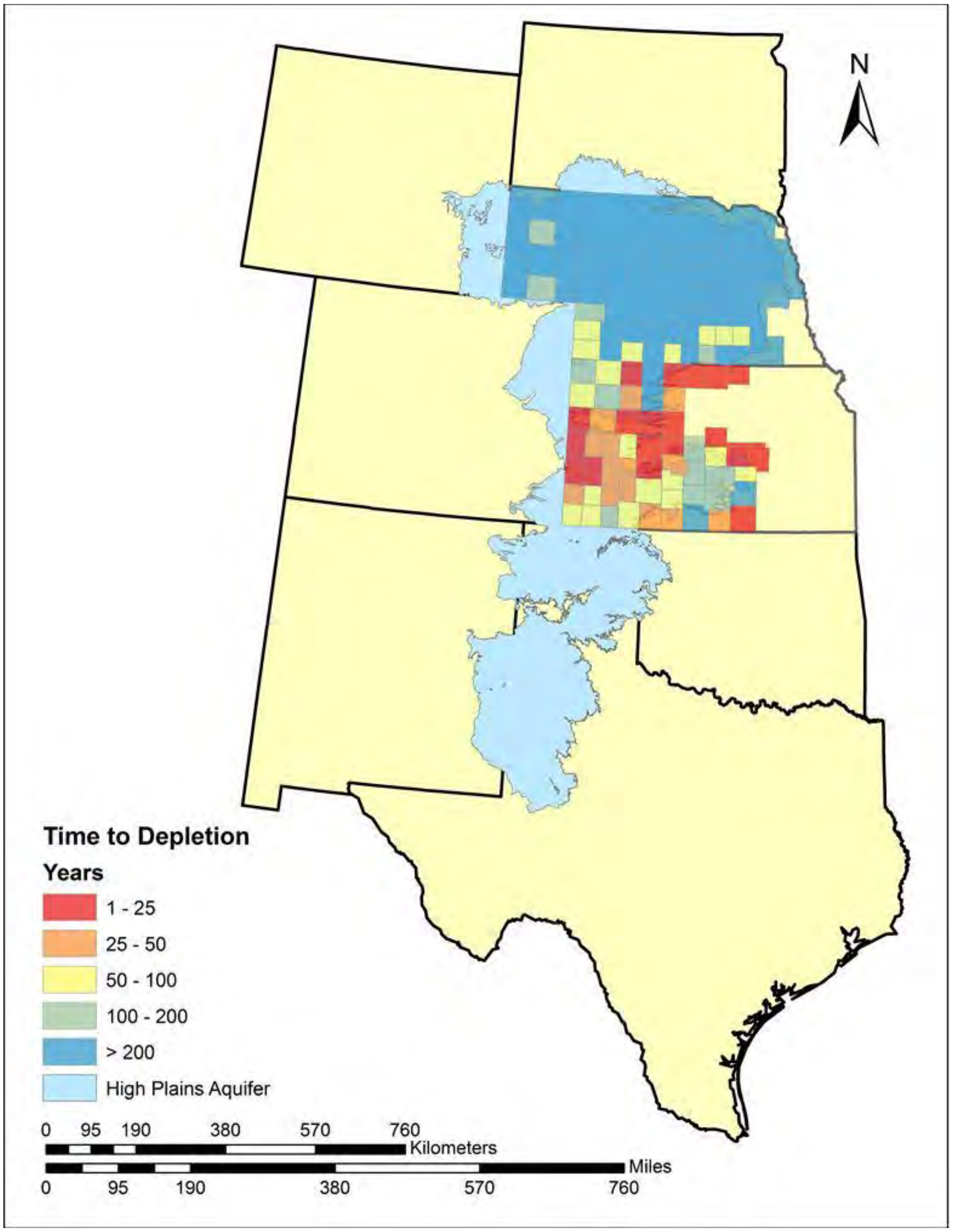

FIGURE 6—WHEN CONTINUED PUMPING OF THE HIGH PLAIN AQUIFER IS LIKELY TO BECOME UNSUSTAINABLE

As groundwater levels fall, obtaining water from the aquifer requires additional energy to pump the water from greater depths, increasing utility costs. To explore the effect of additional cost on farm operations, scenarios representing cost increases of 25 percent, 50 percent and 75 percent over current rates were analyzed. These analyses used current pumping and recharge rates to project groundwater level declines. The timing of projected groundwater decline (Figure 6) is consistent with the variability of irrigation (Figure 5). The time to 50 percent increase in pumping cost is shown (Figure 7).

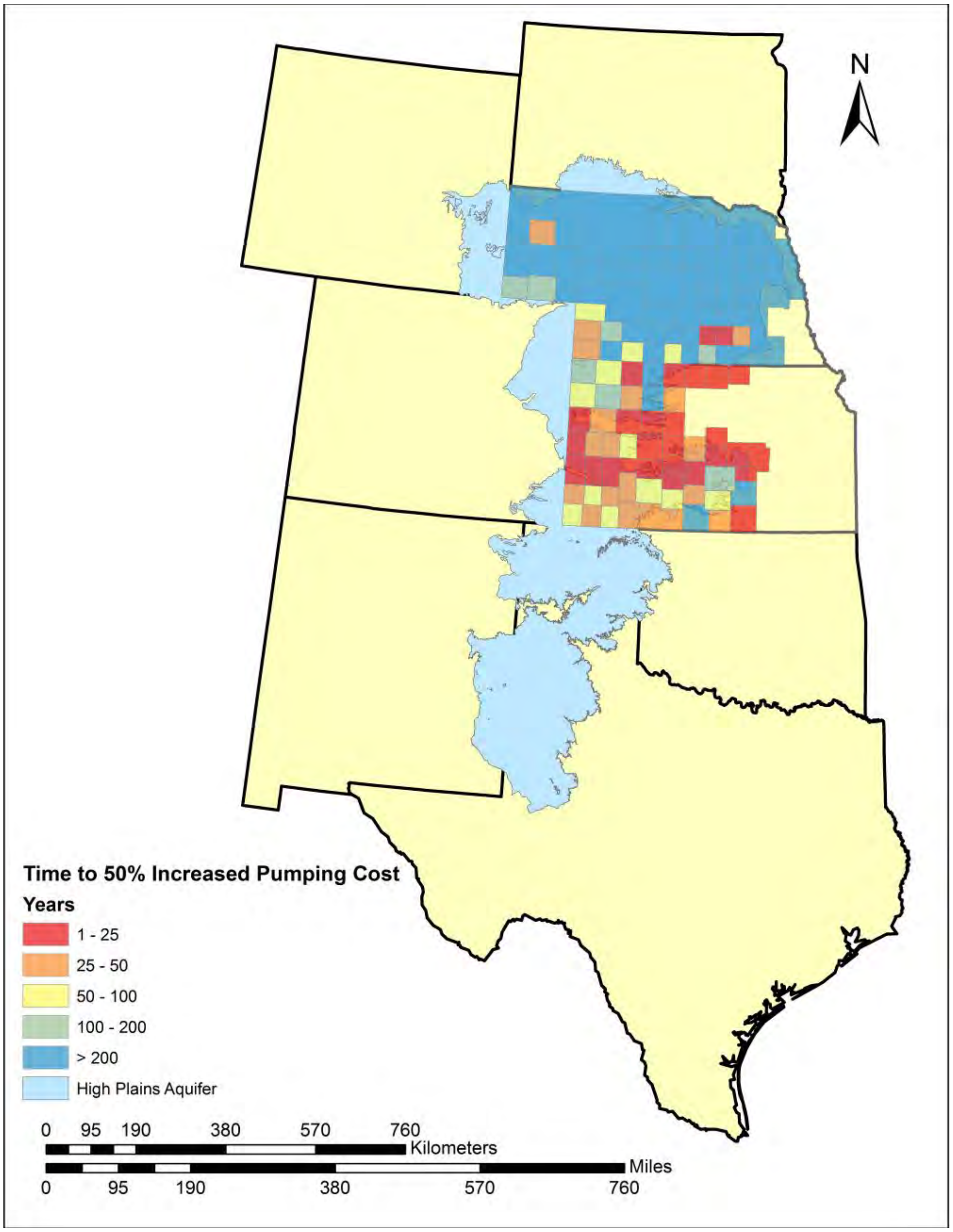

FIGURE 7—WHEN THE COST TO PUMP (LIFT) GROUNDWATER FOR IRRIGATION OR OTHER USES INCREASES BY 50 PERCENT OVER CURRENT RATES

CROP MODELING RESULTS

Projected changes in crop yields (2015-2060) for Dundy County, Nebraska, are shown in Figure 8 through Figure 11, relative to their respective 2015 yields for the Environmental Policy Integrated Climate (EPIC) model dryland simulation (orange line), statistical crop model dryland simulation (green line), and the statistical crop model irrigated simulation (blue line). Similar results were found throughout Kansas and Nebraska. Together, these results represent a range of possible outcomes that arise from future variations in climate, groundwater availability, and agricultural innovation. In absence of any other changes, the EPIC model results show that projected variations in temperature and precipitation impose small downward trends in dryland corn, sorghum, soy, and winter wheat yields. The results of the statistical crop model for dryland and irrigated yields show improvements to crop yields that could arise in the future if improvements to farm operations and technology, including irrigation, are consistent with that of the recent past.

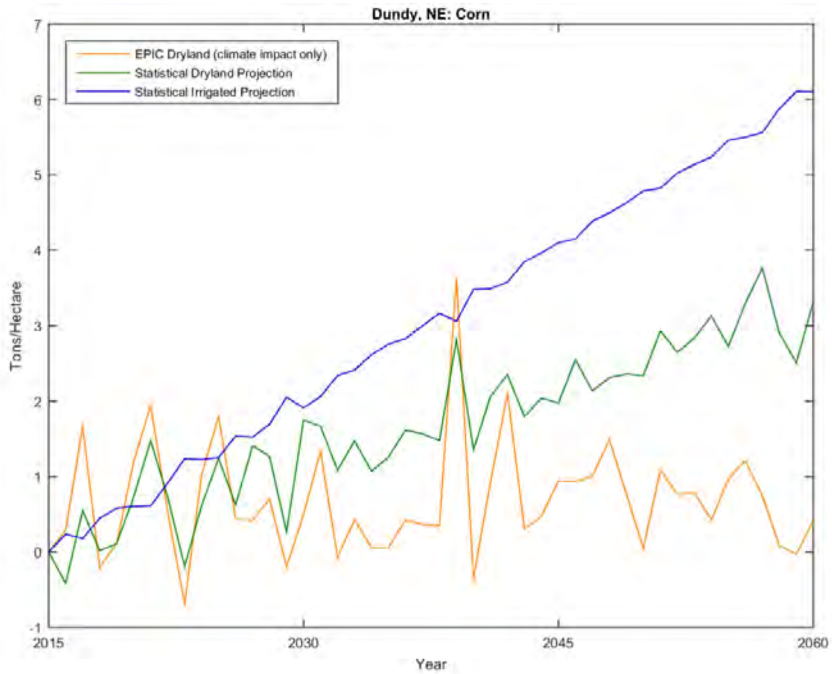

FIGURE 8—RESULTS FROM THE CROP MODELING SIMULATIONS FOR CORN IN DUNDY COUNTY, NEBRASKA

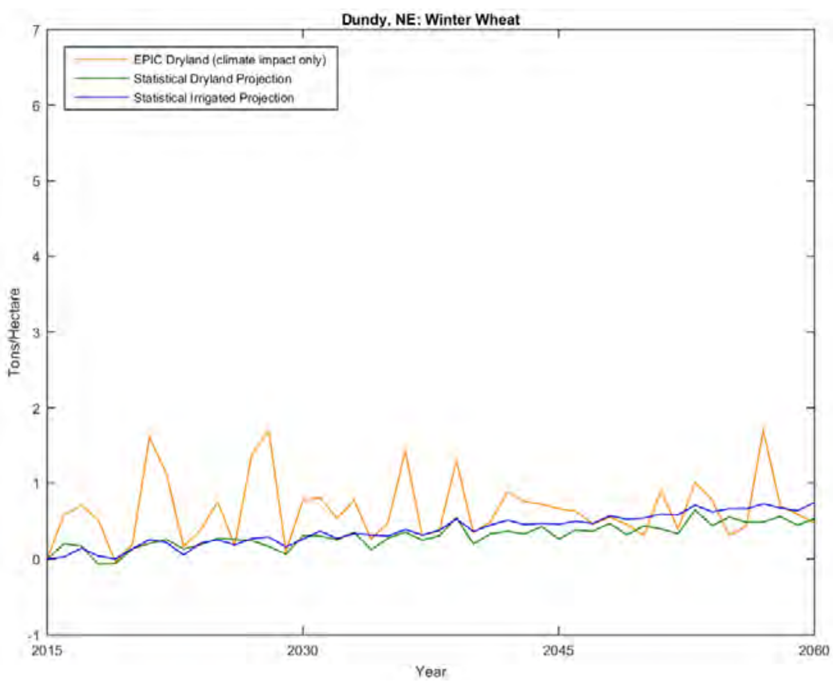

FIGURE 9—RESULTS FROM THE CROP MODELING SIMULATIONS FOR WINTER WHEAT IN DUNDY COUNTY, NEBRASKA

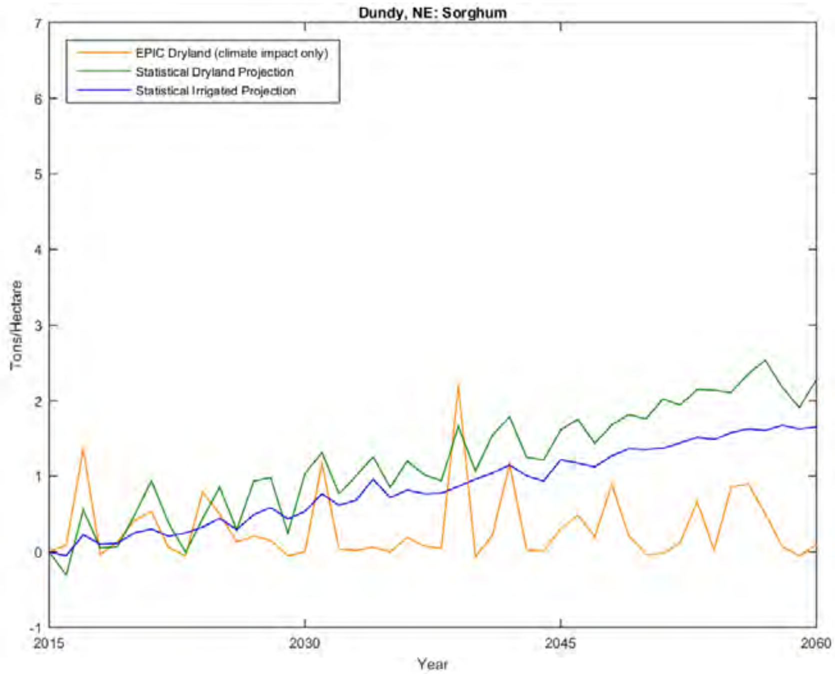

FIGURE 10—RESULTS FROM THE CROP MODELING SIMULATIONS FOR SORGHUM IN DUNDY COUNTY, NEBRASKA

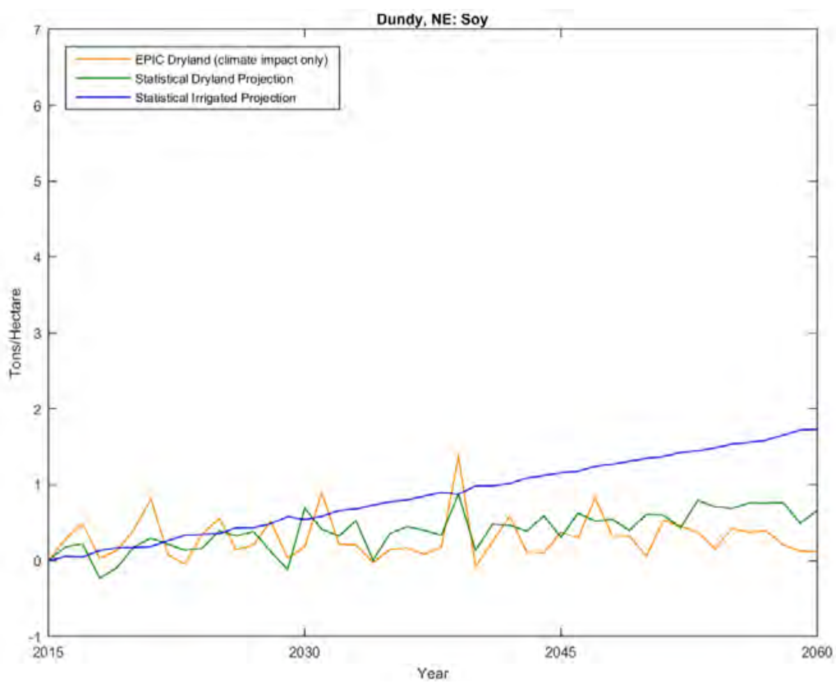

FIGURE 11—RESULTS FROM THE CROP MODELING SIMULATIONS FOR SOY IN DUNDY COUNTY, NEBRASKA

The path that actual yields follow in the future will depend on a number of factors, including the availability of water for irrigation. In the High Plains, farmers have used water supplied primarily by the High Plains Aquifer to maintain the production levels that have strengthened the agricultural sector throughout the High Plains. Whereas farmers have used irrigation to offset the impacts of climate variability on crop yields in the past, 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 farming, resulting in a reduction in agricultural production. Using the National Agricultural Statistics Service (NASS) historical yield data, the average percent difference between irrigated and dryland yield for Dundy County is calculated to be 70 percent for corn, 48 percent for sorghum, 43 percent for soy, and 29 percent for winter wheat. Additionally, transitioning from irrigated to dryland farming increases uncertainty in agricultural production from year to year because dryland crop yields are more dependent on prevailing weather conditions, which vary from year to year.

ECONOMIC ANALYSIS RESULTS

GENERAL ECONOMIC CONDITIONS: KANSAS

Kansas is home to nearly 2.9 million people, with a median household income around $51,332, which varies significantly between counties. Nonfarm employment in the state is around 1.4 million jobs, compared to around 1.0 million jobs in agriculture.

COMPOSITION OF KANSAS GDP

In 2013, Kansas GDP was $144.1 billion.[35] Overall, as shown in Figure 12, 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).[36] Each of the five industries displays a positive growth trend (Figure 12).[37] Although the volume of agriculture products in Kansas is relatively high, the value of the products is relatively low, and representing less than 0.04 percent of output in the state. Largest crops by dollar value include wheat, corn, sorghum, and soybeans. Agricultural and farm output trends in Kansas are shown in Figure 13.

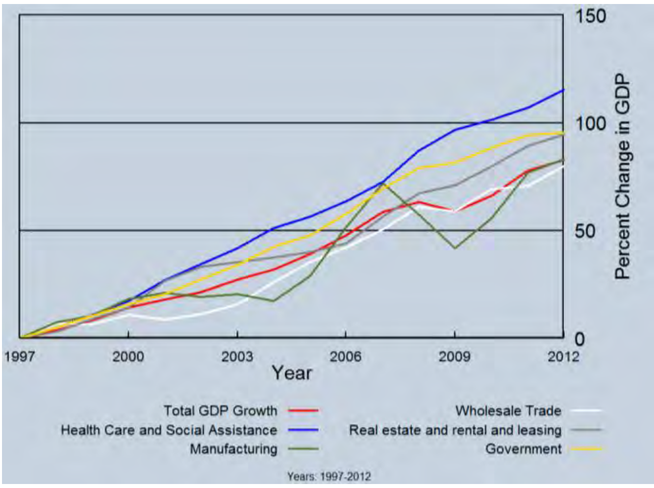

FIGURE 12—LEADING INDUSTRY OUTPUT TRENDS IN KANSAS

35 Bureau of Labor Statistics, "Kansas Economy at a Glance," http: //www.bls.gov/eag/eag.ks.htm, October 1, 2014.
36 http://www.census.gov/eos/www/naics/
37 NAICS is the standard industry classification system formally established by the U.S. Census Bureau. Using the 2-digit NAICS references allows the reader to look up these industries specifically.

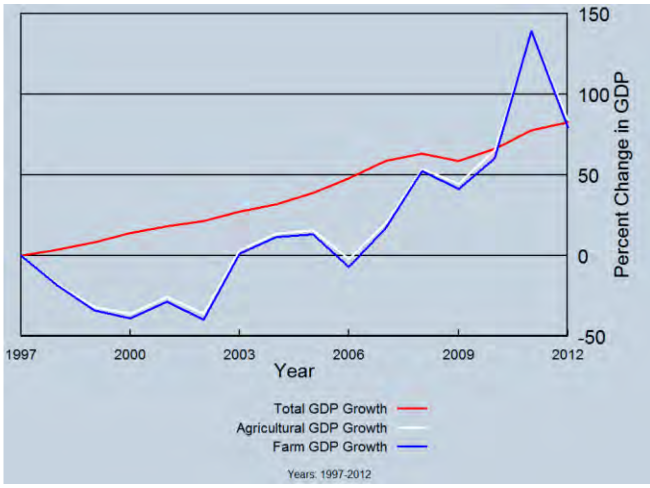

FIGURE 13—AGRICULTURAL AND FARM OUTPUT TRENDS IN KANSAS

EMPLOYMENT IN KANSAS

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 percent). 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 well-being of Kansas is subject to the availability of the High Plains Aquifer.

The farm and non-farm employment by industry sector for Kansas are shown in Figure 14. 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, by as much as 20-25 percent in a year (refer to Figure 14 and Figure 15). 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 installations, public services, and public administration.

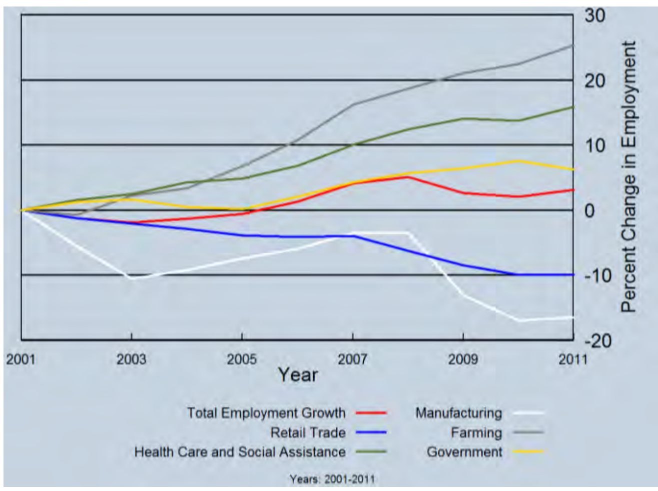

FIGURE 14—LEADING INDUSTRY EMPLOYMENT TRENDS IN KANSAS

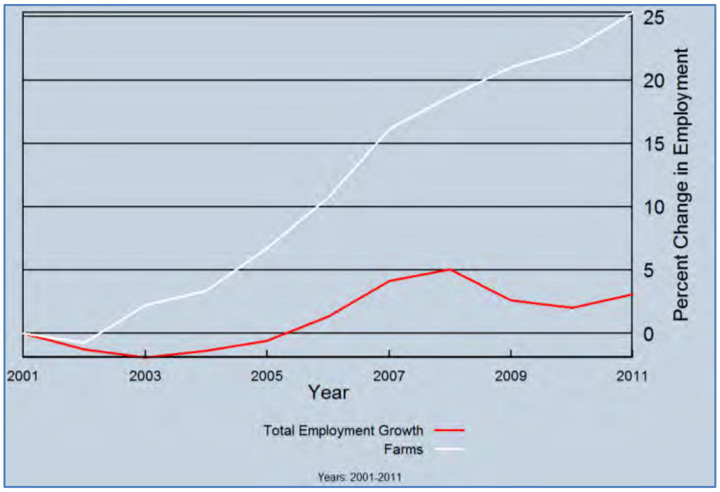

FIGURE 15—FARM EMPLOYMENT TRENDS IN KANSAS

GENERAL ECONOMIC CONDITIONS: NEBRASKA

There are approximately 1.88 million people in Nebraska with a median household income of $45,338 which also varies significantly between counties. In both Kansas and Nebraska, the unemployment rate varies considerably between counties.

COMPOSITION OF NEBRASKA GDP

In 2013, the GDP for Nebraska was $109.6 billion.[38] Output in Nebraska has been growing at a rate which exceeds the national average. During the most recent recession (December 2007 to September 2009, 18 months), Nebraska only experienced a minor bump in unemployment, reaching 4.9 percent in late 2009.[39] At the same time, the agricultural sector outperformed the broader State economy in terms of Industry output growth (see Figure 16). The five largest industries in Nebraska (in terms of output) are Government (Federal and Local), Manufacturing, Agriculture, Real Estate and Rental and Leasing, and Finance. The Agricultural industry has grown by 256 percent since 2004. In all, Nebraska's GDP grew 216 percent since 1997, averaging 5 percent growth per year.

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 therefore act as a more efficient nutrient source.

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[38] 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.
[39] NBER, "Business Cycle Dating Committee of the National Bureau of Economic Research," http: //www.nber.org/cycles/sept2010.pdf, March 18, 2015.

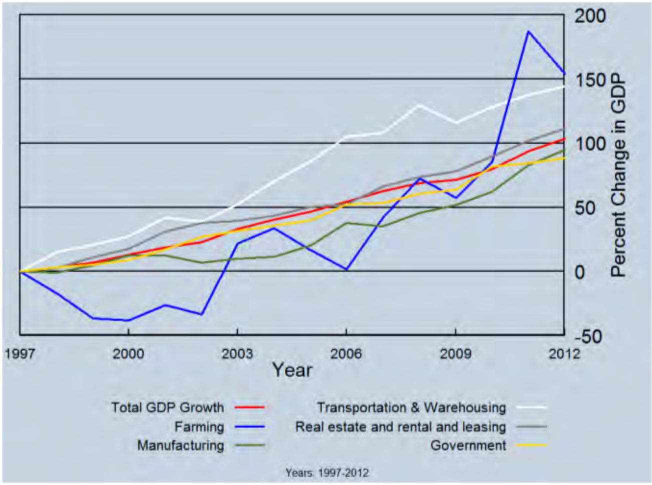

FIGURE 16—LEADING INDUSTRY OUTPUT TRENDS IN NEBRASKA

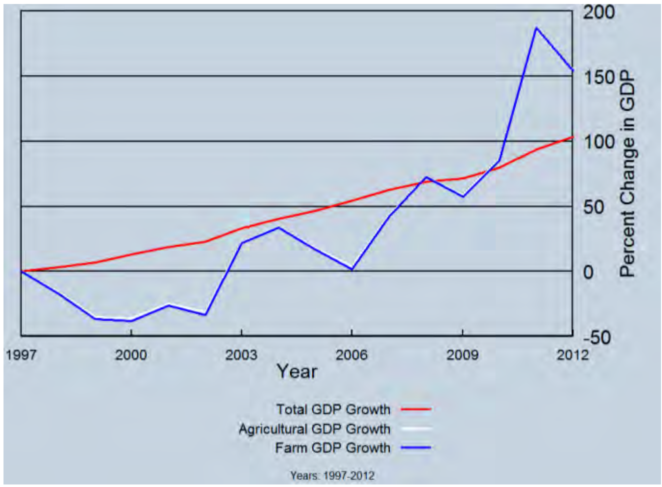

FIGURE 17—AGRICULTURAL AND FARM OUTPUT TRENDS IN NEBRASKA

EMPLOYMENT IN NEBRASKA

Nebraska Agriculture is robust, but accounts for only 1.8 percent of employment. The rest of Nebraska's economy is primarily service oriented, with 848,000 Service industry jobs (86 percent) compared to 138,000 manufacturing positions (14 percent). Despite historic employment growth in agriculture, the Nebraska Department of Labor expects crop and animal production employment to decrease by 11-15 percent by 2022, while services and manufacturing employment is expected to grow. Agricultural and farm output trends in Nebraska are shown in Figure 17.

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.

The non-farm employment by industry sector for Nebraska are shown in 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, as shown in Figure 18, the number of jobs in manufacturing declined during 2009, losing approximately 11 percent of its workforce that year and approximately 4 percent 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 in Nebraska's employment for industries at the two-digit NAICS level is shown in Figure 18.

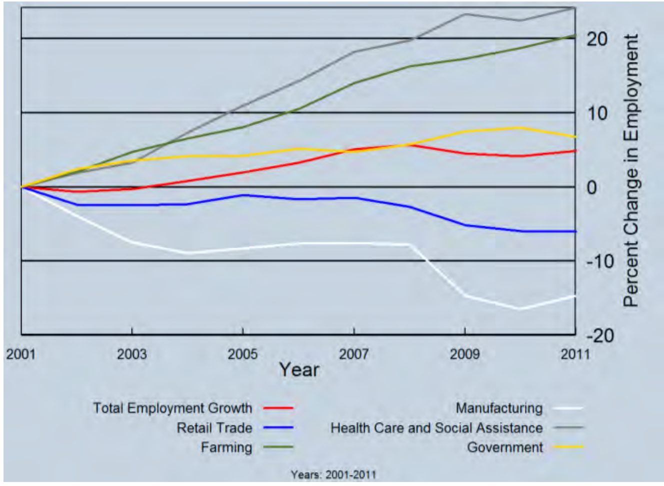

FIGURE 18—LEADING INDUSTRY EMPLOYMENT TRENDS IN NEBRASKA

Nebraska Agriculture GDP contribution has doubled since 1997, with a large portion of this growth attributable to Farming (see Figure 19). At the same time, farm employment has increased 25 percent. 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.

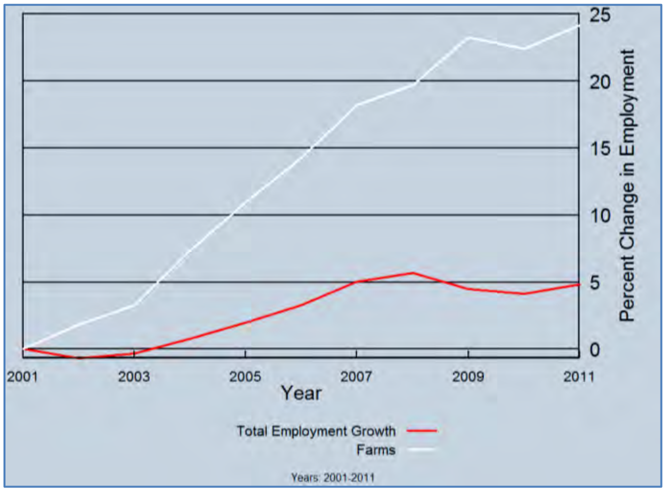

FIGURE 19—FARM EMPLOYMENT TRENDS IN NEBRASKA

ECONOMIC ANALYSIS RESULTS

SCENARIO SET A–FARM PROPRIETOR INCOME

Scenario Set A builds on data resulting from previous climate change effects to the aquifer and crop models projecting yields from the depletion of the aquifer and estimates changes in farm operation market participation decisions, induced by increased groundwater extraction costs and how those changes propagate through the regional economy. Change in market participation was based on an empirically-estimated relationship between extraction costs and farm operation exit decisions. The empirical model used for this study builds on previous work exploring the factors which determine farm operation exit (Hoppe and Korb, 2006). Using farm operation utility costs as a proxy for extraction costs, the empirical model yields an estimated response to exogenously imposed increases in the utility associated with water extraction.

Farm 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). The data set was limited to farm operations which had responded to at least 3 censuses ($n = 234{,}142$).

Increasing extraction costs may marginally increase the likelihood that a farm operation exits the industry. The number of farm operations in Kansas and Nebraska has been trending downward in recent years. Table 1 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 percent of farm operators. Since 1982, cumulative decline in farm operations in Kansas are approximately 16 percent. Annual percent decline for farm operations in Nebraska is approximately 0.6 percent. Cumulatively, this amounts to approximately a 17 percent decline in Nebraska farm operations between 1982 and 2012.

TABLE 1—FARM OPERATION COUNT IN KANSAS AND NEBRASKA (1982-2012)

Years	Farms in Each State	
	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
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 to be captured within the baseline REMI model.[40] Increases in farm exit over the historical average are calculated using the marginal effect of increased utility costs on exit probability estimated by the microeconometric empirical model, combined with hypothetical increases in utility expenditures. This impact is implemented 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, or 75 percent. 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), as the depletion of the High Plains Aquifer is not expected to be instantaneous, but rather a gradual decline.

[40] : Regional Economic Models, Inc. "REMI PI+v1.7 (changes from PI+ v1.6R)," Regional Economic Models, Inc.

Scenario Set A depicts farm exits as decreases to farm proprietor income as this represents the overall shrinking of the farm market. Scenario Set A conditions have different probabilities in Kansas and Nebraska as reflected in the differences in the time to increase pumping costs by 50 percent (see Figure 7). Figure 20 shows the change in projected GDP relative to a baseline (no expected increases in utility costs due to groundwater level decline) for Kansas under three scenarios of energy (utility) cost increases of 25 percent (lower than expected), 50 percent (expected), and 75 percent (higher than expected). Even in the 75-percent scenario, the expected change in projected GDP represents a slight lowering of the projected state GDP growth over the 49-year forecast period.

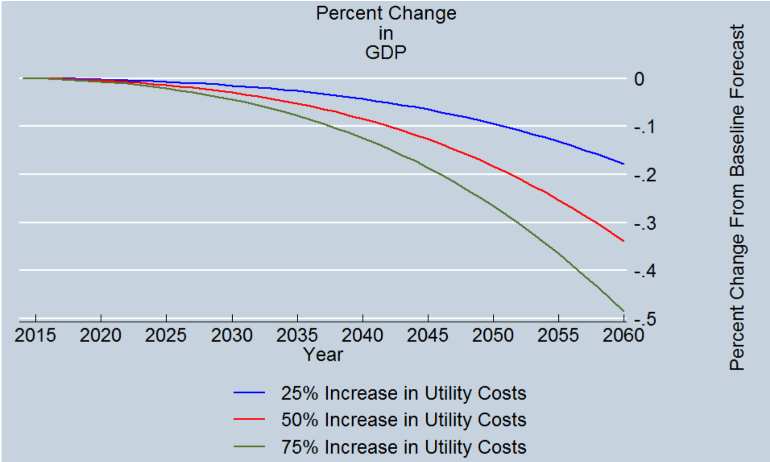

FIGURE 20—KANSAS: ANNUAL PERCENT CHANGE IN GDP, SCENARIO SET A

Figure 21 shows the result for Nebraska projected change in the state GDP due to the scenario assuming a 25 percent increase in utility costs which is higher than expected given the lower rates of groundwater drawdown in Nebraska. As in the case with Kansas, the higher than expected cost increase scenario result represents a slight reduction in the forecast state GDP growth.

In Kansas and Nebraska, utility cost increases can directly affect proprietor income of those involved with agriculture production. As farm operations exit, proprietor income falls, which propagates to all of the industries where proprietor income is spent. 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. These industries correlate to personal disposable income spending or changes in population (Health Care and Social Services).

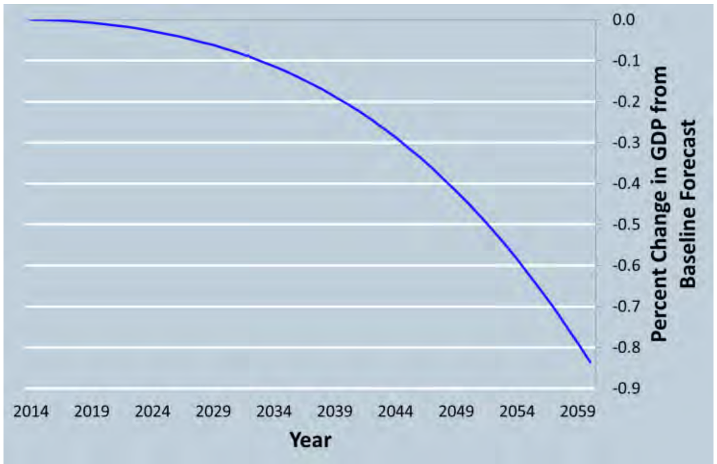

FIGURE 21—NEBRASKA: ANNUAL PERCENT CHANGE IN PROJECTED GDP UNDER SCENARIO SET A WITH 25 PERCENT INCREASE IN UTILITY COSTS

SCENARIO SET B–REDUCED IRRIGATED CROP ACREAGE RESULTS

Scenario Set B estimates the economic impacts of decreased irrigation due to depletion of groundwater resources in Kansas. As shown in the section on Crop Modeling, the historical yield of a given irrigated crop is higher than the yield for the same crop in the absence of irrigation. This impact is modelled as a decrease in farm output. The REMI model calculated the expected change in agricultural industry output associated with a reduction in the percentage of irrigated acreage for 4 crops: corn, soybeans, winter wheat, and sorghum. The per-acre difference in yield associated with switching from irrigation to dryland is calculated as the difference in the yield estimated by the statistical model and the yield estimated by the Environmental Policy Integrated Climate (EPIC) model for dryland. The change in total yield for each crop in each county associated with an exogenous decrease in irrigated acreage is evaluated using 3 scenarios. Scenario Set B assumes that the number of irrigated acres in Kansas decreases by 25, 50, or 75 percent and the number of non-irrigated acres increases by the same amounts. Of course, the impact to the entire agriculture industry within each county must be weighted by each crop's contribution to agriculture industry output.

The impact on annual State GDP for Kansas represents a greater percent change from baseline when compared to Scenario Set A (Figure 22). At the industry sector level, all results for Kansas are dominated by agriculture and forestry support activities.

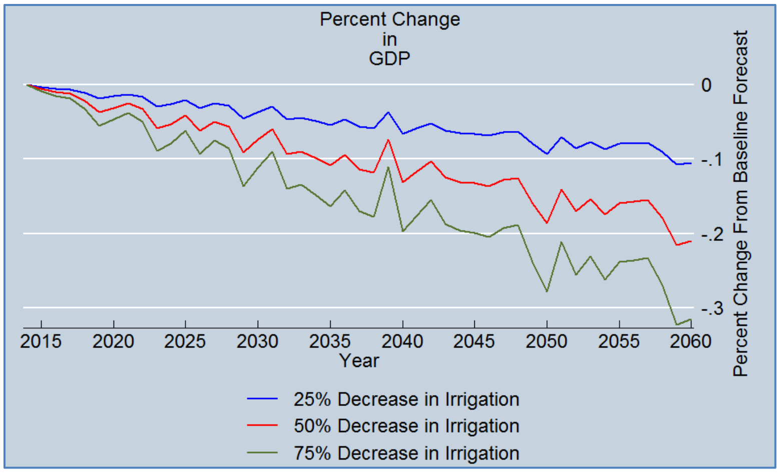

FIGURE 22—KANSAS: ANNUAL PERCENT CHANGE IN GDP, SCENARIO SET B REDUCED IRRIGATED ACERAGE

Although farm operations can adapt to increased resource risk with a variety of decisions such as changing crop rotations or crop types and utilizing new technologies, this analysis considered only two potential responses independently: increased probability of farm exit (translating to decrease in farm proprietor income) and decreased levels of irrigation (translating to decrease output in the agricultural industry). Furthermore, 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).

CRITICAL INFRASTRUCTURE

For Scenario Set A, reduction in farm proprietor’s income (farm exits), the likely primary critical infrastructure affected is the Food and Agriculture Sector. The effect will not be severe, however, because the primary impact is to income and not overall agriculture output.

For Scenario Set B, decreases in agriculture production result from reductions in irrigated crop acreage. The Food and Agriculture, Energy, and Chemical critical infrastructure Sectors are the most likely to be affected due to follow-on effects to food and beverage manufacturing, animal processing, and chemical manufacturing. The likely impact would be market shortage passed on to consumers in the form of higher prices for some goods such as food and transportation fuels.

The Water and Wastewater Systems critical infrastructure Sector will be affected by both growing population demands and declining groundwater levels. Communities at highest risk are those in counties which have less than 50 years of projected aquifer depletion years. These communities face increasing expenses associated with falling groundwater levels (i.e., increased expense to lift water) and costs associated with extending or replacing failing groundwater wells.

The Transportation Systems critical infrastructure Sector is likely to be affected by potentially less market demand for transportation services as a result of less agriculture and chemical (ethanol) related production. While less production would result in an excess supply of transportation infrastructure, it is likely that the Transportation Systems Sector would find alternative customers.

METHODS

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

GROUNDWATER MODELING

To evaluate the economic implications of High Plains Aquifer depletions on Kansas and Nebraska, an estimation of future potential changes in groundwater levels and the associated cost to pump that water to the surface was necessary. Simulation of depth-to-groundwater also provided insight as to how soon the groundwater resource may become exhausted. To accomplish these analyses, a groundwater budget implemented at the county level was formulated. Specifically, groundwater storage, and the related depth to groundwater, was calculated by tracking the annual difference between groundwater inflow (e.g., recharge and river leakage) and groundwater outflow (pumping). Implementing the model required a variety of data, most of which was acquired from the USGS, with supporting information collected from the Kansas Geological Survey, and the Nebraska Department of Natural Resources. Model calibration was performed using measured data tracking changes in groundwater level, aggregated by county, available at 5-year intervals from 1985 to 2010.[41]

CROP MODELING

A range of impacts to agriculture in the High Plains region could arise from future variations in climate, groundwater availability, and agricultural innovation. Two crop models simulated corn, soy, sorghum, and winter wheat yields using downscaled weather inputs generated by the Geophysical Fluid Dynamics Laboratory Coupled Model 3. [42] They included the Environmental Policy Integrated Climate (EPIC) model and a statistical model of stochastic production functions.[43,44,45] The EPIC model is a physical process-based cropping system model which is used here to analyze the impact that future variations in temperature and precipitation have on crop yields, independently from other factors. The statistical crop model projects crop yield as a function of a linear trend in historic yield, precipitation, and temperature. Simulations for both the EPIC and statistical 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 23.[46] Model calibration was performed using historical yield data from the National Agricultural Statistics Service (NASS).[47]

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41 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.
42 Donner et al., 2011, The dynamical core, physical parameterizations, and basic simulation characteristics of the atmospheric component am3 of the GFDL global coupled model CM3. Journal of Climate, 24, 3484–3519.
43 Williams, 1995, The EPIC model. In: Singh, V. P. (Ed.), Computer Models of Watershed Hydrology. Water Resources Publications, Highlands Ranch, CO, pp.909-1000.
44 Isik and Devadoss, 2006, An analysis of the impact of climate change on crop yields and yield variability. Applied Economics, 835-844.
45 Just, R. E., and Pope, R. D. (1978). Stochastic specification of production functions and economic implications. Journal of Econometrics, 67-86
46 NOAA [will update footnote]
47 NASS, "Quick Stats," http: //quickstats.nass.usda.gov/, accessed February 18, 2015.

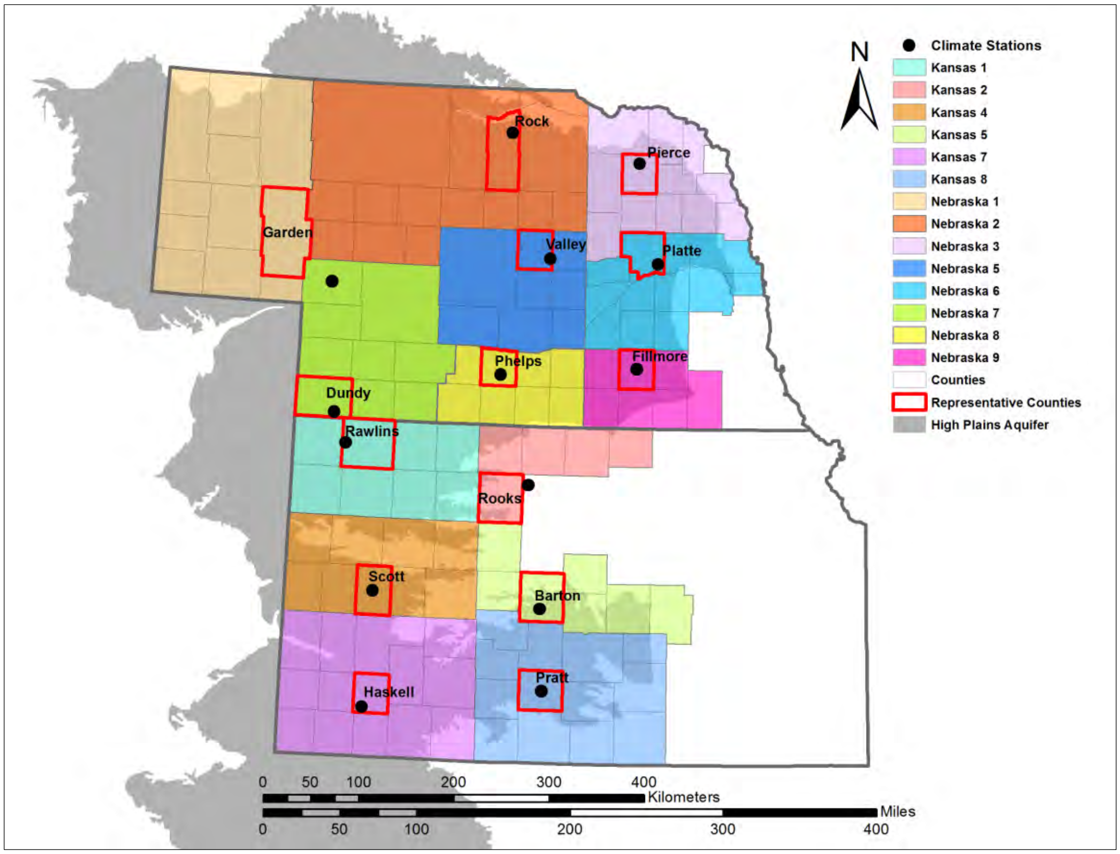

FIGURE 23—SPATIAL EXTENT OF THE CROP MODELING EXPERIMENTS

ECONOMIC MODELING

This study considers two separate market responses to increased resource risk in Kansas and Nebraska. Scenario Set A considers how increased pumping costs due to groundwater level decline impact the likelihood that a farm operation exits the industry. Scenario Set B considers how groundwater depletion reduces irrigation and translates to lower yields and reduced output in the Agriculture Industry. Although these are modelled as mutually-exclusive scenarios, aggregate response to a decrease in water resources would likely include both exit and decreased yield.

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 use inputs provided by other local firms and provide employment to local residents. The personal income of farm operators is often spent in the community where they farm. The regional economic impacts are important to consider in addition to the impacts to the Agriculture Industry. The regional economic consequences of water resource risk for the two scenarios are estimated using the Regional Economic Models, Inc. (REMI) PI+ model, an empirically-validated model that combines aspects of input-output, computable general equilibrium, econometric, and economic geography modeling.[48]

The framework combines microeconometric empirical models with long-term macroeconomic simulation to capture firm, industry, regional, and national level consequences. Furthermore, a qualitative analysis of existing economic conditions in Kansas and Nebraska addresses potential economic consequences which cannot be

[48] 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 difference between the baseline and alternative forecasts. Sandia uses the state-level version of REMI PI+ with 67 industries.

estimated directly. Water use efficiency and profit maximization are at the center of the microeconomic analysis. It is assumed farmers will continue to drill deeper wells until it is no longer profit maximizing to do so. The results of the analysis should not be over-generalized, as they are limited to the specific scenarios. In reality, market response to resource risk is much broader than what is modelled in this study.

CONCLUSION

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 has come at a cost. The High Plains Aquifer, vital to groundwater supply in the High Plains region, is being depleted at a rate far exceeding its recharge. If current water use and management practices are continued, 60 counties in Kansas and 7 in Nebraska could experience aquifer depletion issues in the next100 years.

Shrinking groundwater supplies and changing climatic conditions could pose risks to the High Plains' agricultural production. In the absence of any other changes, future climate projections were found to reduce dryland yields for corn, sorghum, soy, and winter wheat. Although farmers have used irrigation to offset the impacts of climate variability on crop yields in the past, the depletion of the High Plains Aquifer could hinder their ability to do so in the future. The conversion of acreage from irrigated to dryland farming may become increasingly necessary as groundwater levels decline. Such conversion would result in reduced agricultural production throughout the High Plains as well as increased uncertainty in crop yields from year to year.

Having modeled groundwater use and farm production in Kansas and Nebraska, this analysis identified several potential impacts to the economy and the critical infrastructure in these two States:

- Kansas and Nebraska provide significant amounts of commodities by dollar and volume to nearly all contiguous 48 states and Washington, DC.
- Economic impacts will scale with energy costs to extract groundwater. For this analysis, the economic impacts are primarily confined to Kansas and Nebraska.
- 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 food and beverage manufacturing.
- Reductions in irrigated acreage have large implications for critical infrastructure in the High Plains region. Critical infrastructure affected through economic impacts includes both the Food and Agriculture Sector (farms, farm products) and Chemical Sector (ethanol production). Precise implications for the Energy Sector would depend on the centrality of ethanol to the overall transportation fuels portfolio.
- Variations in climate may lead to reductions in crop yields. Although farmers have previously mitigated climate-related losses through irrigation, 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.

ACRONYMS AND ABBREVIATIONS

EPIC	Environmental Policy Integrated Climate
GDP	gross domestic product
MGD	million gallons per day
MW	megawatt
NAICS	North American Industrial Classification System
NASS	National Agricultural Statistics Service
NISAC	National Infrastructure Simulation and Analysis Center
REMI	Regional Economic Models, Inc.
USGS	U.S. Geological Survey

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For more information about the OCIA, visit our Website: www.dhs.gov/office-cyber-infrastructure-analysis.

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Homeland Security

National Protection and Programs Directorate

NPPD Customer Feedback Survey

Product Title:

1. Please select the partner type that best describes your organization. Select One

2. Overall, how satisfied are you with the usefulness of this product?

○ Very Satisfied ○ Somewhat Satisfied ○ Neither Satisfied Nor Dissatisfied ○ Somewhat Dissatisfied ○ Very Dissatisfied

3. How did you use this product in support of your mission?

- ☐ Integrated into one of my own organization's information or analytic products
- ☐ Used contents to improve my own organization's security or resiliency efforts or plans
  If so, which efforts?
- ☐ Shared contents with government partners
  If so, which partners?
- ☐ Shared contents with private sector partners
  If so, which partners?
- ☐ Other (please specify)

4. Please rank this product's relevance to your mission. ***(Please portion mark comments.)***

- ○ Critical
- ○ Very important
- ○ Somewhat important
- ○ Not important
- ○ N/A

5. Please rate your satisfaction with each of the following:

	Very Satisfied	Somewhat Satisfied	Somewhat Dissatisfied	Very Dissatisfied	N/A
Timeliness of product or support	○	○	○	○	○
Relevance to your information needs	○	○	○	○	○

6. How could this product or service be improved to increase its value to your mission? ***(Please portion mark comments.)***

To help us understand more about your organization so we can better tailor future products, please provide (OPTIONAL):

Name: *Position:*
Organization: *State:*
Contact Number: *Email:*

Submit Feedback

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