REGIONAL DIFFERENCES IN CORN ETHANOL PRODUCTION:

PROFITABILITY AND POTENTIAL WATER DEMANDS

A Dissertation

by

LINDSEY MARIE HIGGINS

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2009

Major Subject: Agricultural Economics

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Approved by:

Chair of Committee,	James W. Richardson
Committee Members,	Richard M. Feldman
	Bruce A. McCarl
	Joe L. Outlaw
Head of Department,	John P. Nichols

May 2009

Major Subject: Agricultural Economics

ABSTRACT

Regional Differences in Corn Ethanol Production: Profitability and Potential Water Demands. (May 2009)

Lindsey Marie Higgins, B.S., California Polytechnic State University;

M.S., Texas A&M University

Chair of Advisory Committee: Dr. James W. Richardson

Through the use of a stochastic simulation model this project analyzes both the impacts of the expanding biofuels sector on water demand in selected regions of the United States and variations in the profitability of ethanol production due to location differences. Changes in consumptive water use in the Texas High Plains, Southern Minnesota, and the Central Valley of California, as impacted by current and proposed grain-based ethanol plants were addressed. In addition, this research assesses the potential impacts of technologies to reduce consumptive water use in the production of ethanol in terms of water usage and the economic viability of each ethanol facility. This research quantifies the role of corn ethanol production on water resource availability and identifies the alternative water pricing schemes at which ethanol production is no longer profitable.

The results of this research show that the expansion of regional ethanol production and the resulting changes in the regional agricultural landscapes do relatively little to change consumptive water usage in each location. The California Central Valley

has the highest potential for increased water usage with annual water usage in 2017 at levels 15% higher than historical estimates, whereas Southern Minnesota and the Texas High Plains are predicted to have increases of less than 5% during the same time period. Although water use by ethanol plants is extremely minor relative to consumptive regional agricultural water usage, technological adaptations by ethanol facilities have the potential to slightly reduce water usage and prove to be economically beneficial adaptations to make. The sensitivity of net present value (NPV) with respect to changes in water price is shown to be extremely inelastic, indicating that ethanol producers have the ability to pay significantly more for their fresh water with little impact on their 10 year economic performance.

DEDICATION

To Grandma Martha and Grandma Ludwick.

ACKNOWLEDGMENTS

I would like to thank my committee chair, Dr. Richardson, and my committee members, Dr. Outlaw, Dr. McCarl, and Dr. Feldman, for their guidance and support throughout the course of this research. I am particularly indebted to Dr. Richardson for his unwavering encouragement, support, and enthusiasm. I've been inspired by his passion for his work and the effectiveness at which he communicates that passion to his students and his colleagues. Dr. Richardson is a guide, a teacher, a role model, and a motivator: he has been an incredible mentor to me and I can't thank him enough for everything that I have gained through knowing him and having had the privilege of working with him.

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I feel incredibly lucky to have been able to go through the PhD program with Jody Campiche. I'm certain things would have been far more difficult had we not gone through this together. From sharing the pain of qualifier preparations to celebrating our small successes and from earning the "same grade as her" to becoming each others confidants, she has been a true friend and I am very thankful for that.

After knowing each other for more than 10 years, it took moving to College Station for Michael and I to start dating. Now, five years later, it is clear that moving to College Station was the best decision I've ever made. Michael is the most generous, energetic, and forgiving person I have ever met. He is more than I could have ever hoped to find in a partner. I can't thank him enough for his endless support.

And most importantly, thank you to my family. I am overwhelmed with love when I think about the incredible family I was blessed with. My mom, Lynne, has been a tireless champion of my cause. Never doubting what I could do, my mom has the ability to restore my confidence and put my concerns to rest, no matter what they are or when they occur. I'm inspired by my mom's love, her patience, and her caring nature. I grew up constantly learning things from my dad, Greg, be it about CA native vegetation, motorcycle mechanics, or how to love and appreciate life. And now, even as an adult, I continue to learn from him every day. I'm inspired by his strength, his determination, and his commitment. Beckie, Lauren, Mikey, Mel, and Guy-- thank you all for your support, the encouragement you have given me throughout these 10 years of school, and your ability to make me laugh when I need it the most.

NOMENCLATURE

BGY	Billion Gallons per Year
BRAC	Break Even Risk Aversion Coefficient
CDF	Cumulative Density Function
DDGS	Dried Distillers Grains with Solubles
DWG	Distillers Wet Grains
ET	Evapotranspiration
GSD	Generalized Stochastic Dominance
KOV	Key Output Variable
MGY	Million Gallons per Year
NPV	Net Present Value
PDF	Probability Density Function
RAC	Risk Aversion Coefficient
RFS	Renewable Fuel Standard
SDRF	Stochastic Dominance with Respect to a Function
SERF	Stochastic Efficiency with Respect to a Function

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CHAPTER I

INTRODUCTION

The popularity of ethanol as a near-term alternative fuel over petroleum has rapidly expanded in the United States since 2000. This emphasis on ethanol is due to increased volatility in gasoline prices, the ban on methyl tertiary butyl ether (MTBE) as an octane booster and fuel extender, and due to legislation with the 2005 Energy Policy Act and the subsequent Energy Independence and Security Act of 2007, which mandated 36 billion gallons per year (BGY) of renewable fuel use by 2022. Ethanol production in the United States has increased from 1.47 BGY in 1999 to 6.5 BGY in 2007, using more than 2.4 billion bushels of grain (Renewable Fuels Association 2008a). Ethanol and other biofuels are considered a domestic source of energy that will likely play a substantial role in transportation fuels in the future (Tyson et al. 2004).

Water plays an important role in the production of ethanol and is generally employed as either process water or non-process water. Process water refers to water that mixes directly with ethanol, while non-process water is used in the cooking and cooling stages of production (Zeman 2006). Fresh water is used in the ethanol plant, the boiler, and the cooling tower (Swain 2006). The primary consumptive use of water during the ethanol production process is through evaporation that occurs during cooling

---

This dissertation follows the style of the *American Journal of Agricultural Economics*.

and through waste water discharge (Keeney and Muller 2006). As much as 68% of water used by an ethanol plant is used in the cooling tower (Aden 2007; Rajagopalan 2008; Singh 2008; Wenninger 2007). A large portion of the water used in the cooling tower will be lost to evaporation. Nearly 20% of total water used will become part of the final product being produced (either the ethanol itself or the stillage) (Aden 2007; Rajagopalan 2008; Singh 2008; Wenninger 2007). Although many of today's ethanol plants are designed to have zero waste water from water used in the ethanol plant, waste water is produced from water used in the boiler and cooling tower and must be treated according to local regulations (Burnes et al. 2004; Millison 2008).

Access to an adequate supply of fresh water to satisfy the demands of residential, commercial, and agricultural uses is essential for life, economic growth, and sustainability. Hydrological models project that growing demands for freshwater will surmount the dwindling supply of available water (Falkenmark et al. 1998; Revenga et al. 2000; Vorosmarty et al. 2000). There is a broad acceptance that water-stressed areas (regions that have suffered prolonged water scarcity) have seen water play a definitive role in local, regional, and international disputes (Amery 2002). The U.S. General Accounting Office (2003) reported that under normal weather conditions, over the next 10 years, water managers in 36 states expect to see water shortages (U.S. General Accounting Office 2003). A U.S. Department of Energy report to Congress stresses that "available surface water supplies have not increased in 20 years, and ground water tables and supplies are dropping at an alarming rate" (U.S. Department of Energy 2006). Technological solutions for these water supply shortfalls will be inadequate remedies in

the sense that demandside policies will have to be engaged as well (Griffin 2006). Among these policies are revised and strengthened bodies-of-water law, as well as evolving systems of water marketing and water pricing. As a consequence, economically oriented studies of water issues and approaches have become important contributions toward finding solutions.

Estimates on water use from ethanol production range from 3 to 14 gallons of water per gallon of ethanol produced (Beck 2005; Clayworth 2007; Shapouri and Gallagher 2005). The Minnesota Department of Natural Resources maintains records of ethanol plants' use of water and reports that water usage is generally between 3.5 to 6.0 gallons of water per gallon of ethanol produced (Keeney and Muller 2006; TIAX LLC 2007). Assuming the average ethanol production plant uses 4 gallons of water per gallon of ethanol produced, water use by ethanol production plants was estimated to be more than 25 billion gallons (approximately 79,600 acre-feet) based on the estimated 2007 U.S. ethanol production capacity from the Renewable Fuels Association (2008a). For comparison purposes, the state of Colorado used approximately 75,000 acre-feet for residential purposes in 2000 (Hutson et al. 2005). With expanding ethanol capacities predicted to reach 17 BGY by 2014, fresh water usage by ethanol plants could exceed 209,000 acre-feet annually (Bryant et al. 2006).

Feedstocks are considered to be the largest input cost for the ethanol plants, accounting for up to 70% of per gallon costs (Coltrain 2004; U.S. Department of Agriculture 2006). Corn is the primary feedstock used for ethanol production in the United States, serving as the feedstock for 95% of U.S. ethanol production in 2004

(Coltrain 2004). Consequently, there is a tendency to locate ethanol plants near available corn.

As new ethanol plants go into production, their water demands will compound the water demands of corn growers and other agriculture users in each region. Barbier (2004) found that water scarcity issues are likely to impact the agricultural sector with more immediacy than other water-demanding sectors. Berndes (2002) suggested that biofuel production, such as ethanol, will directly compete with agricultural uses for available water. Tiffany and Eidman (2003) found that ethanol plants located where water availability is limited are particularly vulnerable to economic failure. The following figure, Figure 1, inspired by a similar schematic used by Fingerman, Kammen, and O'Hare (2008) shows the consumptive and non-consumptive uses of water from the field where the feedstock is produced through the production of ethanol.

One option for decreasing the consumptive use of fresh water by ethanol plants is the use of recycled water; although the water doesn't need to be potable, the quality of the recycled water is of concern to ethanol producers (Mowbray and Hume 2007). Water quality is important as a build-up of mineral deposits in the tubing could cause damage to the heat recovery steam generator (Mowbray and Hume 2007). The cooling systems, which utilize the largest quantity of water, is also subject to scaling and this water frequently needs to be softened to reduce the presence of minerals (Mowbray and Hume 2007; Stanich 2007). When low mineral counts are present in the water being used, water can be recirculated within the plant's system before treating it as waste water (Mowbray and Hume 2007). Other external sources of recycled water include storm

water, treated waste water, and reclaimed ground water, with the proper methods, all have the potential of being used in an ethanol plant (Wenninger 2007).

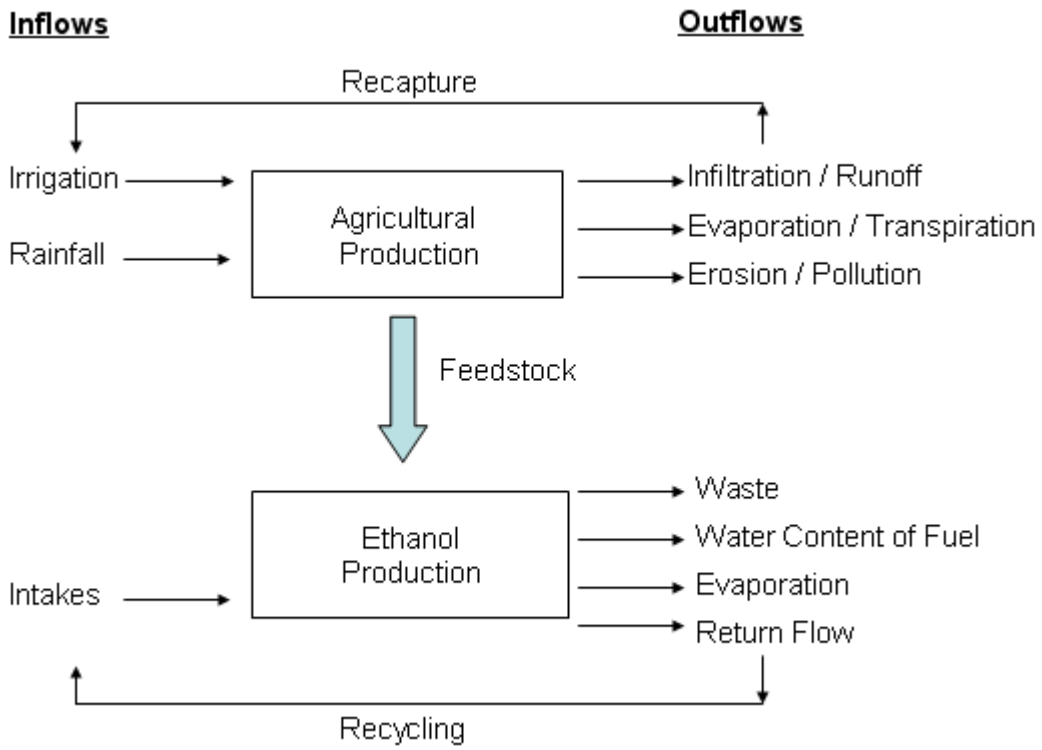

Figure 1. Inflows and Outflows of Water Use in Ethanol Production

As with any growing industry, technologies are being developed that improve the water efficiency of ethanol production. One example is that of membrane technologies, which allows for the use of the ethanol plant's own recycled water in the boiler and cooling tower, thus decreasing the plant's need for fresh water supplies (Coltrain 2004; Whims 2002). Estimates of improved water use efficiencies through utilization of vanguard technologies have put fresh water usage of ethanol facilities at a reduced

amount of 1.5 gallons of water per gallon of ethanol produced (Swain 2006). However, adoption of these technologies is often costly and is often best implemented at the time of construction as it may be even more costly to change the system later on (Wenninger 2007). In order for a plant to adopt such a technology there must be an economic incentive. When water costs are very low, there is little incentive for the ethanol plant to take on the cost of water reduction technologies. However, "water quality and treatment have a significant impact on the profitability of an ethanol plant" and technologies that reduce waste water production may be more likely to be adopted by an ethanol facility (Mowbray and Hume 2007).

The demands a potential ethanol plant will have on local water supplies has not gone without notice. A proposed ethanol plant near Tampa Bay, Florida faced strong opposition from the city of Tampa due to the plant's requested use of 800,000 gallons of water each day at full capacity (Zink 2007). Other new plant proposals are facing similar challenges. A proposed plant near Champaign, IL has been asked to study their potential impact on the Mahomet aquifer before proceeding with construction (Paul 2006). Local communities throughout the country have become vocal about the potential impact of a new ethanol facility on their water resources.

The Texas Water Development Board (2002) makes water use projections based upon type of use and region. Based upon current water supplies, the Texas Water Development Board (2002) estimated that Texas will have an unmet annual need for 7.6 million acre-feet of water for all demand sectors by 2050. The High Plains region of Texas has had many water shortage issues, resulting in adaptations to counteract the

problem. Historically, corn was grown in this region, but as a response to water quantity shortages, the region changed toward the production of less water intensive crops, like cotton (see Figure 2). However, in response to higher corn prices, crop land has been converted from cotton to corn and is expected to continue being converted in upcoming years and thus the demands for agricultural water will likely increase (NASS 2007).

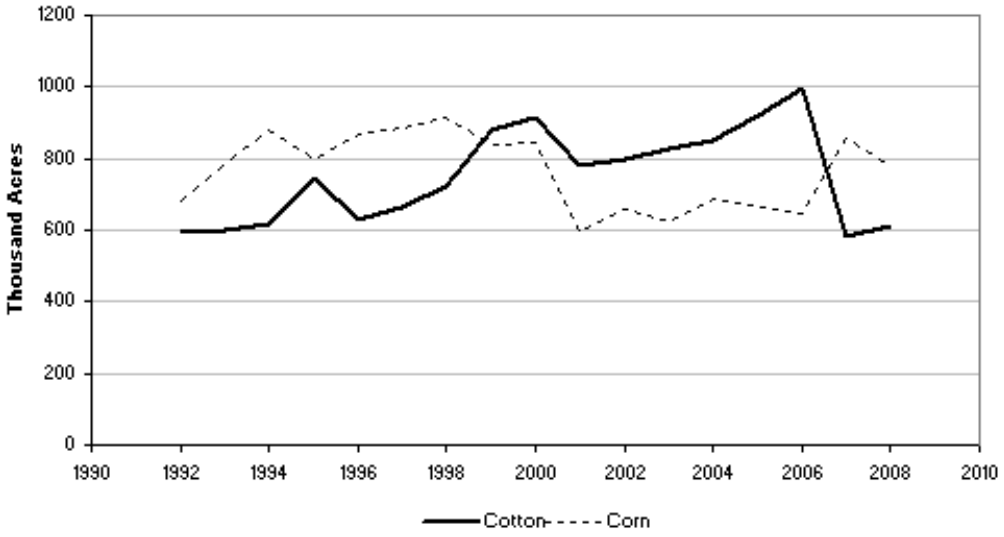

Figure 2. Planted Acreages of Corn and Cotton in the Texas Northern High Plains[1]

The impact an ethanol plant will have on water supplies is dependent upon a number of properties, including the size of the plant, whether the corn is being grown locally or being imported from the Midwest, and the properties of the local fresh water supplies (Keeney and Muller 2006). The majority of water users in the Texas High

[1] Data Source: National Agriculture Statistics Service (2008)

Plains region pump water out of the Ogallala aquifer (also known as the High Plains aquifer). The Ogallala aquifer is one of the world's largest aquifers, lying under eight states in the High Plains region of the U.S. and provides water for an estimated 20% of U.S. irrigated land and drinking water for an estimated 2.3 million people (Dennehy, Litke, and McMahon 2002; Rosenberg et al. 1999).

Unsustainable withdrawals from the Ogallala aquifer have been a public concern since the 1970s (Peterson, Marsh, and Williams 2003; Warren et al. 1982). Although the recharge rates of the aquifer vary by location, it is estimated that ground water withdrawals from the northern Texas portion of the High Plains aquifer exceed recharge rates by 22% in normal years and up to 161% in dry years (Anderson and Snyder 1997; Rosenberg et al. 1999). In some areas, water levels in the Ogallala aquifer have declined more than 100 feet (Bartolino and Cunningham 2003). In 2000, agricultural irrigation was estimated to be responsible for 96% of water withdrawn from the limited recharge Ogallala aquifer (McGuire 2004; Patzek et al. 2005; Rosenberg et al. 1999). Figure 3 offers a comparison of water usage by type of water use. The expansion of biofuels and ethanol production in this region will add pressure to water sources that are already strained. As of January 2008, one 100 million gallon per year (mgy) ethanol plant was in operation and another 100 mgy ethanol plant was under construction in Hereford, Texas which sits directly above the Ogallala aquifer.

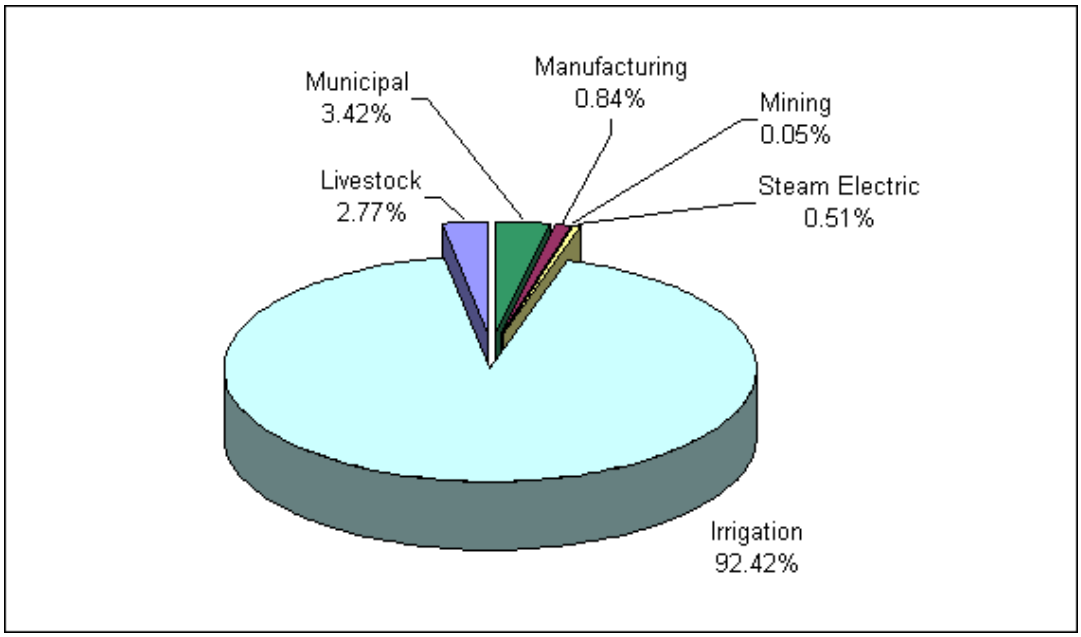

Figure 3. 2006 Texas High Plains Water Usage by Industry[2]

Southern Minnesota and California's Central Valley also present unique opportunities to study the impacts of ethanol expansion on water supplies. With 16 ethanol plants in operation, 5 plants under construction, and a potential for more than 1 BGY capacity, Minnesota is one of the leading states in terms of ethanol production (Minnesota Department of Agriculture 2007a). As a part of the Corn Belt, ethanol plants have rapidly expanded in this part of the country due to proximity to available corn. While there is limited corn available in California's Central Valley, it is one of the most fertile agricultural regions in the United States. Ethanol plants have recently expanded to this region, with plants located in Goshen and Madera producing more than 50 mgy of ethanol, and now provide another competing use for the limited supply of water in the

[2] Source: Texas Water Development Board (2006)

Central Valley. The catalyst for these ethanol plants to locate in California is not the availability of corn as in Southern Minnesota, but rather ethanol demand. California has more registered vehicles than any other state and has stricter air quality standards creating a scenario for high ethanol demand (U.S. Department of Transportation 2003).

Economic theory states that water should be priced using a metric that signals its relative level of scarcity, if economic efficiency is to be achieved (Griffin 2006). Given that water withdrawals from the High Plains aquifer exceed sustainable levels, the relative cost of water is unlikely to reflect the resource's true marginal value. Research has shown that pricing structures improve water conservation in both residential and agricultural settings, but are likely to induce substitution from surface water supplies to ground water sources (Corral and Fisher 1999; Huffaker and Whittlesey 2003; Moore, Gollehon, and Carey 1994; Schuck and Green 2001). As demands on local water supplies continue to grow, it is inevitable that water pricing will begin to play a role in the ability for industrial, agricultural, and municipal users to obtain their water supplies, further justifying the need for an analysis to determine how this will impact the economic performance of planned ethanol plants in the region.

With the passage of the Energy Policy Act, the expanding number of ethanol plants, and the significant investments made in ethanol production over the last few years, it is clear that ethanol will play a rising role in our domestic energy supply. Ethanol's extensive use of water will impact our ground and surface water supplies. The unknowns come from determining the extent to which water supplies will be impacted, the role water plays in the profitability of these ethanol plants, the impact on lesser

valued users, and the role technological advancements will have on water usage by ethanol plants.

Objectives

There are two primary objectives of this research. The first of the two objectives is to generate comparisons of the future economic viability of ethanol production facilities in three diverse regions of the United States. The second primary objective is to estimate future regional consumptive water usage by ethanol facilities and changes in the agricultural landscape due to the expansion of ethanol production to satisfy the conditions set forth in the EISA.

Analyses will be done to address regional water demands and differences in profitability in the Texas High Plains, Southern Minnesota, and the Central Valley of California, as impacted by current and proposed ethanol plants. These three unique regions will provide a diverse evaluation of ethanol's impact on available water resources. Not only are these regions dissimilar in terms of available water supplies, but also in terms of available corn. Addressing each of these regions will provide multifarious results and a methodology that can easily be adopted to evaluate the impacts of ethanol production for other regions in the United States.

In the process of completing this dissertation's objectives, the following set of deliverables will be will be obtained and presented within this research:

1. Estimate the quantity of water that will be used by existing and proposed ethanol plants over a 10 year time period in each of the 3 regions of study.

2. Develop forecasts for changes in crop land use.
3. Based upon the forecasted changes in crop land, determine the change to the quantity of water used for the 3 regions of study over the 10 year study period.
4. Based upon the combined usage of water from ethanol production and crop use changes, predict changes to regional water consumption.
5. Explore the impact of changes in the cost of water on the economic viability of various ethanol production facilities and determine the point at which investment in water saving practices (recycling or otherwise) become efficient.

In addition, this research will allow for the quantification of water impact that forthcoming technologies may have on ethanol's water demands. Further, this analysis will inform investors and managers addressing location decisions or rules for ethanol production plants and policy makers addressing water and ethanol regulations. Perhaps in some circumstances, concerns about available water supplies will rival those of proximity to available feedstock in rendering siting decisions. Comparison is needed to determine which factor plays a greater impact on long-term economic viability.

Many of the current ethanol plants are meeting their water demands via ground water sources, indicating that their water costs are simply the costs of pumping water. However, if plants were expected to account for the value of ground water to competing uses, ethanol plants are expected to become more economically suspect. A report by the Institute for Agriculture and Trade Policy sites recommendations for combating the

increasing demands placed on water supplies by ethanol plants (Keeney and Muller 2006). One of those recommendations is to place a greater economic value on water supplies. This research will provide essential information as to how increasing water costs will impact the economic viability of ethanol producers. To meet this modeling challenge, it will be helpful to assemble the best of available information pertaining to technology options and the associated value of water. This analysis will provide sensitivity results, indicating how responsive ethanol producers' economic viability is to water costs (including the estimation of sensitivity elasticities). Additionally, this approach will be useful to determine the capital threshold in which backstop technologies for the use of water conserving technologies may be an efficient alternative for the plant to adopt.

CHAPTER II

BACKGROUND

As mentioned in the introduction, the three regions this study will investigate are unique for a variety of reasons. The Texas High Plains, Southern Minnesota, and the Central Valley of California differ in terms of water availability, corn availability, the quantity of ethanol being produced, the institutions which govern the use and transfer of water, and the institutions which govern the use and production of ethanol. This chapter will provide the reader with a better understanding of the unique characteristics associated with each region and how those factors may impact the role ethanol production plays on regional water resources.

Ethanol Industry

The ethanol industry in the U.S. has seen dramatic changes in the last 10 years. Although ethanol can be used as a fuel source for flex fuel vehicles that run on E85 (a blend of 85% ethanol and 15% gasoline), the majority of 6.5 billion gallons of ethanol produced in 2007 was primarily used as a fuel oxygenate in E10 fuels (a blend of 10% ethanol and 90% gasoline) (Renewable Fuels Association 2008c; Vedenov and Wetzstein 2008). In the late 1990s ethanol production began increasing (see Figure 4), which is thought to have been aided by the economic incentives that individual states began offering. A federal subsidy of $0.54 per gallon has been in place since 1978 and many states began introducing their own ethanol subsidies during the 1990s, some of

which were up to $0.40 per gallon (Rask 1998). The rapid ethanol production growth rate during the early 2000s can be attributed to the ban on MTBE resulting from ground water contamination that began sweeping across the country. As an alternative to MTBE, and as a means to satisfy the emissions standards associated with the 1990 Clean Air Act Amendments, ethanol earned significant gains in popularity.

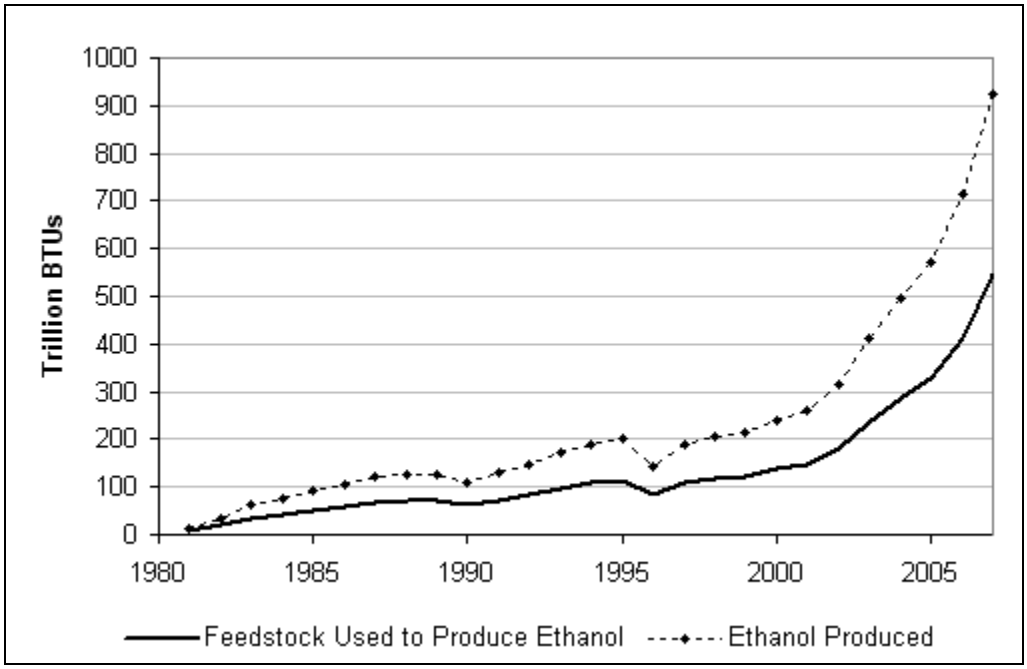

Figure 4. Energy Used to Produce Ethanol and Ethanol Energy Production[3]

The year 2005 brought another boost for ethanol, with the passage of the 2005 Energy Policy Act (Energy Bill). The Energy Bill outlined goals for expanding

[3] Data Source: Energy Information Agency (2008)

renewable fuel consumption by setting a national minimum usage requirement of 7.5 billion gallons by 2012 and extending the ethanol tax incentive through 2010 (Vedenov and Wetzstein 2008). In late 2007, an amendment to the Renewable Fuel Standard (RFS) set by the 2005 Energy Policy Act was signed into law (Hoekman 2009). The revised RFS calls for a more aggressive schedule of renewable fuels implementation, mandating the use of 36 BGY of renewable fuel by 2022.

For every proponent of ethanol there is also a critic. Ethanol has taken the brunt of the blame for high corn prices during the 2006, 2007, and 2008 crop years (see Figure 5). Those using corn as livestock feed or as an input in food manufacturing have been faced with higher input costs. In addition to the rising crop prices argument, many question the environmental benefits of ethanol production, including ethanol's impact on water, air, and soil resources (Patzek et al. 2005; Pimentel 2003). Nevertheless, with the considerable capital investment that has been put into building production facilities across the country and the numerous production incentives and mandates in effect at the federal and state level, ethanol will be around for some time.

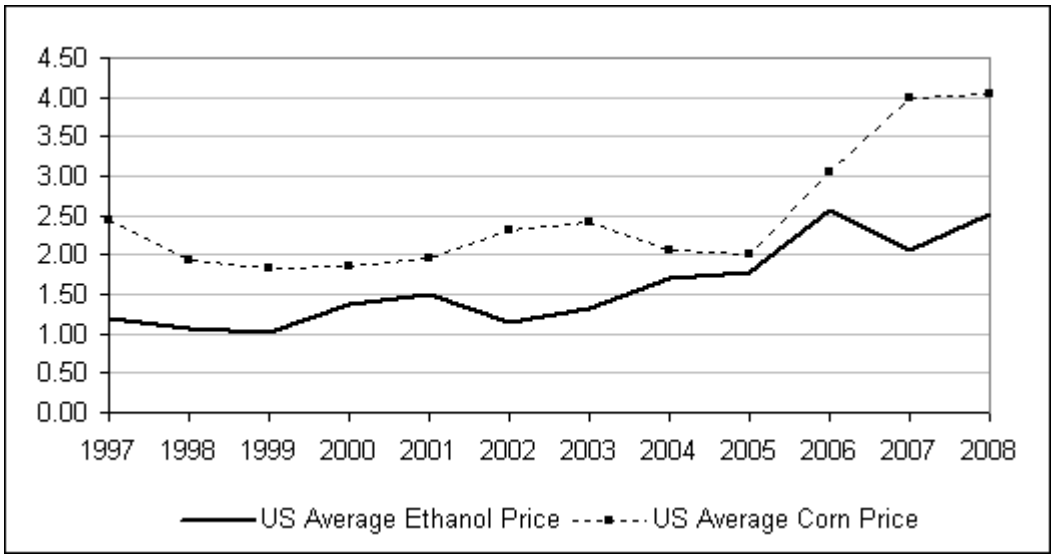

Figure 5. U.S. Average Annual Corn and Ethanol Prices[4]

Texas High Plains

The Texas ethanol industry has made significant strides in the last few years, with more than 500 million gallons per year of production capacity expected to be fully operational in 2008 (State Energy Conservation Office 2008). The four ethanol plants that will be responsible for producing 350 of those 500 million gallons are all located in the Panhandle region of the state, although other facilities that still remain in the planning stages will be located in both central Texas and the Rio Grande Valley.

Although not rich in either corn or water resources, the city of Hereford has become the apparent center of Texas ethanol. The appeal of Hereford relative to other Texas locations appears to come from its livestock feeding operations which are being utilized as an outlet for manure to use a fuel source and as a market for the ethanol by-

[4] Data Sources: National Agricultural Statistics Service (2008) and Hart Energy Publishing (2008)

product and cattle feed, distillers wet grains (DWGs). Panda Ethanol, Inc., headquartered in Dallas, is responsible for the construction of a 105 mgy ethanol bio-refinery in the city of Herford. This facility will be using Midwestern corn as their feedstock and utilize a manure gasification process to fuel the plant with the manure being sourced from area feedlots. Another Hereford facility had construction completed in January of 2008 and is operated by White Energy. White Energy's Hereford facility has a nameplate production capacity of 100 mgy. White Energy will be utilizing corn purchased from Archer Daniels Midland (ADM) as the primary feedstock.

Not far from Hereford, two other ethanol facilities have just completed or are nearing completion of the construction phase. One of which is seventy miles outside of Hereford in the city of Plainview. This Plainview facility is also owned by White Energy and construction was completed on this 100 mgy ethanol plant in January of 2008. Approximately 90 miles from Hereford, Levelland/Hockley County Ethanol has a 40 mgy ethanol facility under construction.

Although there is corn production in the High Plains region of Texas, it is unlikely to be enough to sustain the demands of these ethanol plants. Corn production in the High Plains region of Texas was 176 million bushels in 2007, whereas if the average ethanol plant requires 0.37 bushels per gallon of ethanol it would take more than the entire 2007 High Plains corn crop to support the three ethanol plants in that region (National Agricultural Statistics Service 2008). The majority of ethanol facilities in Texas are indicating that they will be importing their feedstocks from the Midwest. Figure 6 shows a map of Texas and includes the aforementioned ethanol production

facilities along with 2002 corn acreage by county from the 2002 Census of Agriculture (National Agricultural Statistics Service 2008).

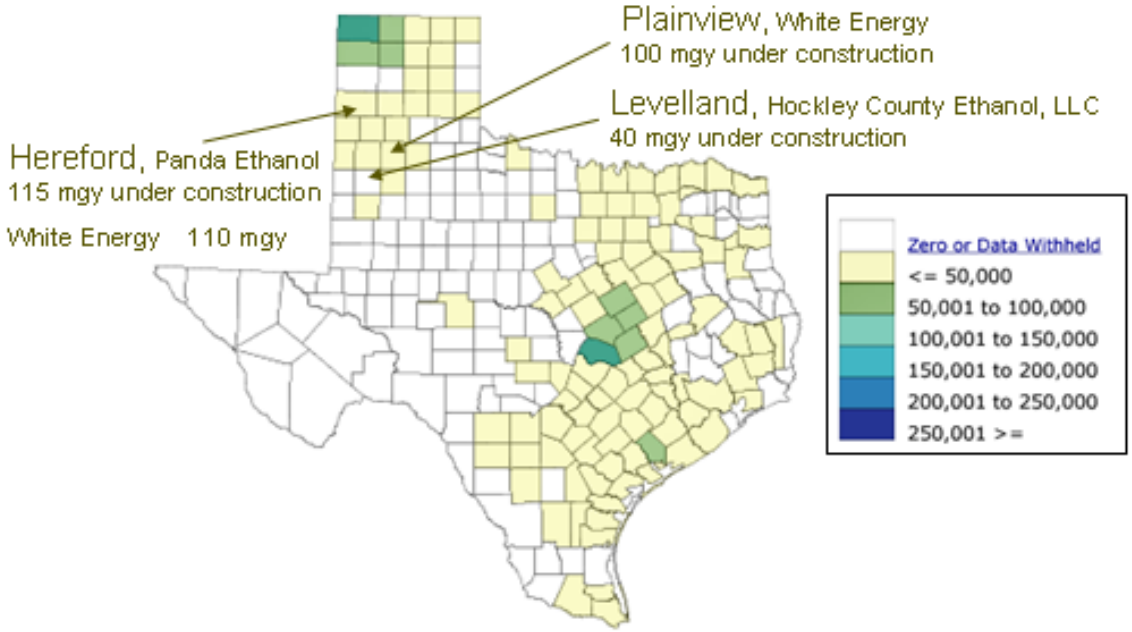

Figure 6. Texas Ethanol Production Facilities and 2002 Corn Planted Acres[5]

The expansion of ethanol production is thought to stimulate local economies and create jobs (Renewable Fuels Association 2008b). Although the expansion of ethanol production in Texas has benefited corn and sorghum producers due to higher commodity prices, the higher input costs faced by the extensive livestock producers in the state make Texas agriculture a net loser when it comes to ethanol production (Anderson et al. 2008). Early in 2008 Texas Governor Rick Perry sought an exemption from the U.S.

[5] Data Source: National Agricultural Statistics Service (2008)

government with regard to the national RFS in response to concern over the rising cost of food and the cost of commodities used to feed livestock (Gralla 2008). Although the request was denied, it represents a new wave of thought with regard to the expansion of ethanol in Texas. In the past, the state of Texas had been encouraging the production of biofuels through the biofuels incentive program, allowing registrants to be eligible for grants from the Texas Department of Agriculture. However, the program did not receive funding for fiscal years 2008 and 2009.

Southern Minnesota

As a part of the Corn Belt, Southern Minnesota has a deeper root in ethanol production. In 2002 Minnesota had 14 fully operational ethanol facilities, while 2008 ethanol facilities have expanded to 17 plants with a total ethanol production capacity of 735 mgy (Groschen 2008). In addition, 6 new facilities are under construction and at least 10 ethanol plants are in the planning stages (Meersman 2008). A majority of the planned facilities will be located in the western part of the state, partially due to the availability of corn in that region; however that region is also one of the least water rich areas of Minnesota and has some of the lowest ground water recharge rates in the state (DeVore 2008; Minnesota Water Science Center 2007). Figure 7 offers a map of ethanol production facilities in the state of Minnesota that are either currently producing or nearing completion of the construction phase along with 2002 county planted corn acreage as reported by NASS in the 2002 census of agriculture (National Agricultural Statistics Service 2008). The significantly higher quantity of corn being produced in the

southern portion of the state is clearly noticeable in Figure 7 relative to the amount of corn that was being produced in the Texas High Plains.

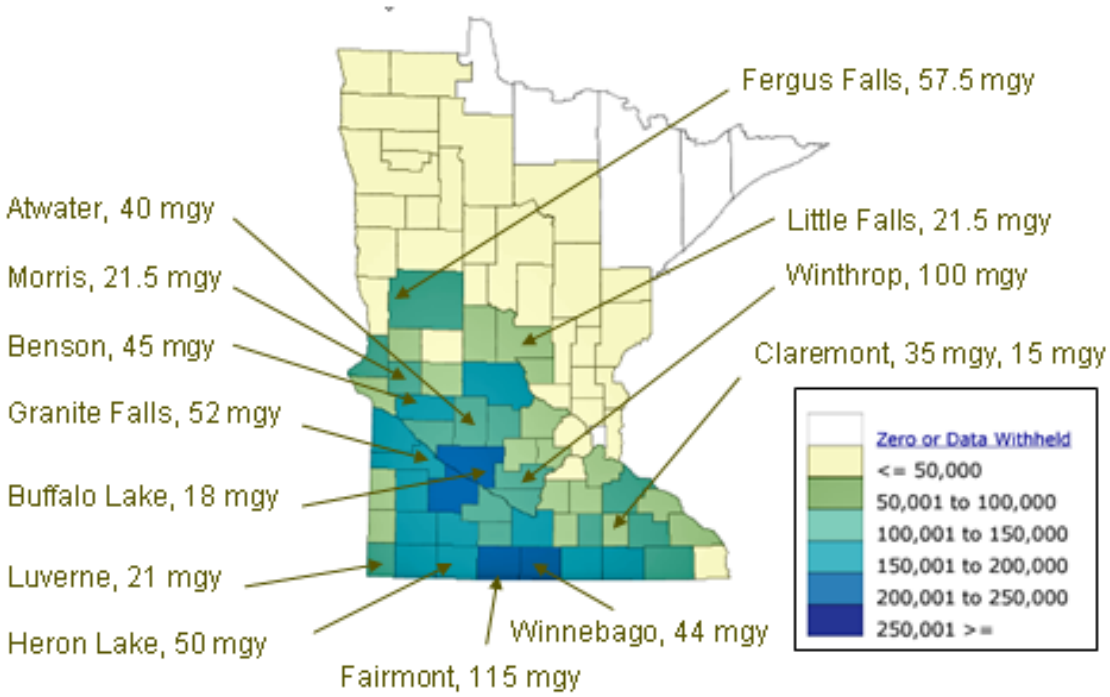

Figure 7. Minnesota Production Facilities and 2002 Corn Planted Acres

Minnesota has been argued to have been the leader in the nation's development of ethanol production (Fernstrum 2007). In 1980, Minnesota implemented a blender's tax credit of $0.04 per gallon of gasoline that was blended with ethanol. A number of legislative measures are in place helping the ethanol industry in the state, including exemptions from certain environmental regulations for ethanol plants, a 2005 mandate setting the minimum statewide ethanol content of 20% for all gasoline sold in the state, and a loan program which offers low interest loans to ethanol producers.

California's Central Valley

No stranger to the consequences of high demands for fuel, the nation's most populous state has begun turning to the use of ethanol. In fact, according to the California Energy Commission, California uses more ethanol than any other state, over 24% of national demand in 2005 (Schremp 2007). While the majority (approximately 80%) of the ethanol used in California is imported by rail from the Midwest, state government officials have actively been seeking to not only expand the use of ethanol but also to expand the ethanol supply produced within the state (Schremp 2007). The California government has made significant efforts in expanding biofuels in the state through developing and adopting a state Alternative Fuel Plan (AFP). The AFP aims to reduce conventional gasoline use and increase the use of alternative fuels (Hoekman 2009). An April 2006 executive order was put into effect and requires 25% of the biofuels used in California to be produced in California as a means to reducing the greenhouse gas (GHG) emissions in the state. This renewable fuel standard promoted an expansion of statewide ethanol production.

Although annual California ethanol production has doubled in capacity between 2005 and 2007, it is still relatively small in scale. Annual ethanol production in California was just over 8 mgy in 2007, which is less than 0.13% of total U.S. ethanol production (Renewable Fuels Association 2008c; Schremp 2007). Relative to higher producing ethanol locations, California has some additional challenges including tougher environmental regulations, higher energy costs, higher feedstock costs, and less access to fuel distribution terminals (Great Valley Center 2004). Satisfaction of air, water, and

land environmental quality regulations in California require additional time-consuming and sometimes costly permitting. Frequently, ethanol facilities in California are required to incorporate pollution abatement devices, adding as much as 5% to the cost of building an ethanol plant (Burnes et al. 2004).

The first two ethanol plants in California were located in the Los Angeles area and took advantage of a locally available biomass source— food and beverage waste products (MacDonald et al. 2003). However, those facilities are quite small, producing less than 10 mgy combined (MacDonald et al. 2003). The state's first ethanol plant of significant size was put into operation in late 2005. This facility was the first to use corn as a feedstock and built to a capacity of 25 mgy. Although the facility, operated by Phoenix Biofuels of Tulare County, had originally planned on expanding production to 35 mgy after the first couple years, there are now reports of the plant suspending operations (Kasler 2008). The second corn-based ethanol plant in California was built by Pacific Ethanol. It is a 40 mgy plant in Madera that has been operational since October of 2006. There has been talk of a 63 mgy plant to be built in Bakersfield, in addition to the three other corn based ethanol facilities that are currently in the construction phase. The Central Valley of California has become the focus for ethanol production in the state. Figure 8 provides a map of the California ethanol production facilities relative to the planted corn acreage as reported by NASS in their 2002 Census of Agriculture (ethanol plants smaller than 10 mgy in capacity are excluded from this figure).

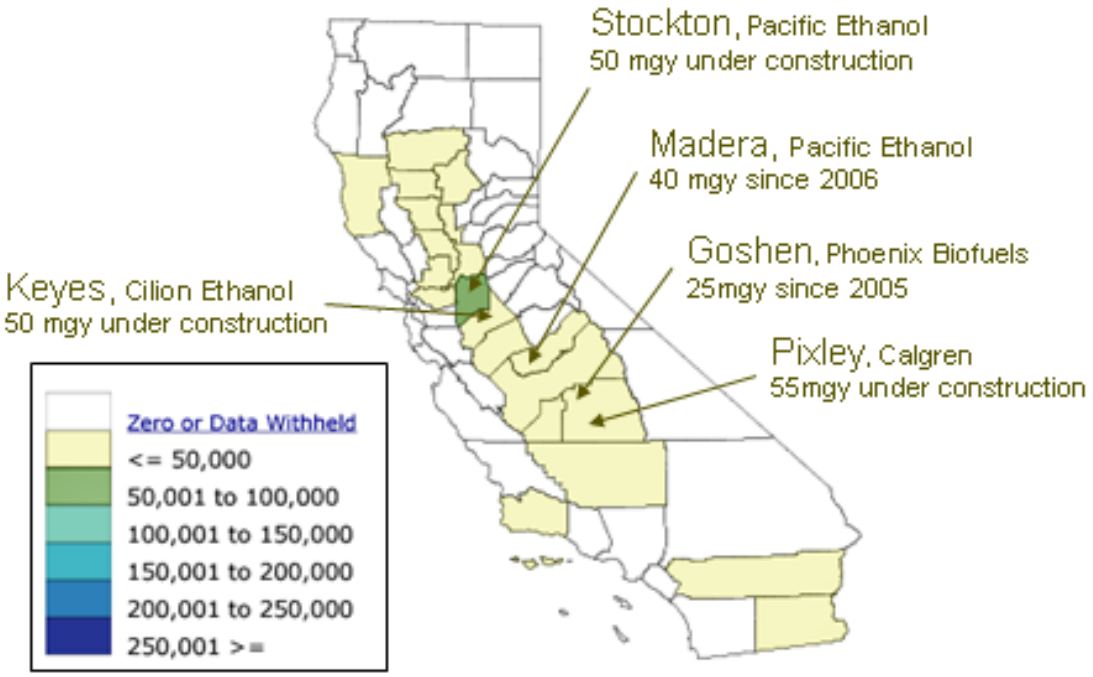

Figure 8. California Ethanol Production Facilities and 2002 Corn Planted Acres

Water Institutions

The complexities and nuances of water law make it a difficult task to summarize. However, given that water law defines the rules in which agents can use water, these laws may affect how much of an impact ethanol production has on local and regional water supplies. Although a large number of governmental agencies may be involved in the management of water resources, water regulations are generally set at a state level. However, from state to state, the legal institutions which define water usage and water

exchange differ. Therefore, this section is designed to give a general overview of water institutions for each of the three states in which this study will encompass.

Water rights are generally considered usufructary in nature, that is, the water is owned by the state or other governing agency, but the right to use the water is given through a number of different laws and doctrines. In general, water doctrines are specified based upon a primary distinction made between surface water and ground water in establishing the rights to use water. Although these two sources of water are connected hydrologically, our legal institutions treat these two differently and independently.

There are two primary ways water is used in the production of ethanol, water used for the production of corn for ethanol and water used directly in the production of ethanol by ethanol plants. Ethanol production facilities have the option of using ground water, surface water, or purchasing water from municipal sources. Several ethanol plants are purchasing grey water from a municipal waste water plant (Stanich 2007). However, the vast majority of ethanol plants utilize ground water as their source of water (Mowbray and Hume 2007; O'Brien et al. 2008). Ground water is a popular water supply choice due to its availability and due to its purity (relative to purchased grey water). On the other hand, corn producers may be relying on either ground or surface water for their irrigation needs, or may be utilizing dry-land farming practices. The decision to utilize each of the practices involves a number of factors, including environmental and economic components.

Historically surface water has been the primary source of water for consumptive uses and consequently surface water law has a richer, more developed history, relative to ground water (Griffin 2006). In fact, much of the country's ground water is unregulated. The riparian doctrine and the doctrine of prior appropriation are the two primary legal institutions associated with surface water, however surface water rights may fall under other rights categories such as prescriptive rights. Riparian rights are reserved for land owners who own property adjacent to a body of water (a river, stream, lake, or pond). Riparian land owners have the option of using a non-quantified quantity of surface water "for beneficial use" without a permit or community notification. Riparian water rights are secured through the ownership of the land and, in general, are not lost due to nonuse of the water supply (Littleworth and Garner 1995). In addition to the restriction of beneficial use on riparian water rights, a number of other restrictions have evolved including the requirement of not transporting the water outside its original watershed. However, although the riparian doctrine attempts to encourage reasonable and beneficial use, it is often thought to encourage virtually unlimited use as the riparian doctrine is evoked as a tort regime—the doctrine is only used once a party has been "injured" by another's water use (Tarlock 2005).

On the other hand, appropriated water rights allows for permitted use of surface water based upon the principle of "first in time, first in right" (Griffin 2006). Key features of appropriative water rights include the fact that senior right holders have a "superior" right to those who have held the right for a shorter amount of time, all water quantities are specifically expressed, and water permits can be transferred among

individuals. In times of shortage, where the water supply is insufficient to meet the needs of all permitted water users, senior water rights holders get to withdraw their appropriated water prior to junior right holders (Littleworth and Garner 1995). Senior right holders have the highest priority and can fulfill their appropriated quantities by withdrawing water to the point where junior rights holders may not be allocated any water in that particular year (Littleworth and Garner 1995). Having the option to transport the appropriated water outside of the watershed allows for improved transferability of appropriated water among individuals.

In addition to the riparian doctrine and the doctrine of prior appropriations, there are other surface water laws in practice, including the Eastern permit system and the correlative shares system. If interested, the reader is advised to refer to Griffin (2006) for a through review of each system.

With a few exceptions, ground water generally falls under state property law (Bruggink 1992). There are four primary doctrines that have been adopted by U.S. states: absolute ownership, reasonable use, correlative rights, and appropriated rights (Bruggink 1992). These doctrines present a range of restrictions on the ability of a landowner to pump and use ground water. The following table, Table 1, outlines some of the main points of the major ground water doctrines, including the Vernon Smith system, which is theoretical in nature. One of the main problems associated with ground water rights systems is the inability of the system to express the opportunity cost of the water. The Vernon Smith system proposes a flexible system to address both components of an aquifer— the renewable water and the stored water (Smith 1977). This system

internalizes the decision to deplete and helps to ensure dynamic efficiency (Griffin 2006). The dynamic efficiency element of water law is also addressed in Table 1.

Table 1. Properties of Ground Water Institutions

System	*Classification*	*Quantity of water*	*Dynamically Efficient*
Absolute Ownership	Weak Common Property	As much as desired	No
Reasonable Use	Common Property	Can't be used wastefully	No
Correlative Rights	Common Property	Safe yield quantity	Maybe
Appropriated Rights	Incomplete Private Property	Quantified	Unlikely
Vernon Smith System	Advanced Private Property	Annual quantity & fixed amount of stored water	Yes

Texas

As the largest state in the continental U.S., it is not surprising to learn that there are large variations in climate and rainfall across the state and the system of rivers, aquifers, and reservoirs that make up the Texas water supply is just as diverse (Kaiser 2005b). With more rainfall in east Texas, significantly more surface water is produced in the watersheds of eastern Texas (Kaiser 2005b).

The source of Texas' water supply is split (57% and 43% respectively) between ground water and surface water (Kaiser 2004). While the majority of ground water is used for agricultural irrigation (80%), municipal and industrial uses consume the majority of the surface water supply at nearly 65% (Kaiser 2004). Ninety seven out of every hundred gallons of ground water used in Texas comes from nine major aquifers

within the state (Kaiser 2005b). Each of the nine aquifers are unique in terms of storage and recharge.

With limited rainfall in the west, the Ogallala aquifer, which underlies much of the Texas panhandle, has one of the lowest recharge rates in the state (Kaiser 2004). Some areas of the Ogallala aquifer experienced more than a 60 foot decline in the time period from 1980 to 1999 (McGuire 2004). Appendix A displays a map of the Ogallala aquifer and it's water level changes during the 1980 to 1990 time period. Much of the portion of the aquifer that is within in the boundary of Texas is plagued with declines in water levels.

Texas, along with California, has some of the more developed water law in the nation. Considered to be state-owned water, the use of surface water in the state of Texas requires a water use permit and is subject to the doctrine of prior appropriations (Kaiser 2005a). Permits are awarded on a first come, first serve basis and limit the total amount of water that can be withdrawn from a water body during a given time period (Texas Commission on Environmental Quality 2008). Permits may be specified as being temporary or unending, or anywhere in between. Permits are likely to include conditions for which withdrawal is allowed. In times of scarcity, the permit holders that have held the permits the longest have the right to withdraw their water prior to less senior permit holders (Kaiser 2005a).

With ground water making up 60% of the water used in the state, Texas landowners have the uncommon right of absolute ownership to the water that lies below their land (Kaiser 2005a). Frequently referred to as the rule of capture and the absolute

dominion rule, the absolute ownership doctrine is the least restrictive ground water legislation in the country and allows each landowner to pump as much water as he or she would like from the underlying aquifer (Goldfarb 1984). Under this doctrine, landowners have the right to capture ground water, the right to the water that is captured and brought to the surface, and the right to use the water captured (Kaiser 2005a). In addition, landowners have the ability to sell or lease any of the three components to their ground water rights (Kaiser 2005a). Although not restricted to the confines of beneficial use as the riparian doctrine requires, ground water users under the rule of capture are not allowed to pump an unlimited amount of water when it is done to maliciously harm a neighbor, when the water is used in a wasteful manner, or when the pumping is done in a negligent manner (Griffin 2006; Kaiser 2005a).

Minnesota

As the state known as the "Land of 10,000 Lakes", Minnesota has a plethora of surface water. Surface water provides an average of nearly 80% of total annual water used within the state (Minnesota Department of Natural Resources 2000). Yet, due to geographic availability and purity, more than 70% of Minnesota's drinking water comes from ground water sources (Minnesota Pollution Control Agency 2003). The majority of ethanol facilities in Minnesota rely on ground water sources, using more than 2 billion gallons per year; however, as ground water resources are becoming increasingly depleted this may be changing (Chang 2008). After an ethanol production facility in its first year of operation in Granite Falls, MN depleted local ground water supplies beyond the plant's proposed water needs, the facility began pumping water from the Minnesota

River (Lane 2008). This action has prompted an investigation by the Minnesota Environmental Quality Board on the water usage by ethanol plants (Lane 2008).

Surface water is subject to the conditions of the riparian doctrine in the state of Minnesota. With respect to ground water usage, Minnesota has adopted the correlative rights model (Delleur 2007). The correlative rights doctrine allows the overlying landowner to withdraw a reasonable quantity of water for beneficial use on the overlying ground. A land owner's share of the available water is proportional relative to the landowner's share of land.

In addition to the riparian common law system for surface water and the correlative rights doctrine for ground water, Minnesota operates under a statutory permit system for high capacity users of both ground and surface water. Established by the Minnesota legislature in 1937, the permit system is an example of a water appropriation program. High capacity water users (those who pump more than 10,000 gallons per day or more than a million gallons per year) are required to have a permit for their withdrawals (Bowman and Clark 1989). Regular monitoring and reporting of pumped water is another requirement of these high quantity users. The state will proportion the permitted water in times of limited supply, placing non power generating high quantity users below the majority of other water users (including domestic water supply, agricultural irrigation, and lower quantity users) (Bowman and Clark 1989). These priorities are specifically outlined in the statute (Minnesota Department of Natural Resources 2006). Permits are evaluated by the Department of Natural Resources and

awarded based upon their potential impacts on natural resources, other water users, water conservation, and their efficiency of use.

The permit system used in Minnesota provides a significant amount of information with regard to water usage. Water use quantities are reported by user categories to the Minnesota Department of Natural Resources and made available to the public (Minnesota Department of Natural Resources 2008). The reported pumpage quantities give us the unique opportunity to determine the water used by the petroleum-chemical processors in Minnesota, which is inclusive of water use by ethanol producers. Figure 9 displays the quantity of water used by petroleum-chemical processors obtained from the Minnesota Department of Natural Resources (2008) relative to the quantity of ethanol produced in the state over the 15 year time period obtained from the Minnesota Department of Agriculture (2007b). Although the water use data provides only a rough estimate of the water used in the production of ethanol, it is nevertheless interesting to compare total water usage to overall state ethanol production. As shown in Figure 9, both ethanol production and water usage have increased over the time frame; however, clearly, ethanol water use has not increased at the same rate as statewide ethanol production. A natural explanation for the difference in ascent can be attributed to improvements in water use efficiency. Without knowing the exact quantities of water used it is impossible to tell exactly how much efficiency has improved, however if all of the water used by petroleum-chemical processors was used in the production of ethanol, the water use per gallon of ethanol would be 7.6 gallons in 2007.

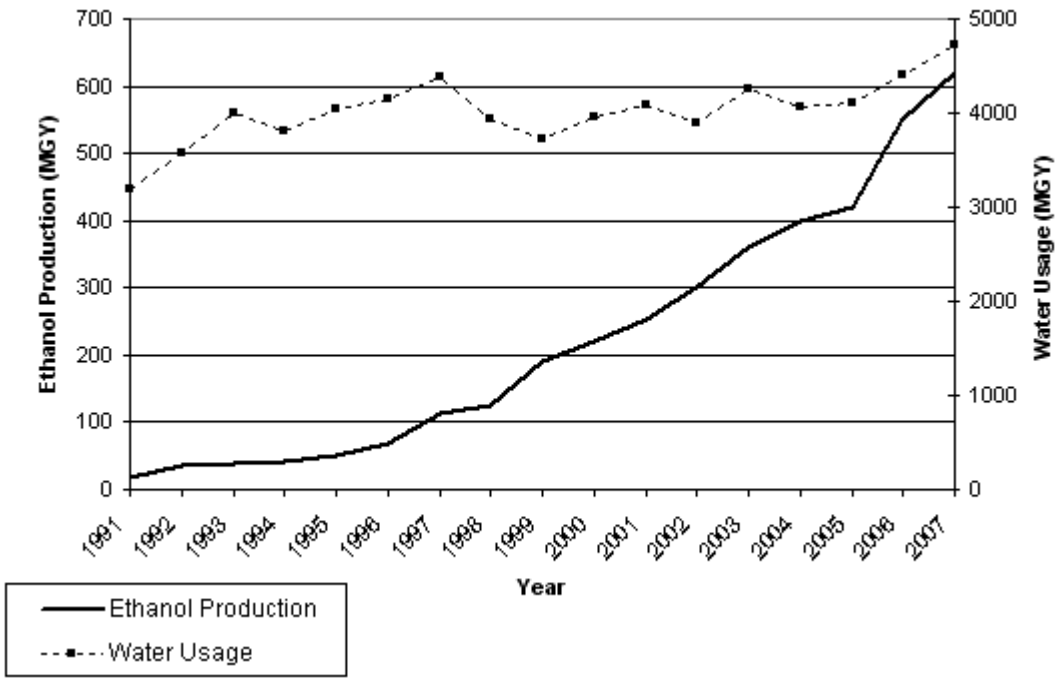

Figure 9. Minnesota Ethanol Production and Ethanol Water Usages[6]

California

The scarcity of California's water supply comes not from a shortage in water quantity as a whole, but from the distribution of the water supply across the state (Littleworth and Garner 1995). Spatial and temporal availability of water within the state has made California a complex environment for water institutions to develop. While the majority of the state's water is available in the northern and eastern parts of the state during the winter months, the largest demand for water occurs during the spring and summer months in the south, west, central part of the state (Jenkins et al. 2004).

[6] Data Sources: Minnesota Department of Agriculture (2007b) and the Minnesota Department of Natural Resources (2008)

This distribution and variability of water supply has resulted in the development of a vast network of water systems run by federal, state, local, and special district agencies.

The Central Valley of California uses more water than any other region in the state, primarily due to agricultural irrigation water (Littleworth and Garner 1995). The Central Valley is one of the richest agricultural regions in the state, with 6 of the state's top 10 agriculture counties residing in the Central Valley region in 2006 (California Department of Food and Agriculture 2007).

California operates under a dual system for surface water, utilizing both the riparian and the prior appropriations doctrines. In California, the riparian doctrine has traditionally been viewed as paramount to appropriated rights, but a set of case law has established that this may not necessarily be true (Chandler 1916; Littleworth and Garner 1995). In general, surface water (and water in underground channels) that is in excess of the beneficial quantities used by existing rights holders may be appropriated (Littleworth and Garner 1995).

With regard to ground water, all land owners above the ground water source have a shared right to "reasonable use" of the water in the correlative rights system used by the state of California. The correlative system for ground water is similar to the riparian system for surface water and treats water as a common property resource. Correlative shares of ground water aim to grant landowners a reasonable quantity of water based on the supply of water available and the reasonable needs of others who use the resource (Goldfarb 1984). However, although the correlative shares system of ground water use

is designed to prevent overuse, it has been suggested that the system is applied unevenly, resulting in excessive ground water mining in regions of the state (Griffin 2006).

Water markets have been championed as a means to improving the efficiency of the water of the water allocation system in California (Anderson 1984; Gardner and Fullerton 1968; Weinberg, Kling, and Wilen 1993). A water market simply allows the transfer of water between a lower valued use and a higher valued use. Typically water transfers are made from agriculturalists and farmers who own a water right to urban and industrial users that are willing to pay the farmer for the right to their water. These water transfers are thought to be an economically efficient way to improve the reliability and quality of the water source (Newlin et al. 2002). Water trading has been occurring in the state of California since the 1970's, however many challenges are still present (Public Policy Institute of California 2003).

Reducing Water Use for Ethanol Production

Technological improvements can be credited with significant declines in the water requirements for ethanol production. At one time estimates of consumptive water use per gallon of ethanol exceeded 10 gallons, but are now thought to be around 3.5 to 4.0 gallons per gallon of ethanol produced (Aden 2007). Additional technological advancements are thought to have the capability of significantly lowering the fresh water requirements of ethanol even further. The breakdown of water usage varies upon the source, however we can approximate that 16% of fresh water is used as process water, 14% is used in the boiler, and 70% of water is used in the cooling tower (Rajagopalan 2008). Equipped with that information we can categorize the approaches used to

decrease the fresh water demands of ethanol production as, a reduction of water used in the boiler, a reduction in the quantity of water required for cooling, the use of an alternative method for cooling, the use of an alternative to fresh water as the source of water (i.e. recycled water), and by practicing water conservation (Rajagopalan 2008).

Water demands in the production of ethanol are closely tied to the energy demands; therefore as improvements are made to bring down the energy required the water requirements will also decline (Aden 2007). As an alternative to distillation, membrane separation technologies have the potential to decrease the required amount of water in the production of ethanol (Aden 2007). Membrane technologies, such as the Siftek system, allow water vapor to be absorbed by the membrane and act as a method to dewater the ethanol (Vaperma 2008). The resulting 99% pure ethanol requires up to 50% less energy and rather than losing water to evaporation, the water collected by the membranes can be pumped out (Sawyer 2007; Vaperma 2008). Up to 40% of the water originally used can be recycled back into the facility (Vaperma 2008).

Another method for reducing the consumptive use of water in the production of ethanol is through finding alternatives to water in a cooling system (Aden 2007). Air is one option. Air-cooled heat exchangers can help reduce the demand for cooling water (Wenninger 2007). Although not feasible in all situations, air-cooled heat exchangers can reduce the cooling tower water requirement by up to 68% (Rajagopalan 2008). The HiCycler patented technology claims to reduce the consumptive use of water in the cooling tower by 20% (Owens 2007). There are many cooling alternatives that could, in theory, be used, including the use of additional chillers, underground cooling coils and

the use of a closed loop cooling tower; however, the costs associated with these alternatives are often prohibitive (Mason 2007).

Perhaps one of the most feasible methods of reducing water usage is through the waste water streams. Many plants in the Midwest, particularly new plants, have zero waste water discharge (referred to as zero liquid discharge or ZLD) (Aden 2007; Wenninger 2007). This water recycling is achieved with the use of centrifuges, evaporation, and anaerobic digestion and involves treating water from the tower blowdown (Aden 2007; Wenninger 2007). The water treatment would typically involve a reverse osmosis system and is estimated to cost around $0.70 per 100 gallons (Rajagopalan 2008).

Along the same lines of internally recycled water is the use of recycled water from external sources. Ethanol facilities have begun to use municipal waste water that would have otherwise been simply discharged (Minnesota Technical Assistance Program 2008). Although the water would have to be softened at an approximated cost of $0.30 per 100 gallons, the use of municipal effluent could be a feasible alternative to freshwater (Rajagopalan 2008).

CHAPTER III

REVIEW OF LITERATURE

The literature required to build the base for the complex task of determining the impact of an expanding ethanol industry on water resources is both vast and pulls from a wide spectrum of academic literature. This literature review will cover studies done on the environmental implications of ethanol production in general (including attempts to quantify and attempts to place an economic value on those implications), water implications of ethanol production, incorporation of risk into decision making, forecasting changes in land use, integrated modeling of hydrology and economics, regional approaches to water quantity and quality analysis, and present some of the key theoretical concepts underlying the problem. Although these topics may seem at a disconnect, each plays an integral role in building the foundation of this dissertation—from justification of the problem to developing an understanding of the methodological approaches used for similar problems and from the challenges associated with regional water studies to being explicitly clear about similar work that has been done on this problem. A natural starting place for this literature review is a thorough review of the previous work that has been done in an attempt to quantify and/or provide valuations of the environmental impacts of ethanol at its various stages of the production-use cycle.

General Environmental Impacts of Ethanol Production and Use

Many believe that ethanol is being promoted despite significant environmental costs (Doering 2004). There are two starkly opposed sides to the environmental story of ethanol (The Economist 2004). One argument of the ethanol camp claims that it is the potential answer to all of our fossil fuel worries, while the other side warns that we may be better off without it. These opposing sides and the political force with which ethanol has been promoted are significant factors which support the need for a comprehensive look at existing literature on the potential environmental benefits and costs of ethanol production and use. Significant material has been written on this subject, often with conflicting results.

In a perfect world, we could make a direct comparison between ethanol fuel and fossil fuels, and then select the better of the two. Christen (2006) pointed out the primary reason it is difficult to make this comparison is that biofuels are produced in a "series of steps that themselves require energy." The extent to which each of those energy components is included in the process will make a difference on the net outcome of the analysis. Despite this challenge, studies have attempted a comparison. An example is Klupfel, Pfeiffer, and Filson (2003) who made a direct comparison between a crop-based fuel economy and our current fossil fuel dependent economy, finding that a crop-based fuel economy is unlikely to "significantly penetrate the energy and materials market without external support in the form of policy and legislation due partially to the prevalence of fossil fuel usage in our society" (Klupfel, Pfeiffer, and Filson 2003). Thus far, that statement holds true for the role of ethanol in our economy. Although it is

debatable whether or not it can be said that ethanol has significantly penetrated the fuel market, it can be said that what has occurred has been aided by policy intervention.

This section of the review of literature will collect two major types of research—studies done on the quantification of ethanol's environmental impacts and those done on the valuation of environmental impacts. Valuation of impacts allows the analyst to compare the benefits of a project or policy to the associated costs. So, ultimately the valuation attempts are the most important for policy applications, but to get to that point we have to first understand what is being valued (i.e. a quantification of the impacts must be done prior to a valuation). Valuation attempts pose the additional challenge of trying to monetize something that isn't easy to monetize. Although there are many different approaches that are used for monetization, they are frequently subject to criticisms and in some cases it may not be possible to monetize an impact. Given that ethanol is fairly new as a mainstream alternative to fossil fuels, a relatively small number of valuation studies have been completed. A significant number of studies have been published on monetizing the external impacts of fossil fuels and, where relevant, the ethanol literature may be able to make consequential gains by applying valuation studies conducted on different energy sources on an ethanol alternative. Therefore, valuation studies not specifically related to ethanol will also be addressed in this paper.

This review of literature will consist of two major components; the first section will address studies specific to a particular "sector" and the second will address comprehensive studies. The sectoral portion of the literature will be organized to follow the production process and use of ethanol from the fields where the corn or biomass

material is produced, to the plants where the ethanol is produced, to the cars running on ethanol, revealing studies done quantifying the externalities and attempting to place a monetary value on the externalities.

Sector Impacts

The valuation of environmental impacts from fuel energy sources present several challenges. In particular, there are many types of damages that should be considered; valuation may come from an emissions standpoint, from a health risk approach, or from a changing agricultural landscape approach (Berndes 2002; Marshall and Greenhalgh 2006; Powlson, Riche, and Shield 2005). These different approaches will be characterized by the sector in which they occur: at a farm level, at a plant level, or at a consumptive level. This paper will look at the environmental impacts and valuation studies which relate to ethanol at each of these levels.

If ethanol satisfied the requirements of the Energy Bill on its own, minimum 2012 ethanol production would result in nearly 25% of our annual corn crop going toward the production of ethanol. As a result of nearly record high corn prices in 2008 and incentives for farmers to capture the demands of the biofuels industry, the agricultural landscape of the U.S. is likely to change shape. An expansion of corn acreage and the potential expansion of energy crops such as switchgrass and hybrid poplars have the capacity to impact our environment in many ways. Marshall and Greenhalgh (2006) forecasted the environmental impacts from increased production of ethanol crops caused by satisfying the requirements set forth in the Renewable Fuels Standard component of the Energy Bill. Considering only the production sector, upon

reaching 15 billion gallons of ethanol production, Marshall and Greenhalgh (2006) estimate an increase of greenhouse gas emissions by nearly 8%.

The first stage of evaluating the impacts of ethanol production on the environment is evaluating the impacts of energy crop production. The economic impacts of expanded energy crop production have been investigated by Updegraff, Baughman, and Taff (2004), Borjesson (1999), and by Powlson, Riche, and Shield (2005). Updegraff, Baughman, and Taff (2004) evaluated the environmental benefits from a conversion of crop land to the production of hybrid polar, an example of a short rotation woody crop used for biomass ethanol production, in the Lower Minnesota River watershed. After accounting for the economic values of impacts on water quality, forest conservation, and carbon sequestration, the authors found that the summed average net benefits justified annual public subsidies from $44 to $96 per hectare (Updegraff, Baughman, and Taff 2004). Powlson, Riche, and Shield (2005) suggested that movement toward perennial energy crops for the production of biomass ethanol will have positive impacts on water quality. Although not specifically citing ethanol, Borjesson (1999) economically evaluated the environmental benefits of replacing food crops with perennial energy crop cultivation in Sweden. Borjesson (1999) stated that the benefits with the highest economic value are the purification of waste water, reduced leaching, and recirculation of sewage sludge. His study found that a conversion of 30% of Sweden's arable land into the production of energy crops could be produced at a cost of $0.70 per giga-joule, once the value of environmental benefits were considered

(Borjesson 1999). This cost can be compared to typical energy crop production costs of $4.40 to $5.00 per giga-joule.

Expansion of corn for ethanol production, as encouraged by the Energy Bill, is thought to exacerbate water and soil quality problems in the U.S. (Marshall and Greenhalgh 2006). Marshall and Greenhalgh (2006) argue that as incentives to produce ethanol persist, so do the incentives for producers to farm more intensively. An expanding bioenergy sector will impact water resources in two ways, through the withdrawal of water for crop irrigation and through increased evapotranspiration (Berndes 2002). Berndes (2002) used a use-to-resource ratio where use refers to water withdrawals and resource refers to water availability. The use-to-resource ratio serves as a convenient measure of water stress. Berndes (2002) calculated that the use-to-resource ratio resulting from large scale bioenergy production was likely to reach more than 25% of available water, indicating a significant stress on water resources. Patzek et al. (2005) concluded that large scale production of crops for the purpose of energy use will lead to increased evapotranspiration from crop land.

The biggest concern with regard to soil resources, as reported by Pimentel et al. (1994), is that corn causes serious soil erosion in the U.S. Pimentel et al. (1994) found that large scale corn ethanol production will erode land at a rate 18 times faster than soil formation. However, there are potential benefits to soil resources from a movement toward ethanol based fuels. An example is an increase in soil organic matter content (Powlson, Riche, and Shield 2005). This increase, as suggested by Powlson, Riche, and

Shield (2005), has the potential to allow for carbon sequestration in the soil and improve soil quality (McLaughlin and Walsh 1998; Reijnders 2006; Sheehan et al. 2003).

The production of ethanol typically involves either a wet or dry milling process. Dry milling plants are most common in the U.S. The process involves grinding the corn kernel into flour and then fermenting the flour to create ethanol. Distiller's grains and carbon dioxide are the two major byproducts. Ethanol plants are subject to continual, strict environmental regulations and inspections; however, this does not eliminate all of the environmental impacts. Swenson (2006) noted that ethanol plants are heavy users of water and create a large amount of waste discharge.

Although not specifically addressing ethanol, Owen (2006a; 2006b) used a life cycle analysis of the stationary energy sector to derive estimates of environmental externalities of electricity generation and then compared these societal costs to private costs. Owen (2006a) pointed out that because there are many unknown impacts of pollution, developing monetary values for these externalities is imprecise. Ultimately, Owen (2006a) obtained damage cost estimates from other studies done specifically on air pollution and computed the cost of traditional and renewable energy technologies. Owen's (2006a) results show that internalization of CO_2 related externalities causes a number of renewable technologies to become competitive with coal-fired plants.

One of the concerns about ethanol is its impact on our drinking water resources, especially following the drinking water contamination caused by the ethanol substitute, MTBE. However, ethanol degrades very rapidly when combined with water and is thus not expected to have a direct impact on drinking water supplies (Williams, Cushing, and

Sheehan 2003). However, Williams, Cushing, and Sheehan (2003) pointed out that spills have an elevated probability due to the transportation requirements of ethanol— it can not be easily transported by pipe (due to its degeneration when combined with water) and that major surface water contamination from ethanol spills will have adverse affects on local ecosystems.

Spatial and temporal variations characterize air pollution making air pollutant emissions difficult to quantify (Delucchi 1998). The Energy Information Agency (2007), among other sources, reports that ethanol produces less carbon dioxide and carbon monoxide, but produces more nitrous oxide and methane than traditional gasoline (Hodge 2002). The addition of ethanol to gasoline causes an increase in volatile organic compounds (VOC) including formaldehyde and acetic acid, resulting in increased toxic air emissions (Hodge 2002; Hrubovcak 1991; Kane et al. 1989).

There are recorded benefits to the usage of ethanol as an alternative fuel (Niven 2005). Farrell et al. (2006) found that the use of ethanol produced from corn as motor vehicle fuel requires up to 95% less petroleum then the equivalent amount of energy from conventional gasoline. In addition, Farrell et al. (2006) found that corn ethanol results in a 13% decline in greenhouse gas emissions. Patzek et al. (2005) found that to drive the same distance, a car using corn ethanol requires twice as much fuel as a car using gasoline. Kammen (2006) found ethanol to reduce greenhouse gas emissions by 18%, although, depending upon the assumptions made, emissions may increase up to 29%.

From an emissions perspective, Johansson (1999) compared costs between traditional fuels, diesel and petroleum, to that of biogas and methanol. Included in Johansson's cost measure are the costs of fuel, capital costs for the changes that potentially need to be made to a vehicle to run on non-traditional fuel, and the environmental cost of the fuel's emissions. Specifically, Johansson considered the cost of volatile organic compounds (VOC), NO_x, particulates, and $C0_2$. He based his emissions quantification on a study done by Egeback et al. (1997) and then applied a per unit damage cost to the total emissions quantity based on Swedish pollution taxes. Johansson (1999) found that, having incorporated the damage costs associated with emissions, in 1996, alternative fuels had higher costs. Johansson's (1999) projections indicate that in 2015 alternative fuels are still likely to have higher costs. However, his results showed that in urban areas alternative fuels could compete with traditional fuels due to the air quality benefits. Johansson (1999) concluded that in order for ethanol-type fuels to be feasible, the economic valuation of emissions must be higher.

Ogden, Williams, and Larson (2004) took a "societal lifecycle approach" to comparing alternative energy, measuring the impact of fossil fuel use in transportation relative to alternative energy sources. The authors incorporated the vehicle's initial cost, the present value of fuel, vehicle maintenance costs, externality costs for oil supply insecurity, and fuel cycle damage costs for pollutants from the fuels into the societal lifecycle measure for 15 different types of vehicles. External costs from pollution are calculated as damages resulting from greenhouse gas emissions, while the external cost for oil supply insecurity is measured as the cost to the U.S. government of providing

security for oil imports from the Middle East. Ogden, Williams, and Larson (2004) reported a major finding of the non-competitiveness of alternative energy fuels until air pollution and oil supply insecurity risks are internalized. Upon internalization of these external costs, the hydrogen fuel cell vehicles have a significantly lower life cycle cost relative to any other options.

However, Owen (2004) pointed to one of the major design flaws in the Ogden, Williams, and Larson (2004) study; an inappropriate methodology for which they derived oil supply insecurity costs. Owen suggested the reader make a critical distinction between control costs and damage costs. Damage costs are a measure of "society's loss of well-being resulting from the damage resulting from a specific environmental impact" (Owen 2004). On the other hand, control costs are the expenditures necessary for society to achieve a given standard. Owen (2004) stressed that the approaches are not interchangeable and that control costs should be viewed as a poor substitute for damage costs, therefore nullifying the results found by Ogden, Williams, and Larson (2004).

Life cycle assessment valuations have been applied to ethanol fueled vehicles by Michealis (1995) and the International Energy Agency (1993). Specifically, Michealis (1995) used estimates of emissions by stages of the production cycle; from the production of the vehicle all the way to exhaust emissions from vehicle operation. Michealis (1995) found that ethanol from biomass and power-generated electric vehicles from non-fossil fuels offer the greatest reduction in greenhouse gas emissions. He stated that cars running on ethanol (from corn or wood) have a 20 to 110% reduction in

greenhouse gas emissions. Michealis (1995) moved into the monetarization phase of his study, using discounted cash flow analysis and costs estimated by International Energy Agency (1993) to compare the costs associated with alternative fueled vehicles to those of gasoline. Depending upon the annual distance traveled, ethanol produced from sugar and wood sources is between $0.0279 and $0.0723 per kilometer more costly than gasoline. However, when pollutant reductions are taken into consideration, ethanol from corn and wood sources are comparable to gasoline with a cost increase of −$0.0072 to $0.0145 per km.

A study by Mapeda, Epplin, and Huhnke (2006) compared the environmental and health risks associated with corn and biomass ethanol as a gasoline additive to those of conventional gasoline. The authors use the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model that was developed at the Center for Transportation Research, Argonne National Laboratory, to estimate air pollutants emitted per mile of vehicle travel (Wang and Lall 1999). Included in the analysis were six different pollutants that were released during all three stages of the fuel life cycle—feedstock, fuel, and vehicle operation. The results show the externality costs to the U.S. in terms of health, air quality, and crop damage caused by each pollutant released resulting from the use of conventional gasoline relative to corn and biomass E10 ethanol. Their findings show improvements in total externalities with the use of E10 relative to conventional gasoline.

Delucchi's (1998) estimated costs of pollutants were used for valuation purposes. The analysis yields estimated costs for conventional gasoline ranging from $6.6 to $68

billion, $7 to $72.2 billion for E10 (a fuel blend made up of 10% ethanol); this increase in cost comes from the fact that vehicle emission reductions are offset by emissions in the production of corn ethanol which causes increases in PM-10.

It isn't surprising that most of the emphasis in the literature has been on quantifying and valuing the environmental impact from a usage basis. The impact of a changing agricultural landscape and the environmental impact from the production of a good are often disregarded. Table 19 in Appendix B offers a summary of the impacts discussed in the above articles. The studies discussed in this section offer specific details on the impacts involved in each particular sector. Much of that detail is lost when we move to quantifying and valuing impacts from a comprehensive approach. Nevertheless, as the next section will discuss, comprehensive approaches to analyzing ethanol's impact attempt to give us a ubiquitous look at ethanol's influence.

Quantification of Comprehensive Impacts

A key outcome from comprehensive approaches to measuring ethanol's impact on environmental resources is total carbon dioxide emissions. Although it is clear from the research that gallon for gallon a vehicle burning ethanol emits less carbon dioxide than traditional fuels, when you account for everything that must occur to get the ethanol into the vehicle, carbon dioxide emissions are greater than expected (Moomaw and Johnston 2008; Nalley and Hudson 2003). As explained by Dias de Olivereira, Vaughan, and Rykiel (2005), CO_2 emissions can be released during the burning of fuel in vehicles, transportation, application of fertilizer, application of insecticide, production of ethanol, or through increases in soil organic carbon. In addition, the production of

ethanol often involves the burning of coal for energy, which may potentially offset CO_2 emission reductions gained from using the ethanol instead of using a fossil fuel.

On the forefront of any ethanol discussion is the net energy balance debate. Morris (2005) referred to the net energy balance debate as the "endless" debate. Net energy value is the traditional way to measure the energy balance of biofuels and is defined as the difference between energy outputs from ethanol relative to the energy of the inputs required to produce ethanol (Bastianoni and Marchettini 1996). The simple question "Does it take more energy to make ethanol than is contained in ethanol?" has complicated answers (Morris 2005). In 1980, the answer was no, but with improved technologies, the answer has become less clear (Morris 2005). Differing technological adoption rates and the speed at which changes are occurring are two significant explanations for the debate over the net energy balance of ethanol. Some of the earliest work on the environmental considerations of ethanol usage was done by Kane et al. (1989). The work by Kane et al. (1989) illustrates just how significant the technological advancements that have occurred in the past decade are with respect to alternative fuels and suggests that the calculation of ethanol's net energy balance is plagued by this rapid and considerable technological advancement.

In general, the net energy balance of ethanol is a ratio comparing the energy output of ethanol relative to the energy input used in the production of ethanol. A "positive" net energy balance of ethanol refers to an outcome where more energy is generated from the ethanol than is used to produce the ethanol and is indicated by a ratio with a value larger than 1.0. On the other hand, a negative net energy balance implies

that more energy is being used to produce ethanol than is gained by using the ethanol itself and is represented with a ratio value less than 1.0.

The primary players at the center of this heated debate are ethanol's most visible critic David Pimentel of Cornell University and Hosein Shapouri of the USDA. Pimentel's more than 20 studies have repeatedly shown that ethanol requires more fossil fuel energy to grow corn and convert it into ethanol, than the energy contained in ethanol (Pimentel 1994; Pimentel 1998; Pimentel 2003; Pimentel and Patzek 2005; Morris 2005). On the other hand, Shapouri and his colleagues repeatedly show a positive net energy balance (Shapouri, Duffield, and Graboski 1995; Shapouri, Duffield, and Wang 2002; and Shapouri, Duffield, McAloon, and Wang 2004). Morris (2005) explained that Pimentel's results stemmed from using out-of-date technologies and that Pimentel fails to account for the energy of ethanol's co-products (Graboski 2002; Morris 2005; Mathpro 2005). Hammerschlag (2006) went a step further and normalized the results from 6 different studies and compared them on the basis of their energy return on investment, finding that Pimentel and Patzek are, relative to the other research teams, using decidedly larger input energy values.

Others have done work in this area, which has helped to shed light on some of the assumptive differences that yield the conflicting results (Graboski 2002). Using a number of different scenarios for the corn used in the production of ethanol and the type of technologies being used at the ethanol plant, Lorenz and Morris (1995) found that with the use of the most efficient technologies ethanol has a positive net energy balance. State-of-the-art practices were able to get the ratio up to 2.51 (Lorenz and Morris 1995).

However, Lorenz and Morris (1995) also revealed the following situations where a negative net energy balance was likely to occur when the ethanol is being produced in ethanol facilities that do not use cogeneration, when using corn that had been grown with irrigation, when using corn that was planted continuously, and other energy inefficient practices at the plant and the farm levels. These inefficiencies caused the energy ratio to drop to approximately 0.7:1, indicating that ethanol was using more energy than it was producing (Lorenz and Morris 1995). An outline of some of the more recent studies, their major assumptions, and their conclusions is presented in Table 2.

Table 2. Comparison of Net Energy Balance Studies

Authors	Year	Corn Yield (BU per acre)	Ethanol Yield (gal per BU)	Energy of Inputs	Output/ Input Ratio	Major Assumptions
Pimentel	1991		2.496		0.68	doesn't include coproduct energy credits
Lorenz and Morris	1995				1.38	used the most efficient technologies available
Wang	1999				0.96	
Ulgiati	1999				1.36	
Shapouri, Duffield, Wang	2001	125		20.2 K BTU per gal	1.33	
Graboski	2002	140	2.68		1.25	
Pimentel	2003		2.496	35.6 GJ per ha	0.78	incldued machinery manufacture energy
Ethanol Across America	2004				1.06	doesn't include coproduct energy credits
Shapouri, et. al.	2004			18.7 K BTU per gal	1.67	
Dias de Oliveria, et. al.	2005	125.1	2.597	20.2 GJ per ha	1.1	didn't include machinery manufacture energy
Pimentel and Patzek	2005	138.5	2.496	37.9 K BTU per gal	0.82	coproduct credit half of USDA's coproduct credit
Hill et. al	2006				1.24	expansive boundaries on energy inputs

Dias de Oliveira, Vaughn, and Rykiel (2005) estimated the quantity of inputs needed for the production of corn ethanol in the U.S. They found the energy equivalent of those inputs, the energy per hectare, accounted for varying production practices across the U.S. and found a “positive” output/input ratio of 1.1, substantially lower than the

ratio they computed for Brazil's sugarcane ethanol of 3.7. They extended the research by conducting sensitivity analysis to find that the difference between best and worst case scenarios is only 9%, with even the worst case scenario in terms of the energy required to produce nitrogen, the ethanol conversion rate, and the corn yield to have a positive net energy balance. Having accounted for the energy balance of ethanol's co-products, Hill et al. (2006) found a positive net energy balance, albeit small, despite their expansive boundary on energy inputs. Hill et al. (2006) attributed their positive result to the recent advances in technological efficiency of the ethanol production process and increased crop yields. Variations in the net energy balance results have been attributed to differences in "corn yields, ethanol conversion technologies, fertilizer manufacturing efficiency, fertilizer application rates, by-product evaluation, and the number of energy inputs" (Kim 2003). Despite the many studies published on this issue, the net energy balance of ethanol still remains divisive.

Another approach to determining the total impact of ethanol is eMergy analysis. The eMergy approach (Odum 1996; Brown and Ulgiati 1999) measures the theromodynamics "of all forms of energy that are directly and indirectly used in a process and converts them into equivalents of one form of energy" (Ulgiati 2001). Specifically, eMergy analysis considers the energy from renewable and non-renewable sources, goods, labor, and materials (Bastianoni and Marchettini 1996). Ulgiati (2001) reiterated, "EMergy is a measure of the global processes required to produce something expressed in units of the same energy form." However, upon application of eMergy analysis, Ulgiati (2001) concluded that ethanol and other biofuels are not yet a viable

alternative (Ulgiati 2001). Bastianoni and Marchettini (1996) made a similar conclusion following the completion of four different biomass case studies, stating "we are still far from sustainable production of biofuels: it seems that biomass energy cannot be a fundamental source of energy in countries showing a high level of energy consumption" (Bastianoni and Marchettini 1996).

A third comprehensive approach to analyzing ethanol that has gained popularity is life-cycle analysis. Life-cycle analysis is used to compare the environmental consequences associated with different products that provide a similar function (Kim and Dale 2003; Owen 2006a). Hodge (2002) used life-cycle analysis to show that, even with the latest technology, more energy is needed to make ethanol than the energy that ethanol gives back. Life-cycle analysis is commonly followed by the application of costs to obtain valuation measures. Michealis (1995) and the International Energy Agency (1993) used a life-cycle analysis approach to determine a value for the impact of fuel usage. Additionally, Kim and Dale (2005) found, through life-cycle analysis, that when biomass from cropping systems is used for the production of biofuels non-renewable energy, energy is saved and greenhouse gasses are reduced.

These comprehensive approaches lack in terms of having a single value that reveals the true impact of expanded ethanol production. The completed studies use a number of different methodologies and approaches to determine the true impact of ethanol. All of which lead to the inevitable problem of having a wide range of results, with little or no agreement on the true impact.

Valuation of Comprehensive Impacts

Several studies have focused on the net carbon dioxide emissions from corn ethanol. Dias de Oliveira, Vaughan, and Rykiel (2005) used an input-output model to obtain an estimate of the ecological footprint left by ethanol production. Using an estimate of the forest area required to sequester CO_2 emitted by various gasoline and ethanol production and consumption processes, the authors found a total ecological footprint of 1.11 ha per automobile per year for gasoline in the U.S. and a footprint of 1.74 ha per automobile per year for E85 ethanol. Patzek et al. (2005) reiterated that carbon dioxide sequestration by corn is nullified when corn ethanol is burned and we are left with additional emissions from fossil fuels used in the production of ethanol. Other studies use zero carbon dioxide emissions, assuming that emitted levels will balance out with the carbon sequestration accruing through increased energy crop production (Ulgiati 2001).

Cost benefit analysis (CBA) is an approach that compares the benefits of a program or policy to the costs of the same program. In the process of completing a CBA the effects under consideration must be quantified and then monetized. The California Energy Commission (2001) conducted a cost benefit analysis on the impact of the biomass-to-ethanol industry in California. The report focused on ethanol produced from woody biomass. The California Energy Commission (2001) broke up the costs and benefits of a 300 mgy biomass-to-ethanol industry in California into three categories: economic costs and benefits, energy impact and potential effects on gasoline and electricity prices, and resource and environmental repercussions. An “avoided cost

method" was used to derive the monetized values of the environmental impact of biomass ethanol production. These avoided costs are based off of either the average trading factors of the pollutants or the cost to the plant of controlling the pollutant. Owen (2004) would argue that this is the wrong type of cost to measure, that we need to incorporate actual damage costs of an impact rather than the costs to control that impact, which is what these avoided costs are. Nevertheless, the total value of the benefits of a biomass-to-ethanol industry in California is estimated to be $40 per bone dry ton of feedstock, which under their assumptions materializes out to be worth $114 million per year.

Summary of Ethanol Impacts

The advancement of ethanol production through legislation will certainly have an effect on our soil and water resources, air quality, and resources. However, the extent to which the impact will be felt is uncertain. It is likely to remain uncertain until the analytical issues of fuel ethanol can be resolved. Nevertheless, there will always be variations in the assumptions made, the technologies used, the yields obtained, and the measured emissions quantities. To provide meaningful results, quantification and valuation studies should address these variations and offer sensitivity analysis with regard to plausible assumptions and differences in technologies.

The valuation studies we have reviewed cover a wide range of possible assumptions and they cover a wide range of possible approaches. The majority of the reviewed studies have focused on the pollution aspect of ethanol. Therefore, until a more comprehensive valuation study addresses the many different aspects of increased

ethanol use, including health risks, impact on soil and water resources, and impact on emissions, ethanol's overall environmental impact will likely remain contentious.

Although often controversial, the valuation of ethanol's environmental impact will allow for appropriate policy making. Hill et al. (2006) pointed out one of the reasons it is important to acknowledge ethanol's environmental impression, is the potential justification (or lack there of) of U.S. subsidies and tax credits. The valuation of environmental costs and benefits could justify those subsidies as a means toward the internalization of the external environmental impacts. Currently, there is a gap in the economic literature when it comes to the comprehensive valuation of alternative fuels. Attempts at valuation of ethanol's impacts have been made, but with little widespread acceptance. Suggestions for future research include the use of a broader risk management context accounting for the life cycle impacts, social costs, and private costs that cannot be ignored.

Legislatively, we are a country moving toward the pervasive use of ethanol and other biofuels. The economic literature can provide key insights into how this movement should be managed through policy tools such as subsidies and taxes, and offer discernment on the true impact of this type of progression.

Prior Research on the Water Implications of Ethanol Production

Given the newness of the expanding ethanol industry, there have been relatively few to tackle the issue of widespread ethanol production and its implications for our water resources. However, there has been increasing concern about the impact expanding ethanol production will have on the nation's water. Recent research in Iowa

attempts to use a ground water availability model to determine the impacts of ethanol producers as new water users in the North West region of Iowa (Iowa Department of Natural Resources 2008). Working within the Dakota aquifer, the researchers were able to map the ground water flow that would result from pumping the wells used by 4 ethanol facilities outside of the city of Hartley, Iowa over a 10 year time frame (Iowa Department of Natural Resources 2008). Based upon the predicted water withdrawals in the water-use permits that have been filed, the simulation results reveal an additional drawdown of 17.1 feet on the city's wells due to the use of water by ethanol facilities over the 10 year time period.

Facing concerns of water depletion, researchers at Kansas State University have attempted to determine the impact of ethanol production on water supplies. Using a hypothetical irrigation schedule to depict the quantity of irrigation water required for ethanol feedstock production and average figures of water use by ethanol plants, O'Brien et al. (2008) calculated the quantity of water used by ethanol plants in Kansas. Although this study looks at a number of other implications of Kansas ethanol production, they fail to go into the implications of the quantity of ground water being used by ethanol production.

Also concerned about the quantity of water being used by corn-based ethanol, Mubako and Lant (2008) measured the water footprint of corn-based ethanol. A water footprint is simply a calculation of the volume of water required in the production of a good. Mubako and Lant (2008) focus their study on the highest corn producing states (Illinois and Iowa) and the state with the most irrigated corn production (Nebraska).

Taking into consideration both irrigation water and rainfall used in the production of corn and evaportranspiration rates, Mubako and Lant (2008) were able to estimate a water footprint for the corn grown to produce the ethanol and then combine that estimate with the water used in the ethanol plants. The authors confirm the water intensive nature of corn-based ethanol production with estimated mass and volumetric ratios that are among the most water intensive products. Although it is noted that the overall net impact on water resources depends upon which crop the corn grown for ethanol is replacing, the authors conclude that the high water costs associated with corn-based ethanol should call into question its subsidization (Mubako and Lant 2008).

Using different hypothetical scenarios of the U.S. biofuels industry by 2030, De La Torre Ugarte et al. (2008) attempt to distinguish the differences between grain ethanol and cellulosic ethanol in terms of water usage and water quality. The first, or base scenario, allowed for the use of 60 BGY of ethanol by 2030 and 1 BGY of biodiesel by 2012, while the alternative scenarios make the assumption that the cellulose-to-ethanol technology will be widely available (and economical) by 2012 and 2015. Through the use of the POLYSYS model, a simulation model of the U.S. agriculture sector developed from a number of other models including POLYSIM (Ray and Richardson 1978), the authors were able to forecast the land use changes in each scenario. Formulas for evapotranspiration allowed the authors to compute the quantity of water necessary to support the land use changes predicted by their model. Although their findings suggest that regional water demands will vary significantly with the use of residual crop material in a cellulose-to-ethanol process, overall, the use of no-till crop

practices and cellulosic technologies would ease demands placed on water resources for the production of biofuels (De La Torre Ugarte et al. 2008). De La Torre Ugarte et al. (2008) make the important point that tradeoffs will exist—changes in feedstock production will have implications for livestock production, which in turn will have implications for water quantity and certainly water quality.

Babcock et al. (2007) explore the water implications of producing alternative energy by utilizing the soil and water assessment tool (SWAT). Initially the authors found the subsidy level required to entice farmers to switch to the production of switchgrass based upon alternative switchgrass yields and ethanol prices (Babcock et al. 2007). These hypothetical subsidy levels were found to be between $44 and $107 per ton. Babcock et al. (2007) then examine the environmental consequences to the forecasted land conversion using scenarios to account for the type of land being put into the production of switchgrass. The authors find that a change to switchgrass from traditional row crops would result in a significant improvement in water quality (Babcock et al. 2007).

Incorporating Risk into Decision Making

Risk and uncertainty, though not technically the same thing[7], are often used to describe a lack of perfect knowledge about an outcome. Hardaker et al. (2004a) explain that because the decisions we make today have consequences in the future, it is impossible to know exactly what those consequences will be. Nevertheless, the rational

[7]Knight (1921) distinguishes risk as situations where the resultant outcome is unknown, but the probabilities of each potential outcome are known, whereas uncertainty describes a situation where neither the outcome nor the probabilities of the potential outcomes are known.

decision maker will often want to account for the potential consequences at the time of the decision making even if the "true" outcome is uncertain. In agriculture, risk is clearly present in the random nature of prices and yields. By definition, risk is the part of the business decision that cannot be controlled by the manager (Richardson 2006).

In one of the most thorough accounts of the history of risk, Bernstein (1998) describes gambling as the "very essence of risk taking" and traces evidence of gambling back to 3500 BC with Egyptian monoliths. However, more formal theoretical risk concepts came forward during the Renaissance period as a result of commerce, trade, and wealth generating activities (Bernstein 1998). Through these early foundations, Pascal and Fermat's development of probability theory in the 17th century, Graunt's early attempts at calculating empirical probabilities in 1665, and Bernoulli's hand in developing our understanding of uncertainty, modern applications of risk analysis have been developed (Bernstein 1998; David 1962; Devlin 2008). Risk in itself is sempiternal, however the methods by which risk is described, controlled, and modeled have matured over time (Mun 2006). Hardaker et al. (2004a) define risk management as the "systematic application of management policies, procedures, and practices to the tasks of identifying, analyzing, assessing, treating, and monitoring risk", therefore we can say that although risk will always be present, our ability to manage and control different aspects of risk have developed over time.

The presence of uncertainty or risk will affect a decision maker's behavior. In general, we know that most people dislike risk, especially when the decision involves a significant level of income or wealth. Individuals who dislike risk are referred to as

being risk averse (Hardaker et al. 2004a). A risk averse individual will behave differently than an individual who is risk neutral or risk loving. As an example, consider two gambles, we'll call them gamble A and gamble B. Gamble A offers a 100% chance of yielding $50, while gamble B offers a 50% chance of yielding $0 and a 50% chance of yielding $100. The calculation of the expected values for each gamble is shown as follows in equations (1) and (2):

(1) $EV(A) = 1.0 * 50 = 50$

(2) $EV(B) = .5 * 0 + .5 * 100 = 50$

As show in equations (1) and (2), both gambles A and B have the same expected value of $50. A risk neutral individual will be indifferent between gamble A and gamble B, or any two gambles with the same expected value regardless of the probability of a significant loss or gain. Conversely, a risk averse individual will take into consideration the 50% chance of earning $0 in gamble B. Within the context of the example gambles given above, an individual would be deemed risk averse if they were willing to exchange the gamble B for a certain sum of money less than $50 (the expected value of gamble B). On the other hand, an individual could be considered risk loving if they were willing to be pay a sum of money larger than the expected value of gamble B ($50) to participate in that gamble.

Although investment decisions are typically made under the conditions of risk and uncertainty, the majority of analyses make the assumption of perfect knowledge and base decisions on either a single point estimate or will use naïve estimates. Frequent

naïve approaches to dealing with risk are to use a single conservative or "worst case" estimate or basing decisions on the most likely or "average" outcome. However, the probability of occurrence for a single point estimate is nearly zero. Decisions based upon the expected outcome over time do not take into consideration that decision makers may deem the probability of a "significant" loss as being unacceptably high. These approaches will lead to biased results as the variance of the outcomes not being taken into consideration. Risk analysis is designed to account for the complete range of outcomes rather than basing decisions on a single, biased expected or overly conservative estimate (Pouliquen 1970).

Monte Carlo Simulation

At varying levels of complexity, there are many approaches to incorporating risk into a decision model, including dynamic programming, non-linear programming, and scenario analysis. Collectively, the approaches used for analyzing a decision under risk are referred to as decision analysis (Hardaker et al. 2004a). Challenges often arise when dealing with multiple sources of risk in a given analysis. Monte Carlo simulation has been used extensively for addressing multiple sources of risk and uncertainty. Relative to traditional mathematical approaches, simulation offers the primary advantage of having the potential to analyze complex models that are (hopefully) more realistic in nature (Clarkson and Simon 1960; Suttor and Crom 1964). Additional advantages of using simulation, as pointed out by Suttor and Crom (1964), include being able to model human behavior and decision making without first developing the associated

mathematical model and the ability to use a simulation model to represent an aggregation of individuals.

Using a simulation approach for decision analysis involves building a mathematical model that represents the system being described by the model (Clarkson and Simon 1960). Within the model, stochastic variables are used to represent "significant" variables that are uncertain. Stochastic variables are variables that are thought to have a key impact on the overall outcome, thus having a significant impact on the business decision under study. For example, in an agricultural simulation model, the prices of the inputs and outputs are often included as stochastic variables in addition to crop yields as those variables directly impact the profitability of a farm. Stochastic variables are specified by the modeler as following a particular probability distribution. Incorporation of stochastic variables is fundamental to the Monte Carlo simulation process.

Monte Carlo simulation involves generating a random value (or draw) for each of the stochastic variables based upon the probability distribution specified by the modeler (Schaefer and Weiss 1971). The draws of the input variables are aggregated into the output variable of interest based on the relationship specified in the model. This process of generating draws of stochastic input variables is repeated and a probability distribution for the output variable is developed (Schaefer and Weiss 1971). Pouliquen (1970) eloquently describes the relatively simple idea behind Monte Carlo simulation, stating that the idea of Monte Carlo simulation is to replicate a great number of projects

with characteristics that are comparable to the project of interest and determine the distribution of returns of the replicated projects.

Correlating Random Variables

The idea behind any model is to create a representation of reality for the purposes of analysis. In a simulation model where stochastic variables are modeled independently, the relationship between variables is lost (i.e. the correlation between the variables is assumed to be zero). Not only does this approach fail to provide a realistic representation of the correlation between the variables, it may also cause added variability in the model and cause a bias in the results (Clements, Mapp, and Eidman 1971; Richardson and Condra 1981). By appropriately correlating random events within the model, the use of a simulation model will not change the significant relationships of the random variables (Lau 2004).

A theoretical approach for the correlation of random variables was first presented by Naylor, Balintfy, Burdick, and Chu (1966). Later, Clements, Mapp, and Eidman (1971) presented a practical procedure for correlating two random events at any desired level. The authors go on to generalize the procedure to account for correlating more than two random events. The Clements, Mapp, and Eidman (1971) procedure involves calculating an A matrix based upon the variance-covariance matrix of the events and combining the A matrix with random normal deviates to obtain correlated or multivariate normal distributions for the random variables. Similarly, Law and Kelton (2000) provide documentation of a procedure to simulate multivariate normally distributed variables.

The asymptotic properties of the normal distribution present some challenges. When applying the normal distribution to variables, negative values of those variables will be realizable during simulations. However, in the case of variables such as price and yield, negative values are not viable and nonsensical. We therefore need to be adept at applying non-normal distributions to variables in our models. Random events that are distributed non-normally present a limitation to the application of the Clements, Mapp, and Eidman (1971) procedure. Richardson and Condra (1978; 1981) describe a more general approach to correlating random variables, an approach that extends beyond the confines of having to use a normal distribution for the random variables. King (1979) and Li and Hammond (1975) provide independent documentation of a procedure for correlating non-normally distributed random variables, King (1979) using a beta distribution.

In the application of multivariate non-normal stochastic variables to determine the effect of farm size on farm survival, Richardson and Condra (1981) applied their procedure by taking the square root of the correlation matrix for the price and yield random variables and multiplying it by a vector of standard normal deviates. Using the error function, the resultant product is transformed to a uniform standard deviate, making the value be between 0 and 1. We are then able to map the value into the appropriate distribution for that particular variable based upon the variables' cumulative density function (CDF). Using empirically estimated marginal distributions and the concept of a joint distribution, Taylor (1990) presents two alternative approaches to the empirical estimation of multivariate non-normal distributions. More recently,

Richardson and Schumann (2004) provide a detailed account of the procedure involved with developing multivariate non-normally distributed variables for use in a simulation model.

The empirical distribution is often beneficial for use in simulation models as it is a distribution based on the observed distribution of the historical data series of the variable in question—it has no set form and its shape is based solely upon the frequencies of the data series used to generate the distribution. This property makes the empirical distribution frequently useful in situations of relatively limited historical data. Richardson, Klose, and Gray (2000) describe a method for including multivariate empirically distributed variables in simulation modeling. Included in the Richardson, Klose, and Gray (2000) paper are steps for estimating the parameters of the empirical distribution. This procedure for developing multivariate empirical (MVE) distributions has sparked the use of MVE in several articles, including Outlaw et al. (2007), Richardson et al. (2007), and Richardson, Lemmer, and Outlaw (2007).

Ranking Risky Scenarios

The use of a stochastic simulation model facilitates the developer to yield a distribution of results for risky alternative management decisions. These scenarios allow the analyst to compare outcomes across alternative management decisions while considering the breadth of uncontrolled possibilities captured through the stochastic nature of the input variables. A challenge arises when attempting to determine which of the given scenarios is preferred, as both the preferences for the outcomes and the probabilities of each outcome will affect the decision maker's preferred alternative

(Hardaker et al. 2004b). Hammond (1974) categorizes the practical challenge of ranking the outcomes of uncertain prospects as being a challenge of either assessing the individual's preferences, or a challenge of doing the calculations on an analytically challenging functional form, or the challenge of size when incorporating all the uncertainties possible into a decision metric.

Given the problem of not knowing a decision maker's utility function or their risk / income preference, analysts have an array of tools that can be used to determine the "best" alternative. Ranging in complexity, rankings based upon the mean, standard deviation, mean-variance, stochastic dominance, certainty equivalence, and stochastic efficiency can be used to rank alternative scenarios (Anderson, Dillon, and Hardaker 1977; Richardson 2006). Rankings based solely on the mean outcomes and the standard deviation of the scenarios results in a loss of valuable information obtained by using a simulation procedure. Mean only rankings ignore the risk for each scenario and standard deviation based rankings of scenarios ignore the income generated by each scenario (Richardson 2006).

The mean-variance approach uses two summary statistics, mean and variance, to represent the distributions of the uncertain alternatives (Yitzhaki 1982). Although relatively frequently used, mean-variance rankings cannot always be used to compare scenarios. Mean-variance rankings will often result in inconclusiveness between scenarios. In addition, mean-variance rankings inherently fail to capture an individual's willingness to trade risk and income (Richardson 2006). Another relatively simple approach for ranking scenarios is based upon relative risk as measured by the scenario's

coefficient of variation (CV). CV is calculated using the mean ($\bar{y}$) and the standard error (s) as displayed in equation (3). Although CV strives to measure the variability relative to each average unit of return, CV does not account for downside tails on the distribution of outcomes (Johnson and Foster 1994; Richardson 2006).

(3) $CV = \frac{s}{\bar{y}} \times 100$

The key advantage to using simulation is the benefit of having a continuous probability distribution of our output variables. A desirable tool for ranking scenarios will be one that takes into consideration the full distribution of outcomes for each proposed alternative. Using an assumption of expected utility of wealth maximization, first and second order stochastic dominance was proposed by Hadar and Russell (1969). Hadar and Russell (1969) developed first and second order stochastic dominance as a means to predicting a decision maker's selection without knowing their utility function, only making the assumption the individual is risk averse. However in empirical settings, it is often the case that first and second order stochastic dominance will fail to have the ability to fully rank all of the alternatives.

Meyer's (1977) introduction of stochastic dominance with respect to a function (SDRF) strives to use a more generalized approach to selection among risky alternatives while still making relatively few assumptions about the decision maker's risk preferences. The generalized stochastic dominance (GSD) approach was developed as a technique to guarantee the ability to rank risky alternatives, given a decision maker with a risk aversion coefficient (RAC) between a particular range. Relieving the burden of

having to know the individual's specific utility function, Meyer's (1977) GSD relies on simply knowing an upper and lower bound for an individual's RAC. The preference rankings achieved by using GSD are general enough to apply to all decision makers who have a RAC within the bounds of the predetermined RAC interval. As a means to further simplify this process, Hammond (1974) and McCarl (1988) proposed solving for the break even risk aversion coefficient (BRAC). McCarl (1988) defines the BRAC as the point in which the preferences between risky alternatives change, given a constant risk aversion utility function. At a BRAC, the decision maker is indifferent between the risky alternatives. As the number of locations where the CDFs for alternative scenarios cross each other increases, the number BRACs will also increase. The process of finding the BRAC allows the analyst to determine ranges of RACs in which individuals would have a given preference ranking and removes the chance of having a situation of no dominance between alternatives that would of occurred if the analyst had used stochastic dominance to rank the alternative scenarios.

Certainty equivalents, as originally defined by Freund (1956), have been proposed as a method for ranking risky alternatives by Hardaker (2000). Certainty equivalence is known to be the amount of money that makes the individual indifferent between a certain outcome and a risky outcome, where the risky outcome has the same mean return as the certain outcome. In the case of risk averse individuals, their certainty equivalent will be less than the expected value of the risky alternative. Certainty equivalence is simply the inverse of the expected utility of an outcome. Therefore, a

procedure that ranks the alternatives by their certainty equivalents is equivalent to ranking alternatives by their expected utility.

Building on the idea of using certainty equivalence to rank risky alternatives, Hardaker et al. (2004b) present another procedure for ranking risky alternatives called stochastic efficiency with respect to a function (SERF). Using certainty equivalents, SERF orders a set of risky alternatives for a given range of risk aversion. Instead of comparing alternatives to each other individually as in the SDRF procedure, SERF compares alternatives simultaneously and can thus produce a more compact efficient set (Hardaker et al. 2004b). SERF offers the added benefit of being able to calculate the utility-weighted risk premiums (the risk premium is defined as being the amount an individual would be willing to pay to convert a risky alternative into a prospect with a certain outcome) between alternatives, giving the analyst a cardinal measure of preference between alternatives (Hardaker et al. 2004b). A number of recently published articles have utilized SERF to compare risky alternatives including Lein, Hardaker, and Flaten (2007), Pendell et al. (2007), and Nartea and Webster (2008).

Applications of Stochastic Simulation

Monte Carlo techniques have been extended to the arena of financial analysis. In a World Bank paper, the use of simulation in financial statement models was first proposed by Reutlinger (1970) as a means to estimating the net present value (NPV) of a proposed investment. Richardson and Mapp (1976) proposed utilizing probabilistic cash flows in a stochastic simulation setting as a preferable method to analyzing investment decisions under conditions of uncertainty.

Included in Richardson and Mapp's (1976) proposal is a detailed description of the preferred methodology for building a stochastic feasibility model, the defining characteristic of this model being probability distributions that are defined for each "influential" input that is risky or unknown. In other words, input variables that are suspected to have an influence on the proposed investment are created as stochastic components of the model. Incorporating the stochastic variables into accounting relationships (in addition to the other static input variables) will result in a stochastic cash flow variable. Using separate probability distributions for each year on each influential variable allows the project to be analyzed over a set time period in the future. Through repetition of a random sampling procedure, a distribution on the key output variable is developed, allowing for the proposed investment to be considered under a large number of possible future states of nature. Use of this methodology for investment decisions provides the decision maker a more complete set of information on the potential performance of the proposed investment.

Building on Reutlinger's (1970) suggestion of using NPV as a key output variable, Richardson and Mapp (1976) defined a summary statistic called the probability of economic success, which refers to the probability that NPV is larger than zero. An investment with a NPV less than zero indicates that the project is not generating a return larger than the investor's discount rate and is, therefore, not a "successful" investment.

One of the primary benefits to using simulation is the ability to use stochastic variables to represent variables with a significant amount of uncertainty, which is characteristic of new or emerging technologies. Ethanol production has rapidly

expanded in the last 10 years, leaving a large amount of uncertainty with regard to the nature of this rapid expansion; therefore the utilization of stochastic simulation has been particularly well suited for the analysis of ethanol production feasibility. Building on the applications of simulation to small business feasibility by Cochran, Richardson, and Nixon (1990), Monte Carlo simulation techniques have been utilized to analyze the feasibility of ethanol production facilities. Using historical variability of prices and production as a measure of future variability, Outlaw et al. (2003) was one of the first studies to use stochastic simulation to project the feasibility of ethanol production in Texas. Richardson et al. (2007) and Lau (2004) also incorporated simulation as a means to determining the potential success of Texas ethanol production. With regard to the feasibility of emerging ethanol production practices in the U.S., Outlaw et al. (2007) used stochastic simulation to analyze the feasibility of integrating ethanol production into an existing sugar mill and Ribera et al. (2007) created a sugarcane-sorghum ethanol feasibility simulation model.

Forecasting Changes in Land Use

The economic theory behind any land use forecasting technique is that land managers will select the activity that maximizes the land's rent, subject to economic, political, and feasibility restrictions. Another linking factor between land use forecasting techniques is the fact that the total availability of land is fixed in quantity, therefore relieving any supply induced price changes and making an increase in one type of land usage done at the expense of (or in exchange for) another type of usage (Binkley and

McKinzie 1984). While these underlying premises are consistent, there are a number of approaches to determining changes in land use.

The literature is rich in regard to agricultural land use change. Many different approaches to forecasting changes in agricultural land use have been implemented, from approaches that use a lagged price effect, as in Smith (1925), to more technologically advanced approaches that incorporate GIS (Dekkers and Koomen 2007; Verburg and Overmars 2007). Dekkers and Koomen (2007) categorize land use forecasts as trend analyses, impact assessments, or scenario studies. While the term trend analyses may be a rather broad generalization of the time series techniques often used within the agricultural economics literature, these approaches will often be combined with scenario and impact assessments. More generally, agricultural acreage modeling is commonly classified as using a time series approach or a structural approach (Houston et al. 1999). This section describes some of the approaches, including both time series and structural, used in forecasting agricultural land use.

Even the earliest attempts at forecasting agricultural acreage were developed out of the economic theory that a producer will plant the crop that is expected to yield the highest profits and a subsequent recognition of the relationship between prices and planted acreage (Smith 1925). Anticipated price of the agricultural commodity will obviously play a role in the farmer's expected profit of producing that commodity and the subsequent decision to plant. At the time of planting the price for the crop is largely unknown, therefore making planting decisions based fundamentally on the producer's

expectation of price. This presents a challenge for modeling as the analyst must decide upon which metric to use as a representation of the producer's expectation of price.

Much of the literature on agricultural supply response has developed out of a Nerlovian lagged price approach; Askari and Cummings (1977) document more than one hundred studies using Nerlove's theory. The distributed lag approach used by Nerlove (1956) hypothesized that a producer's planting decision is a function of expected price. Although many adaptations have been made to the original model, the fundamental Nerlove approach involves 3 equations (Braulke 1982), represented by the equations (4), (5), and (6).

(4) $$A_t^d = \alpha_0 + \alpha_1 P_t^e + u_t$$

(5) $$P_t^e = P_{t-1}^e + \beta\left(P_{t-1} - P_{t-1}^e\right)$$

(6) $$A_t = A_{t-1} + \gamma\left(A_t^d - A_{t-1}\right)$$

The expected price is represented as P^e and actual price represented as P, while the desired planted area is represented as A and the producer's actual planted area is represented as A^d. β is an estimated coefficient that provides an adjustment to the price expectation based upon the accuracy of the farmer's price expectation in the last time period (t-1). γ serves a similar role, acting as a mediator between last year's planted area and the area desired for this year. Through substitution of observable variables between equations (4) through (6), a reduced form specification of planted area consisting of only observable variables is obtainable. Supply elasticities for a wide

range of agricultural commodities have been estimated using this Nerlovian set of equations (Askari and Cummings 1977). As a result of the extensive use of this fundamental set of equations in empirical studies, adaptations, extensions, and suggested improvements have been widespread and are frequently observed in the literature (Braulke 1982).

Another approach for conquering the unobservable price expectation issue was presented by Gardner (1976) who suggested the use of futures prices as a measure of price expectations. Applying the concept to cotton and soybeans, Gardner (1976) concluded the futures prices work "at least as well as" the lagged price approach used by Nerlove (1956; 1958). The findings of Chavas, Pope, and Kao (1983) were consistent with those of Gardner (1976) indicating that futures prices were useful instead of using lagged prices as a predictor of planted acreage. Morzuch, Weaver, and Helmberger (1980) utilized futures prices as a proxy for expected prices in a system of generalized least squares (GLS) equations as a means to forecast wheat acreage, finding that futures prices provide a suitable alternative to using lagged prices for price expectations.

In contrast to the idea that agricultural acreage is fixed in quantity, Brinkley and McKenzie (1984) suggest an improvement to traditional acreage response models through a recognition that there can be conversion of land between agricultural usage and other types of land usage. Expanding land demand equations to allow substitution of land between sectors using a multi-equation GLS, Brinkley and McKenzie (1984) apply their hypothesized improvement to seven "sectors" of land use in the corn-belt states. Five of the seven sectors were agricultural uses, while the remaining two were

not. In addition to providing greater insights to acreage substitution patterns between the sectors considered than a single equation approach would allow, the multi-equation approach hypothesized by Brinkley and McKenzie (1984) provides information about the relationship between the sectors considered in the analysis and those uses that were excluded from analysis.

One of the common elements of a time series approach to forecasting agricultural supply is the use of a trend variable to capture changes in technology over time. However, as Whittaker and Bancroft (1979) point out, the use of a linear trend component will miss technological improvements that follow a nonlinear form. As a means to overcoming this potential problem, Whittaker and Bancroft (1979) suggest estimating a pooled time series model for four states under analysis, where the states make up the cross sections. Comparing corn acreage empirical results to a linear trend model of corn acreage, Whittaker and Bancroft (1979) found that the pooled approach preformed equally as well as a linear trend approach and that pooled time series models should be considered as a flexible structure for overcoming nonlinear trend.

Another extension of some of the more common time series approaches to forecasting agricultural supply, involves allowing for estimated parameters to vary over time. Using a U.S. corn acreage model, White and Shideed (1991) propose the use of time varying parameters to account for technological and structural changes influencing the decision to produce corn. White and Shideed (1991) use a flexible least squares regression procedure and find that results explaining corn acreage in the U.S. are different depending upon whether a constant parameter or a flexible parameter method

was used. White and Shideed (1991) were able to conclude that the varying parameter model outperformed the constant counterpart. Nevertheless, when used for out of sample forecasting, there was not a clear advantage to using the varying parameter approach (White and Shideed 1991).

Recognizing the significant use of both time series and structural approaches to forecasting agricultural acreage, Houston et al. (1999) compared the relative abilities of each model to predict cotton planting in the southeast. Houston et al. (1999) compared a structural model using leading indicators of cotton acreage in the southeast to a time series Box-Jenkins Autoregressive Integrated Moving Average (ARIMA) model. For the purposes of forecasting out of sample, the ARIMA model would be expected to outperform a structural approach due to a structural model's forecasts being reliant upon forecasts of other exogenous variables (Houston et al. 1999). The results of the models estimated by Houston et al. (1999) conform to their original expectations; a well-specified ARIMA model has the potential to out forecast a structural model, however fails to identify the significant indicators of crop acreage.

Several comprehensive models have been developed to predict changes in land use patterns. Considered one of the most extensively applied models, the CLUE (conversion of land use and its effects) model is used to predict agricultural, urban, forest, and land abandonment rates (Verburg and Overmars 2007). The economic simulation model ProLand is designed to determine optimal land use from an economic perspective along with optimal land management practices (Reiher et al. 2006). Designed to calculate the carbon emissions from alternative land uses, the AgLU

(agriculture and land use) model is a stand alone agricultural model that uses an economic framework to predict and simulate changes in global land use (Sands and Leimbach 2003). Although functionally unique, the common component between the aforementioned models (and others that haven't been mentioned) is the models' design to use economic rent to allocate land between alternative land uses, subject to a variety of restrictions depending on the complexity of the model. Frequently these models are used in the simulation of land use projections based upon alternative scenarios and combined with other ecological or hydrological models to determine an environmental outcome of the land use projection (Reiher et al. 2006; Verburg and Overmars 2007).

Risk is a significant consideration when producers are making acreage planting decisions. Risk's role in acreage usage decisions has been explored throughout the agricultural economics literature (Babcock et al. 2007; Chavas and Holt 1990). Chavas and Holt (1990) developed an acreage supply response model under the conditions of expected utility maximization with uncertain prices and yields. Risk and wealth effects were empirically determined to be important considerations in allocating acreage between corn and soybeans (Chavas and Holt 1990).

Government farm policy programs play a role in a farmer's decision to produce and should be considered when estimating an acreage response, especially with regard to planting decisions of corn (Chavas, Pope, and Kao 1983). The short time period for which many policy tools are used makes econometric estimation of supply response a challenge and, as a result of this challenge, a number of alternative approaches have surfaced. Aggregation of years where similar policy tools were in place has been used

by Morzuch, Weaver, and Helmberger (1980) and Duffy, Richardson, and Wohlgenant (1987). Other approaches have integrated farm programs into price expectations (Bailey and Womack 1985; Shumway 1983), while others have used a disaggregated approach (Lee and Helmberger 1985). Chembezi and Womack (1991) use a two part structure, first estimating program participation and then estimating the supply response separately. More recently, McDonald and Sumner (2003) were able to incorporate the rules of farm programs into their model and provide an improved prediction of acreage response. Morzuch, Weaver, and Helmberger (1980) make that conclusion that as a result of significant changes to farm policy programs over the years, it is important to allow for a wide range of parameter estimates and resulting elasticities.

The role of biofuels with regard to changing the agricultural landscape has been of much discussion. In a study by Lee and Kennedy (2008) the causal relationship between biofuels and crop acreage is explored using a Rotterdam demand model for crop acreage. Treating the farmer as a consumer of land, Lee and Kennedy (2008) develop a land allocation function for which an individual producer allocates a given amount of acreage to alternative crops in an attempt to maximize profits. Using annual crop data over the 1963 to 2007 period and estimated acreage values for alternative crops, the empirical Rotterdam model was estimated, resulting in an estimated own acreage elasticity of corn and cotton of .7751 and .8210, respectively. The resulting inelastic acreage value cross elasticities allowed Lee and Kennedy (2008) to conclude that changes in crop acreage is relatively unresponsive to changes in acreage value, however corn was determined to be one of the more substitutable crops.

Just as water availability may limit the options for land use, the changes in type of land use is coupled to changes in water consumption and to changes in the hydrological cycle (Dekkers and Koomen 2007). This linkage between land use and water has prompted a plethora of research in the water resources arena. Economic based sector-level models are frequently used to calculate the changes in land use by sector and then combined with hydrological models to project the changes in the local water balance (Dekkers and Koomen 2007). Dekkers and Kooman (2007) used sector level models to project regional land use and then applied scenario simulations to develop hydrological impact assessments in the face of future uncertainty. Working with an agricultural watershed, Fohrer et al. (2001) aimed to determine the hydrological impact to changes in agricultural land uses. Fohrer et al. (2001) combined spatially distributed scenarios of land use with the hydrological model SWAT. Land use scenarios were developed out of an agro-economic model called ProLand (Fohrer et al. 2001). ProLand software is designed to determine the optimal land usage based upon land rents as constrained by "different natural, technical, economic, and political boundary conditions" (Möller et al. 1999; Reiher et al. 2006).

Integrated Approaches to Modeling Hydrology and Economics

The National Research Council recently published a report highlighting the value of water science research and emphasized the importance of incorporating multiple relevant disciplines (National Research Council 2004). Such multi-disciplinary work frequently requires a detailed understanding and modeling of the physical and economic systems at work, in addition to the human behaviors at work. Natural scientists,

including biologists, geologists, and engineers can create complex models that represent a specific aquifer, river basin, or geological structures. Social scientists, including water economists, often would like to expand these hydrological models to add economic analysis. The resulting models offer the ability to make recommendations, to analyze policy, to provide planning tools for water managers, and to determine efficient allocations of resources. Interdisciplinary work is an essential tool for the analyst doing water related economic research (Frede et al. 2002).

This section reviews published work that has come out of interdisciplinary efforts combining economic and hydrologic models. Specifically, the goal of this portion of the literature review is to review alternative approaches to combining the economic and hydrological aspects of a problem with specific emphasis placed on the linkage between the two types of models. A secondary goal is to identify the considerations that need to be made when attempting interdisciplinary work.

The literature related to integrated approaches of modeling hydrology and economics is organized in this dissertation in the following fashion. The first section discusses general classifications of integrated water models. The next section highlights some example research and describes the details of how the researchers linked the economic components to the physical hydrological components. The final section of this paper provides a discussion of considerations that need to be made when doing integrated water work.

Classification of Integrated Approaches

Integrated modeling of water science and economics may take many different forms. Cockerill et al. (2007) describes the range of integrated water research as being a spectrum. On one end of the spectrum, researchers use existing physical or economic models as a "black box", while at the other end of the spectrum researchers are engaging in "cooperative modeling" (Cockerill et al. 2007). Cooperative modeling involves academics from multiple disciplines and may include the public and/or policy makers as members of the project (Cockerill et al. 2007). The complexities and uniqueness of the research goal will determine whether adapting a prior model completed for a different problem (using a black box approach) is sufficient or if a new hydrological and/or ecological model needs to be designed using a cooperative modeling approach.

When working with several existing or stand-alone models, interdisciplinary models can also be classified in terms of the complexity of the relationships between the individual models used. Cai (2008) classifies models as falling into one of two classifications: compartment modeling and holistic modeling. Holistic modeling combines two (or more) models into a single model that transfers information endogenously between the two components (Cai 2008). The other approach, component modeling, treats each model as a unique sub-model to which the resultant information is eventually coordinated. Similarly, Antle et al. (2001) describe a range of interdisciplinary models based upon how closely the individual models being used are coupled. Coupling is defined as the amount of feedback that occurs between the economic and the physical processes being modeled (Antle et al. 2001).

For the purposes of this review of literature, the integrated models reviewed are categorized in terms of their integration complexity as being feedback models, conceptual models, or single measures of comparison. Feedback models employ complex physical, bio-physical, and/or ecological model components and provide feedback to an economic model (see Rosegrant et al. 2000; Ward and Lynch 1996; Watanabe, Adams, and Wu 2006). In turn, the economic model provides feedback to the physical models for subsequent periods or iterations. There are many different potential linkages between physical models and economics. The models reviewed in this section of the review of literature provide examples of agricultural, soil, and urban development linkages.

Conceptual models are much less complex in terms of the physical characteristics and often employed in the form of a spatial model of surface water characteristics through dynamic programming or optimal control. Finally, integrated research approaches using a single measure of comparison are the least complex physically and the least integrated of the group. These single measures attempt to determine the total impact to an entire system by simply quantifying the impacts. These impacts may have a dollar value assigned to them as in cost benefit analysis (CBA) or remain in varied forms as in multi-criteria analysis. Figure 10 provides a diagram of the categorization of the integrated models reviewed in this study (note that the areas of linkages for the complex physical models are simply three examples and should not be considered an exhaustive representation of all the ways to link physical components to economic models).

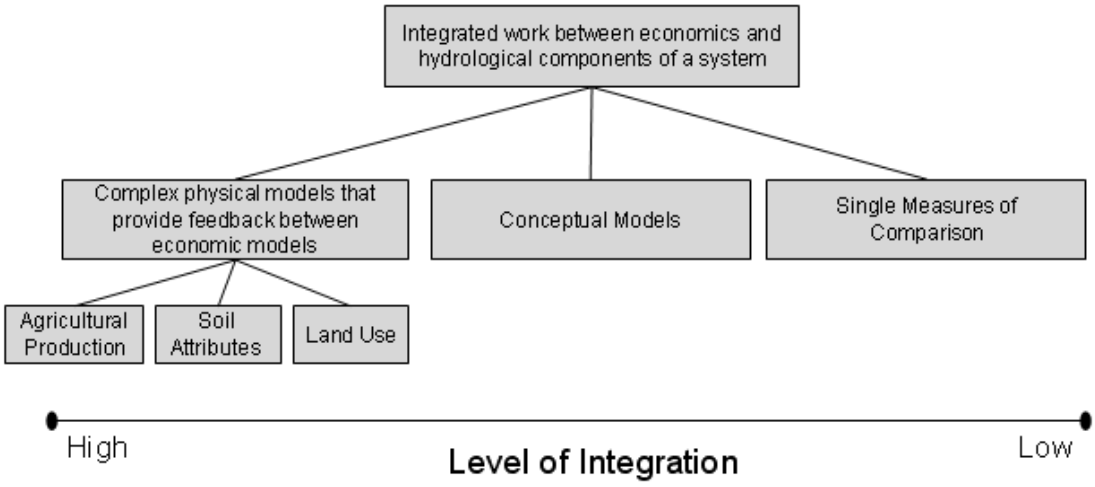

Figure 10. Categorization of Integrated Modeling Approaches

The following section of this paper is designed to give the reader a better idea of specific approaches to integrated water research. The articles that are reviewed in this document have been selected for a number of different reasons. Some articles were selected as they provided a useful example of the type of approach used, while other articles were selected due to their significant number of citations, while still others were selected simply as a representative of a group of articles using that type of approach. Feedback models, conceptual models, and single measures of comparison are all explored in this literature review.

Feedback Models

Feedback models require the highest level of interdisciplinary collaboration. The complex ecological and hydrological models are linked to economic components

through a variety of channels. One common linkage between economics and hydrological aspects is through agricultural production (Addams 2005; Ahrends et al. 2008; Cai, McKinney, and Lasdon 2003). Agricultural production provides a key linkage between economic models and hydrological or physical models due to agriculture's direct relationship to economics and agriculture's direct relationship to the environment (Frede et al. 2002). Literature is abundant with research that has used agricultural production as the factor causing feedback between economic models and physical models. Some of those agricultural models will be explored in this section, in addition to models that are linked through urban development as in Alberti and Waddell (2000) and soil quality characteristics (Frede et al. 2002; Greiner and Parton 1995).

A dissertation by Addams (2005) considers the interaction between humans and water resources of a semi-arid agricultural region of northwest Mexico through a model that utilizes an integrated hydrological-economic-agronomic framework. A physically-based surface water model was combined with a ground water model to depict the hydrological system of the region (Addams 2005). These hydrological models were constructed specifically to be embedded into an economic optimization model via crop production models. The economic component of the analysis took the form of an optimization model representing aggregate farmer decision making for the region in terms of management decisions of irrigation depth, fertilizer application, land preparation, planting dates, and crop mix (Addams 2005). Given a base hydrologic situation, the farmers make their optimal cropping decisions, which results in feedback to the hydrologic models for the next time period. The complete integrated model was

then used to analyze alternative economic, infrastructure, hydrological, and agricultural scenarios (Addams 2005).

Work by Ahrends et al. (2008) identifies optimal irrigated agriculture cropping patterns via a model of the interdependencies between irrigated agriculture and regional water balance in West Africa. The economic component (a non-linear optimization model) of the model was added to an existing physically-based hydrological model created in 2001 (Schulla and Jasper 2001). The combined model was used to represent the interdependencies between maximum agricultural profit, irrigation water quantities, and water availability in the catchment area (Ahrends et al. 2008). Irrigation area, reservoir inflow, precipitation, and potential evapotranspiration were all outputs from the hydrological model, while the economic model provided the cropping patterns and the crop-specific irrigation quantities (Ahrends et al. 2008). Allowing the two models to "communicate" with each other through those key outputs in the coupled model resulted in an ability to analyze optimal cultivation strategies in West Africa.

A spatial multi-agent programming model was used by Berger (2001) to develop an understanding of the process of "innovation and resource use changes" by the individual farm household (Berger 2001). Berger (2001) argues that his multi-agent approach overcomes some of the aggregation problems typical of traditional mathematical programming models. The multi-agent approach allows the interaction between agents with respect to limited resources (Berger 2001). The economic component of the model consists of multiple recursive linear programming models, one for each farm-household, with each farm-household maximizing their expected family

income subject to resource availability constraints and adoption of innovation (Berger 2001). The farm-household's investment and production decisions are linked to a spatial hydrologic sub-model through changes in soil quality, land use, and water supply, which then influence the farm-household decisions in the subsequent period (Berger 2001).

Using the implications of climate change on the Edwards Aquifer as motivation, Chen, Gillig, and McCarl (2001) use predicted changes in water demand and supply induced by climate change as inputs into an existing economic and hydrological model, EDSIM, for the Edwards Aquifer. Developed by a number of different contributors, "EDSIM simulates regional municipal, industrial, and agricultural water use, irrigated versus dryland production and choice of irrigation delivery system (sprinkler or furrow) such that overall regional economic value is maximized subject to legislatively imposed pumping limits" (Chen, Gillig, and McCarl 2001). EDSIM is structured as a mathematical programming model that allows recursive decision making in its two-stage format (Chen, Gillig, and McCarl 2001). The two stage format allows economic decisions to be made by farmers and the results of those decisions in terms of recharge to enter in the second stage of the model (Gillig, McCarl, and Boadu 2001). By using EDSIM to analyze the impact of predicted water supply and demand changes, the authors obtained results indicating the change in the water quantities used by different sectors and changes in economic variables including net farm income and total net welfare (Chen, Gillig, and McCarl 2001). EDSIM was also used by Gillig, McCarl and Boadu (2001) to analyze the tradeoffs between alternative water management strategies with respect to economic and environmental tradeoffs.

Soil characteristics are another method of linking economic and physical variables. The erosion productivity impact calculator (EPIC) is an example of a complex physical-mathematical model developed to address the impact of soil erosion on the productivity of the land (Williams 1990). EPIC has been frequently used to conduct economic studies based upon physical characteristics of a system (Coiner, Wu, and Polasky 2001; Forster et al. 2000; Lakshminarayan, Johnson, and Bouzaher 1995; Limaye et al. 2004; Rinaldi 2001). EPIC includes economics and hydrology as two of its nine subparts or divisions, using the productivity of the soil as the linking factor between the subparts.

McCown et al. (1994) provides a discussion of APSIM, a "holistic" (as Cai 2008 would refer to it) model that uses soil characteristics to endogenously determine the impact on the local hydrology and the changes to the economics of a region through the soil's affect on agricultural yields. APSIM uses a dynamic simulation process that is calibrated to the local system by user entered soil characteristics (McCown et al. 1994).

The economics of managing a catchment area's soil salinity served as the motivation of an agronomic, hydrological, and farm financial integrated model created by Greiner and Parton (1995). The mathematical programming approach used by Greiner and Parton (1995) allows a recursive feedback from the agricultural decisions to soil salinity in the catchment area which then affects the agricultural decisions made in the subsequent iteration or period (Greiner and Parton 1995). As an added complexity, Greiner and Parton (1995) incorporated climate risk into their stochastic analysis.

Another linking factor of hydrologic features and an economic framework is through urban development and changes in land use patterns. Alberti and Waddell (2000) created a model that has the ability to predict environmental stress caused by urban development under alternative scenarios of economic, environmental, demographic, and policy scenarios. Land use and land cover are the core linkages used in this integrated model by Alberti and Waddell (2000). The economic component of the integrated model is built in a random utility framework and is used to determine the optimal development of land (Alberti and Waddell 2000). Their integrated model links decisions made at the socio-economic level to land use and land cover which is then linked to changes in the biophysical system including climate, topography, soil and water systems (Alberti and Waddell 2000). The changes in the biophysical system then provide feedback to the land cover and the land use possibilities in the economic optimization model (Alberti and Waddell 2000).

More recently, Frede et al. (2002) grouped three stand alone models to address their problem of determining the impact of land management changes through changes in the soil quality. A single set of data on soil, topology, land use, management, yield, and costs were used as inputs into a biodiversity physical model, a hydrological model, and an economic model to predict land usage (Frede et al. 2002). The predicted land usage was then used as feedback into the hydrological and physical models, to which resultant measures of landscape services were returned (Frede et al. 2002).

Conceptual Models

Recognizing the value of simplicity, there are methods that provide a means to move away from complex physical models but still allow for modeling the hydrological components of a system. These methods may utilize dynamic optimization (as in the optimal depletion of a ground water supply), optimal control, or may take on a spatial approach.

Dawes, Walker and Stauffacher (2001) developed a simple flow model of ground water whose output is combined with production and economic models to test against the more complex physical models to determine the value-added by complexity. The simple spatial flow model treats the system as a one-dimensional tube modeled with a "ground water equivalent of a diffusion equation" which essentially involves the use of a relatively simple differential equation (Dawes, Walker, and Stauffacher 2001). Their conceptual model was calibrated against a complex physical model and the resulting analysis suggested that while the conceptual model was less accurate the gains in transparency of the model's process outweighed the slight inaccuracies (Dawes, Walker, and Stauffacher 2001).

Dynamic optimization and optimal control are frequently used as methods of modeling water supply and require relatively few physical assumptions about the specific water source and thus requires a lower level of interdisciplinary collaboration (see Griffin 1987; Noel, Gardner, and Moore 1980; Ward and Lynch 1996; Zachariah and Rollins 1999). Zachariah and Rollins (1999) used a model of dynamic optimization that linked consumptive and non-consumptive uses of ground water through an

economic relationship and through physical relationships, where the quantity of ground water is represented as the equation of motion.

Single Measures of Comparison

Rather than use the dynamic and iterative process found in the models described above, multi-criteria assessment (MCA) and cost benefit analysis (CBA) methods attempt to incorporate economic, hydrological, and ecological components into a single comparison between proposed alternatives (Prato et al. 1996). Brouwer and Ek (2004) analyzed alternative flood control policy in the Netherlands through an integrated hydraulic, hydrological, ecological, economic, and social impact assessment using an extended CBA and through the use of the MCA decision criteria. Their approach is unique relative to the feedback models described above in that they use a combination of complex hydrologic models and qualitative expert judgment to come up with a single policy recommendation. Brouwer and van Ek's (2004) approach first analyzes the impact of alternative flood control policies on the system's hydrology. The hydrological impacts are then used as inputs into a hydro-ecological model which was used to predict the changes in vegetation and provide a valuation of the predicted changes (Brouwer and van Ek 2004). This valuation of the ecological changes was combined with a valuation of the social and economic impacts (Brouwer and van Ek 2004). Brouwer and van Ek's resultant analysis yields a single policy recommendation for policy makers.

Returning to the common agricultural linkage, Prato and Herath (2007) use multi-criteria decision analysis (MCDA) to determine the best of five farming systems. Each of the five farming systems was assigned average values for multiple economic and

environmental criteria, including net return, economic risk, and aquatic ecosystems (Prato and Herath 2007). The alternative criteria were weighted in a MCDA fashion based upon earlier survey results and a ranking of the five farming systems were determined (Prato and Herath 2007). The highest ranking farming system was not the system with the highest economic returns allowing the authors to conclude that MCDA provides a useful framework for analyzing decisions that extend beyond a single criteria and beyond a single discipline.

Summary

There are many difficulties associated with developing integrated models. Questions to consider when conducting integrated models include how detailed of a hydrological model to create, how to calibrate the baseline situation, and the ability to achieve integrated basin management in practice (Cai 2008). Dawes, Walker and Stauffacher (Dawes, Walker, and Stauffacher 2001) point out that it is often difficult to have confidence in model results when complex physical models are used. It is difficult enough to follow the flow of information from one model to the next, let alone be able to understand how each model is working, thus creating many skeptics of the modeling process (Dawes, Walker, and Stauffacher 2001). Nevertheless, there is a place for each of the above discussed forms of interdisciplinary work in water economics. The level of integration between physical scientists and applied economists will ultimately be determined based upon the needs of research problem at hand.

Through the above review on how prior research has linked hydrological and economic components in their integrated models, the reader should have a better idea of

how to tie together economic analysis with existing physical models. By no means has this review been exhaustive, but it does serve as a useful representation of the methods by which models are linked. In designing a model that includes the economics of ethanol production and the hydrology of local regions, consideration of the alternative approaches to integrating economics and hydrology is an important consideration.

Regional Approaches to Water Quantity and Quality Analysis

One of the difficulties with using a regional approach to water quantity and quality analysis is perpetuation of the externality. In the sense that, initially a water use externality existed to cause the original problem under study. As the analysis considers the impact of alternative strategies, land use changes, etc. on a particular region (be it in a particular watershed, aquifer, or water conservation district), the impact on peripheral areas is excluded. Therefore, the overall affect (net impact) is left uncertain; however, a regional approach does provide a detailed analysis of the particular region under study. In addition, another justification for the use of a regional analysis is for the policy implications of the model. Rather than looking at the overall result, typical water management agencies are interested in just the impact on their area. While the overall impact may be uncertain, having a complete understanding of the water implications at a local, regional, or watershed level will allow water management agencies to make informed decisions.

Among the existing water research literature, the majority of biophysical water modeling occurs at the watershed level (see Babcock et al. 2007). A watershed refers to a geographical region where the topography of the land allows all water accumulated

within the region to drain to the same outlet. Any water that falls outside of the watershed boundaries will belong to another watershed. Watersheds may often be referred to as drainage basins. Modeling at the watershed level is often considered the most logical basis for modeling and ultimately for managing water resources (Environmental Protection Agency 1996).

Weersink, Jeffrey, and Pannell (2002) highlight some of the farm level approaches to water quality modeling, including the research done by Yiridoe, Voroney, and Weersink (1997) on nitrate leaching using an individual field as the scope of the assessment. In particular, Weersink, Jeffrey, and Pannell (2002) point out that the individual scope used for modeling water resources may be as small as the farm level when inferences can be made based upon this small unit to a larger scale. However, in cases where the issue is of national scale, and/or legislative jurisdiction falls at a national level, local, regional, or watershed analyses serve little purpose.

Theoretical Background

As we move toward solving the problem of determining the water resource impact of the expanding ethanol industry, it is useful to first look to economic theory. There are a number of different directions economic theory can serve as a guide. Economic theory not only provides insight as to how to structure empirical approaches, but also, as Varian (1993) points out, guides the policy science side of economics. Among other things, economic theory describes behavior, tells us which variables are important, and helps to generate useful insights to economic problems (Varian 1993).

Market Failures

In a perfectly competitive market, private decisions in response to price mechanisms will lead to a socially optimal outcome. When a market is not perfectly competitive or there are externalities present, markets can fail to generate the socially optimal outcomes. These market failures are a frequent occurrence in the realm of environmental economics, especially with regard to water resources. The Texas High Plains are an example of a water stressed region of the U.S. where water levels have been rapidly declining. As this study will serve to investigate, ethanol production in this region will serve as an additional stress on water supplies. The root of this problem of rapid water depletion can be attributed to a market failure—a lack of mechanisms communicating that scarcity. "Markets can fail if prices do not communicate society's desires and constraints accurately" (Hanley, Shogren, and White 1997). Although a good may be priced, if the private decisions based upon these prices do not lead to an efficient allocation of resources, a market failure has occurred (Hanley, Shogren, and White 1997).

Profit Maximization Theory

Due to the nature of the agricultural producer being a price taker, the competitive model of economic theory is closely linked to agricultural production. Economic theory assumes that the rational producer will allocate their available acreage among various crop choices to the crop that has the highest expected return. Morzuch, Weaver, and Helmberger (1980) remind us that planted acreage is likely to be a function of expected prices, input prices, weather related indicators, fixed-scale factors, and technology. It is

also assumed that this acreage allocation function is homogenous of degree zero, such that there will be no planting decision changes due to proportional increases in all prices.

CHAPTER IV

ETHANOL PLANT SIMULATION MODEL

Mathematical programming models have been used to determine the economic impacts and feasibility of ethanol production (Braden, Leiner, and Wilhour 1984; Kaylen et al. 2000; Meo 1984; Tembo, Epplin, and Huhnke 2003; Thomassin and Baker 2000). These linear programming models frequently assume fixed coefficients and optimize a given objective function by changing the control variables. Generally speaking, these research studies have focused on the economic impacts of ethanol rather than combining the economic and environmental impacts.

Creating a model to forecast the potential environmental impacts of current and future ethanol production is plagued with uncertainty, particularly due to the rapid changes in technology being experienced by the ethanol industry. Ignoring this risk and uncertainty leads to a unique point estimate that is unlikely to be accurate. Dynamic programming, portfolio analysis, and scenario analysis are all methods that will incorporate these unknowns. Richardson and Mapp (1976) gave the first formal presentation that introduced risk into business investment decisions using stochastic simulation to generate probabilistic cash flows. One of the primary benefits to using a stochastic simulation approach is that the modeler can provide the decision maker with more information than deterministic results allow (Pouliquen 1970; Richardson and Mapp 1976).

Perhaps the key component to creating a model that combines ecological, technological, and economic components of a particular sector is a lack of perfect knowledge with regard to multiple variables. Despite the complexity resulting from uncertainty that is being generated from numerous sources, it is important to incorporate each of these in a model. While some traditional approaches struggle to remain compatible with multiple sources of uncertainty, stochastic simulation remains as the preferred method for modeling multiple sources of uncertainty. Stochastic simulation allows for the evaluation of risk from stochastic environmental variables, input variables, technological variables, and alternative scenario options. Incorporation of probability distributions on each uncertain variable allows the researcher to obtain confidence and/or prediction intervals for the key output variables and, thus, a robust set of results can be obtained (Rossi, Borth, and Tollefson 1993).

Through the creation of a regionally specific stochastic simulation model we will be able to incorporate the multiple sources of uncertainty and achieve this dissertation's objective of obtaining forecasts of the regional differences in the profitability of ethanol production and regional differences in total consumptive water usage by ethanol facilities. A schematic of the model's design is displayed in Figure 11 and shows both the relationship between inputs and outputs for the model that allow us to achieve the objectives of this dissertation. Within in the schematic, the label "t" refers to time series input values that will take on different values for each year of the model, while the label "L" refers to localized input values that will take on different values for each region of study.

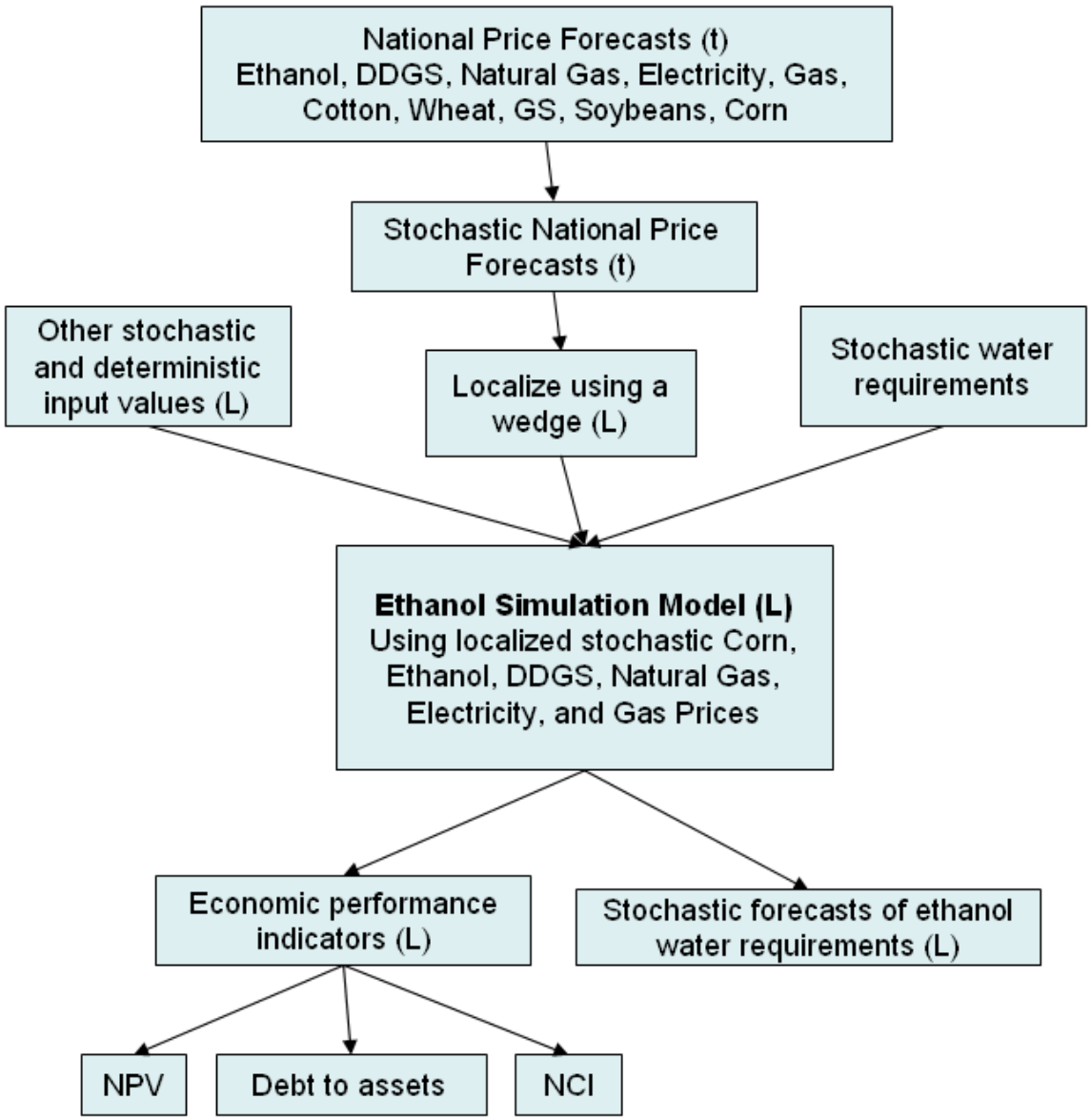

Figure 11. Diagram of the Ethanol Plant Simulation Model

The Monte Carlo simulation model created follows the style of ethanol plant simulation models done by Gill (2002), Herbst et al. (2003), Lau (2004), and Richardson et al. (2007) and will be completed using the Excel add-in, Simetar (Richardson, Schumann, and Feldman 2006). One of the distinguishing features of this model is that it will incorporate probability distributions on the quantity of water required at each particular phase of the ethanol production process. Water use by ethanol production facilities is a stochastic function of stochastic ethanol production. The use of stochastic water is incorporated as the quantity of water being used is not exact. There is variability in water quantity used per gallon of ethanol produced due to differences in delivery systems and the differences in the technologies being employed across ethanol facilities. To capture the risk and uncertainty involved in the hydrological and economic (i.e. corn, ethanol, and natural gas prices) components of the ethanol model, stochastic variables will be utilized. In addition to the standard key output variables (KOVs) for a business model (e.g., net present value), this model will include total water usage by the plant. Simulation of the stochastic variables under alternative scenarios (including alternative prices for water) will allow for robust evaluation of the impacts of water availability on an ethanol plant's economic performance and the impact of a successful ethanol plant on available local fresh water.

Additionally, scenario analysis will be used to analyze KOVs for different water reduction alternatives such as rates of technological adoption in future years and rates of recycled water usage in the production of ethanol. Simulation of the stochastic variables under the alternative scenarios will return probability distributions on each of the KOVs

and allow for robust evaluation of the impacts of water availability on an ethanol plant's economic performance and the impact of an ethanol plant on regional freshwater demand.

Stochastic Variables

By design, a simulation model is dependent upon the stochastic variables created by the analyst. Ethanol price, corn price, DDGS price, gasoline price, electricity price, natural gas price, and interest rate were determined to be the primary variables of interest for determining an ethanol model's probability of success and were thus created as stochastic variables. A historical data series for each of the stochastic variables was collected for the 1990 to 2007 time period. Ethanol and DDGS prices were obtained from Hart's Oxy Fuel News (Hart Energy Publishing 2008). Electricity, natural gas, and gasoline prices were obtained from the Energy Information Agency (2008) and corn prices were obtained from the National Agricultural Statistics Service (2008).

The historical variables were checked for trend and correlation. With many variables displaying a significant level of correlation at the 95% level, it was determined that the stochastic variables should be modeled multivariate empirical (MVE) as percentage deviations from trend (Richardson, Klose, and Gray 2000). Using a percentage deviation from trend approach when generating the stochastic variables ensures that there will be C.V. stationarity for all of the forecasted values. Equations (7), (8), and (9) show the process by which the parameters were specified for the empirical distribution. Equation (7) calculates the percentage difference or error (e_i) between the

historical observation (x_i) and the forecasted value ($\hat{x}_i$). The forecasted value is a result of simple linear trend regression. The percentage deviations from trend (e_i) are then sorted in ascending order (s_i). The stochastic value ($\tilde{x}_i$) is created by applying the stochastic empirical deviate to the trend forecast ($\hat{x}_i$). The stochastic empirical deviate is developed using the sorted percentage deviations from trend (s_i) and the cumulative probability of occurrence ($F\left(x_i\right)$).

(7) $e_i = \dfrac{x_i - \hat{x}_i}{x_i}$

(8) $s_i = sorted\left(e_i\right)$

(9) $\tilde{x}_i = \hat{x}_i * \left(1 + emp\left(s_i, F\left(x_i\right)\right)\right)$

Generation of the MVE stochastic empirical deviate was done using the Excel add-in Simetar (Richardson, Schumann, and Feldman 2006). The emp formula, as displayed in equation (9), provides an interpolation of the sorted percentage deviations based upon the probability of occurrence for each sorted percentage deviation. The probability of occurrence ($F\left(x_i\right)$) is the cumulative density of the sorted deviations. $F\left(x_i\right)$ gives the probability of observing an iteration less than or equal to the s_i . One of the properties of the cumulative density function is that $F\left(x_i\right)$ is between zero and one. This property allows the use of the inverse transform method, in which a uniform

standard deviate is generated. This random number specifies the cumulative probability that should be interpolated according to the original distribution of s_i. This procedure is used to generate MVE stochastic deviates by specifying a correlated uniform standard deviate (CUSD). This CUSD is correlated to the other stochastic variables and is generated to reflect the historical correlation among variables.

The deterministic forecasted variables (identified as $\hat{x}_i$ in equation (9)) were specified differently based upon properties of each variable being developed. In most cases, deterministic forecasts were generated as the mean of the historical period when trend was insignificant or as the forecasted value resulting from a simple trend least squares regression when trend was statistically significant at the 95% level. However for the corn price variable, the deterministic forecast was used as the FAPRI December 2008 baseline forecast for that year (FAPRI 2008b). The decision to use FAPRI corn price forecasts was based upon the desire to have as accurate forecasts as possible in the model and the hypothesis that FAPRI's baseline forecasts would provide a significant improvement in accuracy relative to a simple trend forecast for corn prices.

Once the stochastic variables were generated, the variables were simulated 500 iterations and a battery of validation tests were done on the simulated series to ensure that the stochastic variables were developed correctly. On each individual variable, a two sample t-test was done to test the null hypothesis that the means in the historical series and the simulated series were statistically equivalent. In addition, an F test was done to test the null hypothesis that the variances in each series were equivalent. The correlation among the simulated set of variables was compared to the correlation among

the original set of historical data. In addition, a series of three validation tests was run on the complete set of simulated energy variables. This series of validation tests included a 2 sample Hotelling T^2 test to test the null hypothesis that the mean vectors are equal, a Box's M test to test the null hypothesis that the covariance matrices were equivalent, and a Complete Homogeneity test to test the null hypothesis that the mean vectors and the covariance matrices were equivalent. In all cases, the simulated variables passed the validation tests with a sufficient level of significance to indicate that the MVE variables accurately reflect the original relationships present in the historical data series.

There are a number of other variables that were modeled as stochastic components of the model, but were developed separately from the MVE input variables. These variables include the water used at each stage of the production process. As a result of limited data available on the water used by ethanol facilities, the water use component was developed by collecting average values from a variety of sources including reports and personal communications with managers of ethanol facilities (Gruhlkey 2007; Keeney and Muller 2006; Millison 2008; Swain 2006; Zink 2007). This information was combined to produce a range of water use estimates for each component of the process. The minimum, average, and maximum water usages were used as input values into a GRKS distribution (Richardson, Schumann, and Feldman 2006). The GRKS distribution is a piecewise normal distribution in which half of the distribution is allocated below the specified mean. In addition, two percent of the distribution weight is allocated below the specified minimum. The GRKS distribution is

useful in situations, like this one, where there is a minimum amount of information available to develop a distribution. Stochastic treatment costs and sewage water costs were also developed using the GRKS distribution.

The ethanol plant being modeled was assumed to be operational 365 days per year; however plant operation is subject to occasional breakdowns. Breakdowns were also modeled to follow a GRKS distribution, based on total annual hours the plant isn't in operation. Maximum daily production was calculated as a function of the annual engineered capacity and a nameplate factor. A breakdown was assumed to cause a halt to maximum production, thus yielding a stochastic annual ethanol production capacity as a function of the stochastic breakdown time for the ethanol plant.

Control Variables

This model was designed to be fully interchangeable between the regions of study. With the use of a drop down control menu, the user can designate whether this is to be an ethanol simulation model for the Texas High Plains, for Southern Minnesota, or for the Central Valley of California. In addition, the user has the capability of specifying whether this is a model of the water usage for the entire region's ethanol production or if this is a model of an "average" ethanol plant for the region. The economic component of the model is designed to represent an average ethanol plant in each location, but total regional water usage by ethanol facilities have significant implications and thus is a built in option into the model's user controlled specification. With those two primary control variables or "switches" the model has the capability of being run as six individual

models to estimate the total water usage by ethanol plants. The following table, Table 3, displays the combinations for which this model designed.

Table 3. Possible Model Specifications for Water Usage

	Region	Modeling Size
1	Texas High Plains	Average Ethanol Plant
2	Texas High Plains	Ethanol production of the entire region
3	Southern Minnesota	Average ethanol Plant
4	Southern Minnesota	Ethanol production of the entire region
5	California Central Valley	Average Ethanol Plant
6	California Central Valley	Ethanol production of the entire region

An "average" ethanol plant for each region was dictated based upon existing ethanol production facilities. As expected, based upon data obtained from the Renewable Fuels Association (2008c) the average ethanol plant in California is smaller than the average plant in both the High Plains of Texas and in Southern Minnesota. The size of the average ethanol plant in mgy was used to determine the basis of the variable costs when differences in variable costs were apparent based upon plant size (see APPENDIX D for tables that identify the assumed variable cost differences by region). Additionally, ethanol plants in Southern Minnesota were significantly older than those in the Texas and California regions.

Although national ethanol production forecasts have been made over the analyzed time period, little attention has been made to forecasting local or regional ethanol production. Ethanol production facilities are relatively few in numbers and the establishment of a new facility depends largely on the availability of the significant capital required to begin construction, therefore making local predictions on future ethanol facilities difficult. National ethanol production assumptions were made such that the terms of the EISA would be met. Current regional ethanol production was estimated as a summation of current ethanol plant capacities obtained from the Renewable Fuels Association (2008c) and from the Minnesota Department of Agriculture (2008). Plants that were under construction at the time this model was created were not counted in the total ethanol production capacity for the region. Regional capacities were compared to total US ethanol production to estimate the proportion of total US production occurring in each region.

In 2008, the Texas High Plains was estimated to produce about 2.3% of the national production, while Southern Minnesota and California's Central Valley were estimated to have produced 7.5% and 1.4% respectively. These regional proportions of national ethanol production were assumed to be representative of the future proportions. Therefore, total regional ethanol production potential was assumed to steadily increase in response to national increases in ethanol production, while actual annual ethanol production was modeled as a stochastic function of the stochastic number of operating days per year which is dependent upon the number of breakdowns a plant experiences in a given year. The following table, Table 4, shows the required annual ethanol

production under the EISA, forecasted national ethanol production, and regional rates of ethanol production.

Table 4. National and Regional Annual Ethanol Production Forecasts (MGY)

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
EISA	9,000	10,500	12,000	12,600	13,200	13,800	14,400	15,000	15,000	15,000
U.S.	9,100	12,400	12,600	13,200	13,800	14,400	15,000	15,600	16,200	16,800
Texas High Plains	240	327	332	348	364	380	396	411	427	443
Southern Minnesota	687	936	951	997	1,042	1,087	1,132	1,178	1,223	1,268
CA Central Valley	132	179	182	191	199	208	217	225	234	243

The ethanol model is designed to represent both an average ethanol facility and total ethanol production in each region. In both cases, financial assumptions were made based upon the average plant in each region. For example, on average ethanol facilities in the Southern Minnesota region have been in operation for nearly 10 years, while facilities in both Texas and California are much newer. These differences in the average age of a plant have significant implications for the financial health of the facility and the amount of debt the plant is likely to be carrying. These financial differences are taken into consideration within the model, as the model adjusts the starting year for the loans, adjusts depreciation on capital investments, and adjusts when the capital investments were initially made. Summaries of the assumptions made for each region's ethanol simulation model are available in APPENDIX D.

An additional control variable was incorporated to allow the user added flexibility and was incorporated as a measure of robustness for the stochastic variables

developed within this model. The control variable being referred to allows the user to switch from using the stochastic corn prices developed in this model (see prior section on the development of stochastic variables) and the use of 500 iterations of corn prices simulated by FAPRI in their August 2008 baseline (FAPRI 2008a). Given that corn price plays a significant role in the profitability of an ethanol plant, use of alternative corn price iterations was desirable. When August 2008 baseline numbers were used as the deterministic forecast component of the stochastic variable, few differences in the results are apparent between the two types of model specifications and serves as a check on the precision of the forecasts (it should however be noted that there are significant differences in the crop price forecasts between the August and the December 2008 baseline and that the December 2008 baseline price forecasts were used in the development of this model's results).

Model Assumptions

A number of assumptions need to be made in order to develop a model of this size. Ethanol was assumed to be produced at a rate of 2.8 gallons per bushel of corn. This assumption was made after pulling conversion rates from a wide array of literature (Coltrain 2004; Herbst et al. 2003; Patzek et al. 2005; Shapouri and Gallagher 2005; Tiffany and Eidman 2003; Wang, Saricks, and Santini 1999; Whims 2002) and on the basis that the technology is improving, allowing a greater ethanol yield per bushel of corn over time. DDGS was similarly assumed to be produced at a rate of 18 pounds per bushel of corn utilized (Tiffany and Eidman 2003; Whims 2002).

Beyond these initial assumptions needed to get the model working, a series of calculations done on the relationships between input variables is needed prior to incorporating the information into the economic model. The first of which is the corn supply and the cost of the corn feedstock being used. Annual corn required is calculated as stochastic annual ethanol production divided by the corn to ethanol conversion factor. This total corn requirement can be obtained from two different sources, either local corn supplies or imported corn supplies from the Midwest. The model is designed to "purchase" corn supplies from the cheaper of the two alternatives, where local corn price is calculated as the stochastic national corn price multiplied by a local percentage price wedge. The local price percentage price wedge was calculated as the average percentage difference between the local prices and the national price during the 1990 to 2007 period. Equation (10) represents this relationship between stochastic local price ($\tilde{P}_{CL}$) and stochastic national price ($\tilde{P}_{CN}$) based upon the wedge percentage (W_C) as calculated using equation (11).

$$(10)\ \tilde{\mathrm{P}}_{CL} = \tilde{\mathrm{P}}_{CN} * \left(1 + W_C\right)$$

$$(11)\ W_C = \sum_{t=1990}^{2007} \left(\frac{P_{CLt} - P_{CNt}}{P_{CNt}} \right) / \left(2007 - 1999\right)$$

The model is designed to select the minimum of either the local stochastic price or the stochastic Midwest corn price plus the transportation costs associated with moving the corn from the Midwest to either the Texas High Plains or the Central Valley of

California. When the model is designated as being in the Southern Minnesota mode, the only implicit option for obtaining corn supplies is from the local region. One caveat to purchasing local corn supplies for the Texas and California models is that an assumption was made on the maximum quantity of corn available for purchase by ethanol facilities. The default setting for the model allows for no more than 50% of local corn supplies to be dedicated to the production of ethanol. This 50% value is set up as a control variable and the user as the option of specifying an alternative proportion as desired. The primary logic behind this component is timing and that some of the corn supplies will already be dedicated to other uses at the time and not be available for ethanol producers.

The total cost of obtaining the corn feedstock (C_F) is calculated based upon three different options depending upon how the stochastic local price ($\tilde{P}_{CL}$) compares to the stochastic national price ($\tilde{P}_{CN}$) plus the cost of transportation (C_T) and how the regional quantity of corn required (Q_{rr}) compares to the quantity of locally available corn (Q_L). The quantity of corn required by the ethanol plant (Q_r) is calculated as being the stochastic annual ethanol production divided by the corn to ethanol conversion rate. The quantity of corn locally available (Q_a) is calculated as the forecasted regional corn production times the control variable for the maximum proportion of corn (p_m) that can be purchased locally (set at a value of 50% for the set of model results that follows in the subsequent section). Equation (12) depicts the formula used for calculating the total cost of obtaining the corn feedstock.

$$(12)\quad C_F = \begin{cases} Q_r * \left(\tilde{P}_{CN} + C_T\right) & \text{if } \tilde{P}_{CL} > \left(\tilde{P}_{CN} + C_T\right) \\ Q_r * \tilde{P}_{CL} & \text{if } \tilde{P}_{CL} < \left(\tilde{P}_{CN} + C_T\right) \text{ and } Q_{rr} < Q_a * p_m \\ \tilde{P}_{CL} * Q_r * \left(1 - \left(\frac{Q_{rr}}{Q_a} - p_m\right)\right) + & \\ \quad \left(\tilde{P}_{CN} + C_T\right) * Q_r * \left(\frac{Q_{rr}}{Q_a} - p_m\right) & \text{if } \tilde{P}_{CL} < \left(\tilde{P}_{CN} + C_T\right) \text{ and } Q_{rr} > Q_a * p_m \end{cases}$$

The first two options depicted in equation (12) are relatively straightforward. When the local price of corn is higher than the cost of corn in the Midwest plus transportation costs, the total corn required by the plant will be purchased at the national price of corn plus the cost of transportation. When the local price of corn is less than the price of corn brought in from the Midwest and the corn available in the region (50% of total regional production) is less than the total regional ethanol corn requirement, then the cost of corn is just the local price of corn times the quantity of corn required by the ethanol plant. The last alternative is somewhat more complicated. When corn is locally cheaper, but regional ethanol requirements are larger than the local corn available for ethanol production, a proportion of the corn feedstock is assumed to come from local supplies and a portion from Midwestern supplies. The proportion of corn purchased nationally is assumed to be the proportion by which regional ethanol corn requirements exceeds locally available corn supplies. For example, if 59% of locally available corn is needed for regional ethanol production the difference between that proportion and the

maximum proportion of locally available corn (which is set at 50%) is the proportion of corn that each ethanol facility must purchase from the Midwest (in this example, 9%). The locally purchased corn makes up the remainder of the corn requirement (in this example, 91% of required corn). This calculation should be considered somewhat arbitrary, but it serves as a method by which the ethanol plants being modeled (when the conditions are right) are forced to utilize corn from multiple locations.

Usage of electricity, natural gas, and gasoline was calculated using industry estimates of usage coefficients based upon the quantity of ethanol being produced. The usage coefficients (U_i) were adjusted for differences in average plant size by region and were multiplied by stochastic ethanol production ($\tilde{E}$) to obtain the total input usage (APPENDIX D offers a summary of the assumptions made and usage coefficients for each region's ethanol simulation model). The localized price of the input was calculated using a percentage wedge, similar to the percentage wedges that were used to localize corn prices. Equations (13) and (14) show the procedure for calculating the stochastic localized price ($\tilde{P}_{iL}$) as a function of stochastic national price ($\tilde{P}_{iN}$) and the percentage price wedge (W_i) for each input i. Total input usage was then multiplied by the localized price of the input to obtain the total expense for that input (C_i) as displayed in equation (15) below. Total expense for each input was later carried down as a component of the income statement.

(13) $\tilde{\mathrm{P}}_{iL} = \tilde{\mathrm{P}}_{iN} * \left(1 + W_i\right)$

$$(14)\ W_i = \sum_{t=1990}^{2007} \left(\frac{P_{iLt} - P_{iNt}}{P_{iNt}} \right) / \left(2007 - 1999 \right)$$

$$(15)\ C_i = \tilde{P}_{iL} * U_i * \tilde{E}$$

Economic Model

Forecasting the future economic outlook for ethanol facilities in each of these locations justifies the use of pro forma financial statements. Pro forma financial statements include an income statement, a cash flows statement, and a balance sheet. In addition, the use of pro forma financial statements allow for the incorporation of loan repayment and income taxes in the picture of the business' financial health. Stochastic variables are linked to stochastic revenues and expenses which are then brought through the pro forma financial statements. Ultimately we are able to obtain stochastic measures of cash flows and net present value, which we can simulate and obtain estimates on the probability of economic success over the 10 year planning horizon for these ethanol production facilities.

Income Statement

The first component of the income statement is the total revenue earned by the business. Ethanol facilities obtain receipts from selling blended ethanol, selling DDGS, collecting the federal and possibly a state subsidy, and earning interest on any cash reserves. Ethanol receipts are calculated as stochastic annual ethanol production multiplied by stochastic local ethanol price. Localized ethanol price was calculated

using a percentage wedge built off of historical average ethanol prices in each region. DDGS receipts were calculated similarly, using stochastic DDGS production and stochastic national DDGS prices. Due to the limited availability of historical DDGS price data, DDGS prices were not localized by region. Receipts from the federal subsidy were calculated as $0.51 per gallon of blended ethanol. Set to expire in 2010, the state of Minnesota currently offers a $0.20 subsidy per gallon of ethanol produced. When the model is in Southern Minnesota mode, receipts from the state subsidy are included through 2010. An additional source of revenue for the ethanol facility is earned interest on cash reserves. This earned interest is calculated based upon ending cash in the prior year and an assumed interest rate of 1.5%. Total revenues in each year are summed across all these sources.

The second primary component of the income statement is the expenses. The total input expenses for corn, natural gas, electricity, and gasoline, as described in the prior section on model calculations, were included in the itemized list of expenses in the income statement. Additional expenses included in the income statement were indicated as water costs, other variable costs, operating interest, interest on debt, and interest on cash flow deficit. Water costs were calculated as a function of total fresh and recycled water usage and the stochastic costs of water (refer to the section on the development of stochastic variables for more information). Other variable costs include expenses for the denaturant, chemicals, enzymes, processing materials, management, and labor. These variable expenses were developed based upon industry standards (Beck 2005; Coltrain 2004; Gallagher, Brubaker, and Shapouri 2005; Tiffany and Eidman 2003; Whims 2002)

for variable costs per gallon of ethanol produced with adjustments being based upon the plant size being modeled. Combining variable costs per stochastic annual ethanol production resulted in the stochastic other variable costs that were included on the financial statement.

It was assumed that 15% of total operating expenses were carried on an operating loan, therefore operating interest expenses were calculated as total operating expenses multiplied by 15% multiplied by an operating interest rate. The operating interest rate was calculated as a wedge off of stochastic prime interest. Interest on debt was based upon the proportion of the annual payment on the long term loan that went to pay the interest associated with the loan, while cash flow deficit interest was calculated when there was a cash flow deficit in the prior year. The interest rate for the cash flow deficit was assumed to be the same stochastic interest rate as the interest rate used for the operating loan.

The final outcome of the income statement is the net cash income, which is simply the difference between total receipts and total expenses. Verification on total receipts, total expenses, and net cash income was done by dividing each value by the total ethanol produced to obtain expenses, receipts, and net cash income per gallon of ethanol produced. The values were compared to industry standards to ensure that the model was still providing an accurate representation of various ethanol facilities. This procedure was repeated for all six of the model specifications (see Table 3 in the section on the model assumptions for a list of all model specifications).

Cash Flows Statement

The cash flows statement is made up of two primary ingredients, inflows and outflows. Inflows come from either beginning cash or net cash income (net cash income is a result of the income statement). Beginning cash in the first year of the model (i.e. 2008) was assumed to be zero, while beginning cash in the future years of the model (i.e. 2009– 2017) is the cash reserves in the prior year.

Cash outflows are made up of principal payments on the initial capital / land loan, repayment of a prior year's cash flow deficit, capital improvements, payment of income taxes, and payment of dividends. Based on information obtained from ethanol industry reports, a 100 mgy ethanol plant requires annual capital investments of $1,100,000. This figure was adjusted for the average ethanol facility being modeled and inflated using a forecasted prices paid index (ppi) for the 2008 to 2017 period obtained from FAPRI (2008a). A corporate structure was assumed for the purposes of calculating taxes and dividends were assumed to be paid out at a rate of 35% of positive net cash income. Total outflows were summed and subtracted from total inflows to calculate ending cash.

Balance Sheet

The balance sheet is comprised of total assets and total liabilities, both of which are used to calculated the annual net worth of the business. Total assets are calculated from cash reserves (any positive ending cash from the same year), capitalized start-up costs, PP&E, and assets resulting from capital improvements. Annual capitalized start-up costs were calculated as the initial depreciable capital investment less the

depreciation that occurred in that year. A straight line depreciation method was used having made the assumption of a 20 year depreciable life. Total liabilities included the long term debt and the cash flow deficits.

Key Output Variables

A primary reason for creating a stochastic ethanol economic simulation model was the resulting stochastic key output variables (KOVs) that could be simulated and analyzed. The KOVs of interest for this research include both economic variables and water usage variables.

One of primary economic variables of interest is the net present value (NPV) of the business. Equation (16) shows how NPV was calculated in this model, where i is used to indicate the discount rate. The discount rate is set up as a control variable that the user can specify, however the default setting and the one used for this analysis is 7.5%. Additional economic KOVs include the debt to asset ratio (equation (17)), whether or not the business is considered solvent based upon having a debt to asset ratio of less than 75%, and whether or not the business is considered to be an economic success which is based upon having a NPV larger than 0.

$$(16)\quad NPV = -Beginning\ Equity + \sum_{t=2008}^{2017} \left(\frac{Dividends_t + \Delta Annual\ Net\ Worth_t}{(1+i)^t} \right)$$

$$(17)\ DAR_t = \frac{Total\ Liabilities_t}{Total\ Assets_t}$$

There are a number of water related KOVs that are of interest with regard to this research. The multi-functionality of this model design allows for each of these KOVs to be obtained for both the entire region and an average ethanol plant in each location. The water KOVs of interest are the total water quantity used over the 10 year period, annual water quantity used, and the average water used per gallon of ethanol production. An additional control variable was designed to yield sensitivity results for the user with regard to the costs of obtaining fresh water supplies. A set of six scenarios provide varying levels of water costs to illustrate how the profitability of an ethanol facility changes with regard to increasing water costs. Use of this scenario option in Simetar (Richardson, Schumann, and Feldman 2006) makes simulation of the NPV under each water cost scenario a useful outcome for understanding the role of water in the plant's economic success.

Scenario Analysis

As mentioned in the introduction of this chapter, the use of alternative scenarios allows the analyst to compare the KOV under alternative management schemas while holding everything else constant. Simetar uses the same random number seed for each scenario, thereby presenting a set of simulation results for each management scenario under the same external conditions.

The implementation of water reduction technologies by ethanol facilities was modeled using scenario analysis. The base scenario, scenario one, was designed to model a situation where existing facilities are used and no additional measures are taken to reduce water usage. Scenario two is designed to replicate a zero waste stream system. Boiler and cooling tower blowdown is eliminated from the waste stream, as is the cost to treat waste water. In addition, the technology being imposed in scenario two is assumed to allow reuse of the blowdown water in the ethanol production process, thereby reducing the freshwater requirements for the ethanol plant. The majority of the water used in the production of ethanol is used in the cooling tower and thus, much research has gone into reducing water lost during the cooling stages; scenarios three and four are modeled to capture those technologies. Scenario three involves a reduction in the quantity of water used in the cooling tower by 20%, while scenario four reduces cooling tower water by 40%. Assumed costs for each scenario where added into the capital improvement costs for that year. The following table, Table 5, explicitly states the assumptions used in each of the scenarios, however it should be noted that the assumed variables in each scenario can be adjusted to reflect alternative assumptions on technology as desired by the analyst.

Table 5. Water Reduction Scenarios

Name	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Description	Base	Zero Waste	-20% CT	-40% CT
Cost	$ -	$ 1,000,000	$ 2,000,000	$ 3,750,000
% of Original Water Usage				
Cooling Tower	1	1	0.80	0.60
Process	1	1	1	1
Boiler	1	1	1	1
Waste	1	0	1	1

As a means to discover the economic sensitivity of an ethanol plant to various water rate charges, a separate scenario alternative was modeled for water prices. Various fresh water rates were selected and incorporated as a set of five scenarios. These water rates were selected somewhat arbitrarily and selected as a means to compare the impact on a facilities' NPV. Water prices were incorporated at rates of $30, $120, $1000, and $5000 and labeled as scenario 1, scenario 2, scenario 3, and scenario 4, respectively. These water rates can be altered as desired by the analyst to show the varying degrees of sensitivity of NPV with regard to water price changes. In addition, sensitivity elasticities will be calculated to show the % change in NPV with respect to a one percent change in water price.

CHAPTER V

CROP WATER USAGE

In response to economic signals, agricultural producers have some flexibility in their planting decisions. Increased demand for corn from ethanol plants, livestock producers, and consumers in importing countries have contributed to substantially higher prices in 2007 and 2008, thus changing the economic incentives for growers. Although the total agricultural acreage is unlikely to vary significantly (Energy Information Agency 2007), there may be significant substitution with regard to the crop acres planted. This substitution of planting patterns has the ability to alter regional water usage.

In order to achieve this dissertation's objective of quantifying the regional changes to agricultural water usage from the expansion of corn ethanol production, changes in the agricultural crop mix and the associated consumptive water usage incurred by the new crop mix will need to be generated. This section will outline those two primary components as described visually in Figure 12.

Forecasting Crop Acreage

A producer's decision to plant is based on the expected return of available alternatives. Reed and Riggins (1981) proposed using lagged relative price as an indicator of expected return, where relative price is defined as price divided by fertilizer

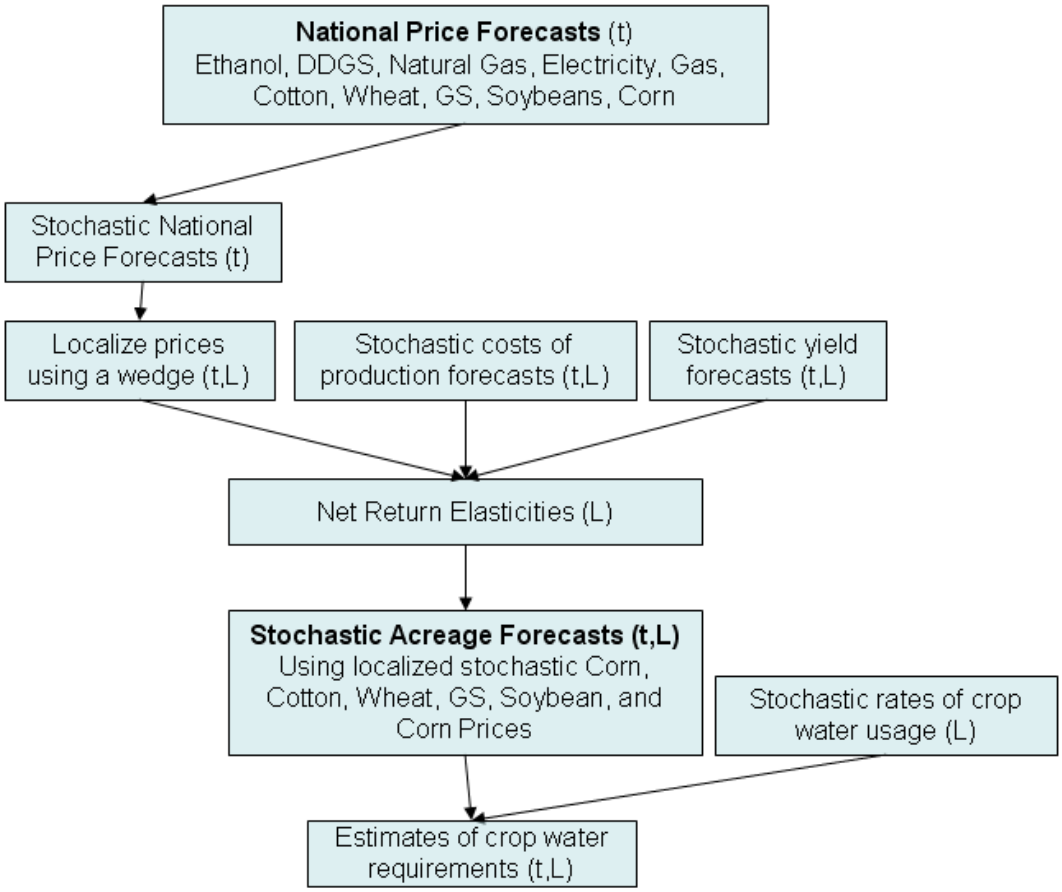

Figure 12. Schematic of the Model for Generating Stochastic Estimates of Crop Water Requirements

costs. Relative price accounts for crop prices and uses fertilizer costs as a proxy for input costs. Following the same logic, this study will account for both revenue streams and cost streams when forecasting corn acreage by incorporating lagged net return variables in the forecast.

Although differences in regional crop substitution patterns dictate specific net return variables in each regional model, the base design used for forecasting acreage supply for corn used in this study is:

$$(18) \qquad AC_{it} = f\left(NRC_{it-1}, NR_{jit-1}, T_t\ , GP_t\ \right)$$

Corn acreage in area i and time period t is represented as AC_{it}. The subscript i is used to represent each of the 3 regions under study, i=1 for the Texas High Plains, i=2 for Southern Minnesota, and i=3 for the Central Valley of California. Additional variables in the equation include lagged net returns of corn (NRC_{it-1}), lagged relative net returns of other crops in the region (NR_{jit-1}), trend (T_t), and a dummy variable used to represent government programs. The subscript j is used to represent the alternative crops grown in each region.

The time series data for these variables comes from a number of different sources. Regional planted acres, harvested acres, and yield were obtained from the National Agricultural Statistics Service (2008). Regional corn planted acreage is of particular interest as that is the variable that will be forecasted, Figure 13 illustrates changes in and the relative magnitudes of regional corn planted acreage over the past 18 years. Yield is generally reported as yield unit (e.g. bushels) per harvested acre. While

this is useful in some instances, for the purposes of forecasting planted acreages, it was more appropriate to use a yield based upon planted acreage. Therefore, yield, planted acres, and harvested acres were collected to make the simple yield conversion. These data points were collected based upon NASS (National Agricultural Statistics Service) crop reporting districts, the Texas High Plains region in this study corresponded to NASS district 11, the Northern High Plains, while Southern Minnesota combined NASS districts 70, 80, and 90, and the Central California region is represented by NASS district 51, the San Joaquin Valley. National and region crop prices were also obtained from NASS (2008).

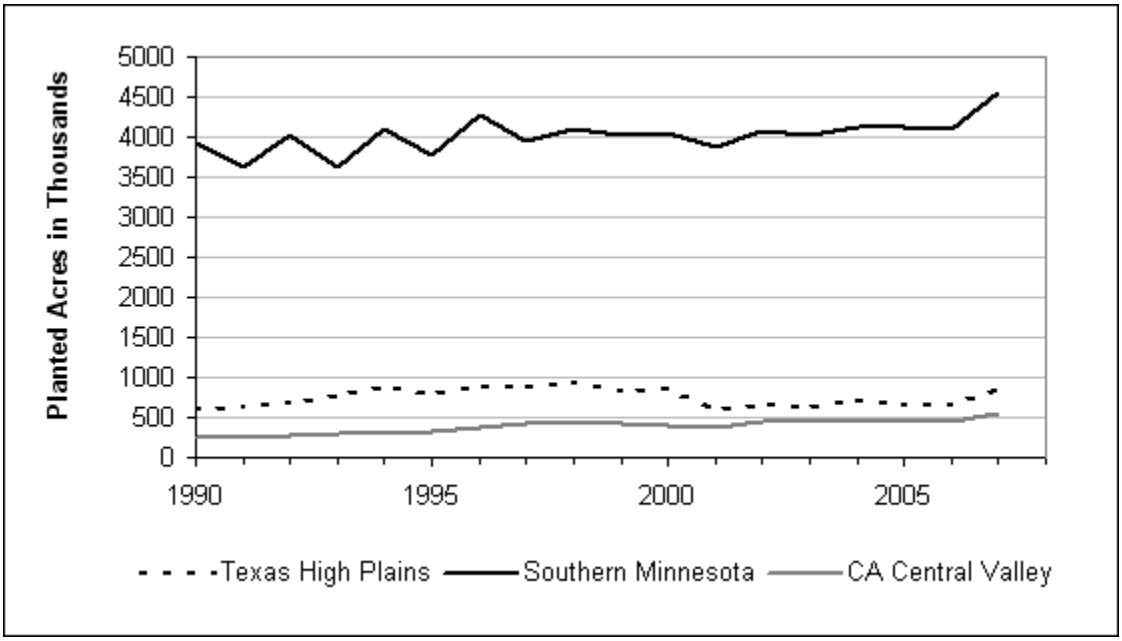

Figure 13. Regional Corn Planted Acres[8]

[8] Data Source: National Agricultural Statistics Service (2008)

When available, regional costs of production were obtained from the Economic Research Service (2008). The Economic Research Service (ERS) changed their reporting districts and methods during the mid 1990s. As a method of dealing with this change, the average percentage difference between national costs of production for that crop and the regional costs of production for the crop in question were used to approximate regional costs of production in the early 1990s. Costs of production data was not available from ERS for tomatoes grown in California. Instead, costs of production were obtained from the University of California Cooperative Extension (2007).

Annual net returns for corn and other crops was calculated for the 1990 to 2007 period by using the state average price for each crop and the regional planted acre yields to calculate the revenues per planted acre. Revenues per planted acre were used in conjunction with regional crop production cost estimates from ERS to calculate regional estimates of net returns per planted acre. For the purposes of this research, it is assumed that the crop substitution is occurring in the short term and subsequently the substitution of corn acreage for perennial crops is not considered.

One of the assumptions that needed to be explicitly made with regard to forecasting changes in land use, is the assumption of homogenous land. In the sense that, land currently dedicated to the production of cotton in the High Plains of Texas can be relatively easily converted to the production of corn (or another crop). This homogeneity assumption is employed throughout the following analysis, however because this analysis is done in a relatively short term time frame (10 years of analysis)

the assumption is made that no major land use changes will occur. More specifically, land dedicated to perennial crops such as fruit trees or vines in the Central Valley of California was assumed to not be taken out of production. This analysis assumes that substitution between the major crops in each region that are annually grown crops can occur seamlessly.

Texas High Plains

Prior to forecasting acreage, it is of paramount importance to have an understanding of the agriculture in the region of study. The Northern High Plains region of Texas is rich in wheat, cotton, and corn. The following figure, Figure 14, depicts Northern High Plains planted acreages for the 2006 crop year. The ordinary least squares regression used to forecast corn acreage in the Texas High Plains will need to account for the prevalence of wheat, cotton, and sorghum acreage in the region.

Depicted in Table 6 are the results of the OLS regression used to forecast corn acreage (CA) in the Texas High Plains. Variables included in the regression were corn net returns lagged one period (variable name C_NR $(t-1)$), wheat net returns lagged one period (variable name W_NR $(t-1)$), a trend variable (T), and a dummy variable (D) used to represent differences in government programs (see equation (19)). Grain sorghum net returns lagged one period and cotton net returns lagged one period were not significant even at the 90% level. The dummy variable was incorporated as an intercept shifter variable and designed to pick up differences during the 1990 to 1996 period, relative to 1996 through 2007, as some of the most significant changes to the farm bill

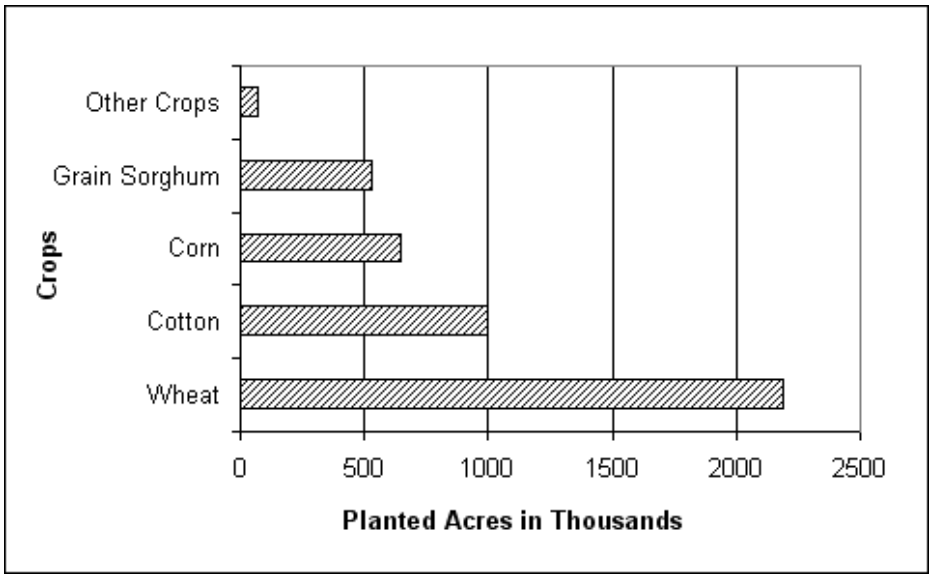

Figure 14. 2006 Northern High Plains Planted Acreage by Crop[9]

Table 6. Texas High Plains OLS Regression Results for Corn Acreage Identified by Equation (19)

Variable	Beta	S.E.	t-test	Prob (t)	Elasticity
Intercept	54,054,961.2	340.12	6.502	0.000	
C_NR (t-1)	979.92	340.12	2.881	0.018	0.296
W_NR (t-1)	-4,020.16	1,262.67	3.184	0.011	-0.023
Trend	-26,756.23	4,159.09	-6.433	0.000	-69.648
Dummy	422,562.97	85,606.69	4.936	0.001	0.039
R2	0.848				
RBar2	0.781				
MAPE	4.584				

[9] Data Source: National Agricultural Statistics Service (2008)

occurred during the Federal Agriculture Improvement and Reform Act of 1996, commonly referred to as the "Freedom to Farm" act.

(19) $CA_{HP} = f\left(C_NR_{HP,t-1}, W_NR_{HP,t-1}, T, D\right)$

The estimated coefficients, statistics on the coefficients, elasticities estimated at the mean, and goodness of fit statistics for the regression results are all included in Table 6. All variables in the model are significant at the 95% level. The goodness of fit statistics indicate that a relatively large proportion (approximately 85%) of the variability in planted corn acres in the Texas High Plains is being explained by the four independent variables listed above. The mean absolute percent error (MAPE) provides a measure of the accuracy of the ex post forecasts of corn acreage and indicates just a 4.58% error in forecasting historical corn acreage observations.

Of particular interest in Table 6 are the estimated elasticities own and cross elasticities. The acreage response elasticity for corn is estimated to be 0.296, indicating that a one percent change in net returns will induce a 0.296 percent change in corn planted acreage in the Northern High Plains of Texas. This elasticity is relatively high compared to other estimates of corn acreage response elasticities (including Chembezi and Womack 1992; Ray and Richardson 1978; Wu and Adams 2002). However, it should be noted that estimated acreage response elasticities typically are estimated as a function of price rather than net returns, a one percent change in price would be expected to yield different consequences than a one percent change in net returns. Lee and Kennedy (2008) estimated corn acreage elasticities using acreage value and obtained a

similarly large estimate. In addition, it should also be noted that these are regional acreage response elasticities, not national averages.

The estimated cross acreage response elasticity for wheat is inelastic and of the expected sign. While not included in the final specification, when grain sorghum lagged net returns were included in the model, the grain sorghum mean elasticity was also inelastic, but had a positive sign. This positive relationship between grain sorghum net returns and corn planted acreage can be attributed to the high level of correlation between corn and grain sorghum net returns, during the time period used in the estimation corn and grain sorghum had a correlation coefficient of 0.99 and thus caused the regression to be plagued with multicollinearity.

Although a significant amount of historical corn acreage variability was captured in the regression, the use of the OLS parameter estimates to provide conditional ex ante forecasts of corn acreage would fail for two reasons. First, since corn acres have begun to increase beyond historically observed levels in the High Plains, we may be undergoing a structural shift that is not captured in the regression model. The OLS regression model was developed using historical observations that, due to structural changes, are possibly out of range with future acreages. The estimated parameters may not be appropriate for forecasting beyond the range of historical observations. Second, in order to predict the changes in agricultural land use across the Texas High Plains region, it is necessary to capture the relationship and the substitution patterns between crop production patterns. It is not sufficient to estimate increases in corn planted acreage, as we must also consider alternative crop production changes that freed the

agricultural acreage to allow an increase in the production of corn. In the econometric model that was estimated, the lagged net returns of only one other crop were statistically significant and thus have limited means by which to forecast future corn acreage. From the OLS regression results obtained, we only have one estimate of cross supply elasticities between agricultural crops. With this in mind, the results of the OLS regression on crop acreage in the Texas High Plains are not sufficient to allow forecasting the of agricultural land use changes over the 10 year time frame.

As an alternative, we were able to obtain regional supply elasticities over the 2008 to 2017 time from FAPRI (2008b). The elasticity matrix included own and cross supply elasticities for the major crops in each region as a function of net returns. The Texas High Plains region is considered part of FAPRI's "Southern Plains" regional designation, along with the rest of the state of Texas and Oklahoma and New Mexico. Table 7 below displays the complete matrix of net return elasticities for crops in the Southern Plains over the 2008 to 2017 time period.

Table 7. Matrix of 2008–2017 Net Return Elasticities for the Southern Plains[10]

	Corn	Cotton	Oats	Peanuts	Rice	Soybeans	Sorghum	Wheat
Corn	0.592	-0.054	-0.042	-0.021	-0.040	-0.048	-0.057	-0.095
Cotton	-0.054	0.459	-0.076	-0.038	-0.073	-0.086	-0.061	-0.150
Oats	-0.001	-0.002	0.113	-0.001	0.000	-0.003	-0.003	-0.004
Peanuts	-0.001	-0.002	-0.001	0.252	0.000	-0.002	-0.002	-0.004
Rice	-0.005	-0.009	0.000	0.000	1.515	-0.009	-0.009	-0.015
Soybeans	-0.002	-0.004	-0.004	-0.001	-0.004	0.516	-0.004	-0.007
Sorghum	-0.001	-0.002	-0.002	-0.001	-0.002	-0.002	0.024	-0.003
Wheat	-0.100	-0.157	-0.141	-0.070	-0.135	-0.160	-0.113	0.245

[10] Source: FAPRI (2008b)

There are some notable differences between the estimated own response elasticity using the OLS regression (estimated at 0.296) and own response elasticity obtained from FAPRI for corn (given as 0.592). In addition, there were differences in the supply cross elasticity between corn and wheat in the OLS regression (estimate of −0.023) and the FAPRI estimate (given as −0.095). Differences can be expected due to alternative methodologies, however this discrepancy is likely attributed to alternative specifications of regions and FAPRI's use of farm program payments as a component of net returns. Nevertheless, for the sake of completeness, FAPRI's set of net return elasticities estimates for eight Southern Plains crops will be used to forecast the agricultural land use changes in the Texas High Plains.

Forecasted land usage is dependent on not only the estimated elasticities, but also on forecasted net returns. Forecasted net returns are a function of forecasted costs of production, forecasted yields, and forecasted prices. With so much future uncertainty lingering within the land use forecasts, it is imperative that these usage forecasts are stochastic. Stochastic land usage is calculated by using stochastic forecasts for costs of production, yields, and prices to develop a stochastic estimate of net returns. The deterministic net return elasticities are then applied to the stochastic estimates of net returns.

Deterministic forecasts of regional corn production costs were forecasted using a simple trend regression on the historical national costs data series obtained from the Economic Research Service discussed at the beginning of this chapter. The trend regression proved to be highly significant with a p-value of less than 0.01. The

estimated parameters were then used to deterministically forecast national corn costs of production through 2017. Corn costs of production were modeled multivariate empirical, having been correlated other crop costs of production and having incorporated the national deterministic costs forecasts. National stochastic corn costs of production were regionalized using a wedge developed from historical national and regional costs of production. The wedge that was used was calculated as the average percentage difference between corn costs in the high plains ($C_{j,hp}$) and corn costs of production nationally ($C_{j,n}$) over the 1990 to 2007 time period. Equation (20) depicts the formula for calculating this wedge where the subscript j is used to represent the crop being considered (in this case j=corn).

$$(20)\quad W_{j,hp} = \frac{\sum_{i=1990}^{2007} \frac{\left(C_{j,hp,i} - C_{j,n,i}\right)}{C_{j,n,i}}}{2007 - 1990}$$

Stochastic national corn prices were developed in conjunction with the stochastic set of multivariate empirical variables that were created for use in the economic model and described in depth in the preceding chapter on the economic simulation model (see page 102 for details of the development of the stochastic variables). Use of the same stochastic corn prices for both the economic ethanol simulation model and the development of corn acreage forecasts provide a key linkage between the models. This linkage ensures that corn acreage response is conditional on the same price that is driving the economic outcomes of ethanol production and allows us to join together the

water implications of each component. Independence between models would result in two distinct outcomes. These stochastic national prices were localized using an average percentage difference between historical national corn prices and historical state corn prices (similar to the wedge that was used to localize corn costs of production).

The only remaining component of net returns in this model is the stochastic yield forecasts. Deterministic forecasts of national corn yields were taken from FAPRI's (2008b) December 2008 baseline. The deterministic forecasts, along with historical national yields obtained from FAPRI's (2008b) historical data, were used to generate stochastic national yields. Stochastic national yields were localized using an average wedge that was calculated as the difference between national yields and regional yield estimates. Yields were converted to a planted acre basis by using the average ratio of harvested acres to planted acres.

Stochastic net returns per planted acre were then calculated using the simple mathematical relationship between costs, prices, and yields. The expected value for corn net returns per planted acre in the Texas High Plains region is relatively high in comparison to historical net returns. This can be attributed to higher corn prices and increasing yields. Costs of production are increasing over the analyzed time frame, but at a rate that doesn't match the increases in revenue. Calculated net return in 2007 was $530 per planted acre, while the mean forecasted net return for corn in 2010 is $570.

The stochastic estimates of net returns per planted acre for corn are then combined with the regional own net return elasticity estimate to obtain planted acreages of corn over the forecast time period. The remaining set of net return elasticity estimates

is used to generate stochastic planted acres for cotton, oats, soybeans, sorghum, and wheat. Among the cross elasticity estimates, wheat acreage is the most sensitive to changes in the net returns of corn. Therefore, as the net returns of corn increase and corn planted acres increase, we will see a proportionally larger impact on wheat acreage in the region relative to the other crops being analyzed. As an intermediate result, Texas High Plains forecasted acreage was simulated 500 iterations using Simetar (Richardson, Schumann, and Feldman 2006). The simulation shows corn acreage steadily increasing in the Texas High Plains, while planted acreage for the other crops declines. Results of the simulation are summarized in a series of charts presented in APPENDIX C, while average selected averages from the simulated series are displayed in Table 8.

Table 8. Historical and Forecasted Texas High Plains Planted Acreages and Percentages Changes

	Historical	*Simulated Means*		2007 to 2017	% change
	2007	2008	2017	Change	
Corn	855,500	896,467	1,119,264	263,764	31%
Cotton	584,700	582,162	562,105	(22,595)	-4%
Oats	41,000	40,860	39,754	(1,246)	-3%
Soybeans	9,900	9,862	9,559	(341)	-3%
Sorghum	628,000	625,103	602,181	(25,819)	-4%
Wheat	2,501,000	2,481,833	2,328,499	(172,501)	-7%
Total acreage	4,620,100	4,636,286	4,661,362	41,262	1%

As an additional measure of validation on intermediate model results, it is important to analyze the simulated acreages to understand the changes to the total agricultural makeup of the region. **Error! Reference source not found.** provides a side

by side comparison of 2007 planted acreages for the major field crops in the region and the simulated mean planted acreages in 2008 and 2017. It is easy to see that corn acreage has increased over the 10 year time period (by over 30%), while planted acreages for the other selected crops have declined. Total agricultural acreage devoted to these six crops in the Texas High Plains region increases by under 1% between 2017 and 2007. This occurs as the own and cross net returns elasticities were not perfectly homogenous of degree zero (if they were, the increase in corn acreage would be matched by an equal decline in the acreage of the substitute crops). The small increase in total agricultural acreage can be attributed to land taken out of CRP programs, land that is no longer fallowed, and land that was historically used for another type of agricultural production and being put into the production of one of these six field crops.

Southern Minnesota

As part of the nation's heartland, Southern Minnesota is known for its production of corn and soybeans. Combining acreages from the three NASS districts (Southwest, South Central, and Southeast) that make up the southern part of the state, Figure 15 depicts the overwhelming lead that corn and soybeans have in terms of planted acres relative to other crops in the region.

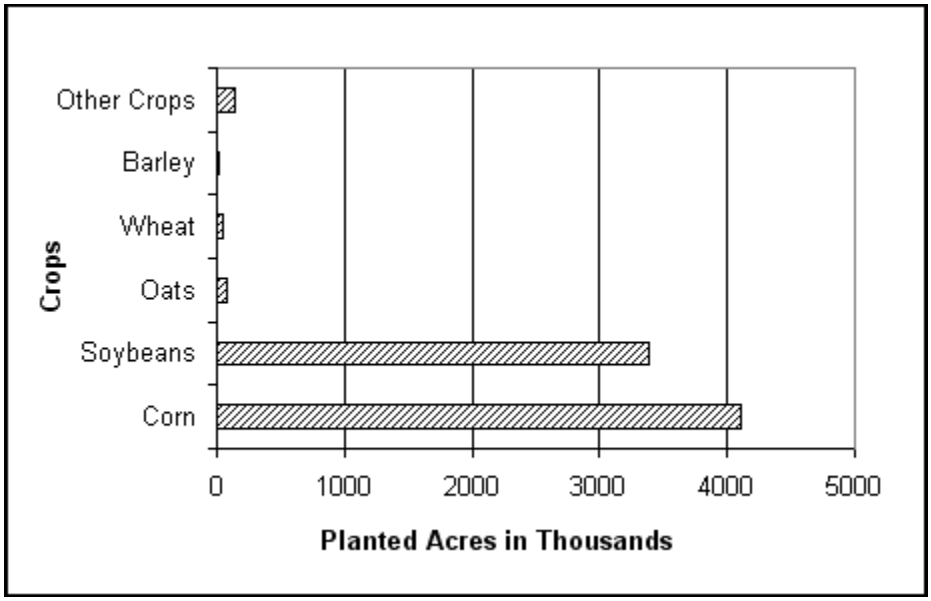

Figure 15. 2006 Southern Minnesota Planted Acreage by Crop[11]

The regression results for corn planted acreage (variable name CA) in Southern Minnesota as a function of lagged corn net returns (variable name C_NR (t −1)), lagged wheat net returns (variable name W_NR (t −1)), lagged soybean net returns (variable name SB_NR (t −1)), and a dummy variable used to pick up differences in government payment programs are presented in Table 9 (see equation (21)). Lagged net returns for Oats was included in the initial regression, but was not significant at the 90% level, nor was the trend variable. Both insignificant variables were removed and the regression was re-estimated using just the four independent variables listed below.

(21) $CA_{SM} = f\left(C_NR_{SM,t-1}, W_NR_{SM,t-1}, SB_NR_{SM,t-1}, D\right)$

[11] Data Source: National Agricultural Statistics Service (2008)

Table 9. Southern Minnesota OLS Regression Results for Corn Acreage Identified by Equation (21)

Variable	Beta	S.E.	t-test	Prob (t)	Elasticity
Intercept	3,443,431.40	122,270.98	28.2	0.000	
C_NR (t-1)	3,765.77	888.39	4.239	0.003	0.138
W_NR (t-1)	-2,482.89	1,078.70	-2.302	0.050	-0.028
SB_NR (t-1)	-2,605.36	1,389.15	-1.876	0.098	-0.100
Dummy	642,517.14	145,644.17	4.412	0.002	0.145
R2	0.844				
RBar2	0.766				
MAPE	1.462				

The regression results for the Southern Minnesota Region reveal the use of four independent variables that were significant at the 90% level to forecast corn acreage with a relatively high degree of accuracy (MAPE of 1.462). Relative to the acreage response elasticities estimated for the Texas High Plains region, these regional estimated elasticities are more in line with our expectations which can be attributed to the significant percentage of the nations' corn that comes from the Corn Belt region, of which Southern Minnesota is part of. The wheat cross elasticity (-0.028) is similar in magnitude to the wheat cross elasticity estimated for the Texas High Plains region (-0.023). Both of the estimated cross elasticities for wheat and soybeans were inelastic and of the expected sign.

As in the case of the Texas High Plains regression, the OLS results are not sufficient for use in the forecasting of 10 years of changes to the agricultural landscape. Regional net return supply elasticities were obtain from FAPRI (2008b) and were used to make regional crop acreage forecasts. Southern Minnesota is estimated as a portion of

the Lake States region used by FAPRI (2008b). The complete matrix of elasticities is presented below in Table 10.

Table 10. Matrix of 2008–2017 Net Return Elasticities for the Lake States[12]

	Barley	Corn	Oats	Soybeans	Sunflower	Wheat	Canola
Barley	0.311	-0.002	-0.003	-0.002	-0.002	-0.002	-0.003
Corn	-0.339	0.362	-0.439	-0.326	-0.294	-0.304	-0.567
Oats	-0.005	-0.004	0.289	-0.004	-0.004	-0.004	-0.009
Soybeans	-0.217	-0.187	-0.281	0.404	-0.188	-0.195	-0.363
Sunflower	-0.002	-0.001	-0.002	-0.001	0.404	-0.001	-0.003
Wheat	-0.023	-0.019	-0.029	-0.021	-0.020	0.237	-0.038
Canola	0.000	0.000	0.000	0.000	0.000	0.000	0.417

Forecasting agricultural net returns for Southern Minnesota cropland was done in a series of steps. Initially, stochastic forecasts for national prices, yields, and costs were generated multivariate empirical as discussed in preceding sections of this dissertation. Localization of these stochastic variables was done using wedges developed off of historical data. The wedges were applied and localized net returns were calculated as localized price multiplied by localized yield per planted acre less localized costs per planted acre. Stochastic forecasts of corn net returns were then used to forecast stochastic barley, corn, oats, soybean, and wheat planted acreages over the 10 year time period.

[12] Source: FAPRI (2008a)

Table 11. Historical and Forecasted Southern Minnesota Planted Acreages and Percentages Changes

	Historical	*Simulated Means*		2007 to 2017	%
	2007	2008	2017	Change	Change
Corn	4,545,000	4,608,730	5,600,227	1,055,227	23%
Barley	9,500	9,375	6,853	(2,647)	-28%
Oats	76,900	75,592	48,884	(28,016)	-36%
Soybeans	2,922,500	2,885,619	2,140,517	(781,983)	-27%
Wheat	36,100	35,675	27,106	(8,994)	-25%
Total acreage	7,590,000	7,614,990	7,823,586	233,586	3%

Five hundred iterations of agricultural planted acreage for the Southern Minnesota region was completed as a means of intermediate model validation. The results of the simulations are summarized in a series of figures presented in APPENDIX C. In addition, Table 11 presents an even more concentrated summary of the simulation results. Table 11 compares 2007 planted acreage for each of the five major crops in Southern Minnesota to the average of the simulated planted acreages. As expected, corn acreage is shown to increase more than 20% over the 10 year time frame, while the alternative crops show significant declines in planted acreages. Total regional agricultural acreage dedicated to these five crops increases by just 3% over the 10 year time period.

Oats planted acreage shows the largest of those declines in planted acreage, with an average of a 36% decline over the period. Although a 36% change in acreage sounds rather large, oat acreage makes up just 1% of total acreage in the region. The significant change in the agricultural landscape comes from the substitution of soybean acreage for

corn acreage. Corn and soybean planted acres go from making up 60% and 39% of the total 2007 land planted in these five crops, respectively, to making up 72% and 27% in 2017, respectively. In both cases, 2007 and 2017, total planted acreages by crops other than corn and soybeans make up just over 1% of the remaining agricultural acreage. Figure 16 provides a visual for the changing make-up of agricultural acreage in Southern Minnesota based upon the forecasts done in this research, depicting the overwhelming majority of acres dedicated to corn and soybeans and the shift from soybean acreage to corn acreage. The acreages used to make up the 2007 component of Figure 16 are historical values, while the remaining 2008 to 2017 values are means calculated from the simulation results.

The forecasted shifts in agricultural land will have numerous implications for the region. The later sections of this chapter will describe the methods used to determine the water implications of these changes in agricultural acreages for Southern Minnesota and when combined with water usage by ethanol facilities, the results chapter will describe the overall impact on Southern Minnesota water resources.

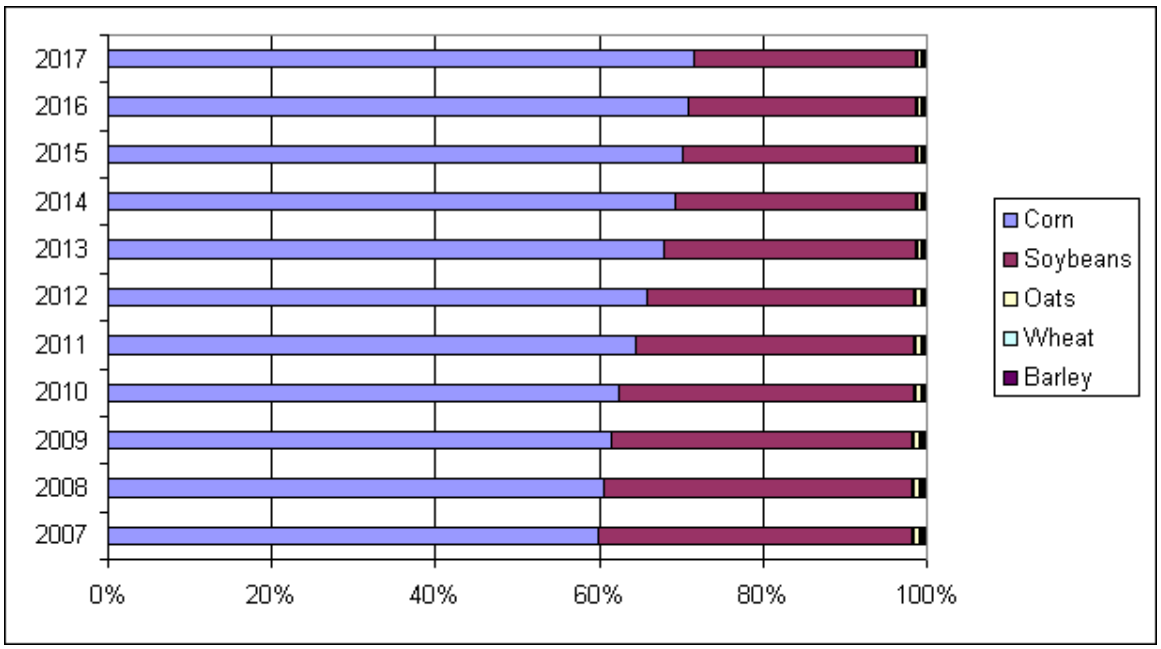

Figure 16. Southern Minnesota Major Cropland Shifts Based on Land Usage Forecasts

California's Central Valley

The six counties that make up the San Joaquin Valley of California make up one of the richest agricultural regions in the state. As Figure 17 illustrates, the leading agricultural crops based upon 2006 planted acreage were corn, wheat, cotton, oats, and tomatoes in the San Joaquin Valley.

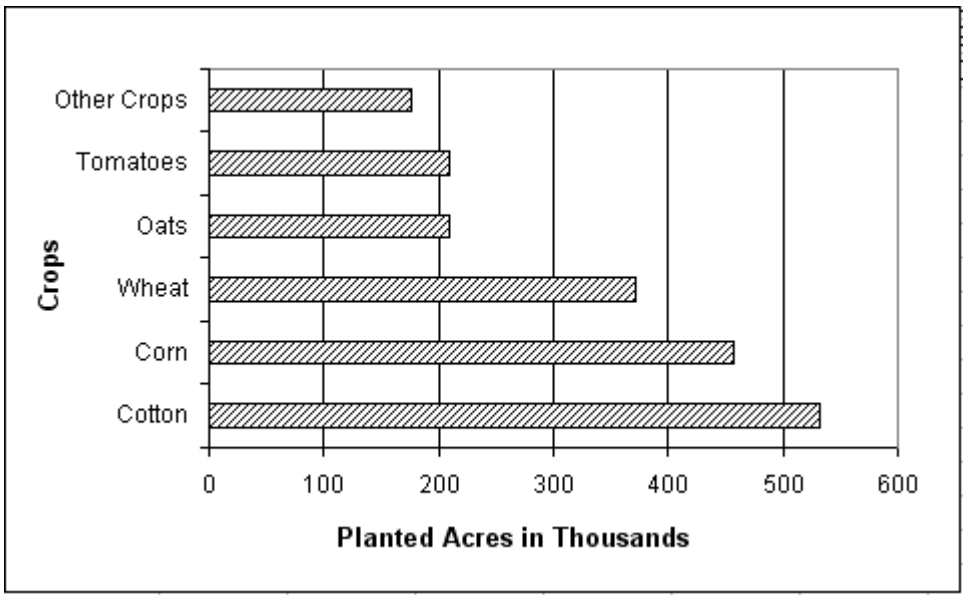

Figure 17. 2006 San Joaquin Valley Planted Acreage by Crop[13]

Taking into consideration the predominate field crops that are grown in the San Joaquin Valley a number of different OLS regression models were estimated prior to selecting the model that appears in Table 12 as the best model. The model that is presented in Table 12 uses independent variables lagged corn net returns (variable name

[13] Data Source: National Agricultural Statistics Service (2008)

C_NR (t −1)), lagged tomato net returns (variable name TM_NR (t −1)), a trend variable, and a dummy variable used to represent different implications of government programs on corn acreage (see equation (22)). Model specifications that included lagged wheat, cotton, and oat net returns were attempted without significant results at the 90% level.

(22) $CA_{CV} = f\left(C_NR_{CV,t-1}, TM_NR_{CV,t-1}, T, D\right)$

Table 12. California Central Valley OLS Regression Results for Corn Acreage Identified by Equation (22)

Variable	Beta	S.E.	t-test	Prob (t)	Elasticity
Intercept	-33,299,892	7,317,065	-4.551	0.001	
Trend	16824.0	3654.9	4.603	0.001	85.2
C_NR (t-1)	378.30	150.84	2.508	0.028	0.118
TM_NR (t-1)	-38.13	41.47	-0.919	0.376	-0.066
Dummy	60,613.80	24,882.15	2.436	0.031	0.108
R2	0.92958				
RBar2	0.90610				
MAPE	4.76227				

The model generated in the OLS regression for corn acreage in the Central Valley of California fits the historical data slightly better than the other regional OLS models fit their respective historical data. This improvement in fit is surprising, as there are a plethora of other cropping alternatives available to producers in the San Joaquin Valley. Nevertheless, the model presented above in Table 12 provides some interesting results and significant relationships. Notably, lagged corn net returns are significant at the 95% level and provide a mean elasticity estimate of 0.118. Although the elasticity

estimate is relatively low compared to what we would normally expect, the own price elasticity estimated may be attributed to the high number of substitute crops available to the producer. The dummy variable is also highly significant, representing the structural change caused by variations in farm bill programs. Although incorporated in the model specified in Table 12, lagged tomato net returns were not significant at any reasonable level of significance.

Although the specified OLS regression model displays an ability to explain historical variations in planted acreage, we are left in a situation similar to the one we were in with the other region's OLS model results. The OLS results don't yield us enough power to forecast total regional changes to the agricultural landscape for two reasons: we are forecasting beyond the range of historical observations and the we don't have enough cross elasticities. Therefore, as in the other regions, we will rely on net return supply elasticities from FAPRI (2008b) to create forecasts of crop acreage in the Central Valley of California. California is included in FAPRI's "Far West" region, along with Arizona, Idaho, Nevada, Oregon, Utah, and Washington. So although the elasticities cover a much broader region than the elasticities attempted to generate in this research, the use of FAPRI's elasticities provide a significant improvement in terms of completeness. The full matrix of FAPRI's 2008-2017 net return elasticities for states in the Far West region are displayed in Table 13.

Table 13. Matrix of 2008–2017 Net Return Elasticities for the Far West[14]

	Barley	Corn	Cotton	Oats	Rice	Wheat
Barley	0.235	-0.016	-0.053	-0.022	-0.009	-0.016
Corn	-0.094	0.501	-0.137	-0.058	-0.045	-0.074
Cotton	-0.020	-0.009	0.670	-0.012	-0.010	-0.016
Oats	-0.010	-0.004	-0.015	0.263	-0.003	-0.008
Rice	-0.028	-0.025	-0.082	-0.020	0.426	-0.022
Wheat	-0.145	-0.114	-0.383	-0.162	-0.063	0.190

Table 14. Historical and Forecasted California Central Valley Planted Acreages and Percentage Changes

	Historical	*Simulated Means*		2007 to 2017	%
	2007	2008	2017	Change	Change
Corn	545,000	572,801	849,750	304,750	56%
Barley	41,000	40,607	28,788	(12,212)	-30%
Oats	184,000	182,914	148,312	(35,688)	-19%
Rice	12,000	11,945	10,145	(1,855)	-15%
Wheat	498,000	494,225	377,113	(120,887)	-24%
Cotton	175,900	173,443	104,483	(71,417)	-41%
Total acreage	1,455,900	1,475,934	1,518,592	62,692	4%

[14] Source: FAPRI (2008b)

As in the case of the Texas High Plains and Southern Minnesota, the regional net return elasticities were combined with stochastic forecasts of annual regional net returns per planted acre to obtain stochastic estimates of planted acreages. Stochastic planted acreages were simulated 500 iterations and examined as intermediate results. Table 14 displays mean values for the 2008 and 2017 simulated planted acreages of the top six field crops in the Central Valley region, while APPENDIX C offers a more detailed display of the annual simulation results for each crop in a series of fan graphs.

One of the primary acreage changes revealed by the simulation results is the significant increase in corn planted acreage. By 2017, corn acreage has increased 56% relative to 2007 planted acreages. This increase is offered in conjunction with a significant amount of variability on stochastic planted acreage. The variability is slightly higher than the variability experienced in the other two regions on forecasted corn acreage. Texas and Minnesota regions had coefficients of variation (CV) in the ranges of 8-12, while the CVs for the California region were nearly 30 in most years. Net returns per planted acre for corn in the Central Valley during the base year, were relatively low. Relatively small monetary changes in net returns per acre yield large percentage deviations from the per acre net returns in the base period. As a result, there are significant variations in the planted acreages. Nevertheless, the forecasts are in line with our expectations. Added variability in a region like the California Central Valley can easily be justified due the large number of substitute crops available.

Also revealed in Table 14 is that more than 1/3 of the change in acreage planted in corn comes from acreage planted in wheat. Cotton experiences the largest percentage

decline in planted acres (41%) over the 10 year period. Total regional acreage planted in these six crops increases by under 4% between 2017 and 2007. Although this percentage of land increase is larger than the other two regions, it is smaller in absolute value and can once again be attributed to the significant number of alternative crops that can be grown in the region.

Forecasting Crop Water Usage

At this point it should prove useful to offer a definition of consumptive water use. Water withdrawals and water applied to a crop is not necessarily the same thing as consumptive use of water. Within in this research, consumptive use refers to water that is removed from immediate use by another application through evaporation, transpiration, incorporation in another product, or consumption. As Griffin (2006) points out, consumption is more of an immediate, local unavailability as over time all water tends to return to earth.

Agricultural water use is a result of soil evaporation and plant transpiration, collectively known as evapotranspiration (ET). Evapotranspiration is "the collective term used to include water discharged to the atmosphere as a result of plant transpiration and evaporation from soil and surface-water bodies" (Shaffer and Runkle 2007). The rate of ET, expressed as a volume per land area, is synonymous with the rate of consumptive water use. Evapotranspiration rates are affected by annual rainfall, soil types, irrigation methods, local rainfall, and, perhaps most importantly by energy from solar radiation (California Department of Water Resources 1998; Shaffer and Runkle 2007).

A plant's water requirements are supplied through either rainfall or through irrigation water (applied water). Equation (23) details the relationship between irrigation requirements, plant ET, and rainfall. Evapotranspiration and evapotranspiration of applied water (ETAW) are frequently measured and recorded for all different types of land cover. When rainfall occurs, ETAW will always be less than ET (California Department of Water Resources 2005). Effective rainfall refers to the quantity of water available in the soil to the plant as a result of rain.

(23) Net Irrigation Requirement = Evapotranspiration – Effective Rainfall

Because of the diversity of the selected regions with regard to the aforementioned contributors to differences in ET rates in addition to significant differences in hydrology, soil conditions, geology, and climate, there is thus no "one-size-fits-all" model for determining the crop water usage in each of these selected regions. The following sections will discuss the multiple methodologies used to predict crop water usage in this research based upon the forecasted acreage changes.

Texas High Plains

The annual crop water requirement for analyzed crops in the Texas High Plains was estimated using potential evapotranspiration and crop coefficients, Equation (24) shows the general formula for estimated water requirements for crop j as a function of potential evapotranspiration (PET_i) and crop coefficients (Kc_{ij}).

(24) $W_j = \sum_i PET_i * Kc_{ij}$

The subscript i is a reference to the month for which the values are estimated. The PET_i value shows the estimated potential monthly evaporation and Kc_{ij} is the estimated crop coefficient for crop j in month i. Crop coefficients are normally estimated based upon the growing stage of the crop; therefore, by identifying the growing season in the Texas High Plains we were able to apply an appropriate crop coefficient for each month. The growing seasons for the six analyzed crops in the Texas High Plains were identified as follows according to the commodity calendar published by the Texas A&M Department of Agricultural Communications (2007) and replicated below in Table 15

Table 15. Planting and Harvesting Times for Selected Commodities Grown in the Texas High Plains

	Plant	Harvest
Corn	mid Apr - mid May	mid Sept - mid Oct
Cotton	May - Jun	Nov - Dec
Oats	Sept - Oct	May - July
Soybeans	May - Jun	Oct - mid Nov
Sorghum	May	mid Sept - Oct
Wheat	Sept - Oct	May - July

Historical average potential evapotranspiration for the Texas High Plains was taken from a data series maintained by the Irrigation Technology Center in the Texas AgriLife Extension Service (2009). With 89 years of historical data, the Lubbock station served as the representative city for the Texas High Plains region covered in this research. Crop coefficients based upon the stage of production were obtained from the FAO in a document authored by Allen, Pereira, Raes, and Smith (1998). In addition to

the estimates of average crop coefficients, the Allen, Perieira, Raes, and Smith (1998) report also contained estimates of the length of time for each growing season by crop. With that information and the growing season information from

Table 15, crop coefficients were assigned to a particular month and then combined with potential evapotranspiration for that month, yielding the annual average crop water requirement for each crop in the Texas High Plains. Crop water requirements were made stochastic by using high and low potential evapotranspiration in the historical data series for the Texas High Plains. Stochastic crop water requirements were combined with stochastic acreage forecasts to obtain stochastic estimates of crop water usage.

Southern Minnesota

There is significant variability in evapotranspiration rates across the state of Minnesota, with higher ET rates occurring in Western Minnesota due to the dry air influence and in Southern Minnesota due to higher temperatures (Minnesota Department of Natural Resources 2000). These factors made it important to create localized estimates of crop water usage for the Southern Minnesota region. The North Dakota Agricultural Weather Network (2009) maintains detailed weather and crop water usage data for 60 weather stations in North Dakota and parts of Minnesota. Historical ET rates for Corn, Barley, Oats, Soybeans, and Wheat were collected for Southern Minnesota going back to 2002. ET rates were reported as daily values. Cumulative daily ET rates through the estimated growing season were used to represent annual crop water usage.

Of the five crops analyzed in the Southern Minnesota region, corn had the highest average crop water usage at 1.55 acre-feet per acre, followed by soybeans and wheat. The absolute variability associated with annual changes in corn crop water use was higher than the other crops (corn had the highest standard deviation), however the relative variability associated with corn crop water usage was the lowest among the five crops (corn had the smallest coefficient of variation).

The historical ET observations showed no apparent signs of a trend; all crops had p-values associated with a simple trend regression that were larger than .75. However, there was a high degree of correlation between historical observations, with every cross correlation coefficient testing significant at the 95% level. Therefore, based upon the limited historical observations, the clear lack of trend in the observations, and the strong degree of correlation between the observed rates of crop water usage, it was determined that the ET rates should be modeled using a correlated GRKS distribution. Correlated uniform standard deviates (CUSDs) were generated off of a correlation matrix built off of the historical data points. Historical minimum, middle, and maximum rates of ET for each crop were used as the parameters for the GRKS distribution in addition to the CUSDs.

Stochastic rates of ET were applied to the stochastic forecasts for planted acres resulting in stochastic forecasts for crop water usage in Southern Minnesota. Key output variables associated with regional crop water usage were identified as being annual water usage by each crop, total crop water usage by all five crops, annual change in crop

water usage, and change in crop water usage relative to estimated 2007 and 2008 quantities. Each KOV was simulated 500 iterations to obtain resulting distributions.

California Central Valley

The 2003 Farm and Ranch Irrigation Survey (United States Department of Agriculture 2003) shows California as having been one of the top states in terms of irrigated agriculture over the last twenty years. Water use for irrigation in the San Joaquin River hydrological regions comes from a number of different sources. Local surface water supplies the region with nearly half of its water requirements, while imported surface water make around 20% of the region's water supply (California Department of Water Resources 1993). There is some reliance on ground water, as ground water sourced irrigated agriculture land in the San Joaquin River region accounted for 30% of the region's irrigated acreage (California Department of Water Resources 2005).

The California Department of Water Resources maintains records on historical irrigated crop area, crop water use, urban water use, and managed wetlands water use (California Department of Water Resources 2008). Crop water use data includes crop evapotranspiration (ET), effective precipitation, crop evapotranspiration of applied water, the consumed fraction of water, and estimates of applied water by crop for each of the hydrological regions in the state. ET is a measurement of the loss of water to the atmosphere and is a function of many different factors, including temperature, humidity, soil characteristics, and characteristics of the plant. Complex models and formulas have been designed to provide estimates of ET based upon weather, soil, and crop input data.

Although not as accurate as the estimates from complex models, the historical rates of ET for the San Joaquin region will be used in this study for a number of reasons. First, since this model is being completed at a regional level, specific soil characteristics are not known, rather a regional estimate of ET rates based on average characteristics is sufficient. Second, the use of a historical data series, albeit small, allows us to create a stochastic ET series.

The primary pieces of data collected from the California Department of Water Resources are the total ET and the ET of applied water (ETAW). ETAW is the consumptive portion of water applied to irrigated crops, while total ET includes both applied water and rainfall sources. Given the minimal historical data available, a GRKS distribution was used on the historical rates of ET and ETAW (Richardson, Schumann, and Feldman 2006). It should be noted that this approach to modeling the forecasted changes in agricultural consumptive water use is highly simplified and fails to account for many meteorological, climate, and hydrological factors, nevertheless it serves as dynamic method by which to estimate changes in consumptive water based upon changes in agricultural land use. In addition, by holding all the other variables constant, we are able to glean a concentrated comparison of the differences to consumptive water usage as a result of changes in agricultural acreage.

Stochastic rates of ET, ETAW, and applied water (AW) in the form of acre-feet per acre were generated from the historical data series for more than twenty different crops, including the crops for which we forecasted supply. Combining stochastic ET and the forecasted crop acreage, yielded regional consumptive water usage by each of

the crops (identified by subscript i in equations (25), (26), and (27)). Within the San Joaquin region the crops include corn, barley, oats, rice, wheat, and cotton. Total regional consumptive water use (CWU_T) is simply the summation of consumptive agricultural water usage over all the crops in the region (see equation (25)).

(25) $CWU_T = \sum_i ET_i * A_i$

Based upon the historical proportion of irrigated acreage by crop for the San Joaquin region, assumptions were made on future proportions of the forecasted acreages that would be irrigated for each crop (IP_i). Use of the assumed irrigation proportion (IP_i), stochastic ETAW ($ETAW_i$), and stochastic acreage forecasts (A_i) for each crop allowed us to obtain a stochastic estimate of consumptive water use from applied water (CWU_{AW}). In addition, we estimated total regional irrigation water, otherwise known as applied water and referenced as AW_T in equation (27) by using stochastic crop applied acreage along with forecasted acreage and the proportion of irrigated acreage.

(26) $CWU_{AW} = \sum_i ETAW_i * A_i * IP_i$

(27) $AW_T = \sum_i AW_i * A_i * IP_i$

CHAPTER VI

RESULTS

The primary objective of this research—quantification of the water demand impact of expanding ethanol production on three diverse regions of the U.S.—is based upon a combination of several intermediate results to provide those forecasted estimates of regional water use. The individual pieces of the complete model provide intermediate results that are worthy of our attention. This results section will provide a thorough representation of the intermediate and the final, primary, results. Some of the intermediate results include:

1. Economic results from the ethanol plant simulation model
2. Water usage by ethanol production facilities
3. Scenario analysis on the ethanol plant simulation model
4. Agricultural water usage

Rather than organizing the results by model component, as done in prior sections of this dissertation, the results follow a more logical path when grouped by region. Therefore, the following three sections will detail the results of the models by location. Before moving in to a discussion of the results, it should be noted that the model created to analyze the economics and the water usage by ethanol production facilities was simulated under the varying model specifications and for the alternative sets of KOVs (economic variables, water variables, and scenario variables) as discussed in CHAPTER IV. The assumptions used to generate each of the ethanol plant simulation models are

available in APPENDIX D. The resulting outcomes for each region of analysis are presented below.

Texas High Plains

Ethanol Plant Simulation Model

The results for the model specification of the Texas High Plains region illustrates one of the primary reasons in which a stochastic simulation model is highly desirable—the net present value (NPV) for the ethanol plant after 10 years appears to be relatively high in expected value mode ($14 million), but upon simulating the variable, a much broader picture of the plant's economic situation is depicted. An average ethanol plant in the Texas High Plains has just a 55% chance of having positive NPV after 10 years. The following cumulative density function (CDF), displayed as Figure 18, shows the NPV of an average ethanol facility in the High Plains of Texas after 10 years. There is a significant amount of variability that isn't being captured by the average (expected value) NPV, as NPV can extend from close to negative $287 million and all the way up to more than $172 million.

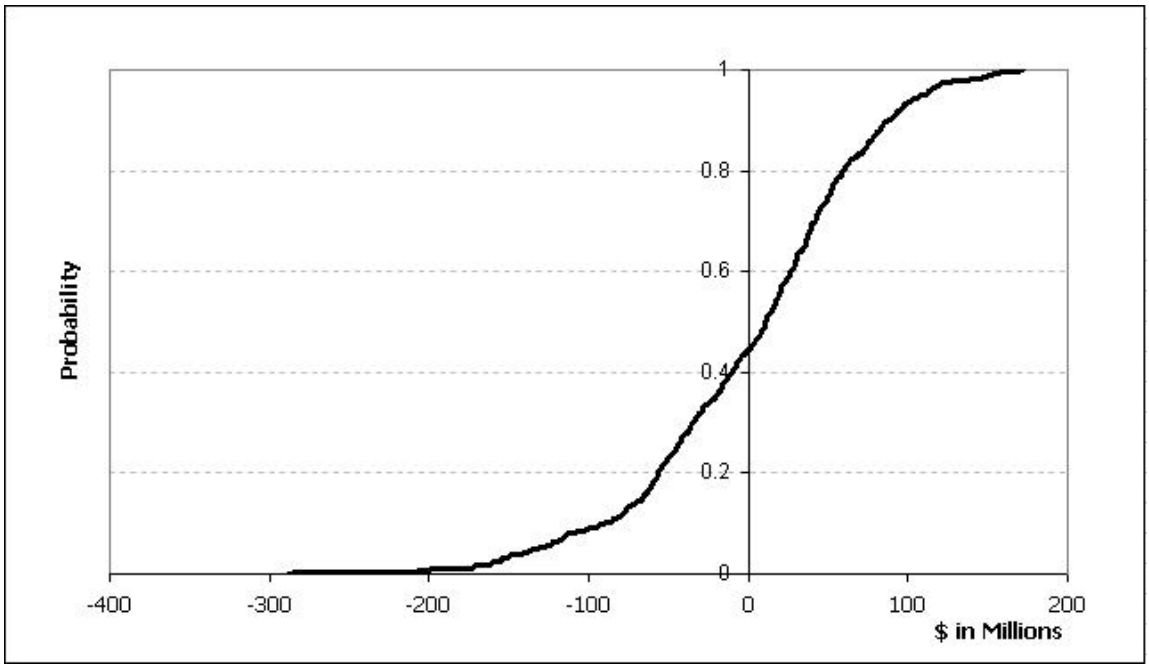

Figure 18. CDF Illustrating NPV for a Texas High Plains Ethanol Plant

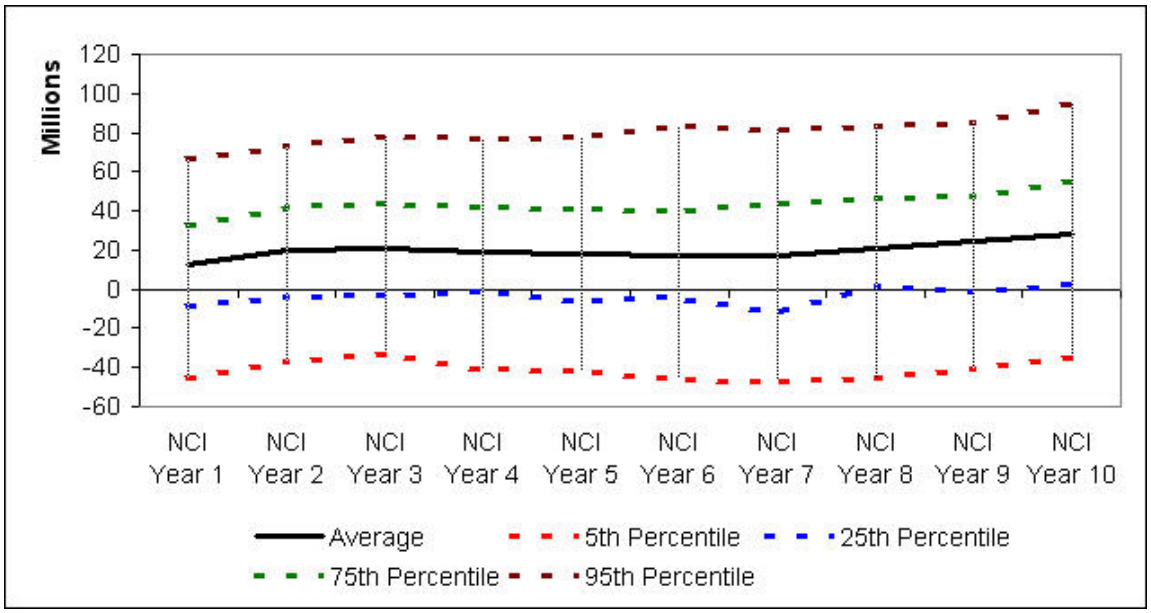

Figure 19. Fan Graph Illustrating NCI for a Texas High Plains Ethanol Plant

An additional simulation was done on annual net cash income (NCI) to show the variability in net cash income over time. In general, during the first couple years of operation the ethanol facility has higher probabilities of a negative net cash income in any given year, but as time goes on and interest expenses on debt begin to diminish, the ethanol plant has an increasing opportunity for revenues to exceed expenses. A fan graph for NCI over the 10 year planning horizon is depicted in Figure 19. Fan graphs show the range of probable outcomes for the variable in each year. In this case, there is a 50 percent chance (green 75th percentile line minus the blue 25th percentile line in Figure 19) that net cash income in year 10 will be between $2.7 million and $55 million.

Another tool we have at our disposal for analyzing the simulated results of net cash income is a stoplight chart. A stoplight chart illustrates the probabilities of being above and below user specified values for a simulated series. In the case of our 10 year series of net cash income it is useful to use a stoplight chart to illustrate the probability of having net cash income less than zero in any given year relative to the probability of having net cash income larger than $50 million. Figure 20 illustrates this stoplight chart for the average ethanol facility in the Texas High Plains. It is easy to see that the probability of achieving annual net cash income larger than $50 million is increasing over time, to the point where there is a 31% chance of this event occurring in year 10. At the same time, we see some fluctuations in the probability of having a negative net cash income, but a general downward trend in the probability of having net cash income less than $0 in any year, reaching just 23% in the final year.

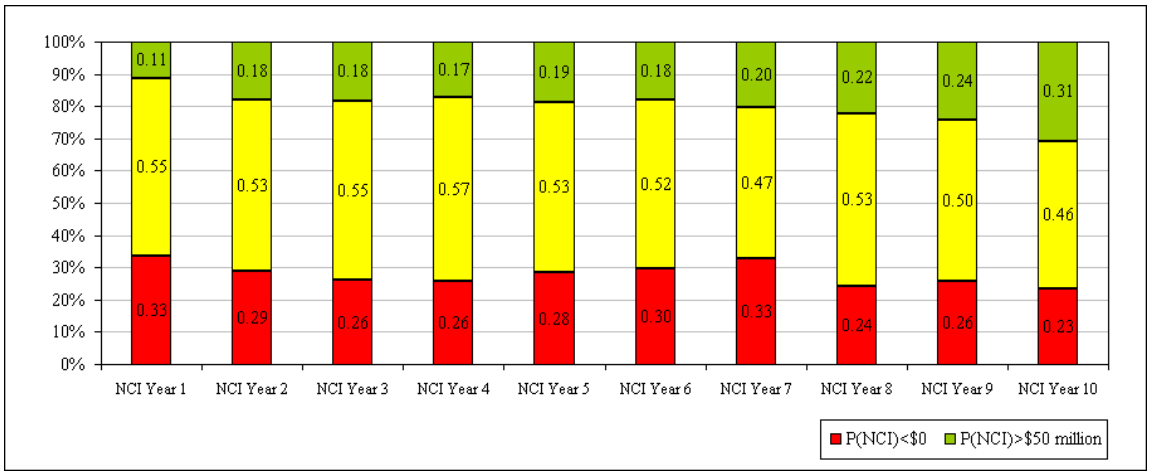

Figure 20. Stoplight Chart for an Average Ethanol Plant in the Texas High Plains Illustrating the Probability of Having Net Cash Income Less Than $0 or Greater Than $50 Million

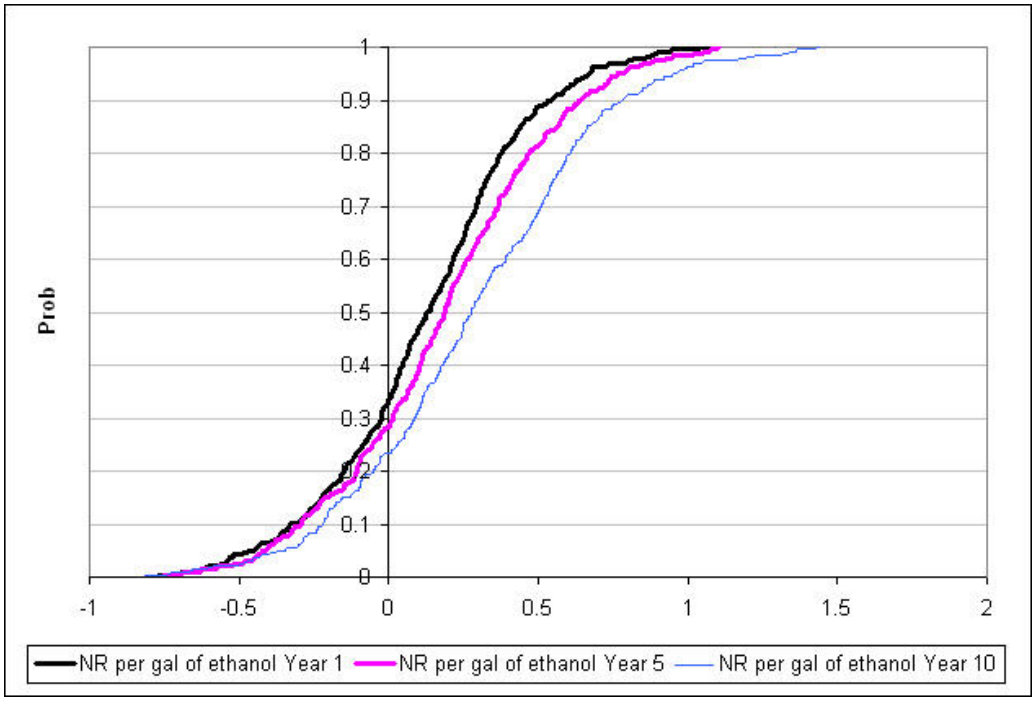

Figure 21. CDF of Net Returns per Gallon of Ethanol for the Average Ethanol Plant in the Texas High Plains in Years 2008, 2012, and 2017 ($/gallon)

To obtain a better understanding of the factors contributing to the plant's economic performance over the 10 year period, it is useful to breakdown the plant's finances on a per gallon of ethanol basis. By design, variable costs per gallon of ethanol are increasing due to inflation; however revenues per gallon of ethanol appear to be making up the difference in increased expenses per gallon (revenues are increasing at an average rate of 2% per year). This is evident as average net returns per gallon of ethanol show a steady increase over the 10 year time period. In 2008, average net returns per gallon were around $0.12, while in 2017 they have more than doubled to $0.28 per gallon. However, there is still a significant amount of variability. In 2008 there was a 34% probability of having negative net returns per gallon of ethanol; while in 2017 that probability has been reduced to 23%. The distributions on net returns per gallon have been shifted to the right.

Figure 21 displays a cumulative density function for net returns per gallon of ethanol produced at the beginning, middle, and end of the time period analyzed (years 2008, 2012, and 2017). Figure 21 clearly shows that for the top 95% of the distribution at every probability there is a higher associated net return per gallon. At the bottom tail of the distribution, the three distributions begin crossing each other. There are lower minimum net returns per gallon in 2017 relative to both 2008 and 2012, revealing evidence of increasing variability over time.

Another way to break down the financial performance the ethanol facility is experiencing is to look at the variability on total costs and where they are being incurred. Corn costs make up the largest component of corn production costs—making up

between 55% and 58% of per gallon expenses. However, this percentage appears to be declining over time. Both corn costs and total costs per gallon are rising over time, but the proportion of total costs that can be attributed to corn costs are declining over time. A box plot of the make-up of per gallon ethanol production costs in 2017 as a percentage of total costs is shown in Figure 22. The advantage of using a box plot is showing the full range of observations within the simulated distribution. Corn costs and all other variable costs have the largest amount of variability and, as expected, make up the largest proportions of production expenses. On the other hand, financing costs make up a relatively small proportion of production expenses (between 4% and 15%) and have less relatively variability (as measured by the coefficient of variation).

Overall the average ethanol facility in the Texas High Plains has a 55% probability of economic success (55%) after 10 years of operation and their outlook appears to be improving over time. However, there is still a significant amount of risk involved in the investment and the risk adverse investor may not want to consider it.

With regard to water usage by the ethanol facility, our simulation results show average per gallon water usage at 3.99 gallons which corresponds to approximately 399 million gallons per year for the average Texas High Plains ethanol facility. Annual water usage by an average ethanol plant in this region ranges from 234 to around 660 million gallons (between 730 and 2,000 acre-feet). Figure 23 shows the distribution of 2017 fresh water usage by an average Texas High Plains ethanol facility in acre-feet per year. Over the 10 year production period this amounts to an average of 3.99 billion gallons (12.2 thousand acre-feet) of water per facility.

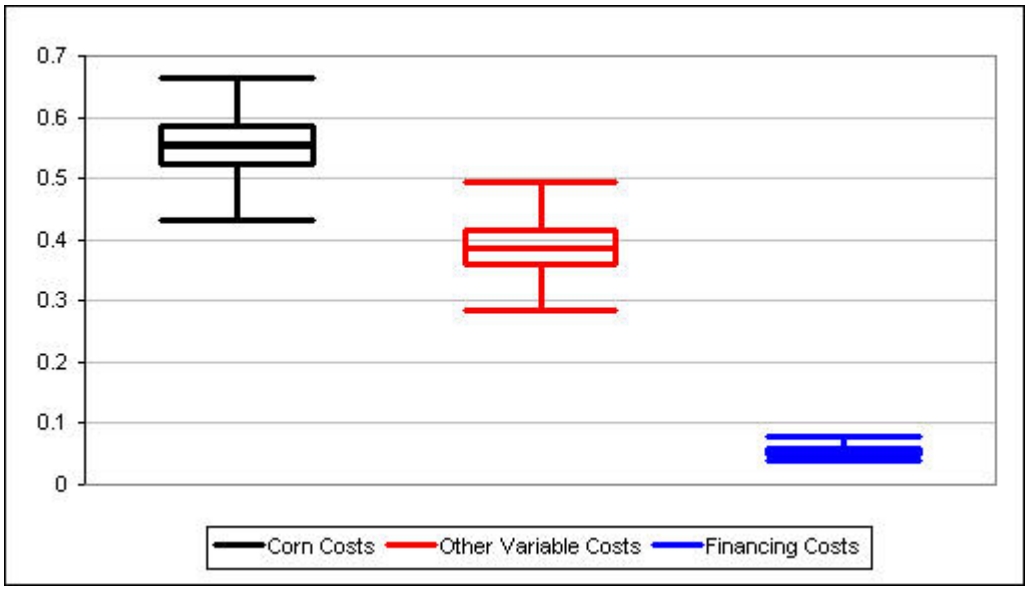

Figure 22. Box Plot of Ethanol Production Costs by Type of Cost as a Percentage of Total Production Costs Per Gallon of Ethanol Produced for an Average Plant in the Texas High Plains

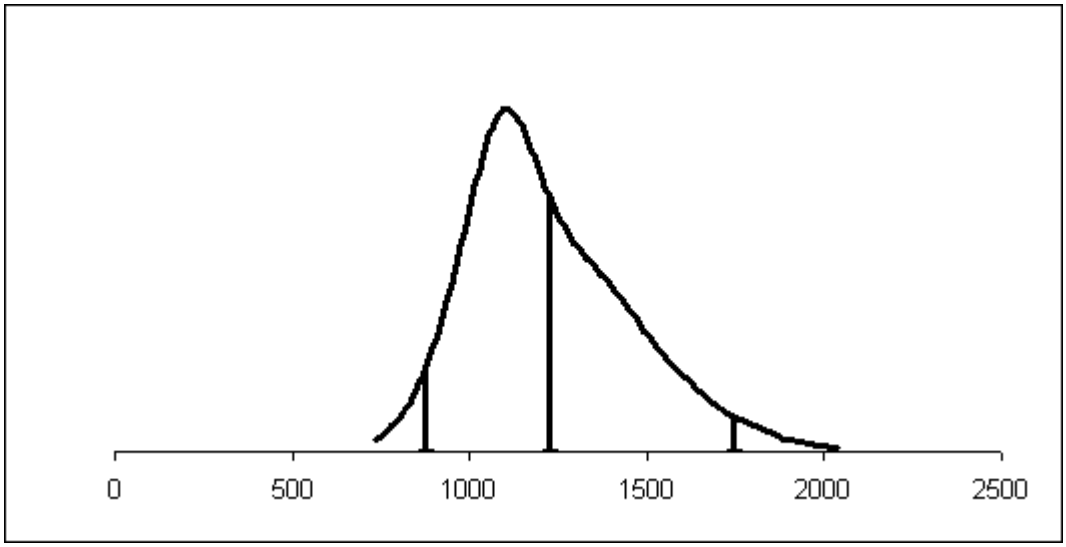

Figure 23. PDF Approximation of 2017 Total Fresh Water Usage by an Average Texas High Plains Ethanol Plant (in Acre-Feet)

Generation of waste water from the ethanol facility amounts to a sizeable amount of waste. In an average year, a Texas High Plains ethanol facility will produce around 118 million gallons of waste water, with variability between 89 and 160 million gallons. The following figure, Figure 24, illustrates the distribution of 2017 waste water produced from an average ethanol plant in the Texas High Plains in million gallons. The treatment costs associated with this quantity of waste water are not insignificant-- they average between $5.6 and $6.5 million per year. In 2017, there is a 50% probability that treatment costs will be between $5.3 and $8.2 million. The variability on those costs in any given year is a function of the variability of the waste water produced and the stochastic per gallon treatment cost that was incorporated in the model design. As a result of these treatment costs, the ethanol facility is likely to try to implement technology to reduce or eliminate waste streams.

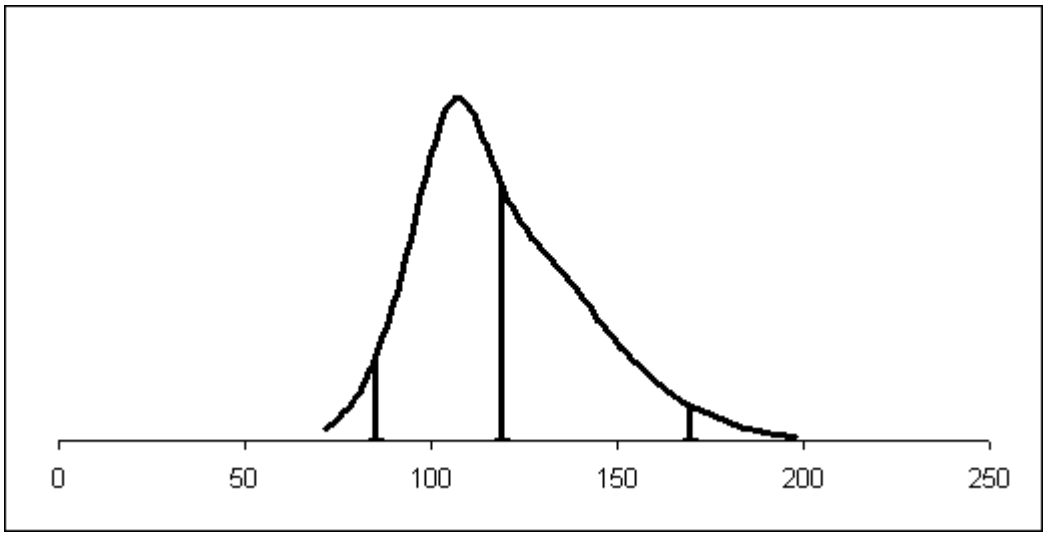

Figure 24. PDF Approximation of the Distribution of 2017 Annual Waste Water Produced by the Texas High Plains Ethanol Plant (in Million Gallons)

Water Price Scenarios

In an attempt to show the impact of increasing water prices on the economic outlook of an average ethanol facility in the Texas High Plains, a scenario analysis was run using different costs associated with obtaining fresh water. Water prices were selected arbitrarily as a means to show the sensitivity of net present value to changes in the cost of obtaining fresh water for use in the ethanol plant. Water prices were set at rates of $30, $120, $1000, and $5000 per acre-foot and referred to as scenario 1, scenario 2, scenario 3, and scenario 4, respectively. To put these costs in perspective, a charge of $5000 per acre foot is equivalent to a water price of $0.02 per gallon.

Figure 25 displays a CDF of the distribution of NPV under the alternative water price scenarios. The movement from a water price of $30 per acre-foot to $120 per acre-foot does little, if anything, to the economic viability of this ethanol facility. In both cases, the probability of being an economic success is 55% and the mean NPV changes less than 1% between scenarios. A movement to water costs of $1,000 per acre-foot (scenario 3) begins to make a slightly larger impact on NPV over the 10 year period. The probability of this average Texas High Plains ethanol facility being an economic success under scenario 3 drops to 50% and the mean NPV drops by about 10% relative to scenario 1. Arguably the first "real" impact we see on NPV as a result of the water price scenarios occurs in scenario 4, where water price has risen to $5000 per acre-foot. The probability of economic success drops to 36% and the average NPV falls by more than 53% in scenario 4 relative to NPV in scenario 1. In addition the lower end of the distribution on NPV has decreased by approximately 28%, with a minimum value of less

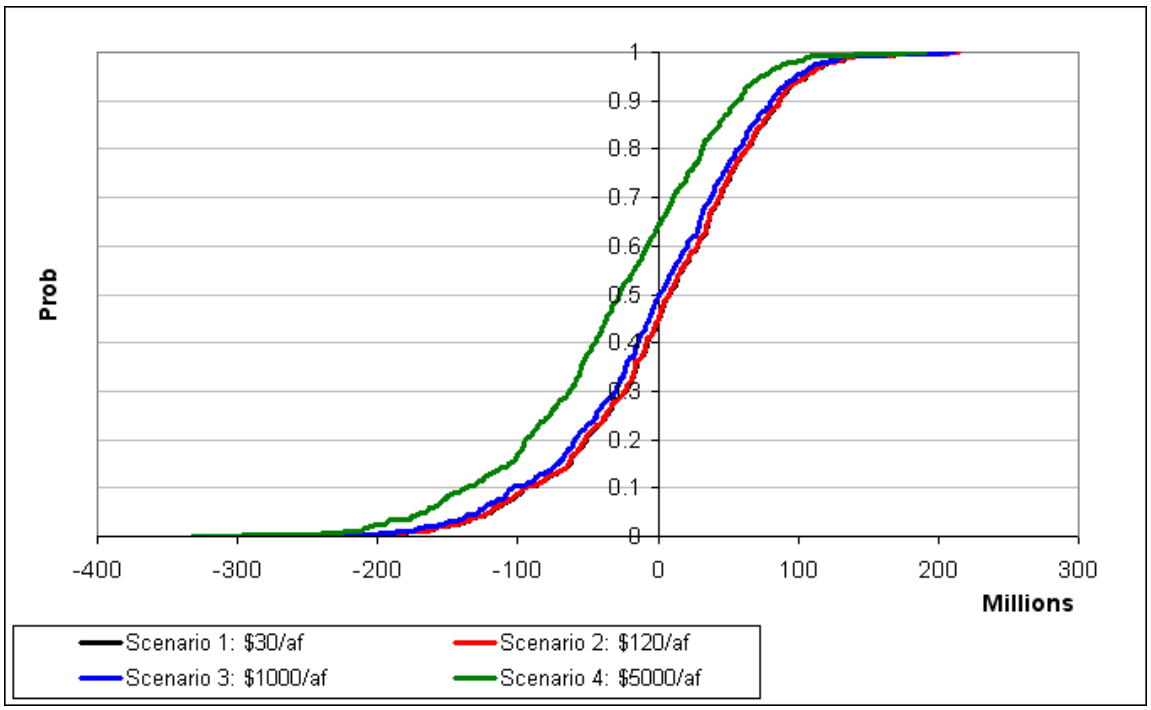

Figure 25. CDF of NPV for Alternative Water Price Scenarios for an Average Ethanol Plant in the Texas High Plains

than -$330 million. However, a 28% probability of economic success is still a better probability of economic success than the California ethanol plant starts out. The minimal change in NPV with slight increases in water costs indicates that an ethanol facility in the Texas High Plains has significant leverage in their willingness to pay for fresh water. In other words, a concern over increased water usage by area water authorities is not likely to be rectified by charging ethanol facilities for the use of water, unless water prices begin to reach levels of $1000 per acre foot and beyond.

Using the water price in scenario 1, a sensitivity elasticity for NPV with respect to water price was calculated. As expected, the sensitivity elasticity revealed the marked unresponsiveness between NPV and water price with an elasticity of -0.04. A one percent change in water price will result in a 0.04% decline in net present value. As a measure of comparison, a sensitivity elasticity of NPV with respect to corn price was calculated. Corn price is, of course, a stochastic variable, so the sensitivity elasticity was calculated off of the deterministic price forecast for corn in 2009 that was used in building the stochastic corn price variable. In the case of corn price, a 1% change in the forecasted price of 2009 corn leads to a 4.6% change in NPV in the opposite direction. NPV is very elastic (or sensitive) to changes in the price of corn in a single year, while rather inelastic (or insensitive) to the price of water throughout the entire 10 year period.

Water Reduction Scenarios

There were three water reduction scenarios that were explored in this research. All three of these scenarios were compared to the base situation (noted as scenario 1 throughout this section of the research). Scenarios 2 through 4 are described in detail in

earlier sections of this document, but, in general, scenario 2 implements a zero waste stream program, while scenarios 3 and 4 reduce water used in the cooling tower. By running alternative water reduction scenarios we are interested in determining two things: the impact of the water reduction on total water use by the ethanol plant and the impact of the water reduction on the economic performance of the ethanol facility.

On average, 2017 water use will be reduced by approximately 28% with the implementation of scenarios 2 and 4, while scenario 3 reduces total water use by 14% in 2017. Figure 26 shows the distribution of total consumptive use of fresh water by an average ethanol facility in the Texas High Plains in 2017 by water reduction scenario. Scenario 2 and scenario 4 have a nearly identical distribution, although the scenarios themselves are quiet different—scenario 2 relies on recycling what would have been waste water for the plant, while scenario 4's reduction is a result of improved technologies that are reducing the need for water in the cooling tower. Although the distributions on water usage are highly similar, we would expect significantly different economic implications of these ethanol facilities. The reasons for the economic differences are twofold, the cost of implementing the technologies is significantly different and the costs associated with waste water treatment should prove to be substantial.

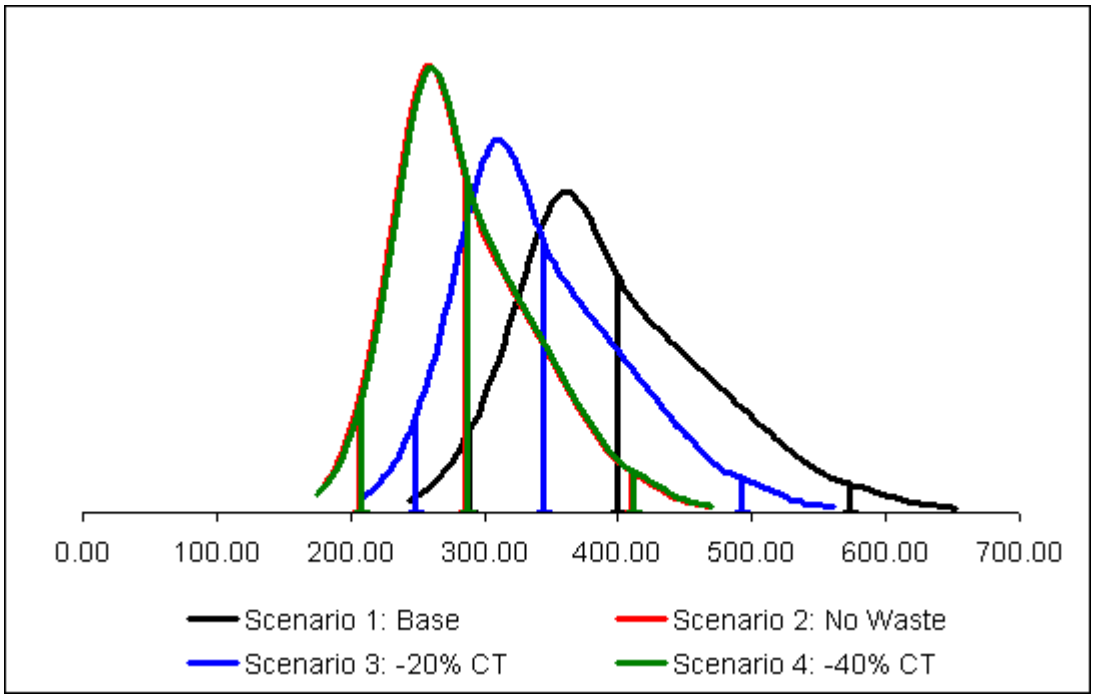

Figure 26. PDF Approximations of 2017 Fresh Water Usage in Million Gallons by Scenario for an Average Ethanol Plant in the Texas High Plains

Scenario 3 also shifts the distribution of fresh water usage by the ethanol facility to the right, although not as substantially as scenarios 2 and 4. On a per gallon basis scenario 3 works out to an average of 3.43 gallons of water compared to the base situation of 3.99 gallons per gallon of ethanol, while scenarios 2 and 4 are able to reduce per gallon water usage to just 2.87 gallons.

Another water usage result of interest is the distribution of waste water usage by scenario. Figure 27 shows a representation of the simulation results in the form of a PDF for waste water production in 2017 by scenario. Scenario 2 was designed to be an elimination of waste water streams and thus does not appear in the figure. Both scenario

3 and scenario 4 show declines in waste water generation relative to the base scenario (specifically a 16% and 32% decline, respectively) and, as expected, scenario 4 shows an average of a 19% decline in waste water relative to scenario 3. The decline in waste water has a monetary value to it as well. Relative to the base scenario, in 2017 a reduction in treatment costs associated with scenario 4 results in an average cost savings of $2.2 million and scenario 3 has an average overall cost savings of $1.1 million.

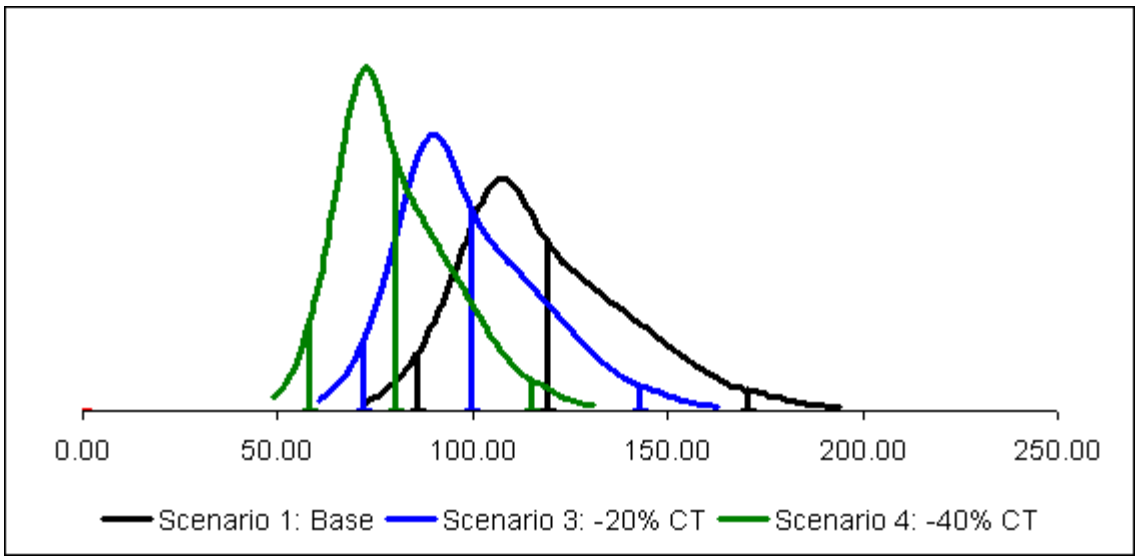

Figure 27. PDF Approximations of 2017 Waste Water Usage in Million Gallons by Scenario for an Average Ethanol Plant in the Texas High Plains

Although we know that there is a cost savings associated with annual treatment costs, in order to judge the impact of these water reduction scenarios on the economic viability of the ethanol plant we need to compare net present value simulation results. Figure 28 displays a CDF for NPV for each alternative scenario. Scenario 2, the

scenario which eliminates the waste water streams from the ethanol facility, shows the most significant shift in net present value. Scenario 2 has a 73% chance of being an economic success, relative to 55% in the base scenario. At all probabilities, scenario 2 has a higher expected NPV. The differences between the base scenario and scenarios 3 and 4 aren't as noticeable or as substantial. Scenario 3 improves the probability of an economic success by 1% and scenario 4 improves the probability by just over 3% relative to the base scenario. Although it is hard to tell from Figure 28, the three water reduction scenarios will be preferred to the base situation in all cases. Stochastic efficiency with respect to a function under a power utility function reveals that under all reasonable levels of risk aversion, scenarios 2 through 4 all preferred to the base scenario.

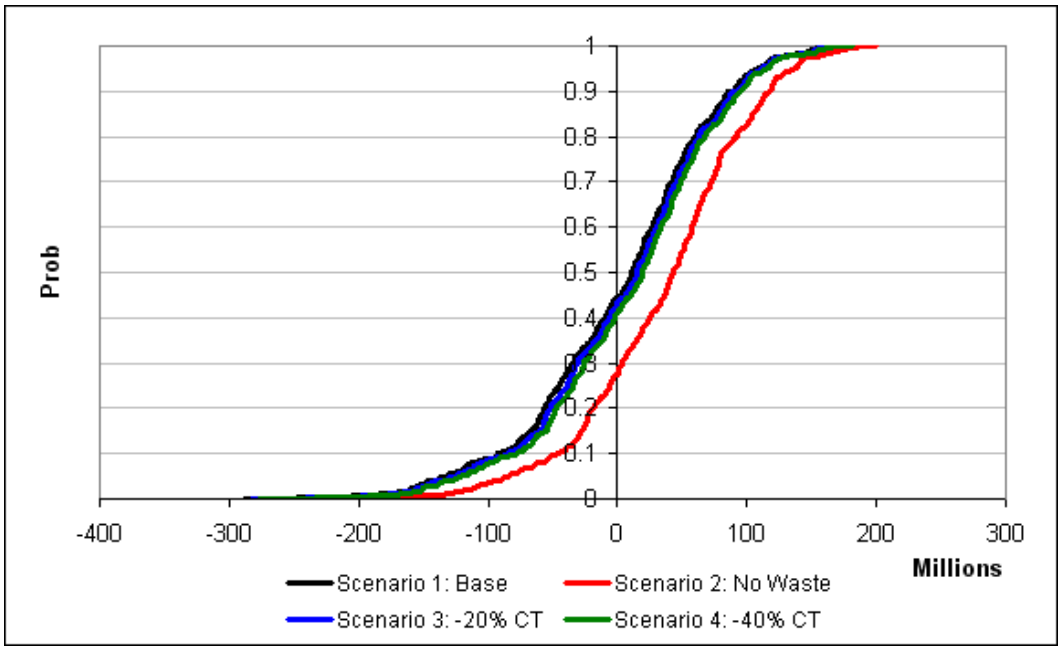

Figure 28. CDF of 2008-2017 NPV Under Alternative Water Reduction Scenarios for an Average Ethanol Plant in the Texas High Plains (in Millions)

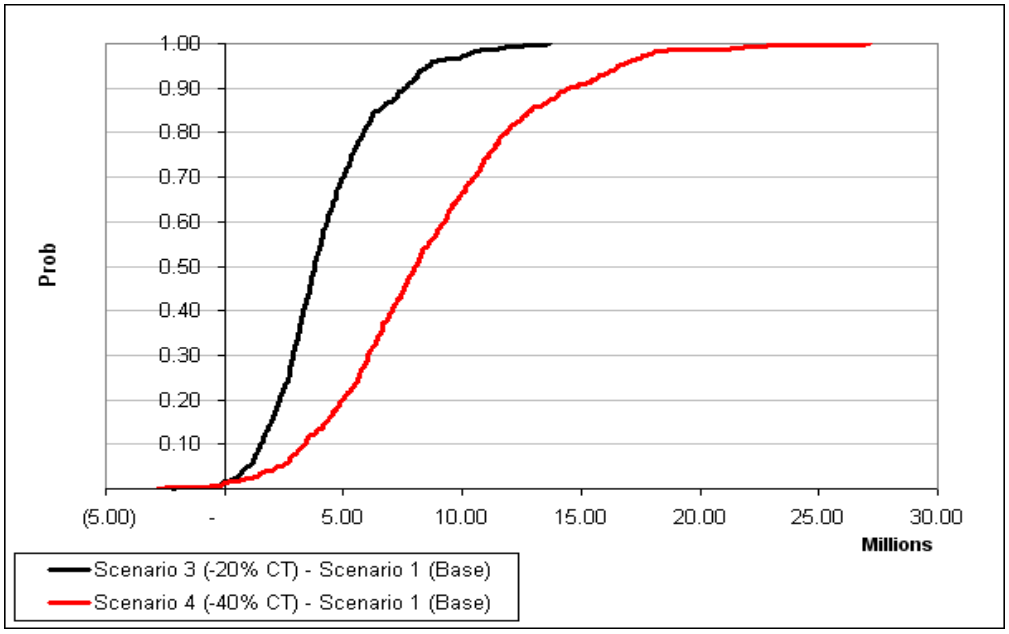

Figure 29. CDF of the Differences Between NPV by Scenarios Relative to the Base Scenario for an Average Texas High Plains Ethanol Plant (in Millions)

Although there is limited visibility of the differences, there are differences in scenarios 3 and 4. Figure 29 shows a CDF of the distribution of the difference between scenario 3 and the base scenario alongside the distribution of the difference between scenario 4 and the base scenario. The divergence between the two distributions is clear in Figure 29, as the distributions begin pulling apart from each other as economic conditions for the plant improve. The differences are relatively minor in the context of total NPV, but this is an opportunity to take a closer look at the differences between scenario outcomes. Scenario 3 outperforms scenario 4 approximately 99% of the time. The remaining 1% occurs when economic conditions are so unfavorable that the higher capital investment required to implement scenario 4 does not pay off.

Agricultural Water Usage

Having applied stochastic rates of consumptive water use to stochastic land use changes we obtained stochastic consumptive agricultural water usage. When combined with total regional stochastic fresh water usage for ethanol production, we have a stochastic estimate of the water used as a result of the changing agricultural landscape and increased ethanol production over the next 10 years in the Texas High Plains region. The following section will describe the results of the total regional agricultural water usage for the High Plains.

The Texas High Plains acreage forecasts are characterized by a 31% increase in planted corn acreage over the 10 year time period and a decline in planted acres for the 5 other crops that were analyzed in this research. Among the crops being analyzed, cotton and corn are the most significant water users—cotton, more substantially than corn,

therefore making the net affect on agricultural water usage of great interest. Was the land that was converted into a relatively more water intense corn crop replacing enough acreage that was formerly devoted to less water intense crops to induce a net increase in consumptive agricultural water usage or did replacement of cotton acreage allow a net decline in agricultural water usage?

Based upon the simulation results, average annual agricultural water usage in the Texas High Plains region increases by just 2% during the analyzed time frame, from 7.8 million acre-feet (MAF) to 8.1 MAF. The variability associated with the distribution of water usage stays relatively constant during the time period, increasing just slightly in the final years of analysis. Figure 30 displays a fan graph for the simulated distributions of annual agricultural water usage in the Texas High Plains by the six analyzed crops (corn, cotton, oats, soybeans, sorghum, and wheat).

It should be noted that the total land area devoted to production of these 6 analyzed crops increases during the 10 year time period by a total of 0.89%. This is a result of the elasticities being used to calculate the changes in land usage not being homogenous of degree zero. By comparing estimated agricultural water usage in 2007 to forecasted agricultural water usage on a per acre basis we are accounting for the increase in acreage and have a means to compare water usage intensities. Table 16 provides acreage and water usage estimates to allow for water intensity comparisons to be drawn. Agricultural water usage increased during the analyzed time frame, however the percentage by which water usage increases is mediated by increases in total agricultural acreage. Water usage intensities increase by just 0.03% from an estimated

1.68 acre-feet per acre in 2007 to 1.73 acre-feet per acre in 2017. It should be noted that this analysis fails to account for the prior water usage on the additional acreage added to the production of these field crops. The land may have been fallow or in an alternative use, but with all likelihood had some sort of plant life as coverage and thus had some consumptive use of water associated with it. The water usage on the surplus acreage (the 1% addition to agricultural land devoted to the production of these six crops) is only incorporated as an increase in usage and not the net change in usage (as was calculated for the remaining 99% of agricultural acreage in this region). Therefore, the water usage intensities for 2017 will still be slightly inflated from their true values.

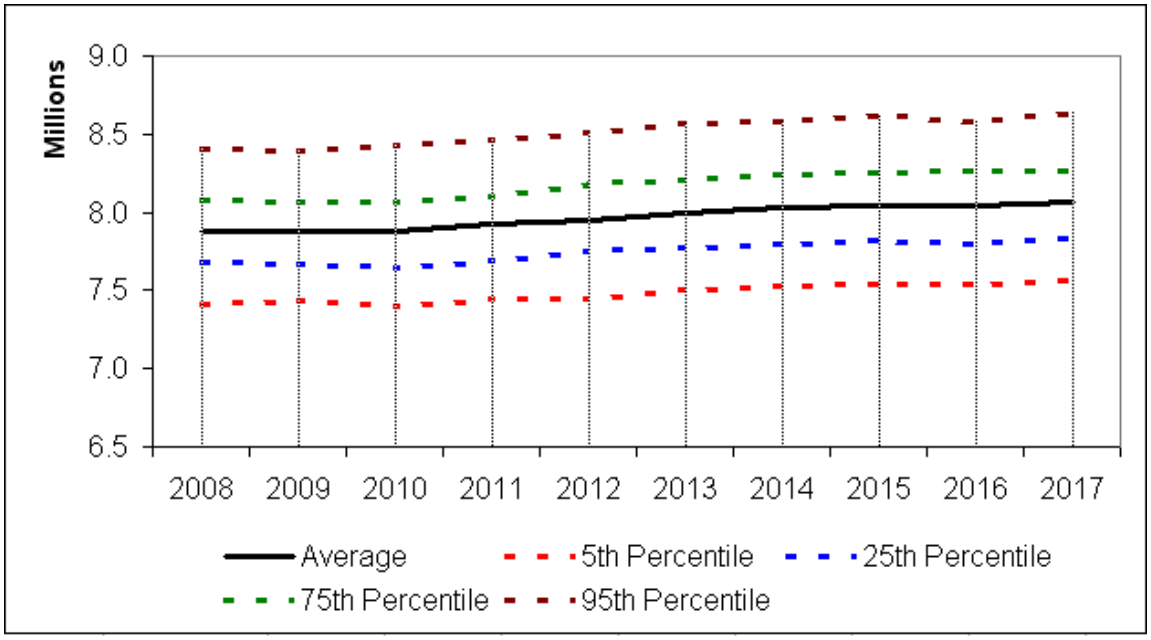

Figure 30. Fan Graph of Forecasted Total Regional Agricultural Water Usage in the Texas High Plains (in Million Acre-Feet)

Table 16. Comparison of Texas High Plains Total Crop Acreage and Agricultural Water Usage

	Historical	*Simulated Means*	
	2007	2008	2017
Total acreage	4,620,100	4,636,286	4,661,362
Total AF water	7,747,740	7,881,197	8,061,189
Avg. AF / Acre	1.68	1.70	1.73
2007 % Δ		0.01	0.03

Using this idea of water use intensity and results from earlier simulations, a normalized distribution of water usage was developed using the simple formula expressed in equation (28).

$$(28)\quad NW_i = \sum_j \left(A_{ij}\right) / TW_i$$

Total planted acres for the region was calculated by summing planted acreages for individual crops (A_{ij}) across each simulated iteration (noted by subscript i). Total planted acreage was then divided by total agricultural water usage in that same iteration (TW_i), yielding a distribution of normalized of water usage (NW_i), measured in acre-feet of water per acre. Figure 31 offers a comparison of the distributions of regional agricultural water usage in 2008 and 2017 on an acre-foot per acre basis. The distributions reveal only a slight rightward shift by 2017 indicating an increase in water usage intensity.

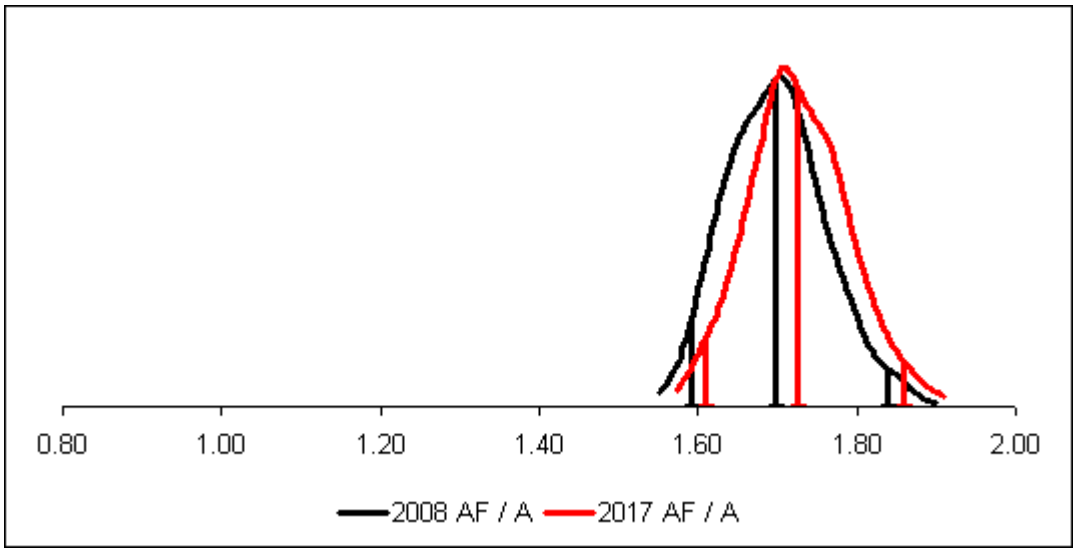

Figure 31. PDF Approximation of 2008 and 2017 Normalized Agricultural Water Usage in the Texas High Plains (in Acre-Feet per Acre)

By looking at how year-to-year changes in total water usage provides an indication where times of water stress may occur, ceteris paribus. Water supply factors are not being taken into consideration and thus increases in demand may not necessarily correspond to periods of water stress. The following figure, Figure 32, reveals the distribution of annual agricultural water changes in demand relative to estimated agricultural water usage in the prior year. In response to the increasing variability in the forecasted crop acreage and the combined variability of the stochastic crop water usage rates, changes in agricultural water usage experience increasing variability as well. Figure 32 shows the relatively smooth increase in total water used from year to year and that the total increase in water usage is not marked by any spikes between years.

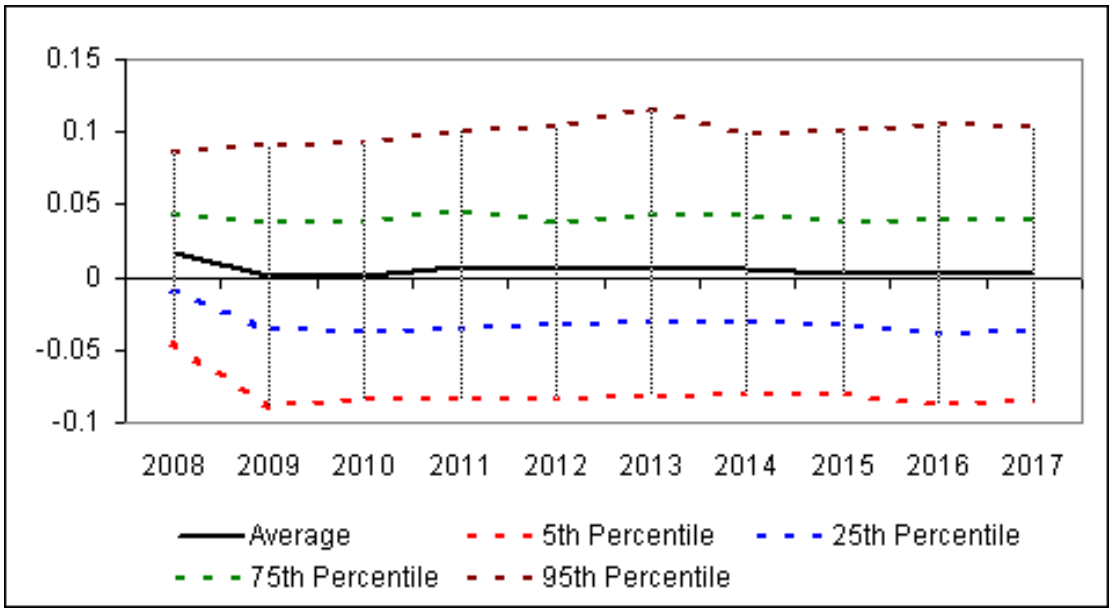

Figure 32. Fan Graph of Forecasted Annual Percentage Changes in Agricultural Water Usage in the Texas High Plains

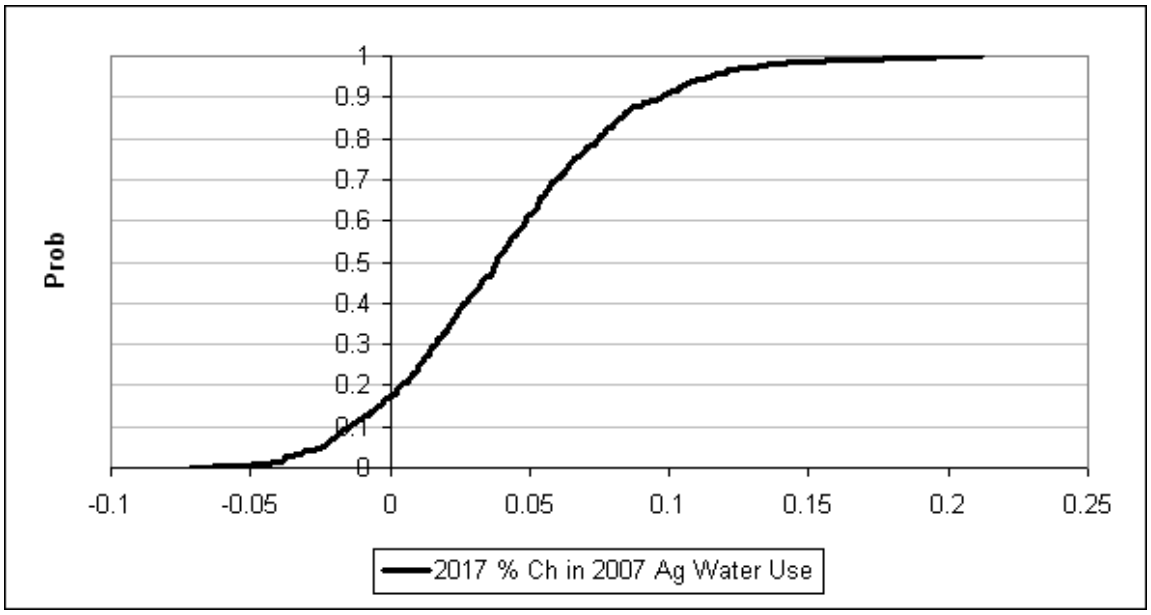

Figure 33. CDF of the Distribution of Agricultural Water Usage in 2017 as Percentage of Estimated 2007 Agricultural Water Usage in the Texas High Plains

At the end of the analyzed time period, there is a relatively high probability of having an increase in total agricultural water usage. Figure 33 shows the distribution of the percentage change in agricultural water usage in 2017 relative to estimated agricultural water usage in the Texas High Plains in 2007. There is an approximately 83% probability of having an increase in consumptive use of agricultural water. Based upon the simulated distribution, there is a very slim probability of agricultural water usage increasing more than 20% over the 10 years (approximately 1% of the time).

As expected, there is a strong correlation between the changes in corn acreage changes and changes in agricultural water usage. Figure 34 shows a line graph that depicts the relationship between annual percentage changes in corn acreage and annual percentage changes in agricultural water usage. As discovered earlier, increases in agricultural water usage occur at a relatively steady pace over the analyzed time frame and thus appear to do little in response to corn acreage. There is, however, a positive correlation of .77 between changes in corn acreage and changes in agricultural water usage.

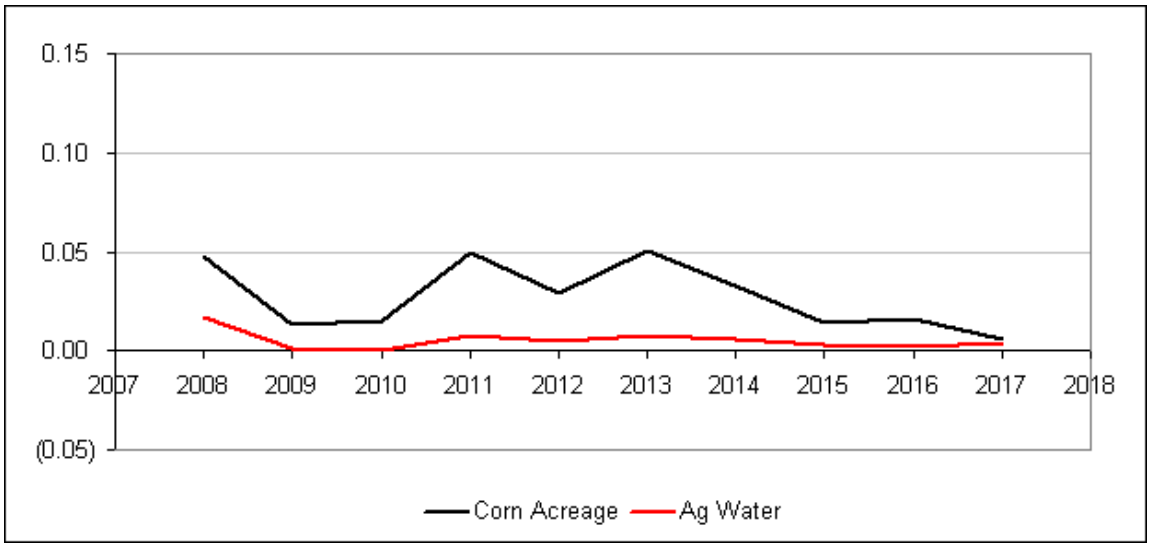

Figure 34. Line Graph Displaying the Relationship between Texas High Plains Annual Percentage Changes in Agricultural Water Usage and Annual Percentage Changes in Corn Acreage

Total Regional Water Usage

Combining total agricultural water usages with simulated forecasts of total water used by all the ethanol facilities in the Texas High Plains, we are able to elicit estimated distributions on total regional changes in agricultural and ethanol related water demands. As a percentage of total (total here is referring to agricultural and ethanol related) water demands in the region, the consumptive use of water by ethanol facilities to produce ethanol is extremely minor. In any given year, ethanol plants in the Texas High Plains are accounting for less than .01% of the regions total water usage. Figure 35 shows the result of combining ethanol production water usage and total regional agricultural water usage for the Texas High Plains, displayed as a fan graph. As expected, total water usage is increasing over the 10 year period. By 2017, water usage has increased by

nearly 200,000 acre-feet; however, this is a relatively small increase relative to the total quantity of water being used. The increase in water usage amounts to a 2% increase when compared to estimates of 2007 agricultural and ethanol water usage. The increase in water usage occurs rather steadily over the time period with the largest annual increase occurring in 2013. The variability remains relatively constant throughout the time period, with a 200 to 300 thousand acre foot window of variability occurring around the average estimates of water usage.

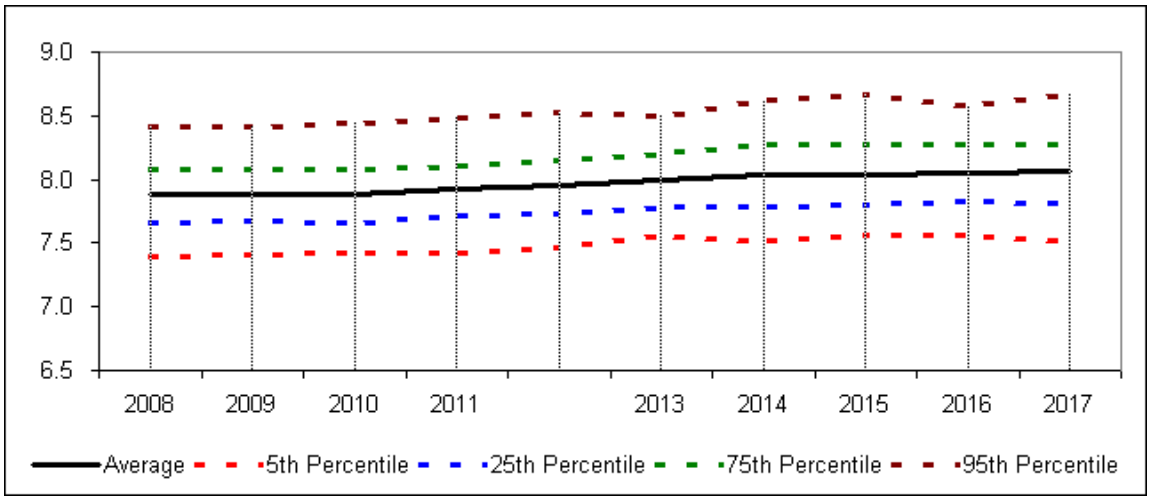

Figure 35. Fan Graph of Total Regional Texas High Plains Agricultural and Ethanol Related Water Usage (in Million Acre-Feet)

To identify the changes in water usage that are directly related to ethanol usage, we would have to be operating in a vacuum where no other outside influences are being taken into consideration. That is not the case in the real world and it is not the case in this model. We've forecasted agricultural input and output prices to generate forecasts

of net returns. From net return forecasts, we applied estimated regional elasticities and finally stochastic ET rates were applied to stochastic acreage forecasts. Each element of that process includes outside forces that cannot be directly attributed to the production of ethanol; however, the point of this research is that ethanol production is a component of these forecasts. Therefore, it is useful to look at the changes in water usage as a means to getting a sense of how ethanol contributes to overall water usage relative to estimates from the base year (2007). Figure 36 shows a comparison of the distributions for regional agricultural water usage and ethanol related water usage. Relative to 2008, the CDF approximation for 2017 shows just a slight shift in the distribution to the right.

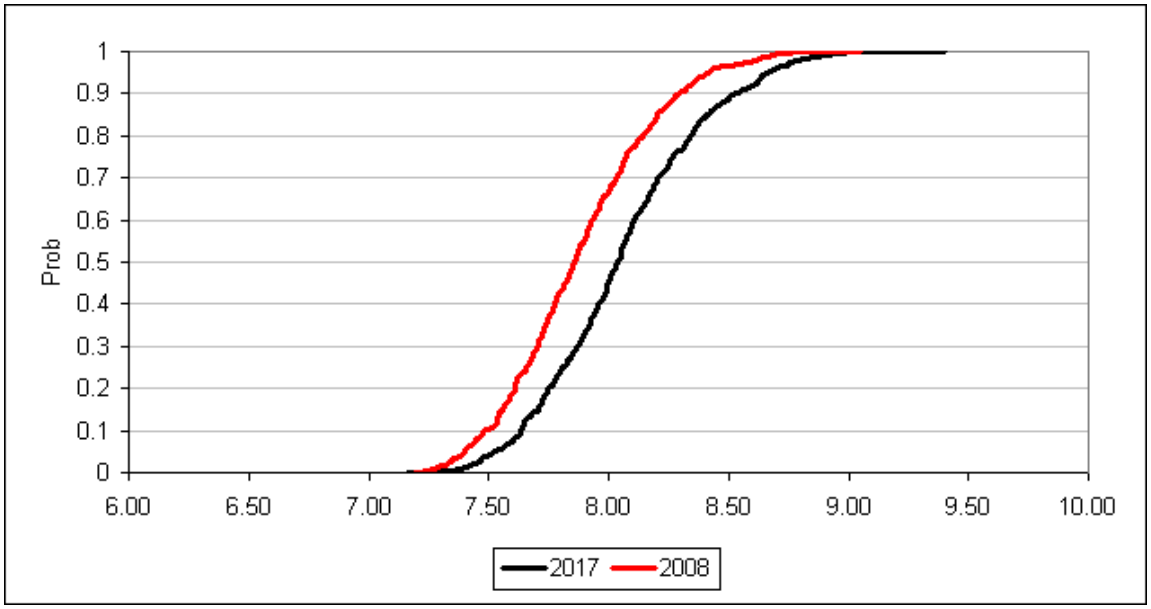

Figure 36. CDF Approximation of Agricultural Water Usage and Ethanol Related Water Usage in the Texas High Plains

The following figure, Figure 37, shows the distribution of percentage changes in water usage in 2017 relative to estimated Texas High Plains water usage in 2007. This distribution takes into account consumptive use of agricultural water by the six analyzed crops along with the consumptive use of water used by the ethanol facilities in the region. As the distribution below shows, there is an 83% chance of having an increase in total consumptive water usage relative to 2007.

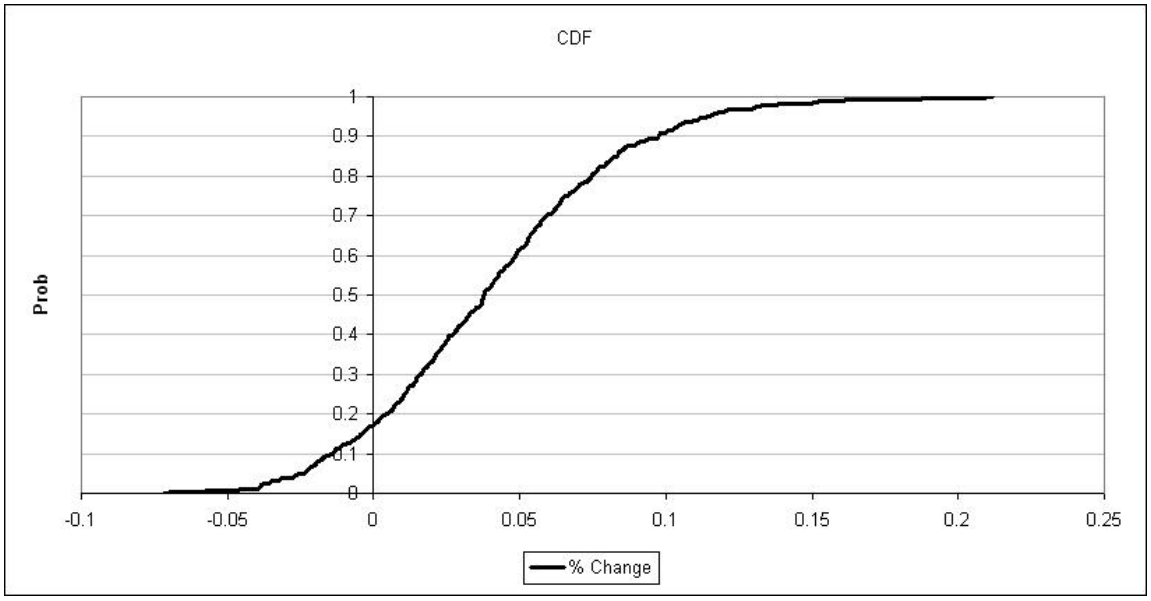

Figure 37. CDF Approximation of the Distribution of Percentage Change in 2017 Total Texas High Plains Regional Agricultural Water Usage and Ethanol Production Water Usage Relative to Estimated 2007 Values

An interesting, however deceptive, way to look at the change in water usage is to compare the consumptive use of water used in the production of corn in 2007 to 2017. This is deceptive, as it fails to account for the water usage that was occurring on the land

prior to being converted into the production of corn, yet a useful means to get a sense of the additional water being devoted to the production of corn. Figure 38 offers a comparison of the distribution for 2017 combined consumptive usage of water for the production of corn and the production of ethanol relative to an estimate of 2007 consumptive water usage for the production of corn and the production of ethanol in the Texas High Plains. In the figure below, the black line represents the estimated consumptive water usage for 2007, while the red line shows a CDF approximation of the distribution for corn and ethanol related water usage in 2017. Clearly the conversion of acreage to corn and the addition of ethanol facilities in the region has resulted in a substantial increase in water usage devoted to those two uses. There is a less than 1% probability of 2017 water usage being less than or equal to 2007 water usage and a 50% probability of using 540,000 more acre-feet of water in 2017 than in 2007.

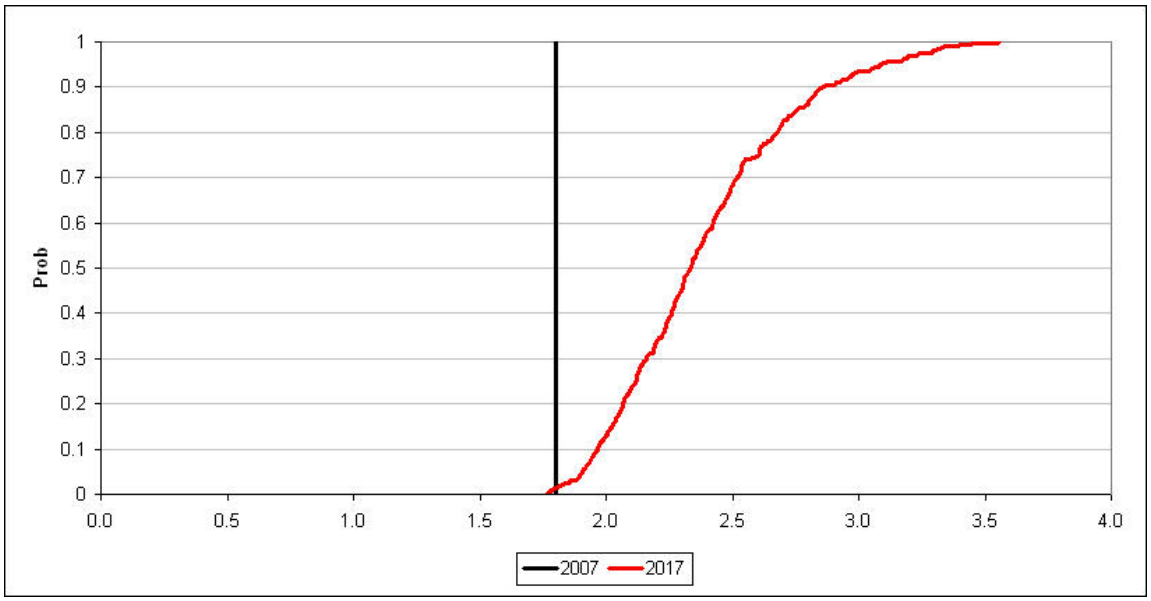

Figure 38. Comparison of Estimated 2007 Corn Water Usage and Ethanol Production Water Usage Relative to the Distribution of 2017 Corn Water Usage and Ethanol Production Water Usage in the Texas High Plains (in Million Acre-feet)

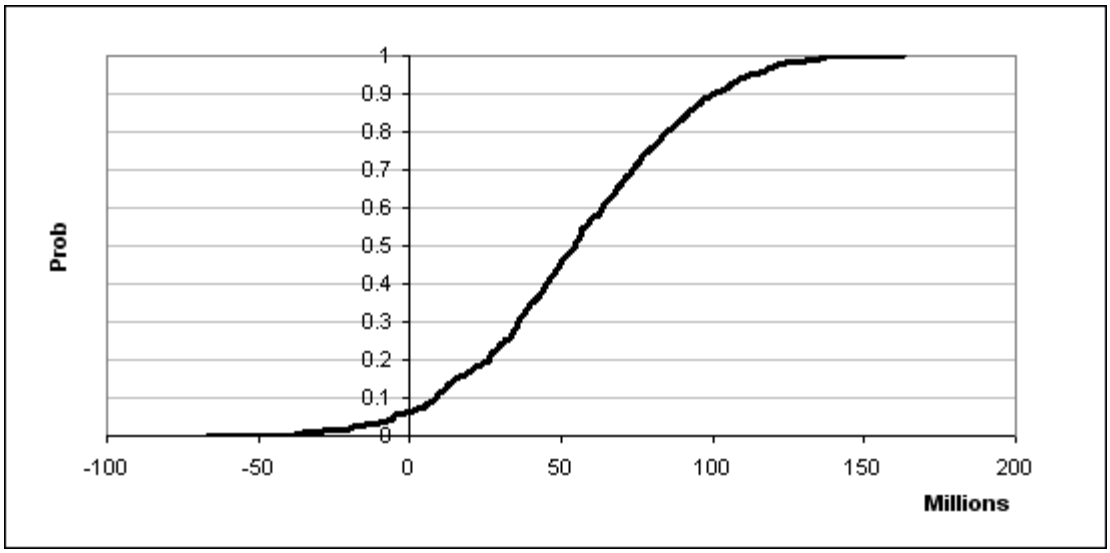

Figure 39. CDF of the Distribution on NPV for an Average Ethanol Plant in Southern Minnesota

Southern Minnesota

Ethanol Plant Simulation Model

An average ethanol facility in Southern Minnesota enjoys a fairly high probability of economic success, significantly higher than the other two regions in this study. The ethanol plant simulation model that was built for this study was run 500 iterations and the resulting distribution on NPV revealed a 94% probability that NPV would be greater than 0. Figure 39 shows the distribution of NPV in millions of dollars. The mean NPV is just over $54 million with the bulk of the distribution (nearly 80%) occurring between $100 million and $10 million.

Annual net cash income is able to tell a more informative story about the ethanol plant's economic situation. Figure 40 shows a fan graph of the distribution of annual net cash income for an average ethanol facility in Southern Minnesota. The most striking thing about this figure is the distinct drop in net cash income that occurs between years 3 and 4. This 43% decline in average net cash income is a result of the state subsidy expiring in that year. In the early years of this plant's lifespan a state subsidy of $0.20 per gallon of ethanol produced was incorporated as a source of income for the plant, however the subsidy is set to expire in 2010. At $0.20 per gallon and average annual production of over 60 million gallons, the state subsidy was contributing more than $12 million in revenues for the facility. However, it appears that without the state subsidy, the ethanol plant would be in a relatively healthy economic situation, as evidenced by the net cash income distributions for years 4 through 10.

On average, years 4 through 10 have net cash income of between $17 and $19 million. In the last three years there is a slight upward trend in average net cash income; however, that trend is also met with additional variability surrounding the forecasts. Year 10 has the highest absolute variability with a standard deviation of $23 million and the second highest level of relative variation (as measured by the coefficient of variation). This increased variation is expected as we are less certain about the distant future relative to the near future. At no point during the analyzed time period does the probability of having a negative net cash income increase beyond 23%, while at the same time the probability of annual net cash income exceeding $60 million ranges between 2% and 9%.

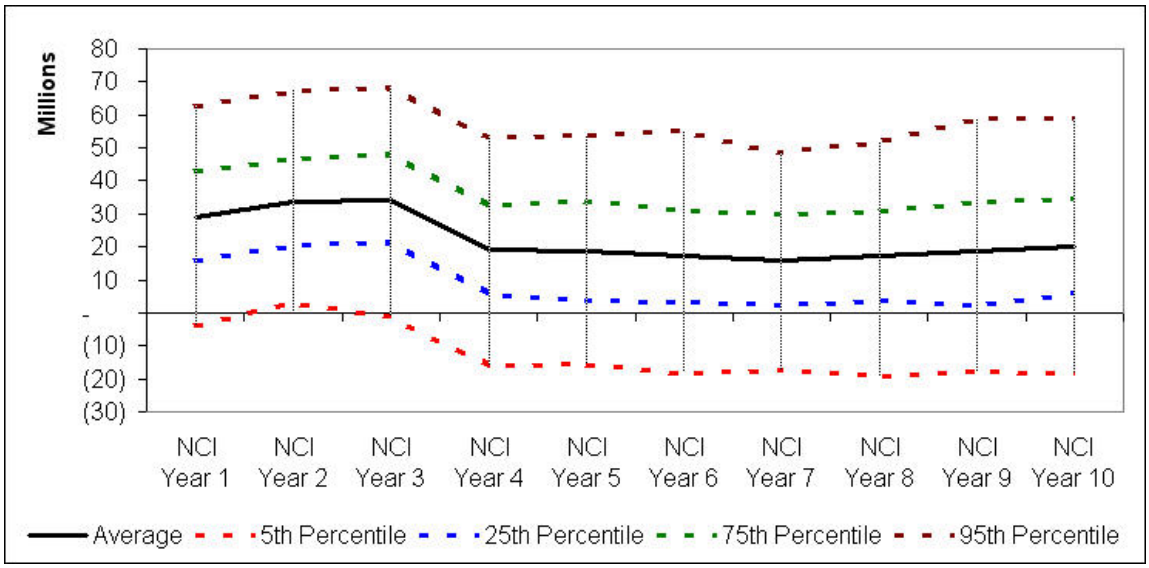

Figure 40. Fan Graph of Annual Net Cash Income for an Average Ethanol Plant in Southern Minnesota

Dissecting the results further, it is useful to look at variable costs and net returns on a per gallon basis. As a result of the inflation rates used on the variable costs of production, average per gallon variable costs steadily increase over the 10 year period. Per gallon revenues experience a drop in year 4 due to the discontinuation of the state subsidy, but in general show an increasing trend. Figure 41 depicts a bar chart comparing annual average per gallon revenues to per gallon costs and shows how the margin between the two (or in this case, per gallon net return) changes over time. Figure 41 does not address the variability that is predicted for net returns per gallon, and in fact, significant variability does exist. Although average net returns are between $0.24 and $0.52 per gallon, there is nearly a 20% probability of having negative net returns per gallon in year 10, up from year 1 in which there was just a 7% probability of having negative net returns per gallon of ethanol produced. The smallest probability of having a negative net return per gallon occurs in years one through three, where the state subsidy is still in effect.

By breaking the per gallon costs by source we are able to better identify the role corn costs are playing in the economic outlook for this Southern Minnesota ethanol plant. Relative to the other two regions of study in this dissertation, Southern Minnesota has the advantage of locally available corn and thus does not have to pay the additional unit costs associated with transporting corn. And, as expected, corn costs make up a smaller proportion of total costs per gallon relative to the other two regions under study. In Southern Minnesota, annual average corn costs can be expected to account for around 50% of total costs per gallon of ethanol in any given year.

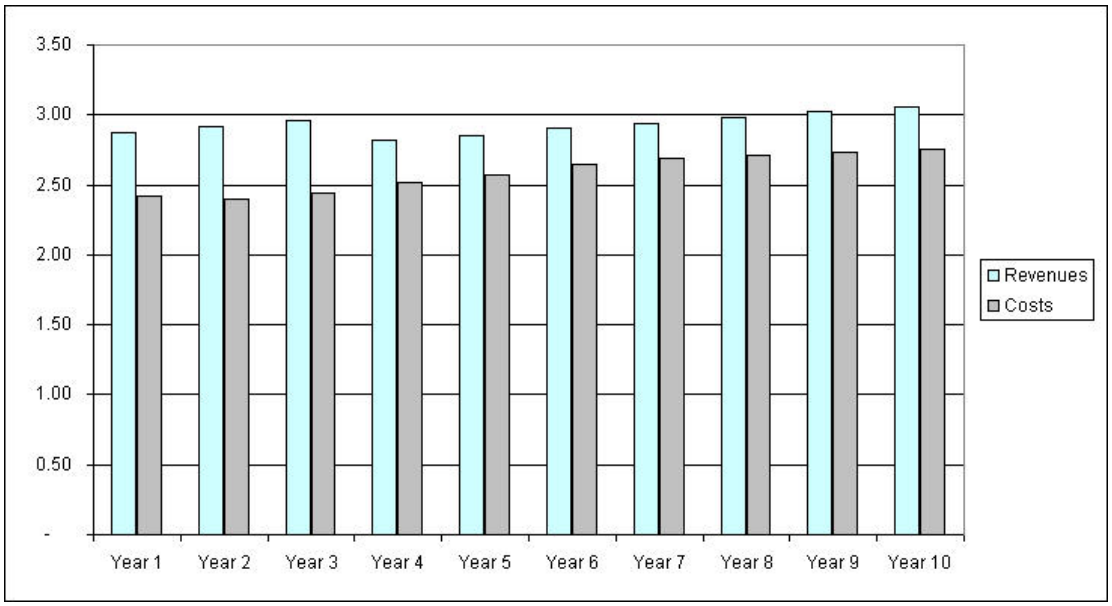

Figure 41. Bar Chart of Forecasted Annual Per Gallon Revenues and Costs for an Average Ethanol Plant in Southern Minnesota

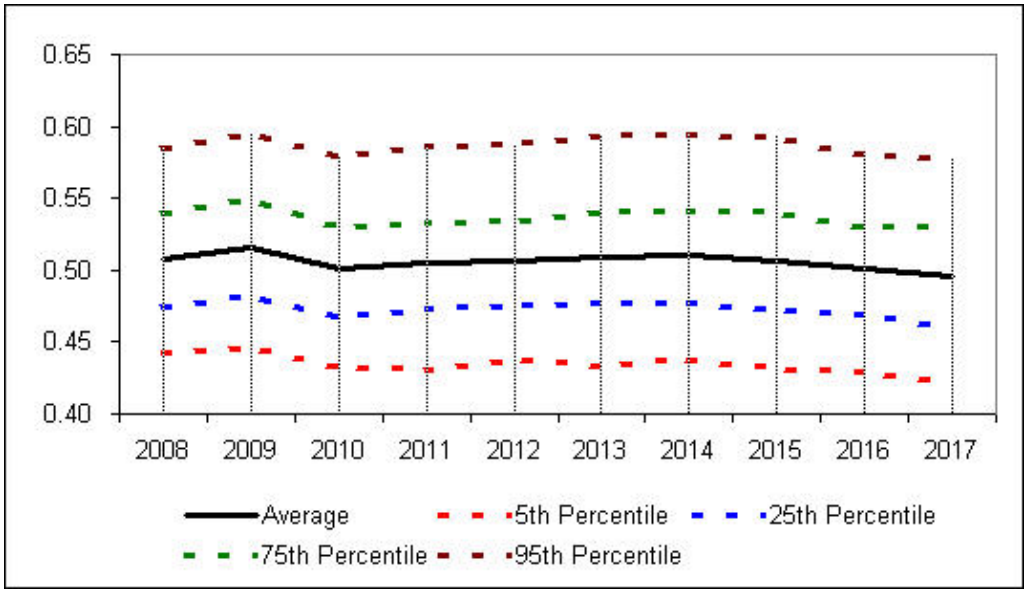

Figure 42. Fan Graph of Per Gallon Corn Costs as a Percentage of Total Costs Per Gallon for an Average Ethanol Plant in Southern Minnesota

Figure 42 shows a fan graph of the relationship between corn costs and total costs on a per gallon basis. Toward the end of the analyzed period, corn costs begin making up a slightly smaller proportion of total costs (note that the scale on the y axis is not set to begin at zero). This occurs as a result of the variable costs inflation factor. In general corn costs make up the largest single component of total costs and attribute the most amount of relative variability to the distribution of corn costs. Financing costs are fairly consistent at contributing approximately 5% to total costs per gallon of ethanol produced in each year, however financing costs do have increasing variability over time.

From a water usage perspective, the average Southern Minnesota ethanol plant uses an average of 3.99 gallons of water per gallon of ethanol. This amounts to more than 257 million gallons annually and more than 2.5 billion gallons of water over the 10 year time period. Annual water usage ranges from 150 to 420 million gallons (between 470 and 1,300 acre-feet). The distribution of 2017 annual water usage by an average ethanol facility is depicted in Figure 43 below.

As expected, the waste water generated by this ethanol facility is not minor. On average, the ethanol facility produces around 76 million gallons of waste water annually, with variability in any given year ranging from 45 and 126 million gallons per year. Figure 44 offers a CDF of the distribution of waste water produced by the Southern Minnesota ethanol facility in 2017. On average, the treatment costs associated with this waste production will be between $3.9 million and $4.4 million. Relative to total costs per gallon of ethanol produced, these treatment costs are relatively small—accounting for 2% to 3% of total per gallon costs.

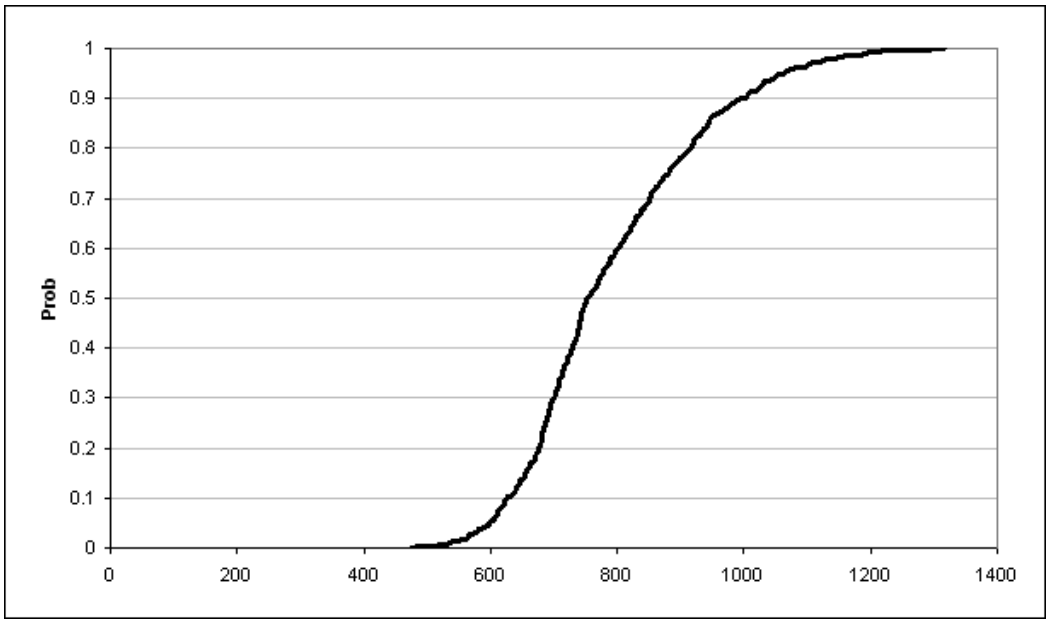

Figure 43. CDF of 2017 Fresh Water Usage by an Average Southern Minnesota Ethanol Plant (in Acre-Feet)

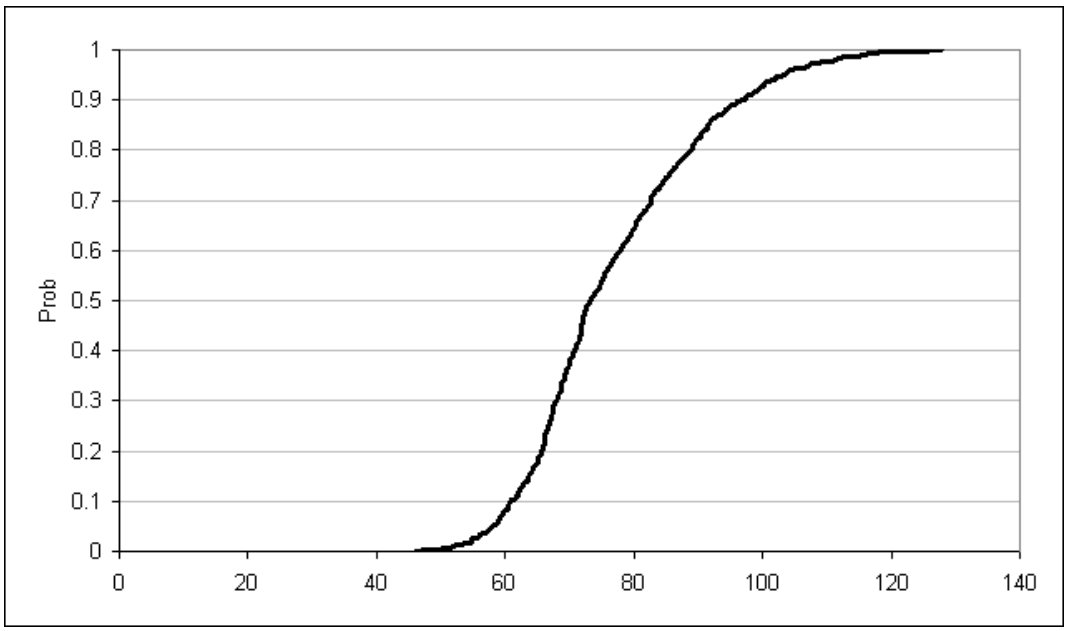

Figure 44. CDF of the Distribution of 2017 Annual Waste Water Produced by an Average Ethanol Plant in Southern Minnesota (in Acre-feet)

Water Price Scenarios

With regard to the price scenarios analyzed and their impact on the economic performance of the Southern Minnesota ethanol plant, the results were as expected. Figure 45 shows a CDF for NPV under each scenario. Scenario 4, which was the scenario that had water price up to $5000 per acre-foot, was the first scenario to show a real impact on NPV for this average Southern Minnesota ethanol plant, reducing the probability of being an economic success down to 79% from where it was originally at 94%. Scenario 3, with water costs at $1000 per acre-foot, has a probability of economic success of 92% and has a mean NPV value just 7% lower than scenario 1 and scenario 2.

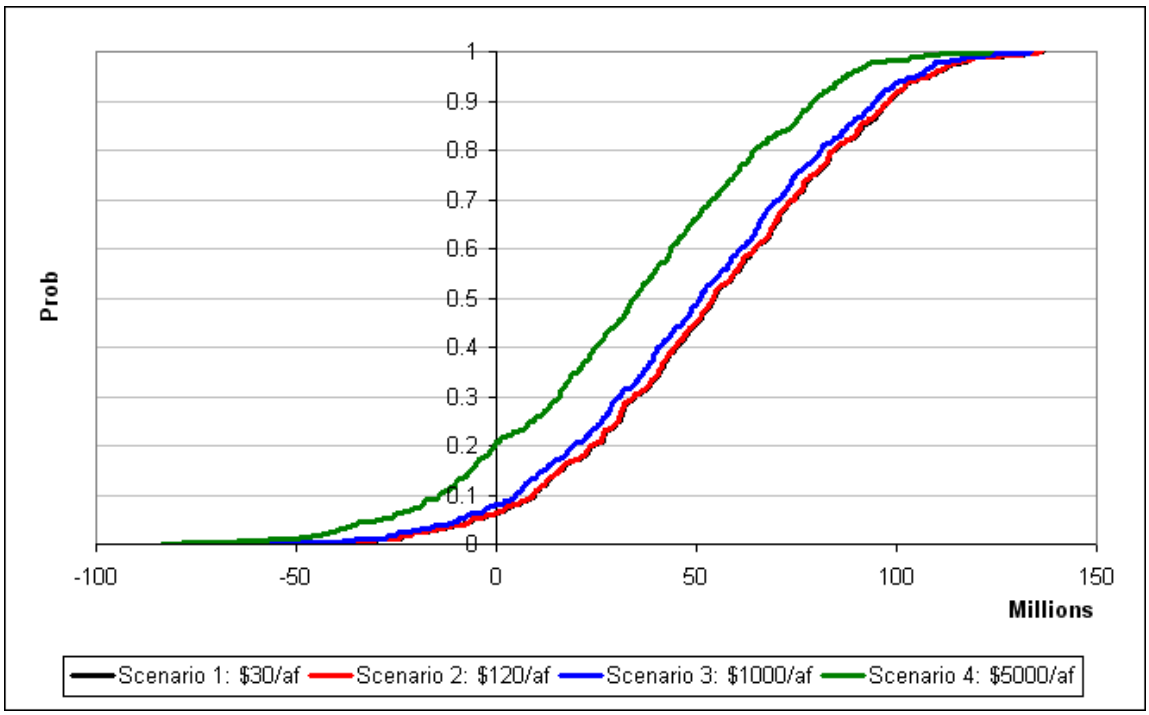

Figure 45. CDF of NPV for Alternative Water Price Scenarios for an Average Ethanol Plant in Southern Minnesota

Using the water price in scenario 1, a sensitivity elasticity for NPV with respect to water price was calculated for an average ethanol plant in Southern Minnesota. As expected, the sensitivity elasticity revealed the marked unresponsiveness between NPV and water price with an elasticity of -0.03. A one percent change in water price will result in a 0.03% decline in net present value. As a measure of comparison a sensitivity elasticity of NPV with respect to corn price in 2009 was calculated. A one percent change in the 2009 corn price deterministic forecast used to develop stochastic corn prices results in a -3.8% change in NPV. Therefore we can conclude that there is a high degree of elasticity between NPV and corn price, while the relationship between NPV and water price is highly inelastic.

Water Reduction Scenarios

By running a scenario analysis on alternative water reduction alternatives for the ethanol facility, we are able to make simple comparisons as to which alternative will have the greatest implications for water usage by the ethanol facility and which alternatives will have the greatest economic impact on the plant. The first thing we are interested in finding out is how much of an impact each water reduction scenario had on the total quantity of fresh water required by the ethanol facility. A comparison of the simulated distributions for each scenario is displayed in Figure 46. As expected, scenarios one through three use less water than our base scenario—each scenario PDF is shown as a shift to the left, relative to the base scenario. Scenarios two and four depict the greatest shift and the greatest average decline in water usage and while they appear to be the same distribution in the figure below, there are differences in water usage under

each scenario with scenario two showing the greatest decline in overall water usage. In the base scenario, 2017 water usage averaged 257 million gallons, while scenarios 2 and 4 offer a nearly 30% decline in average water usage. Scenario 3 resulted in an average of a 14% decline in water usage. From a purely water usage perspective, scenario two would be preferred as it offers the most significant reduction in water usage. Scenario two was the alternative in which waste water was eliminated from the system.

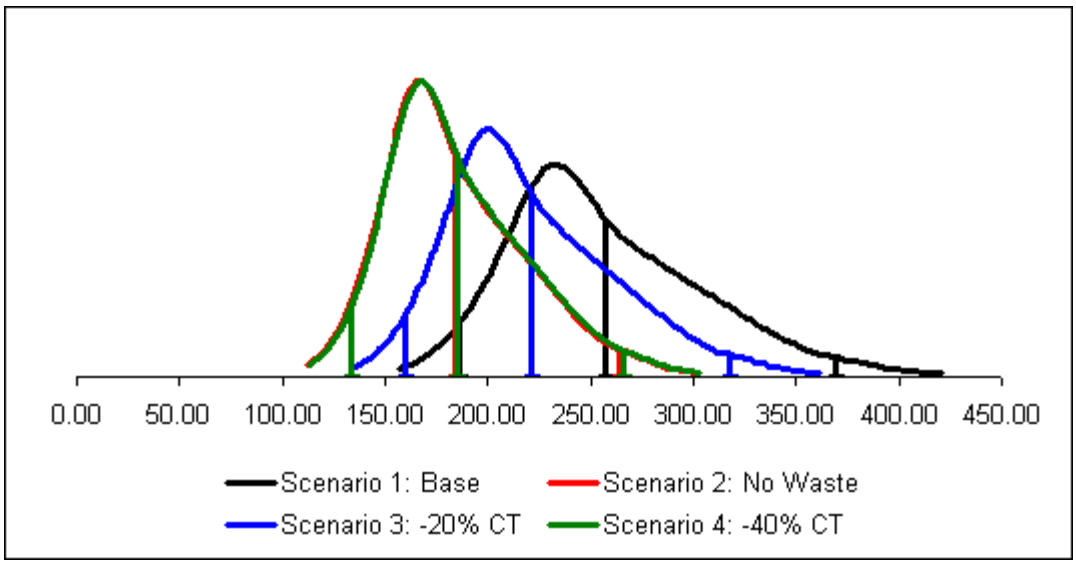

Figure 46. PDF Approximation of the 2017 Distribution of Fresh Water Usage in Million Gallons by Scenario for an Average Ethanol Plant in Southern Minnesota

Waste water is also impacted by the implementation of these water reduction scenarios. Figure 47 shows a comparison of the water reduction scenarios and their impact on the distribution of waste water generated in 2017. Scenario two is not shown as that scenario involved implementing technology such that the waste water stream was completely eliminated. Scenarios three and four both offer a reduction in waste water

usage, as evidenced by the shifts shown in the distributions in Figure 47. Scenario 3 reduces average annual waste water generation by approximately 16% while scenario 4 reduces average annual waste water generation by approximately 33% relative to the base scenario. These average reductions in waste water result in an average expected cost savings on treatment of waste water of nearly $767,000 for scenario three and $1.5 million for scenario 4 in 2017.

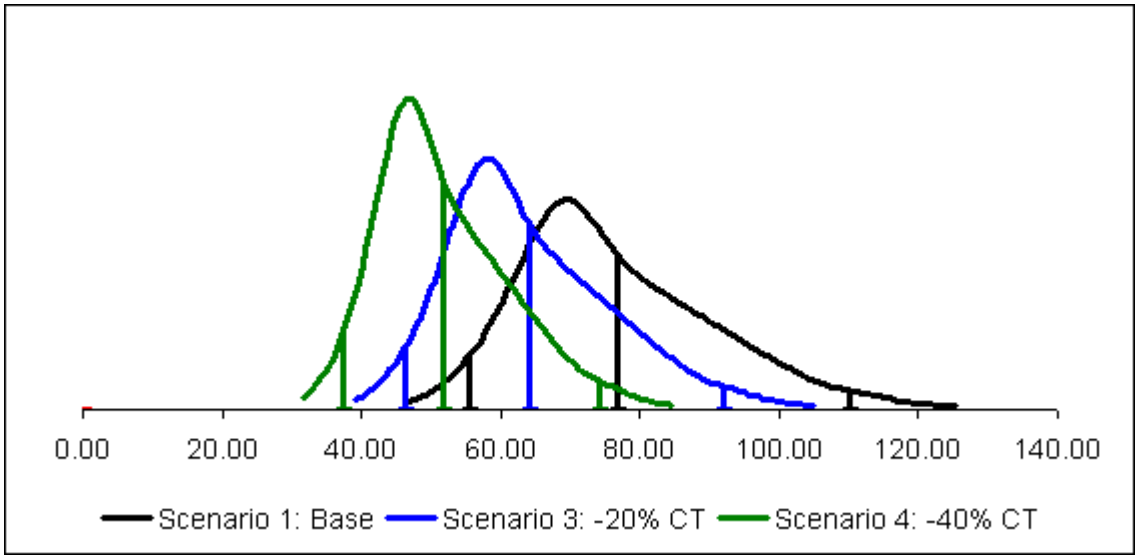

Figure 47. PDF Approximation of 2017 Waste Water Usage by Scenario for an Average Southern Minnesota Ethanol Plant (in Million Gallons)

Without the economic incentive to adopt these water reduction scenarios, there is little hope of an ethanol plant doing so. Despite the sizable capital investment required to get these water reduction scenarios in operation, there appears to be economic benefits to doing so. Scenario two shows the clearest evidence of economic benefits by adopting

the water reduction scenario as shown in Figure 48. By eliminating the waste water generated by the ethanol plant, the facility is able to shift the distribution on their NPV to the right. The shift on the distribution of NPV is of a relatively minor magnitude and the probability of having a negative NPV is reduced by just 2%. Scenarios 3 and 4 cause little noticeable change to the original NPV distribution; however, they offer an improvement relative to the base scenario. Average NPV after the 10 year period is $54 million in the base scenario, $56 million in scenario 3, and $58 million in scenario 4. Scenario 3 does cross the base scenario toward the very bottom of the distribution. Over the majority of the distribution scenario 3 is preferred to the base scenario.

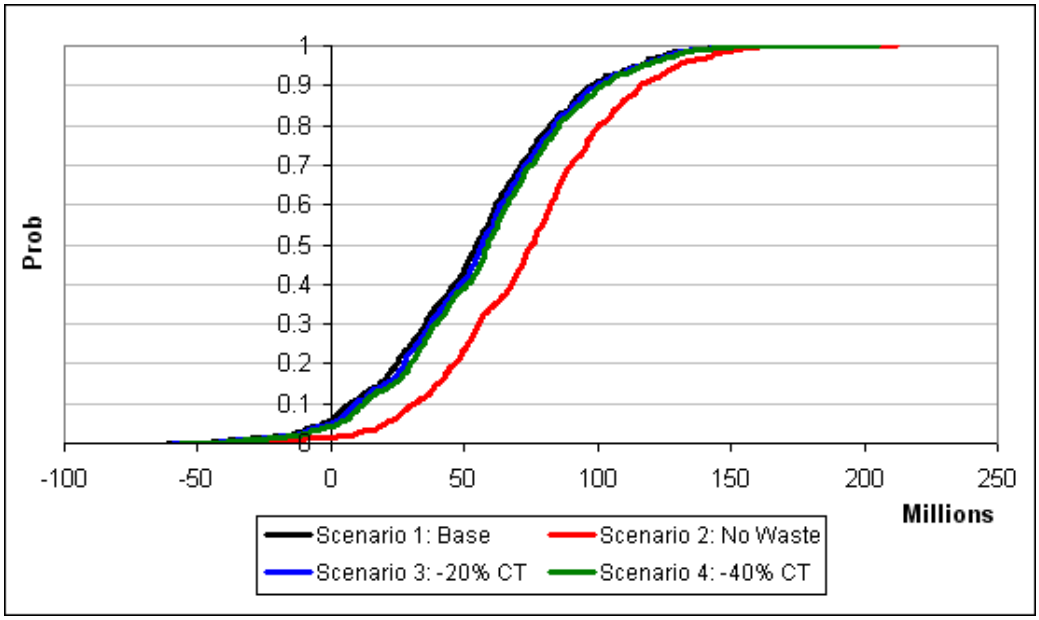

Figure 48. CDF of NPV under Alternative Water Reduction Scenarios for an Average Ethanol Plant in Southern Minnesota (in Millions)

By taking a closer look at the differences between scenarios four and three relative to the base scenario, we can get a better indication of the differences between the distributions. Figure 49 shows a comparison of the differences between NPV in scenario 3 and scenario 4 relative to NPV for the base scenario. Approximately 80% of the time there is less than a $3 million difference between scenario 3 and the base scenario, while that same difference occurs less than 35% of the time between scenario 4 and the base scenario. The fact that both distributions have a portion of the distribution on the negative side of the axis indicates that the base scenario is preferred to each of these scenarios in a small fraction of the time (approximately 4% of the time). From Figure 49 it is clear that the two distributions displayed cross at the left hand tail of the distribution. This is an indication that, relative to the scenario three, scenario four is not preferred at all points along the distribution. It turns out that scenario 3 is preferred relative to scenario 4 approximately 2% of the time.

Because the distributions of NPV with regard to scenarios do cross, we are not able to tell which one would be preferred by a risk adverse individual just by looking at the CDF, therefore making the use of a SERF analysis a necessary tool to determine the preferred alternative. A SERF analysis was run on NPV for each of the analyzed scenarios, Figure 50 shows a SERF chart under a power utility function. Clearly, Scenario two is preferred under all reasonable levels of risk aversion. From the SERF analysis, it is clear that all three scenarios are preferred to the base scenario and that scenario four is preferred to scenario three.

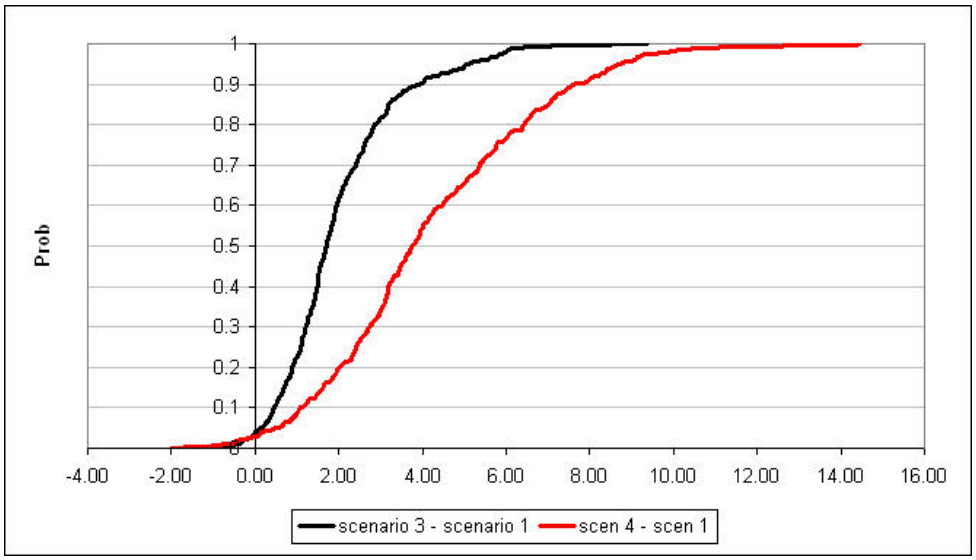

Figure 49. CDF of the Differences between NPV by Scenarios for an Average Southern Minnesota Ethanol Plant (in Millions)

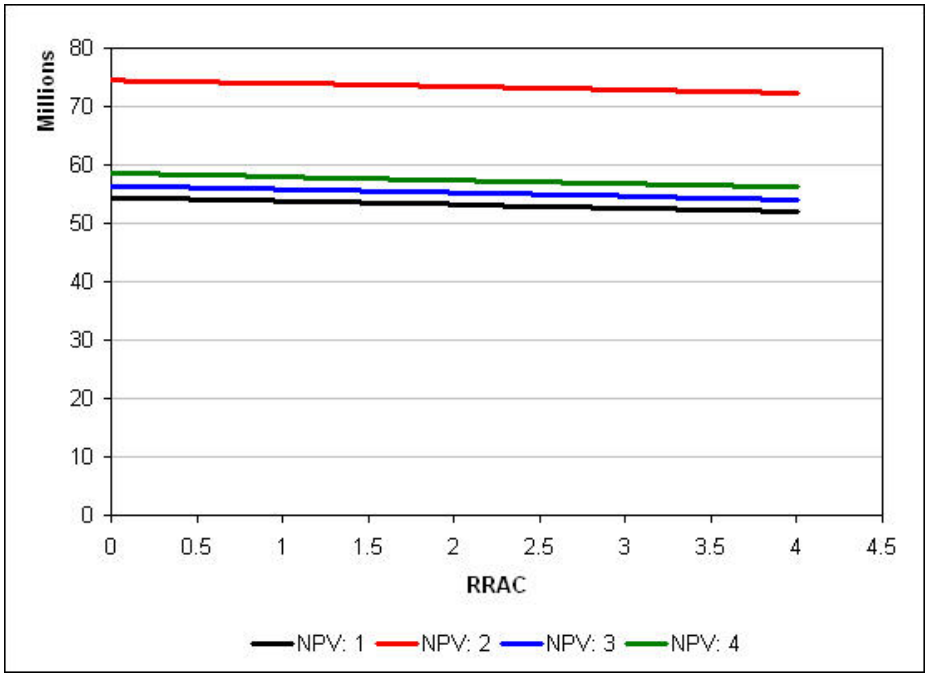

Figure 50. SERF Chart for NPV under Alternative Water Reduction Scenarios for an Average Ethanol Plant in Southern Minnesota

Agricultural Water Usage

Forecasted land use changes in Southern Minnesota are characterized by a 23% increase in planted corn acreage and a decline in the planted acreages of the other 4 crops. Oats and barley experienced the largest percentage decline in planted acreages relative to historical values, whereas soybeans planted acreage was forecasted to have the largest overall decline in planted acreage at approximately 270,000 acres. Corn uses more water per planted acre than the other four crops analyzed in this region, so we would expect to see increases in agricultural water usage as a result of this analysis. The simulated regional agricultural water usage was obtained after having taken stochastic annual ET rates and applying them to stochastic acreage forecasts.

Having simulated agricultural water usage by the 5 analyzed crops in the Southern Minnesota regions over the 10 year period, the results indicate that 2017 average water usage will be approximately 11.7 million acre-feet with variability between 8.6 million and 15.4 million acre-feet. This is in comparison to estimated 2007 water usage of 11.6 million acre-feet. Table 17 shows a comparison of selected years in terms of total planted acreage dedicated to the production of these five crops and estimates of average water usage. As mentioned in the preceding section on results for the Texas High Plains, total agricultural acreage dedicated to the production of these five crops increases during the analyzed time period (amounting to an increase of just over 3%) and thus total water usage needs to be put in context with regard to the area being considered. It should be noted that since the 3% increase in agricultural acreage is being converted from a use other than the production of these 5 crops it is impossible to

identify the water that was previously being demanded for the land use before its conversion to these agricultural uses. Therefore, it should be noted that the change in water usage estimates are likely to be slight overestimates as previous water usage on those 3% of acres are not being considered.

Table 17. Comparison of Southern Minnesota Total Crop Acreage and Agricultural Water Usage

	Historical	*Simulated Means*	
	2007	2008	2017
Total acreage	4,620,100	4,636,286	4,661,362
Total AF water	11,631,584	10,882,497	11,690,583
Avg. AF / Acre	2.52	2.35	2.51
2007 % Δ		(0.07)	(0.00)

Based upon our hypothesis that agricultural water usage would be increasing during the time period in direct response to corn being the most water intensive crop being analyzed in this region and the substantial increase in corn planted acres, these results are somewhat surprising. Closer investigation reveals that estimates of 2007 average ET rates were higher than historical rates, indicating that 2007 was a year in which there were particularly high agricultural water demands for all of the crops being analyzed. If we instead compare water usage to average agricultural water usage during recent history, the results are more in line with our expectations. Historical average water usage intensity occurred at a rate of 2.42 acre-feet per acre as compared to forecasted 2017 water usage intensity of 2.51 acre-feet per acre. This increase in intensity amounts to an increase of nearly 500,000 acre-feet of water.

Figure 51 depicts a PDF approximation of the distributions of forecasted water usage intensity for 2009 and 2017. Over time, as more corn acreage replaces less water intensive crops in this region, the distribution on water usage is pulled to the right, resulting in a higher average water usage intensity, but also the potential for much higher water usage (up to nearly 2.00 acre-feet per acre). The distribution on 2017 water use intensity displays more variability in total consumptive water usage as both tails extend further than the distribution for 2009 water usage. So, as expected, the increasing corn planted acreage will result in increases in crop water demands, however the increases are relatively small.

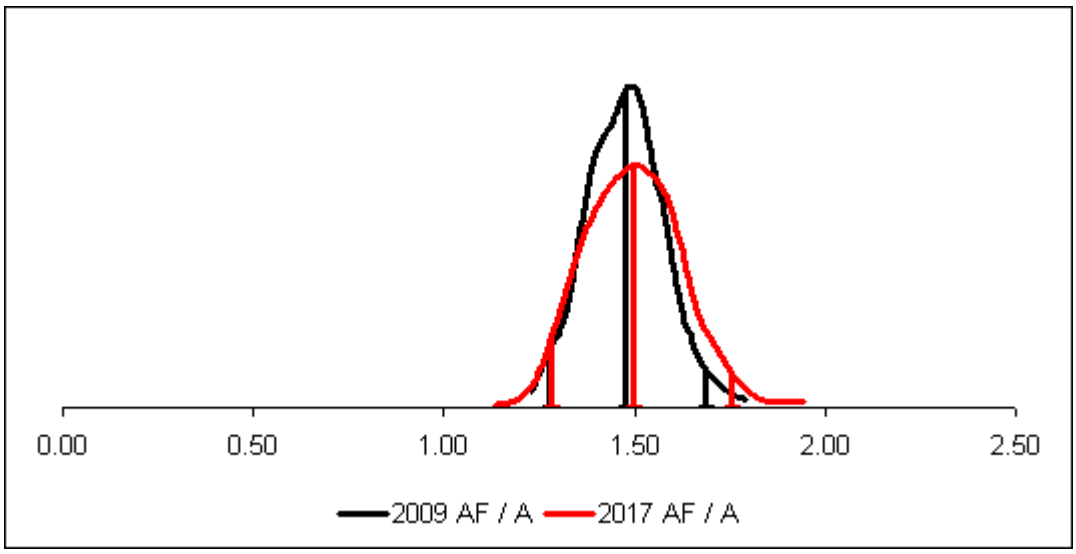

Figure 51. PDF Approximation of Normalized Agricultural Water Usage in Southern Minnesota for Years 2009 and 2017 (in Acre-Feet per Acre)

The change in total water quantity is useful for identifying the potential for water stress after the 10 year period relative to some base period. Figure 52 shows the distribution of the percentage change in annual agricultural water usage dedicated to these five crops in 2017 relative to estimated water usage in 2007. The distribution covers both positive and negative percentage change values and thus we cannot say with certainty that water usage will increase during the time period, in fact there is only a 17% probability that agricultural water usage will have a decline in crop water demands relative to 2007. There is, however, an 80% probability that there will be an increase in crop water demands of up to 98% more than 2007 estimated crop water demands. And on average, 2017 is expected to experience a 4% increase in crop water demands relative to 2007 rates.

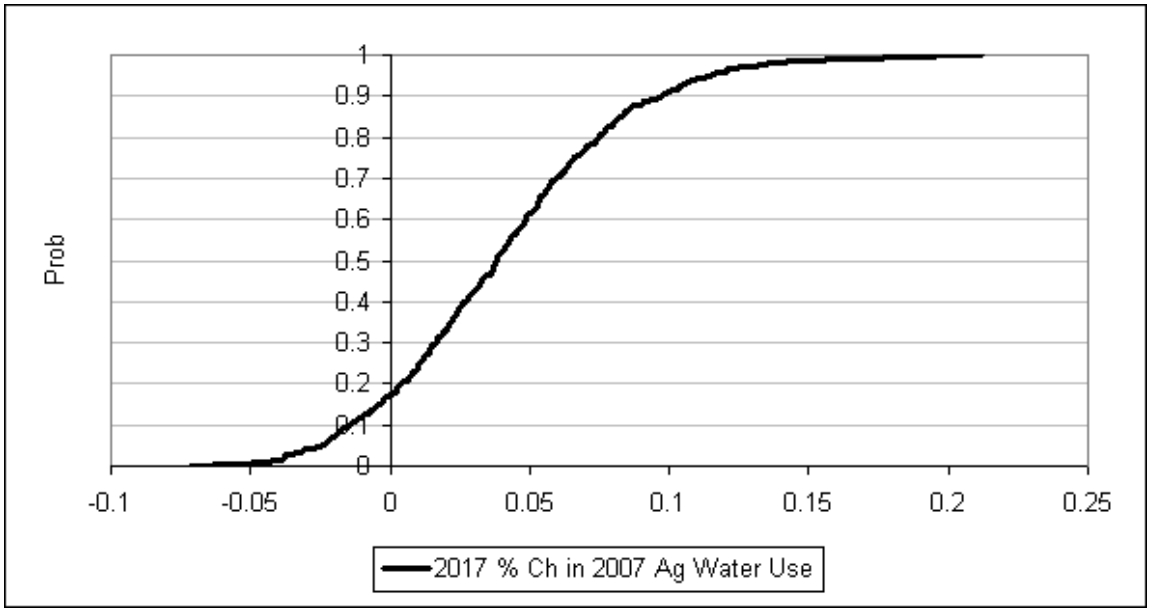

Figure 52. CDF of the Percentage Change in Southern Minnesota Agricultural Water Usage in 2017 Relative to 2007

By looking at the changes in water usage on an annual basis, we can identify years in which there appears to be a potential for water stress. Again, the reader should be reminded that we are only looking at one aspect from a demand side perspective and ultimately the combination of all water supply and water demand factors will determine water stress; however, this serves as a glimpse of how agricultural water use changes may participate as one of those factors. Figure 53 shows a fan graph that illustrates annual percentage changes in crop water requirements by these 5 crops in Southern Minnesota over the 10 year period. On average, each year is marked with just a slight increase from the prior year's water usage. The significant variability around the average annual percentage change indicates that there is nearly an equal probability of experiencing a decline in crop water demands relative to the prior year. Year 4 has the smallest probability of using less water relative to the prior year, at a probability of 47%. By year 10, there is a 30% probability of having a 1% to 10% increase in water use relative to the crop water requirements in year 9.

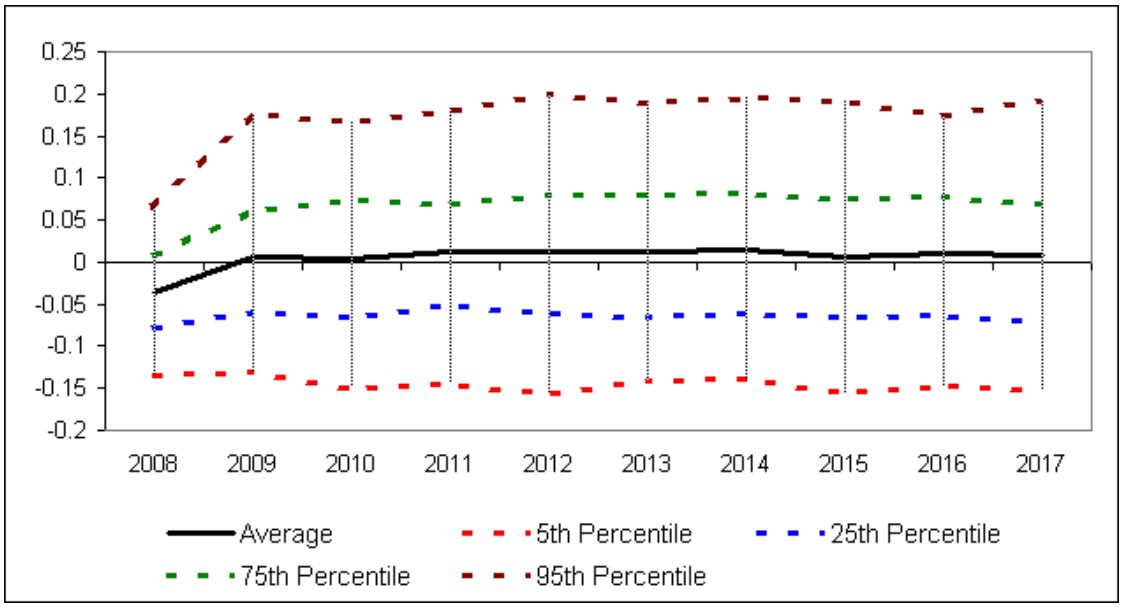

Figure 53. Fan Graph Illustrating Percentage Annual Change in Southern Minnesota Crop Water Demands

Another interesting comparison is to look at the relationship between annual percentage changes in crop water demands relative to annual percentage changes in corn planted acres. Within this region, corn is the crop with the highest water demands, so we expect to see a strong relationship between changes in corn acreage and changes in regional water demands. Figure 54 visually depicts the relationship between annual percentage changes in regional crop water demands and corn planted acreage. As mentioned previously, 2007 had relatively high ET rates, thus causing 2008 to show a relatively significant decline in the annual water usage of 3%. Although the line graph in Figure 54 displays some positive correlation between the two series, the relationship doesn't appear to be as strong as the relationship between crop water usage and corn acreage in the other regions analyzed in this dissertation.

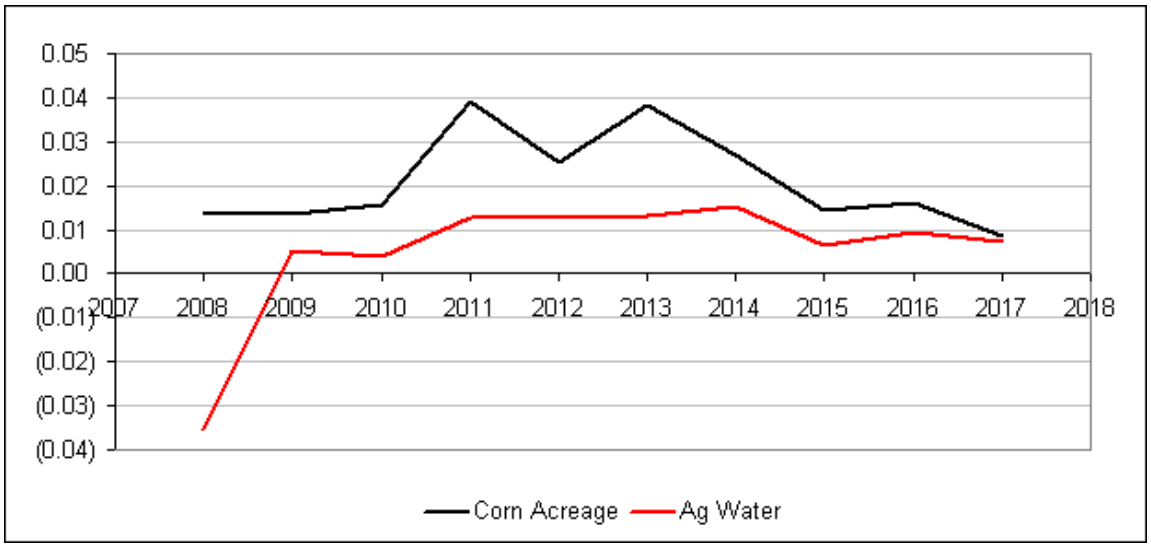

Figure 54. Relationship Between the Annual Percentage Change in Corn Planted Acreage and Agricultural Water Used in Southern Minnesota

The correlation between the two series is 0.42 and is not significant at the 90% level. The other two regions in this study show stronger signs of correlation between changes in corn acreage and changes in crop water demands. One reason that can be used to explain the low degree of correlation between the two series is the closeness of ET rates between corn and soybeans—from the historical data series, soybeans use, on average, just 11% less water than corn in the Southern Minnesota region. As a consequence, replacement of soybean acreage with corn acreage does little to overall crop water demands. By making corn and soybean ET rates stochastic, we are setting up a situation where soybeans could use more water than corn (even though the historical correlation between soybean and corn ET rates was incorporated into the model design). Figure 55 shows a comparison of the distributions of crop water requirements in 2017

for both corn and soybeans and the significant overlapping that occurs within the distributions.

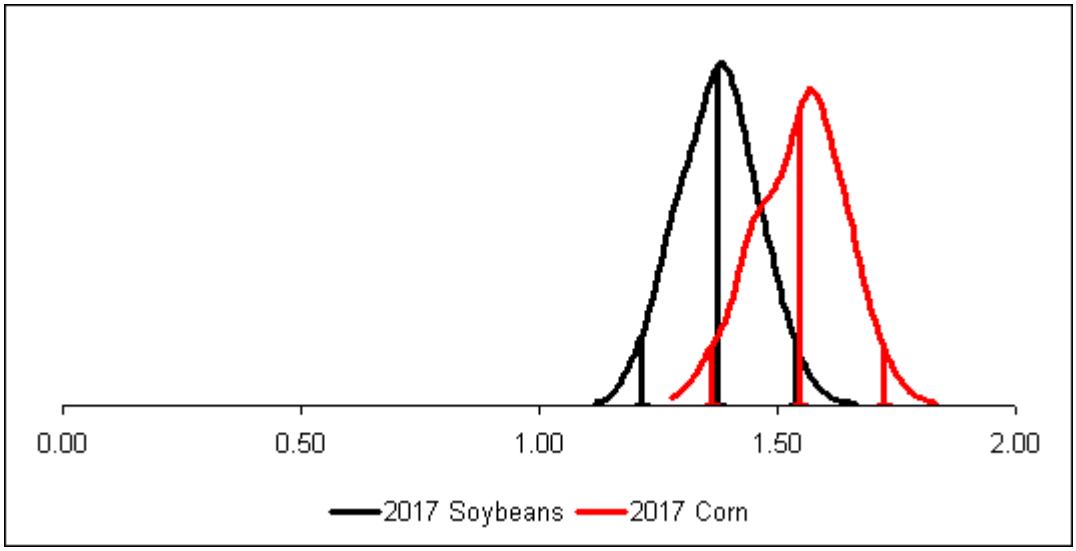

Figure 55. PDF Approximation of 2017 Crop Water Requirements for Corn and Soybeans in Southern Minnesota in Acre-Feet per Acre

Total Regional Water Usage

Incorporating both simulated forecasts of crop water usage along with forecasts of ethanol water usage reveal estimates of what we are referring to total regional water usage. Combining these two sources of water demand provide insight as to the impact of expanding ethanol production and the resulting increase in corn planted acres on local water quantities. From purely a quantity used perspective, Figure 56 displays the forecasted distribution of consumptive water due to changes in agricultural production and ethanol production in Southern Minnesota. A slow, but steady increase in total

water usage is depicted in the figure. By year 10, this increase amounts to a 4% increase in average water usage relative to average water usage in year 1. 2008 water usage was estimated at 11.2 million acre-feet, while 2017 average water usage was forecasted to be 11.7 million acre-feet. The magnitude of the variability surrounding the average forecasts displays a slight trend of approximately 10% that is significant at the 95% level. On average, 50% of the time annual water usage will be within 1 million acre-feet of the simulated mean values for annual water usage.

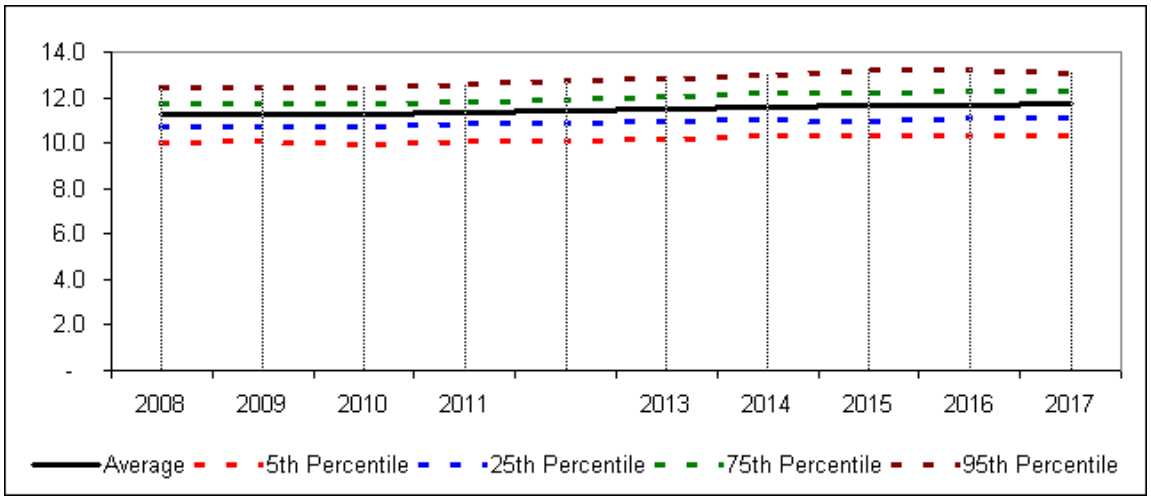

Figure 56. Fan Graph of Total Regional Agricultural and Ethanol Related Water Usage in Southern Minnesota (in Million Acre-Feet)

Of the totals for regional water usage, the proportion that is coming from the production of ethanol is extremely small. Ethanol related water usage will be less than 0.005% in any given year. It has been shown that water usage by ethanol facilities will

increase during the analyzed time period, but the contribution of that water to total regional agricultural and ethanol water usage is extremely minor.

A closer look at the divergence in water usage between 2008 and 2017 is displayed in Figure 57. Agricultural and ethanol water usage in 2017 has a higher mean value, has potential to reach higher maximum values, but also has the potential to reach lower minimum values. The additional uncertainty surrounding total water usage in 2017 has created a situation where the 2017 completely encases the distribution for 2008 water usage, nevertheless we would generally expect higher overall crop and ethanol water demands relative to 2008.

The truth to the statement that everything is relative rings true here as well. Relative to estimated water usage in 2007, the change in water usage is less distinct. Figure 58 depicts the distribution of percentage changes in 2017 agricultural and ethanol water usage while using estimated 2007 consumptive water usage as a base year. Crop water usage in 2007 was high in relation to historical estimates and thus little difference is shown between the mean values for 2017 relative to estimated 2007 values—the average of the 2017 simulated values shows just a 1% increase in total water usage. As shown in Figure 58, there is a 48% probability of using less water in 2017 than in 2007 for agricultural and ethanol related purposes.

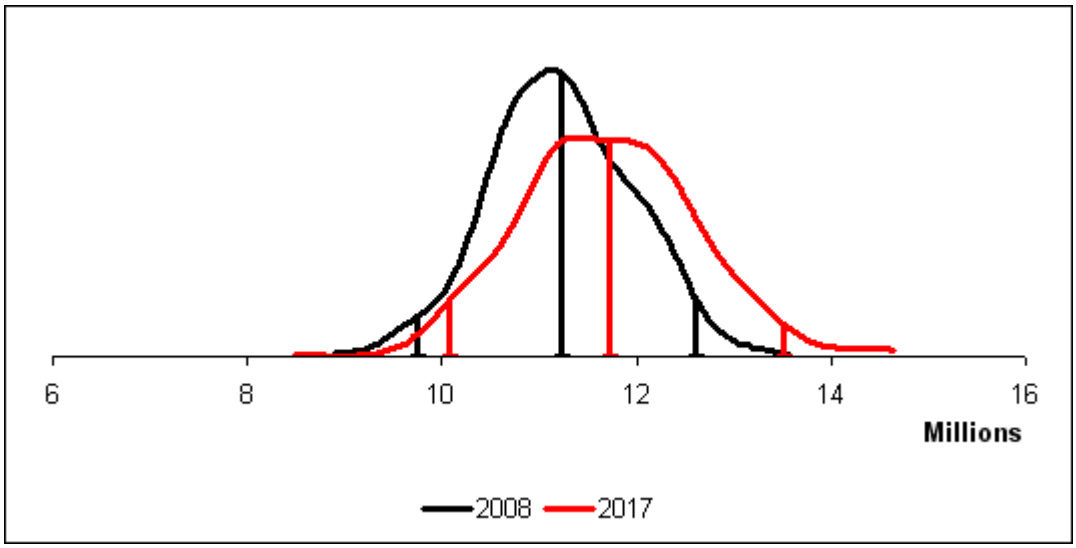

Figure 57. PDF Approximation of the Distribution of Total Southern Minnesota Agricultural and Ethanol Production Consumptively Used Water in 2008 and 2017 (in Million Acre-Feet)

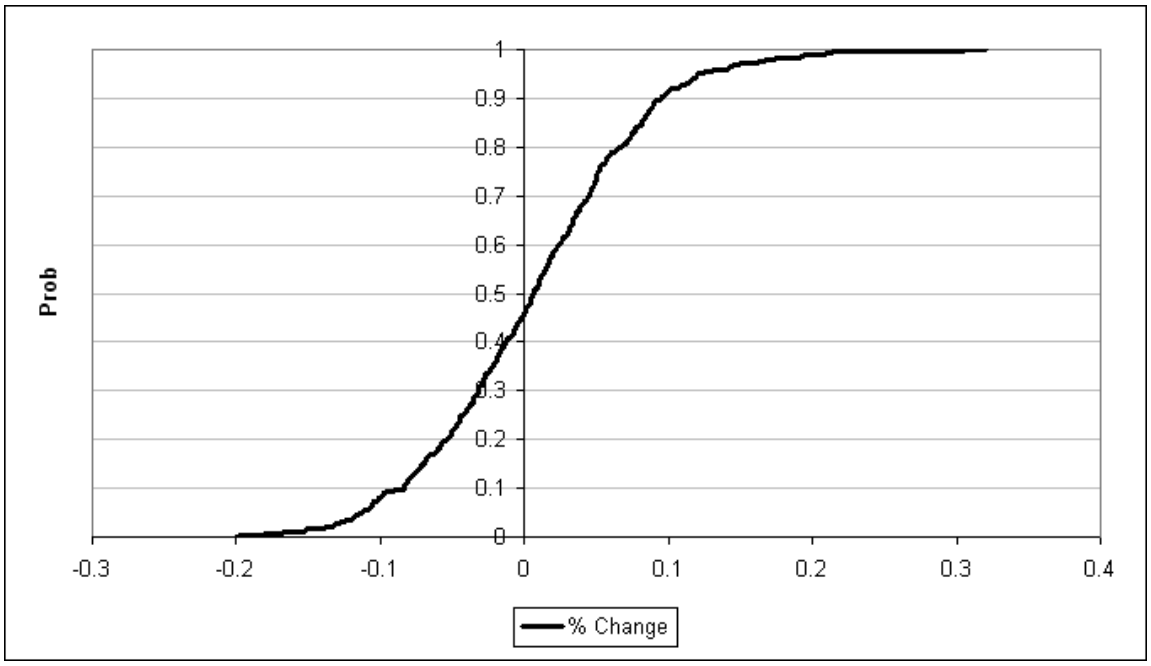

Figure 58. CDF of the Percentage Change in Agricultural and Ethanol Related Water Usage in Southern Minnesota in 2017 Relative to Estimated Water Usage in 2007

California Central Valley

Ethanol Plant Simulation Model

The average California ethanol facility modeled in this study has limited probability of economic success. In expected value, the facility has a net present value after year 2017 of negative $33 million. Upon simulation, the distribution on the net present value iterations shows a 14% chance of economic success (see Figure 59). Although the tails of the distribution extend from a maximum of $69 million to a minimum of -$167 million, approximately 50% of the weight of the distribution lies between positive and negative $40 million. There is a 74% chance that this ethanol facility has negative ending cash reserves after the 10 year time period. In addition, the probability of being solvent is degrading as time goes on. Using a criterion of 75% as the maximum dept to asset ratio for solvency, the probability of being solvent in 2008 is 88%, however by 2017 that probability drops to 34%.

Stepping back to an annual basis, the facility's annual net cash income provides a deeper insight into their financial performance. As Figure 60 illustrates, relative to the amount of potential variability, average net cash income appears to be relatively constant. However, average annual net cash income is varying between a loss of $3 million in year one to a surplus of $7 million in year ten. We also notice an increasing trend in average net cash income during the last three years of simulation.

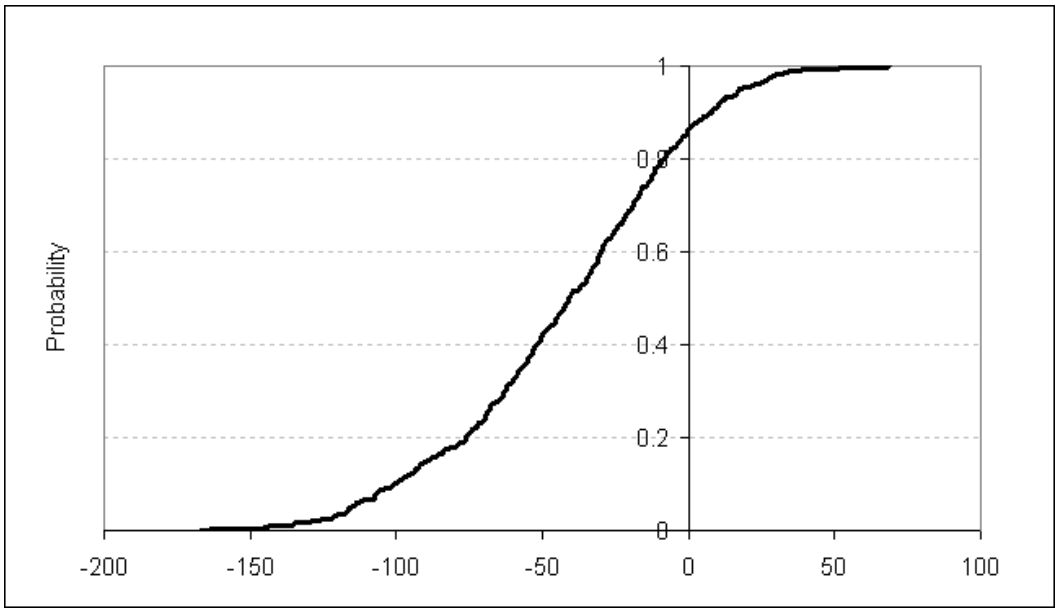

Figure 59. Cumulative Density Function of Net Present Value for a California Central Valley Ethanol Plant

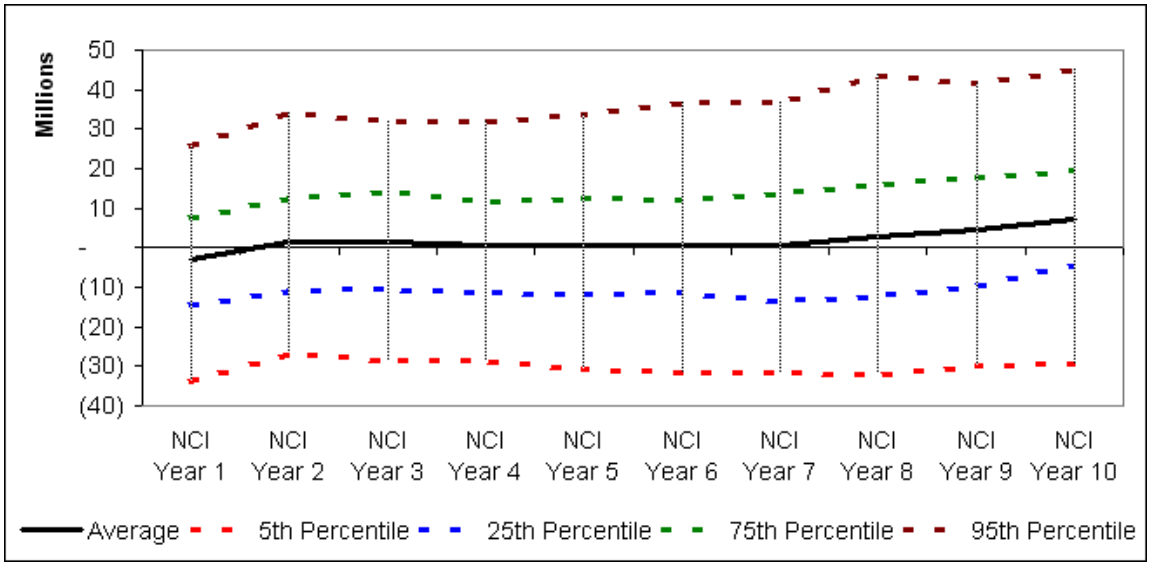

Figure 60. Annual Distribution of Net Cash Income for the California Central Valley Ethanol Plant

The variability associated with net cash income is quite significant. By year ten, the range in which 50% of the observations fall is expanding, yet the range for which 90% of the observations fall is beginning to contract. This dichotomy is evident in Figure 60 as well as Figure 61. And the explanation for this is twofold. The increased variability among the interior portion of the distribution is a function of the use a multivariate empirical distribution of percentage deviations from trend. A percentage deviation from trend design imposes heteroskedasticity, such that we have increasing risk over time (we are less certain about the distant future relative to the near future). On the other hand, decreased variability around the tails suggests that there is slightly more certainty about the extremes. After eight or nine years of operation the ethanol facility should be relatively more stable and less affected by a single event (such as high feedstock input costs or low ethanol prices).

It is difficult to understand the reasons for such an overall poor probability for economic success just by looking at the results information presented thus far. By piecing out economic performance on a per gallon of ethanol basis, it is easier to identify the variability experienced in the simulation results. Figure 61 depicts the variability in net returns per gallon of ethanol produced for the California ethanol facility. Net returns per gallon show an increasing trend during the last three years, peaking in year 2017 with an average net return per gallon of ethanol of $0.14. This increase in net returns is attributed to revenues that are increasing at a rate faster than costs. A simple trend regression on average annual costs and revenues per gallon of ethanol produced revealed a highly significant increasing trend for both variables, however the revenue streams

appear to be increasing by nearly 6% per year, yet costs are increasing at a rate of 4.3% per year.

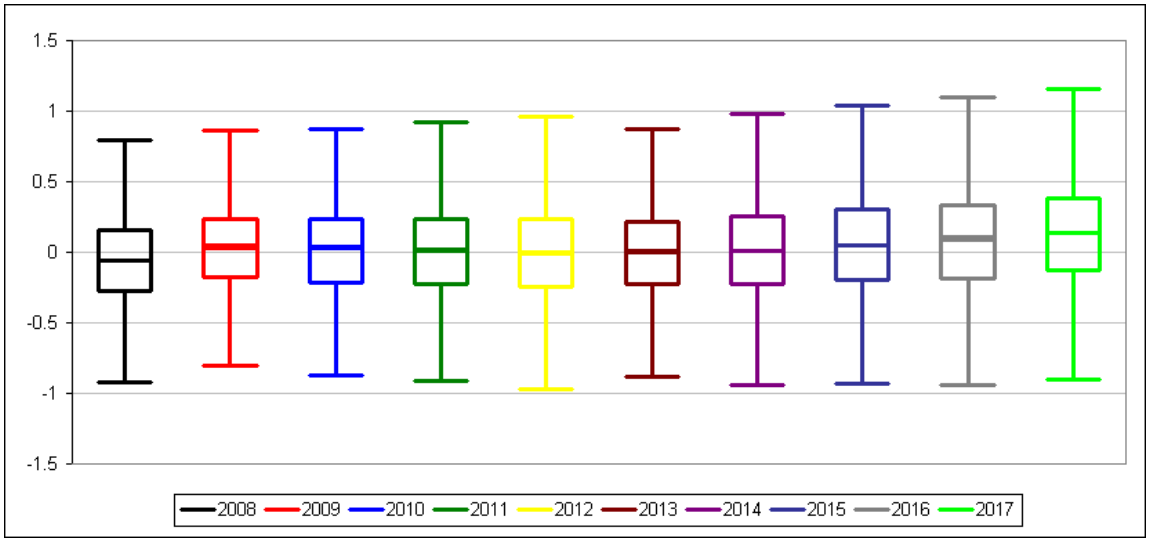

Figure 61. Box Plot of Forecasted Annual Net Returns per Gallon of Ethanol Produced for the Average California Central Valley Ethanol Plant

Ethanol production costs are largely made up by the cost of corn. On average, in any given year corn costs can be expected to account for between 53% and 55% of corn costs per gallon of ethanol. The distribution on corn costs per gallon of ethanol is relatively tightly dispersed, as corn costs will make up between 50% and 60% of 2008 production costs per gallon approximately 90% of the time. There is a slight increase in the variability over time, by 2017 90% of the time corn costs make up between 46% and 60% of productions costs per gallon of ethanol. On a percentage basis, all other variable costs provide a relatively constant contribution to total production costs per gallon of

ethanol produced. The "other variable cost" category as used in this context is simply an aggregation of all variable costs other than the cost of the corn feedstock. All other variable costs provide approximately 39% of per gallon production costs in any given year. Financing costs can be expected to make up between 6% and 8% of total expenses per gallon of ethanol production with an increasing amount of variability over time. Figure 62 depicts the distribution for the three expense categories as a percentage of per gallon ethanol production costs in 2017.

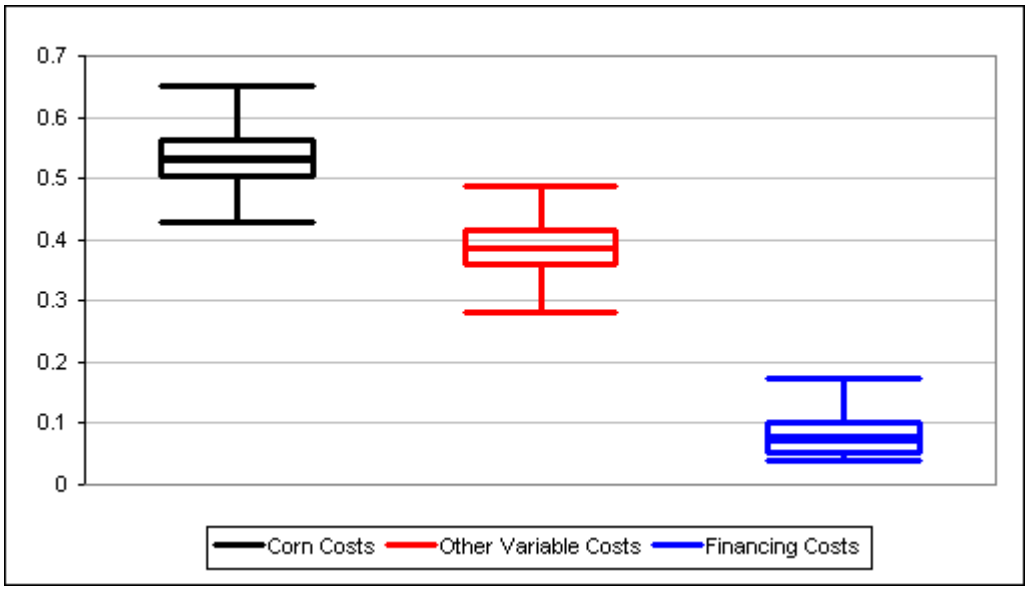

Figure 62. 2017 Ethanol Production Costs by Type of Cost as a Percentage of Total Production Costs Per Gallon of Ethanol Produced in the Central Valley of California

Overall, the California Central Valley ethanol facility being modeled has a poor outlook for economic success. Relative to the simulation results for the other regions, the California plant is competing with higher corn prices, higher energy costs, increased

permitting costs, and a lower availability of local corn supplies, all of which are contributors to the relatively poor performance.

In terms of consumptive water use by the average ethanol plant in California, our results show an average of 3.99 gallons of water per gallon of ethanol produced. Annual fresh water use ranges from 163 to 455 million gallons (500 to 1,400 acre-feet) and remains constant from year to year. The distribution of 2017 fresh water usage by an average California Central Valley ethanol facility in acre-feet per year is shown in Figure 63. Over the 10 year production period this amounts to an average of 2.76 billion gallons (8.5 thousand acre-feet) of water per facility.

Waste water generated from the ethanol facility would amount to an annual average of 63 million gallons, with variability between 36 and 104 million gallons per year. Figure 64 shows the distribution of the waste water produced by the ethanol facility in 2017. The treatment costs associated with the waste water being produced are estimated to be between on average between $2.7 and $3.1 million per year. The costs associated with treating the waste water may provide the incentive to adopt technology such that waste streams are eliminated. This concept will be explored further as we move into the results of our waste water reduction strategies.

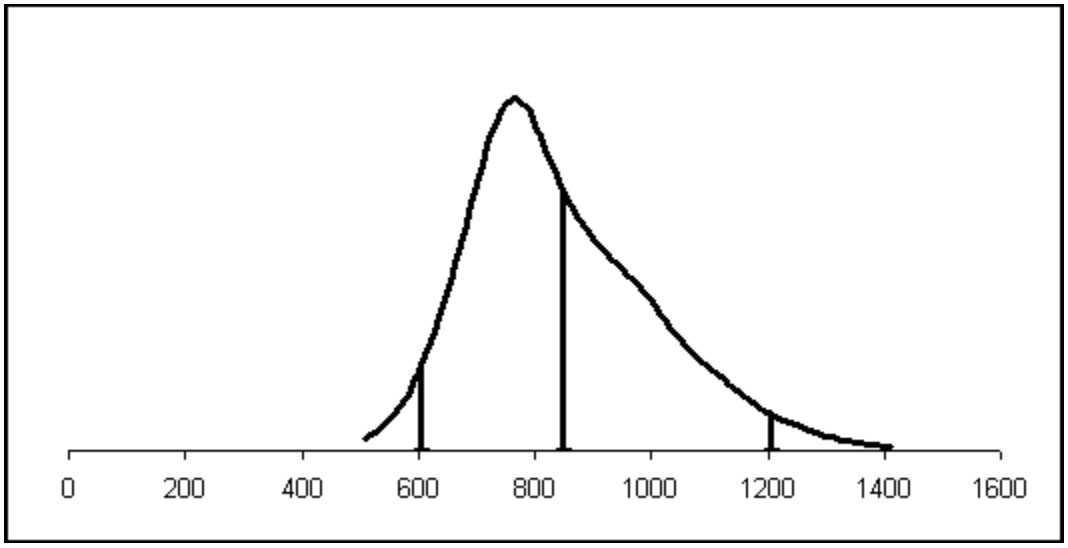

Figure 63. PDF Approximation of 2017 Total Fresh Water Usage by an Average California Central Valley Ethanol Plant (in Acre-Feet)

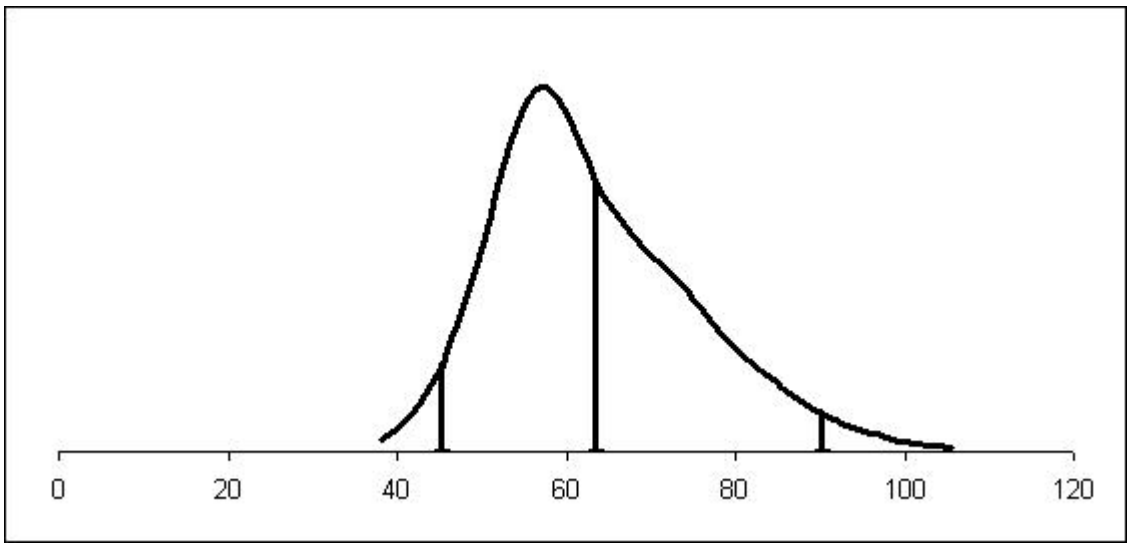

Figure 64. PDF Approximation of the Distribution of 2017 Annual Waste Water Produced by an Average California Central Valley Ethanol Plant (in Million Gallons)

Water Price Scenarios

The distributions of NPV under the alternative scenarios are shown in Figure 65. For an ethanol plant that already has a fairly bleak economic outlook, the additional cost of water doesn't make the situation any better. However, water prices of $30 and $120 do little to change the overall outcome, as the probability of economic success for scenario 1 and scenario 2 is 14% in both cases. With water costs of $1000, scenario 3 has a 13% chance of being considered an economic success and if the ethanol facility had to encounter water costs of $5000 per acre-foot the probability of being an economic success would drop down to just 4%. Under scenario 4 the mean NPV is a loss of $66 million, relative to the loss of $44 million in the case of scenario 1 and scenario 2.

For this ethanol plant in California, a sensitivity elasticity for NPV with respect to water price was calculated using the water price established in scenario 1. As expected, the sensitivity elasticity revealed the marked unresponsiveness between NPV and water price with an elasticity of -0.03. A one percent change in water price will result in a 0.03% decline in net present value. As a measure of comparison, a sensitivity elasticity of NPV with respect to corn price in 2009 was calculated. Stochastic corn price is built off of deterministic forecasts. The sensitivity elasticity was calculated by changing the deterministic forecasts of 2009 corn prices and measuring the resultant change in NPV. The results show NPV to be highly sensitive to corn prices, as a 1% change in 2009 corn price results in a 3.7% decline in NPV. This is in stark contrast to the relative insensitivity of NPV to changes in water prices.

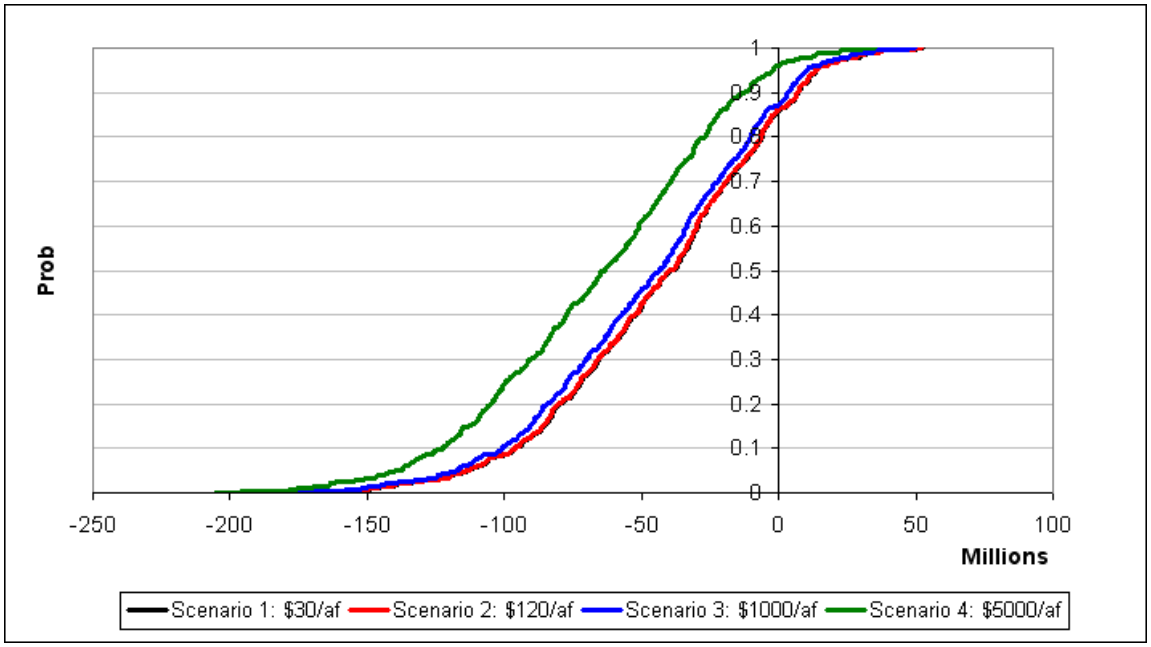

Figure 65. CDF of NPV for Alternative Water Price Scenarios for an Average Ethanol Plant in the California Central Valley

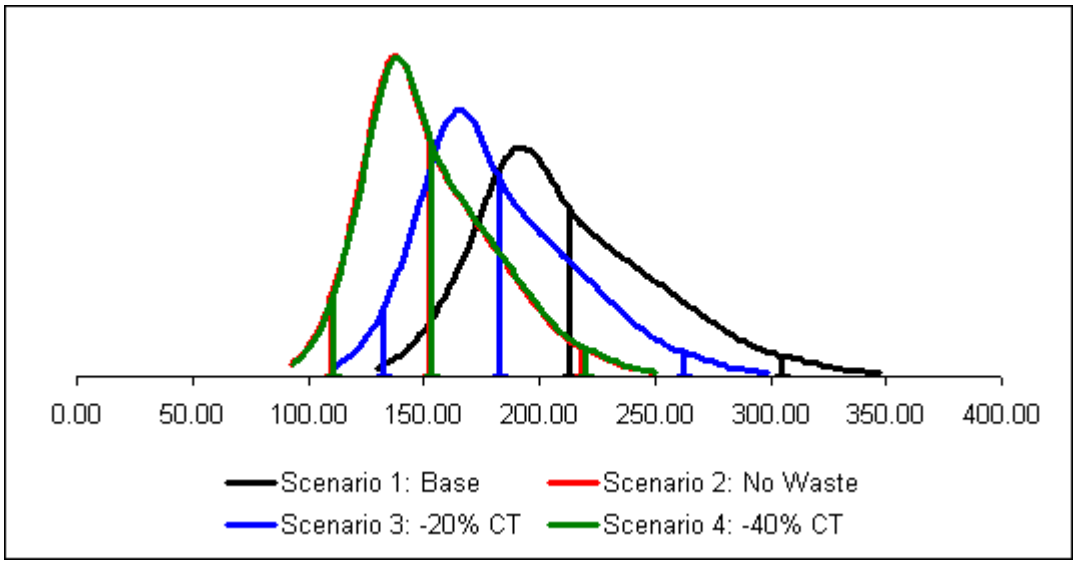

Figure 66. PDF Approximations of 2017 Fresh Water Usage in Million Gallons by Scenario for an Average Ethanol Plant in the California Central Valley

Water Reduction Scenarios

Implementation of a water reduction strategy would obviously reduce the fresh water used by this ethanol facility, but the question is how much of a total reduction it would mean to water consumption and what would it mean to the economic performance of the facility. Through the use of scenario analysis, three different strategies for implementing technology in which the facilities' requirements for fresh water are reduced were analyzed. Scenario one is the base scenario in which existing technologies are employed, scenario two reduces the plant to a zero waste stream plant, while scenarios three and four reduce the water use in the cooling tower by 40% and 60%, respectively. Upon implementation of each of these strategies, consumptive use of fresh water is reduced in the plant. On average 2017 water use would be reduced by approximately 28% with the implementation of scenarios 2 and 4, while scenario 3 reduces total water use by 14%. Figure 66 shows the distribution of the 2017 water usage in millions of gallons for an average ethanol plant in the California Central Valley by water reduction scenario. Scenario 4, which is a reduction of cooling tower water by 40%, and scenario 2, where waste water usage is reduced to nothing, are almost identical in terms of their water usage distributions. All four scenarios present similar distributions on the use of fresh water; they simply impose varying shifts to the distribution of fresh water use.

Total waste water used varies as a result of each water reduction scenario. The simulation results showing these variations by PDF approximations for an average plant in 2017 are presented in Figure 67. Scenario 2 does not show up on the figure by design, as scenario 2 represents a situation where technologies have been implemented that allow for the elimination of waste water streams. Scenario 2 aside, the remaining three scenarios display significant variability in the waste water that is produced. Scenario 4 shows the largest reduction in waste water, reducing average 2017 waste water by 37%, with annual 2017 waste water generation at 42 million gallons, down from 63 million gallons. This reduction in waste water usage corresponds to a cost savings for the ethanol plant of more than $1.1 million, assuming average 2017 sewage treatment costs. Scenario 3 indicates an average decline in waste water generation of 16%, with average 2017 waste water usage at 53 million gallons. The associated cost savings of this savings in waste water is more than $590,000, assuming average 2017 water treatment costs.

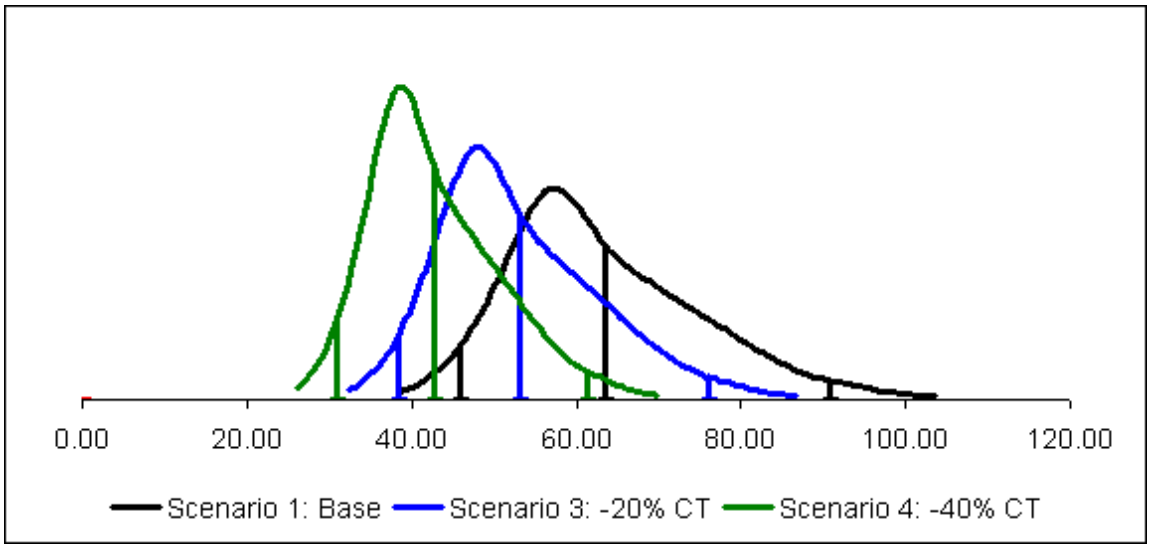

Figure 67. PDF Approximations of 2017 Waste Water Usage in Million Gallons by Scenario for an Average Ethanol Plant in the California Central Valley

What role do the changes in water usage have on the ethanol plant's economic viability? Simulation of net present value under alternative reveals the impact of these water reduction strategies on the overall economic performance of the ethanol facility. Scenario 2, with its elimination of waste water treatment costs shows the most significant improvement in economic performance for the plant. Although still operating at a loss, scenario 2 provides a slight improvement in the probability of economic success at 30%, relative to the 14% chance of economic success in the base scenario. Thus, despite the cost of implementing a zero waste system, which was hypothesized to be $2 million, the cost savings is more than recovered.

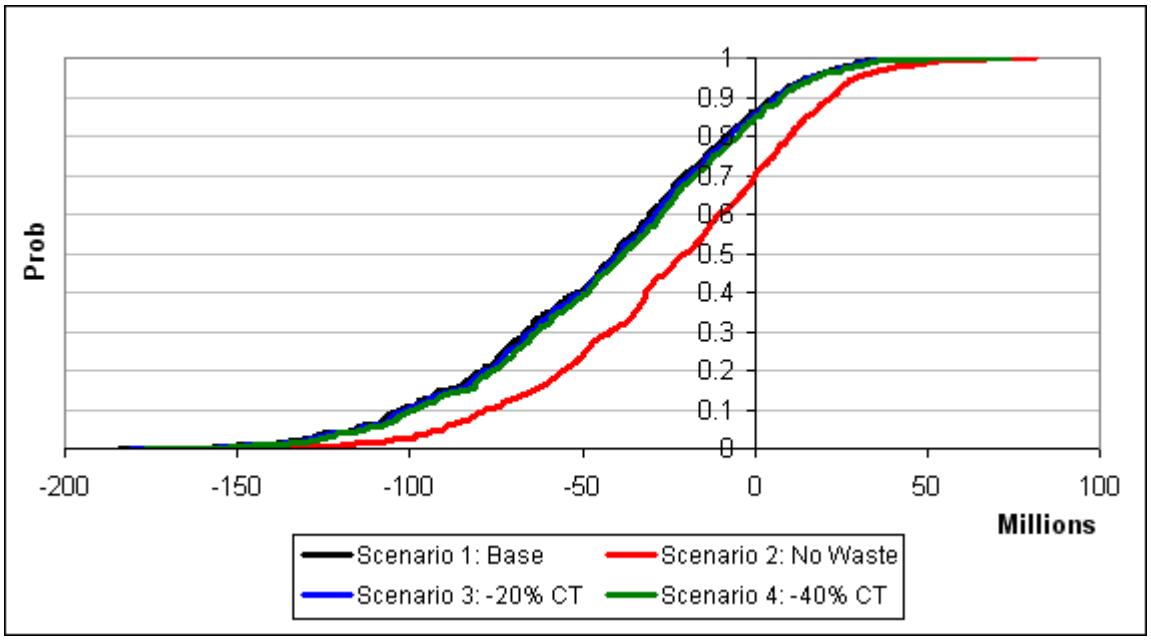

Figure 68. CDF of 2008-2017 NPV Under Alternative Water Reduction Scenarios for an Average Ethanol Plant in the California Central Valley

Scenario 2 also has a significant increase in the potential variability. As a percentage of the mean value, scenario 2's minimum observed NPV is significantly lower than the minimum NPV values observed in the remaining three scenarios as a percentage of their mean values. From a shear numerical perspective, scenario 2's minimum NPV is not as low as those of the alternative scenarios, but as a percentage of the mean value, there is quite a difference. When other variables are not working in the ethanol plant's favor, water reduction strategies make little impact on the economic performance of the plant. The reverse is true at the other end of the spectrum. However, within the middle ranges of the distribution, the economic gains from eliminating waste water streams are proportionally more significant. In Figure 68 this concept is displayed

by the varying horizontal distance between the NPV line for scenario 2 and the NPV lines for the other scenarios.

As Figure 68 shows, there are little observed differences between scenarios 1, 3, and 4. Scenarios 3 and 4, designed to reduce cooling tower water, resulted in a decreased amount of fresh water usage and waste water generation, however these reductions did not generate noticeable differences in the distribution of net present value. However, upon closer inspection, there are differences in NPV between those scenarios. By subtracting NPV in scenarios 3 and 4 from NPV in scenario 1 a distribution of those differences is obtained.

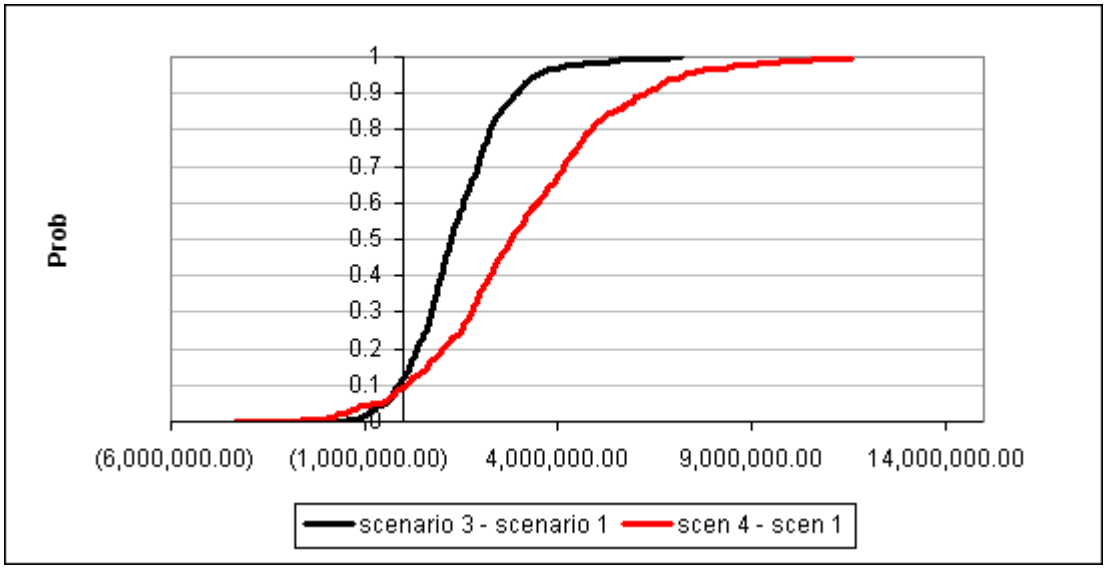

Figure 69. CDF of the Differences Between NPV by Scenarios for an Average California Central Valley Ethanol Plant

Figure 69 provides a CDF of the differences in NPV between scenarios 3 and 4 relative to scenario 1. Although these differences are minimal in the context of the full distribution NPV, this concentrated view of NPV shows the variability between scenarios. In the negative region of the distributions displayed in Figure 69, the scenario 1 has a larger NPV than the scenario being used in the comparison and represents the proportion of the time in which the technologies used in scenarios 3 and 4 are not able to recoup the investment costs of implementation. This occurs for scenario 3 approximately 12% of the time and 9% of the time for scenario 4. This indicates that nearly 90% of time the economic gains in reducing water usage by adopting scenario 4 strategies outweigh the capital costs of implementation, however since the gains are masked by the overall poor performance of this ethanol facility and a manager may be unlikely to adopt such strategies. Approximately 93% of the time, NPV for scenario 4 offers a more substantial improvement to NPV in the base scenario relative to NPV in scenario 3, indicating non-linear returns to investments made on water reduction technologies.

From the results discussed above, it is clear that scenario 2 provides the best alternative for the ethanol facilities, based upon the NPV after 10 years of operation. But, as second and third alternatives, which of the other scenarios are preferred? Granted the shear probability of economic failure makes this analysis of limited value as the facilities show little investment value, but for the sake of completeness it is included. Making the assumption of a power utility function, a SERF analysis was done on the

NPV for each of the four water reduction scenarios. As expected, for all reasonable values of the ARAC, scenario 2 is the preferred alternative. Significantly below scenario 2, scenario 4 is the second most preferred alternative over all reasonable values of risk aversion. As Figure 70 displays, the lines of the alternative scenarios do not cross indicating that, in this case, the scenario ranking is consistent whether the decision maker is risk neutral or risk averse.

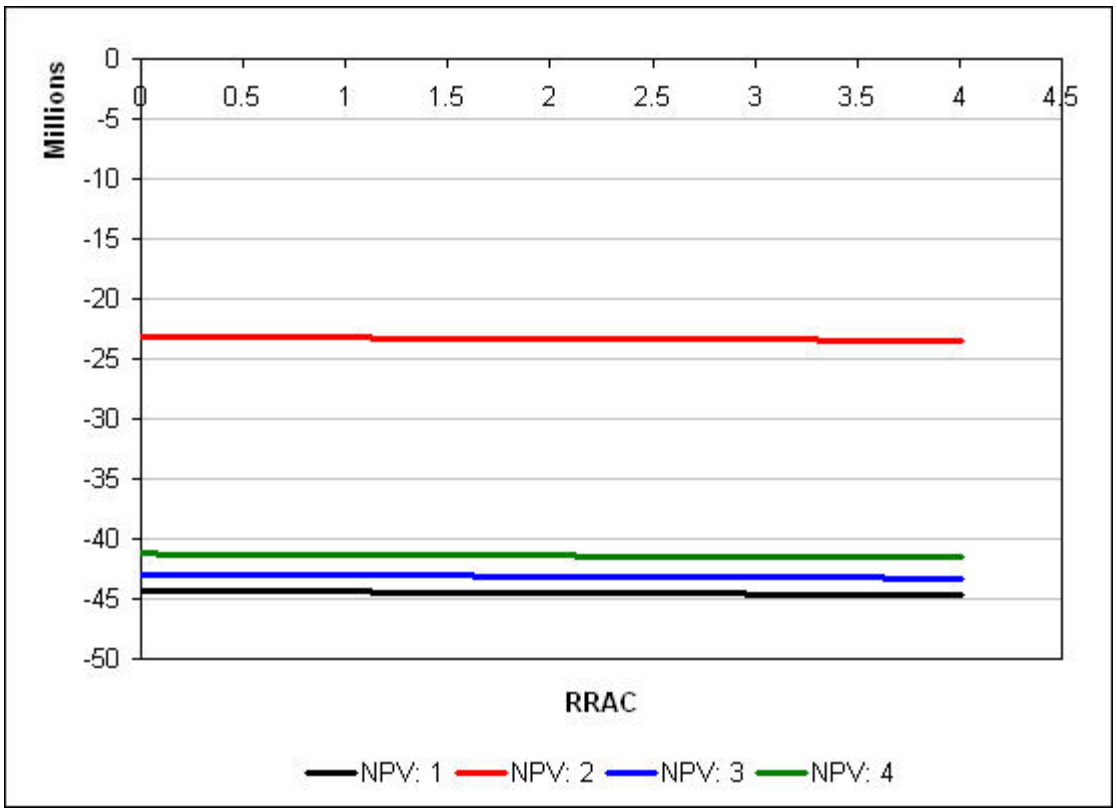

Figure 70. SERF Chart for NPV under Alternative Water Reduction Scenarios for an Average Ethanol Plant in California's Central Valley

Agricultural Water Usage

The California Central Valley land use changes were characterized by increasing corn acreage and a general decline in planted acreage for the other crops included in this analysis. Aside from rice and cotton, corn uses more fresh water per planted acre than the other crops included in this study. So the question becomes, what is the net impact on agricultural water use over the 10 year period given the substantial increase in corn planted acreage and the decline in cotton and rice planted acreage in the California Central Valley? Applying stochastic rates of ET to stochastic acreage forecasts, we are able to obtain simulation results for agricultural water use in the Central Valley region of California.

Results from simulations run on total agricultural water use by the 6 analyzed crops in the California Central Valley, show 2008 annual usage between 1100 and 2400 thousand acre-feet and 2017 annual usage between 1100 and 2700 thousand acre-feet. However, the reader is cautioned about comparing these water quantities directly, as the total planted acreage for the crops analyzed has also increased over the time period. Total agricultural water usage is, thus, not being directly compared on the same land basis. Based on an estimate for 2007 agricultural water usage (estimate was based on reported estimates of crop ET rates and reported planted acreages), average annual water usage appears to have increased 15% between 2007 and 2017. However, the 4% increase in acreage planted in those six analyzed crops between 2007 and 2017 serves as a component of water usage increase. By normalizing the values using an acre-foot per acre measurement instead of total quantity of water used we are able to get a better sense

of how water usage intensity has increased. As shown in Table 18, there appears to be an increase in water usage intensity by about 10% between the historical rate and the average simulated value in 2017. So, although overall water quantity consumed by regional agricultural practices has increased by 15%, approximately two-thirds of that response is due to an increase in water intensive cropping decisions and the other one-third can be attributed to increases in the overall planted acreage dedicated to those six crops.

Table 18. Comparison of California Central Valley Total Crop Acreage and Agricultural Water Usage

	Historical	*Simulated Means*	
	2007	2008	2017
Total acreage	1,455,900	1,475,934	1,518,592
Total AF water	1,801,200	1,835,658	2,074,621
Avg. AF / Acre	1.24	1.24	1.37
2007 % Δ		0.01	0.10

Figure 71 shows a PDF approximation of these normalized distributions for both 2008 and 2017. The two distributions show similarities in shape and skewedness, the one primary difference between the two is the rightward shift illustrated in the 2017 distribution, representing an increase in agricultural water usage intensity across the board. At the beginning of this section, the question was posed as to the net effect of forecasted increases in a somewhat water intensive crop (corn), relative to decreases in highly water intensive crops (rice and cotton) and decreases in three minimally water intensive crops. Figure 71 gives us our answer—the net effect is an increase in water

usage intensity. We can infer that with regard to water usage, the decrease in rice and cotton acreage did not make up for the increase in corn acreage.

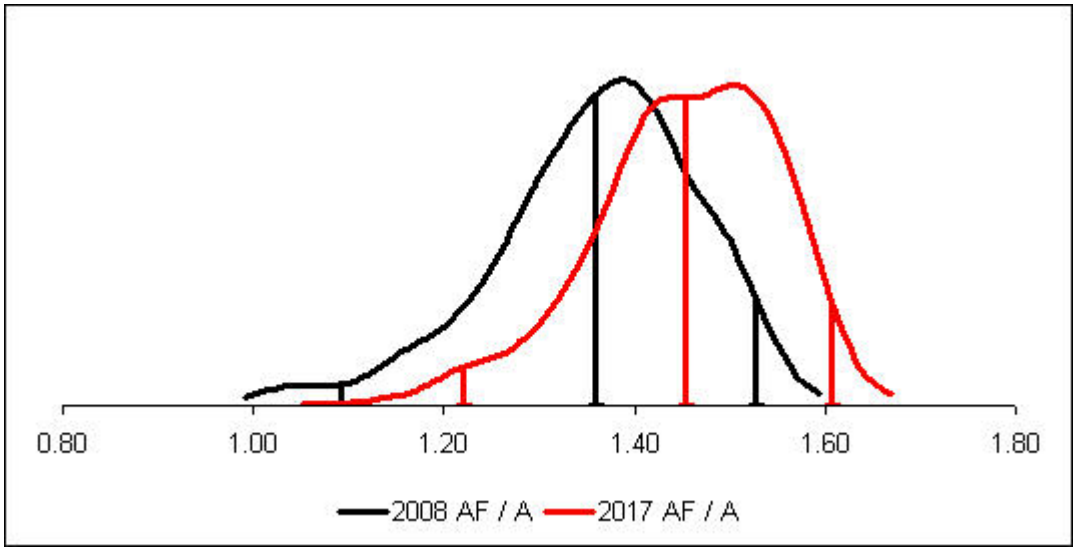

Figure 71. PDF Approximation of the Distribution of Normalized Agricultural Water Usage in the California Central Valley for Years 2008 and 2017 (in Acre-Feet per Acre)

Although not necessarily useful for comparing water usage intensities, total water quantities are useful for analyzing the overall changes in water demands. The following figure, Figure 72, depicts a PDF approximation of the simulated percentage change in California Central Valley agricultural water use in 2017 compared to the base year of 2007. These results depict a 16% chance that agricultural water use will decline over the 10 year simulated time period. The bulk of the distribution (50%) is centered between 0.03 and 0.28, indicating that most likely water use will increase between 3% and 38%

relative to the base year. Although we can't be certain of an increase in agricultural water usage, the resulting distribution points in that direction.

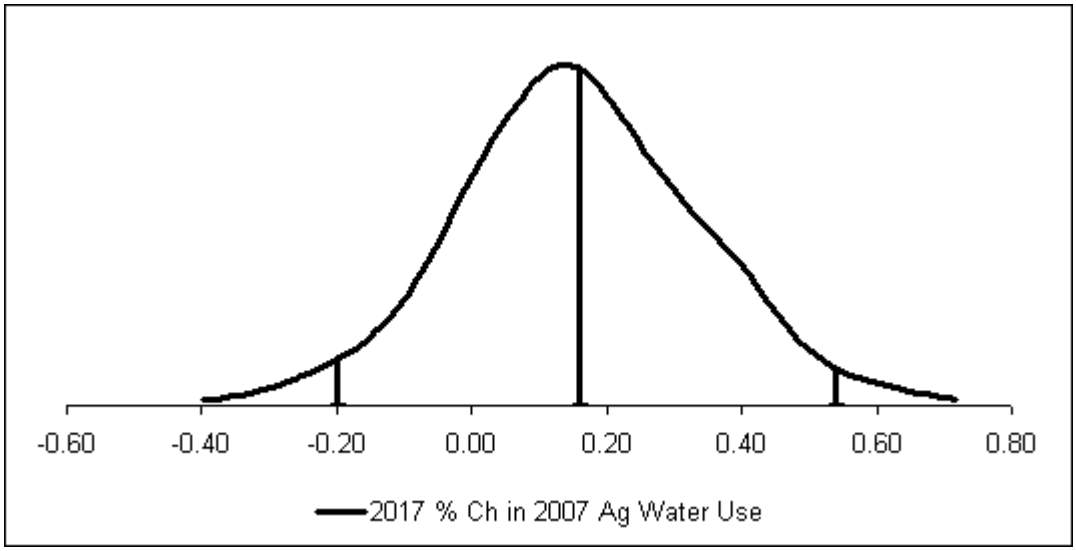

Figure 72. PDF Approximation of the Percentage Change in California Central Valley Agricultural Water Use in 2017 Relative to 2007

Looking at water usage on an annual basis reveals more detailed information about changes in water use from year to year. Figure 73 displays a fan graph illustrating the distribution around average annual percentage change in simulated agricultural water usage in the Central Valley of California for 2008 to 2017. In this case, percentage change is calculated with respect to the prior year's agricultural water usage. Annual percentage changes are useful as they easily depict rapid changes in water demands and may give insight on years in which water stress is likely to occur, under certeris paribus conditions on water supply. On average each year's agriculture water usage increases relative to the prior year. However, the variability surrounding those average percentage

changes indicates that there is almost an equal likelihood of a decrease in agricultural water use. The year with the smallest probability of having a percentage decrease in water use relative to the prior year is 2017, coming in at 29%. As measured by the coefficient of variation, in general, the variability of the distribution around mean percentage change in annual agricultural water use is increasing over the 10 year period. Years 2011 and 2012 depict relatively large increases from the prior years, with average increases of 7% and 6% respectively.

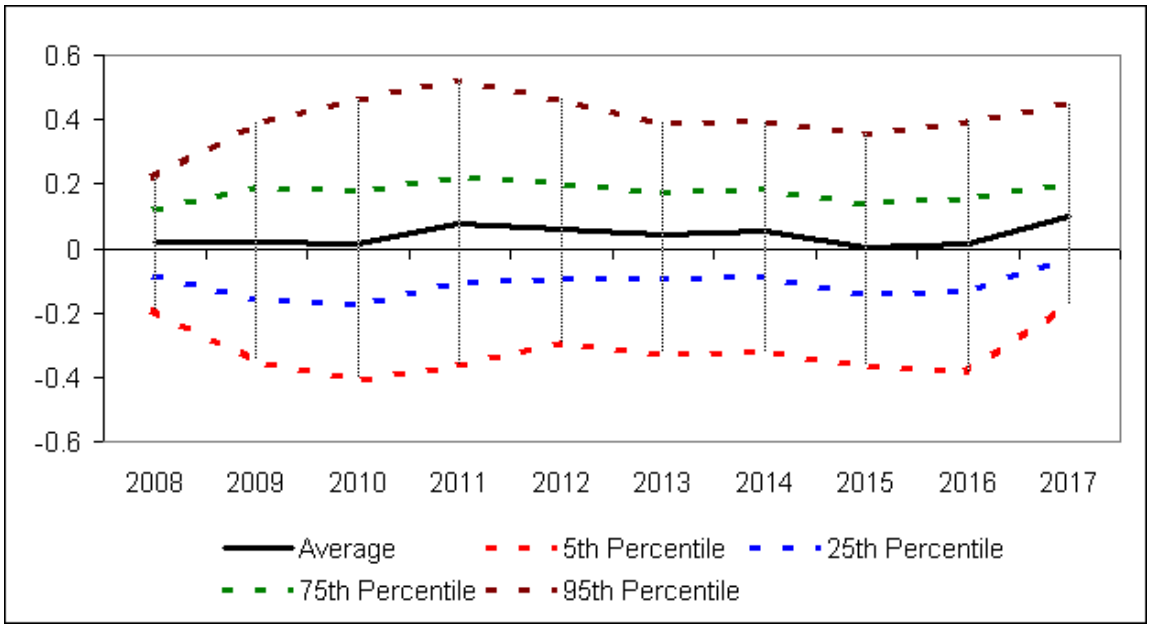

Figure 73. Fan Graph Illustrating Percentage Annual Change in California Central Valley Agriculture Water Use

Further generalizations of the forecasted changes in agricultural water use are done by comparing the change in agricultural water use to the changes in corn acreage in the California Central Valley. Simulation results show a high degree of correlation between average annual percentage changes in corn planted acreage and agricultural water usage. Figure 74 illustrates this correlation between mean values.

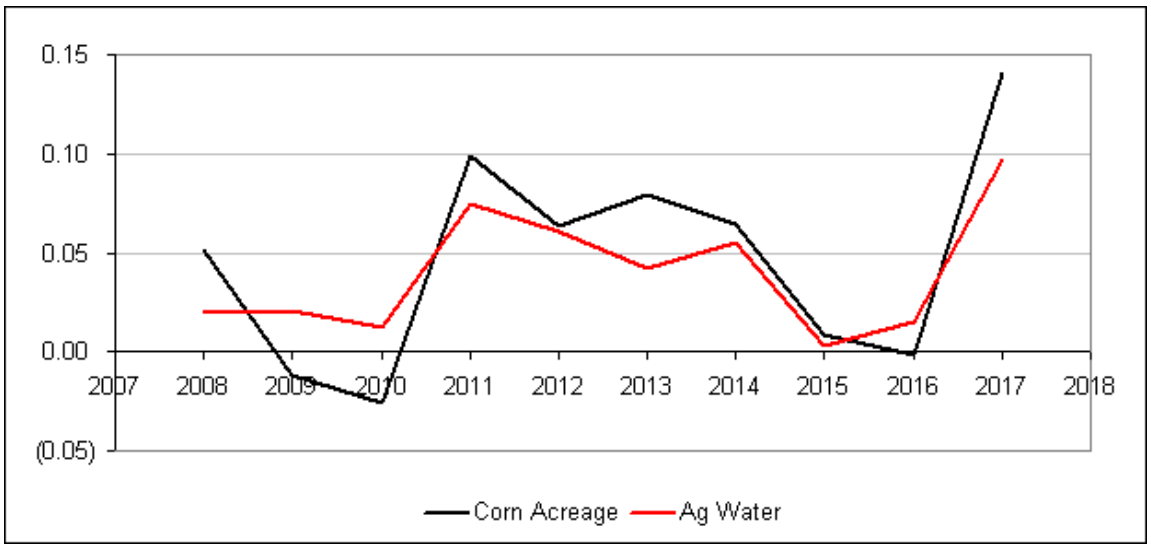

Figure 74. Relationship between the Annual Percentage Change in Corn Planted Acreage and Agricultural Water Used in the California Central Valley

Total Regional Water Usage

By combining agricultural water usage with total regional ethanol water usage, we have forecasted estimates of the role ethanol will play in the future of California Central Valley water demand over the next 10 years. Figure 75 displays the forecasted distribution of consumptive water usage due to changes in agricultural production and ethanol production related water usage in the California Central Valley. From the figure

below, it is clear that there is a slight upward trend in water usage with a significant amount of variability each year. Water usage in 2008 was estimated at 1.8 million acre-feet, while 2017 average water usage was forecasted to be 2.1 million acre-feet, showing a 13% increase in average usage. Average water usage initially declines in 2009 and 2010 by just 1% and 2% respectively. This decline can be traced back to a decline in planted acreage between 2008 and 2009 in all crops other than corn and subsequently, a decline in average total water usage by all agricultural crops analyzed in this study other than corn.

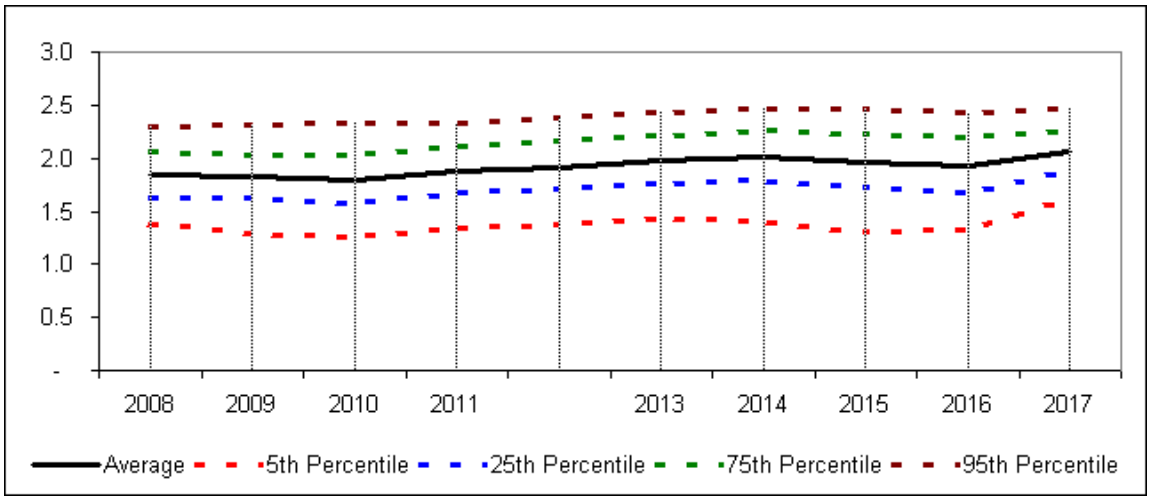

Figure 75. Fan Graph of Total Regional Agricultural and Ethanol Related Water Usage in the California Central Valley (in Million Acre-feet)

Based upon the 500 iterations run in the simulation, there is a 50% probability that 2017 ethanol related water usage will be between 1.6 and 2.3 million acre-feet, while in 2008 there is a 50% probability that regional consumptive water usage will be

between 1.6 and 2.0 million acre-feet. From that information alone, we know that the lower end of the distribution didn't move as much as the upper end of the distribution. It is highly relevant to point out that consumptive water usage by ethanol facilities accounts for less than 0.5% in any given year. The proportion of water being used by ethanol facilities is increasing, but is still an extremely minor component of total ethanol water usage in the California Central Valley.

We can take a closer look at the distributions for water usage by looking at a CDF of the distributions. Figure 76 offers a CDF distribution of the simulated values for total regional ethanol related consumptive water usage for 2008 and 2017. Figure 76 confirms our findings in Figure 75 and shows a distribution that has been pulled to the right, with a higher mean water usage and higher probability of using more than 2,500 thousand acre-feet of water (5% probability in 2017 and 0% probability in 2008).

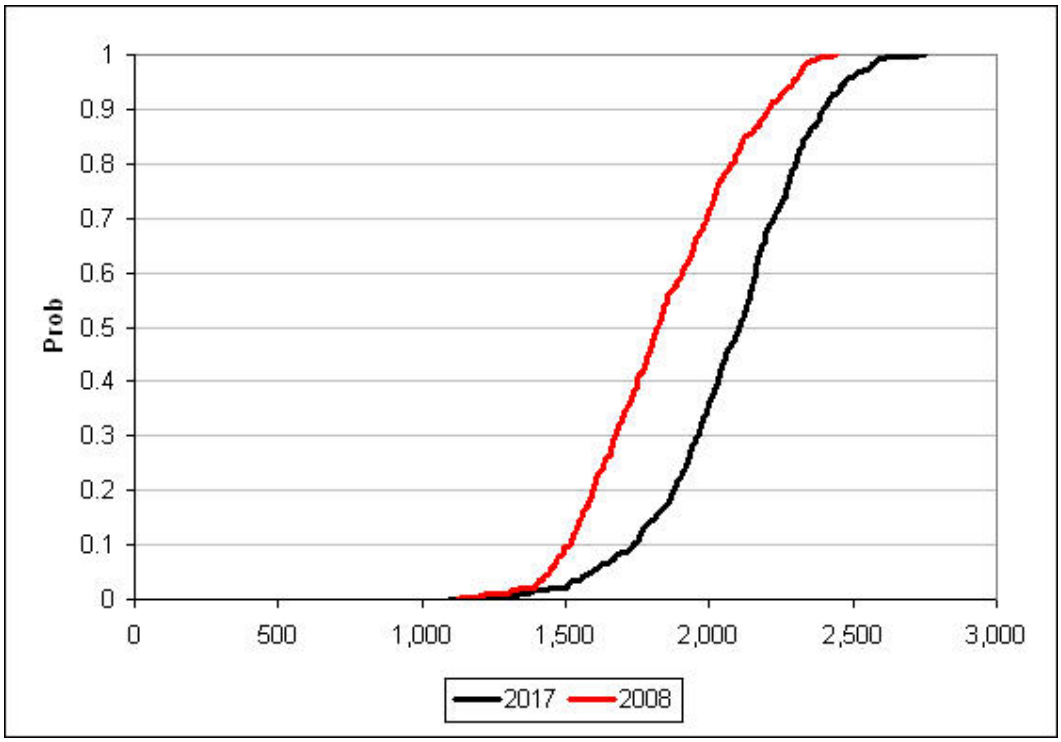

Figure 76. CDF Approximation of the Distribution of Total California Central Valley Regional Agricultural and Ethanol Production Consumptively Used Water in 2008 and 2017 (in Thousand Acre-feet)

CHAPTER VII

CONCLUSIONS

The results of this research present some surprising conclusions with regard to regional water usage stimulated by the expanding ethanol industry. Total changes in water usage, due to the changing agricultural landscape and due to increases in ethanol production, do relatively little to alter the consumptive water usage in the three selected study regions. Increases in water usage are, of course, relative to the basis they are being compared to, so several different stories can be told. However, relative to 2007 agricultural and ethanol production water usage, on average the Texas High Plains region can expect a 2% increase, while Southern Minnesota shows just a 1% increase in water usage. The California Central Valley has the most substantial increase in consumptive water usage with 2017 average water usage estimated to be 15% higher than estimated water usage in 2007.

Regional water usage by ethanol plants is shown to increase over the next 10 years, but the increases in water usage dedicated to the production of ethanol are extremely minor when put into the context of regional agricultural consumptive water usage and the changes being generated by the shifting agricultural landscape, accounting for less than 0.01%. Individual ethanol plants have little economic sensitivity with regard to changes in the price they pay for water with elasticities in the neighborhood of -0.03 for all three locations. Therefore, attempts at decreasing the water usage by an individual facility through raising the cost of water are likely to be ineffective and, in

fact, the ethanol plant will show a very high willingness to pay for water. However, an approach that could prove to have some effective results at reducing the consumptive water usage by an ethanol plant is the adoption of water reducing technologies. Particularly responsive to technologies that reduce waste water generated by a facility, it has been shown that sizable capital investments are easily offset by cost savings and that improvements to the probability of economic success are likely to occur upon implementation of water reducing technologies.

In addition to a better understanding of the role water resources will play in the future of ethanol production, this research provides useful comparisons of the economic outlook of ethanol facilities in three distinctly different locations across the United States. With plentiful access to corn, the supply oriented ethanol plants located in Southern Minnesota have the highest probability of economic success. On average, plants in this location are expected to have a positive NPV after 10 years of operation approximately 94% of the time. The Texas High Plains suffered because of corn availability, with a 55% probability of economic success, but not nearly as much as the California Central Valley is hurt by corn availability, with a probability of economic success sinking to a mere 14%.

Limitations and Future Research

As with any research, this research is not without its limitations. It is fruitful to take the time to point out both the advantages and some of the disadvantages that were embedded in the design and implementation of this model. The model created and described within the context of this research contains several advantages relative to other

models of similar characteristics. First, the model is easily adaptable. As desired by the analyst, alternatives can be incorporated to update and change the model to meet changing demands. New ethanol water reduction technologies can be implemented in the scenario analysis (or the existing ones can be modified to meet other capital or technological changes) and ethanol production costs and technologies can be easily changed. Water prices can easily be changed and their impact on the NPV of the plant can be determined. Once changes have been made to the model's design specifications, the analyst simply needs to re-simulate the model and a new set of results are obtained. The following sections will describe some of the limitations of the research.

Demand

One of the major assumptions that was included in this research was the assumption of perfectly inelastic demand for water. While this may be close to a reality for ethanol producers (as water costs play such a minor role in their total costs and the water price elasticities that were estimated were nearly inelastic), we know this isn't true for agricultural producers. Previous studies of agricultural irrigation water demand elasticities have wide variations in magnitude, however the majority of studies estimate irrigation water demand to be relatively inelastic with elasticities in the range of -0.02 to -0.56 (Scheierling, Loomis, and Young 2004). Plans for future work on this model include estimation and incorporation of regional irrigation water demand elasticities to approximate a demand schedule for agricultural water.

By incorporating agricultural water demand elasticities and estimating changes in the cost of water to agricultural producers, forecasts of water usage will decline from

their current estimates. With current estimated changes in water usage in the Texas High Plains and Southern Minnesota at very small levels, the incorporation of less than perfectly inelastic demand may reduce water usage to a point where there is virtually no change from estimated historical rates. Incorporation of agricultural water usage elasticities for water usage in the California Central Valley is likely to be the most interesting place to do so, as water usage over the 10 year period is California is forecasted to increase by upwards of 15%.

Other Impacts

Although the water usage in the production of the corn feedstock and production of the ethanol were quantified, there are other impacts resulting from the expanding production of ethanol that have not been considered within the context of this research. Our analysis started with production of corn and stopped with the production of ethanol, while in reality the production process isn't so detached. Inputs are obtained and used in the production of the corn and ethanol will be transported to a final location, these activities may have some implication for water usage.

Leakage and Indirect Effects

Although insights into regional implications of ethanol production have developed from this research, the reader should be reminded that these are just regional snapshots of what might happen, not overall impacts of ethanol's role on water resources. Corn use is a primary example of this leakage effect. Corn was modeled as either coming from local supplies or being transported in from somewhere else. The

water implications of the imported corn supply are an externality to the system being modeled. But, just because they are external to the modeling system and external to the user (purchaser) of the corn, doesn't mean there are not implications. The expansion of corn production could expand agriculture into non-agriculturally productive lands, which will have economic and environmental implications. These leakages are not accounted for.

In addition there are many indirect effects of a changing agricultural landscape due to biofuels production. Use of significant proportions of local corn supplies will result in less available corn for livestock feeding. A change in regional livestock production has the potential to influence local water quality. The displacement of one crop for another crop will affect total U.S. production of both crops. Significant production changes could ultimately affect trade balances between the U.S. and other nations, which would have many indirect effects (Fingerman, Kammen, and O'Hare 2008). Other indirect effects that have not been considered include effects on input markets, the prices of other goods, labor markets, and secondary economic impacts.

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APPENDIX A

OGALLALA AQUIFER DEPLETION RATES

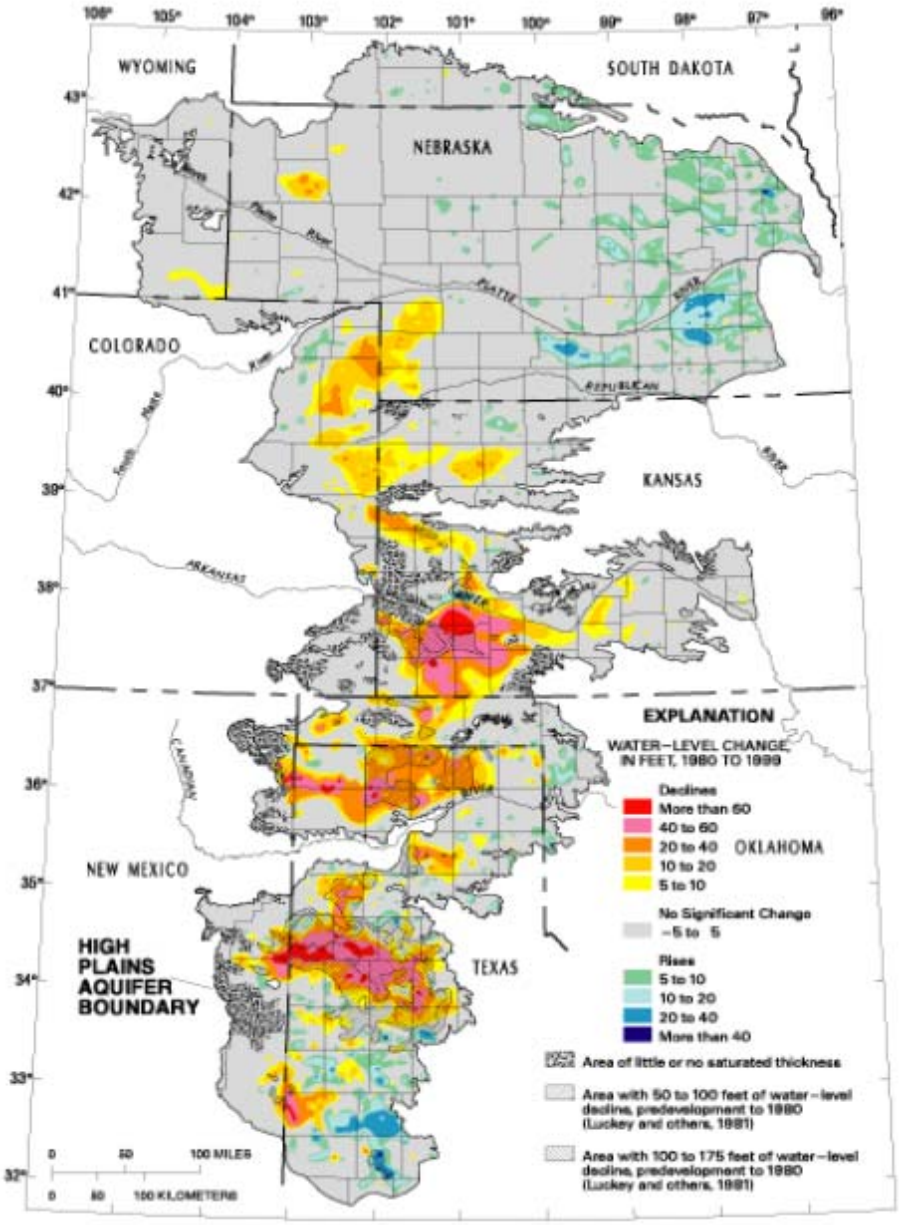

Figure 77. USGS Ogallala Aquifer Water Level Changes from 1980 to 1999[15]

[15] Source: McGuire (2004)

APPENDIX B

SUMMARY OF ETHANOL LITERATURE

Table 19. Summary of Literature on the Environmental Impacts of Ethanol

Summary of Ethanol Impacts			
	Negative	Positive	Authors
Energy Crop Production			
Soil	Rapid erosion		Pimentel
		Increased organic matter	Powlson, Riche, and Shiel
Air	Increased GHG emissions		Marshall and Greenhalgh
Water		Water quality	Powlson, Riche, and Shield
	Use up to 25% of avail.		Bernedes
	Increased withdrawals		Marshall and Greenhalgh
	Increased evaptranspiration		
Others		Net Benefit	Updegraff, Baughman, and Taff
Ethanol Production			
Air	Carbon Dioxide emissions		RFA
Water	Waste discharge		Swenson
Usage			
Air	More VOCs		Kane
	More Nitrus Oxide	Less Carbon Monoxide	EIA
	More Methane	Less Carbon Dioxide	EIA
	Less Fuel Efficiency		Patzek
		Less GHGs	Kammen
Water	Surface water contamination	No direct impact on drinking water	Williams, Cushing, and Sheehan
Others		Less foreign dependence	Ogden, Williams, and Larson

Table 20. Summary of Literature on the Economic Input Costs of Ethanol ($/gal)

Source:	(Shapouri, Duffield, and Wang 2002)	(Whims 2002)	(Whims 2002)	(Whims 2002)	(Burnes et al. 2004)	(Tiffany and Eidman 2003)	(Beck 2005)	(Coltrain 2004)	(Hurt, Tyner, and Doering 2006)	(Plevin and Mueller 2008)
Plant Size		15 mgy	30 mgy	40 mgy	40 mgy		<200 mgy	40 mgy		
Energy							0.178		0.383	
Electricity	0.041	0.064	0.060	0.060	0.060	0.055				0.050
Natural Gas	0.090	0.118	0.111	0.111	0.190	0.160				0.270
Chemicals	0.034	0.033	0.030	0.028		0.047	0.088		0.182	0.190
Enzymes	0.056	0.055	0.050	0.048		0.048		0.080		
Denaturant	0.023	0.030	0.030	0.030		0.035				
Water / Sewage	0.008				0.026	0.006	0.009			
Maintenance	0.036	0.035	0.030	0.027	0.003		0.031			
Mgmt & Labor	0.110	0.067	0.045	0.040	0.090		0.060			0.030
Proc. Materials					0.110					
Proc. Costs	0.020	0.025	0.022	0.020					0.297	
Total Variable Costs	0.417	0.427	0.378	0.364	0.479	0.136	0.366		0.862	0.540
Fixed Expenses							0.045			
Sales, admin		0.035	0.031	0.028						
Capital, interest										
Total Costs less corn		0.462	0.409	0.392		0.3624	0.411			0.73
Corn						0.76		50%		1.61
Total Costs						1.1224				2.35

APPENDIX C

FORECASTED ACREAGE SIMULATION RESULTS

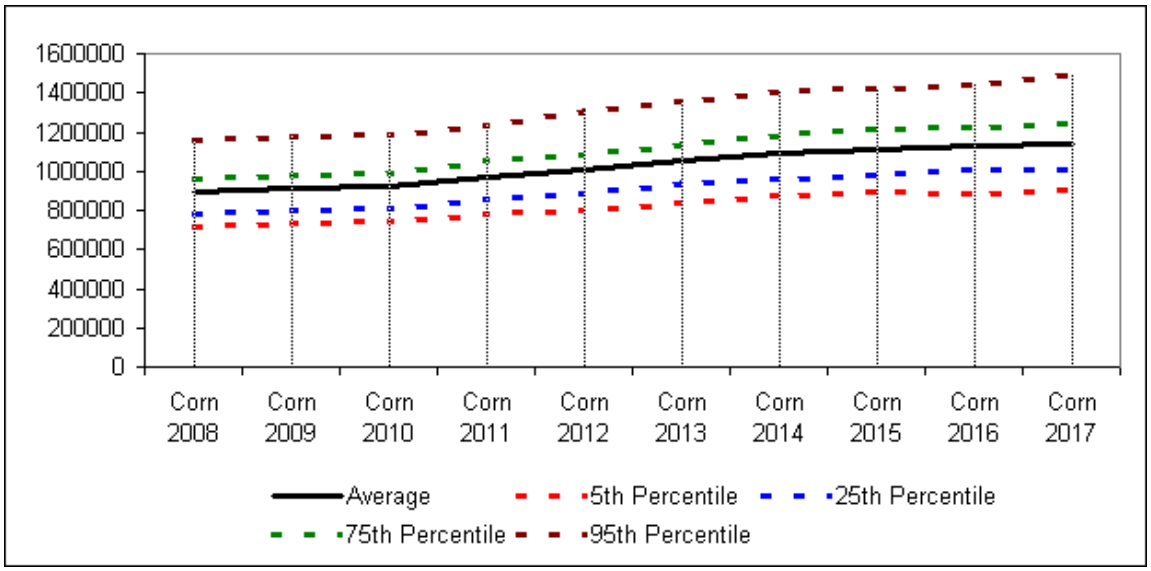

Figure 78. Fan Graph of 2008-2017 Simulated Corn Planted Acreage in the Texas High Plains Region

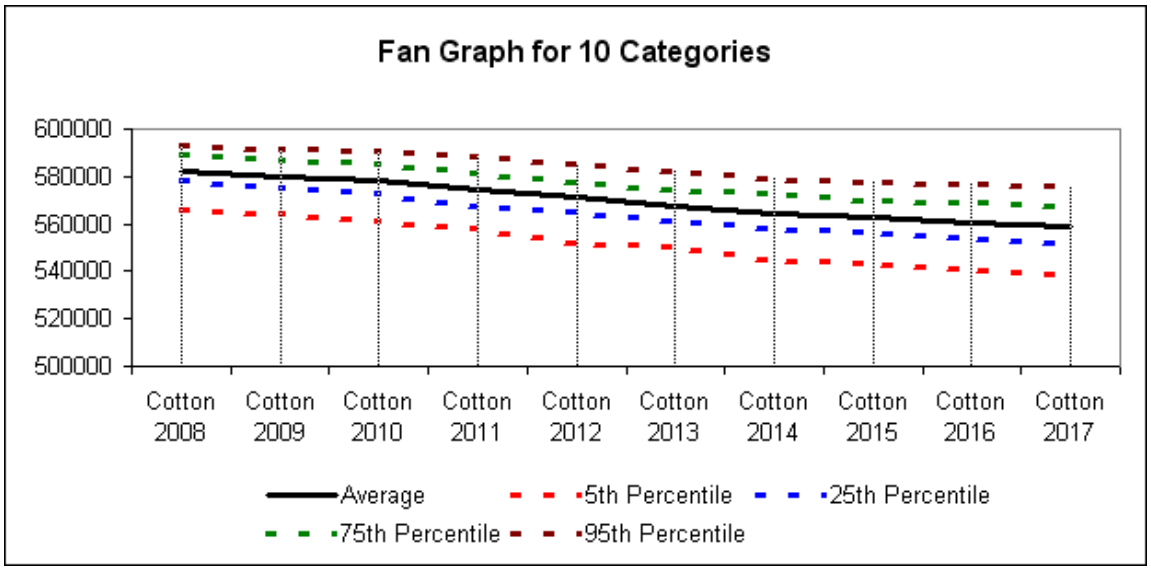

Figure 79. Fan Graph of 2008-2017 Simulated Cotton Planted Acreage in the Texas High Plains Region

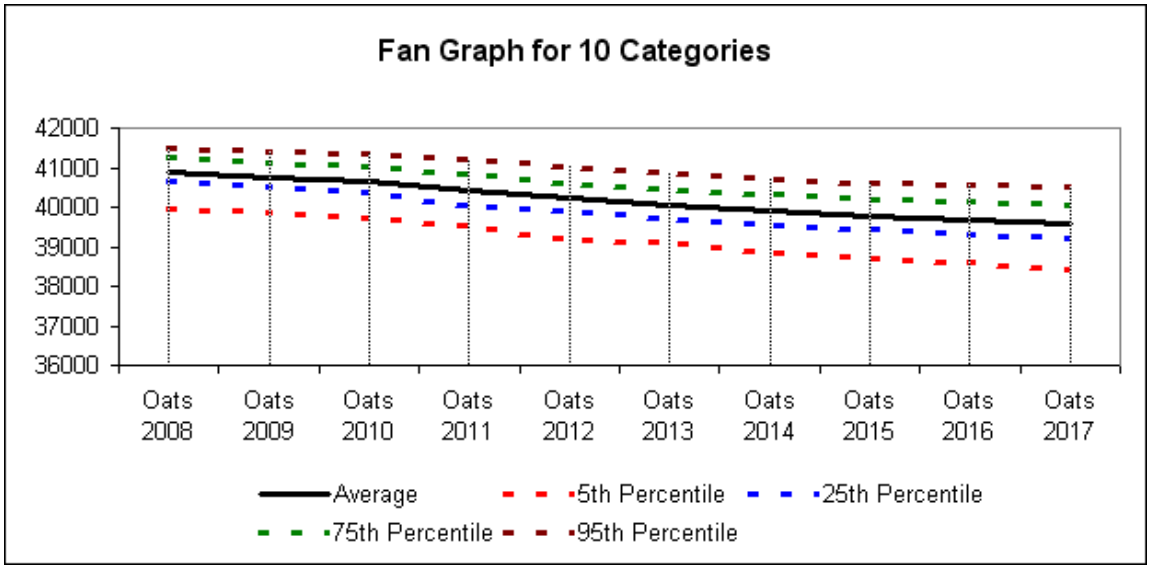

Figure 80. Fan Graph of 2008-2017 Simulated Oats Planted Acreage in the Texas High Plains Region

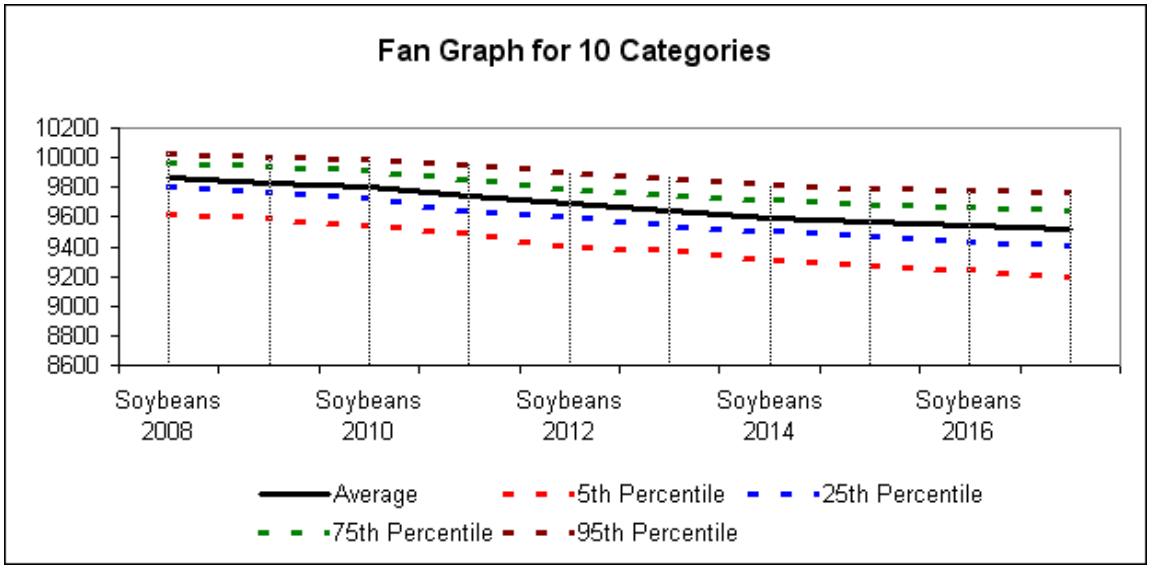

Figure 81. Fan Graph of 2008-2017 Simulated Soybeans Planted Acreage in the Texas High Plains Region

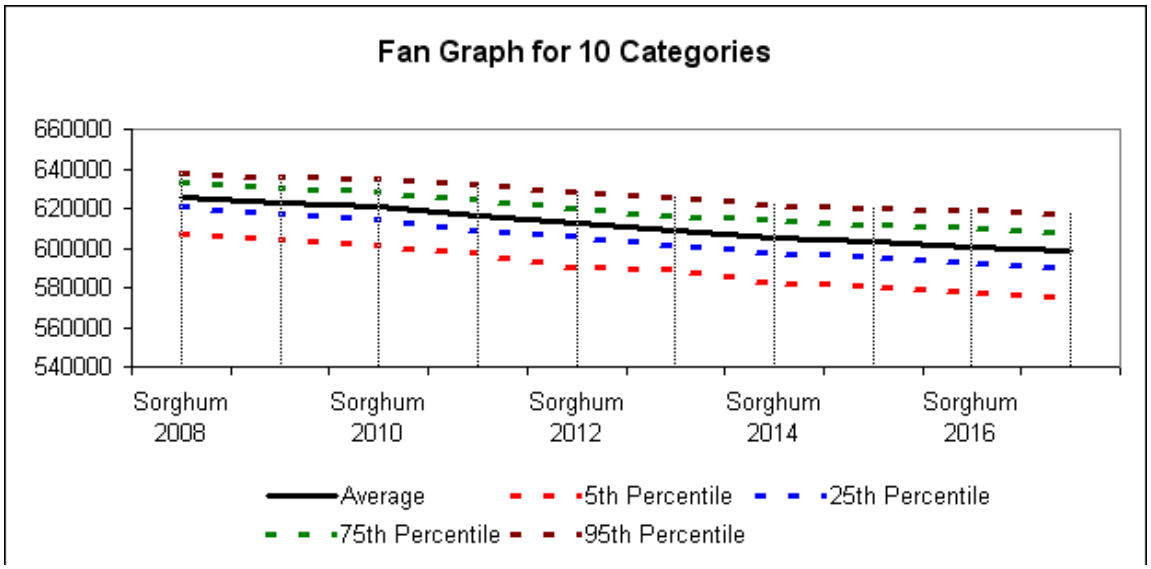

Figure 82. Fan Graph of 2008-2017 Simulated Sorghum Planted Acreage in the Texas High Plains Region

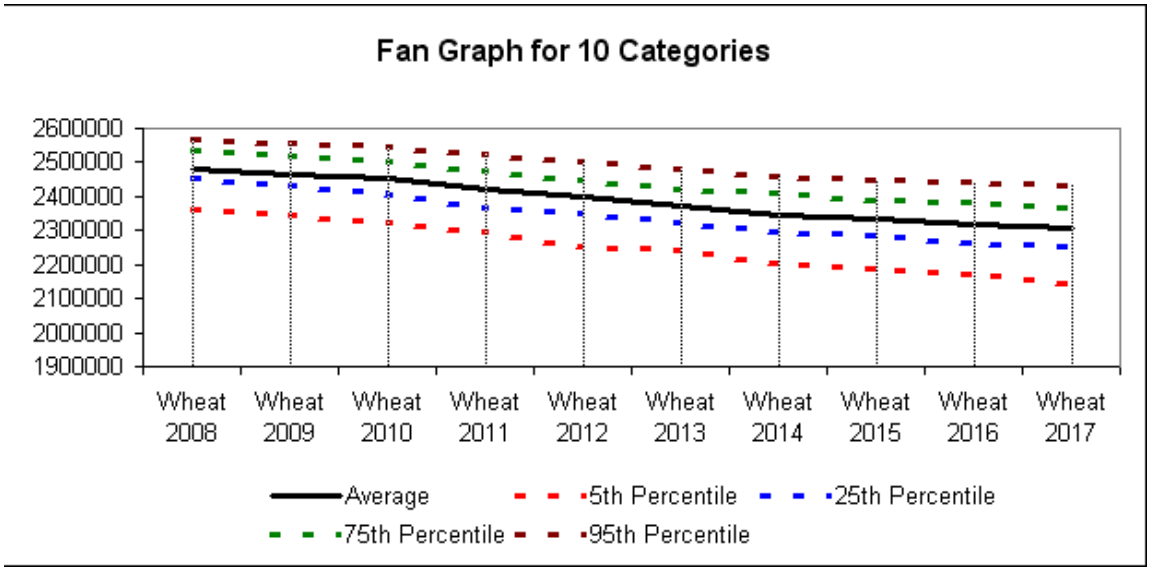

Figure 83. Fan Graph of 2008-2017 Simulated Wheat Planted Acreage in the Texas High Plains Region

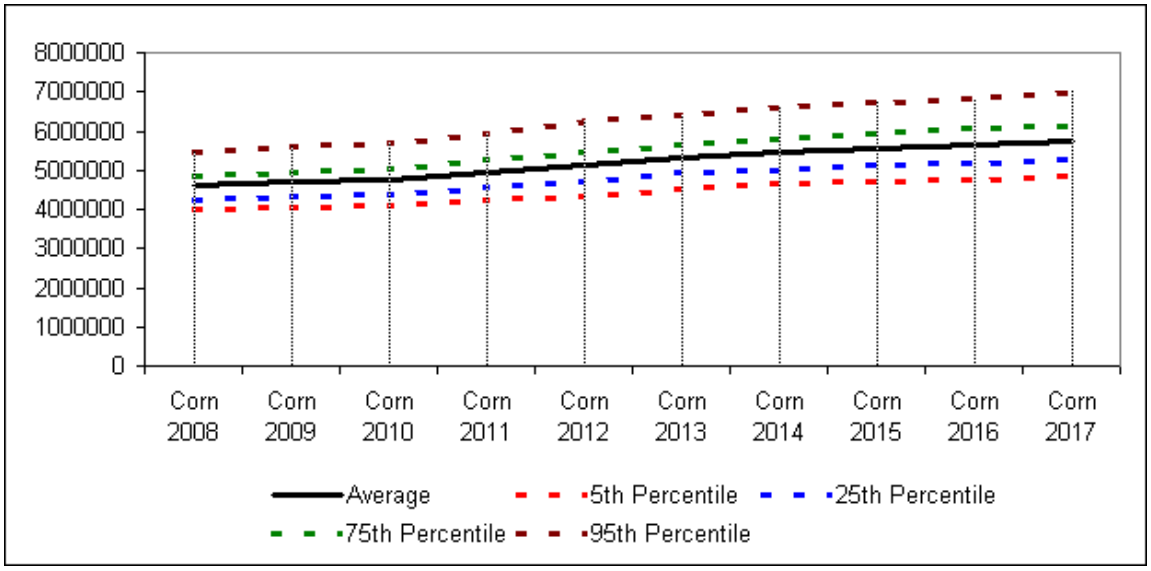

Figure 84. Fan Graph of 2008-2017 Simulated Corn Planted Acreage in the Southern Minnesota Region

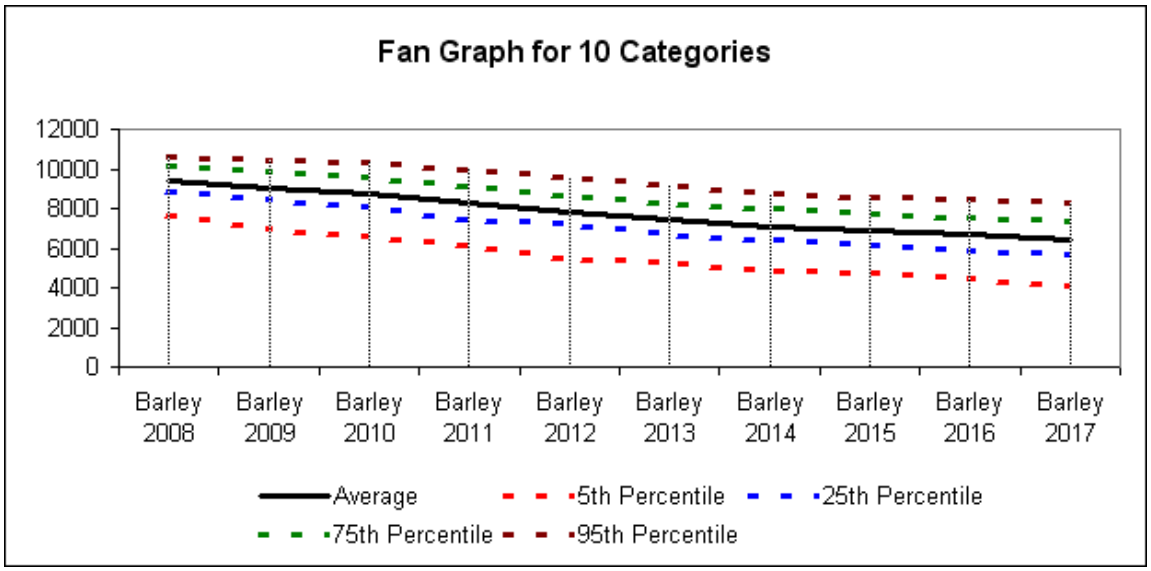

Figure 85. Fan Graph of 2008-2017 Simulated Barley Planted Acreage in the Southern Minnesota Region

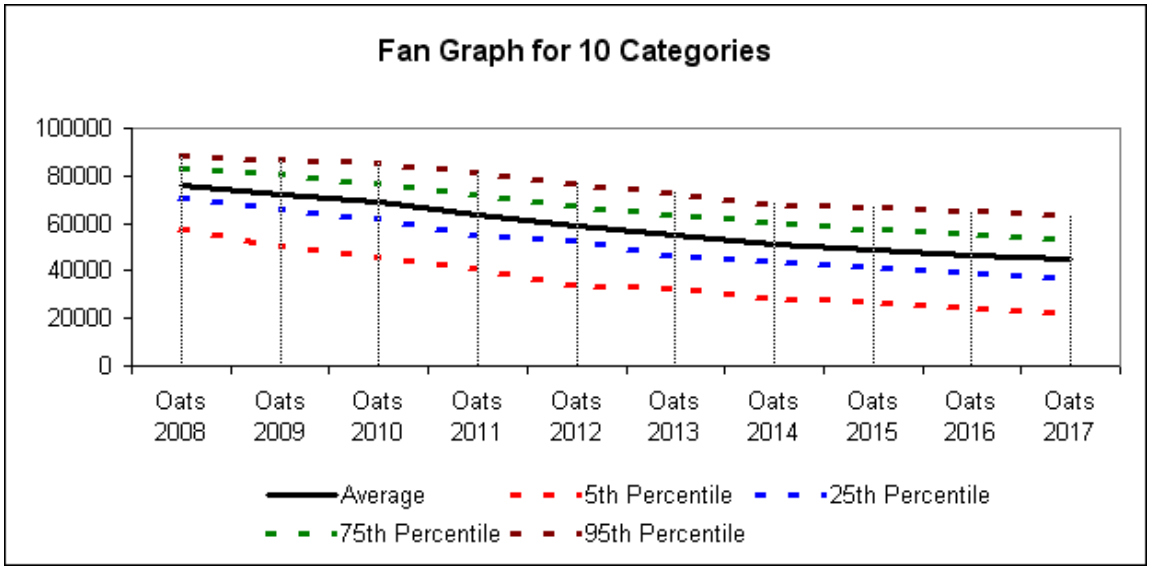

Figure 86. Fan Graph of 2008-2017 Simulated Oats Planted Acreage in the Southern Minnesota Region

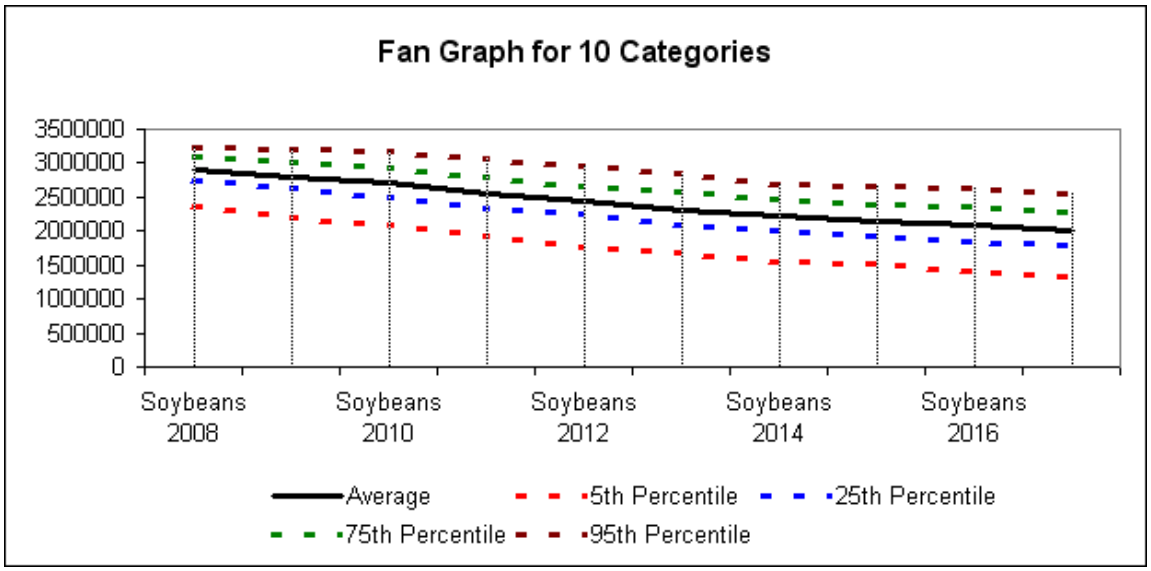

Figure 87. Fan Graph of 2008-2017 Simulated Soybeans Planted Acreage in the Southern Minnesota Region

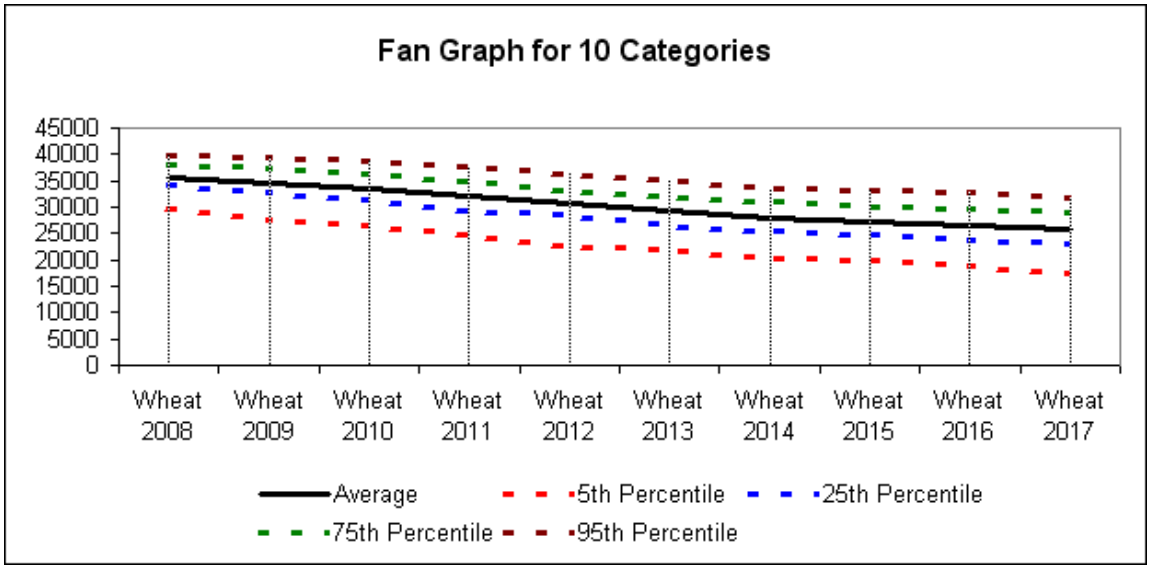

Figure 88. Fan Graph of 2008-2017 Simulated Wheat Planted Acreage in the Southern Minnesota Region

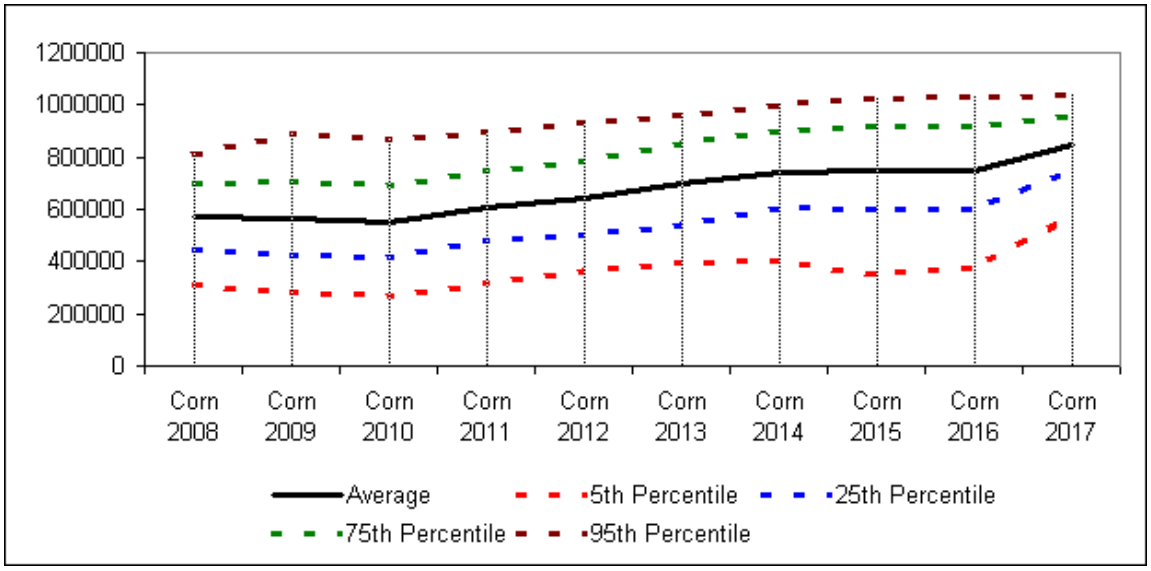

Figure 89. Fan Graph of 2008-2017 Simulated Corn Planted Acreage in the California Central Valley Region

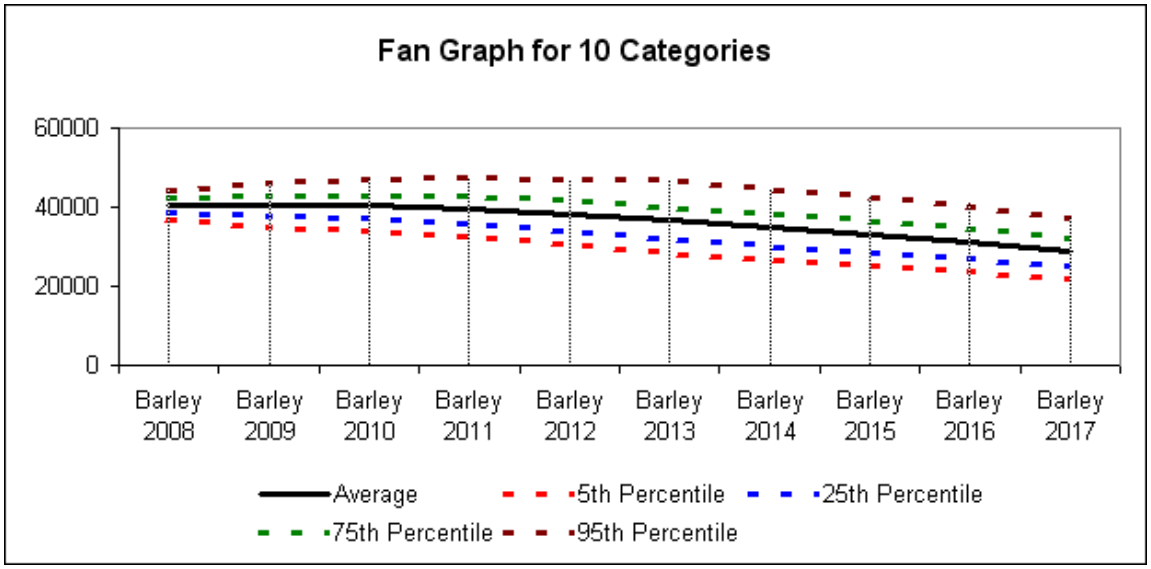

Figure 90. Fan Graph of 2008-2017 Simulated Barley Planted Acreage in the California Central Valley Region

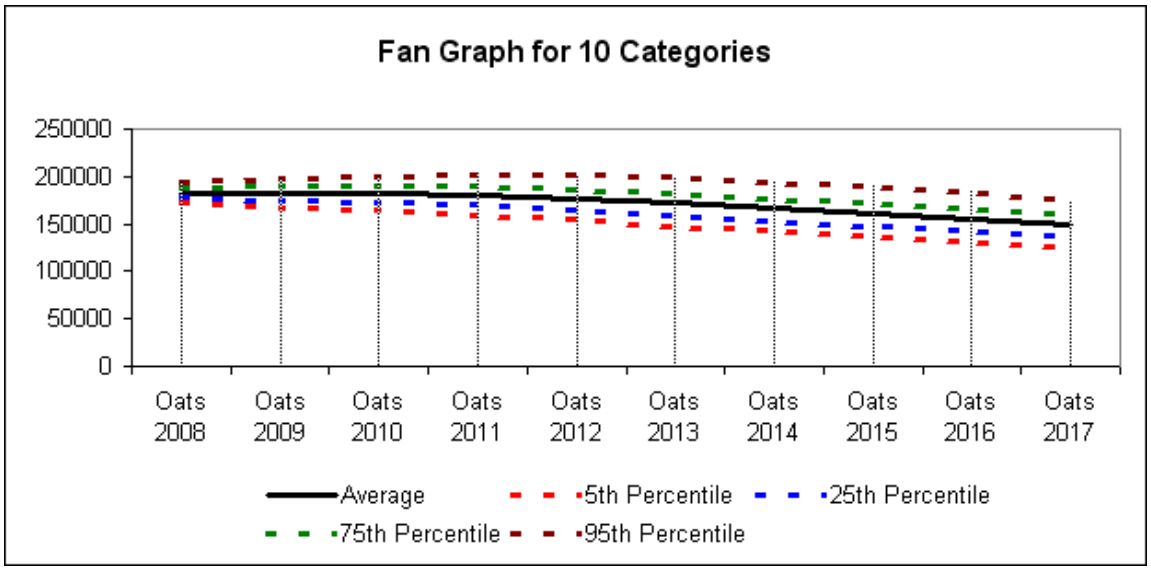

Figure 91. Fan Graph of 2008-2017 Simulated Oats Planted Acreage in the California Central Valley Region

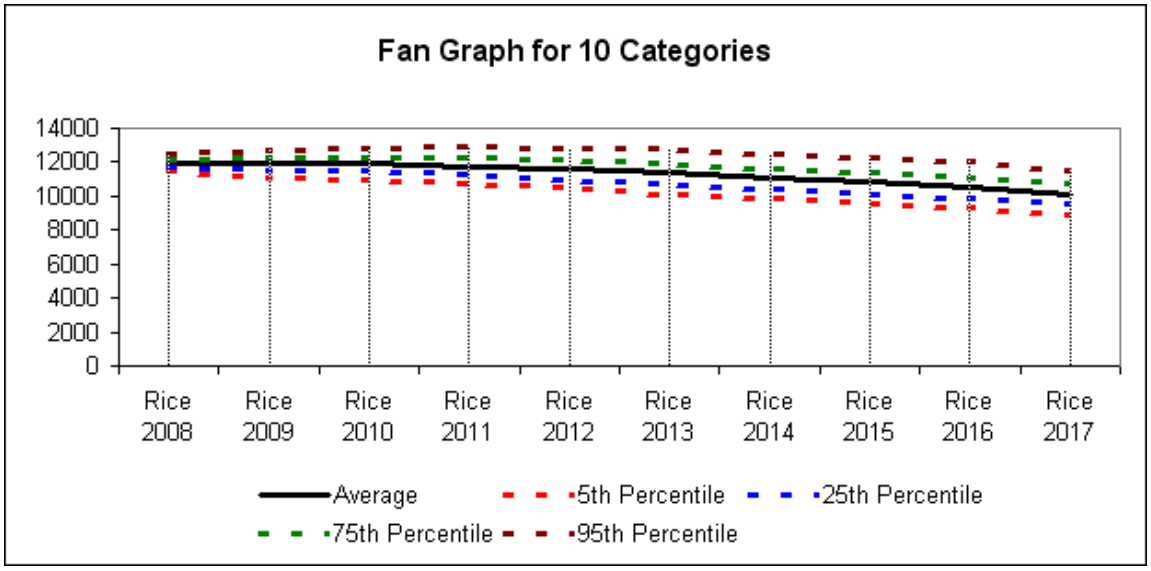

Figure 92. Fan Graph of 2008-2017 Simulated Rice Planted Acreage in the California Central Valley Region

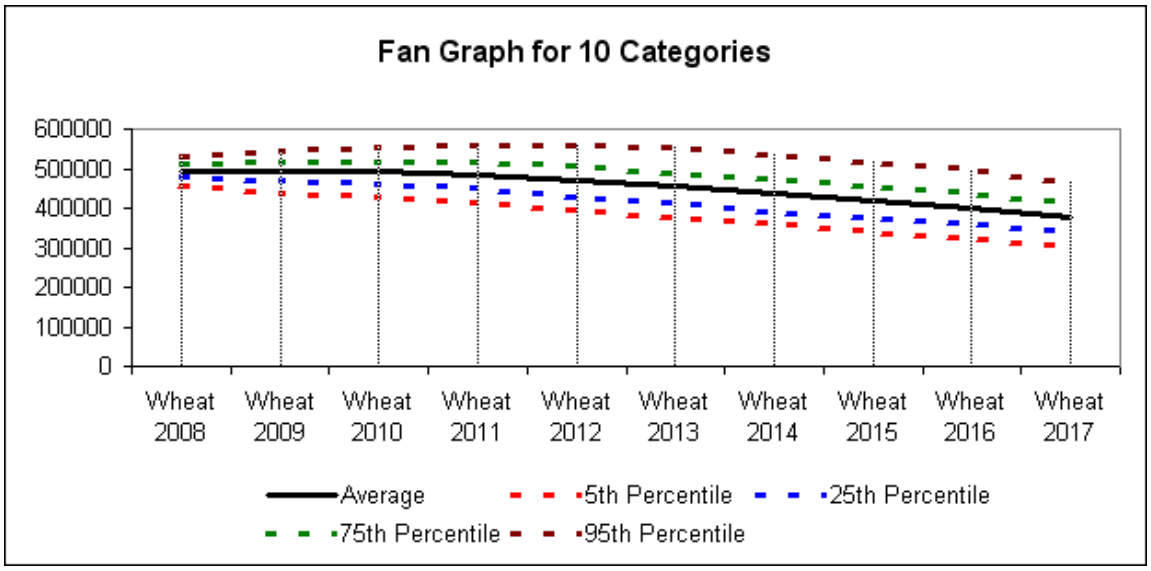

Figure 93. Fan Graph of 2008-2017 Simulated Wheat Planted Acreage in the California Central Valley Region

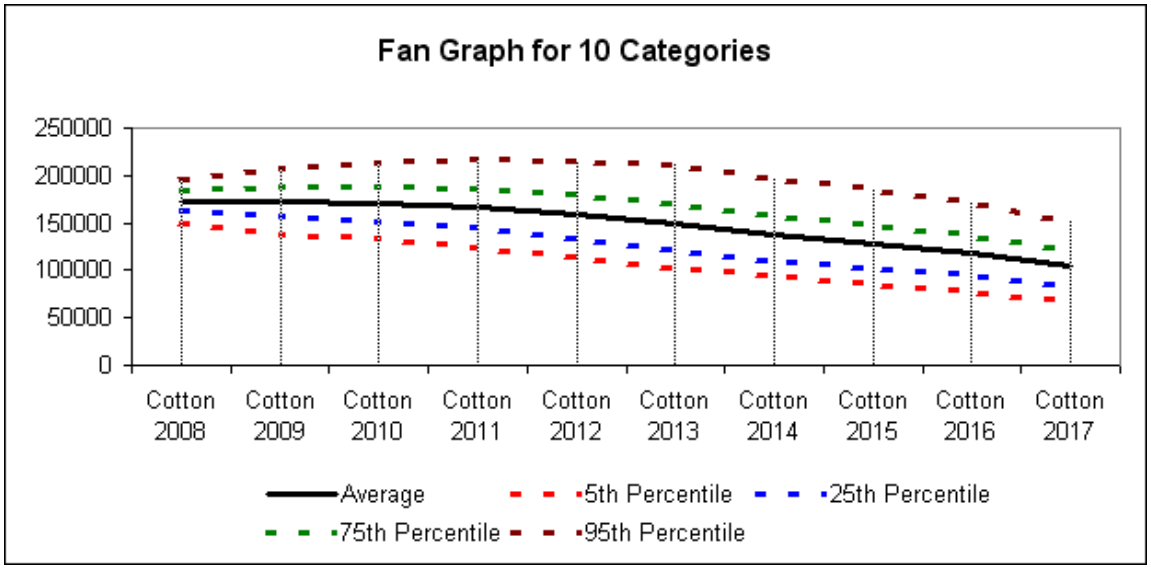

Figure 94. Fan Graph of 2008-2017 Simulated Cotton Planted Acreage in the California Central Valley Region

APPENDIX D

ETHANOL PLANT SIMULATION MODEL ASSUMPTIONS

Table 21. Summary Table of the Assumptions Used in the Texas High Plains Ethanol Plant Simulation Model

Ethanol Model Summary Sheet Texas High Plains Region								
Assumptions					**Budget for an Example Year**			
Facility					**Production (2008 values)**			
Nameplate capacity		88,750,000	gal		Ethanol	Stoch	95,076,703	gal
Nameplate factor		115%			DDGS	Stoch	305,604	tons
Max annual Production		102,062,500	gal					
2008 regional capacity		240,000,000	gal		**Sales Prices (2008 values)**			
Construction cost		$ 199,687,500			Local ethanol price	Stoch	$ 1.94	per gal
Per gal capacity		$ 1.80			DDGS price	Stoch	$ 102.89	per ton
Per gal production		$ 1.57						
Startup year		2007			**Resource Usage (2008 values)**			
					Corn	Stoch	33,955,965	bu
Receipts					Natural Gas	Stoch	4,628,856	MCF
Ethanol conversion		2.80	gal/ bu		Electricity	Stoch	169,779,826	KWH
DDGS production		18.00	lbs/gal		Water	Stoch	399,271,869	gal
Federal Subsidy		$0.51	per gal					
State Subsidy		$0.00	per gal		**Resource Costs (2008 values)**			
					Local corn price	Stoch	$ 4.36	per bu
Inputs					Local natural gas price	Stoch	$ 9.52	per MCF
Natural Gas		0.05	MCF/gal		Local electricity price	Stoch	$ 6.73	per KWH
Electricity		1.79	KWH/gal					
Water	Stoch	4.00	gal/gal		**Production Receipts (per gal of ethanol in 2008)**			
					Ethanol	Stoch	$ 2.03	
Financing					DDGS	Stoch	$ 0.33	
Percent Debt		0.5			Subsidy		$ 0.54	
Length of Loan		20			Total	Stoch	$ 2.90	
Starting loan year		2007						
Dividend as % NCI		35%			**Production Costs (per gal of ethanol in 2008)**			
Depreciable capital		98%			Corn	Stoch	$ 1.43	
Depreciable life		20	years		Natural Gas	Stoch	$ 0.44	
Annual capital replacement	2008	$ 976,250			Electricity	Stoch	$ 0.11	
					Denaturant (Gasoline)	Stoch	$ 0.07	
Interest Rates					Water (sewage and fresh)	Stoch	$ 0.06	
Long term loan rate		8.50%			Enzymes		$ 0.05	
Interest rate	Stoch	7.72%			Repairs and Maintence		$ 0.04	
Wedge for operating loan		0.040			Management and Labor		$ 0.06	
Financed operating costs		25%			Other processing costs		$ 0.10	
					Total other variable costs		$ 0.27	
Regional Adjustments (as % of national price)					Interest (long term, operating, and deficit)	Stoch	$ 0.16	
Ethanol Price		0.00						
DDGS Price		-			Total Variable Costs	Stoch	$ 2.56	
Natural Gas		(0.16)						
Electricity Price		(0.01)			**Net Returns (per gal of ethanol in 2008)**	Stoch	$ 0.34	
Gas Prices		(0.06)						
Corn Prices		0.12						
Corn Transportation costs	Stoch	0.60	$/bu					

Table 22. Summary Table of the Assumptions Used in the Southern Minnesota Ethanol Plant Simulation Model

Ethanol Model Summary Sheet Southern Minnesota Region								
Assumptions					**Budget for an Example Year**			
Facility					**Production (2008 values)**			
Nameplate capacity		57,250,000	gal		Ethanol	Stoch	61,331,169	gal
Nameplate factor		115%			DDGS	Stoch	197,136	tons
Max annual Production		65,837,500	gal					
2008 regional capacity		687,000,000	gal		**Sales Prices (2008 values)**			
Construction cost		$ 118,507,500			Local ethanol price	Stoch	$ 1.84	per gal
Per gal capacity		$ 1.66			DDGS price	Stoch	$ 102.89	per ton
Per gal production		$ 1.44						
Startup year		1998			**Resource Usage (2008 values)**			
					Corn	Stoch	21,903,989	bu
Receipts					Natural Gas	Stoch	2,985,938	MCF
Ethanol conversion		2.80	gal/ bu		Electricity	Stoch	109,519,944	KWH
DDGS production		18.00	lbs/gal		Water	Stoch	257,558,473	gal
Federal Subsidy		$0.51	per gal					
State Subsidy		$0.20	per gal		**Resource Costs (2008 values)**			
					Local corn price	Stoch	$ 3.62	per bu
Inputs					Local natural gas price	Stoch	$ 10.19	per MCF
Natural Gas		0.05	MCF/gal		Local electricity price	Stoch	$ 5.09	per KWH
Electricity		1.79	KWH/gal					
Water	Stoch	4.00	gal/gal		**Production Receipts (per gal of ethanol in 2008)**			
					Ethanol	Stoch	$ 1.93	
Financing					DDGS	Stoch	$ 0.33	
Percent Debt		0.5			Subsidy		$ 0.74	
Length of Loan		20			Total	Stoch	$ 3.00	
Starting loan year		1998						
Dividend as % NCI		35%			**Production Costs (per gal of ethanol in 2008)**			
Depreciable capital		98%			Corn	Stoch	$ 1.23	
Depreciable life		20	years		Natural Gas	Stoch	$ 0.47	
Annual capital replacement	2008	$ 629,750			Electricity	Stoch	$ 0.09	
					Denaturant (Gasoline)	Stoch	$ 0.07	
Interest Rates					Water (sewage and fresh)	Stoch	$ 0.06	
Long term loan rate		8.50%			Enzymes		$ 0.06	
Interest rate	Stoch	7.72%			Repairs and Maintence		$ 0.04	
Wedge for operating loan		0.040			Management and Labor		$ 0.09	
Financed operating costs		25%			Other processing costs		$ 0.11	
					Total other variable costs		$ 0.33	
Regional Adjustments (as % of national price)					Interest (long term, operating, and deficit)	Stoch	$ 0.15	
Ethanol Price		0.02						
DDGS Price		-			Total Variable Costs	Stoch	$ 2.42	
Natural Gas		(0.15)						
Electricity Price		0.08			**Net Returns (per gal of ethanol in 2008)**	Stoch	$ 0.58	
Gas Prices		0.04						
Corn Prices		(0.07)						
Corn Transportation costs	Stoch	-	$/bu					

Table 23. Summary Table of the Assumptions Used in the California Central Valley Ethanol Plant Simulation Model

Ethanol Model Summary Sheet CA Central Valley Region								
Assumptions					**Budget for an Example Year**			
Facility					**Production (2008 values)**			
Nameplate capacity		47,300,000	gal		Ethanol	Stoch	50,671,865	gal
Nameplate factor		115%			DDGS	Stoch	162,874	tons
Max annual Production		54,395,000	gal					
2008 regional capacity		131,500,000	gal		**Sales Prices (2008 values)**			
Construction cost		$ 102,806,550			Local ethanol price	Stoch	$ 1.98	per gal
Per gal capacity		$ 1.74			DDGS price	Stoch	$ 102.89	per ton
Per gal production		$ 1.51						
Startup year		2007			**Resource Usage (2008 values)**			
					Corn	Stoch	18,097,095	bu
Receipts					Natural Gas	Stoch	2,466,985	MCF
Ethanol conversion		2.80	gal/ bu		Electricity	Stoch	90,485,474	KWH
DDGS production		18.00	lbs/gal		Water	Stoch	276,205,828	gal
Federal Subsidy		$0.51	per gal					
State Subsidy		$0.00	per gal		**Resource Costs (2008 values)**			
					Local corn price	Stoch	$ 4.92	per bu
Inputs					Local natural gas price	Stoch	$ 10.30	per MCF
Natural Gas		0.05	MCF/gal		Local electricity price	Stoch	$ 9.88	per KWH
Electricity		1.79	KWH/gal					
Water	Stoch	4.00	gal/gal		**Production Receipts (per gal of ethanol in 2008)**			
					Ethanol	Stoch	$ 2.08	
Financing					DDGS	Stoch	$ 0.33	
Percent Debt		0.5			Subsidy		$ 0.54	
Length of Loan		20			Total	Stoch	$ 2.94	
Starting loan year		2007						
Dividend as % NCI		35%			**Production Costs (per gal of ethanol in 2008)**			
Depreciable capital		98%			Corn	Stoch	$ 1.57	
Depreciable life		20	years		Natural Gas	Stoch	$ 0.48	
Annual capital replacement	2008	$ 520,300			Electricity	Stoch	$ 0.17	
					Denaturant (Gasoline)	Stoch	$ 0.08	
Interest Rates					Water (sewage and fresh)	Stoch	$ 0.06	
Long term loan rate		8.50%			Enzymes		$ 0.06	
Interest rate	Stoch	7.72%			Repairs and Maintence		$ 0.04	
Wedge for operating loan		0.040			Management and Labor		$ 0.09	
Financed operating costs		25%			Other processing costs		$ 0.11	
					Total other variable costs		$ 0.33	
Regional Adjustments (as % of national price)					Interest (long term, operating, and deficit)	Stoch	$ 0.17	
Ethanol Price		0.04						
DDGS Price		-			Total Variable Costs	Stoch	$ 2.87	
Natural Gas		0.07						
Electricity Price		0.65			**Net Returns (per gal of ethanol in 2008)**	Stoch	$ 0.08	
Gas Prices		0.10						
Corn Prices		0.27						
Corn Transportation costs	Stoch	1.01	$/bu					

Table 24. Summary Table of the Deterministic National Price Forecasts Used

Ethanol Model Summary Sheet Deterministic National Prices					
	Ethanol Price	Natural Gas Price	Electric Price	Gas Price	Corn Price
	$/gal	$/MCF	$/KWH	$/gal	$/bu
2008	1.91	10.97	5.58	1.64	3.93
2009	1.96	11.39	5.64	1.71	3.93
2010	2.02	11.81	5.71	1.78	3.89
2011	2.07	12.22	5.78	1.85	4.05
2012	2.13	12.64	5.84	1.93	4.14
2013	2.18	13.05	5.91	2.00	4.27
2014	2.24	13.47	5.97	2.07	4.38
2015	2.29	13.89	6.04	2.15	4.37
2016	2.35	14.30	6.10	2.22	4.37
2017	2.40	14.72	6.17	2.29	4.34

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