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Irrigation Adoption, Groundwater Demand and Policy in the U.S. Corn Belt, 2040-2070

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IRRIGATION ADOPTION, GROUNDWATER DEMAND AND POLICY IN THE U.S. CORN BELT, 2040-2070

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To the many I love

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ABSTRACT

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Climate change across the U.S. Corn Belt will significantly increase precipitation variability and temperatures by midcentury. Corn and soybean producers will seek to find strategies that may help to mitigate the potentially negative effects on yield. The adoption of irrigation technology has increased over the last several decades to improve yields in areas with insufficient rainfall, and is currently being adopted by producers who are choosing to minimize risk due to weather variability. To see if this trend in irrigation adoption has the potential to expand in the wake of climate change, this study uses weather data from four General Circulation Models (GCMs) under Representative Concentration Pathway (RCP) 8.5 and crop yields, and water use from a crop model to evaluate the profitability of the irrigation investment. The data drives Net Present Value and internal rate of return calculations of investment in irrigation equipment for the present (1980-2005) and midcentury (2040-2070). Simulations of potential water applied for irrigated crops is also examined in contemporary and future time periods, to see how relative water demand may shift for current irrigators, and potential new irrigators. A

companion online decision support tool was developed for extension audiences based on the contemporary climate data and default economic parameters developed in this thesis.

The Net Present Value of irrigation investment for midcentury producers is largely driven by the yield response to irrigation by soybeans under future climate conditions. While the irrigation of corn is profitable in some locations, namely the western Corn Belt, the locations where irrigating corn is profitable in the future is largely the same as in the contemporary period. Under future weather conditions, the area where irrigating soybeans becomes profitable is greatly expanded, likely due to CO_2 fertilization effects and higher temperatures in the northern Corn Belt. Projected irrigation water demand increases across the entire Corn Belt, both from a relative increase in applications from current irrigators, and an increase in the total number of irrigators across the central and eastern Corn Belt. The increase in the profitability of irrigation, and the potential increases in water demanded have important policy implications for the future, if we are to mitigate the potential impacts of climate change while ensuring water supplies are available and safe for the future.

CHAPTER 1. INTRODUCTION

1.1 Overview

In the last several decades, corn yields in the United States have increased dramatically. This is due to a variety of factors, such as improved management, the breeding of better hybrid seed, and more targeted applications of fertilizers and pesticides. In recent years, due to government initiatives and high prices, the acreage planted in corn is also at an all-time high. Farmers are constantly looking for ways to cut costs and improve yield. However, for the first time in history, projected corn yields are expected to go down in the future, due to the impacts of global climate change, primarily due to extreme weather events (Karl 2009). Climate change will affect different regions of the world in vastly different ways. Besides a gradual warming of the globe, precipitation patterns will change, and more extreme weather events will occur. According to the US Global Change Research Program, heavy downpours throughout the central United States are currently experiencing a significant upward trend, and the region is expected to see an increase in the span of time between rainfall events. Additionally, the variability in the weather from season to season will be more pronounced (Karl 2009). Although the near term projection of the Midwest climate may not lead to a vast change in the composition of the primary crops farmed, farmers will have to devise adaptation strategies to avoid a reduction in yields.

Under the Representative Concentration Pathway (RCP) 8.5, which models how the climate will be affected if current emission practices continue on their current trajectory, there are significant changes in precipitation and temperature projected. Figures 1 and 2 show a map of the Corn Belt with projected changes in average monthly temperature (degrees C) and precipitation (in mm) under RCP 8.5. Figure 3 shows how both precipitation and temperatures changes for each county across the Corn Belt. Table 1 identifies the state averages of these precipitation and temperature changes from the contemporary to future periods. Generally, there is an increase in precipitation across the Corn Belt, and dramatic increases in temperature under the RCP 8.5 conditions. Some areas in the south and west are projected to get hotter and drier while others may experience an increase in overall rainfall and temperature. Increasing mean temperatures everywhere will combine with changes in precipitation and evapotranspiration to determine crop water stress in different locations. Clearly, the projected weather conditions in the future do not match the past. If farmers are looking to continue in the production of corn and soybeans in a few decades, changes in management strategies will likely be necessary in order to remain profitable.

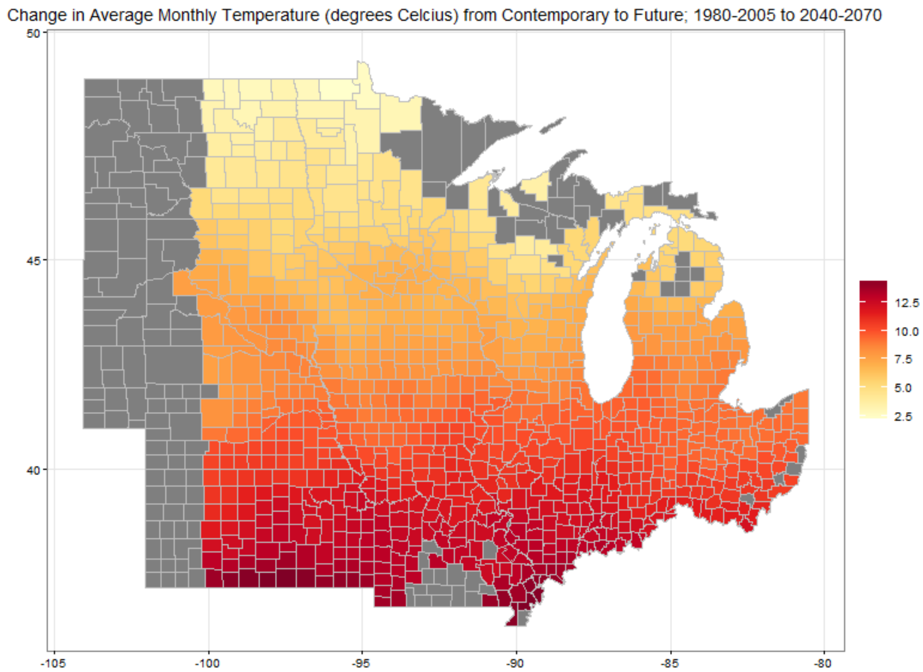

Figure 1. Changes in Average Monthly Temperature (degrees Celsius) from Contemporary (1980-2005) to Future (2040-2070), under RCP 8.5

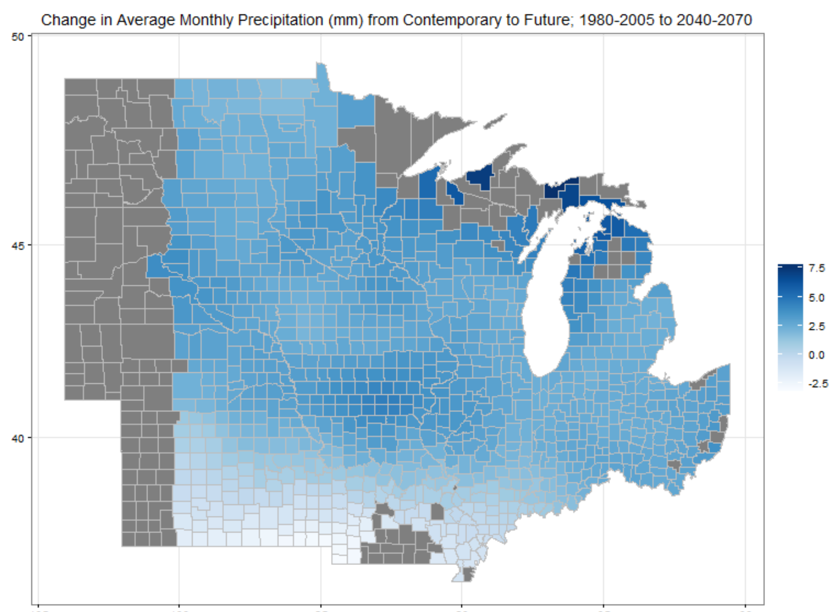

Figure 2. Changes in Average Monthly Precipitation (mm) from Contemporary (1980-2005) to Future (2040-2070), under RCP 8.5

Figure 3. Changes in Precipitation and Temperature under Climate Change for each County in the U.S. Corn Belt (1980-2005 to 2040-2070), under RCP 8.5

Table 1. State Averages of Monthly Changes in Precipitation and Temperature from 1980-2005 to 2040-2070

State	Change in Precipitation (mm)	Change in Temperature (degrees C)
Illinois	2.018	11.039
Indiana	2.232	10.842
Iowa	3.180	8.594
Kansas	-0.283	12.418
Michigan	3.546	7.317
Minnesota	2.954	5.776
Missouri	0.779	12.089
Nebraska	2.468	9.348
North Dakota	2.389	4.082
Ohio	2.720	9.923
South Dakota	2.000	7.128
Wisconsin	3.156	6.393

As shown in Figure 3, a significant portion of the Corn Belt will experience a major increase in temperature (5-10 degrees C) and a minor increase in precipitation (2-3 mm) on an average monthly basis under RCP 8.5. However, there are some notable exceptions. Many parts of Wisconsin and Michigan are projected to experience larger increases in precipitation, and a smaller increase in temperature. Other states, especially Kansas, Missouri, and Illinois are projected to experience the largest increases in temperature along with potential decreases (or minimal change) in monthly precipitation.

One of the current ways that farmers are working to mitigate current variability in precipitation is through the adoption of irrigation technology. Traditionally, in the twelve state Corn Belt region, irrigation has been adopted primarily in the western-most states (Kansas, Nebraska, South Dakota, and North Dakota). In states with higher normal precipitation, irrigation is often used for the highest-valued crops, such as seed corn. Although irrigation technology will not assist with the potential flooding events that could occur more frequently, these systems should provide a more stable amount of water available to crops under a more variable climate.

There are some concerns about the growth of irrigated agriculture. Currently, U.S. agriculture "accounts for 80-90 percent of the Nation's consumptive water use" (Schaible and Aillery 2012). Water rights in the western United States have defined the face of agriculture in that region. In states that have just started to irrigate, however, water scarcity has historically been less of an issue, and current policies in many Midwestern states do not heavily regulate groundwater and surface-water pumping for irrigation. Additionally, the impending changes in the timing of precipitation due to climate change will only aggravate this situation. This could become a concern for the future of water resources.

The problem is that irrigation may become an increasingly-relied upon strategy to mitigate potential corn production losses across the Midwestern United States, which will impact traditionally water-abundant watersheds and groundwater resources.

The objective is to estimate the extent of future irrigation installations by assessing the profitability of irrigation investment, how future irrigation will potentially impact groundwater use, and the implications for the adequacy of current water policies in the Corn Belt under projected climate change.

1.2 Hypotheses

H_1: By midcentury, climate change will increase the total area where the installation of irrigation equipment is cost-effective in the Corn Belt.

1. The installation of irrigation equipment will be associated with the change in precipitation patterns, especially the occurrence of drought conditions.

To gain a better understanding of the effects climate change may have on the future adoption of irrigation technology, the goal is to evaluate counties on the cost-effectiveness of adopting irrigation technology in current and future time periods. The use of irrigation equipment will be considered cost-effective when a farmer will break-even on the investment over the assumed twenty-year life of the irrigation system. This is an extensification effect.

H_2: Past history of crop water stress will be associated with increased water demand in drought years.

In years of drought, as determined by the Standardized Precipitation Evapotranspiration Index (SPEI), the increase in the demand for irrigation water supplies across the Corn Belt will be determined based on crop model simulation triggers. Using climate models for projected rainfall in years that are considered “moderately dry” or “extremely dry” by the SPEI, the water balance within the crop model is used to determine the amount of water required to maintain an optimal soil-water balance, compared to SPEI “normal” years in the same time span.

CHAPTER 2. LITERATURE REVIEW

This section discusses the range of literature relevant to the study, including the motivation behind the research, other works that aim to accomplish similar goals, and the work that is used as the basis for the methodology of this study.

First, this explores the projections of climate change impacts on corn and soybean production in the Corn Belt, including temperature, rainfall, and evapotranspiration differences in the region. Then, the potential role of irrigation across the Corn Belt is discussed, including current trends in irrigation adoption and the factors that lead to irrigation adoption. Next, the projected adoption of irrigation technology, and changes in irrigation demand in the wake of climate change is reviewed. This includes studies that explore many of the same questions that are the subject of this thesis, but use different methods or take place in different regions. Special attention will be directed to General Circulation Models (GCMs), Regional Circulation Models (RCMs) and crop growth simulation models, as these are the most prevalent tools in studies of this nature, and are also implemented in this research. Finally, a comparison of different water policies and irrigation water management practices is conducted, and literature studying the interaction between irrigation demand and different water policies is highlighted. A summary of the economic impacts that are considered in these studies is presented, and the conclusion of this section discusses the economic contributions that the present study will make to the current literature.

2.1 Climate Change in the Corn Belt, and its Effects on Corn and Soybean Production

There are many intricacies in the effects of climate change on the Midwestern United States. There are differing viewpoints on what exactly will occur in the region, but the general conclusion is that precipitation will increase across the Corn Belt and there will be a rise in precipitation variability. The effect that climate change will have on crop yields is mixed, dependent on crop type, the crop model used, and the climate change projections used in the study.

2.1.1 General Impacts of Climate Change on Temperature, Precipitation, and Extreme Weather

In general, it is projected that climate change will not have as dramatic an impact on the Midwestern United States as in other parts of the world, such as coastal regions. However, many of the expected changes in climate have the ability to cause major impacts on the crops traditionally farmed across the Corn Belt.

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), from 2013, is the most comprehensive aggregation of research on the global impacts of climate change. It discusses potential climate change impacts on extreme weather events, temperature, and precipitation globally and regionally. The IPCC report concludes that the occurrence of extreme weather events will be more likely across the Midwestern US, and that overall precipitation has the potential to increase in the region. Consistent with the general results from the IPCC, a report by Madsen and Figdor looks at trends in precipitation under climate change for each state in the US. Their procedure follows that of Kunkel et al., and they determine that rainfall will increase across the Corn Belt, precipitation will be more intense, and that storms with extreme precipitation are becoming more common. Additionally, they conclude that there will be more drought and that the extreme precipitation events will "punctuate longer intervals of relatively dry weather" (Madsen and Figdor 2007, Kunkel et al. 1999). Similarly, a study conducted by Gutowski et al. (2009) reports that extreme precipitation events have increased over the last 50 years in the United States, and that an increase in droughts is likely across North America (Gutowski 2009). The future of precipitation extremes globally is affected by a variety of factors, such as temperature changes, the efficiency of precipitation, and vertical velocity. These factors are studied in further detail by O'Gorman and Schneider (2009) and Muller et al. (2001). O'Gorman and Schneider attribute the change in precipitation extremes to the increase in atmospheric water vapor, the upward velocity, and the temperature at the time of the precipitation event. Muller et al. also evaluate atmospheric temperature, vertical velocity, and precipitation efficiency to evaluate precipitation extremes, and largely arrive at the same conclusion.

2.1.2 Impacts of Climate Change on Corn and Soybeans

There are many factors that can affect the production of corn and soybeans in future climate scenarios. Many of them directly relate to temperature, rainfall, and extreme weather, which can affect the growing season, crop emergence rates, and the major growth and development stages of plants. Other effects are harder to predict, such as the impact of CO_2 on the transpiration rates of crops. Some of the climate changes projected across the Midwest are positive for either corn or soybeans, and other changes may result in a decline of yields in various sections of the Corn Belt. Although both positive and negative effects are expected to occur, the general consensus points to farmers continuing to grow corn and soybeans across the study region in the near future.

A USDA technical bulletin (Walthall et al. 2013) summarizes much of the general projection information on how agriculture will be shifted by climate change. It focuses on crops across different regions of the United States. A now-classic paper on how climate change may affect corn yields across the United States is Liverman et al (1986). Their combination of a crop growth simulation model and regional environmental conditions in the YIELD crop model was a pioneer for research in this specialty, and paved the way for other “hybrid” models. With a focus on the Great Plains, Liverman found that future irrigated corn yields were higher in sunny and cold scenarios, compared to cloudy, hot, and extremely dry conditions. Lobell et al. (2011) present the findings of a global analysis of crop production impacts due to climate change over the 1980-2008 time period, with a focus on corn, wheat, soybeans, and rice. Although they do not find a major change in temperature trends in the United States, and only a minor reduction of yields for crops, this may partly be attributed to an inability to explicitly evaluate extreme temperature and precipitation events in the model.

Climate change also has the potential to impact planting and harvesting dates for corn and soybeans. Climate change in North Dakota has already been found to extend the growing season for corn by 12 days compared to a century ago (Badh and Akyuz 2009). Badh and Akyuz (2010) also look at growing degree days (GDDs) across the northern Great Plains (including North Dakota, South Dakota, and Nebraska) section of the Corn

Belt, finding that there has been an increase in less “ideal days” over time for crops which cannot flourish as quickly.

It is widely discussed that increased CO_2 in the atmosphere may lead to more robust crops, since plants require CO_2 for growth. Overall, the effect of CO_2 fertilization is considered to be an important factor in crop simulations under future climate, although the size of the impact of CO_2 fertilization on crops is still uncertain (Challinor et al 2005, Iizumi et al 2009, McGrath and Lobell 2011). A study conducted by Attavanich and McCarl (2014) discusses how increases in CO_2 may affect yields. Using an econometric model and data from 1950-2009, they determine that soybean yields will directly respond positively to elevated CO_2 levels generally, and both corn and soybeans benefit from elevated CO_2 levels under drought stress (Attavanich and McCarl2014). McGrath and Lobell (2011) also suggest that the CO_2 fertilization effect can double when crops undergo water stress, due to lower transpiration rates and increased soil moisture. Southworth et al (2002) uses the SOYGRO crop model and the HadCM2-GHG GCM for nine locations in the Great Lakes area, and they report soybean yield increases of up to 120% higher than current yields under climate change and CO_2 fertilization, with the southernmost areas (southern IL and IN) reporting little to no increases in yield. They find that the CO_2 fertilization effects specifically increase yields by 20%. Elliott et al. (2013) looks at a combination of several GCMs, global gridded crop model (GGCMs) and global hydrological models (GHMs), and identifies potential yield changes under increased irrigation with and without CO_2 fertilization. For RCP 8.5 (with CO_2 emissions continuing at current levels), the yield increases look to be approximately 10-40% across the Corn Belt region. Additionally, they suggest that irrigation water use is expected to decrease in the future with CO_2 fertilization, but would increase overall if CO_2 fertilization did not have an impact on crop growth.

Many field studies were conducted throughout the 1980s with respect to crop responses to CO_2 fertilization, and the yield responses are largely in line with the simulation results. Lawlor and Mitchell (1991) provide an overview of studies on a variety of crops, and estimate that a doubling of CO_2 concentration would lead to a 30-40% increase in soybean yields, based on 19 field experiments. They also predict that a C4 crop, such as corn, would have a lesser response to CO_2 fertilization compared to a C3 crop like soybeans, which is similar to the findings of the simulation studies.

Many studies using crop modeling systems also contribute greatly to our understanding the impacts of climate change on specific crops. For example, Ojima et al. (2002) discuss Great Plains ecosystem and agricultural impacts based on climate change scenarios from two different GCMs. Evaluating the decades of 2025-2034 and 2090-2099, they project an increase in temperatures and a small increase in precipitation (in 2099 projections). Additionally a study conducted by Mearns et al. (1999) evaluated the CERES and EPIC crop models for maize and wheat on high and lower spatial resolution GCMs and RCMs to determine their relative effectiveness in measuring the impacts of climate change. This study focused on Nebraska and Iowa, while including parts of Kansas and Missouri. Looking at these two popular crop models, Mearns found that CERES projected a decrease in corn yields under both the coarser and finer resolutions, while EPIC only projected a corn yield decrease using the GCM. Overall, it was determined that the choice of crop model made a major impact on the results of a climate change study, given that the GCMs and RCMs used remained constant across the crop models. The GCM used was developed by the Commonwealth Scientific and Industrial Organization (CSIRO) and the RCM used was RegCM, developed by Giogi et al. (1993).

Additionally, a working paper by Paustian in 2000 “Preliminary Draft Crop Model Analysis of Climate and CO2 Effects” compares different crop models and their relative effectiveness and uncertainties in measuring the impacts of climate change. Paustian compares four different crop models: Century, Ceres, DNDC and EPIC over seven different locations, four of which are located in the Corn Belt (Columbus, OH, North Platte, NE, Topeka, KS, and Fargo, ND) (Paustian 2000).

2.2 Climate Change Effects on Water Resources and Aquifers

It is projected that climate change will have major impacts on the water resources of the world. Precipitation pattern changes will affect the recharge rates of different aquifers. Additionally, soil moisture will be affected, along with runoff rates. This can especially be seen in regions that depend on snowpack as a source of water, but effects can be seen all across the world. Many studies go into great detail about how climate change will impact the processes for water storage and retention, but these studies do not consider change in the demand for water.

A detailed literature review of climate change effects on water use in the Great Plains was developed by the Spears et al. from the Department of the Interior (2013), and discusses the impacts on water resources all across the Western United States, including a focus on Kansas and Nebraska. It suggests that there is not enough information on how climate change will affect irrigation water demand, and suggests that irrigation demand could be increased due to temperature increases and precipitation variability, or could decrease due to an increase in crop failures or pest infestations.

The U.S. Climate Change Science Program (SAP 4.3) discusses that streamflow is increasing across the continental United States, and that the occurrence of drought decreased over the 20th century (Backland 2008). However, with a focus specifically on the Great Plains, Kustu et al. (2010) identified widespread negative streamflow trends over the Ogallala aquifer despite the recent precipitation increases across the Great Plains (Garbrecht et al., 2004). SAP 4.3 also discusses changes in runoff, which are projected to increase in eastern regions of the United States, but decrease across the interior of the west (Backlund 2008). Barnett et al. (2008) reaches a similar conclusion, stating that up to 60% of the climatic trends in soil moisture/runoff are human-related. Overall, the disagreement between studies suggests that Backlund is right in the premise that many of the aquifer assessments were designed without directly thinking about climate change, and that further study is needed to confirm changes in water resources under the direction of climate change (Backlund 2008).

A contrasting study by Eheart (1999) looks at the effect irrigation has on Midwestern water resources. The analysis shows that there is a potential for surface water to be heavily affected by an increase in irrigation and a decrease in runoff across several Midwestern states. However, it does use an older IPCC report (1996) that predicts a decrease in precipitation, and thus a decrease in runoff. According to the Fifth Assessment Report, there is likely to be an increase in precipitation in the region. However, under the assumptions that the paper made about precipitation, the irrigation modeling techniques implemented are valuable in the context of this study (Eheart 1999).

2.3 Irrigation as a Form of Adaptation

Irrigation is a commonly identified solution to adapt to the effects of climate change. The ability to regularly apply water to a field is invaluable to farmers in reducing the risks associated with uncertain weather. Although this cannot help in wet years, irrigation has been widely adopted to cope with systemic water shortages in arid areas, and to help in years of protracted drought or sub-seasonal drought conditions that result from low rainfall during a portion of the growing season. Because this is a big investment for farmers to make to reduce their risk, it is important to evaluate why farmers choose to adopt irrigation systems, and evaluate the characteristics of farmers who decide that irrigation is the right decision for their farm.

Heatherly, Wesley, and Elmore (1990) compare corn, soybean, and sorghum responses to irrigation water. They also calculate the gross income per unit of land area, and looked at economic efficiency between the crops. Irrigation was not used across the entire season, but just at the most important stages. They also did not conduct the evaluation with a full crop budget, looking primarily at returns and costs of water. Lamm, Stone, and O'Brien (2007) simulate corn, soybean, sorghum, and sunflower irrigation requirements from 1972-2005 in northwestern Kansas. They look at net returns for the irrigated crops, and find that soybeans are the most profitable. With the volatility of the net return, corn could easily be more profitable with a relatively minor price shift.

2.3.1 Why do Farmers Choose to Irrigate?

Farmers choose to irrigate in the United States for a variety of reasons, and a study conducted by the USDA (Caswell, 2001) aimed to pinpoint those reasons. This study uses a binomial adoption model to evaluate the main factors that influence farmers in their decision to irrigate. It took a look at five watersheds across the United States. It evaluated the Central Nebraska River Basin inside the study region defined for this research. The major factors that influence irrigation decisions are weather-related, including higher average temperatures and lower average rainfall amounts. Outside of the climate-related factors, farmers who own their own land, have attended college, participate in conservation reserve programs, and plant corn are more likely to irrigate. The closeness of a field to a water source and the slope of the land are also major irrigation factors. A multinomial model was used to evaluate the adoption of gravity and sprinkler irrigation systems. Many of the same factors were at play, and corn farmers were more likely to adopt sprinkler systems than gravity systems. Overall, the study finds that human capital, land ownership, choice of crop, and the climate play major roles in the choice to irrigate (Caswell 2001).

2.3.2 How Irrigation is Changing across the United States

The Farm and Ranch Irrigation Survey (FRIS), conducted by USDA every five years, tracks the current use of irrigation across the United States. In general, it depicts that the use of irrigation equipment across most of the Corn Belt is increasing (see Figure 1).

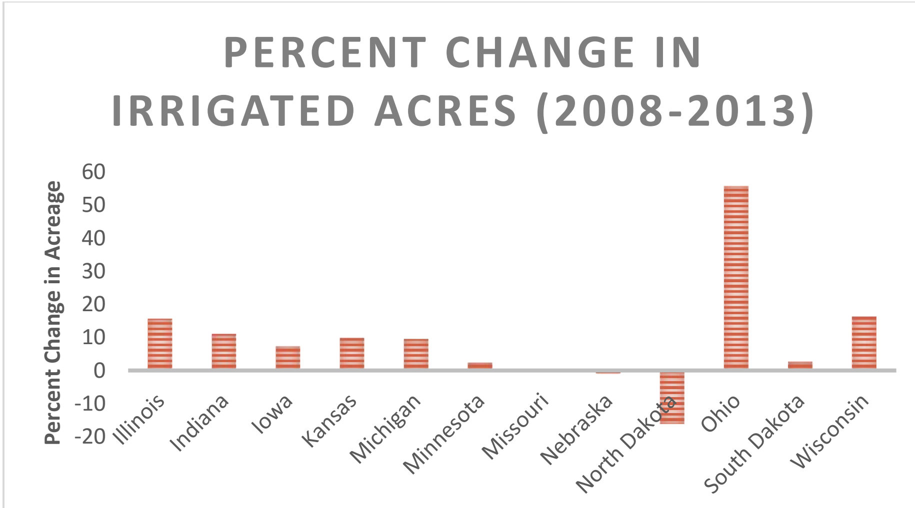

Figure 4. Percent Change in Irrigated Acres across U.S. Corn Belt (2008-2013)

A USDA Economic Research Service (1996) study that uses some of the FRIS data together with data from the Agricultural Resource Management Survey (ARMS) analyzes soil, nutrient, and water management practices used in corn production. There are a few things that are illuminated through an evaluation of the data. First, surface water is not heavily used for the irrigation of corn. Groundwater is used in 90% of irrigated corn and has more irrigated acres than any other crop. Finally, there is more of a focus on an improvement in irrigation efficiency, and less of a focus on implementing new irrigation systems. The data studied were exclusively from Kansas, Nebraska and Texas, so this is not representative of the Corn Belt region that is the focus of the current study. Therefore, it is important to look at the most recent FRIS Survey, which was conducted in 2013.

It is also important to understand the common types of irrigation systems that are present and useful to farmers in the Corn Belt. The FRIS discusses the general types of systems that are most commonly used by state, and where the water is sourced from. This isn't generally broken down by type of crop, but a variety of state Extension publications discuss the major systems used in corn and soybean production, the economics of purchasing an irrigation system, and the factors that affect this major choice (e.g. Harrison 2009).

2.3.3 Irrigation Tools: Investment

Understanding the economic implications of investing in an irrigation system is vital to understanding why the increase in irrigation installation in the Corn Belt is occurring. Aside from a few extension documents, there is not a lot on investment in irrigation, especially in the central and eastern Corn Belt. There are, however, several tools that discuss irrigation systems, their use, and (some) costs, after the time of purchasing. A prominent example of scheduling tools of this nature is "CROPWAT: A Computer Program for Irrigation Planning and Management," designed and implemented by the Food and Agriculture Organization of the United Nations (Smith 1992). CROPWAT is an irrigation scheduler, which is helpful to farmers that already have irrigation systems and are looking to improve efficiency or yields.

2.4 Irrigation and Climate Change: Impacts on Water Resources, Yields

There are many studies that look at irrigation and climate change in combination. These studies are generally done on a global scale, and look at the impacts that irrigation will have on water resources, or the combined impact that irrigation and climate change will have on crop yields.

Typically, the use of GCMs and crop models is imperative to these kinds of studies, and several important examples of this work are outlined below.

2.4.1 Projected Impact Irrigation will have on Crop Yields under Future Scenarios

A study that looks into crop responses for corn in the face of climate change is Tung and Haith (1998). This study looks at irrigated corn in a few locations across the United States under 100-year weather projections from 1988-2088, using 1961-1988 data as a reference. Compared to New York and Oklahoma, Indiana experienced the least difficulty in obtaining water for irrigation, and the damage to yields was not severe, due to an increased water supply and a longer growing season that mostly alleviates the adverse effects of increased evapotranspiration and shifts in sunlight during critical growth stages.

2.4.2 Projected Adoption of Irrigation Technology

There are few studies that discuss how irrigation demand will shift in response to climate change, but a great deal of information about how irrigation demand will shift with respect to currently irrigating farmers. Seo et al (2008) looks at the factors that go into the decision to buy irrigation equipment. Although this study primarily looks at farmers who are looking to upgrade their irrigation system, they still evaluate the investment costs, exit costs, and volatility rates of adopting irrigation technology. Overall, they acknowledge that investment in irrigation equipment is a major expense, and once farmers install irrigation equipment, it is unlikely that they will choose to not irrigate their crop, even in the case of inefficient irrigation systems (Seo 2008).

2.4.3 Changes in Irrigation Demand in Future Time Periods

There are several studies that discuss the prospect of current irrigators changing their demand for irrigation water, in various regions, and using different crop models. For example, Dominguez-Faus et al. 2013) uses the crop model GEPIC and various GCMs to evaluate increased irrigation water across the Corn Belt over 2010-2050. This study mostly looks at an increase in the water use intensity of irrigated corn, with a focus on corn used in ethanol production. This is primarily based on increased evaporative demand requirements, paying special attention to Ogallala aquifer. McNider et al (2015) use griDSSAT and hydrologic modelling to look at irrigation demand across the southeastern United States, and the impact that irrigation demand shifts could have on aquifers in the area. It uses the CERES maize crop model, calibrating the yields using the minimum Root Mean Square Error and the NASS county yields, a process developed by Jagtap and Jones (2002). It also uses a cropland data layer to locate agricultural areas growing crops of interest. They do not consider new investment in irrigation, but focus on irrigation water demand, and while they don't specifically look at future irrigation water demand, they can look at real time water availability using a combination of the crop model and a hydrologic model.

Mohan (2014) uses various GCMs for impacts on irrigation water in India over 2010-2070. This study briefly talks about economic impacts through a discussion of the expansion in the context of water planning and management. However, the preferences of individual farmers are not considered. Similarly, Gondim et. al. (2009) uses climate models for impacts on irrigation water demand in Brazil from 2009-2040; Lee and Huang (2014) look at irrigation water demand changes in Northern Taiwan in the wake of climate change, but does not look at an increase in irrigation system adoption. On a global scale, Fischer et al. (2007) uses the International Institute for Applied Systems Analysis (IIASA) modelling system for impacts on irrigation water across globe from 1990-2080. Other global studies, by Döll (1999), and Liu et al (2009), evaluate similar problems.

2.5 Do Climate Models Work Accurately in this Type of Question

It is important to understand the limitations of global climate models as inputs to irrigation research. Several of the climate-based studies described earlier focused on accurately depicting increased water vapor in the atmosphere in GCMs, along with precipitation variability. The ability to identify an anthropogenic influence on observed multi-decadal changes in water vapor is not affected by ‘‘model screening’’ based on GCM quality. This is also found for climate simulations focusing specifically on the Western U.S. (Pierce et al. 2009). A popular store of information for climate modelers is the Coupled Model Intercomparison Project phase 5 (CMIP5), where over 20 groups coordinate to create a multi-model climate change experiment, used in the IPCC reports.

Even with the immense coordination and advanced estimation techniques, there is some evidence that the CMIP5 global climate models may underestimate decadal to multi-decadal precipitation variability in western North America, complicating projections of future precipitation changes and drought in this region (Ault et al. 2011). Seager et al. (2012) notes that the global average tendency towards an intensified hydrological cycle may not be evident in all locations, depending on the particular changes in precipitation and evaporation in a region and how they might be affected by a tele-connected ENSO response.

Rosenzweig et al. (2014) compares several GCMs within the Agricultural Model Intercomparison Project (AgMIP), including five GCMs and 4 RCPs for crop responses to climate change and irrigation. They find that climate change has a strong negative impact on crop yields, especially when nitrogen stress is included in the crop models. The pDSSAT crop model tended to fall in the middle of the other crop models when it comes to the results, and is one of the most widely used gridded crop models. This is a global gridded simulation, and estimates full and no irrigation, and provides data to the public (the data used in this study). They find that the uncertainty with soybeans is higher than with maize overall, and the variability between crop models is also significant.

Glotter et al. (2014) evaluates the effectiveness of the use of RCMs in altering projections of yield under climate change. Largely, they conclude that, with bias-correction done to the crop models, the results from a GCM are indistinguishable than those from a geographically refined RCM. An RCM involves a dynamic or statistical downscaling, and Glotter and co-authors evaluate the dynamic delta-method. Dynamic downscaling does reduce the bias associated with topology differences but was found to continue to underestimate yields in the Upper Midwest. They suggest that variation due to climate may be small because of how effective a mean monthly bias correction is at matching simulated yields to historic yields.

2.6 Irrigation Impacts on Rainfall and Aquifers

Irrigation from the Ogallala Aquifer has possibly impacted rainfall patterns across the Great Plains region (Harding and Snyder 2012a). In general, irrigation is associated with an increase in rainfall. However, in a companion study (Harding and Snyder 2012b), it was determined that expanding irrigation leads to water losses from increased evapotranspiration, and that these effects overwhelm any precipitation increases due to irrigation. They conclude that irrigation promotes net water loss over the Great Plains.

2.7 Water Policy

Taking into account the connection between water policies and irrigation demand is paramount to understanding the future outlook for irrigation demand. Water policies are indicated to have a major role in the adoption of irrigation, as found in Carey and Zilberman (2002). They discuss irrigation technology adoption, while analyzing the impact that water markets can have on irrigation water demand, using dynamic optimization of farmer behavior and empirical data. They determined that water policies can have a major impact on the adoption of irrigation technology, and that extreme weather events also play a major factor in the choice to adopt irrigation technology. Some studies focus on the impact that policies in general have on the adoption of irrigation technology such as Gollehon and Quinby (2006), which discusses change in water withdrawals and policies

Other studies look at water policy impacts more implicitly. There are several papers that assess the impacts of water pricing on agricultural water demand. For example, a study in Georgia, which experiences a significant amount of precipitation annually, shows the impact of water pricing in a location that primarily uses irrigation as a supplement (Mullen 2009). The study by Mullen et al. finds that intraseasonal water use changes more based on the pricing of water than as a result of changing crop prices. However, a change in crop prices has a greater impact on water use than explicit changes in water pricing. Alvarez et al. (2004) similarly found that agricultural water use in the same region is impacted mildly by explicitly pricing water. In summary, demand for commodities is a driver of water use, and accurately capturing water prices is essential for the development of a strong model.

2.7.1 Representative Aquifer Studies

There are several case studies from across the world, especially in areas where water conservation is already an important issue. In the Corn Belt, the most common study region is the water-stressed areas of Kansas and Nebraska, such as the Ding and Peterson (2012) study mentioned in section 2.2.1 of this thesis. Most other parts of the Corn Belt have received little attention, although Tung and Haith (1998) evaluate irrigated corn in Indiana (with minimal discussion of water policy discussion). A final study in the Corn Belt includes climate change impacts on reclamation for water supplies and related water resources within eight major Western U.S. river basins, including the Missouri River Basin. The report (Reclamation 2011) includes an original assessment of natural hydrology impacts under projected climate conditions.

Another study encompassing the Ogallala Aquifer (Bulatewicz et al. 2010) has similar goals to this thesis. Using linked groundwater-crop-economic model, the study investigates different water policies by changing the parameters within one of the models.

As a retrospective study, it evaluates the impacts of two potential water policies, had they been implemented in 1991, and compares this to actual water use from 1991-2004. The two sustainable water use policies considered are the regulation of water use using prior appropriation doctrine, and an incentive-based voluntary buy-back program. The study also evaluates recharge, and determines that water use would have to be reduced by 90% in some high priority areas (under the regulatory policy). In the voluntary program, a reduction of water use by 34% would match the natural recharge rate. Through a combination of models, this case study provides insight into how to model crops and economics to represent different water policies in representative aquifers.

Elsewhere in the United States, Hoekama et al (2009) "addresses the impacts of climate change at a scale applicable to the management of water resources," by evaluating the Payette River Basin in Idaho (Hoekema et al 2010). Some case studies from Southeast Asia, similar to the Payette River Basin study, can be found in Shrestha (2014).

While most water policy discussion focuses on locations that are water-scarce today, there are some regions focused on water use that currently have a surplus of water. In Minnesota, for example, water policies are stricter than across most of the water-rich states in the central and eastern Corn Belt. Although the permitting system is less rigorous than those in the Western Corn Belt, Minnesota monitors and enforces unpermitted pumping today (Freshwater Society 2013).

Wisconsin is another state where water is plentiful. Luczaj and Masarik (2015) evaluate water quantity issues here, noting that the primary concerns lie in sandy parts of the state, where irrigation is more prevalent, and where confined aquifers are located.

While most of the water used in Wisconsin is from surface water resources, as in many water-rich states, irrigation is still the largest use of groundwater. Under reasonable use doctrine, overuse of groundwater resources has occurred, and only recently was the relationship between groundwater and surface water recognized as a part of state legislation. However, across most of Wisconsin, there is still no true regulation of water quantity, besides registration and reporting requirements (Luczaj and Masarik 2015). An exception to this is the 2003 Groundwater Protection Act 310, which allows for the creation of Water Management Areas, and the management has led to increased deals with neighboring communities, and the expanded use of surface water, over the use of groundwater in sensitive aquifers.

2.8 Contributions of the Present Study

Based on the literature, it is clear that irrigation is an important factor for farmers to consider as they plan for more uncertainty under future climate change. It is also clear that the impacts of irrigation on water use in the Midwest may be significant. It is important for both policymakers and farmers to be able to understand what place irrigation may have in their future, so that the investment in irrigation equipment is well-founded and water policies in the region manage competing needs of future water users. This study aims to understand the economic decision to invest in irrigation in the future under different water policies in the Corn Belt. While there is a significant amount of literature that recognizes the need for this type of study, most of the research to date focuses on the science of climate change and irrigation use, or on water policies in the region. There are several factors that this study considers that are not commonly found in large-scale studies of climate change and irrigation: the farm-level economics of investment in an irrigation system and the evaluation of additional irrigation water demand in future drought years. These important factors, along with the integration of hydrological and climate science with policy form the gap in the literature that this study aims to fill.

2.8.1 Economics

Most studies do not evaluate the impact that economics plays in farm-level irrigation investment decisions. This is primarily because prior studies generally do not consider an expansion of irrigated acres (new investment), and focus instead on how much water current irrigators will use in projected future climate scenarios. This study will be the first attempt to quantify the scale of new irrigation investment for maize-based cropping systems based on decentralized grid-cell level economics. Additionally, many hydrological or modeling based studies that do not take economics into account do not consider whether farmers would be willing to pay for the increase in the irrigation water requirements. This study will shed new light on questions about irrigation behavior under climate change in historically water-rich areas by taking a closer look at what a representative farmer in different locations around the Corn Belt would choose to do. If it would not be profitable to irrigate, perhaps the future irrigation demands will not be as dramatic as those found in previous studies. It is also possible that, with the inclusion of new irrigators, the demand for irrigation water will be increased more dramatically.

2.8.2 Scale

The scale of this study is unique because there are few studies that use this level of detail across such a large area. Although many GCMs cover areas in detail, many of the studies that relate to this topic are done at a global level with very coarse resolution, or at a much smaller aquifer level. Being able to focus this study across such a valuable agricultural area, with this level of detail will be unique.

2.8.3 Irrigation Water Demand under Varying Weather Conditions

Although the impact of extreme weather events has been studied fairly extensively in the climate literature, the links to irrigation demand are minimal. Most studies related to irrigation demand focus on decades at a time. In the sense of climate itself, this study will as well, but it will also provide the unique opportunity to look at how irrigation water demand changes across the distribution of extreme weather years at mid-century.

This study will not be able to look at extreme precipitation events, which is where many of the climate change papers focus their attention. Instead, I will look at drought over extended periods of time, and will use economic criteria to evaluate whether and where investment in irrigation systems is a privately efficient means of managing sub-seasonal and seasonal drought.

2.8.4 Connection Between Water Policies and Irrigation Water Demand

While water policies are often discussed in smaller-scale studies, such as the aquifer level, there is less information available about how water policies across a large area may influence irrigation water demand. Although the Ogalalla aquifer and the water policies in Kansas and Nebraska are well studied, those in the central and eastern Corn Belt are not frequently evaluated with respect to irrigation. Considering the role of water policies in studies on irrigation water demand is not common, even though these policies may have a large impact in sensitive areas. Integrating the science and policy seeks to inform decision making, for farmers and policymakers in the future.

CHAPTER 3. METHODOLOGY

Shifts in precipitation patterns may spur changes in the demand for irrigation equipment across the Corn Belt, potentially leading to a greater demand for groundwater and the over-extraction of groundwater in new areas. To examine how future climate will impact irrigation adoption and water use, we first develop an irrigation investment calculator, designed to determine whether the installation of irrigation equipment is profitable. The irrigation investment calculations can be used as metrics to determine whether irrigation is a sound economic investment. In order to calculate the profitability of irrigation, the Net Present Value (NPV) is calculated for an investment in irrigation equipment over the assumed twenty-year lifetime of an irrigation system (Schlegel and Tsoodle 2009). The number of years where irrigation may be profitable are also calculated, dependent on location-specific weather and soil information.

By running this tool across all of the counties in the Corn Belt under current and future weather conditions, we can estimate potential future shifts in irrigated acres, along with changes in water demand. By evaluating the results and investigating the impact that future demand and current groundwater policies have on aquifers, we can forecast the potential impact that irrigation may have on groundwater extraction.

3.1. Irrigation Investment Calculator

The irrigation investment calculator is designed to evaluate whether the purchase of an irrigation system would be profitable for a farmer over the lifetime of the equipment. We first want to evaluate whether investing in irrigation equipment will be beneficial for a farmer who is currently thinking about establishing and using an irrigation system over the next twenty years, using prices from 2015 and simulated historical weather for 1980-2005 (hereafter referred to as the contemporary climate). The results for the contemporary climate will then be compared to where irrigation investment is projected to be profitable in 2040-2070. The investment calculator was developed for the 12-state Corn Belt region, which is comprised of a few states that already heavily irrigate, and others that currently irrigate relatively few corn and soybean acres. The calculator structure is based on a spreadsheet-based decision support tool developed by Roger Betz, with Lyndon Kelley and Dennis Stein from Michigan State University's Extension Service (Betz 2014).

The spreadsheet originally designed by Betz provides the basic framework for developing the investment calculator that can be used for research and extension purposes. The tool combines capital cost and loan information, crop and labor variable costs, and yield expectations of the producer. This works well for farmers on an individual basis, who have a great deal of knowledge about their farms and the opportunity to customize their inputs to best suit their needs. In order to use the tool for climate change adaptation research purposes over a large-scale area, providing the best-available data for each location in the study region for the present and future (2040-2070) time periods is essential. Primarily, this involves requires information on historic and future yields and weather scenarios by location. After the accumulation and processing of this data occurs and is implemented within the structure of the decision support tool, two versions of the calculator result. The first is focused on the contemporary period and is designed as a web-based tool as a part of the Useful to Usable project, a USDA-funded program that provides decision support for a variety of weather and climate risks faced by corn-producers across the Corn Belt. A second version of the tool was built as an R program (version 3.1.1; R Core Team, 2014) to conduct this research and evaluate the NPV of irrigation investment and potential irrigation water demand at all locations across the entire region under different climate regimes. The default for both versions of the tool compares the profits for 160 acres of irrigated land to 160 acres of unirrigated land, under the same mix of corn and soybeans, to determine irrigation profitability for the farmer, based on historic yields, irrigation costs and benefits and climate for each location. The R program provides information on the future yields, irrigation quantities and profitability based on projected climate change.

To provide up-to-date financial information and location-specific weather history to the irrigation investment calculator, all relevant parameter values were updated from Betz's spreadsheet tool (latest version was 2012) to reflect the highest resolution of data available. The process of updating the information, and the methodology behind the updates are detailed in the next section. When a user accesses the online version of the decision support tool (Appendix C), region-specific costs and county specific yields and climate are the basis for the default values provided by the irrigation investment tool.

3.1.1 Data Kept Constant over Time

In order to isolate the effects of climate change on the irrigation investment decision, many of the variable costs, crop prices, and loan information are preserved from the 1980-2005 time period to the 2040-2070 window. In order to capture the full effects that future weather variability may have on the adoption of irrigation, the choice to avoid predictions of prices or technological change was consciously made, but remains another important source of uncertainty into the future.

3.1.1.1 System Cost/Acres Covered (From Original Spreadsheet)

The traditional system used in irrigating corn and soybeans is a center pivot irrigation system. These are typically high-efficiency systems, and are commonly used to cover large areas of open-air crops. Thus, a center pivot system was assumed for across the entirety of the Midwest region. A common sized center pivot system is installed to cover a quarter section of land equal to 160 acres; this is the system size we consider for the irrigation investment analysis. This is used to compare the profitability of installing irrigation equipment to cover the same quantity of unirrigated land. All initial costs reflect this size of system.

3.1.1.2 Loan Information (From Original Spreadsheet)

The purchase price, salvage value, loan terms, income tax classifications, and interest rate were also kept constant across the region. Currently, common loan structures do not vary significantly across the Corn Belt, and alteration of these values by region may artificially indicate a location to be more profitable for irrigation. These constant values are listed in Table 1.

3.1.1.3 Income Tax Information

Income tax information is made standard across the twelve state region, similar to the capital cost and loan information. An irrigation system falls under the same type of property class information for federal taxes across the entire region. While both MACRS and ADS-SL methods of calculating depreciation are built into the original capital model and are options in the online version of the tool, the MACRS depreciation rate is used for the climate change study. The assumed values are located in Table 2.

Table 2. Capital Costs, Loan, and Income Tax Information

Capital Cost and Loan Information	**Value**	**Income Tax Information**	**Value**
Purchase Price for System	$225,000	Loan Terms in Years	7 years
Acres Irrigation System Covers	164 acres	Marginal Income Tax Rate	43.7% (Fed + State + Soc. Security)
Life of System in Years	20 years	Additional First Year Depreciation	$50000
Salvage Value of Investment	$67,500	Opportunity Cost of Capital	8.00%
Amount of Purchase Price Borrowed	$200,000	MACRS Property Class	7 years
Interest Rate for Borrowed Money	4.5%	ADS-SL Years	10 years

3.1.1.4 Variable Costs

Price information for corn and soybeans are adopted from the current price forecasts calculated by USDA. The prices are not changed for future time periods, similar to the rest of the financial data. Instead, sensitivity analysis is conducted, to show how the prices affect potential irrigation adoption.

The 2015 Purdue Crop Cost and Return Guide was consulted for input cost information for many of the expenses a farmer encounters throughout the growing season, including: seed, fertilizer, chemicals, fuel, repairs, crop insurance, and trucking costs (for both unirrigated and irrigated crops). These data are used for every county in the region, despite some minor price variation that may occur in different regions. The Purdue Crop Cost and Return Guide does not contain values for irrigated crop insurance, so the irrigated crop insurance values are from a Kansas State Research and Extension Cost-Return Budget (Ibendahl 2008). Additionally, the Crop Cost and Return Guide did not contain information about irrigation equipment repairs, so the state level data (Table 24) from the 2008 USDA Farm and Ranch Irrigation Survey (FRIS) were included for irrigation equipment (NASS 2008). This allows for the irrigated acres to include both the standard repair costs and the irrigation-specific repair costs. Finally, several more recent input values for irrigated crops are available from 2013 FRIS data, such as the irrigation energy requirements (NASS 2013). The values and their sources are found in Table 3.

Table 3. Variable Costs for Unirrigated and Irrigated Crops (Example from Tippecanoe County, IN)

Variable Expenses per Acre	**Dryland Soybeans**	**Dryland Corn**	**Irrigated Soybean**	**Irrigated Corn**	**Source**
Seed	$75.00	$124.00	$75.00	$124.00	2015 Purdue Crop Cost and Return Guide (Average Productivity Soil) (September 2013 Estimates)
Fertilizer	$57.00	$144.00	$57.00	$144.00	2015 Purdue Crop Cost and Return Guide (Average Productivity Soil) (September 2013 Estimates)
Chemicals	$28.00	$43.00	$28.00	$43.00	2015 Purdue Crop Cost and Return Guide (Average Productivity Soil) (September 2013 Estimates)
Drying Cost	$0.00	$51.78	$0.00	$52.80	Betz (2014) Irrigation Investment Capital Model, based on yield per acre
Irrigation Energy	$0.00	$0.00	$22.56	$22.56	2013 FRIS Table 12 (by state) "Total Energy Expenses for pumping, per irrigated acre in the open, assuming water from wells"
Fuel & Oil	$15.00	$25.00	$15.00	$25.00	2015 Purdue Crop Cost and Return Guide
Repairs	$18.00	$22.00	$26.44	$32.83	2015 Purdue Crop Cost and Return Guide *Plus* Table 24 2008 FRIS maintenance/repair cost per irrigated acre
Crop Insurance	$23.00	$33.00	$11.50	$11.50	2015 Purdue Crop Cost and Return Guides with Kansas State University Crop Insurance Estimates for Irrigated Corn and Soybeans
Trucking	$5.14	$17.26	$5.20	$17.60	2015 Purdue Crop Cost and Return Guide
Marketing	$2.57	$8.63	$2.60	$8.80	Betz (2014) Irrigation Investment Capital Model

3.1.1.4 Labor Information

The labor costs and hours worked per acre are separated based on irrigated labor and unirrigated labor, since worker skills and wages vary depending on the specialized irrigation tasks. The "Center-Pivot Irrigated Corn Budget" from Kansas State University study was used to value family and "regular" labor (O'Brien and Duncan 2008). This value was assumed across the Corn Belt. The 2013 FRIS was consulted for the value of irrigation labor, and this value is state-specific.

3.1.2 Data that Vary Based on Current/Future Climate Predictions

There are several calculations that depend on weather and soil information that is considered to be site-specific. In order to most accurately represent the location-specific information, we looked to find the most complete and accurate source of data. Much of the information with respect to corn and soybean yields and irrigation quantities is sourced from different crop models of the parallel Decision Support System for Agrotechnology Transfer (pDSSAT) series (Jones et al. 2003; Hoogenboom et al. 2010). Corn data is developed from the Crop Environment REsource Synthesis (CERES) model (Jones and Kiniry 1986), and soybean data is from CROPGRO-Soybean model (Boote et al. 1998), both of which are part of the pDSSAT suite of crop models. The inputs and outputs from these crop models include information on crop yields, precipitation, evapotranspiration, along with irrigation water applied, based on local soil and weather parameters. These data are available as part of the Agricultural Model Intercomparison Project (AgMIP) simulation archives. Details of how this information is gathered, sorted, adjusted, and implemented into the investment tool follows.

3.1.2.1 Wet/Dry/Average Years Based on the SPEI

In order to understand how yields and irrigation water quantities varied due to extreme weather in each county, we must classify different weather into “dry,” “average,” and “wet” years. This information is presented visually in the online version of the irrigation investment calculator, and in this thesis for additional analysis of H_2 looking at water use in years classified as dry, moderately dry, and extremely dry. We used the Standardised Precipitation Evapotranspiration Index (SPEI) to classify each grid cell in each historic year (1980-2005) as being a dry, wet, or average year based on gridded global climate model data (discussed in greater detail below). The SPEI was designed by Dr. Sergio M. Vicente-Serrano at the Instituto Pirenaico de Ecologia, Spanish National Research Council (Vicente-Serrano et al. 2010) and is one of several measures of crop moisture stress widely used today. The SPEI measures drought and extremely wet periods by normalizing monthly water balance (precipitation less potential evapotranspiration) data. The SPEI looks at the number of standard deviations that this water balance in a given year is away from the historical mean for that location, using a normal distribution. We used these standard deviations to determine the incidence of dry and wet years in each location.

Unlike several other common classifications of weather, the SPEI takes into account the potential evapotranspiration. This is especially important for studies involving future climate, as temperature increases are able to factor into this calculation. According to Mavromatis (2007), simplistic ways of calculating the potential evapotranspiration are as effective in the SPEI calculation as more complex measures. Therefore, with the climate input data available from the AgMIP project, we have enough information to calculate potential evapotranspiration using the simple Thornthwaite method (Thornthwaite 1948). This method uses monthly mean temperatures as the basis for the calculation. Therefore, the monthly potential evapotranspiration (PET) in mm is calculated by

$$PET = 16K\left(\frac{10T}{I}\right)^{m} \tag{1}$$

Here, T is the monthly mean temperature in Celsius. I is the sum of the monthly heat index values i, which is calculated using the monthly mean temperature data as follows:

$$i = \left(\frac{T}{5}\right)^{1.514} \tag{2}$$

The coefficient m depends on I, as shown:

$$m = (6.75 * 10^{-7})I^3 - (7.71 * 10^{-5})I^2 + (1.79 * 10^{-2})I + 0.492 \tag{3}$$

The correction coefficient, K, is calculated by referencing the latitude and the month, as follows:

$$K = (\frac{N}{12})(\frac{NDM}{30}) \tag{4}$$

NDM is the number of days of the month, and N is the maximum number of sun hours available daily, calculated as follows:

$$N = (\frac{24}{\pi})\omega_s \tag{5}$$

The angle of the sun rising, calculated hourly, is ω_s, calculated as shown:

$$\omega_s = \arccos(-tan\varphi tan\delta) \tag{6}$$

Here, φ is the latitude (radians) and δ is the solar declination (radians), calculated by:

$$\delta = 0.4093sin\left(\frac{2\pi J}{365} - 1.405\right) \tag{7}$$

J is the average Julian day of the month.

With the calculation of the PET, a simple water balance equation is constructed, using the mean monthly precipitation in mm (P) and the monthly PET. For month i, the calculation is as follows:

$$D_i = P_i - PET_i \tag{8}$$

The D_i values are aggregated across six month time intervals. Since we look specifically at the 6-month SPEI in October, which covers the entirety of the growing season, we sum the D_i values from May through October. After testing a variety of distributions, Vicente-Serrano determined that a log-logistic distribution was an appropriate distribution across different time scales, with respect to extreme values. The log-logistic distribution is given by:

$$F(x) = \left[1 + \left(\frac{\alpha}{x - y}\right)^{\beta}\right]^{-1} \tag{9}$$

Using this distribution, the SPEI can then be calculated by the following:

$$SPEI = W - \frac{2.515517 + 0.902853W + 0.010328W^2}{1 + 1.432788W + 0.189269W^2 + 0.001308W^3} \tag{10}$$

$$W = \begin{cases} \sqrt{-2\ln(Pr)}\ for\ Pr \leq 0.5 \\ \sqrt{-2\ln(1 - Pr)}\ for\ Pr > 0.5 \end{cases} \tag{11}$$

Here, Pr is the probability of exceeding a specific threshold of D_i, and is calculated by $\mathrm{Pr} = 1 - F(x)$. The average SPEI value is zero, and the standard deviation is one.

The monthly precipitation and temperature variables from CMIP5 needed to calculate the SPEI are included in the archived input files used by AgMIP in their various crop models. The R package ‘SPEI’ (Begueria and Vicente-Serrano 2013) was used to calculate the potential evapotranspiration using the Thornthwaite method (Thornthwaite

1948), and then to calculate the 6-month October SPEI. For each year, if the SPEI indicated that the year was at least one standard deviation away from the mean water balance in the area, it was considered to be a “non-normal” year, and classified as either dry (SPEI ≤ -1) or wet (SPEI ≥ 1). From there, the probability of a dry, average or wet year occurring can be calculated from the contemporary climate data. The same process is followed to calculate the SPEI for each future year in each location using the AgMIP climate input data.

3.1.2.2 Irrigated/Unirrigated Yields and Water Use Information

In order to best represent the corn and soybean yields, along with irrigation application quantities across the region, crop model data is implemented into the irrigation investment calculator. Other sources of data were considered, such as the NASS county yield data. However, NASS data does not separate information between irrigated and unirrigated yields across much of the Corn Belt, which leads to a potentially higher-than-representative set of yields for unirrigated values, and little to no irrigated crop-specific data. It is known that simulated crop data can be biased in parts of the Midwestern US due to an overestimation of temperatures (Glotter et al. 2014). Therefore we use the NASS yield information available to bias-correct the unirrigated simulated yield data. There are several notable differences between the CERES Maize and CROPGRO-Soy crop models designed to represent the differences between corn and soybean growth; the details and differences are outlined next.

3.1.2.3 Yield Information

No original crop growth modeling was conducted in this research. The irrigated and unirrigated yields from pDSSAT are available globally on a 0.5 by 0.5 degree latitude/longitude grid. These data were downloaded from the Globus file transfer system (www.globus.org), using Joshua Elliott's GGCM file transfer endpoint (jelliott#ggcmi). There are data available for several GCMs created, maintained and run by different research groups around the world: GFDL, HadGEM, IPSL, MIROC, and NorESM. As MIROC is known to simulate hotter and drier contemporary conditions than observed across the Midwestern US, the crop simulation data simulated using the remaining four GCMS are averaged to give an estimation of the irrigated and unirrigated yields at each grid point. Using individual GCMs was considered, rather than an ensemble estimate, but this was abandoned in favor of the multi-model mean because this better represented the level and inter-annual variation in yields in the observed NASS county yields than crop simulations based on any single GCM.

In order to compare gridded simulated yield data with NASS county yields, the yield data from the crop model were converted into area weighted county yields based on the proportion of land in each grid cell that falls within a county boundary. The NetCDF4 files obtained from AgMIP were converted into comma delimited files, and overlaid with shapefiles of county boundaries obtained from the United States Census Bureau. For each county that has boundaries intersecting with two or more grid cells, the yield of each grid cell is averaged based on the proportion of the county the grid cell covers. Since the yields reported by the simulation data are dry weights, the weights are adjusted to reflect market weights, assuming 15.5% moisture content for corn and 13% moisture content for soybeans.

The simulated yields were then bias corrected following the procedure in Jagtap and Jones (2002) to minimize the root mean square error (RMSE) between the observed NASS county yield, $\hat{g}$, and the area-weighted simulated yield, $\acute{y}$, in each county by selecting non-negative coefficient Y_c to solve:

$$\min_{Y_c} \left(\sum_{t=1}^{T_c} (\widehat{g_t} - Y_c \acute{y}_t)^2 \right)^{1/2} \quad (12)$$

A separate correction coefficient is calculated for each county in the region to account for systematic individual differences in yield that the crop models may not capture or that results from the area-weighting procedure used to construct county yield estimates. Then the coefficient is applied to the unirrigated yields in both the current and future time periods.

This procedure varied depending on how extensive the NASS county yield information was for a given county. The NASS county yield data has information available for unirrigated and irrigated yields for a limited number of counties in the region of study. For the rest of the region, all yields reported are combined, including both irrigated and unirrigated acreage. The states that separated irrigated from unirrigated yields were the counties where irrigation regularly occurs, including North Dakota, South Dakota, Nebraska and Kansas for corn, and Nebraska and Kansas for soybeans.

For the counties that have contemporary reported yields separated into irrigated and unirrigated categories, irrigated and unirrigated bias-correction coefficients are separately calculated for each county and applied to the simulated yields. This process is the same for both corn and soybeans.

For the counties that combine the irrigated and unirrigated acreage in the reported NASS county yields, which is most of the Corn Belt, the yield reported by NASS is treated as an unirrigated yield. A bias-correction coefficient is calculated using the NASS county yield data and the unirrigated simulated crop data (for both corn and soybeans). This bias correction coefficient is applied to unirrigated yields in the contemporary and future time periods. In order to estimate a bias correction coefficient for irrigated simulated data, a combination of FRIS and NASS data is used. The FRIS reports mean irrigated and unirrigated yields, by crop, for each state. The percent difference that FRIS reports between unirrigated and irrigated yields for each state is applied to the reported NASS county yields in order to estimate irrigated yields on a county level. Then, the same bias correction procedure in equation (12) is conducted. The minimization of the RMSE between the irrigation-adjusted NASS yield and the simulated yield yields a bias correction coefficient for each county and crop.

For counties that had less than 3 years of NASS county yield data reported from 1980-2005, no bias-correction of the simulated data could be performed. These counties are low producers of corn and soybeans, and were eliminated from the remainder of the analysis. There are a few individual urban counties without significant NASS data, along with much of the Lake of the Ozarks and the Upper Peninsula of Michigan.

3.1.3 Irrigation Water Application Data

The pDSSAT model measures soil water through the top 40 cm of the soil moisture profile, and automatically irrigates when the soil moisture is considered to be too low. Irrigation quantities are determined by triggers that engage whenever soil moisture falls below 80% of a soil's water holding capacity, and stop applying water when 100% soil moisture is reached (Elliott et al. 2013). The soil moisture content on a given date is determined by recent weather, soil texture, evapotranspiration, and runoff, as in a general water balance. The irrigation system efficiency was assumed to be 75%. Although these parameters are the same for corn and soybeans, the water application amounts vary significantly across the crops due to differences in plant water uptake and evapotranspiration. The simulated irrigation quantities are comparable with the USDA Farm and Ranch Irrigation Survey data on current irrigation practices. The coarseness of the state-level FRIS data makes this comparison difficult, but the pDSSAT values both over- and under-estimate the mean water application quantity for both crops in each state, largely depending on the soil type.

Related to the quantity of irrigation water applied over the course of the growing season, the soil texture varies across the region. The pDSSAT crop model uses the Harmonized world soil database, developed by the Food and Agriculture Organization of the United Nations (FAO), to determine the soil texture of each 0.5 degree grid cell. This classifies soil types into coarse, medium, and fine texture (>35% clay soils), and provides a variety of information on water holding capacity, bulk density, and other useful attributes. It uses the USDA soils information as inputs for the database. The database provides information down to 30 arc-seconds, but the information is aggregated to the grid-cell level for the running of the simulations.

3.1.4 Choice of GCM and RCP

The choice of GCM and Representative Concentration Pathway (RCP) is a major factor in understanding the impacts that climate change may have on irrigation. With the information from pDSSAT, there is less certainty in the decision of the appropriate GCM to use. In several studies that have access to data from a variety of GCMs, an average of the results is taken (Tebaldi and Knutti 2007; Palmer et al 2005; Ueda et al. 2006). Taking a multi-model approach has the potential to smooth out some of the variance that can occur in individual GCMs and the future, and reduce the number of extreme events cited. However, averaging can provide consistent, reportable results that avoid a single GCM having undue influence on the research findings. In this case, four of the GCMs are averaged; the GCM MIROC is not included in the averaging (see 3.2.2.1 above). The Coupled Model Intercomparison Project Phase 5 (CMIP5) has investigated multiple RCPs included in the most recent IPCCC Climate Assessment Report. There are several RCPs available, each based on a different trajectory of atmospheric CO_2 concentration that pertains to a different radiative exposure (watts m^{-2}) in the future period. To show the effects of a plausible high emission scenario that does not include a specific climate change mitigation target (Riahi et al 2011), RCP 8.5 is chosen for analysis in this study.

3.2 Calculations from the Irrigation Investment Calculator

3.2.1 Net Present Value

The irrigation investment calculator uses location-specific weather and yield information as inputs to a NPV calculation of discounted after tax cash flow. The underlying data for this calculation is identified in Figure 5. The NPV calculation is the difference in value that the farmer will receive from irrigating compared to not irrigating. It is not the profits that the farmer will receive over the course of the growing season. This calculation takes into account the principal investment, the interest payment, depreciation, gross margin, salvage value, and the income tax specifications. These values, aside from the gross margin, are held to the constant values in Table 1. The gross margin is based on the probability of having a dry, wet, or average year, along with the costs and yield associated with those weather types. It is calculated for an irrigating and non-irrigating farmer, and the difference is used in the Net Present Value calculation. A standard NPV calculation is made over the assumed twenty year lifespan of the irrigation system. Additionally, the Internal Rate of Return (IRR) is measured. IRR is the discount rate that makes the NPV of the cash flows from the irrigation investment equal to zero. Generally, for a producer, the IRR is calculated to determine if the return on investment satisfies the target for the business.

The Net Present Value after Tax, net Cash Flow, used to determine the profitability of irrigation investment, is calculated using Equations 13-27. The associated parameters, definitions, and units can be found in Table 4.

$$NPV\ After\ Tax\ net\ Cash\ Flow = -\sum_{i=1}^{T} PV\ After\ Tax\ Cash\ Outflow_i \quad (13)$$

The NPV after Tax Cash Outflow, calculated annually, depends on the annual after tax cash outflow and the after tax opportunity cost of capital, as shown in Equation 14:

$$PV\ After\ Tax\ Cash\ Outflow_i = \frac{After\ Tax\ Cash\ Outflow_i}{(1+A)^i} \tag{14}$$

The after tax opportunity cost of capital is based on the opportunity cost of capital and the marginal income tax rate, as shown:

$$A = (B)(1-R) \tag{15}$$

The after tax cash outflow is calculated based on the principal investment, interest payments, irrigation-weighted gross margins, salvage value, depreciation, and interest rate of the loan, as seen in Equation 16:

$$After\ Tax\ Cash\ Outflow_i = P_i + I_i - GM_i - S_i - \rho(I_i + D_i - GM_i - S_i) \tag{16}$$

The annual principal payment depends on the annual loan payment, interest payment and the beginning value. The annual loan repayment depends on the interest rate of the loan, the number of years of the loan, and the loan amount. See below:

$$P_i = \begin{cases} BV_i & if\ Pay - I_i > BV_i \\ Pay - I_i & if\ Pay - I_i \le BV_i \end{cases} \tag{17}$$

$$Pay = \frac{\rho}{1-(1+\rho)^{-N}} * L \tag{18}$$

As shown in Equations 19 and 20, the interest payment depends on the interest rate of the loan, and the annual beginning value, which depends on the previous year’s beginning value and principal investment:

$$I_i = \rho * BV_i \tag{19}$$

$$BV_i = \begin{cases} BV_{i-1} - P_{i-1} & if\ BV_{i-1} - P_{i-1} > 0 \\ 0 & if\ BV_{i-1} - P_{i-1} \leq 0 \end{cases} \tag{20}$$

The gross margin calculations depend on the production costs of producing corn and soybeans, with and without irrigation, as found in Equations 21-23:

$$GM_i = GM_{irr_i} - GM_{unirr_i} \tag{21}$$

$$GM_{irr_i} = a * (g_{irr_i} - (l_{irr} + sd_{irr} + f_{irr} + ch_{irr} + d_{irr} + en_{irr} + \eta_{irr} + r_{irr} + \alpha_{irr} + t_{irr} + m_{irr}) \tag{22}$$

$$GM_{unirr_i} = a * (g_{unirr_i} - (l_{unirr} + sd_{unirr} + f_{unirr} + ch_{unirr} + d_{unirr} + \eta_{unirr} + r_{unirr} + \alpha_{unirr} + t_{unirr} + m_{unirr}) \tag{23}$$

While individual input costs can differ between dryland and irrigated production, the only additional input category are the pumping costs for irrigators, which has no analog in dryland production.

The gross income from production (for g_{irr_i} irrigated or g_{unirr_i} unirrigated crops) depends on the crop rotation planted, along with the yields and prices of corn (subscript c) and soybeans (subscript s):

$$g = rot_c\ (y_c * pr_c) + rot_s\ (y_s * pr_s) \tag{24}$$

The salvage value only affects the final year of the irrigation system lifetime, as represented in Equation 25:

$$S_i = \begin{cases} SV & if\ i = T \\ 0 & if\ i \neq T \end{cases} \tag{25}$$

Table 4. Parameters used in the Net Present Value Calculations of Irrigation Investment

Parameter or Variable	Definition, Units
i	Year Index
T	System Lifetime (total years)
PV	Present Value in dollars
A	After Tax Opportunity Cost of Capital (%)
B	Opportunity Cost of Capital (%)
R	Marginal Income Tax Rate (%)
P	Principal Investment (annual payments) in dollars
I	Interest Payment in dollars
GM	Irrigation Weighted Gross Margins in dollars
S	Salvage Value (annual) in dollars
SV	Salvage Value of Equipment in dollars
D	Depreciation in dollars
BV	Beginning Value in dollars
ρ	Annual Interest Rate of Loan (%)
a	Number of acres irrigation system covers
g	Gross income in dollars
l	Costs of Labor in dollars
sd	Costs of Seed in dollars
f	Costs of Fertilizer in dollars
ch	Costs of Chemicals in dollars
d	Drying Costs in dollars
en_{irr}	Irrigation Energy Costs in dollars
l_{irr}	Irrigation Labor Costs in dollars
η	Fuel Costs in dollars
r	Repairs in dollars
α	Crop insurance in dollars
t	Trucking costs of product in dollars
m	Marketing costs of product in dollars
rot	Crop rotation (%)
y	Yield in bu/acre
pr	Crop price in dollars/bu
c	Corn
s	Soybean
Pay	Payment (Annual) in dollars
N	Loan Term in Years
L	Size of Loan in dollars

The Net Present Value is calculated for each county across the Corn Belt. If the NPV is positive in a given county, irrigation investment is generally considered to be profitable. This calculation and classification takes place for both the contemporary (1981-2005) and future (2041-2070) climate, all else held constant, and the results are the basis for conclusions about the hypotheses set out in this research.

3.2.2 When Is Irrigation Worth It?

Even if irrigation investment is not profitable over the entire useful life of an investment, it may still be profitable in specific years. Because there is data on each year, it is useful to know whether a farmer in a particular location finds irrigation profitable in a dry year(s), even if it is not profitable in other years in the current climate. If the incidence of dry years becomes higher in the future, the farmer may be inclined to consider irrigation, even when it is not profitable in all of the years of the system lifetime.

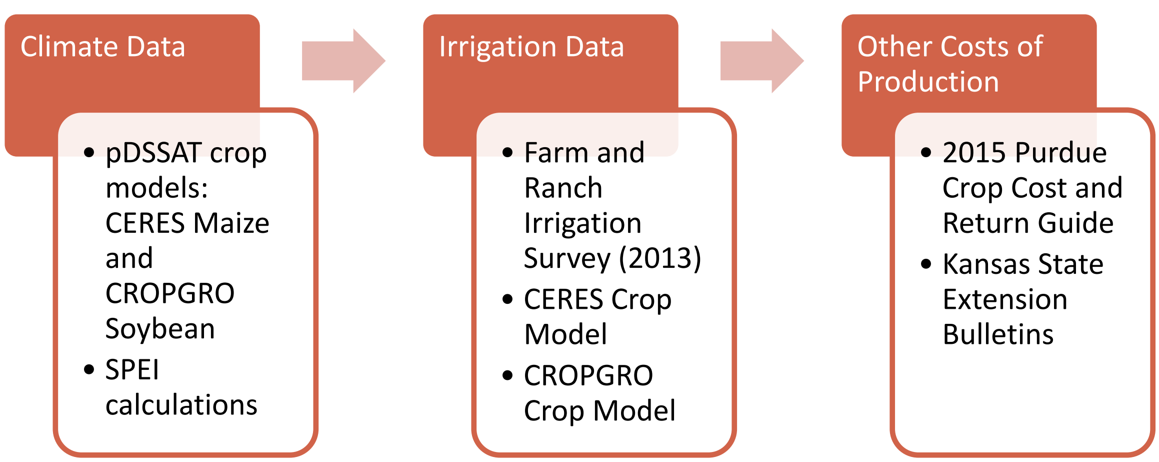

Figure 5. Data Sources for Primary Factors of Irrigation Investment Decision

3.3 Hypothesis-Specific Methods

3.3.1 Hypothesis 1

To test H_1, a baseline set of locations where irrigation investment is profitable in the current climate regime is needed. Location-specific annual SPEI, cost and yields are used to calculate the NPV of an irrigation investment in all of the counties in the Corn Belt located east of the 100th meridian. There is generally a major difference in precipitation and climate across the 100th meridian that is not always captured by the simulation. The unirrigated yields west of the 100th meridian are often much poorer than the results presented in the NASS county yield data. Additionally, corn and soybeans west of the 100th meridian tend to be exclusively irrigated, and so the NPV results do not change significantly over time. The results will be used to develop a map of the counties where it is profitable to irrigate in the contemporary climate (1980-2005). If a county finds it more profitable to irrigate than not, it will be listed as an irrigated county. To check that the classification of counties as being irrigated is correct, we look at the 2012 Census of Agriculture data for acreage of irrigated and unirrigated corn and soybeans at the county-level. If over half of the cultivated acres for corn and soybeans are irrigated, a county is considered to be an irrigating county. The counties deemed as irrigating will be compared to the irrigation profitability calculations, to see how well the irrigation investment calculations agree with the best available data on currently irrigated production.

To determine where irrigation investment is profitable in the projected climate period (2041-2070), we replicate the process followed for the contemporary period using the simulated county crop yields under dryland and irrigated conditions holding all other parameters constant. Again, counties where it is more profitable to irrigate (compared to rain-fed) will be listed as irrigated counties, and the incidence of those counties will be compared to the counties in which it is profitable to irrigate presently. Those counties that go from irrigation being unprofitable in the contemporary climate to profitable at mid-century represent potential expansions of irrigated area in the Corn Belt, providing an estimate of the shift in total area where installation of irrigation equipment is profitable by mid-century. The total area shift will provide evidence to test the first hypothesis.

3.3.2 Hypothesis 2

To examine how water demand in drought years will change, we will use the NPV, with and without irrigation, based on potential irrigation water use information from the crop models. We want to determine the incidence of drought years (compared to average years) in future time periods using the SPEI information. We can calculate the SPEI for each location in the future, using the actual evapotranspiration from the crop models and GCM precipitation. Then we look to see which counties have changed their irrigation "status." In counties that show a change in irrigation water demanded by midcentury, we will estimate the change in water used during years of drought, by looking at the relative crop stress levels between an SPEI-base "normal" future year and a future year of drought. Irrigation adjusts the relative water supply to reduce the expected crop stress. We can compare this shift in demand for irrigation water to the average change in water use by midcentury, to provide an estimate of the relative demand shift in future years of drought.

Drought years will be considered moderately or extremely dry, according to the SPEI bin (from H_1). To make sure that this is an appropriate measure of drought years, it is necessary to run sensitivity analysis on the 6-month (growing season) SPEI values, by comparing the results to other drought indices. Once the drought years are determined, an evaluation of the amount of irrigation water required in years of drought compared to average years will be conducted. In order to determine the irrigation application information, the irrigation quantities from the DSSAT crop models used for corn and soybeans will be sorted by the SPEI bins. The moderately dry and extremely dry years will be compared to the average years to determine quantity differences.

In areas where irrigation investment is profitable in the contemporary period, the change in potential irrigation water demand will be calculated by $\Delta_W = W_1 - W_0$, where W denotes water quantity in the contemporary (subscript 0) and future (subscript 1) time periods.

In areas where irrigation investment is not profitable in the contemporary period and becomes profitable in the mid-century period, the change in potential irrigation demand is equal to the total quantity of irrigation water applied.

CHAPTER 4. RESULTS

This section details the results from the methods outlined in Chapter 3. Details of the Net Present Value for farmers under contemporary and future time periods will be presented first, followed by sensitivity analysis for various prices, crop mixes, and crop responses to CO2 fertilization. The section will conclude with relative water demand changes and scenarios under different weather years.

4.1 Net Present Value

Using the inputs to the irrigation investment tool and methodology described in Chapter 3, the Gross Margins for irrigated and unirrigated crops across the Corn Belt were calculated in R for 908 counties. These results were used in Excel to calculate the Net Present Value and the Internal Rates of Return for each county. The Net Present Value and Internal Rates of Return (before and after tax) for each county can be found in Appendix B. Figures 6 and 7 are maps of the Net Present Value results across the Corn Belt for the contemporary and future time periods, respectively. These estimates are the Net Present Value of a twenty-year investment in an irrigation system for corn and soybean producers across the Corn Belt.

Figure 8 is a map of the differences in Net Present Value from the contemporary to the future period. The crop prices and production costs are evaluated for the 2014-2015 marketing year for both contemporary and future investment, to focus attention on the differences in weather and yield, rather than changes in projected crop prices. The RCP used for the future climate scenario is RCP 8.5, and CO_2 fertilization effects are included in the results.

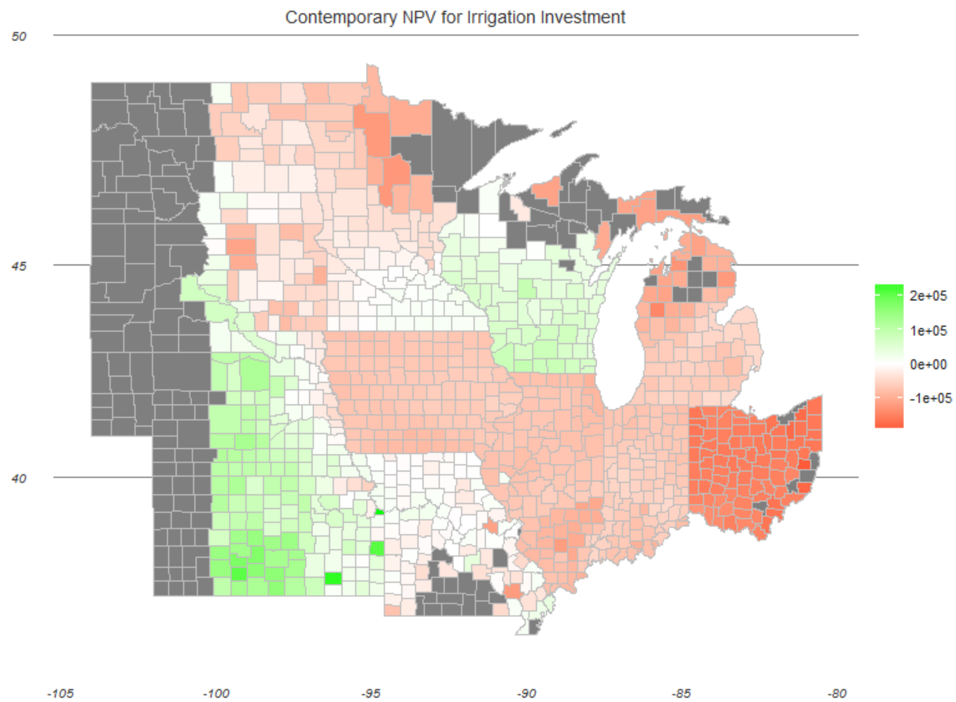

Figure 6. Net Present Value of Irrigation Investment in the Contemporary Period (1980-2005)

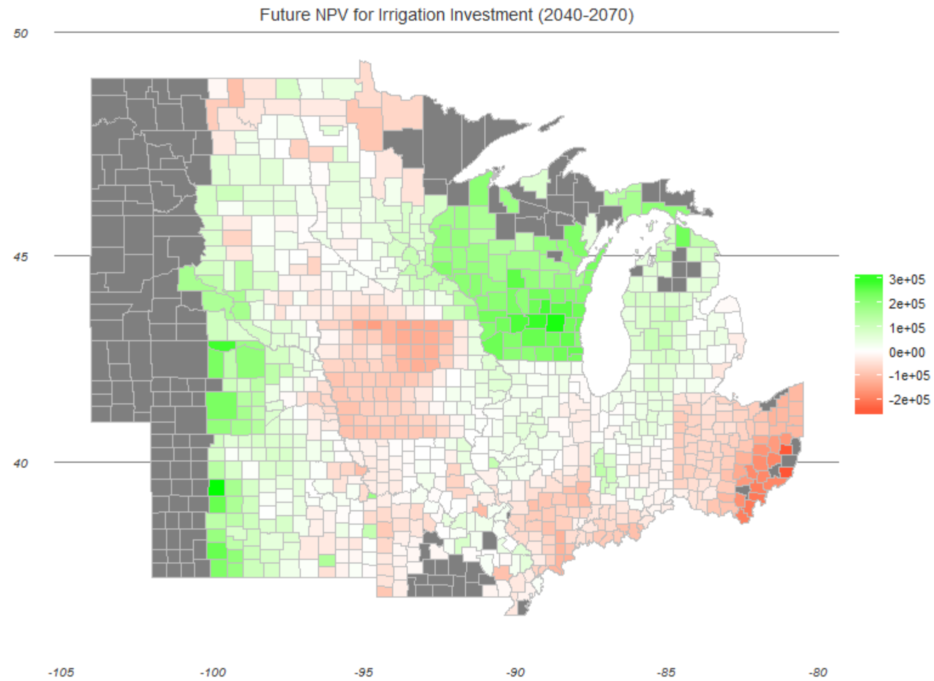

Figure 7. Net Present Value of Irrigation Investment in the Future (2040-2070)

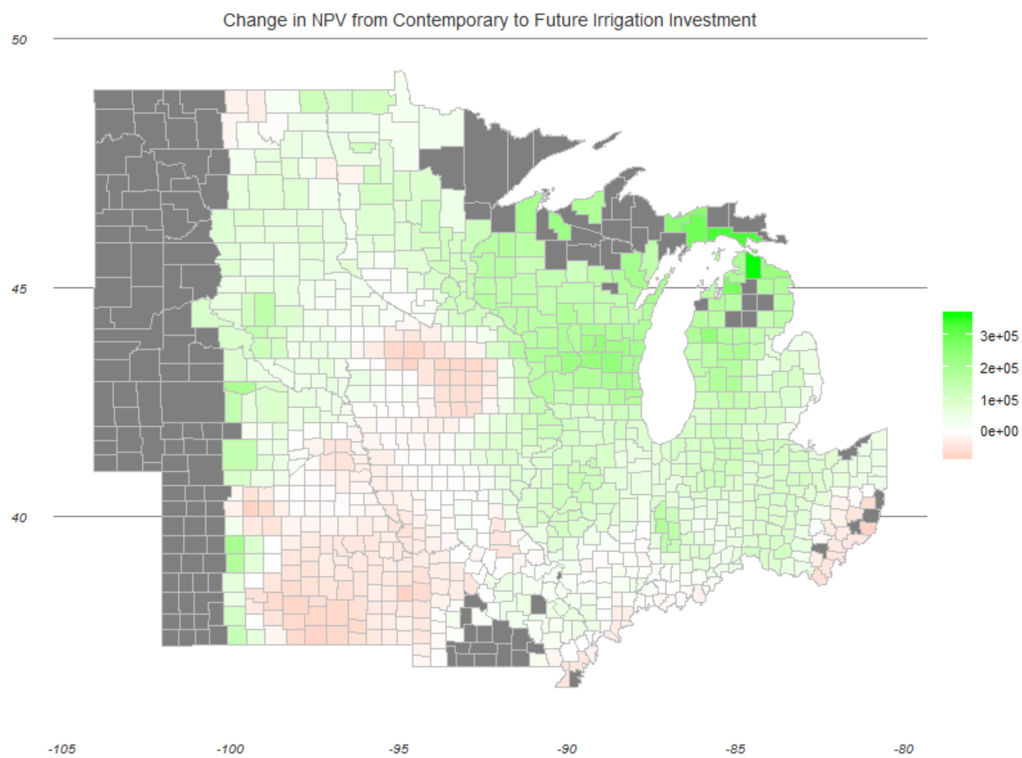

Figure 8. Difference in Net Present Value of Irrigation Investment from the Present to the Future

The calculation of the Internal Rate of Return from irrigation investment can provide additional insight into the choices of producers. Although a positive Net Present Value may indicate that irrigation investment is a wise decision for producers, the rate of return to the investment may be too low to justify the investment. Not only are other investments potentially more profitable, there are other factors not explicitly accounted for in the investment decision that require effort on the part of the producer, such as the time and energy required to install the irrigation system or the process of hiring new laborers. In an effort to capture the realistic investment decision that may be made by a producer in the contemporary and future time periods, Figures 5 and 6 look at counties with an After Tax IRR greater than 6.40% as “irrigating” (denoted by the teal locations), counties with an After Tax IRR less than 2.70% as “not irrigating” (locations in black), and counties with an After Tax IRR in between 2.70% and 6.40% as potential irrigators (locations in yellow-green). This IRR range was chosen to match a Net Present Value range of approximately -$15000 to $15000. Figure 9 illustrates the irrigating counties in the contemporary period. Notably, the western Corn Belt and Wisconsin are deemed to be locations where irrigation is potentially a worthwhile investment.

Figure 11 depicts a significant change in the number of counties where irrigation becomes potentially profitable in the future time period. There is a significant increase in the number of irrigating counties, especially in Illinois, Michigan, and Indiana. There is a decrease in the counties considered to be irrigating in eastern Kansas, and this could be due to several reasons, such as the state-wide value for the water price, the inability to adjust the number of acre-inches of water applied, or a lesser crop response to irrigation.

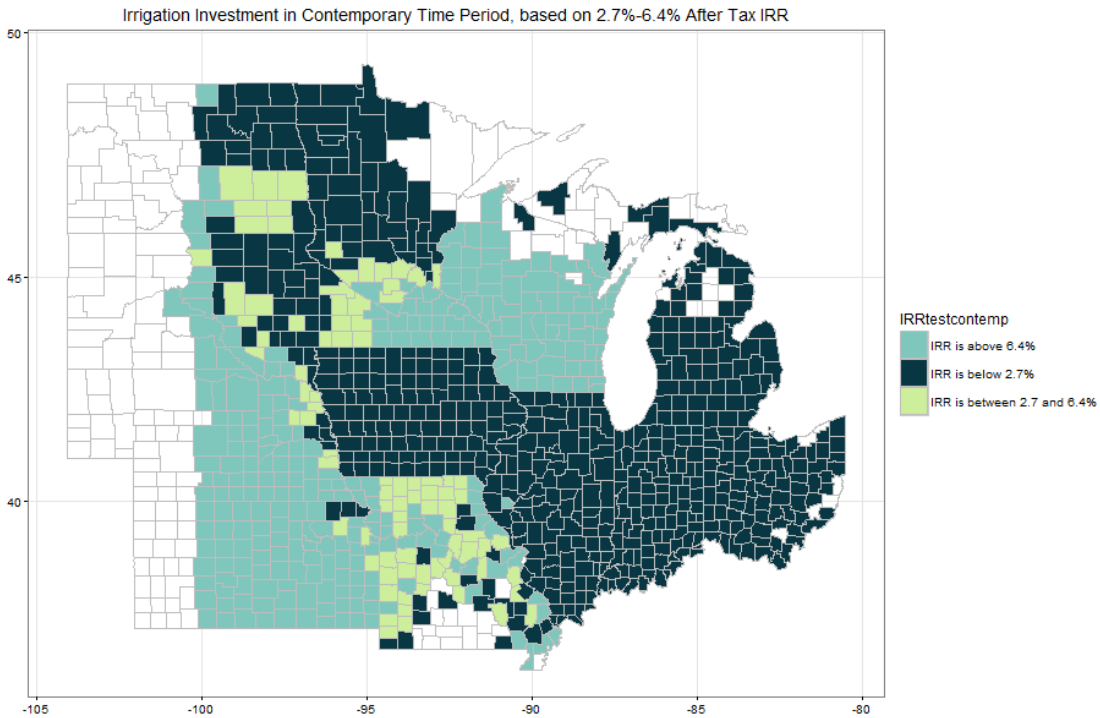

Figure 9. After Tax IRR Thresholds by County in 1980-2005, Between 2.70% and 6.40%

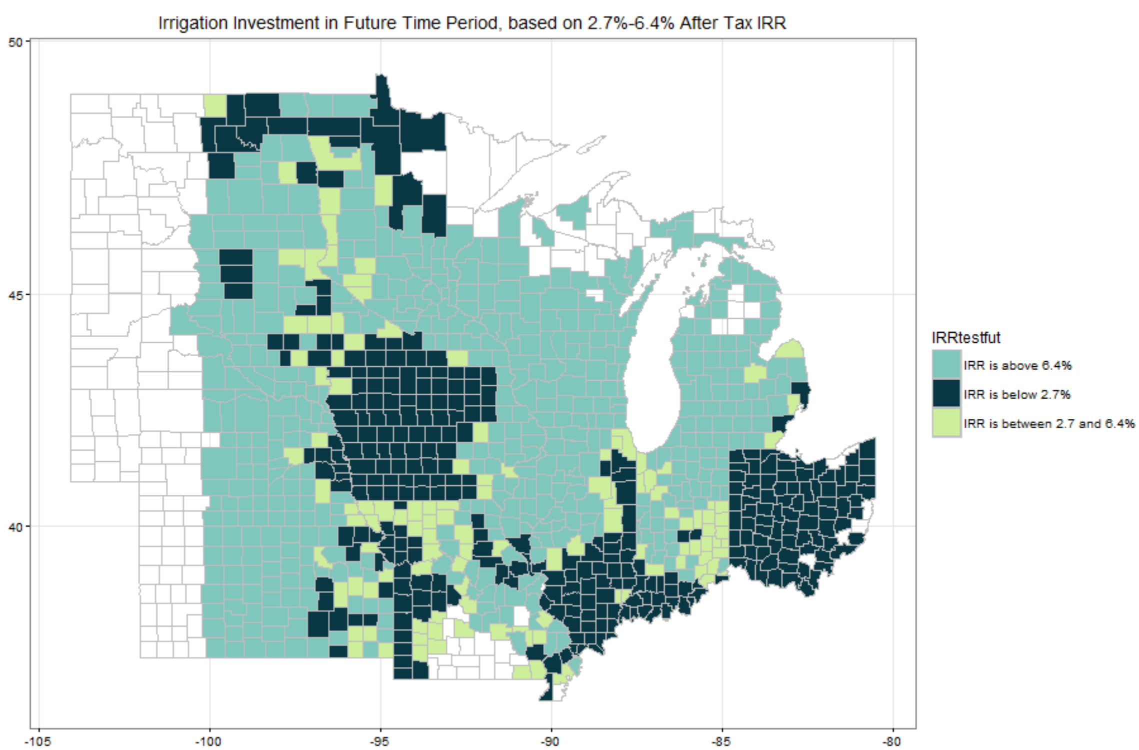

Figure 10. After Tax IRR Thresholds by County in 2040-2070, Between 2.70% and 6.40%

In an effort to validate the preceding results, we turn to the latest version of the Agricultural Census (2012), to see how many acres are currently cultivated under irrigation. The 2012 Census provides county-level information on the number of acres planted by crop, along with the number of those acres that are irrigated.

Figure 11 depicts the aggregate proportion of maize and soybeans that are cultivated under irrigation, on a county level. This is done by taking the sum of irrigated soybean and irrigated corn acres, and dividing this by the total number of acres cultivated in corn and soybeans, as displayed in Equation 27.

$$prop. of\ irr\ corn\ and\ soy = \frac{irr\ \ acres\ corn + irr\ acres\ soy}{total\ acres\ corn + total\ acres\ soy} \tag{26}$$

It is important to note that the number of acres irrigated for corn reflects the irrigated acreage for corn harvested for grain only, rather than for grain and seed. This provides a more accurate basis for comparison to the study conducted here, which is based on prices for corn for grain. Had prices been adjusted to reflect corn grown for seed, the number of counties in which irrigation would be deemed profitable would increase under this study.

There is general consensus between the Agricultural Census, the NPV map and the IRR map to which counties are irrigating in the contemporary climate. There are a few differences. For example, the Agricultural Census does not indicate the same level of irrigation in Missouri that the simulation does, except in southern Missouri. Additionally, this study does not show the western border of Minnesota to be irrigating, but assuming actual investment has occurred where it is profitable, the Agricultural Census suggests that there is profitability in that region. There is a great deal of consistency, however, across Nebraska and Kansas, the northern edge of Indiana, and the southern part of Missouri.

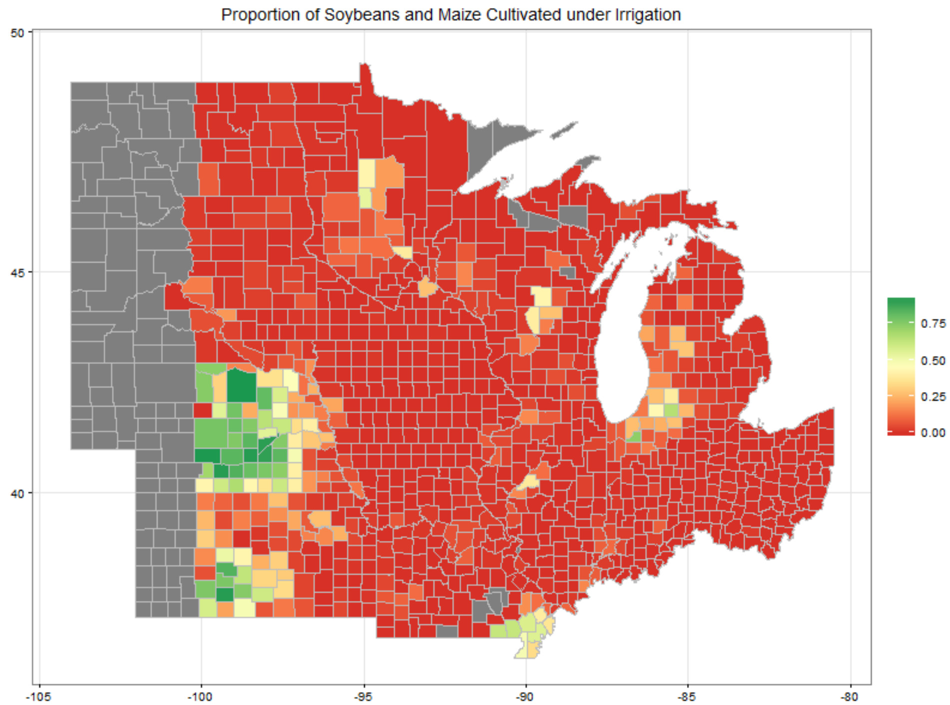

Figure 11. Proportion of Soybeans and Maize Cultivated under Irrigation: 2012 USDA Agricultural Census

In the contemporary period, the Net Present Value results behave as expected. There are clear differences across the Corn Belt, corresponding to locations where irrigation investment may or may not be profitable. In general, moving from west to east, irrigation becomes less profitable. However, in eastern locations where there is a significant amount of sandy soil, irrigation investment becomes more profitable. In states that are historically known as being irrigators, there is a significant amount of irrigation taking place, such as Kansas, Nebraska, South Dakota, and North Dakota.

Additionally, there is a significant amount of variability, even within the states classified as irrigators. In Kansas, for example, there is a significant shift in irrigation profitability moving from the west to the east side of the state. This shift occurs in both the simulated data and in the Agricultural Census data (see Figures 2 and 7). This indicates that, even with the state-wide values obtained for many of the variable costs of production, the estimations of yield and water applications drive the calculation of the investment decision in a direction that matches the observed trends in irrigation currently.

When examining the simulated Net Present Value of irrigation investment in a location like Missouri, there appear to be some discrepancies between the simulated results and the actual acreage planted across the state. In general, the irrigation investment tool indicates that there are more locations where irrigation is potentially profitable today than where irrigation is actually occurring. Part of this can be ascribed to the assumptions that are made during the study. However, just because a location has a positive Net Present Value of irrigation investment does not mean that a farmer is necessarily going to become an irrigator in that area. Due to the size of an irrigation system, along with the costs and risks associated with the installation and usage of such as system, it is important to remember that the NPV has to reach a certain threshold before a producer is willing to take on that risk. Additionally, in many locations across the Corn Belt, there is the opportunity to produce other crops (with or without irrigation) that may be more profitable than producing irrigated corn and soybeans. Thus, the derived set of potential irrigators in the contemporary period aligns well with both the data available on irrigation in the Corn Belt, and the overall expectation of investment in this area.

The other location where there are differences between the NPV results and the Agricultural Census data is in Wisconsin. This is likely due to the bias-correction process for the irrigated soybean yields. Since Wisconsin does not currently irrigate a lot of soybeans, the FRIS reports that the increase in yield between unirrigated and irrigated soybeans is higher in Wisconsin than in any other location in the Corn Belt. After the bias-correction process, the adjusted simulated yield for irrigated soybean data in Wisconsin is likely somewhat higher than what is representative across the region, and the results should be evaluated more closely.

The Net Present Value estimations for a future crop rotation of corn and soybeans are also representative of what is expected under future weather conditions. There is an increase in the expected net benefits from irrigation across the eastern Corn Belt. Notably, irrigation is still not considered profitable across Iowa, Ohio, much of Minnesota, and the northernmost locations in the region. The potential expansion of irrigation could be due to several different factors. Part of this may be due to increased precipitation variability, which has varying effects on yields in dry and wet years. Notably, the predicted increase in precipitation variability leads to a substantial decrease in yields in future dry years. The addition of irrigation water in these years can stabilize producer yields and profits. In wet years, the yield response to the additional water is not as great as the decrease in yields due to lack of water in drier years. This is important because it indicates that the increased variability in precipitation does not necessarily lead to the same mean yield. Providing irrigation water in these circumstances can lead to benefits for producers great enough to become profitable in the projected climate despite not currently being a profitable investment.

Irrigation is expected to remain an unprofitable investment in some of the wettest locations across the Corn Belt, such as eastern Ohio and in Minnesota. In other locations, such as Iowa, where some of the most fertile soils are located, irrigation is not expected to become profitable in mid-century. In many locations, the soil texture allows for better

Plant Available Water (PAW), and irrigation may not be as necessary, compared to sandy soils, even with a potential increase in extreme weather events. Figure 8 depicts locations that show a transition from a negative NPV to a positive NPV when moving from the contemporary period to the future. The locations in green show the counties that are considered to be new irrigators (not profitable in the contemporary period). To be cautious, it is important to note that this distinction is made based solely on a positive NPV. The returns to the investment may still be too low for many producers in the region to make the decision to invest in irrigation technology, but the required rate of return varies by individual farm operation.

Figure 13 shows the locations across the Corn Belt where irrigation is no longer expected to be profitable based on simulated yields. There are not many counties that fall into this category, though there are many more that become less profitable irrigators by mid-century than they are today (see Figure 4). The counties that do fall into this category raise a few questions. Primarily, this shows the limitations of this analysis in a couple of different ways. First, most of the locations where irrigation is no longer considered to be profitable are located in eastern Nebraska and Kansas, along with a couple of locations in southern Minnesota. In practice, the western parts of KS and NE experience water prices that are higher than the most eastern locations, due to water scarcity and need. However, there is spatial variation in the cost of pumping that the state-wide data from FRIS does not capture. Where water is scarcer in the western Corn Belt, the cost of pumping and/or acquiring water are likely higher than more eastern locations that are traditionally water abundant. This could potentially lead to an underestimation of water costs in the western parts of Kansas and Nebraska, and an overestimation of water costs in the east.

A second issue that could potentially arise in the analysis is the lack of a behavioral component for irrigation water applications. The crop model automatically applies irrigation water when the soil moisture reaches 80% of the capacity of the profile, which is considered to be 40 cm deep. Water is then added until 100% of the soil moisture capacity is reached, assuming 75% efficiency. While the water application quantities, when compared with the Farm and Ranch Irrigation Survey values are reasonable, there may be reasons in this location why the yield response to that irrigation water may be different than in other locations. Producers may choose to add more or less water to their fields, due to the choice of a different soil moisture thresholds, an adherence to traditional application quantities, or a lack of water availability, among other choices. These changes in water application strategies are unable to be evaluated within this study. Finally, these may have been locations where the Net Present Value of installing irrigation equipment was marginal at best, and the difference between future NPV and contemporary NPV is not particularly significant (see Figure 8).

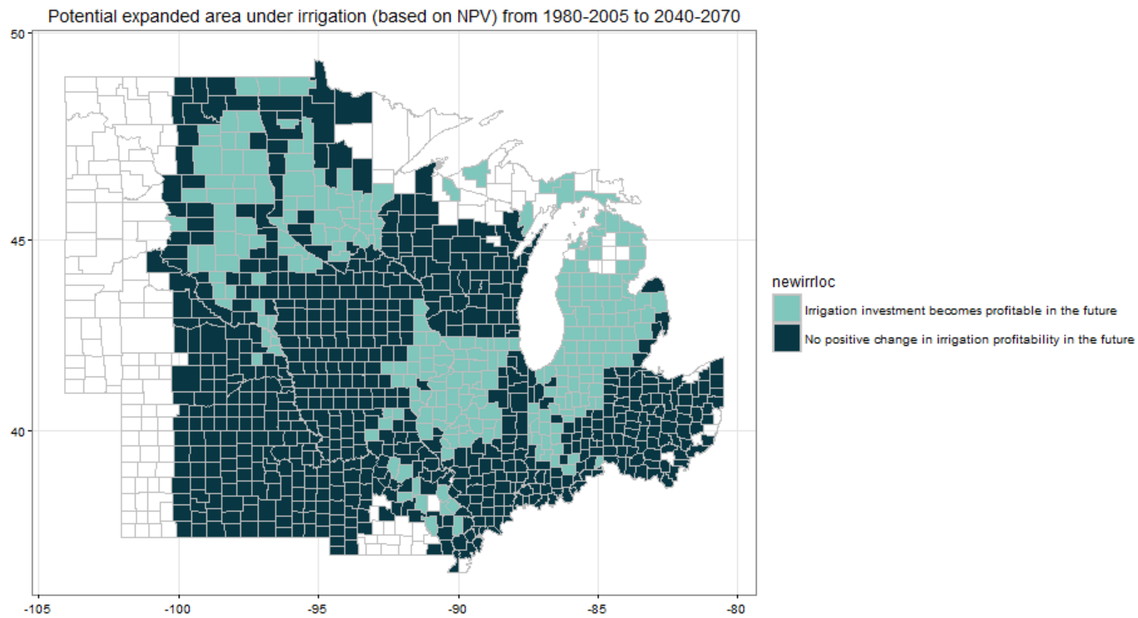

Figure 12. Newly Profitable Locations, under Future Climate Conditions, Based on NPV > 0

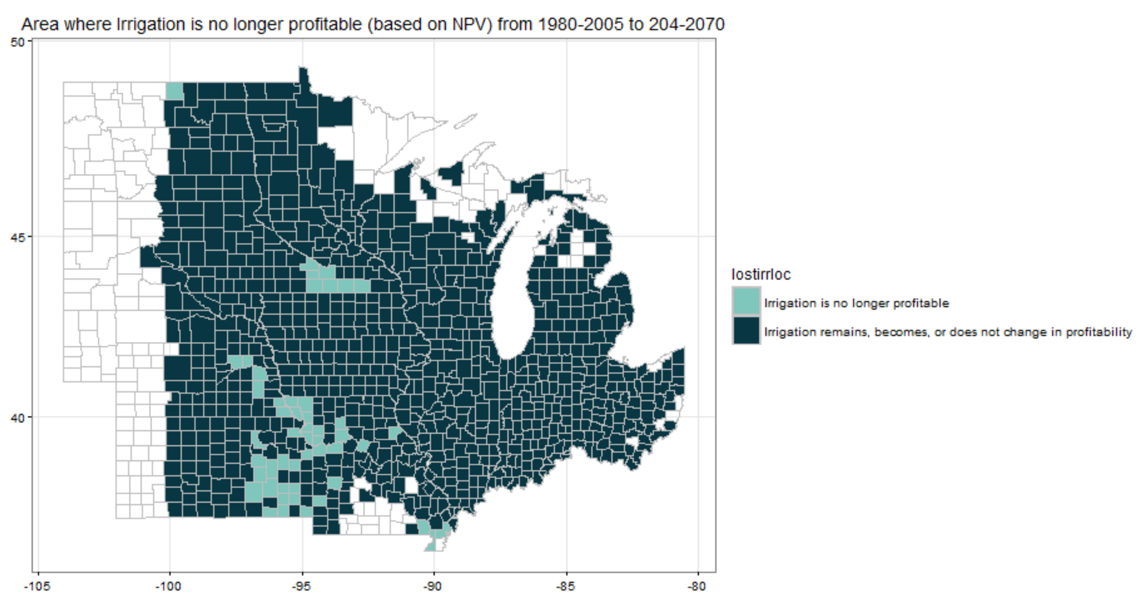

Figure 13. Locations Where Irrigation is no Longer Profitable, under Future Climate Conditions, NPV < 0

Another important consideration to make in the calculation of the Net Present Values is the impact that crop prices have on the value of the investment. All calculations that are shown here reflect market prices from the 2015/2016 growing season. However, these prices have varied significantly over time. To show how the profitability of investment may change under different prices, the Net Present Value is calculated for several different crop prices, as outlined in Table 2. The prices obtained are from the monthly "USDA Long-Term Projections" publication by the Economic Research Service.

Table 5. Crop Prices for Corn and Soybeans used in Various Net Present Value Estimations.

Price of corn for grain, dollars/bu	Price of soybeans, dollars/bu	Marketing Year	Source
$3.65	$8.90	2015/2016	USDA Long-Term Projections (Feb 2016)
$4.45	$13.00	2013/2014	Interagency Agricultural Projections Projections (Feb 2015)
$4.16	$9.87	2004-2014 (Decadal Average)	NASS Quick Stats
$3.75	$9.35	2025 (Projected)	USDA Long-Term Projections (Feb 2016)

Figures 14 and 15 show the NPV for the contemporary and future time periods under 2013/2014 crop prices (higher than 2015/16), indicating that an investment in irrigation would be more profitable under the higher output prices. Figures 16 and 17 illustrate the NPVs under the average of the crop prices for the decade of 2004-2014, and Figures 18 and 19 show the NPVs under the projected 2025 crop prices. All of the crop prices in the alternate scenarios are higher than the prices used in the primary calculations (based on the 2015/2016 marketing prices). Therefore, in general, irrigation is considered to be profitable in at least as many geographical areas as is demonstrated throughout the rest of the study given the simulated yield response to irrigation and climate. This is important to note, especially as crop prices change over the uncertain future. There is the potential for crop prices to increase based on less stable crop production, or decrease if corn and soybeans are produced in areas that are previously not considered prime locations for the crops. All of these factors have a significant impact on the decision to install irrigation equipment, especially if a long-term shift in crop prices occurs, influencing the profitability and the risk associated with the investment decision. This study does not estimate what the potential crop price shifts may be, but Figures 14-19 provide a range of pricing scenarios intended to indicate a reasonable range of corn and soybean prices in the next few decades, barring major shifts in demand or supply of these commodities.

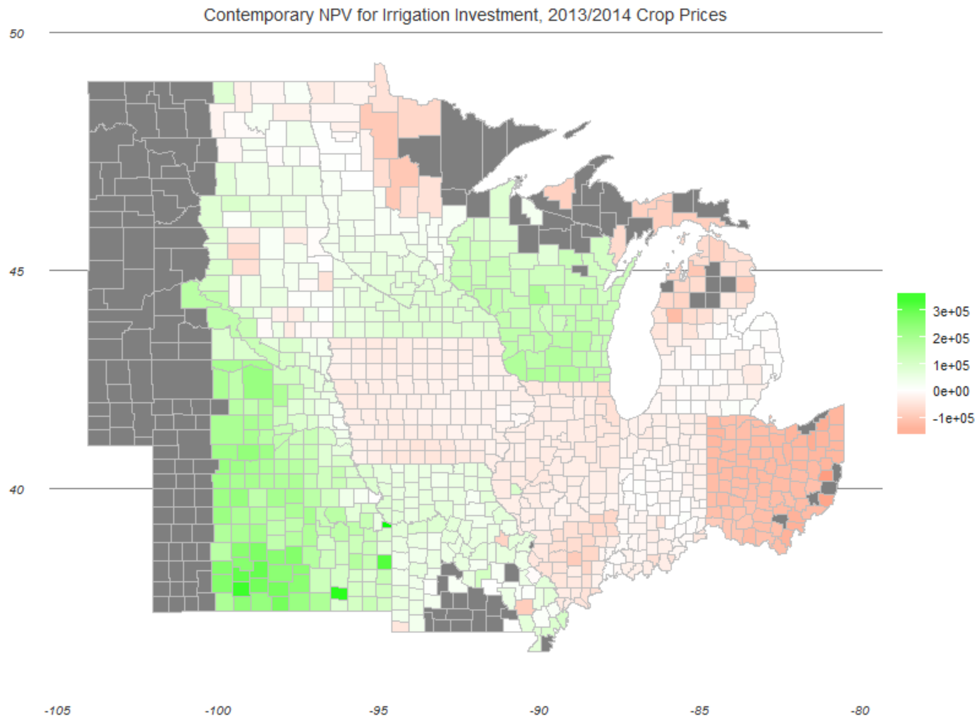

Figure 14. Contemporary NPV for Irrigation Investment, under 2013/2014 Crop Prices

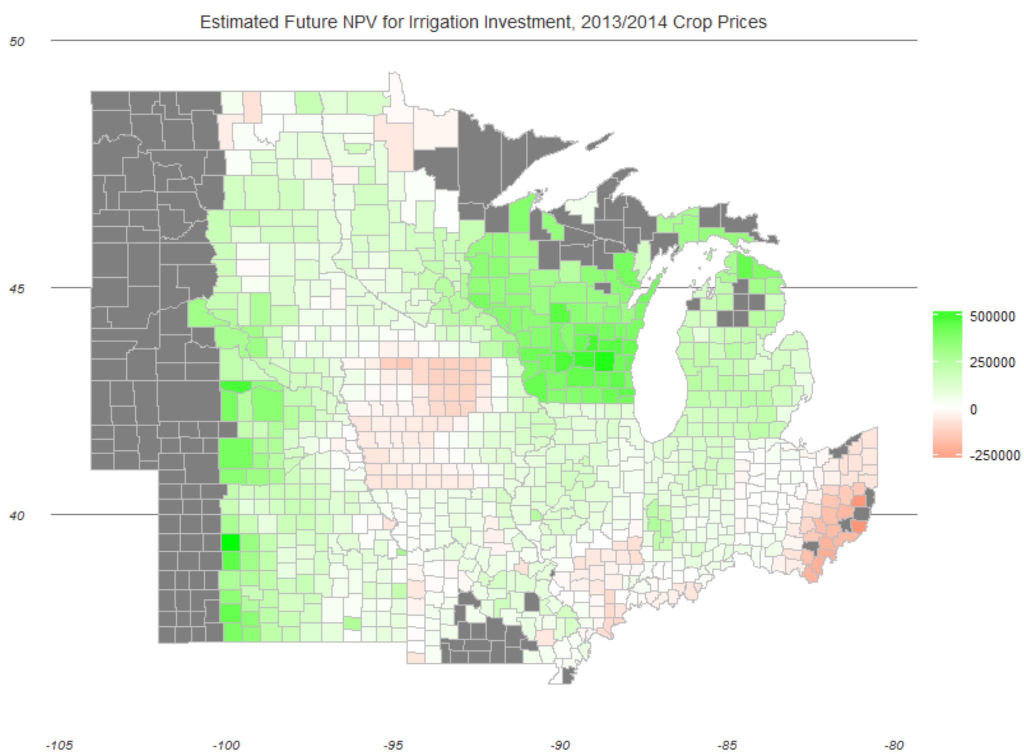

Figure 15. Future NPV for Irrigation Investment, under 2013/2014 Crop Prices

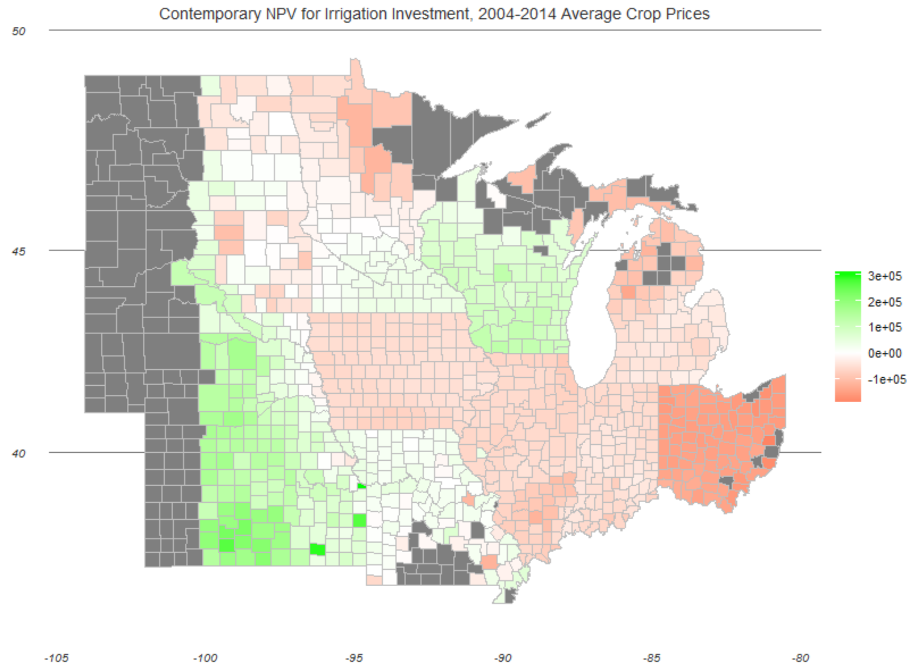

Figure 16. Contemporary NPV for Irrigation Investment, under 2004-2014 Decadal Mean Crop Prices

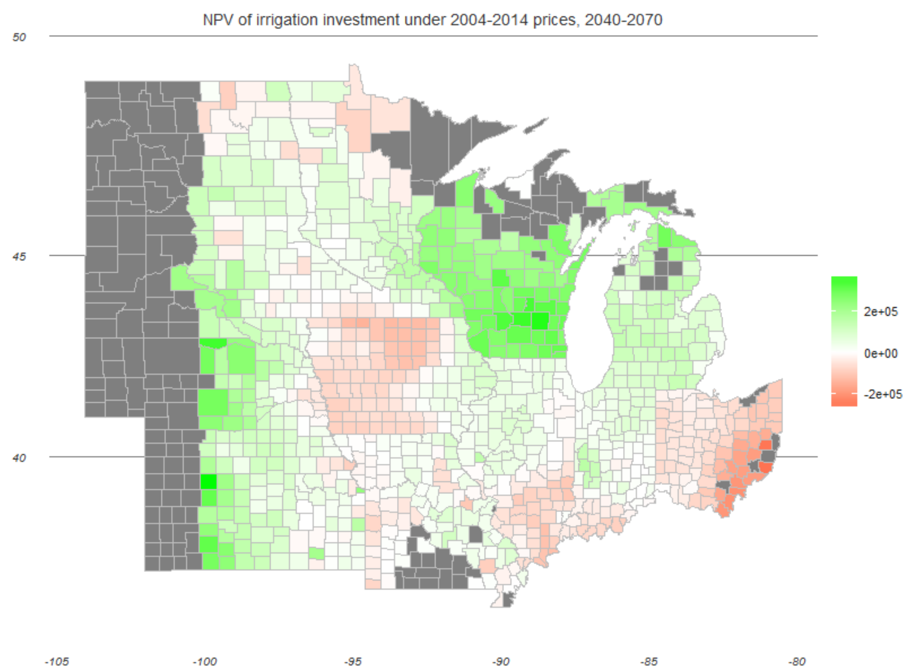

Figure 17. Future NPV for Irrigation Investment, under 2004-2014 Decadal Mean Crop Prices

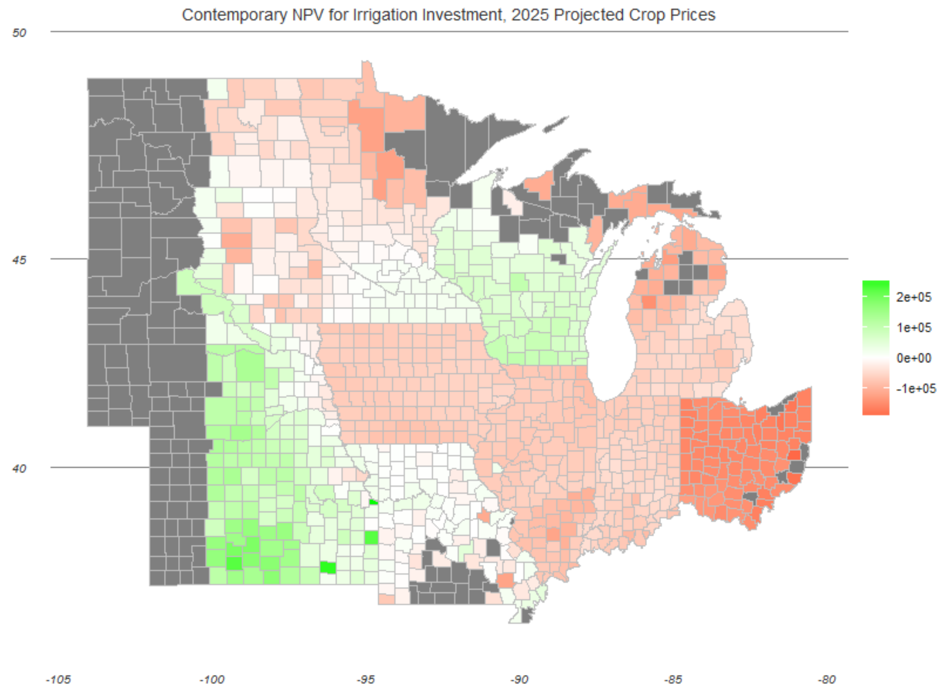

Figure 18. Contemporary NPV for Irrigation Investment, under 2025 Projected Crop Prices

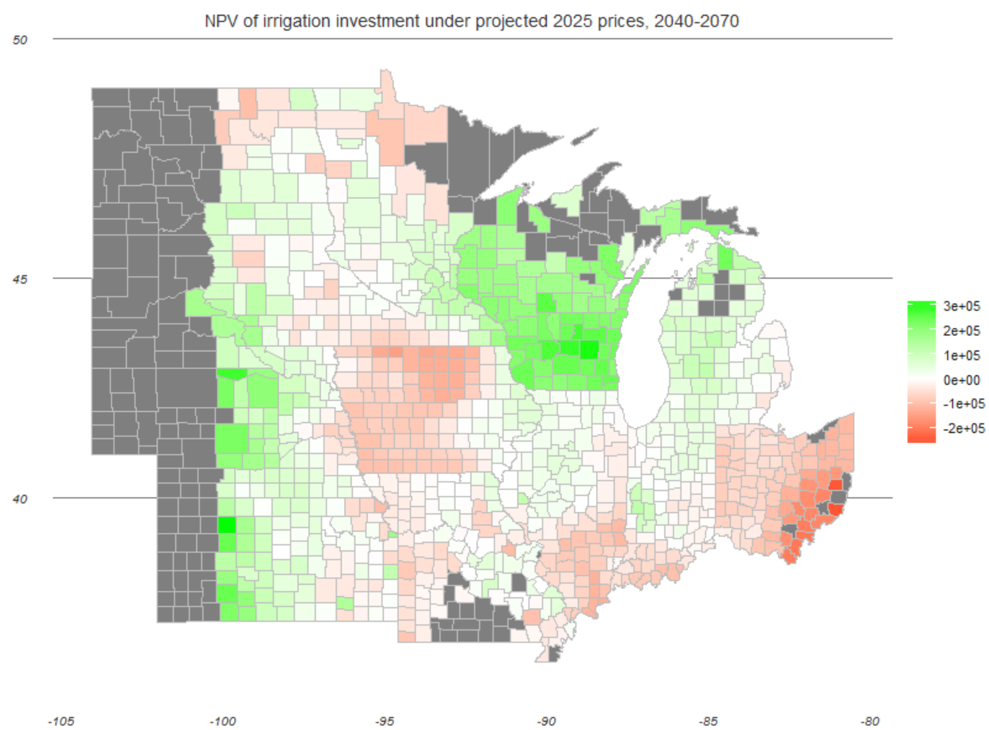

Figure 19. Future NPV for Irrigation Investment, under 2025 Projected Crop Prices

Another factor that influences the calculation of the Net Present Value is to look specifically at the rotational share of each individual crop, or of just planting corn or soybeans alone. The responses of the two crops to the future climate and weather variability are significant.

The Net Present Value maps of contemporary and future irrigation investment for a producer that exclusively plants corn are shown in Figures 16 and 17. These figures show several key relationships that are occurring with corn production. First, there is a significant decrease in irrigation investment profitability under future conditions (see below also). This is likely due to the fact that corn is a C4 plant. The effects of climate change on C4 crop yields tend to be negative. There are some locations, in northern areas, where corn responds better to an increase in temperatures, but in the hotter and drier locations, such as in Kansas and Nebraska, corn does not see any advantages from the increase in temperatures. Additionally, the benefits of CO_2 fertilization that occur in C3 crops (soybeans), such as increased soil moisture, and advantages in transpiration of plants do not occur in corn. This makes corn a less profitable crop across the board, whether irrigated or not.

Figures 22 and 23 show the annual gross margins of corn for a dryland farmer. This is different than the other figures, because it strictly takes into account the costs of dryland farming, along with the resulting yields and prices. No irrigation investment is considered, and therefore no NPV of the investment is calculated. The results are shown in dollars per acre. This is used to identify how the profitability of producing corn is diminished across the region under future climate conditions. Irrigation may provide benefits in some of these areas, but not enough for farmers to find the investment to be profitable over the lifetime of the system.

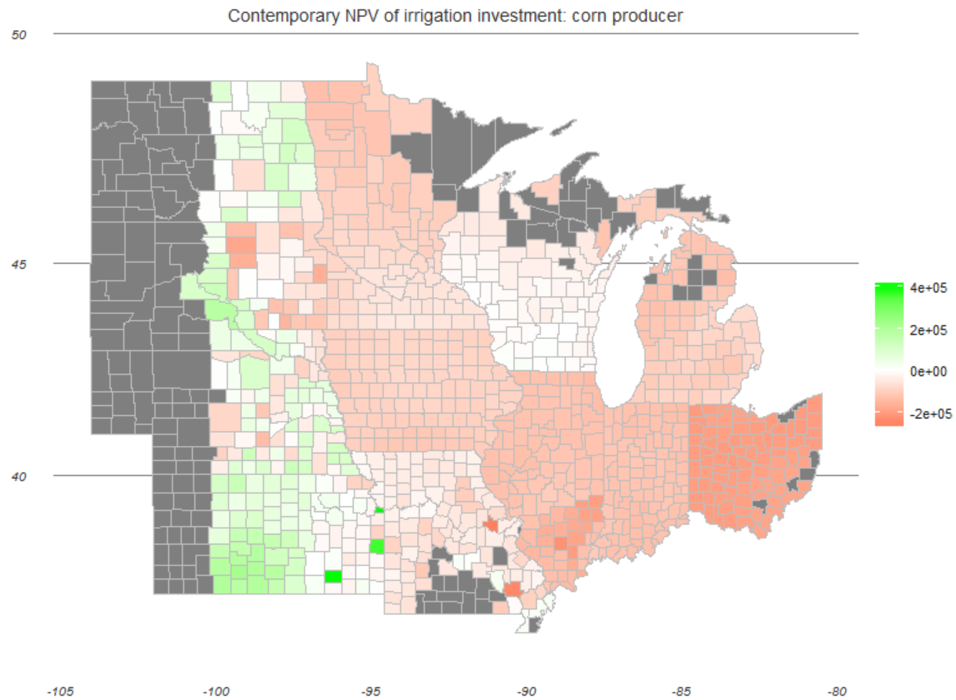

Figure 20. Contemporary NPV for Corn Production

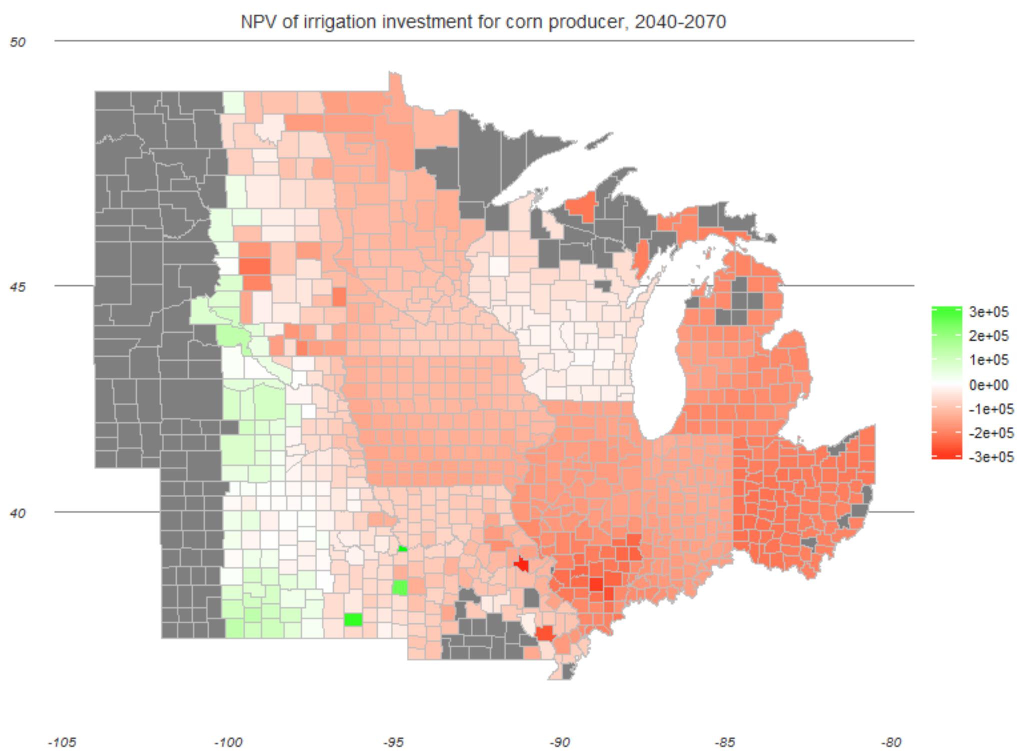

Figure 21. Future NPV for Corn Production

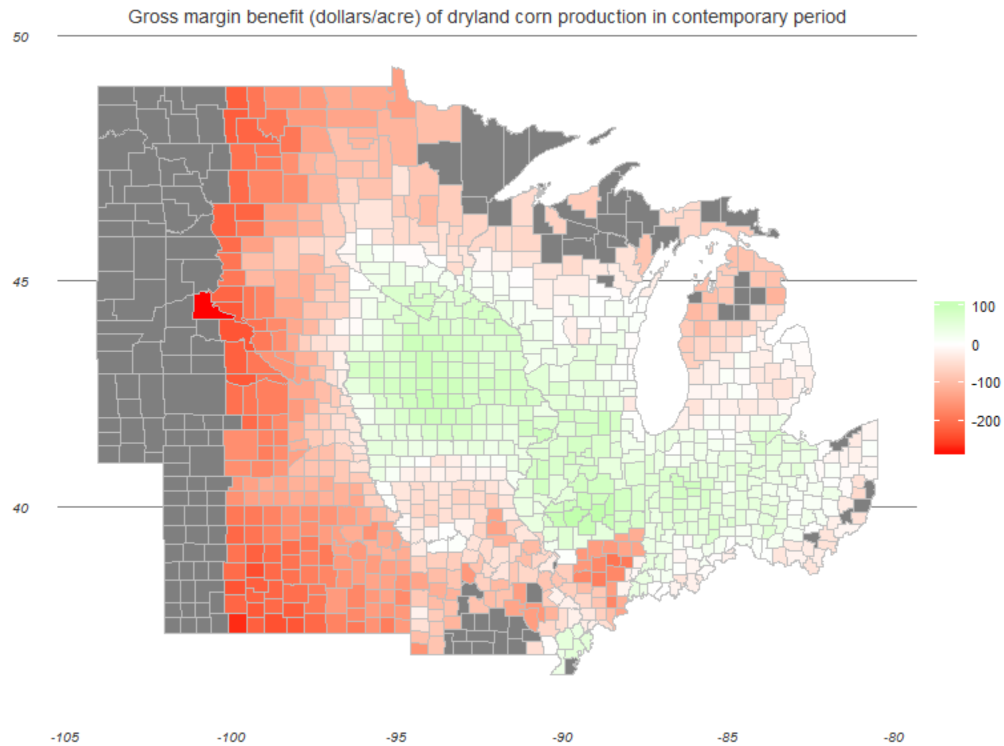

Figure 22. Annual Gross Margins (Dollars per Acre) for a Contemporary Dryland Corn Producer

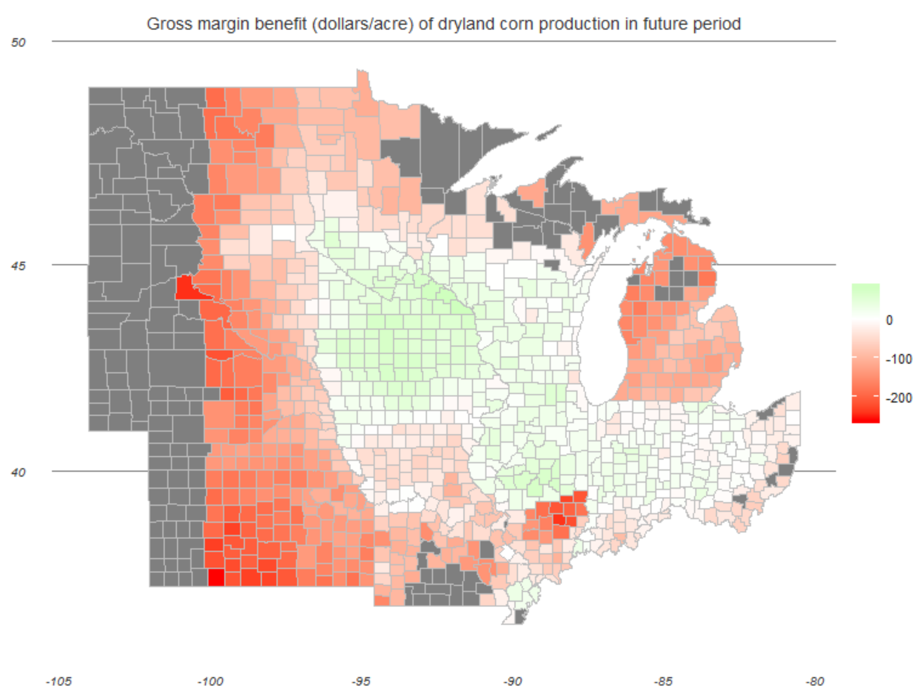

Figure 23. Annual Gross Margins for a Future Dryland Corn Producer

For soybeans, the irrigation investment decision is a bit different. There is a significant difference in the profitability of irrigation investment for soybeans based on simulated yields, especially with respect to future weather scenarios. The locations where irrigation is profitable for corn tend to also be profitable for soybeans, which is an expected result of this study. However, in the future time period, irrigating soybeans tends toward being a wise investment choice over a large extent of the study area. The crop response to irrigation in soybeans is significantly higher than that of corn in the pDSSAT model, and therefore the increase in potentially irrigated acres in the future is driven by the profitability of irrigated soybeans, even when considering a crop mix of 50% corn, 50% soybeans. The Net Present Value of irrigation investment for soybeans in the contemporary and future periods are found in Figures 24 and 25, respectively.

There are several potential reasons for this response. First, this study takes into consideration CO_2 fertilization, which has a much larger impact on soybeans (C3 plant) than on corn (C4 plant). The benefits of CO_2 fertilization include reduced transpiration rates, conservation of soil water, and the ability to grow more quickly. The interaction of the continuous water availability (non-limiting factor) through irrigation and the increased atmospheric CO_2 lead to significantly higher yields in the future compared to the present. There are other physiological differences between corn and soybeans that can lead to different yield responses to climate change. Higher temperatures have tendency to impact corn more severely than soybeans, and, once the temperature reaches high enough levels, the corn plant closes its stomata and stops growing. Additional irrigation water during this time is not beneficial for plant growth. In contrast, soybeans do not stop growing under higher temperatures, and irrigation water can mitigate the effects of hot weather.

The differences in crop response to climate change depend on CO2 fertilization, precipitation, and temperature. Corn is negatively affected by higher temperatures, minimally affected by CO_2 fertilization, and positively affected by precipitation. Soybeans are minimally affected by higher temperatures, positively affected by CO_2 fertilization, and positively affected by precipitation. These relationships can be seen through the following equations:

$$\Delta\, corn\ yield = f(temp\ (-), CO_2\ fertilization\ (0), precipitation\ (+)) \qquad (27)$$

$$\Delta\, corn\ yield = f(temp\ (0), CO_2\ fertilization\ (+), precipitation\ (+)) \qquad (28)$$

In the projections for the Corn Belt, corn and soybeans will experience significantly higher temperatures and levels of CO_2, along with small positive or negative changes in precipitation. This indicates that corn is likely to suffer under climate change, while soybeans have the potential to increase in yield. The crop-specific results for the NPV care in line with these expectations.

Additionally, there are systematic differences in the way that corn and soybeans respond to future climate scenarios by model design. Although the weather timing and irrigation triggers are the same for the two crops, there are two different crop models used—CERES for corn and CROPGRO for soybeans— because the two different crops respond differently to weather and have different growth processes. There is, however, also the potential for an unknown bias to favor soybean production. Although there is a strong indication that soybeans will flourish compared to corn in future simulation data, it is wise to remain cautious before making any claims that only soybeans will be produced in the region in the future. Thus, most of the remainder of this study continues to look at a crop mix of corn and soybeans, and considers each crop individually when there are key differences in water use or profitability.

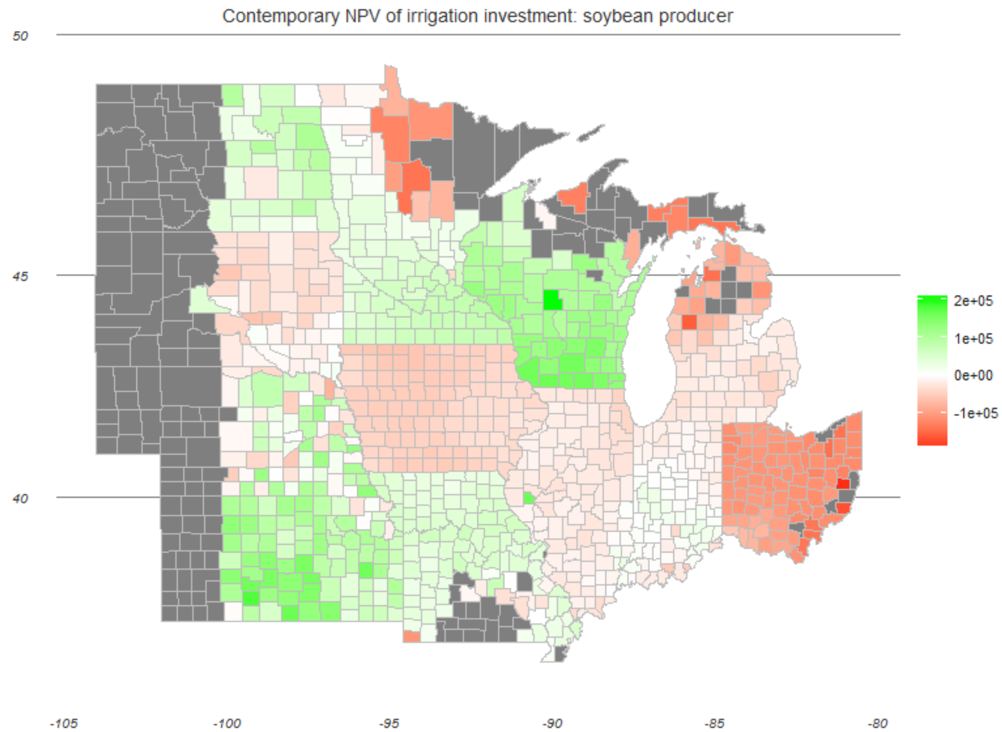

Figure 24. Contemporary NPV of Irrigation Investment Decision for Soybean Production

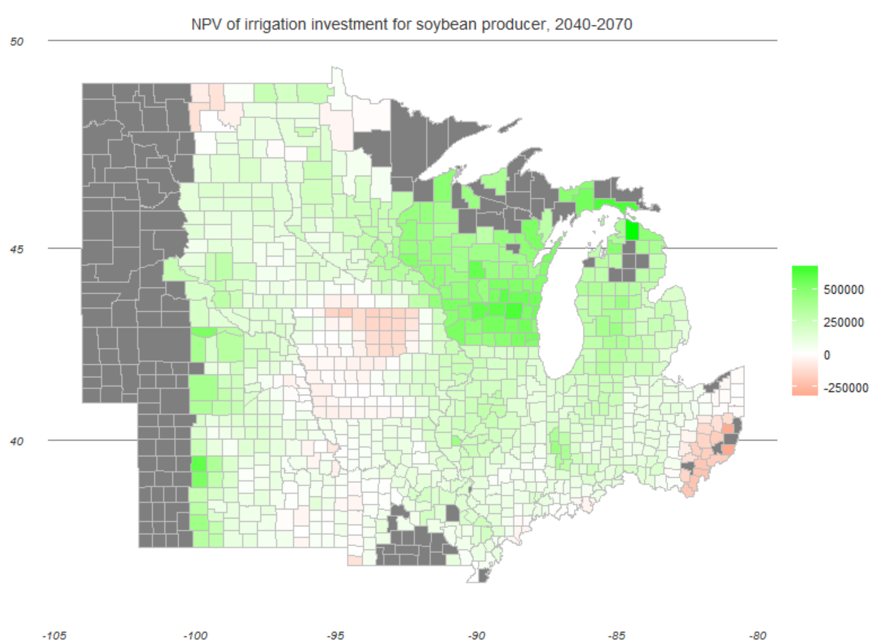

Figure 25. Future NPV of Irrigation Investment Decision for Soybean Production

The influence that CO_2 fertilization has on the results of the crop model is significant. The literature is consistent in recognizing the fact that CO_2 fertilization will occur, and will have major impacts on crop production. However, there is still uncertainty with respect to the size of the impact CO_2 fertilization will have on crop production in the future. To account for this, this study evaluates a range of potential CO_2 fertilization effects. While all previous figures consider the CO_2 fertilization effects to be exactly as modeled by pDSSAT, Figures 26, 27, and 28 show the estimated future Net Present Value for irrigation calculated based on an 80% crop yield response, a 60% crop response, and a 50% crop response, respectively, as a percentage of the soybean yield increase simulated by pDSSAT. Since yields are lower in both of the scenarios, and all crop production costs that are not directly influenced by yield remain constant, the NPV for the 80%, 60% and 50% yield response scenarios are lower than the previously presented results (100% yield response). This range of fertilization effects was chosen as a robustness test for the results.

Even when considering these additional scenarios, the results indicate that future irrigation investment is likely to be profitable across a large portion of the Corn Belt. Even if pDSSAT overestimates future yields under CO_2 fertilization, there are still many newly profitable irrigation areas across the region. Along with the varying crop prices, these scenarios serve as a sensitivity analysis to check the robustness of the study findings, and indicate that there is the potential for major shifts in irrigation investment across the Corn Belt by midcentury.

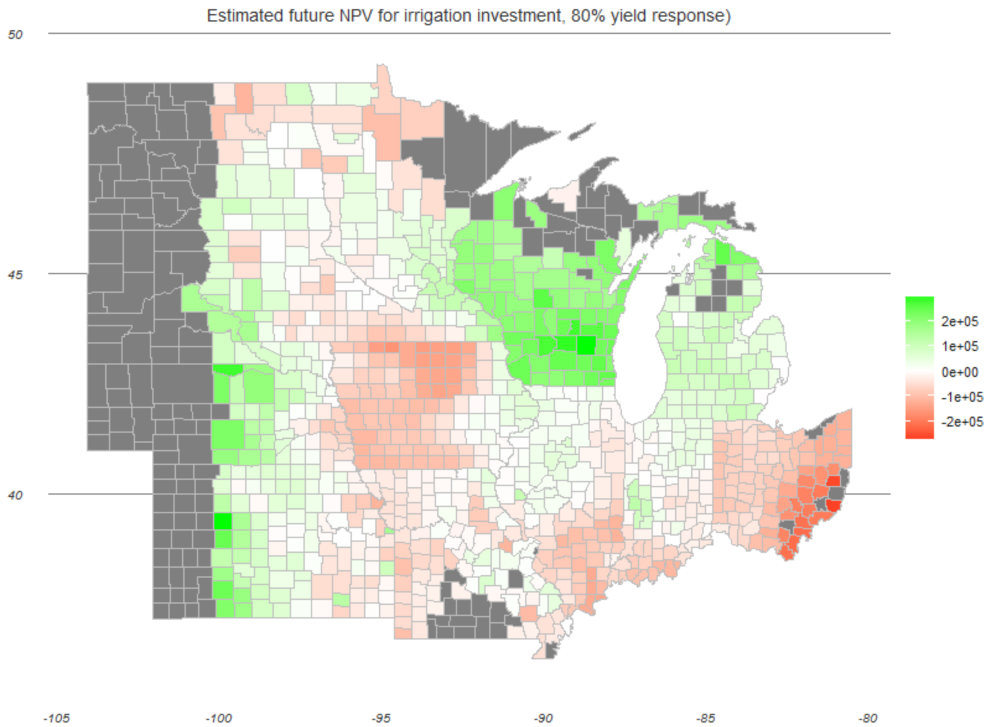

Figure 26. NPV of Future Irrigation Investment for 80% Yield Response

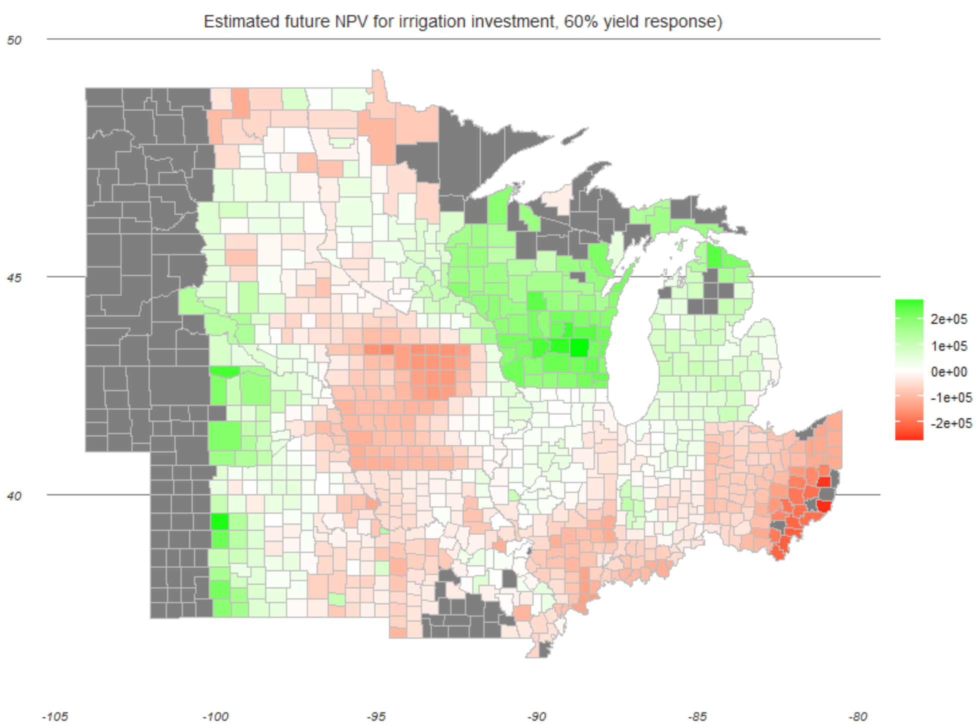

Figure 27. NPV of Future Irrigation Investment for 60% Yield Response

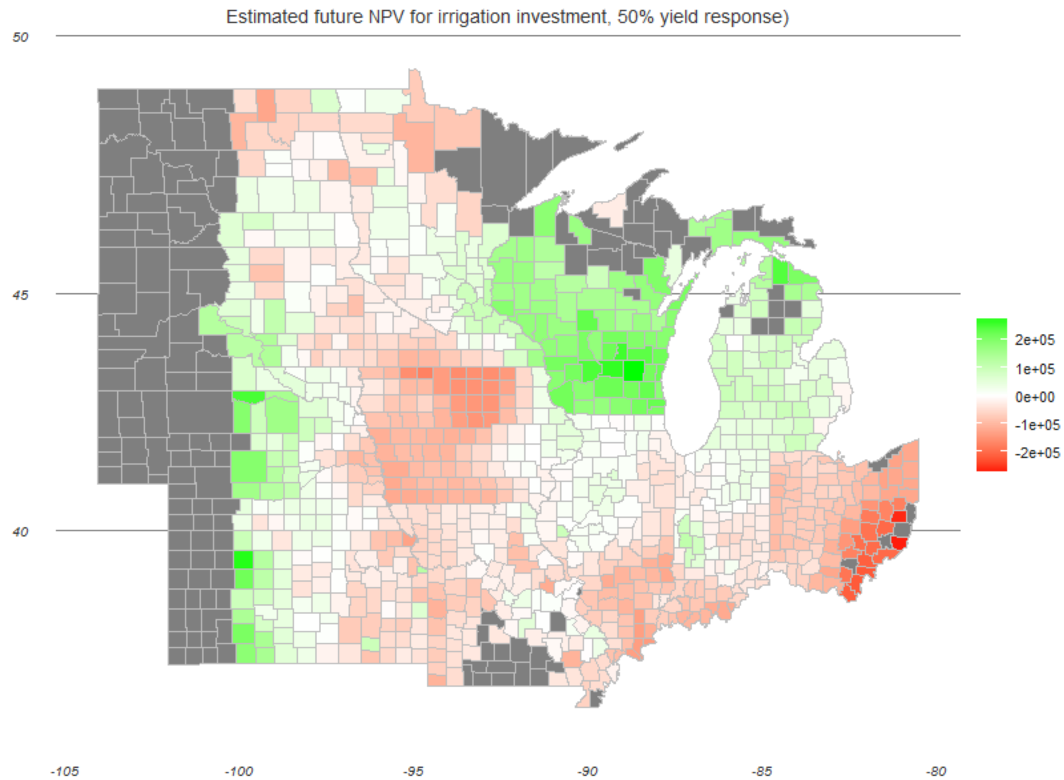

Figure 28. NPV of Future Irrigation Investment for 50% Yield Response

4.2 Irrigation Water Application

This section highlights the quantities of water applied by a representative farmer in each county. The data come directly from the pDSSAT simulations, assuming that the irrigation system is 75% efficient, and is triggered when the soil moisture content reaches 80%. The average annual application of water by irrigators in each of the counties, assuming a crop mix of 50% corn and 50% soybeans under contemporary weather conditions, can be found in Figure 24. Figure 25 displays the same water quantity information for the future period, and Figure 26 plots the difference in irrigation water applied between the contemporary and future time periods. As can be seen in the figures below, on average, more irrigation water is applied in the future time periods, with only a few locations needing to irrigate less. This indicates that the increase in precipitation variability leads to an increase in periods that are dry enough to trigger irrigation events, which are driven by plant growth and weather.

Areas where irrigation quantities do not experience an increase tend to map to locations that are not profitable for irrigation investment in the future. For example, in eastern Minnesota and Iowa, the irrigation quantities are relatively lower than in other locations across the Corn Belt. Additionally, the amount of water applied between the contemporary and future time periods tends to decrease. The benefits received by irrigation are likely lower than in other locations. This maps directly to the NPV maps in the future, where it is not profitable to invest in irrigation, both in the contemporary and the future time periods.

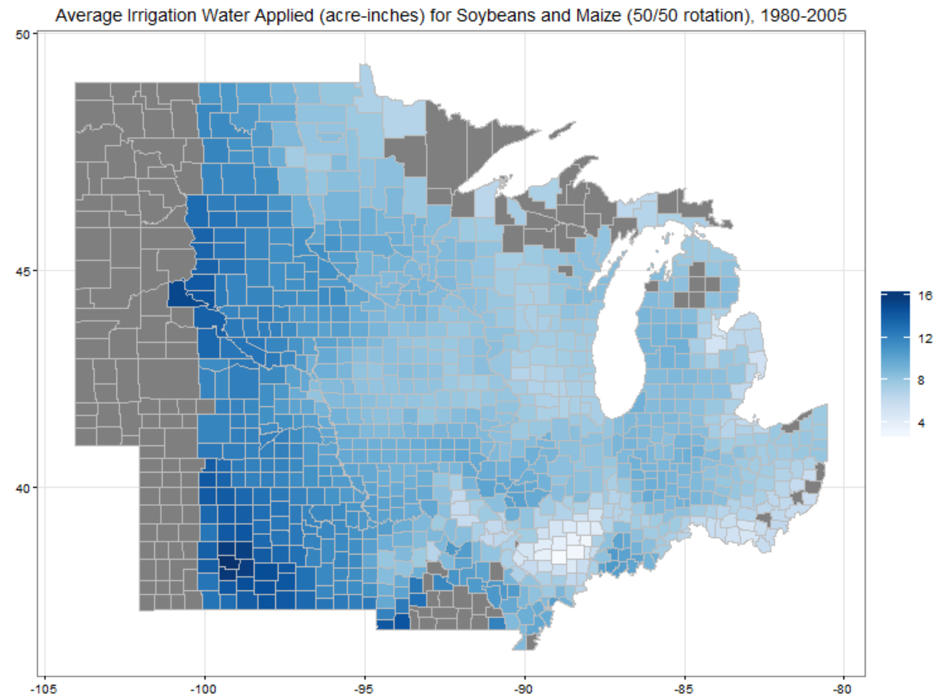

Figure 29. Irrigation Water Applied to a 50/50 Corn and Soybean Mix in Contemporary Period

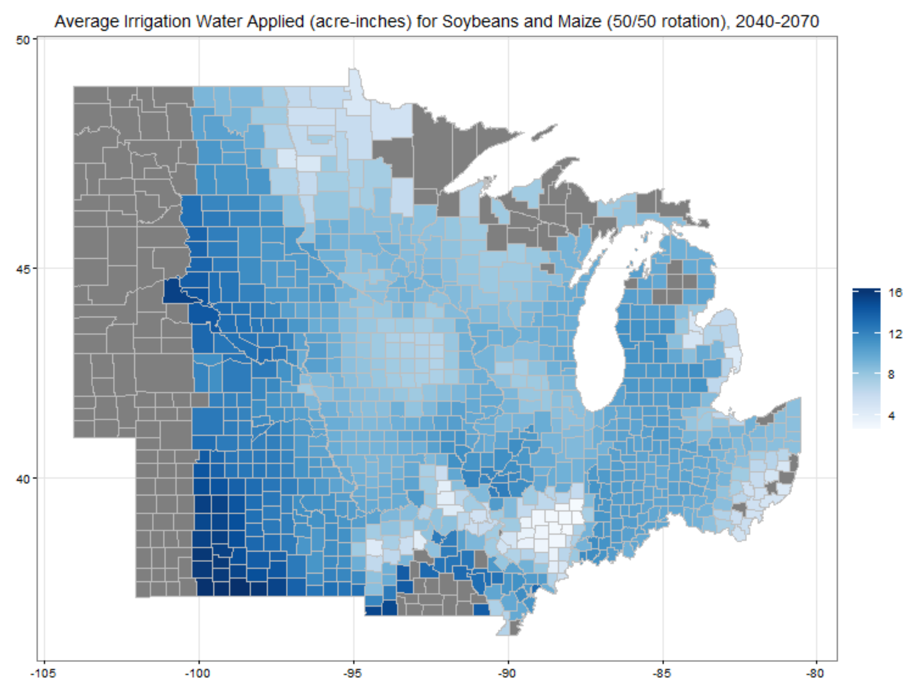

Figure 30. Irrigation Water Applied to a 50/50 Corn and Soybean Mix in Future Period

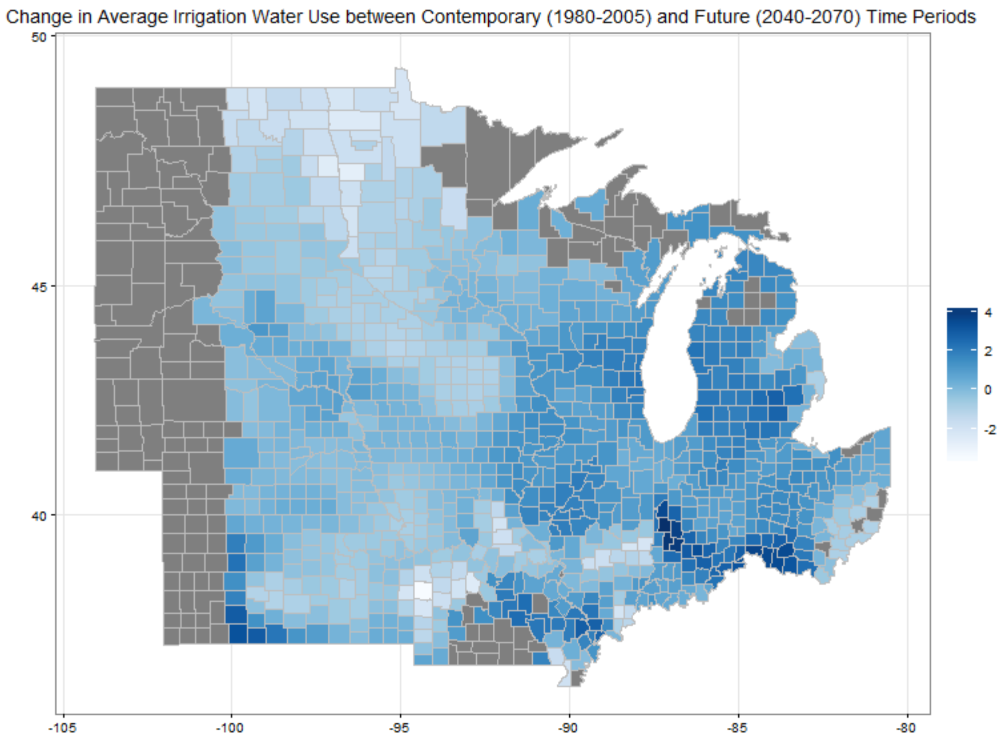

Figure 31. Difference in Irrigation Water Applied between Contemporary and Future Time Periods

Figure 32 plots the quantity of water applied (for a 50/50 crop mix) to examine water use in more detail in the counties considered to be "irrigating" because there is a positive Net Present Value from irrigation investment. Figure 33 looks at the water application quantities for irrigating counties in the future period. Both figures are based on data that underlies Figures 29 and 30, displayed earlier. These are used solely to highlight the difference in potential irrigation water demanded by crop producers in the future.

The current literature on future irrigation water demand primarily studies the relative shift in water demand in the future. Traditionally, in these studies, producers either irrigate or do not, in both the contemporary and the future time period. There is no consideration of producers shifting between irrigating and dryland farming in the two periods. Unfortunately, this means that previous studies are unable to capture the change in the water demanded under future weather conditions. It can be seen that the newly irrigating counties in Figure 33 that were white in Figure 32 have the potential to increase irrigation from zero to around 10 acre-inches per year. This change in potential water demand has the ability to significantly impact water supplies in the Great Lakes region. Comparatively, current irrigators increasing irrigation by 2 to 4 acre-inches of water is not nearly as dramatic of an increase, but is still very important. The change in irrigation water demand in currently irrigating locations could cause strain in already water-stressed hydrological areas. In Kansas and Nebraska, for example, a significant increase in water use likely cannot occur, due to the water policies in the area. If producers were unconstrained and able to apply as much water as is modeled in pDSSAT for the future period, the Ogallala aquifer would be significantly impacted by the increase in water use.

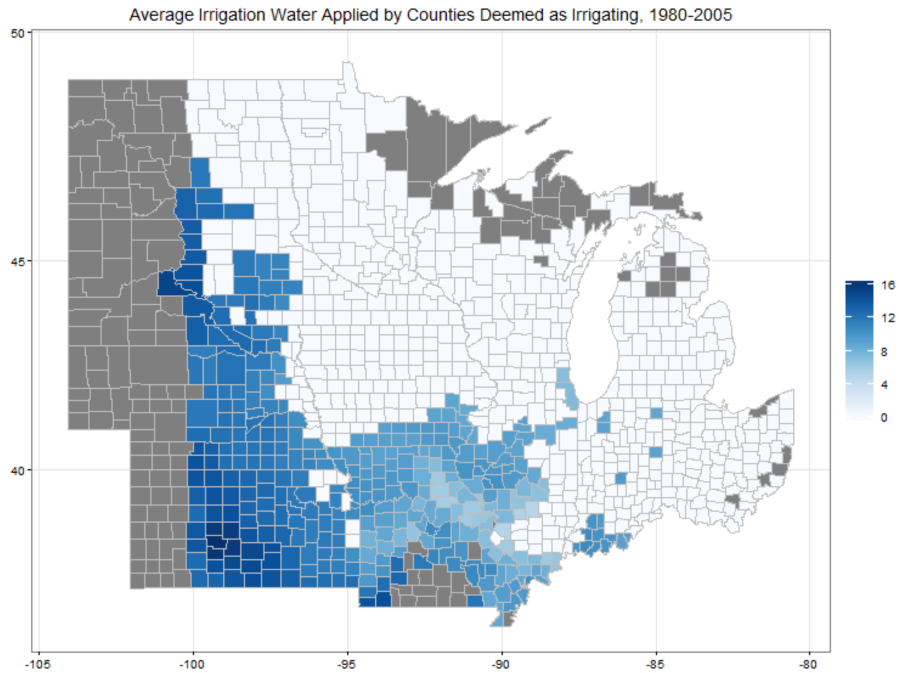

Figure 32. Irrigation Water Application for Contemporary Irrigating Counties

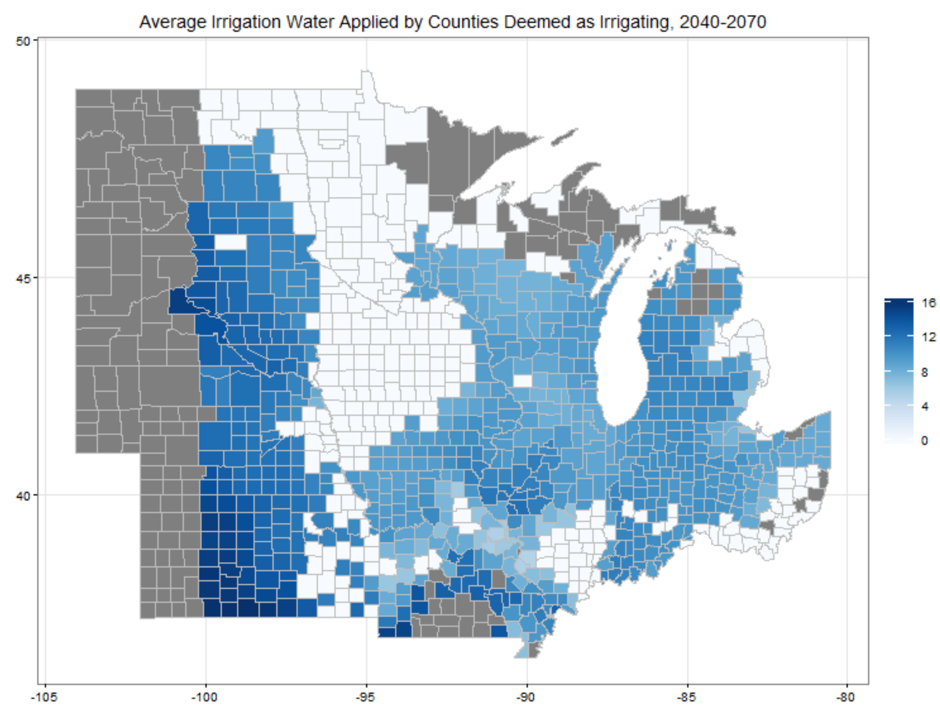

Figure 33. Irrigation Water Application for Future Irrigating Counties

In order to verify that the water application quantities reflect similar values to what producers are currently applying to their crops, we evaluate the differences between the irrigation quantities applied by the simulation compared to the quantities from the 2013 Farm and Ranch Irrigation Survey. Although the Farm and Ranch Irrigation Survey only has state-specific values, it can still serve as an empirical point of comparison to the simulation. The state averages of the irrigation quantities for corn and soybeans from the FRIS and the simulation data in the contemporary and future time periods are reported in Table 3.

In general, the crop models overestimate the amount of water farmers report applying to soybeans. The crop model applies more water in every state in the Corn Belt— by several inches in more than one location—than is reported by farmers in the 2013 FRIS. For corn, the water applied by the simulation is much closer to the values reported by the USDA survey with overestimation in some states and underestimation in others. In general, it seems like the water applied for corn in the simulation is in line with what farmers report applying. An additional thing to note is that, in general, the Farm and Ranch Irrigation Survey reports that corn requires more irrigation water than soybeans. In contrast, the simulation data from the pDSSAT model applies more water to soybeans than to corn. If less water were applied in pDSSAT, consistent with FRIS, the simulated yields would likely be affected. Regardless, it is likely that the water applied for soybeans in the simulation model is an overestimation.

In the future time period, irrigation water applications for corn and soybeans do not necessarily increase across the states. In fact, for corn in general, the average quantity of water applied, by state, decreases. This is in line with several studies that predicted precipitation levels that remained constant or increased over time. In contrast, for soybeans, there tends to be an increase in water use. This increase in water applied is significant enough that the overall water application for a mix of corn and soybeans increases from the contemporary to the future time periods, as seen in Figure 31. This increase in water use for soybeans compared to corn must be due to the plant growth and its water requirements. The same weather data and GCMs are used for both corn and soybeans, so the change in soil moisture must be due to the plant uptake.

Due to the significant differences in corn and soybean water use, it is important to provide information on the water use by the crops separately. Figure 34 shows the simulated water application for corn in the contemporary period and Figure 35 shows the corresponding water application in the future. Figures 36 and 37 depict the contemporary and future period water applications for soybeans.

In order to understand how precipitation variability comes into play for producers, it is important to see how relative water demand shifts under years of drought. First, we classify each year for each county as experiencing dry, wet, or normal weather using the Standard Precipitation Evapotranspiration Index explained in the methods. Then, the respective years' irrigation application quantities are associated with wet, dry, or normal years. The difference in the water applied in a dry year, compared to a normal year is displayed in Figures 38 and 39 for the contemporary and future time periods.

Table 6. Quantities of Irrigation Water Applied by pDSSAT Simulation and 2013 Farm and Ranch Irrigation Survey

State	1980-2005 Water Applied (acre-inches): Corn	1980-2005 Water Applied (acre-inches): Soybeans	2040-2070 Water Applied (acre-inches): Corn	2040-2070 Water Applied (acre-inches): Soybeans	2013 FRIS Water Applied (acre-inches): Corn	2013 FRIS Water Applied (acre-inches): Soybeans
Illinois	6.1	8.7	5.3	10.9	8.4	8.4
Indiana	7.5	9.7	6.7	13.7	6	4.8
Iowa	7.1	10.4	6.0	11.8	7.2	6
Kansas	11.7	13.6	8.6	17.0	15.6	10.8
Michigan	8.1	7.9	7.3	11.9	6	4.8
Minnesota	7.6	10.6	6.2	10.4	7.2	7.2
Missouri	6.8	11.9	5.7	13.0	10.8	8.4
Nebraska	11.3	12.3	8.5	14.7	12	10.8
North Dakota	11.1	12.0	8.3	11.2	8.4	6
Ohio	6.3	8.4	5.5	11.3	4.8	3.6
South Dakota	11.6	13.3	9.2	15.0	8.4	7.2
Wisconsin	7.6	8.1	6.4	11.2	8.4	7.2

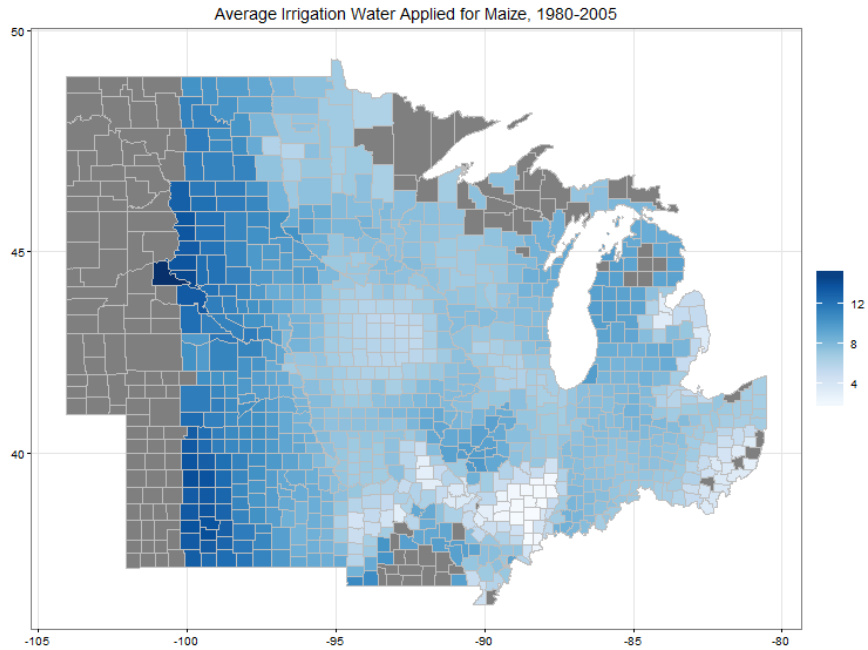

Figure 34. Irrigation Water Application for Contemporary Corn Producers (acre-inches)

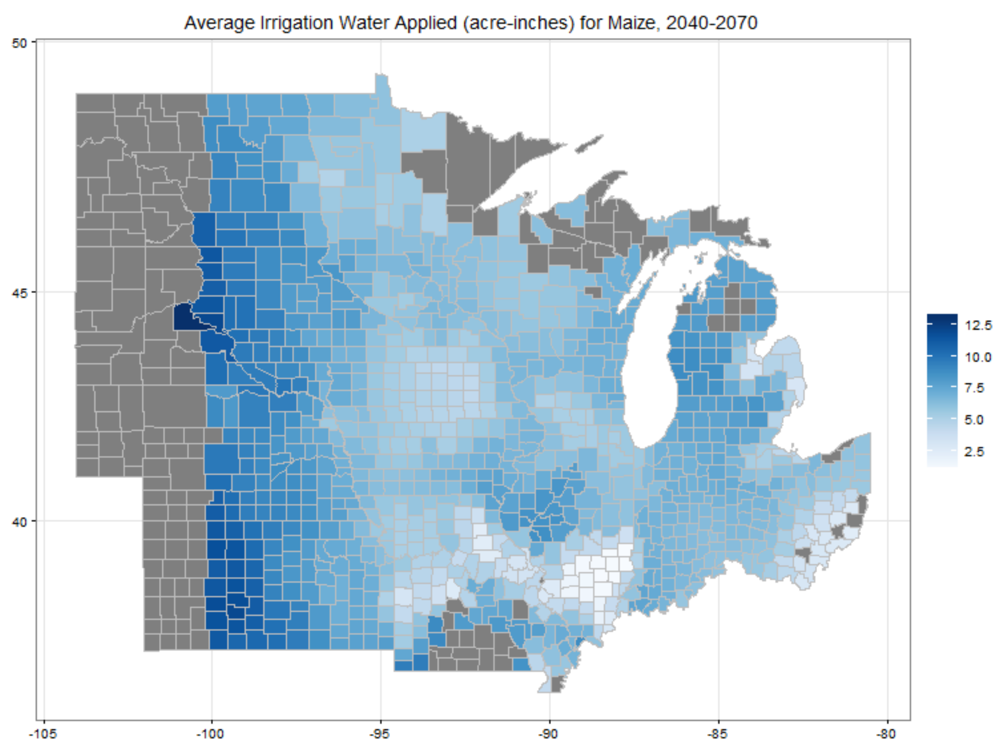

Figure 35. Irrigation Water Application for Future Corn Producers (acre-inches)

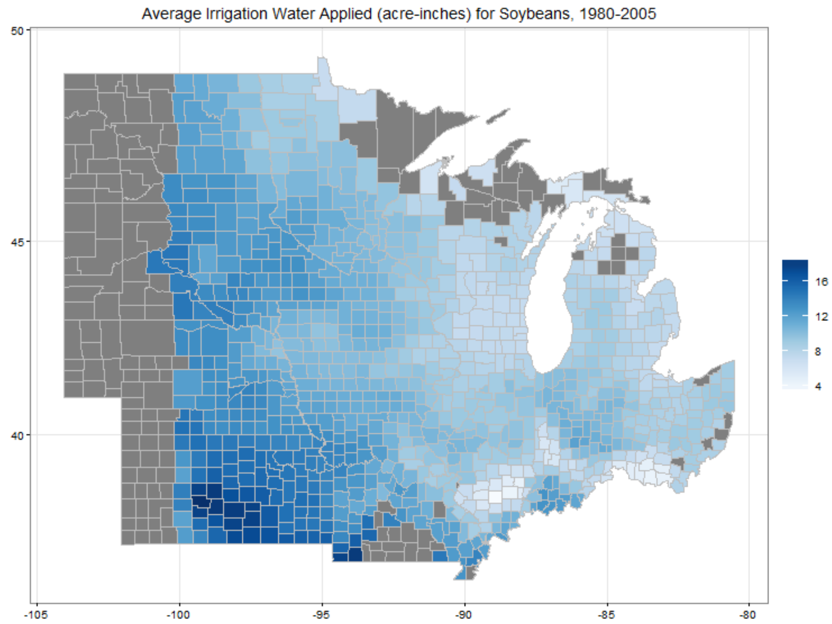

Figure 36. Irrigation Water Application for Contemporary Soybean Producers (acre-inches)

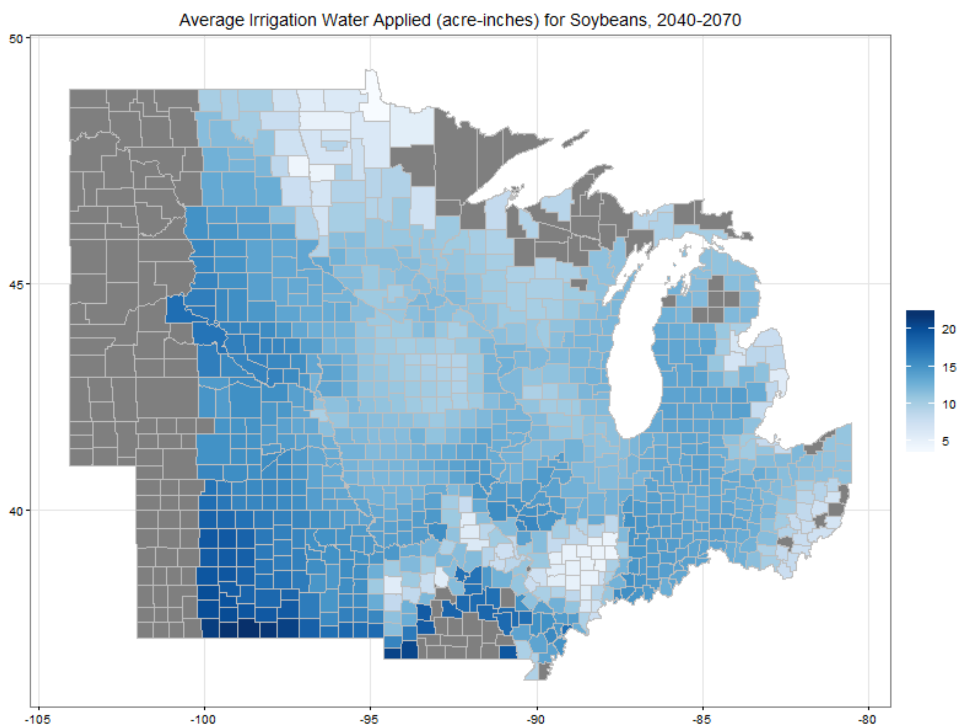

Figure 37. Irrigation Water Application for Future Soybean Producers (acre-inches)

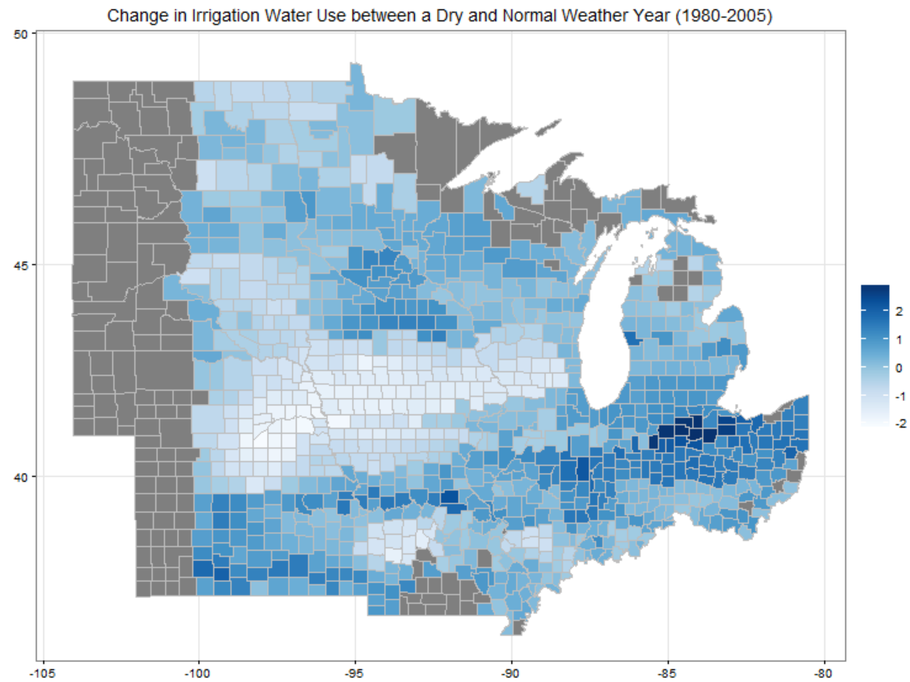

Figure 38. Difference in Irrigation Water Applied between a Dry and Normal Rainfall Year (1980-2005)

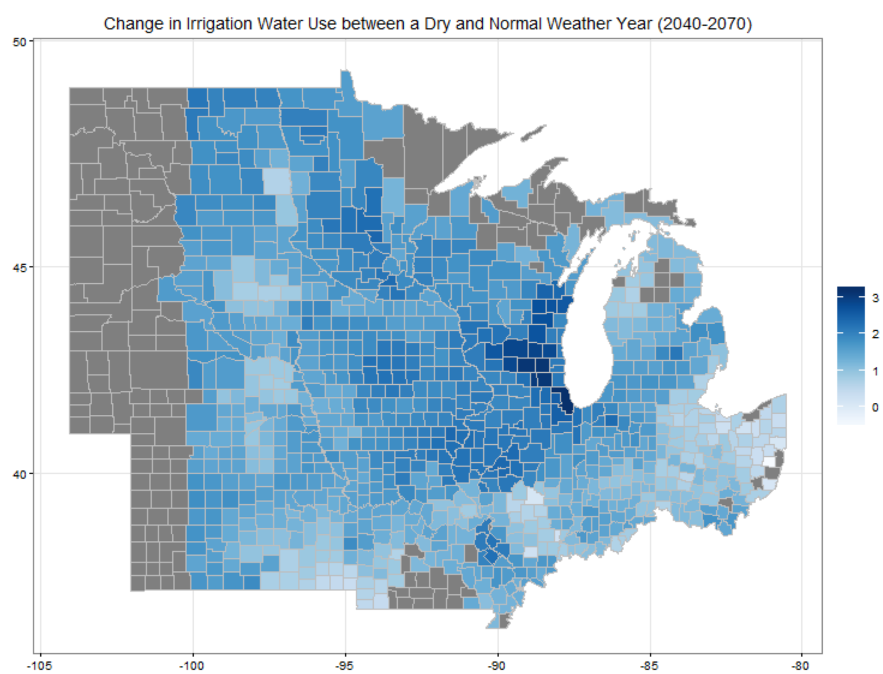

Figure 39. Difference in Irrigation Water Applied Between a Dry and Normal Rainfall Year (2040-2070)

With respect to the first hypothesis (H_1), there is a projected increase in the total area where irrigation is considered to be a profitable investment. By looking at the Net Present Value of investment in irrigation equipment, and changing only the climate-related variables, there is a significant increase in the number of counties that could find an irrigation decision to be cost-effective. This potential increase in irrigating areas is primarily found in the Great Lakes area, with the western part of the Corn Belt already irrigating, and Iowa and Minnesota generally choosing not to irrigate. Previously, in the Great Lakes region, the potential profitability for irrigation systems were at best marginal. The investment decision is primarily driven by the yield response of soybeans to irrigation, under the changes in weather, with soybeans receiving a larger yield boost due to irrigation than corn does. This change in profitability is primarily due to the temperature (and the resulting changes in evapotranspiration), but is also linked to changes in precipitation patterns. The impacts from changing precipitation patterns are especially evident in the southwestern part of the Corn Belt.

The second hypothesis (H_2), suggested that relative demand shifts for water would occur in years considered to be especially dry, as determined by the SPEI. Through the use of the growing season (May-October) 6-month SPEI, every year was classified as “dry”, “normal”, or “wet” for each county. By evaluating the potential irrigation water applications between dry and normal years, both in the contemporary and future periods, there is an increase in the demand for irrigation water in dry years. Additionally, this increase in demand for water between dry and normal years is higher in the future time period, suggesting that more extreme growing season droughts have the potential to occur.

If irrigation becomes a commonly or predominantly used tool for corn and soybean producers to mitigate yield climate change, a significant change in irrigation water application will occur. There is a general increase in irrigation water applied among counties that currently irrigate when going from the contemporary to the future period. There is also an increase in irrigation water use from newly irrigating counties that greatly outnumber counties that no longer find it profitable to irrigate under future climate conditions. Finally, there is an increase in the difference between the amount of water applied in years considered to be normal compared to years considered to be dry. This suggests the potential for serious consequences with respect to water use in water-sensitive areas, and emerging water management challenges in historically water abundant locations where irrigation may become common.

CHAPTER 5. CONCLUSIONS

Climate change across the Corn Belt has the potential to have significant impacts on yields, crop choices, and water use under future weather conditions. While precipitation is likely to increase across much of the Corn Belt in the future climate, there is also expected to be a significant rise in temperature across all of the Corn Belt. If global greenhouse gas emissions continue on their current trajectory following IPCC RCP 8.5, climate change could raise the average monthly temperature across much of the Corn Belt by more than 5 degrees Celsius (see Figure 1) in some of the most drought-sensitive locations. This increase in temperature will raise the water requirements for both corn and soybeans, even after accounting for the CO_2 fertilization effects, which mediate some of the increased water demand. The increase in potential irrigation water demand is forecasted to exceed the increase in growing season precipitation under projected climate. Additionally, the precipitation increases are accompanied by an increase in precipitation variability whereby water may not be consistently available throughout the growing season. Climate change—temperature, precipitation and weather patterns and variability—is expected to result in more extreme weather events, such as drought. These factors combine to make irrigation a potentially more profitable investment in many locations in the future than it is today. This economic study examines the potential expansion of irrigation in the Corn Belt under plausible future weather conditions.

In the face of the precipitation and temperature changes that are projected across the Corn Belt in the future, it is clear that corn and soybean producers in the region will want to adjust their practices to mitigate detrimental impacts on their crops, and potentially take advantage of any positive impacts climate change may have in their location. This study looks specifically at irrigation as one strategy to maximize the profitability of corn and soybean production.

The potential profitability of irrigation under climate change is driven by the potential profitability of soybeans in this analysis. The yield response of corn to irrigation water is less than that of soybeans, and irrigation systems appear to be less profitable for corn. While there is a projected increase in the total area where investing in irrigation for corn becomes profitable in mid-century, this increase is much less significant than that of the increase in potentially profitable irrigated soybeans. Not only do soybeans respond better to climate change due to CO_2 fertilization, but soy also responds better to additional water application through irrigation according to the CERES-Maize and SOYGRO crop models in the DSSAT suite of crop models. Higher temperatures and greater evapotranspiration in the projected future climate lead to a higher crop demand for water in both corn and soybean plants. However, soybeans respond positively to higher temperatures with increased yields, while the higher temperatures negatively affect corn in many locations. Schlenker and Roberts (2009) point out that yields have a tendency to increase up to 29 degrees C for corn and 30 degrees C for soybeans. Exposure to temperatures beyond that leads to a significant potential drop-off in yield, with a more severe decline in yield for corn. The future climate combined with a lack of CO_2 fertilization benefits translates into corn yield losses that cannot be prevented or offset in many regions, even under irrigation. Of course, this is not the case everywhere across the Corn Belt and areas where corn has traditionally been irrigated tend to remain as profitable irrigating locations. The largest potential increase in irrigated acres in the future will be for soybean production if yield response to climate change and irrigation are consistent with crop growth simulations that are the basis for this analysis.

The large increase in soybean yields could be a cause for concern within the crop model. The considerable increase in soybean yields in the future, even before irrigation, could partially explain the significant increase in water use between the two periods and may be part of the explanation for why irrigated soybeans consume more water than corn in the future. Although several field studies have been conducted to try to understand what soybean yields will look like under CO_2 fertilization, there is still uncertainty about the magnitude of the beneficial effects in the future climate. This is especially true for irrigated soybeans, which are not well-studied in the eastern part of the Corn Belt that historically does not irrigate soy or commodity corn. Other studies, such as Southworth et al. (2002) predict the same level of yield increases as the model results found here. However, the significant increases in yield, specifically under irrigation are large, and are a major factor in the potential profitability of irrigation investment. Taking this into consideration, this study examined yields if only 60% or 80% of the predicted yield increases (for both corn and soybeans) are realized with the same amount of potential irrigation, to explore whether the level of irrigation extensification into new areas is robust. During this process, all non-yield specific costs are kept constant. Although the Net Present Value decreases if lower irrigated yields result, the calculations indicate that an investment in irrigation for soybeans would still be profitable across the majority of the area considered to be irrigating if 100% of the simulated irrigated yields are achievable.

Although the impacts of irrigation on corn yield are not predicted to be profitable enough to warrant the purchase of an irrigation system, with the opposite being true for soybeans in many locations, there are several other factors at play that could impact the profitability of investment. A major factor is crop prices. Depending on how agricultural policy and demand change over the next decades, the prices for corn and soybeans could be volatile affecting the attractiveness of the investment decision. The USDA’s current price projections for 2025 were used to evaluate the profitability of irrigation investment, but are so similar to the 2015 prices the two sets of results are almost indistinguishable. Other price ranges are evaluated, including the relatively high prices observed during the 2013/2014 marketing season; there are clear expansions in the areas where investment is profitable due to higher prices. Similarly, although the current crop prices used in the calculations are relatively low, lower prices would make the investment less desirable. Similarly for the costs of the various inputs to crop production, or even the cost of the system in general, higher costs at the same or reduced prices will reduce profitability. These are all difficult to predict and beyond the scope of this study.

Another important factor to consider is the assumption about which crops are planted and their share of land in a crop rotation. If soybean yields and irrigation profitability are as high as suggested by this study, there could be a shift in crop production across the Corn Belt. All else constant, dryland and irrigated corn would be less profitable than investing in irrigated soybean production. This would likely be a temporary bubble in irrigation technology expansion, and crop prices would adjust to the change in supply, but there could be a race to innovate in the near term. However, it is also possible that farmers keen on rotating their crops, or committed to producing corn will be slow adopters of the new technology. This could limit the expansion of irrigation investment. Although this study points to a situation where irrigation is likely to be adopted by producers, a shift in the demand for corn or other crops, producer preferences, or policy factors have the potential to drastically change the use of irrigation to adapt to climate change.

As a whole, we are left with the prospect that irrigation will become an increasingly relied upon strategy to mitigate the impacts of future climate change on agriculture. This has many implications for agriculture and water use in the region.

There are a few limitations of this study with respect to water use that are important to keep in mind. First, because this study does not involve original crop modeling it is unable to consider water policies that limit water use in locations that already experience water restrictions (or have limited or no access to groundwater for irrigation). Water use restrictions apply primarily to the western Corn Belt. Thus, estimates of the potential amount of water applied to crops may exceed the water quantities available for producers to use. Irrigation water is automatically added to the soil profile if moisture falls below a threshold of 80% of soil water holding capacity. This has an impact on the cost of the water to the user (which is overestimated), but also has a major impact on the projected yields even at the assumed 75% efficiency rate. While there is information available about the water applied and the resulting yields, there is not data available to develop a relationship between the yield and the water applied for a specific location, making it impossible to estimate yields if water supply were restricted below the simulated irrigation amounts. The implications of such water restrictions, whether a result of policy or hydrology, may be significant. In some locations that are currently irrigating, restrictions on water use may render the simulated yields infeasible, both currently and in the future. Without considering any cost of water (which is likely to be relatively low but is unpriced in this analysis), this model overestimates the potential profitability of investment in these locations. One way to minimize this effect within the study was to restrict the area of study to only locations east of the 100th meridian. Counties that are corn and soybean producers west of the 100th meridian are primarily irrigators today, and will likely continue to be in the future.

Second, the comparison of the counties where irrigation is predicted to be profitable to the areas already irrigated according to the agricultural census showed that areas with the most severe water policy restrictions were irrigating as predicted. In all likelihood, given that the modeled Net Present Value of investment is high in this region and that irrigation is already present in these locations, investing in irrigation is still a wise move. However, the quantitative estimates for the NPV in this region are likely inflated.

The water scarce western Corn Belt has implemented many policies to try to maintain a sustainable supply of water into the future. Although the producers often still pay less for water than it is worth, the existence of a price compared to other, eastern Corn Belt states without water pricing suggests that some level of conservation is occurring. Other policies, such as restricting the number of acre-inches pumped annually or in a series of years, well-drilling moratoriums, or limits on irrigated acres in agricultural districts, all work to conserve water in sensitive areas. Under future climate conditions, these are also locations that will continue to have trouble with water scarcity, but there are water policies in place that can be adjusted to better serve the community at large.

In the eastern Corn Belt, such water policies do not exist. In fact, most agricultural producers merely have to report the amount of water that they intend to pump and there is no permitting process for smaller irrigators. If irrigation becomes more prevalent in these areas in the future, there will be a need for policies to monitor water use and make sure that supplies are sufficient for all uses in the region. Additionally, in many of these locations, there is no explicit price for water and its cost is merely the cost of the electricity required to pump water out of the ground. This is not a sustainable or economically efficient practice, especially in locations where water demand is expected to increase. Even in traditionally water abundant locations where water is a less-sensitive issue, the relative demand for irrigation water in years of drought could potentially impact the water supplies of the region. A substantial plan, such as the state water plan developed in Minnesota, is essential at the state and local levels for understanding water supplies and strategies for dealing with drought, irrigation, and urban and rural water needs.

Given the relative increase in the demand for irrigation water estimated in this study, there is a significant need for proactive water policy. If this occurs, the costs of water are likely to increase across the Corn Belt, which would impact the cost of using irrigation water within the study. Even without new water policy implementation, if irrigation becomes more heavily utilized across the Midwest, the costs of pumping water will increase with any reduction of the groundwater table. Without an ability to interact the crop growth model with a hydrological model of aquifers in the region, or a way to determine which farmers are using surface v. groundwater in their irrigation practices, there is no simple way to estimate costs of pumping groundwater as this activity increases over time, and is not considered within this study.

5.1 Future Studies

This analysis points to many opportunities for further investigation. There are several limitations of this study that could be addressed, such as the costs of pumping groundwater over time or a more substantial examination of projected crop prices and volatility that could be implemented to provide interesting results. There are also many expansions of the simulation study that could provide further insight on farmer preferences, behavior, or irrigation under climate change.

There are potentially great insights to be gained from studying a few representative aquifers in the region. By focusing on some select locations, there is an opportunity to see how the shifts in irrigation profitability and relative water demand suggested by the current study may affect the water available within an aquifer, especially during periods of projected drought. This could have many implications for designing forward-thinking policies that could be implemented within a region, by providing general estimates on the use of water resources for irrigation in the future. To be able to interact this information with water policies already in place would also be valuable. Additionally, adding current policies and water restrictions within the model could provide insight into policy choices for the future. This would require some sort of water-crop yield relationship to be determined by location, but the ability to restrict water and evaluate the resulting yields and profitability would provide a more accurate representation of irrigation across the western Corn Belt, and potentially highlight future trends across the region.

Other potential future research could expand the adaptation choices that a farmer may make within the model. This study contributes to the current literature by adding in a profitability component to research that largely looks specifically at the agronomic or hydrological effects of climate change in terms of irrigation. The current model lacks the ability for farmers to consider several decisions. One way to add a decision-making component would be to allow producers to choose how much water to apply to their crops; another would be to allow for adjustments in crop rotations. There are a few tactics available to implement this, but allowing for a producer to choose a crop mix that is not a 50/50 or a 0/100 rotation, and providing for an interior solution based on the profitability of irrigation in each county could provide insights on future supply of these crops, and a better estimation of how demand for irrigation technology could shift across the Corn Belt. Of course, alternative crops are another option. Related to this, future studies could also look more in-depth at the risk associated with irrigation investment, and how it may differ between large and small firms. This could potentially be done using a real options framework, and could help describe the additional risks that may lead farmers to not choose to install irrigation equipment, even in locations where the NPV is positive.

Clearly, there are many opportunities to extend this work in future research in this area. The opportunity to have data at this resolution across the Corn Belt that can be manipulated in different ways, allows the opportunity for valuable interdisciplinary work. This study is designed to provide an overview of how irrigation adoption could plausibly expand over the next several decades, and the potential implications it may have for water resources and policy needs. Hopefully, this research can serve as a basis for future work to develop adaptation strategies for climate change in the Corn Belt.

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APPENDICES

Appendix A: R Code Used in Analysis

```
#All R code written by Molly A. Van Dop, unless otherwise noted.
#Code was used to extract and process netcdf files and calculate economic gross margins
#Code not meant to be an exhaustive user guide, rather documentation of methods

#Example NetCDF4 File Extraction
# Based on University of Oregon Professor P.J. Bartlein’s geography course notes:
# http://geog.uoregon.edu/bartlein/courses/geog607/Rmd/netCDF_01.htm
#Code for conversion of NetCDF4 file to text file of 2001-2005 corn yield data (NorESM)

#Read a NetCDF file using the ncdf package.
# The file is assumed here to be a CF-compliant

# “classic”€ • NetCDF file. First, set the values for some temporary variables.
# ncname is the name of the netCDF file
# dname is the name of the variable that will be read in.
#Then open the NetCDF file using the ncdf open.ncdf() function.

ncname <- "pdssat_noresm1-m_hist_ssp2_co2_noirr_yield_mai_annual_2001_2005-"

ncfname <- paste(ncname, ".nc4", sep = "")
dname <- "yield_mai"  # note: yield_mai is the variable name in the nc4 file

# open a NetCDF file
ncin <- nc_open(ncfname)
print(ncin)
#3
# Next, the coordinate variables longitude and latitude are read using the ncvar_get()
function in ncdf4.
# The number of longitude and latitude values are determined using the dim() function:

lon <- ncvar_get(ncin, "lon")
nlon <- dim(lon)
head(lon)

lat <- ncvar_get(ncin, "lat", verbose = F)
nlat <- dim(lat)
head(lat)

print(c(nlon, nlat)) # confirms the dimensions of the data

#4
```

```
# Next, read the time variable (using the ncvar_get()  function),
# its attribute units (using the ncatt_get() function), and
# also get the number of times using the dim() function.
# Time here is expressed in the udunits “time since”€ • format, and will be
# converted to a human-readable form later.

t <- ncvar_get(ncin, "time")
tunits <- ncatt_get(ncin, "time", "units")
nt <- dim(t)

#5
# Next, read the time variable (again using the ncvar.get() function),
# and its attribute units (using the ncatt.get() function).

yield_mai.array <- ncvar_get(ncin, dname)
dlname <- ncatt_get(ncin, dname, "long_name")
dunits <- ncatt_get(ncin, dname, "units")
fillvalue <- ncatt_get(ncin, dname, "_FillValue")
dim(yield_mai.array)

# Get the time variable and its attributes using the ncvar_get() and
# ncatt_get() functions, and also get the number of times using the dim() function.

t <- ncvar_get(ncin, "time")
tunits <- ncatt_get(ncin, "time", "units")
t  # list the values

nt <- dim(t) #get the number of time values and list them
nt

# Print the time units string. Note the structure of the time units attribute.
# The object tunits has two components hasatt (a logical variable), and
# tunits$value, the actual “time since” string.
tunits

# The variable and its longname, units and fill value (_FillValue) attributes are read next.
yield_mai.array <- ncvar_get(ncin, dname)
dlname <- ncatt_get(ncin, dname, "long_name")
dunits <- ncatt_get(ncin, dname, "units")
fillvalue <- ncatt_get(ncin, dname, "_FillValue")
dim(yield_mai.array)   # verify the size of the array

#6
# Next, a set of “global attributes”€ • (or metadata) are read.
#
```

```
title <- ncatt_get(ncin, 0, "title")
institution <- ncatt_get(ncin, 0, "institution")
comment1 <- ncatt_get(ncin, 0, "comment1")
comment2 <- ncatt_get(ncin, 0, "comment2")
contact <- ncatt_get(ncin, 0, "contact")
#datasource <- ncatt_get(ncin, 0, "source")
#references <- ncatt_get(ncin, 0, "references")
#history <- ncatt_get(ncin, 0, "history")
#Conventions <- ncatt_get(ncin, 0, "Conventions")

# The attribute values can be listed by printing their values, e.g.
title$value

#7
# At this point, we're done with the input data set, so close it using the nc_close()
function.
nc_close(ncin)


# third section of linked webpage enetitled,
# "Convert the time variable"

#8
# The time variable, in â□œtime-sinceâ□□ units can be converted into “real”□□ (or
more easily readable)
# time values by splitting the time tunits$value string into its component parts, and then
using
# the chron() function to determine the absolute value of each time value from the time
origin.

# split the time units string into fields
tustr <- strsplit(tunits$value, " ")
tdstr <- strsplit(unlist(tustr)[3], "-")
tmonth = as.integer(unlist(tdstr)[2])
tday = as.integer(unlist(tdstr)[3])
tyear = as.integer(unlist(tdstr)[1])
chron(t, origin = c(tmonth, tday, tyear))

# pDSSAT DATA NOTE: Time variables do not makes sense as "time since 1/1/1901"
and data seems to be missing


# fourth section of linked webpage entitled,
# "Replace NetCDF fillvalues with R NAs"
```

```
# In NetCDF file, values of a variable that are either missing or simply not available (i.e.
ocean grid points
# in a terrestrial data set) are flagged using specific â□œfill valuesâ□□ (_FillValue) or
# missing values (missing_value), the values of which are set as attributes of a variable.
In R, such
# unavailable data are indicated using the â□œNAâ□□ value. The following code
fragment illustrates
# how to replace the NetCDF variables "fill values" with R's "NA" to denote values not
available.

#9
# this R command is used to replace _FillValue values in the array with R-compatible
"NA" values in the same array
yield_mai.array[yield_mai.array == fillvalue$value] <- NA
head(yield_mai.array)  #used to verify that the NA values have indeed replaced the fill
values


#10
# The total number of non-missing (i.e. land, except for Antarctica) grid cells can be
gotten by determining
# the length of a vector of values representing one slice from the brick, omitting the NA
values:
length(na.omit(as.vector(yield_mai.array[, , 1])))


# section 5 of linked webpage entitled,
# "Get a single time slice of the data, create an R data frame, and write a .csv file"

# NetCDF variables are read and written as one-dimensional vectors (e.g. longitudes),
# two-dimensional arrays or matrices (raster â□œslicesâ□□), or multi-dimensional
# arrays (raster â□œbricksâ□□). In such data strucures, the coordinate values for each
grid
# point are implicit, inferred from the marginal values of, for example, longitude,
# latitude and time. In contrast, in R, the principal data structure for a variable
# is the data frame. In the kinds of data sets usually stored as NetCDF files, each row in
# the data frame will contain the data for an individual grid point, with each column
# representing a particular variable, including explicit values for longitude and latitude
# (and perhaps time). In the pDSSAT data set here, the variables consist of longitude,
# latitude and 10 columns of annual simulated yield values, with the full data set thus
# consisting 'r nlon' by 'r nlat' rows and 'r nt+2' columns.


#create a long vector yield_mai.vec.long using the as.vector() reshaping
#function, and verify its length, which should be 2592000
```

```
yield_mai.vec.long <- as.vector(yield_mai.array)
length(yield_mai.vec.long)

#18
#Then reshape that vector into a 259200 by 10 matrix using the matrix() function
#and verify its dimensions, which should be 259200 by 10
yield_mai.mat <- matrix(yield_mai.vec.long, nrow = nlon * nlat, ncol = nt)
dim(yield_mai.mat)
head(na.omit(yield_mai.mat))

#Create the second data frame from the yield_mai.mat matrix
lonlat <- expand.grid(lon, lat)
yield_mai.df02 <- data.frame(cbind(lonlat, yield_mai.mat))
names(yield_mai.df02) <- c("lon", "lat", paste(dname, as.character(1), sep = "_"))
options(width = 110)
head(na.omit(yield_mai.df02, 20))
#write the second data frame out as a .csv file, dropping NAs
csvfile2 <- "7all_pdssat_noresm1-
m_hist_ssp2_co2_noirr_yield_mai_annual_2001_2005.csv"
write.table(na.omit(yield_mai.df02), csvfile2, row.names = FALSE, sep = ",")

nc_close
```

Example NPV Caluclation

Code for NPV of irrigation investment for contemporary corn producers in Iowa

```
#Set wd
setwd("C:/Users/mvandop/Desktop/Data ready for processing")

#Capital Cost and Loan Information
#Year Purchased
yearpur <- 2016
#Purchase Price for Entire System Installed
purprc <- 225000
#Tillable Acres without Irrigation
tilacres <- 160
#Irrigated Acres System Covers
irracres <- 160
#Life of System in Years and Assumptions
syslife <- 20
```

```
#Salvage Value of Investment at End of Evaluate Time Period
salval <- 67500
#Amount of Purchase Price Borrowed
purprcbor <- 200000
#Annual Interest Rate for Borrowed Money
intrt <- 4.5
#Loan Term in Years
loanlen <- 7

#Income Tax Information
#Marginal Income Tax Rate
martxrt <- 43.7
#MACRS Property Class
macrs <- 7
#ADS-SL Years
adssl <- 10
#Depreciation Method
depmeth <- 1
#Additional First Year Depreciation
dep <- 50000
#Opportunity Cost of Capital
oppcost <- 8.00


#Crop Production Information
#set wd!
aggdf = read.csv("aggregated_data_IA_03282016.csv")
#Value of Family and Regular Labor
famlab <- 9.65
#Variable Cost per Acre-in of Water
varcosth2o <- 3.54
#Value of Irrigation labor
irrlab <- 12.8

#Crop Production: Unirrigated Soybeans
#Rotation
unirrsoyrot <- 0.5
#Average Yield
unirrsoyyield <- aggdf[, 5]
#Average Irrigation Water Quantity
unirrsoyh2o <- 0
#Labor Hours
unirrsoylabhr <- 1.9
#Irrigation Labor Hours
unirrsoyirrlabhr <- 0
```

```
#Price per Bu
unirrsoyprc <- 8.90
#Gross Income
unirrsoygrinc <- unirrsoyprc*unirrsoyyield
#Variable Expenses per Unit
#Seed
unirrsoyseed <- 75
#Fertilizer
unirrsoyfert <- 57
#Chemicals
unirrsoychem <- 28
#Drying Cost per bu
unirrsoydry <- 0
#Water Energy and Distribution Cost
unirrsoywateren <- unirrsoyh2o*varcosth2o
#Irrigation Labor
unirrsoyirrlab  <- unirrsoyirrlabhr*irrlab
#Fuel and Oil
unirrsoyfuel <- 15
#Repairs
unirrsoyrep <- 18
#Utilities
unirrsoyutil <- 1
#Crop Insurance
unirrsoyins <- 23
#Trucking per bu
unirrsoytru <-  0.10*unirrsoyyield
#Marketing per bu
unirrsoymar <- 0.05*unirrsoyyield
#Labor (Total)
unirrsoylab  <- unirrsoylabhr*famlab

#Total Variable Costs
unirrsoytotvar <- unirrsoyseed + unirrsoyfert + unirrsoychem + unirrsoydry + 
unirrsoywateren + unirrsoyirrlab + unirrsoyfuel + unirrsoyrep + unirrsoyutil + unirrsoyins 
+ unirrsoytru + unirrsoymar + unirrsoylab

#Gross margin per Crop
unirrsoygmcrp <-  unirrsoygrinc-unirrsoytotvar

#Gross Margin per Rotation
unirrsoygmrot <- unirrsoygmcrp*unirrsoyrot


#Crop Production: Unirrigated Maize
```

```
#Rotation
unirrmairot <- 0.5
#Average Yield
unirrmaiyield <- aggdf[, 2]
#Average Irrigation Water Quantity
unirrmaih2o <- 0
#Labor Hours
unirrmailabhr <- 3.0
#Irrigation Labor Hours
unirrmaiirrlabhr <- 0
#Price per Bu
unirrmaiprc <- 3.65
#Gross Income
unirrmaigrinc <- unirrmaiprc*unirrmaiyield
#Variable Expenses per Unit
#Seed
unirrmaiseed <- 124
#Fertilizer
unirrmaifert <- 144
#Chemicals
unirrmaichem <- 43
#Drying Cost per bu
unirrmaidry <- 0.3*unirrmaiyield
#Water Energy and Distribution Cost
unirrmaiwateren <- unirrmaih2o*varcosth2o
#Irrigation Labor
unirrmaiirrlab  <- unirrmaiirrlabhr*irrlab
#Fuel and Oil
unirrmaifuel <- 25
#Repairs
unirrmairep <- 22
#Utilities
unirrmaiutil <- 5
#Crop Insurance
unirrmaiins <- 33
#Trucking per bu
unirrmaitru <-  0.10*unirrmaiyield
#Marketing per bu
unirrmaimar <- 0.05*unirrmaiyield
#Labor (Total)
unirrmailab  <- unirrmailabhr*famlab

#Total Variable Costs
```

```
unirrmaitotvar <- unirrmaiseed + unirrmaifert + unirrmaichem + unirrmaidry +
unirrmaiwateren + unirrmaiirrlab + unirrmaifuel + unirrmairep + unirrmaiutil +
unirrmaiins + unirrmaitru + unirrmaimar + unirrmailab

#Gross margin per Crop
unirrmaigmcrp <-  unirrmaigrinc-unirrmaitotvar

#Gross Margin per Rotation
unirrmaigmrot <- unirrmaigmcrp*unirrmairot


#Crop Production: Irrigated Soybeans
#Rotation
irrsoyrot <- 0.5
#Average Yield
irrsoyyield <- aggdf[, 6]
#Average Irrigation Water Quantity
irrsoyh2o <- aggdf[, 7]
#Labor Hours
irrsoylabhr <- 1.9
#Price per Bu
irrsoyprc <- 8.90

#Gross Income
irrsoygrinc <- irrsoyprc*irrsoyyield
#Irrigation Labor Hours
irrsoyirrlabhr <- 0.5
#Variable Expenses per Unit
#Seed
irrsoyseed <- 75
#Fertilizer
irrsoyfert <- 57
#Chemicals
irrsoychem <- 28
#Drying Cost per bu
irrsoydry <- 0
#Water Energy and Distribution Cost
irrsoywateren <- irrsoyh2o*varcosth2o
#Irrigation Labor
irrsoyirrlab  <- irrsoyirrlabhr*irrlab
#Fuel and Oil
irrsoyfuel <- 15
#Repairs
irrsoyrep <- 26.23
#Utilities
```

```
irrsoyutil <- 1
#Crop Insurance
irrsoyins <- 5
#Trucking per bu
irrsoytru <-  0.10*irrsoyyield
#Marketing per bu
irrsoymar <- 0.05*irrsoyyield
#Labor (Total)
irrsoylab  <- irrsoylabhr*famlab

#Total Variable Costs
irrsoytotvar <- irrsoyseed + irrsoyfert + irrsoychem + irrsoydry + irrsoywateren +
irrsoyirrlab + irrsoyfuel + irrsoyrep + irrsoyutil + irrsoyins + irrsoytru + irrsoymar +
irrsoylab

#Gross margin per Crop
irrsoygmcrp <-  irrsoygrinc-irrsoytotvar

#Gross Margin per Rotation
irrsoygmrot <- irrsoygmcrp*irrsoyrot



#Crop Production: Irrigated Maize
#Rotation
irrmairot <- 0.5
#Average Yield
irrmaiyield <- aggdf[, 3]
#Average Irrigation Water Quantity
irrmaih2o <- aggdf[, 4]
#Labor Hours
irrmailabhr <- 3.0
#Price per Bu
irrmaiprc <- 3.65
#Gross Income
irrmaigrinc <- irrmaiprc*irrmaiyield
#Irrigation Labor Hours
irrmaiirrlabhr <- 0.5
#Variable Expenses per Unit
#Seed
irrmaiseed <- 143
#Fertilizer
irrmaifert <- 184
#Chemicals
irrmaichem <- 58
```

```
#Drying Cost per bu
irrmaidry <- 0.3*irrmaiyield
#Water Energy and Distribution Cost
irrmaiwateren <- irrmaih2o*varcosth2o
#Irrigation Labor
irrmaiirrlab  <- irrmaiirrlabhr*irrlab
#Fuel and Oil
irrmaifuel <- 25
#Repairs
irrmairep <- 30.23
#Utilities
irrmaiutil <- 5
#Crop Insurance
irrmaiins <- 5
#Trucking per bu
irrmaitru <-  0.10*irrmaiyield
#Marketing per bu
irrmaimar <- 0.05*irrmaiyield
#Labor (Total)
irrmailab  <- irrmailabhr*famlab

#Total Variable Costs
irrmaitotvar <- irrmaiseed + irrmaifert + irrmaichem + irrmaidry + irrmaiwateren +
irrmaiirrlab + irrmaifuel + irrmairep + irrmaiutil + irrmaiins + irrmaitru + irrmaimar +
irrmailab

#Gross margin per Crop (per acre)
irrmaigmcrp <-  irrmaigrinc-irrmaitotvar

#Gross Margin per Rotation (per acre)
irrmaigmrot <- irrmaigmcrp*irrmairot


#Gross Margin Benefit with Irrigation
#Gross Margin no irrigation (all acres)
gmunirr <- (unirrsoygmrot+unirrmaigmrot)*tilacres
#Gross Margin irrigation (all acres)
gmirr <-
((irrsoygmrot+irrmaigmrot)*irracres)+((unirrsoygmrot+unirrmaigmrot)*(tilacres-
irracres))


#All Acres
gmbenefitall <-  gmirr-gmunirr
#per Irrigated Acre
```

```
gmbenefitper <- (gmirr-gmunirr)/tilacres
write.table(gmbenefitall, file = "gmbenefitallIApar_contemp_pr15.csv")


#Net Present Value Discounted After Tax Flow
NPVatncf = sum(NPVatco)
NPVatco = atco/(1 + atoppcostcapital)
atoppcostcapital = (oppcostcapital)(1 - marginctaxrate)
```

Example Thornthwaite and SPEI Calculation

Code for PET and SPEI calculation for grid cells along 36.75 degrees latitude

```
# Do everything by individual location

#latitude 36.75
tas3675 = read.csv("tas_36.75.csv")

tstas1 <- xts(tas3675$X.103.75, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn1 <- thornthwaite(Tave=tstas1, lat=36.75)
write.table(thorn1, file="thornindiv.csv", append = TRUE)

tstas2 <- xts(tas3675$X.103.25, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn2 <- thornthwaite(Tave=tstas2, lat=36.75)
write.table(thorn2, file="thornindiv.csv", append = TRUE)

tstas3 <- xts(tas3675$X.102.75, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn3 <- thornthwaite(Tave=tstas3, lat=36.75)
write.table(thorn3, file="thornindiv.csv", append = TRUE)

tstas4 <- xts(tas3675$X.102.25, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn4 <- thornthwaite(Tave=tstas4, lat=36.75)
write.table(thorn4, file="thornindiv.csv", append = TRUE)

tstas5 <- xts(tas3675$X.101.75, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn5 <- thornthwaite(Tave=tstas5, lat=36.75)
write.table(thorn5, file="thornindiv.csv", append = TRUE)

tstas6 <- xts(tas3675$X.101.25, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn6 <- thornthwaite(Tave=tstas6, lat=36.75)
write.table(thorn6, file="thornindiv.csv", append = TRUE)

tstas7 <- xts(tas3675$X.100.75, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn7 <- thornthwaite(Tave=tstas7, lat=36.75)
```

```
write.table(thorn7, file="thornindiv.csv", append = TRUE)

tstas8 <- xts(tas3675$X.100.25, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn8 <- thornthwaite(Tave=tstas8, lat=36.75)
write.table(thorn8, file="thornindiv.csv", append = TRUE)

tstas9 <- xts(tas3675$X.99.75, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn9 <- thornthwaite(Tave=tstas9, lat=36.75)
write.table(thorn9, file="thornindiv.csv", append = TRUE)

tstas10 <- xts(tas3675$X.99.25, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn10 <- thornthwaite(Tave=tstas10, lat=36.75)
write.table(thorn10, file="thornindiv.csv", append = TRUE)

tstas11 <- xts(tas3675$X.98.75, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn11 <- thornthwaite(Tave=tstas11, lat=36.75)
write.table(thorn11, file="thornindiv.csv", append = TRUE)

tstas12 <- xts(tas3675$X.98.25, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn12 <- thornthwaite(Tave=tstas12, lat=36.75)
write.table(thorn12, file="thornindiv.csv", append = TRUE)

tstas13 <- xts(tas3675$X.97.75, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn13 <- thornthwaite(Tave=tstas13, lat=36.75)
write.table(thorn13, file="thornindiv.csv", append = TRUE)

tstas14 <- xts(tas3675$X.97.25, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn14 <- thornthwaite(Tave=tstas14, lat=36.75)
write.table(thorn14, file="thornindiv.csv", append = TRUE)

tstas15 <- xts(tas3675$X.96.75, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn15 <- thornthwaite(Tave=tstas15, lat=36.75)
write.table(thorn15, file="thornindiv.csv", append = TRUE)

tstas16 <- xts(tas3675$X.96.25, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn16 <- thornthwaite(Tave=tstas16, lat=36.75)
write.table(thorn16, file="thornindiv.csv", append = TRUE)

tstas17 <- xts(tas3675$X.95.75, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn17 <- thornthwaite(Tave=tstas17, lat=36.75)
write.table(thorn17, file="thornindiv.csv", append = TRUE)

tstas18 <- xts(tas3675$X.95.25, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn18 <- thornthwaite(Tave=tstas18, lat=36.75)
write.table(thorn18, file="thornindiv.csv", append = TRUE)
```

```
tstas19 <- xts(tas3675$X.94.75, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn19 <- thornthwaite(Tave=tstas19, lat=36.75)
write.table(thorn19, file="thornindiv.csv", append = TRUE)

tstas20 <- xts(tas3675$X.94.25, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn20 <- thornthwaite(Tave=tstas20, lat=36.75)
write.table(thorn20, file="thornindiv.csv", append = TRUE)

tstas21 <- xts(tas3675$X.93.75, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn21 <- thornthwaite(Tave=tstas21, lat=36.75)
write.table(thorn21, file="thornindiv.csv", append = TRUE)

tstas22 <- xts(tas3675$X.93.25, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn22 <- thornthwaite(Tave=tstas22, lat=36.75)
write.table(thorn22, file="thornindiv.csv", append = TRUE)

tstas23 <- xts(tas3675$X.92.75, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn23 <- thornthwaite(Tave=tstas23, lat=36.75)
write.table(thorn23, file="thornindiv.csv", append = TRUE)

tstas24 <- xts(tas3675$X.92.25, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn24 <- thornthwaite(Tave=tstas24, lat=36.75)
write.table(thorn24, file="thornindiv.csv", append = TRUE)

tstas25 <- xts(tas3675$X.91.75, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn25 <- thornthwaite(Tave=tstas25, lat=36.75)
write.table(thorn25, file="thornindiv.csv", append = TRUE)

tstas26 <- xts(tas3675$X.91.25, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn26 <- thornthwaite(Tave=tstas26, lat=36.75)
write.table(thorn26, file="thornindiv.csv", append = TRUE)

tstas27 <- xts(tas3675$X.90.75, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn27 <- thornthwaite(Tave=tstas27, lat=36.75)
write.table(thorn27, file="thornindiv.csv", append = TRUE)

tstas28 <- xts(tas3675$X.90.25, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn28 <- thornthwaite(Tave=tstas28, lat=36.75)
write.table(thorn28, file="thornindiv.csv", append = TRUE)

tstas29 <- xts(tas3675$X.89.75, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn29 <- thornthwaite(Tave=tstas29, lat=36.75)
write.table(thorn29, file="thornindiv.csv", append = TRUE)
```

```
tstas30 <- xts(tas3675$X.89.25, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn30 <- thornthwaite(Tave=tstas30, lat=36.75)
write.table(thorn30, file="thornindiv.csv", append = TRUE)

tstas31 <- xts(tas3675$X.88.75, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn31 <- thornthwaite(Tave=tstas31, lat=36.75)
write.table(thorn31, file="thornindiv.csv", append = TRUE)

tstas32 <- xts(tas3675$X.88.25, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn32 <- thornthwaite(Tave=tstas32, lat=36.75)
write.table(thorn32, file="thornindiv.csv", append = TRUE)

tstas33 <- xts(tas3675$X.87.75, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn33 <- thornthwaite(Tave=tstas33, lat=36.75)
write.table(thorn33, file="thornindiv.csv", append = TRUE)

tstas34 <- xts(tas3675$X.87.25, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn34 <- thornthwaite(Tave=tstas34, lat=36.75)
write.table(thorn34, file="thornindiv.csv", append = TRUE)

tstas35 <- xts(tas3675$X.86.75, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn35 <- thornthwaite(Tave=tstas35, lat=36.75)
write.table(thorn35, file="thornindiv.csv", append = TRUE)

tstas36 <- xts(tas3675$X.86.25, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn36 <- thornthwaite(Tave=tstas36, lat=36.75)
write.table(thorn36, file="thornindiv.csv", append = TRUE)

tstas37 <- xts(tas3675$X.85.75, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn37 <- thornthwaite(Tave=tstas37, lat=36.75)
write.table(thorn37, file="thornindiv.csv", append = TRUE)

tstas38 <- xts(tas3675$X.85.25, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn38 <- thornthwaite(Tave=tstas38, lat=36.75)
write.table(thorn38, file="thornindiv.csv", append = TRUE)

tstas39 <- xts(tas3675$X.84.75, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn39 <- thornthwaite(Tave=tstas39, lat=36.75)
write.table(thorn39, file="thornindiv.csv", append = TRUE)

tstas40 <- xts(tas3675$X.84.25, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn40 <- thornthwaite(Tave=tstas40, lat=36.75)
write.table(thorn40, file="thornindiv.csv", append = TRUE)

tstas41 <- xts(tas3675$X.83.75, as.Date(tas3675$Date, format='%m/%d/%Y'))
```

```
thorn41 <- thornthwaite(Tave=tstas41, lat=36.75)
write.table(thorn41, file="thornindiv.csv", append = TRUE)

tstas42 <- xts(tas3675$X.83.25, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn42 <- thornthwaite(Tave=tstas42, lat=36.75)
write.table(thorn42, file="thornindiv.csv", append = TRUE)

tstas43 <- xts(tas3675$X.82.75, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn43 <- thornthwaite(Tave=tstas43, lat=36.75)
write.table(thorn43, file="thornindiv.csv", append = TRUE)

tstas44 <- xts(tas3675$X.82.25, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn44 <- thornthwaite(Tave=tstas44, lat=36.75)
write.table(thorn44, file="thornindiv.csv", append = TRUE)

tstas45 <- xts(tas3675$X.81.75, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn45 <- thornthwaite(Tave=tstas45, lat=36.75)
write.table(thorn45, file="thornindiv.csv", append = TRUE)

tstas46 <- xts(tas3675$X.81.25, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn46 <- thornthwaite(Tave=tstas46, lat=36.75)
write.table(thorn46, file="thornindiv.csv", append = TRUE)

tstas47 <- xts(tas3675$X.80.75, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn47 <- thornthwaite(Tave=tstas47, lat=36.75)
write.table(thorn47, file="thornindiv.csv", append = TRUE)

tstas48 <- xts(tas3675$X.80.25, as.Date(tas3675$Date, format='%m/%d/%Y'))
thorn48 <- thornthwaite(Tave=tstas48, lat=36.75)
write.table(thorn48, file="thornindiv.csv", append = TRUE)


#SPEI Calculation
#Set working directory and load required packages
setwd("C:/Users/mvandop/Dropbox/irrigation_shared")
#library(xts)
library(SPEI)
library(timeSeries)

tasdata = read.csv("ave_tas_celsius_formatall.csv")
lesslongtas = read.csv("lesslong_tas.csv")

#test for single latitude
tas3675 = read.csv("tas_36.75.csv")
#trying to create a time series object
```

```
xts(tas3675$X.103.75, as.Date(tas3675$Date, format='%m/%d/%Y'))
trial2ts3675 <- xts(tas3675[, 3:50], as.Date(tas3675$Date, format='%m/%d/%Y'))
trialtstas <- xts(tasdata[, 3:50], as.Date(tasdata$Date, format='%m/%d/%Y'))
trial3tstas <- xts(lesslongtas[, 3:28], as.Date(lesslongtas$Date, format='%m/%d/%Y'))
thornthwaite(Tave=trialtstas, lat=tasdata$lat)
thornthwaite(Tave=trialts3675, lat=tas3675$lat)
```

Example Map Generation

Code for NPV map in the contemporary period

```
# Load required packages
library(XLConnect)    # for loadWorkbook(...) and readWorksheet(...)
library(rgdal)        # for readOGR(...)
library(RColorBrewer) # for brewer.pal(...)
library(data.table)   # for joining together datasets
library(ggplot2)      # for creating maps
library(maps)         # for overlay work with shp files

# Set working directory
setwd("C:/Users/mvandop/Dropbox/Daily")

# Load Excel workbook and specific worksheet (should contain data identified by FIPS
#code)
wb <- loadWorkbook("NPV_contemp_100meridian_04202016.xlsx")
df <- readWorksheet(wb,"contemp gross margin pr15")        # this sheet has the npv data

# read in Census Bureau county-level shapefile data https://www.census.gov/geo/maps-
#data/data/tiger.html
US.counties <- readOGR(dsn=".",layer="gz_2010_us_050_00_5m")

# Leave out information from states that aren't in the Corn Belt, by State code
US.counties <- US.counties[!(US.counties$STATE %in%
c("01","02","04","05","06","08","09","10","11","12","13","15","16","21","22","23","24",
"25","28","30","32","33","34","35","36","37","40","41","42","44","45","47","48","49","
50","51","53","54","56","72")),]

# Create data frame with county boundary (polygon) data, and identify each polygon with
#FIPS data
county.data <- US.counties@data
county.data <- cbind(id=rownames(county.data),county.data)
county.data <- data.table(county.data)
county.data[,FIPS:=paste0(STATE,COUNTY)] # this is the state + county FIPS code
```

```
as.character(county.data$FIPS)
setkey(county.data,FIPS)
npv.data <- data.table(df)
npv.data$FIPS <- as.character(npv.data$FIPS)
setkey(npv.data,FIPS)
county.data[npv.data,npv:=NPV]

# Use FIPS code to match county polygons to data frame; identify npv data in worksheet
#as the data to be mapped
map.df <- data.table(fortify(US.counties))
setkey(map.df,id)
setkey(county.data,id)
map.df[county.data,npv:=npv]

# Use ggplot to generate map of NPV data
ggplot(map.df, aes(x=long, y=lat, group=group, fill=npv)) +
  scale_fill_gradientn("",colours=brewer.pal(9,"RdYlGn"))+
  geom_polygon()+coord_map()+
  labs(title="Contemporary NPV for Irrigation Investment",x="",y="")+
  theme_bw()
```

Appendix B County-level NPV of Irrigation Investment

County	Contemporary Period (1980-2005)			Future Period (2040-2070)		
FIPS	NPV	IRR before tax	IRR after tax	NPV	IRR before tax	IRR after tax
17001	-77820.18	-0.06	-0.06	3080.26	0.06	0.07
17003	-79022.94	-0.06	-0.07	-72677.00	-0.05	-0.06
17005	-89302.98	-0.08	-0.08	-105371.76	-0.10	-0.11
17007	-77695.47	-0.06	-0.06	9442.40	0.07	0.08
17009	14016.27	0.08	0.09	121204.56	0.24	0.26
17011	-70611.02	-0.05	-0.05	26835.67	0.10	0.11
17013	-70422.13	-0.05	-0.05	-50035.18	-0.02	-0.02
17015	-69384.90	-0.05	-0.05	46455.57	0.13	0.14
17017	-75259.26	-0.06	-0.06	27237.10	0.10	0.11
17019	-71309.99	-0.05	-0.05	-19029.05	0.03	0.03
17021	-59440.28	-0.03	-0.03	-21960.90	0.03	0.03
17023	-105071.46	-0.10	-0.11	-111605.37	-0.11	-0.12
17025	-99147.92	-0.09	-0.10	-78182.31	-0.06	-0.06
17027	-90955.96	-0.08	-0.09	-85282.03	-0.07	-0.08
17029	-62579.49	-0.04	-0.04	-55431.40	-0.03	-0.03
17031	-89197.11	-0.08	-0.08	-5835.43	0.05	0.05
17033	-99531.01	-0.09	-0.10	-113681.78	-0.12	-0.12
17035	-108439.60	-0.11	-0.11	-102135.70	-0.10	-0.10
17037	-69169.50	-0.05	-0.05	25553.18	0.10	0.10
17039	-71496.69	-0.05	-0.05	11051.20	0.08	0.08
17041	-69925.49	-0.05	-0.05	-23559.92	0.02	0.02
17043	-80595.01	-0.06	-0.07	-114.52	0.06	0.06
17045	-61230.52	-0.03	-0.04	-65592.57	-0.04	-0.04
17047	-58018.04	-0.03	-0.03	-18305.93	0.03	0.03
17049	-93831.78	-0.08	-0.09	-84962.95	-0.07	-0.08
17051	-88994.78	-0.08	-0.08	-94654.07	-0.09	-0.09
17053	-76422.76	-0.06	-0.06	-14100.89	0.04	0.04
17055	-70810.45	-0.05	-0.05	-69135.65	-0.05	-0.05
17057	-79826.06	-0.06	-0.07	32450.78	0.11	0.12
17059	-64964.65	-0.04	-0.04	-97718.02	-0.09	-0.10
17061	-70275.77	-0.05	-0.05	8739.02	0.07	0.08
17063	-76481.87	-0.06	-0.06	-25946.41	0.02	0.02
17065	-105806.17	-0.10	-0.11	-125437.32	-0.13	-0.14
17067	-76624.29	-0.06	-0.06	1649.24	0.06	0.07
17069	-93537.78	-0.08	-0.09	-128095.15	-0.14	-0.15
17071	-70249.48	-0.05	-0.05	2920.95	0.06	0.07
17073	-70908.14	-0.05	-0.05	23191.98	0.09	0.10
17075	-77426.16	-0.06	-0.06	-24090.87	0.02	0.02

17077	-83274.01	-0.07	-0.07	-34598.98	0.01	0.01
17079	-98383.62	-0.09	-0.10	-93278.56	-0.08	-0.09
17081	-120572.50	-0.13	-0.13	-101118.26	-0.10	-0.10
17083	-66179.61	-0.04	-0.04	-27614.35	0.02	0.02
17085	-78068.94	-0.06	-0.06	32742.39	0.11	0.12
17087	-78161.91	-0.06	-0.06	-74637.72	-0.06	-0.06
17089	-73116.23	-0.05	-0.06	36452.83	0.11	0.12
17091	-79374.51	-0.06	-0.07	-32908.36	0.01	0.01
17093	-76983.36	-0.06	-0.06	-6134.15	0.05	0.05
17095	-70390.39	-0.05	-0.05	37678.69	0.12	0.12
17097	-94386.47	-0.09	-0.09	13525.70	0.08	0.09
17099	-74739.15	-0.06	-0.06	24108.45	0.10	0.10
17101	-71934.71	-0.05	-0.05	-67094.04	-0.04	-0.05
17103	-70546.24	-0.05	-0.05	13469.40	0.08	0.09
17105	-77247.44	-0.06	-0.06	-8800.03	0.05	0.05
17107	-70383.75	-0.05	-0.05	23076.51	0.09	0.10
17109	-72721.04	-0.05	-0.06	27828.70	0.10	0.11
17111	-81166.40	-0.07	-0.07	38271.15	0.12	0.13
17113	-71915.74	-0.05	-0.05	19355.49	0.09	0.09
17115	-68734.95	-0.05	-0.05	2300.41	0.06	0.07
17117	-66300.60	-0.04	-0.04	-18488.84	0.03	0.03
17119	-75823.51	-0.06	-0.06	-42282.51	-0.01	-0.01
17121	-94096.83	-0.09	-0.09	-85499.80	-0.07	-0.08
17123	-75297.28	-0.06	-0.06	46627.73	0.13	0.14
17125	-80964.74	-0.07	-0.07	22071.62	0.09	0.10
17127	-86371.56	-0.07	-0.08	-119324.56	-0.12	-0.13
17129	-74109.29	-0.05	-0.06	33755.22	0.11	0.12
17131	-70207.32	-0.05	-0.05	7839.47	0.07	0.08
17133	-80615.79	-0.06	-0.07	-55755.78	-0.03	-0.03
17135	-67119.47	-0.04	-0.05	-52014.55	-0.02	-0.02
17137	-74729.64	-0.06	-0.06	35305.86	0.11	0.12
17139	-63437.97	-0.04	-0.04	-37016.45	0.00	0.00
17141	-72082.95	-0.05	-0.05	15601.19	0.08	0.09
17143	-75469.37	-0.06	-0.06	58419.34	0.15	0.16
17145	-84006.31	-0.07	-0.07	-47049.48	-0.01	-0.01
17147	-68884.48	-0.05	-0.05	890.14	0.06	0.06
17149	-71704.19	-0.05	-0.05	-22367.50	0.02	0.03
17151	-87715.21	-0.08	-0.08	-122600.76	-0.13	-0.14
17153	-75246.58	-0.06	-0.06	-78539.45	-0.06	-0.06
17155	-71715.15	-0.05	-0.05	71006.35	0.17	0.18
17157	-87359.28	-0.07	-0.08	-58960.08	-0.03	-0.03
17159	-82765.36	-0.07	-0.07	-63943.54	-0.04	-0.04
17161	-70644.96	-0.05	-0.05	19980.90	0.09	0.10

17163	-78184.04	-0.06	-0.06	-68076.44	-0.05	-0.05
17165	-89211.37	-0.08	-0.08	-123254.61	-0.13	-0.14
17167	-66947.48	-0.04	-0.05	22592.75	0.09	0.10
17169	-79308.69	-0.06	-0.07	16056.55	0.08	0.09
17171	-72368.48	-0.05	-0.05	20543.35	0.09	0.10
17173	-69432.39	-0.05	-0.05	-50317.85	-0.02	-0.02
17175	-69467.50	-0.05	-0.05	46548.77	0.13	0.14
17177	-76054.76	-0.06	-0.06	15801.27	0.08	0.09
17179	-73032.90	-0.05	-0.06	46047.30	0.13	0.14
17181	-74032.74	-0.05	-0.06	-28154.70	0.02	0.02
17183	-70508.72	-0.05	-0.05	-37752.50	0.00	0.00
17185	-53700.56	-0.02	-0.02	-9456.11	0.04	0.05
17187	-67024.22	-0.04	-0.05	17278.47	0.09	0.09
17189	-89766.09	-0.08	-0.08	-78927.51	-0.06	-0.07
17191	-103410.94	-0.10	-0.11	-79224.25	-0.06	-0.07
17193	-70292.29	-0.05	-0.05	-56358.79	-0.03	-0.03
17195	-71976.22	-0.05	-0.05	30489.25	0.11	0.11
17197	-81809.01	-0.07	-0.07	-23473.91	0.02	0.02
17199	-79114.00	-0.06	-0.07	-72564.88	-0.05	-0.06
17201	-80229.99	-0.06	-0.07	8445.02	0.07	0.08
17203	-71805.00	-0.05	-0.05	53122.70	0.14	0.15
18001	-70719.19	-0.05	-0.05	12157.35	0.08	0.08
18003	-71074.07	-0.05	-0.05	44101.02	0.13	0.14
18005	-50283.75	-0.02	-0.02	37383.29	0.12	0.12
18007	-60199.25	-0.03	-0.03	4157.55	0.06	0.07
18009	-71461.66	-0.05	-0.05	-633.73	0.06	0.06
18011	-58523.81	-0.03	-0.03	1301.25	0.06	0.07
18013	-89375.80	-0.08	-0.08	-11919.01	0.04	0.04
18015	-56133.24	-0.03	-0.03	20441.97	0.09	0.10
18017	-61759.02	-0.04	-0.04	28447.91	0.10	0.11
18019	-61157.93	-0.03	-0.04	-37666.29	0.00	0.00
18021	-57614.47	-0.03	-0.03	98001.78	0.21	0.22
18023	-57189.19	-0.03	-0.03	-38.19	0.06	0.06
18025	-97380.11	-0.09	-0.10	-101816.65	-0.10	-0.10
18027	-63341.56	-0.04	-0.04	-55825.89	-0.03	-0.03
18029	-60322.51	-0.03	-0.04	3670.10	0.06	0.07
18031	-46849.97	-0.01	-0.01	-11726.47	0.04	0.04
18033	-80252.21	-0.06	-0.07	45617.98	0.13	0.14
18035	-68417.48	-0.05	-0.05	-13518.33	0.04	0.04
18037	-66399.01	-0.04	-0.05	-60011.26	-0.03	-0.03
18039	-69048.27	-0.05	-0.05	43394.18	0.12	0.13
18041	-62671.56	-0.04	-0.04	-21797.31	0.03	0.03
18043	-92720.96	-0.08	-0.09	-104921.30	-0.10	-0.11

18045	-49950.85	-0.02	-0.02	106233.88	0.22	0.24
18047	-60910.07	-0.03	-0.04	-7010.49	0.05	0.05
18049	-71593.36	-0.05	-0.05	27848.93	0.10	0.11
18051	-55155.15	-0.03	-0.03	-37691.45	0.00	0.00
18053	-64833.11	-0.04	-0.04	20892.67	0.09	0.10
18055	-65592.08	-0.04	-0.04	-11849.50	0.04	0.04
18057	-62577.00	-0.04	-0.04	-18166.81	0.03	0.03
18059	-61430.67	-0.04	-0.04	-35907.15	0.00	0.00
18061	-77396.32	-0.06	-0.06	-102755.61	-0.10	-0.10
18063	-53454.46	-0.02	-0.02	8717.18	0.07	0.08
18065	-65865.07	-0.04	-0.04	-20775.11	0.03	0.03
18067	-57492.35	-0.03	-0.03	30818.29	0.11	0.11
18069	-68460.04	-0.05	-0.05	52040.17	0.14	0.15
18071	-62092.60	-0.04	-0.04	5940.30	0.07	0.07
18073	-70523.84	-0.05	-0.05	-1328.47	0.06	0.06
18075	-76181.59	-0.06	-0.06	-8701.76	0.05	0.05
18077	-58014.51	-0.03	-0.03	-13995.06	0.04	0.04
18079	-55382.67	-0.03	-0.03	-16548.85	0.03	0.04
18081	-56743.66	-0.03	-0.03	-5870.16	0.05	0.05
18083	-55986.25	-0.03	-0.03	-39689.05	0.00	0.00
18085	-67632.82	-0.04	-0.05	39309.50	0.12	0.13
18087	-74151.36	-0.05	-0.06	42369.00	0.12	0.13
18089	-72958.14	-0.05	-0.06	-8377.53	0.05	0.05
18091	-72333.62	-0.05	-0.05	30642.60	0.11	0.11
18093	-77385.68	-0.06	-0.06	-37685.69	0.00	0.00
18095	-58796.50	-0.03	-0.03	-10981.82	0.04	0.05
18097	-64247.10	-0.04	-0.04	-38424.41	0.00	0.00
18099	-70223.99	-0.05	-0.05	15676.74	0.08	0.09
18101	-66677.06	-0.04	-0.05	-54705.88	-0.03	-0.03
18103	-65060.09	-0.04	-0.04	38122.12	0.12	0.13
18105	-69799.10	-0.05	-0.05	1930.07	0.06	0.07
18107	-48506.30	-0.02	-0.02	73689.04	0.17	0.18
18109	-54491.02	-0.02	-0.03	35300.18	0.11	0.12
18111	-65487.09	-0.04	-0.04	-13377.18	0.04	0.04
18113	-73004.47	-0.05	-0.06	49837.86	0.13	0.14
18115	-82799.09	-0.07	-0.07	-14417.31	0.04	0.04
18117	-68822.80	-0.05	-0.05	-50341.62	-0.02	-0.02
18119	-62780.34	-0.04	-0.04	70178.44	0.17	0.18
18121	-52475.50	-0.02	-0.02	131124.59	0.26	0.28
18123	-77583.15	-0.06	-0.06	-85768.90	-0.07	-0.08
18125	-71329.76	-0.05	-0.05	-70879.41	-0.05	-0.05
18127	-70957.09	-0.05	-0.05	16605.87	0.08	0.09
18129	-48681.73	-0.02	-0.02	-50093.51	-0.02	-0.02

18131	-74599.72	-0.06	-0.06	5835.42	0.07	0.07
18133	-51411.09	-0.02	-0.02	103696.88	0.22	0.23
18135	-69135.19	-0.05	-0.05	-6268.03	0.05	0.05
18137	-54204.97	-0.02	-0.03	-20208.53	0.03	0.03
18139	-52913.67	-0.02	-0.02	-18305.84	0.03	0.03
18141	-73954.88	-0.05	-0.06	24425.09	0.10	0.10
18143	-60802.62	-0.03	-0.04	-28540.28	0.01	0.02
18145	-55864.88	-0.03	-0.03	-17037.70	0.03	0.04
18147	-74943.76	-0.06	-0.06	-86607.77	-0.07	-0.08
18149	-79796.81	-0.06	-0.07	-5693.77	0.05	0.05
18151	-79019.77	-0.06	-0.07	47901.57	0.13	0.14
18153	-54733.87	-0.03	-0.03	-38430.50	0.00	0.00
18155	-80966.55	-0.07	-0.07	-28302.94	0.02	0.02
18157	-61669.21	-0.04	-0.04	6652.04	0.07	0.07
18159	-56067.38	-0.03	-0.03	8879.40	0.07	0.08
18161	-56678.92	-0.03	-0.03	-5124.75	0.05	0.05
18163	-62793.93	-0.04	-0.04	-65529.08	-0.04	-0.04
18165	-57212.48	-0.03	-0.03	31168.01	0.11	0.11
18167	-62724.94	-0.04	-0.04	-2679.10	0.05	0.06
18169	-66226.34	-0.04	-0.04	54802.17	0.14	0.15
18171	-57631.44	-0.03	-0.03	28653.83	0.10	0.11
18173	-74259.19	-0.05	-0.06	-88720.77	-0.08	-0.08
18175	-72718.50	-0.05	-0.06	-57968.61	-0.03	-0.03
18177	-66904.05	-0.04	-0.05	-10544.08	0.04	0.05
18179	-68625.37	-0.05	-0.05	27678.31	0.10	0.11
18181	-62951.33	-0.04	-0.04	-11574.71	0.04	0.04
18183	-70306.87	-0.05	-0.05	59139.85	0.15	0.16
19001	-73818.70	-0.05	-0.06	-73118.34	-0.05	-0.06
19003	-75437.98	-0.06	-0.06	-78720.96	-0.06	-0.07
19005	-72440.46	-0.05	-0.05	52244.99	0.14	0.15
19007	-82611.35	-0.07	-0.07	-89108.41	-0.08	-0.08
19009	-72152.16	-0.05	-0.05	-80832.14	-0.06	-0.07
19011	-62714.16	-0.04	-0.04	-247.03	0.06	0.06
19013	-63361.74	-0.04	-0.04	-78143.21	-0.06	-0.06
19015	-67086.29	-0.04	-0.05	-93525.63	-0.08	-0.09
19017	-62305.42	-0.04	-0.04	-87658.79	-0.08	-0.08
19019	-62212.75	-0.04	-0.04	-24684.60	0.02	0.02
19021	-69110.28	-0.05	-0.05	-63656.51	-0.04	-0.04
19023	-68561.61	-0.05	-0.05	-130727.65	-0.14	-0.15
19025	-69020.33	-0.05	-0.05	-67858.81	-0.05	-0.05
19027	-69963.88	-0.05	-0.05	-82704.69	-0.07	-0.07
19029	-73577.14	-0.05	-0.06	-80119.00	-0.06	-0.07
19031	-55096.26	-0.03	-0.03	44418.72	0.13	0.14

19033	-68899.61	-0.05	-0.05	-134454.23	-0.15	-0.16
19035	-68003.00	-0.05	-0.05	-61938.70	-0.04	-0.04
19037	-68274.21	-0.05	-0.05	-109593.61	-0.11	-0.12
19039	-86389.53	-0.07	-0.08	-85389.02	-0.07	-0.08
19041	-74031.60	-0.05	-0.06	-82198.81	-0.07	-0.07
19043	-66541.96	-0.04	-0.05	46341.98	0.13	0.14
19045	-60135.18	-0.03	-0.03	67146.18	0.16	0.17
19047	-74722.86	-0.06	-0.06	-83464.18	-0.07	-0.07
19049	-67839.55	-0.05	-0.05	-88156.56	-0.08	-0.08
19051	-80169.42	-0.06	-0.07	-64235.84	-0.04	-0.04
19053	-82479.40	-0.07	-0.07	-88763.49	-0.08	-0.08
19055	-61308.04	-0.04	-0.04	31801.93	0.11	0.12
19057	-65599.80	-0.04	-0.04	6162.49	0.07	0.07
19059	-78140.48	-0.06	-0.06	-140626.86	-0.16	-0.17
19061	-65220.75	-0.04	-0.04	69885.69	0.17	0.18
19063	-74860.23	-0.06	-0.06	-155651.50	-0.18	-0.19
19065	-64639.68	-0.04	-0.04	-36601.26	0.00	0.00
19067	-68744.58	-0.05	-0.05	-131993.74	-0.14	-0.15
19069	-67968.96	-0.05	-0.05	-127990.03	-0.14	-0.15
19071	-67541.32	-0.04	-0.05	-101063.32	-0.10	-0.10
19073	-67037.82	-0.04	-0.05	-88949.91	-0.08	-0.08
19075	-63471.28	-0.04	-0.04	-124677.91	-0.13	-0.14
19077	-72872.81	-0.05	-0.06	-86067.28	-0.07	-0.08
19079	-67187.98	-0.04	-0.05	-117523.48	-0.12	-0.13
19081	-69594.19	-0.05	-0.05	-134452.81	-0.15	-0.16
19083	-65694.82	-0.04	-0.04	-130495.59	-0.14	-0.15
19085	-72243.14	-0.05	-0.05	-90012.48	-0.08	-0.08
19087	-66411.16	-0.04	-0.05	19108.84	0.09	0.09
19089	-71346.61	-0.05	-0.05	-124992.77	-0.13	-0.14
19091	-69035.16	-0.05	-0.05	-80237.83	-0.06	-0.07
19093	-71653.35	-0.05	-0.05	-74201.55	-0.05	-0.06
19095	-65075.30	-0.04	-0.04	24745.59	0.10	0.10
19097	-69497.98	-0.05	-0.05	66299.88	0.16	0.17
19099	-62768.04	-0.04	-0.04	-32583.88	0.01	0.01
19101	-73315.31	-0.05	-0.06	-14687.48	0.04	0.04
19103	-65998.09	-0.04	-0.04	17360.98	0.09	0.09
19105	-61678.34	-0.04	-0.04	51820.50	0.14	0.15
19107	-65706.59	-0.04	-0.04	10527.59	0.07	0.08
19109	-71717.63	-0.05	-0.05	-121395.01	-0.13	-0.13
19111	-72800.97	-0.05	-0.06	1688.04	0.06	0.07
19113	-63734.28	-0.04	-0.04	18376.34	0.09	0.09
19115	-67994.55	-0.05	-0.05	-2634.25	0.05	0.06
19117	-83117.82	-0.07	-0.07	-73246.03	-0.05	-0.06

19119	-77716.19	-0.06	-0.06	-68783.48	-0.05	-0.05
19121	-73032.80	-0.05	-0.06	-76788.67	-0.06	-0.06
19123	-64636.93	-0.04	-0.04	-10927.09	0.04	0.05
19125	-71338.31	-0.05	-0.05	-39190.90	0.00	0.00
19127	-61956.49	-0.04	-0.04	-69582.50	-0.05	-0.05
19129	-70600.41	-0.05	-0.05	-102811.30	-0.10	-0.10
19131	-66553.31	-0.04	-0.05	-138164.49	-0.15	-0.16
19133	-76550.14	-0.06	-0.06	-96542.69	-0.09	-0.09
19135	-81641.23	-0.07	-0.07	-68027.50	-0.05	-0.05
19137	-71747.74	-0.05	-0.05	-88358.66	-0.08	-0.08
19139	-65127.75	-0.04	-0.04	13313.13	0.08	0.08
19141	-69631.55	-0.05	-0.05	-37624.79	0.00	0.00
19143	-76629.14	-0.06	-0.06	-83905.51	-0.07	-0.07
19145	-73771.56	-0.05	-0.06	-101041.43	-0.10	-0.10
19147	-73646.28	-0.05	-0.06	-80523.51	-0.06	-0.07
19149	-68208.04	-0.05	-0.05	-28378.58	0.02	0.02
19151	-68566.62	-0.05	-0.05	-41766.47	-0.01	0.00
19153	-65406.37	-0.04	-0.04	-53972.93	-0.02	-0.02
19155	-70440.68	-0.05	-0.05	-100733.96	-0.10	-0.10
19157	-64618.70	-0.04	-0.04	2854.15	0.06	0.07
19159	-84106.46	-0.07	-0.07	-90369.06	-0.08	-0.08
19161	-71415.76	-0.05	-0.05	-76843.21	-0.06	-0.06
19163	-54394.88	-0.02	-0.03	44131.37	0.13	0.14
19165	-71284.88	-0.05	-0.05	-78435.51	-0.06	-0.06
19167	-66297.68	-0.04	-0.04	-11375.90	0.04	0.04
19169	-66780.48	-0.04	-0.05	-92636.86	-0.08	-0.09
19171	-62899.85	-0.04	-0.04	-27036.68	0.02	0.02
19173	-83864.67	-0.07	-0.07	-99761.52	-0.09	-0.10
19175	-78676.49	-0.06	-0.07	-77545.82	-0.06	-0.06
19177	-77866.43	-0.06	-0.06	-20908.34	0.03	0.03
19179	-71764.85	-0.05	-0.05	-45514.56	-0.01	-0.01
19181	-74016.72	-0.05	-0.06	-64129.84	-0.04	-0.04
19183	-62918.97	-0.04	-0.04	25817.90	0.10	0.11
19185	-85137.04	-0.07	-0.08	-89615.88	-0.08	-0.08
19187	-67117.06	-0.04	-0.05	-88695.26	-0.08	-0.08
19189	-69888.42	-0.05	-0.05	-142590.47	-0.16	-0.17
19191	-69184.23	-0.05	-0.05	-38389.94	0.00	0.00
19193	-77860.28	-0.06	-0.06	-68909.84	-0.05	-0.05
19195	-66227.33	-0.04	-0.04	-137505.64	-0.15	-0.16
19197	-68498.87	-0.05	-0.05	-122384.85	-0.13	-0.14
20001	2318.08	0.06	0.07	-38873.77	0.00	0.00
20003	44660.39	0.13	0.14	6814.06	0.07	0.07
20005	13438.12	0.08	0.09	-16800.88	0.03	0.04

20007	125573.62	0.25	0.27	106425.18	0.22	0.24
20009	148499.61	0.29	0.31	102733.03	0.22	0.23
20011	45178.73	0.13	0.14	4027.80	0.06	0.07
20013	-40668.31	0.00	0.00	-68122.09	-0.05	-0.05
20015	35741.79	0.11	0.12	-35423.77	0.00	0.01
20017	32443.85	0.11	0.12	-24825.65	0.02	0.02
20019	8439.40	0.07	0.08	-49539.74	-0.02	-0.02
20021	24513.90	0.10	0.10	-4841.87	0.05	0.06
20025	98362.31	0.21	0.22	231417.54	0.41	0.44
20027	96723.62	0.21	0.22	57105.18	0.15	0.16
20029	86646.85	0.19	0.20	48097.48	0.13	0.14
20031	72261.30	0.17	0.18	37420.07	0.12	0.12
20033	135529.64	0.27	0.28	199795.34	0.36	0.39
20035	81239.88	0.18	0.20	9601.40	0.07	0.08
20037	31778.38	0.11	0.12	8571.79	0.07	0.08
20041	82080.80	0.18	0.20	47458.85	0.13	0.14
20043	-56638.36	-0.03	-0.03	-106248.30	-0.10	-0.11
20045	42282.18	0.12	0.13	6445.89	0.07	0.07
20047	175502.59	0.33	0.35	135155.46	0.27	0.28
20049	228937.68	0.41	0.44	158903.30	0.30	0.32
20051	92063.47	0.20	0.21	163901.69	0.31	0.33
20053	56471.56	0.14	0.16	1894.88	0.06	0.07
20057	148669.18	0.29	0.31	259185.22	0.45	0.49
20059	39613.79	0.12	0.13	-2647.00	0.05	0.06
20061	47431.98	0.13	0.14	9414.39	0.07	0.08
20065	112935.09	0.23	0.25	314143.25	0.54	0.58
20073	23151.21	0.09	0.10	-35702.47	0.00	0.01
20077	158392.92	0.30	0.32	88437.90	0.19	0.21
20079	133397.18	0.26	0.28	72171.74	0.17	0.18
20083	145410.20	0.28	0.30	195871.43	0.36	0.38
20085	-1340.47	0.06	0.06	-44627.38	-0.01	-0.01
20087	46175.66	0.13	0.14	17586.36	0.09	0.09
20089	96352.51	0.21	0.22	76387.77	0.18	0.19
20091	14028.94	0.08	0.09	-21447.73	0.03	0.03
20095	159742.48	0.30	0.32	88926.95	0.19	0.21
20097	206023.20	0.37	0.40	209188.73	0.38	0.40
20099	46272.89	0.13	0.14	12129.08	0.08	0.08
20103	-16934.05	0.03	0.04	-56684.77	-0.03	-0.03
20105	57972.80	0.15	0.16	12353.65	0.08	0.08
20107	207649.17	0.38	0.40	122540.01	0.25	0.26
20111	28911.41	0.10	0.11	-19488.73	0.03	0.03
20113	142380.11	0.28	0.30	85003.06	0.19	0.20
20115	74597.18	0.17	0.18	26325.45	0.10	0.11

20117	29231.20	0.10	0.11	8499.23	0.07	0.08
20121	-10340.57	0.04	0.05	-57891.19	-0.03	-0.03
20123	66781.42	0.16	0.17	36288.87	0.11	0.12
20125	22660.48	0.09	0.10	-19493.02	0.03	0.03
20127	20858.41	0.09	0.10	-23511.91	0.02	0.02
20131	-23256.76	0.02	0.03	-55859.32	-0.03	-0.03
20133	18243.33	0.09	0.09	-13790.23	0.04	0.04
20135	68544.68	0.16	0.18	134815.79	0.26	0.28
20137	110631.87	0.23	0.24	144763.04	0.28	0.30
20139	36960.87	0.12	0.12	-5585.82	0.05	0.05
20141	83260.19	0.19	0.20	87268.33	0.19	0.21
20143	58333.27	0.15	0.16	12909.84	0.08	0.08
20145	137344.11	0.27	0.29	79918.07	0.18	0.19
20147	121624.67	0.24	0.26	79847.27	0.18	0.19
20149	65778.28	0.16	0.17	20771.25	0.09	0.10
20151	162789.09	0.31	0.33	111876.82	0.23	0.25
20155	131458.92	0.26	0.28	55675.89	0.14	0.15
20157	97587.16	0.21	0.22	80719.47	0.18	0.19
20159	138691.62	0.27	0.29	73734.01	0.17	0.18
20161	44650.07	0.13	0.14	-432.36	0.06	0.06
20163	85664.59	0.19	0.20	173175.75	0.32	0.35
20165	136092.30	0.27	0.29	135451.89	0.27	0.28
20167	101482.92	0.21	0.23	99750.86	0.21	0.23
20169	74357.81	0.17	0.18	21639.36	0.09	0.10
20173	132751.12	0.26	0.28	57742.38	0.15	0.16
20177	59923.10	0.15	0.16	18220.26	0.09	0.09
20183	58712.68	0.15	0.16	7198.08	0.07	0.08
20185	173110.35	0.32	0.35	102277.79	0.22	0.23
20191	112690.12	0.23	0.25	33730.12	0.11	0.12
20195	81739.82	0.18	0.20	259639.92	0.46	0.49
20197	61382.71	0.15	0.16	16761.56	0.08	0.09
20201	66265.96	0.16	0.17	49223.72	0.13	0.14
20205	24312.18	0.10	0.10	-12371.57	0.04	0.04
20207	13601.29	0.08	0.09	-27972.90	0.02	0.02
20209	237576.06	0.42	0.45	189763.40	0.35	0.37
26001	-123248.21	-0.13	-0.14	38113.15	0.12	0.13
26003	-111915.40	-0.11	-0.12	142542.24	0.28	0.30
26005	-61431.17	-0.04	-0.04	55767.43	0.14	0.15
26007	-97344.18	-0.09	-0.10	88518.35	0.19	0.21
26009	-129394.72	-0.14	-0.15	146705.55	0.28	0.30
26011	-59550.04	-0.03	-0.03	51410.66	0.14	0.15
26015	-59204.45	-0.03	-0.03	86535.94	0.19	0.20
26017	-49276.30	-0.02	-0.02	10159.29	0.07	0.08

26021	-62644.72	-0.04	-0.04	32458.60	0.11	0.12
26023	-55132.34	-0.03	-0.03	49688.58	0.13	0.14
26025	-61982.99	-0.04	-0.04	62747.20	0.15	0.17
26027	-61365.19	-0.04	-0.04	39101.27	0.12	0.13
26029	-100446.53	-0.09	-0.10	87067.66	0.19	0.21
26031	-114300.57	-0.12	-0.12	248060.50	0.44	0.47
26035	-96640.11	-0.09	-0.09	77484.82	0.18	0.19
26037	-57277.79	-0.03	-0.03	58245.36	0.15	0.16
26045	-54390.77	-0.02	-0.03	84152.57	0.19	0.20
26047	-102301.26	-0.10	-0.10	91180.94	0.20	0.21
26049	-71588.43	-0.05	-0.05	33866.40	0.11	0.12
26051	-67918.01	-0.05	-0.05	68417.86	0.16	0.17
26055	-109303.34	-0.11	-0.12	65923.94	0.16	0.17
26057	-48260.51	-0.02	-0.02	70927.14	0.17	0.18
26059	-61897.76	-0.04	-0.04	18037.34	0.09	0.09
26063	-46764.90	-0.01	-0.01	-8505.37	0.05	0.05
26065	-58294.49	-0.03	-0.03	55558.84	0.14	0.15
26067	-55761.91	-0.03	-0.03	125921.14	0.25	0.27
26069	-91001.41	-0.08	-0.09	66907.88	0.16	0.17
26073	-70528.63	-0.05	-0.05	124181.36	0.25	0.27
26075	-65818.60	-0.04	-0.04	31553.89	0.11	0.11
26077	-59585.73	-0.03	-0.03	62667.92	0.15	0.17
26079	-102427.16	-0.10	-0.10	64964.89	0.16	0.17
26081	-64256.07	-0.04	-0.04	112352.26	0.23	0.25
26085	-146562.43	-0.17	-0.18	89118.34	0.19	0.21
26087	-59936.55	-0.03	-0.03	43734.04	0.13	0.13
26089	-111805.74	-0.11	-0.12	47927.03	0.13	0.14
26091	-46088.77	-0.01	-0.01	29075.26	0.10	0.11
26093	-67707.51	-0.04	-0.05	24469.52	0.10	0.10
26097	-117275.29	-0.12	-0.13	212719.42	0.38	0.41
26099	-53226.20	-0.02	-0.02	-4580.17	0.05	0.06
26101	-106893.56	-0.10	-0.11	61926.30	0.15	0.16
26105	-90562.85	-0.08	-0.08	91883.47	0.20	0.21
26107	-91822.83	-0.08	-0.09	91107.84	0.20	0.21
26109	-103560.66	-0.10	-0.11	48354.57	0.13	0.14
26111	-51097.86	-0.02	-0.02	80391.28	0.18	0.19
26115	-44307.94	-0.01	-0.01	-3602.46	0.05	0.06
26117	-71345.87	-0.05	-0.05	105143.35	0.22	0.23
26119	-94204.36	-0.09	-0.09	91315.22	0.20	0.21
26121	-78652.12	-0.06	-0.07	74350.61	0.17	0.18
26123	-78636.71	-0.06	-0.06	76383.45	0.18	0.19
26125	-80905.41	-0.07	-0.07	5655.32	0.07	0.07
26127	-92377.63	-0.08	-0.09	47294.00	0.13	0.14

26129	-82793.01	-0.07	-0.07	54640.29	0.14	0.15
26131	-112736.69	-0.11	-0.12	73492.39	0.17	0.18
26133	-101738.99	-0.10	-0.10	74851.48	0.17	0.19
26139	-66946.28	-0.04	-0.05	73555.23	0.17	0.18
26141	-95397.92	-0.09	-0.09	129049.65	0.26	0.27
26145	-51172.52	-0.02	-0.02	261.35	0.06	0.06
26147	-46725.40	-0.01	-0.01	-29028.93	0.01	0.02
26149	-51538.92	-0.02	-0.02	76169.30	0.18	0.19
26151	-53756.49	-0.02	-0.02	486.26	0.06	0.06
26153	-113645.33	-0.12	-0.12	173626.18	0.32	0.35
26155	-64179.20	-0.04	-0.04	10401.96	0.07	0.08
26157	-49019.93	-0.02	-0.02	31213.11	0.11	0.11
26159	-70200.01	-0.05	-0.05	12033.42	0.08	0.08
26161	-64941.67	-0.04	-0.04	20606.45	0.09	0.10
26163	-67749.96	-0.04	-0.05	-39826.88	0.00	0.00
26165	-111609.26	-0.11	-0.12	49777.52	0.13	0.14
27001	-89395.28	-0.08	-0.08	-45513.00	-0.01	-0.01
27003	-41251.19	0.00	0.00	73700.20	0.17	0.18
27005	-50272.80	-0.02	-0.02	56521.43	0.15	0.16
27007	-123926.89	-0.13	-0.14	-94429.90	-0.09	-0.09
27009	-31741.44	0.01	0.01	66888.97	0.16	0.17
27011	-35858.12	0.00	0.00	36706.70	0.11	0.12
27013	6830.20	0.07	0.07	-22425.05	0.02	0.03
27015	2354.30	0.06	0.07	-13202.72	0.04	0.04
27019	4168.61	0.07	0.07	63034.71	0.16	0.17
27021	-125551.63	-0.13	-0.14	-38846.44	0.00	0.00
27023	-16120.70	0.03	0.04	-5615.93	0.05	0.05
27025	-35364.94	0.00	0.01	79906.21	0.18	0.19
27027	-36928.69	0.00	0.00	-4509.11	0.05	0.06
27029	-66774.66	-0.04	-0.05	8082.53	0.07	0.08
27033	-3415.91	0.05	0.06	-35889.22	0.00	0.00
27035	-89097.12	-0.08	-0.08	27219.21	0.10	0.11
27037	6594.35	0.07	0.07	125465.73	0.25	0.27
27039	7155.67	0.07	0.07	19847.80	0.09	0.10
27041	-37897.88	0.00	0.00	34102.17	0.11	0.12
27043	10536.59	0.07	0.08	-45731.67	-0.01	-0.01
27045	9601.92	0.07	0.08	100316.43	0.21	0.23
27047	11534.21	0.08	0.08	-25474.23	0.02	0.02
27049	11313.93	0.08	0.08	125749.47	0.25	0.27
27051	-27400.71	0.02	0.02	33854.80	0.11	0.12
27053	-10030.13	0.04	0.05	116553.71	0.24	0.25
27055	14177.20	0.08	0.09	186208.83	0.34	0.37
27057	-96110.12	-0.09	-0.09	-1252.42	0.06	0.06

27059	-39995.17	0.00	0.00	66361.43	0.16	0.17
27063	-1237.29	0.06	0.06	-74383.64	-0.06	-0.06
27065	-41437.85	0.00	0.00	59061.40	0.15	0.16
27067	-11266.27	0.04	0.04	4912.78	0.07	0.07
27069	-78892.70	-0.06	-0.07	19364.31	0.09	0.09
27071	-102598.41	-0.10	-0.10	-68068.26	-0.05	-0.05
27073	-27965.63	0.02	0.02	2402.33	0.06	0.07
27077	-87651.47	-0.08	-0.08	-60119.99	-0.03	-0.03
27079	5205.26	0.07	0.07	55112.71	0.14	0.15
27081	-32529.95	0.01	0.01	-9565.08	0.04	0.05
27083	-16608.88	0.03	0.04	16203.44	0.08	0.09
27085	-1017.66	0.06	0.06	7412.11	0.07	0.08
27087	-51524.79	-0.02	-0.02	61194.88	0.15	0.16
27089	-64534.31	-0.04	-0.04	-34337.81	0.01	0.01
27091	9643.66	0.07	0.08	-67952.83	-0.05	-0.05
27093	-13952.91	0.04	0.04	39301.71	0.12	0.13
27095	-34987.79	0.01	0.01	81379.57	0.18	0.20
27097	-42620.75	-0.01	-0.01	57364.47	0.15	0.16
27099	11103.98	0.08	0.08	-6970.96	0.05	0.05
27101	-15433.60	0.04	0.04	-20058.32	0.03	0.03
27103	11651.22	0.08	0.08	21505.49	0.09	0.10
27105	-11174.64	0.04	0.05	-48143.38	-0.01	-0.02
27107	-47240.57	-0.01	-0.01	-71017.85	-0.05	-0.05
27109	10061.62	0.07	0.08	38728.76	0.12	0.13
27111	-31040.31	0.01	0.01	51769.94	0.14	0.15
27113	-72255.05	-0.05	-0.05	-28427.97	0.02	0.02
27115	-38340.53	0.00	0.00	83600.35	0.19	0.20
27117	-25269.44	0.02	0.02	-24407.74	0.02	0.02
27119	-49654.91	-0.02	-0.02	-26.09	0.06	0.06
27121	-25424.54	0.02	0.02	-11453.12	0.04	0.04
27123	-55747.45	-0.03	-0.03	50273.29	0.14	0.15
27125	-58363.03	-0.03	-0.03	58498.67	0.15	0.16
27127	-3741.49	0.05	0.06	10601.20	0.07	0.08
27129	2483.45	0.06	0.07	7442.63	0.07	0.08
27131	9237.21	0.07	0.08	110914.82	0.23	0.24
27133	-4104.02	0.05	0.06	-20095.43	0.03	0.03
27135	-66738.06	-0.04	-0.05	43848.31	0.13	0.13
27139	4199.34	0.07	0.07	123567.29	0.25	0.26
27141	-22625.79	0.02	0.03	90640.78	0.20	0.21
27143	-2323.11	0.06	0.06	18372.92	0.09	0.09
27145	-23284.37	0.02	0.03	48969.15	0.13	0.14
27147	6047.57	0.07	0.07	61561.73	0.15	0.16
27149	-19762.07	0.03	0.03	19734.29	0.09	0.10

27151	-22580.69	0.02	0.03	-21094.72	0.03	0.03
27153	-39483.20	0.00	0.00	29732.39	0.10	0.11
27155	-29492.68	0.01	0.02	-6366.85	0.05	0.05
27157	17670.07	0.09	0.09	109536.12	0.23	0.24
27159	-41349.20	0.00	0.00	30468.15	0.11	0.11
27161	10875.61	0.08	0.08	39058.75	0.12	0.13
27163	-4125.06	0.05	0.06	133475.17	0.26	0.28
27165	6955.75	0.07	0.07	-41044.83	0.00	0.00
27167	-36149.32	0.00	0.00	-12186.92	0.04	0.04
27169	16063.96	0.08	0.09	146527.81	0.28	0.30
27171	-11552.42	0.04	0.04	82222.57	0.18	0.20
27173	-15436.94	0.04	0.04	11165.46	0.08	0.08
29001	-4083.95	0.05	0.06	3910.42	0.06	0.07
29003	6501.11	0.07	0.07	-32409.00	0.01	0.01
29005	18151.23	0.09	0.09	-6919.32	0.05	0.05
29007	-17341.35	0.03	0.03	-65511.85	-0.04	-0.04
29009	-22355.00	0.02	0.03	-26090.70	0.02	0.02
29011	6979.79	0.07	0.07	-35691.90	0.00	0.01
29013	-21571.53	0.03	0.03	-87787.11	-0.08	-0.08
29015	-4916.25	0.05	0.06	-39873.01	0.00	0.00
29017	-6142.52	0.05	0.05	20863.36	0.09	0.10
29019	-2084.57	0.06	0.06	596.52	0.06	0.06
29021	17123.26	0.08	0.09	-35860.44	0.00	0.00
29023	9687.82	0.07	0.08	-12206.46	0.04	0.04
29025	-6327.01	0.05	0.05	-26145.77	0.02	0.02
29027	-75.29	0.06	0.06	1522.66	0.06	0.07
29031	11336.91	0.08	0.08	57059.67	0.15	0.16
29033	13716.58	0.08	0.09	-817.94	0.06	0.06
29037	-4154.19	0.05	0.06	-60039.13	-0.03	-0.03
29039	-13917.14	0.04	0.04	-12249.83	0.04	0.04
29041	7628.85	0.07	0.08	29612.31	0.10	0.11
29045	1647.16	0.06	0.07	61637.17	0.15	0.16
29047	8172.70	0.07	0.08	-25973.46	0.02	0.02
29049	9378.73	0.07	0.08	-28706.45	0.01	0.02
29051	3189.77	0.06	0.07	47222.71	0.13	0.14
29053	3595.89	0.06	0.07	7892.28	0.07	0.08
29055	-29045.89	0.01	0.02	21665.11	0.09	0.10
29057	-9069.18	0.04	0.05	-19548.00	0.03	0.03
29061	-3920.14	0.05	0.06	-15090.93	0.04	0.04
29063	-3159.44	0.05	0.06	-29977.21	0.01	0.01
29065	-38812.42	0.00	0.00	-5195.13	0.05	0.05
29069	12997.97	0.08	0.08	-37879.14	0.00	0.00
29071	3158.16	0.06	0.07	31600.69	0.11	0.11

29073	-6783.69	0.05	0.05	30357.74	0.11	0.11
29075	-823.53	0.06	0.06	-16230.14	0.03	0.04
29077	-23337.36	0.02	0.03	-10404.29	0.04	0.05
29079	-778.63	0.06	0.06	-5639.03	0.05	0.05
29081	-3412.81	0.05	0.06	-4070.06	0.05	0.06
29083	-16505.96	0.03	0.04	-50868.27	-0.02	-0.02
29085	-21161.89	0.03	0.03	-15986.35	0.03	0.04
29087	20820.51	0.09	0.10	-19860.59	0.03	0.03
29089	8709.08	0.07	0.08	-6320.49	0.05	0.05
29093	-31769.77	0.01	0.01	-1496.15	0.06	0.06
29095	8382.51	0.07	0.08	-28666.37	0.01	0.02
29097	-608.79	0.06	0.06	-48337.80	-0.02	-0.02
29099	-11797.84	0.04	0.04	12305.00	0.08	0.08
29101	-4517.37	0.05	0.06	-37983.14	0.00	0.00
29103	-2110.86	0.06	0.06	-23345.01	0.02	0.03
29105	-29505.26	0.01	0.02	-12877.18	0.04	0.04
29107	23813.30	0.10	0.10	-8593.79	0.05	0.05
29109	-9444.27	0.04	0.05	-19083.81	0.03	0.03
29111	2360.21	0.06	0.07	45688.65	0.13	0.14
29113	-13930.99	0.04	0.04	-25201.62	0.02	0.02
29115	-5506.07	0.05	0.05	13198.85	0.08	0.08
29117	877.10	0.06	0.06	-5797.33	0.05	0.05
29119	-75244.42	-0.06	-0.06	-92823.80	-0.08	-0.09
29121	-2873.96	0.05	0.06	-2131.32	0.06	0.06
29123	-34678.31	0.01	0.01	-8917.50	0.05	0.05
29125	-25342.84	0.02	0.02	12181.85	0.08	0.08
29127	10100.69	0.07	0.08	36716.75	0.11	0.12
29129	-3326.54	0.05	0.06	-4496.11	0.05	0.06
29131	-429.90	0.06	0.06	-1422.88	0.06	0.06
29133	35299.77	0.11	0.12	11576.99	0.08	0.08
29135	-5753.21	0.05	0.05	-5837.73	0.05	0.05
29137	-24749.86	0.02	0.02	-71444.72	-0.05	-0.05
29139	-5433.06	0.05	0.05	-24591.02	0.02	0.02
29141	-10686.71	0.04	0.05	-59608.96	-0.03	-0.03
29143	26407.50	0.10	0.11	-19578.11	0.03	0.03
29145	-18048.02	0.03	0.03	-45197.64	-0.01	-0.01
29147	2596.16	0.06	0.07	-20637.05	0.03	0.03
29151	8494.12	0.07	0.08	59102.93	0.15	0.16
29157	9394.11	0.07	0.08	64684.10	0.16	0.17
29159	-24112.29	0.02	0.02	-60310.83	-0.03	-0.04
29161	40138.56	0.12	0.13	82716.92	0.19	0.20
29163	8349.16	0.07	0.08	19511.39	0.09	0.10
29165	16589.67	0.08	0.09	-28925.42	0.01	0.02

29167	-41277.07	0.00	0.00	-12961.10	0.04	0.04
29169	401.78	0.06	0.06	13987.90	0.08	0.09
29171	-8250.90	0.05	0.05	-183.92	0.06	0.06
29173	2254.27	0.06	0.07	-11224.86	0.04	0.04
29175	-7376.28	0.05	0.05	-8595.52	0.05	0.05
29177	-5487.17	0.05	0.05	-32406.52	0.01	0.01
29179	-3398.78	0.05	0.06	14877.38	0.08	0.09
29181	-45128.35	-0.01	-0.01	-16460.38	0.03	0.04
29183	8017.82	0.07	0.08	17129.37	0.08	0.09
29185	4489.96	0.07	0.07	-22638.89	0.02	0.03
29186	-46489.82	-0.01	-0.01	39.25	0.06	0.06
29187	-9450.43	0.04	0.05	39465.24	0.12	0.13
29189	1187.30	0.06	0.07	22786.09	0.09	0.10
29195	20074.16	0.09	0.10	18736.70	0.09	0.09
29197	-6773.03	0.05	0.05	6470.31	0.07	0.07
29199	-2413.51	0.05	0.06	30336.09	0.11	0.11
29201	-31633.66	0.01	0.01	-30210.49	0.01	0.01
29205	-29045.51	0.01	0.02	-70438.92	-0.05	-0.05
29207	-36137.23	0.00	0.00	-37690.38	0.00	0.00
29211	-17336.84	0.03	0.04	-195.99	0.06	0.06
29217	-15122.96	0.04	0.04	-64949.88	-0.04	-0.04
29219	-113976.73	-0.12	-0.12	-109708.51	-0.11	-0.12
29223	-122576.22	-0.13	-0.14	-101444.42	-0.10	-0.10
29227	-18621.09	0.03	0.03	-30441.71	0.01	0.01
31001	90724.05	0.20	0.21	82855.15	0.19	0.20
31003	91252.62	0.20	0.21	132810.45	0.26	0.28
31011	37462.93	0.12	0.12	42217.09	0.12	0.13
31015	103205.07	0.22	0.23	195599.92	0.36	0.38
31017	93961.48	0.20	0.22	237444.81	0.42	0.45
31019	128129.06	0.25	0.27	178703.34	0.33	0.35
31021	-35957.34	0.00	0.00	-54506.29	-0.02	-0.03
31023	48832.32	0.13	0.14	3471.01	0.06	0.07
31025	-5334.05	0.05	0.05	-31705.31	0.01	0.01
31027	14982.99	0.08	0.09	55973.26	0.14	0.15
31035	77295.94	0.18	0.19	75149.37	0.17	0.19
31037	10457.45	0.07	0.08	-37467.09	0.00	0.00
31039	-13871.64	0.04	0.04	-17075.95	0.03	0.04
31041	96136.06	0.21	0.22	237636.85	0.42	0.45
31043	-3472.56	0.05	0.06	24561.75	0.10	0.10
31047	110941.57	0.23	0.24	205291.62	0.37	0.40
31051	-6553.69	0.05	0.05	36971.13	0.12	0.12
31053	-26599.04	0.02	0.02	-75961.32	-0.06	-0.06
31055	-29181.39	0.01	0.02	-60391.67	-0.03	-0.04

31059	73864.15	0.17	0.18	68890.90	0.16	0.18
31061	100036.89	0.21	0.23	34914.39	0.11	0.12
31065	105874.74	0.22	0.24	79547.80	0.18	0.19
31067	35867.13	0.11	0.12	28629.51	0.10	0.11
31071	59265.82	0.15	0.16	83453.66	0.19	0.20
31073	116803.77	0.24	0.25	96930.95	0.21	0.22
31077	90655.26	0.20	0.21	141609.66	0.28	0.29
31079	109913.68	0.23	0.24	151572.69	0.29	0.31
31081	63357.92	0.16	0.17	71521.04	0.17	0.18
31083	93929.26	0.20	0.22	9916.48	0.07	0.08
31089	121065.42	0.24	0.26	209223.61	0.38	0.40
31093	71166.02	0.17	0.18	123016.70	0.25	0.26
31095	54594.57	0.14	0.15	45609.07	0.13	0.14
31097	53350.40	0.14	0.15	47031.19	0.13	0.14
31099	101187.57	0.21	0.23	69026.80	0.16	0.18
31103	99674.55	0.21	0.23	293357.55	0.51	0.54
31107	36024.30	0.11	0.12	93724.56	0.20	0.22
31109	7117.56	0.07	0.07	-21637.05	0.03	0.03
31115	75412.31	0.17	0.19	104250.84	0.22	0.23
31119	5282.48	0.07	0.07	16996.07	0.08	0.09
31121	59738.98	0.15	0.16	77303.14	0.18	0.19
31125	46367.48	0.13	0.14	55875.07	0.14	0.15
31127	13185.89	0.08	0.08	-3675.99	0.05	0.06
31129	86435.78	0.19	0.20	83290.67	0.19	0.20
31131	21009.85	0.09	0.10	4557.67	0.07	0.07
31133	46664.01	0.13	0.14	38008.42	0.12	0.13
31137	111219.55	0.23	0.24	58608.59	0.15	0.16
31139	51681.11	0.14	0.15	114047.02	0.23	0.25
31141	16042.62	0.08	0.09	-7558.19	0.05	0.05
31143	39907.08	0.12	0.13	31337.84	0.11	0.11
31147	16807.49	0.08	0.09	-3054.24	0.05	0.06
31149	65445.83	0.16	0.17	130840.93	0.26	0.28
31151	60039.72	0.15	0.16	54052.48	0.14	0.15
31153	-13338.58	0.04	0.04	-42340.22	-0.01	-0.01
31155	15315.39	0.08	0.09	-39425.14	0.00	0.00
31159	48176.10	0.13	0.14	28457.26	0.10	0.11
31163	99648.74	0.21	0.23	175985.31	0.33	0.35
31167	-2955.42	0.05	0.06	32713.36	0.11	0.12
31169	92753.65	0.20	0.21	82813.74	0.19	0.20
31173	-19088.26	0.03	0.03	7326.70	0.07	0.08
31175	101614.66	0.21	0.23	147305.64	0.28	0.30
31177	-45466.49	-0.01	-0.01	-63571.27	-0.04	-0.04
31179	8151.58	0.07	0.08	52885.11	0.14	0.15

31181	91748.90	0.20	0.21	61607.84	0.15	0.16
31183	80393.53	0.18	0.19	138734.98	0.27	0.29
31185	50897.02	0.14	0.15	43670.33	0.13	0.13
38003	-20995.30	0.03	0.03	63090.77	0.16	0.17
38005	-56639.14	-0.03	-0.03	-35951.21	0.00	0.00
38017	-16477.56	0.03	0.04	10027.68	0.07	0.08
38019	-63151.27	-0.04	-0.04	-41093.82	0.00	0.00
38021	-3606.35	0.05	0.06	58237.09	0.15	0.16
38027	-28885.24	0.01	0.02	32951.57	0.11	0.12
38029	11152.01	0.08	0.08	90095.22	0.20	0.21
38031	-33561.89	0.01	0.01	28412.15	0.10	0.11
38035	-22359.23	0.02	0.03	20857.30	0.09	0.10
38039	-57166.06	-0.03	-0.03	14023.85	0.08	0.09
38043	6350.63	0.07	0.07	69400.61	0.16	0.18
38045	-8474.56	0.05	0.05	58055.22	0.15	0.16
38047	22465.85	0.09	0.10	105407.64	0.22	0.24
38051	-45823.87	-0.01	-0.01	14011.48	0.08	0.09
38063	-44019.71	-0.01	-0.01	8645.55	0.07	0.08
38067	-37009.65	0.00	0.00	88281.28	0.19	0.21
38069	-64201.22	-0.04	-0.04	-83166.68	-0.07	-0.07
38071	-32173.56	0.01	0.01	-39585.93	0.00	0.00
38073	-11279.60	0.04	0.04	47686.72	0.13	0.14
38077	-33148.05	0.01	0.01	21598.73	0.09	0.10
38079	14268.02	0.08	0.09	-13201.42	0.04	0.04
38081	-22131.11	0.02	0.03	58480.80	0.15	0.16
38091	-32865.40	0.01	0.01	229.04	0.06	0.06
38093	-19075.51	0.03	0.03	53591.39	0.14	0.15
38095	-72354.76	-0.05	-0.05	-105706.97	-0.10	-0.11
38097	-53031.23	-0.02	-0.02	-77679.92	-0.06	-0.06
38099	-76387.32	-0.06	-0.06	-37636.74	0.00	0.00
38103	-61291.32	-0.04	-0.04	-34662.79	0.01	0.01
39001	-151925.60	-0.17	-0.18	-94077.26	-0.09	-0.09
39003	-158366.50	-0.18	-0.20	-73933.39	-0.05	-0.06
39005	-161753.20	-0.19	-0.20	-85155.38	-0.07	-0.08
39007	-162657.33	-0.19	-0.20	-114728.22	-0.12	-0.12
39009	-164397.72	-0.19	-0.20	-205630.15	-0.26	-0.27
39011	-157795.16	-0.18	-0.19	-66123.95	-0.04	-0.04
39015	-139808.81	-0.16	-0.16	-54566.16	-0.02	-0.03
39017	-149168.50	-0.17	-0.18	-70178.50	-0.05	-0.05
39019	-162048.08	-0.19	-0.20	-167626.87	-0.20	-0.21
39021	-154130.36	-0.18	-0.19	-65188.49	-0.04	-0.04
39023	-152852.26	-0.18	-0.19	-62411.37	-0.04	-0.04
39025	-138055.56	-0.15	-0.16	-45200.36	-0.01	-0.01

39027	-140746.80	-0.16	-0.17	-42172.38	-0.01	-0.01
39029	-161787.92	-0.19	-0.20	-115892.92	-0.12	-0.13
39031	-151622.61	-0.17	-0.18	-172053.10	-0.20	-0.22
39033	-154072.39	-0.18	-0.19	-49596.94	-0.02	-0.02
39037	-155656.81	-0.18	-0.19	-79344.44	-0.06	-0.07
39039	-163094.33	-0.19	-0.20	-70439.92	-0.05	-0.05
39041	-156292.80	-0.18	-0.19	-79985.36	-0.06	-0.07
39043	-151982.11	-0.17	-0.18	-83804.37	-0.07	-0.07
39045	-151962.05	-0.17	-0.18	-138740.34	-0.15	-0.16
39047	-145291.80	-0.16	-0.17	-48411.50	-0.02	-0.02
39049	-155709.28	-0.18	-0.19	-81254.12	-0.07	-0.07
39051	-149092.60	-0.17	-0.18	-38085.48	0.00	0.00
39053	-163594.91	-0.19	-0.20	-212035.40	-0.27	-0.28
39055	-174047.04	-0.21	-0.22	-123831.08	-0.13	-0.14
39057	-154001.29	-0.18	-0.19	-72785.22	-0.05	-0.06
39059	-145083.17	-0.16	-0.17	-192861.83	-0.24	-0.25
39061	-130449.02	-0.14	-0.15	-23967.23	0.02	0.02
39063	-153415.69	-0.18	-0.19	-56173.93	-0.03	-0.03
39065	-158987.73	-0.18	-0.20	-56505.51	-0.03	-0.03
39067	-190304.17	-0.23	-0.25	-255757.62	-0.33	-0.35
39069	-147706.44	-0.17	-0.18	-62709.48	-0.04	-0.04
39071	-138612.47	-0.15	-0.16	-29271.93	0.01	0.02
39073	-154130.97	-0.18	-0.19	-164201.57	-0.19	-0.20
39075	-161409.45	-0.19	-0.20	-139871.15	-0.16	-0.16
39077	-158700.11	-0.18	-0.20	-71503.23	-0.05	-0.05
39079	-146628.11	-0.17	-0.18	-179748.67	-0.22	-0.23
39083	-157096.09	-0.18	-0.19	-92475.29	-0.08	-0.09
39087	-149418.05	-0.17	-0.18	-205037.19	-0.25	-0.27
39089	-154696.04	-0.18	-0.19	-126499.83	-0.13	-0.14
39091	-158753.10	-0.18	-0.20	-65496.38	-0.04	-0.04
39093	-163188.56	-0.19	-0.20	-82264.57	-0.07	-0.07
39095	-148673.06	-0.17	-0.18	-39253.35	0.00	0.00
39097	-153414.89	-0.18	-0.19	-67700.08	-0.04	-0.05
39099	-162689.48	-0.19	-0.20	-114431.61	-0.12	-0.12
39101	-156611.91	-0.18	-0.19	-69154.08	-0.05	-0.05
39103	-162480.63	-0.19	-0.20	-97917.58	-0.09	-0.10
39105	-165471.81	-0.19	-0.21	-213352.99	-0.27	-0.28
39107	-158320.51	-0.18	-0.19	-82255.12	-0.07	-0.07
39109	-154249.37	-0.18	-0.19	-62497.86	-0.04	-0.04
39111	-179387.85	-0.22	-0.23	-260311.47	-0.34	-0.36
39113	-157920.27	-0.18	-0.19	-77895.83	-0.06	-0.06
39115	-152294.08	-0.17	-0.19	-190724.84	-0.23	-0.25
39117	-157367.66	-0.18	-0.19	-77256.41	-0.06	-0.06

39119	-153138.29	-0.18	-0.19	-182633.76	-0.22	-0.23
39123	-150014.03	-0.17	-0.18	-71163.99	-0.05	-0.05
39125	-162690.54	-0.19	-0.20	-87504.77	-0.08	-0.08
39127	-149185.17	-0.17	-0.18	-186880.80	-0.23	-0.24
39129	-150476.83	-0.17	-0.18	-101352.30	-0.10	-0.10
39131	-147401.29	-0.17	-0.18	-116782.85	-0.12	-0.13
39133	-163551.18	-0.19	-0.20	-116406.03	-0.12	-0.13
39135	-154751.69	-0.18	-0.19	-87372.67	-0.07	-0.08
39137	-155588.47	-0.18	-0.19	-70367.38	-0.05	-0.05
39139	-157921.73	-0.18	-0.19	-72253.73	-0.05	-0.05
39141	-148905.52	-0.17	-0.18	-85829.18	-0.07	-0.08
39143	-151360.78	-0.17	-0.18	-45088.23	-0.01	-0.01
39145	-143547.20	-0.16	-0.17	-98721.76	-0.09	-0.10
39147	-156104.91	-0.18	-0.19	-63518.45	-0.04	-0.04
39149	-156623.38	-0.18	-0.19	-67645.68	-0.04	-0.05
39151	-160799.48	-0.19	-0.20	-115393.14	-0.12	-0.12
39153	-174569.92	-0.21	-0.22	-123345.80	-0.13	-0.14
39155	-160201.98	-0.19	-0.20	-110214.51	-0.11	-0.12
39157	-155176.94	-0.18	-0.19	-161923.84	-0.19	-0.20
39159	-159266.97	-0.18	-0.20	-65888.49	-0.04	-0.04
39161	-159245.45	-0.18	-0.20	-89203.93	-0.08	-0.08
39165	-147035.55	-0.17	-0.18	-54548.24	-0.02	-0.03
39167	-151449.99	-0.17	-0.18	-192487.56	-0.24	-0.25
39169	-157113.88	-0.18	-0.19	-90914.16	-0.08	-0.09
39171	-162531.87	-0.19	-0.20	-47164.17	-0.01	-0.01
39173	-148796.87	-0.17	-0.18	-42816.03	-0.01	-0.01
39175	-157817.51	-0.18	-0.19	-54250.01	-0.02	-0.03
46003	-61686.43	-0.04	-0.04	39406.67	0.12	0.13
46005	-9226.87	0.04	0.05	78404.48	0.18	0.19
46009	28473.90	0.10	0.11	64611.28	0.16	0.17
46011	-44132.90	-0.01	-0.01	-20010.98	0.03	0.03
46013	-38916.98	0.00	0.00	8875.44	0.07	0.08
46015	53144.01	0.14	0.15	175141.99	0.33	0.35
46017	24928.77	0.10	0.10	170760.33	0.32	0.34
46021	7302.82	0.07	0.08	77204.92	0.18	0.19
46023	53612.41	0.14	0.15	90479.23	0.20	0.21
46025	-26628.78	0.02	0.02	7220.68	0.07	0.08
46027	-14526.29	0.04	0.04	45942.03	0.13	0.14
46029	-27586.56	0.02	0.02	1727.39	0.06	0.07
46035	-15542.48	0.03	0.04	19044.11	0.09	0.09
46037	-26623.91	0.02	0.02	28700.47	0.10	0.11
46039	-96609.38	-0.09	-0.09	-73137.19	-0.05	-0.06
46043	-4496.19	0.05	0.06	37757.90	0.12	0.12

46045	-112048.63	-0.11	-0.12	-71536.96	-0.05	-0.05
46049	-102822.17	-0.10	-0.10	-38781.58	0.00	0.00
46051	-53003.77	-0.02	-0.02	-22371.58	0.02	0.03
46053	18917.59	0.09	0.09	69110.40	0.16	0.18
46057	-59096.38	-0.03	-0.03	-42076.37	-0.01	-0.01
46059	-15623.92	0.03	0.04	136094.96	0.27	0.29
46061	-84779.28	-0.07	-0.08	-47374.81	-0.01	-0.01
46065	64485.78	0.16	0.17	135802.73	0.27	0.28
46067	19768.58	0.09	0.10	64563.57	0.16	0.17
46069	-64487.36	-0.04	-0.04	48375.54	0.13	0.14
46073	-14446.56	0.04	0.04	87225.30	0.19	0.21
46077	-45785.75	-0.01	-0.01	-12549.63	0.04	0.04
46079	-21586.80	0.03	0.03	14110.14	0.08	0.09
46083	-29955.17	0.01	0.01	-2406.59	0.05	0.06
46085	70795.28	0.17	0.18	162956.54	0.31	0.33
46087	-63228.39	-0.04	-0.04	-9568.27	0.04	0.05
46089	-85450.72	-0.07	-0.08	-32785.61	0.01	0.01
46091	-81392.69	-0.07	-0.07	-13036.95	0.04	0.04
46097	-80478.29	-0.06	-0.07	-45803.63	-0.01	-0.01
46099	-62794.43	-0.04	-0.04	-25172.46	0.02	0.02
46101	-52516.55	-0.02	-0.02	-44384.07	-0.01	-0.01
46107	23247.46	0.09	0.10	68242.95	0.16	0.17
46109	-56973.62	-0.03	-0.03	-3046.95	0.05	0.06
46111	-76902.29	-0.06	-0.06	-23510.94	0.02	0.02
46115	-24502.20	0.02	0.02	35190.02	0.11	0.12
46117	73849.00	0.17	0.18	172618.55	0.32	0.34
46119	34303.96	0.11	0.12	92454.78	0.20	0.21
46123	16519.20	0.08	0.09	101025.58	0.21	0.23
46125	-23165.84	0.02	0.03	39069.69	0.12	0.13
46127	-23654.43	0.02	0.02	12084.94	0.08	0.08
46129	-3532.02	0.05	0.06	77417.50	0.18	0.19
46135	3157.65	0.06	0.07	48512.89	0.13	0.14
55001	35427.95	0.11	0.12	210269.79	0.38	0.41
55005	35839.96	0.11	0.12	202646.62	0.37	0.39
55007	10721.04	0.08	0.08	213962.78	0.39	0.41
55009	31057.43	0.11	0.11	176246.74	0.33	0.35
55011	60717.11	0.15	0.16	214404.48	0.39	0.41
55013	17861.88	0.09	0.09	186073.96	0.34	0.37
55015	51349.41	0.14	0.15	227333.41	0.41	0.43
55017	45534.91	0.13	0.14	192591.12	0.35	0.38
55019	34324.43	0.11	0.12	177826.08	0.33	0.35
55021	70067.74	0.17	0.18	297986.58	0.51	0.55
55023	64961.26	0.16	0.17	226217.00	0.40	0.43

55025	81839.90	0.18	0.20	259647.22	0.46	0.49
55027	75971.40	0.17	0.19	310426.81	0.53	0.57
55029	37432.75	0.12	0.12	240661.30	0.43	0.46
55033	43523.27	0.13	0.13	194061.55	0.36	0.38
55035	46609.42	0.13	0.14	200293.17	0.36	0.39
55039	60435.68	0.15	0.16	271252.14	0.47	0.51
55043	83705.33	0.19	0.20	254463.04	0.45	0.48
55045	81154.46	0.18	0.20	213647.25	0.39	0.41
55047	57745.02	0.15	0.16	289601.15	0.50	0.54
55049	64891.46	0.16	0.17	225531.80	0.40	0.43
55051	-27456.11	0.02	0.02	190636.56	0.35	0.37
55053	48821.92	0.13	0.14	202897.17	0.37	0.39
55055	63502.30	0.16	0.17	248966.95	0.44	0.47
55057	49266.33	0.13	0.14	240605.00	0.43	0.46
55059	64975.33	0.16	0.17	242762.98	0.43	0.46
55061	43521.92	0.13	0.13	223208.74	0.40	0.43
55063	55943.93	0.14	0.15	217894.71	0.39	0.42
55065	91238.98	0.20	0.21	217639.83	0.39	0.42
55067	43199.22	0.12	0.13	198743.14	0.36	0.39
55069	2999.65	0.06	0.07	119630.96	0.24	0.26
55071	45153.84	0.13	0.14	225729.67	0.40	0.43
55073	36280.54	0.11	0.12	179926.47	0.33	0.36
55075	26605.88	0.10	0.11	231349.01	0.41	0.44
55077	36475.61	0.11	0.12	252450.79	0.44	0.48
55079	39469.77	0.12	0.13	220993.25	0.40	0.42
55081	46259.72	0.13	0.14	215153.73	0.39	0.41
55083	30898.17	0.11	0.11	208617.29	0.38	0.40
55087	54586.20	0.14	0.15	204501.63	0.37	0.40
55089	48564.89	0.13	0.14	257231.99	0.45	0.48
55091	55233.77	0.14	0.15	213279.94	0.38	0.41
55093	58164.20	0.15	0.16	227771.21	0.41	0.43
55095	39817.99	0.12	0.13	203776.56	0.37	0.40
55097	46135.11	0.13	0.14	205665.78	0.37	0.40
55101	65914.81	0.16	0.17	262557.21	0.46	0.49
55103	56648.69	0.15	0.16	245846.19	0.43	0.46
55105	84076.57	0.19	0.20	229314.13	0.41	0.44
55107	17354.14	0.09	0.09	146611.86	0.28	0.30
55109	40748.91	0.12	0.13	192837.31	0.35	0.38
55111	65440.91	0.16	0.17	283108.04	0.49	0.53
55113	1593.68	0.06	0.07	164966.56	0.31	0.33
55115	40788.84	0.12	0.13	183971.80	0.34	0.36
55117	49094.53	0.13	0.14	252483.61	0.44	0.48
55119	20602.50	0.09	0.10	159881.02	0.30	0.32

55121	57138.32	0.15	0.16	218136.63	0.39	0.42
55123	62125.70	0.15	0.16	246663.85	0.44	0.47
55127	72162.31	0.17	0.18	249754.91	0.44	0.47
55129	10837.59	0.08	0.08	190024.53	0.35	0.37
55131	48674.56	0.13	0.14	246769.71	0.44	0.47
55133	56400.57	0.14	0.16	262148.66	0.46	0.49
55135	42032.31	0.12	0.13	182929.49	0.34	0.36
55137	51489.62	0.14	0.15	245847.95	0.43	0.46
55139	50148.34	0.14	0.15	233298.47	0.42	0.44
55141	89766.56	0.20	0.21	270880.86	0.47	0.51

Appendix C Useful to Usable Irrigation Investment DST

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