Using Average Net Returns and Risk Measures to Compare Irrigation Management Strategies

by

FRANCES BRETZ

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Major Professor
Dr. Nathan Hendricks

ABSTRACT

Risk and uncertainty are inherent in agriculture especially when lack of precipitation needed for crop production is common. Precipitation in the High Plains is highly variable. To supplement precipitation, the Ogallala Aquifer, a large underground water storage reservoir, was developed for irrigation. However, as the saturated thickness of the aquifer decreases, the rate at which water can be extracted decreases (i.e., well capacities). Limited well capacities induce risk in agricultural production because producers may not be able to irrigate sufficiently in dry years.

This study's objective was to develop a method to assist producers in comparing alternative irrigation management strategies in the face of risk due to a limited well capacity. The objective was accomplished by simulating average net returns for 172 different irrigation strategies across 30 years (1986-2015) of historical weather (Kansas Mesonet 2016). Management strategies include different combinations of corn and wheat production under full irrigation, moderate irrigation, deficit irrigation, and dryland production. Three risk measures were applied to the average net returns: Value at Risk (VaR), expected shortfall, and standard deviation.

The risk-return tradeoff is estimated for management strategies for two well capacities, 300 GPM (gallons per minute) and 600 GPM. Estimating these risk measures can help producers better evaluate the best irrigation strategy compared to the approach of only comparing average net returns.

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ACKNOWLEDGEMENTS

I promised myself that I would earn my Masters degree; however, time slipped by until I embarked on the journey in January 2015. It is now May 2017 and I will graduate with a Master of Agribusiness (MAB) from Kansas State University at age 63.

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I want like to thank so many family and friends who encouraged me during this 2½ years to "cross that MAB finish line!" They are too numerous to name for fear I may miss just one important person.

DEDICATION

I wish to dedicate this thesis to two people important in my life. They are my sister and brother-in-law, Natalie and William Steffens. Always encouraging and always giving in any way possible.

I also want to dedicate this thesis to Leon New, Agricultural Engineer, who was a colleague for 12 years at Texas A&M AgriLife Research and Extension Center at Amarillo. He has been a mentor and friend for many years.

CHAPTER I: INTRODUCTION

The Ogallala Aquifer is an underground water storage reservoir. This 174,050 square mile aquifer stretches beneath the Great Plains in portions of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. Specifically, 30,500 square miles of the semi-arid region of western Kansas lie above the aquifer (Dugan et al. 1994).

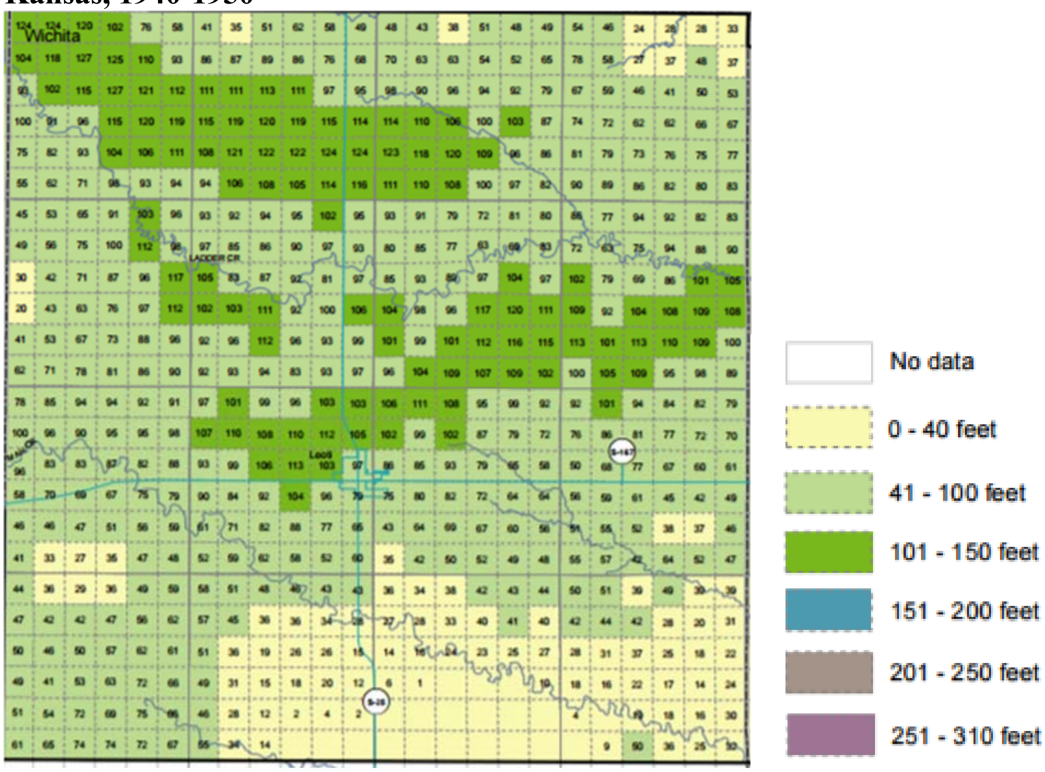
Depletion of the Ogallala Aquifer is occurring because the rate of extraction exceeds the rate of recharge in many areas of this reservoir. This study's primary objective is to develop a method to assist producers in assessing the risk of implementing alternative irrigation strategies for corn and wheat. The objective is accomplished by simulating average net returns for each irrigation strategy. To evaluate uncertainty, three risk measures are used: Value at Risk (VaR), expected shortfall, and standard deviation.

1.2 Study Focuses on Wichita County, Kansas

Although the Ogallala Aquifer spans thousands of acres, this study focuses on Wichita County in western Kansas comprised of 719 square miles (U.S. Census Bureau 2010). Agriculture is the principal source of income and precipitation can be a constraint due its variability within the year and from year-to-year. For example, during the 30 year period from 1986 to 2015, annual precipitation averaged 18.61 inches, but these quantities varied from 8.26 inches in 2012 to 27.10 inches in 1993 (Kansas Mesonet 2016).

With several decades of irrigated agriculture development and intermittent precipitation, a series of steps have occurred in Wichita County, Kansas, with regards to irrigation and the aquifer. Predevelopment of the Ogallala Aquifer (1940-1950) revealed a saturated thickness, “defined as the distance from the water table to the base of the aquifer” (McGuire et al. 2012), at 101 to 150 feet (dark green) in the northern and central sections of the county. Surrounding these locations, the saturated thickness was between 41 feet to100 feet (light green). A small portion of the county predominantly to the south had a saturated thickness of 0 to 40 feet (beige) (Kansas Geological Survey 2016) (Figure1.1).

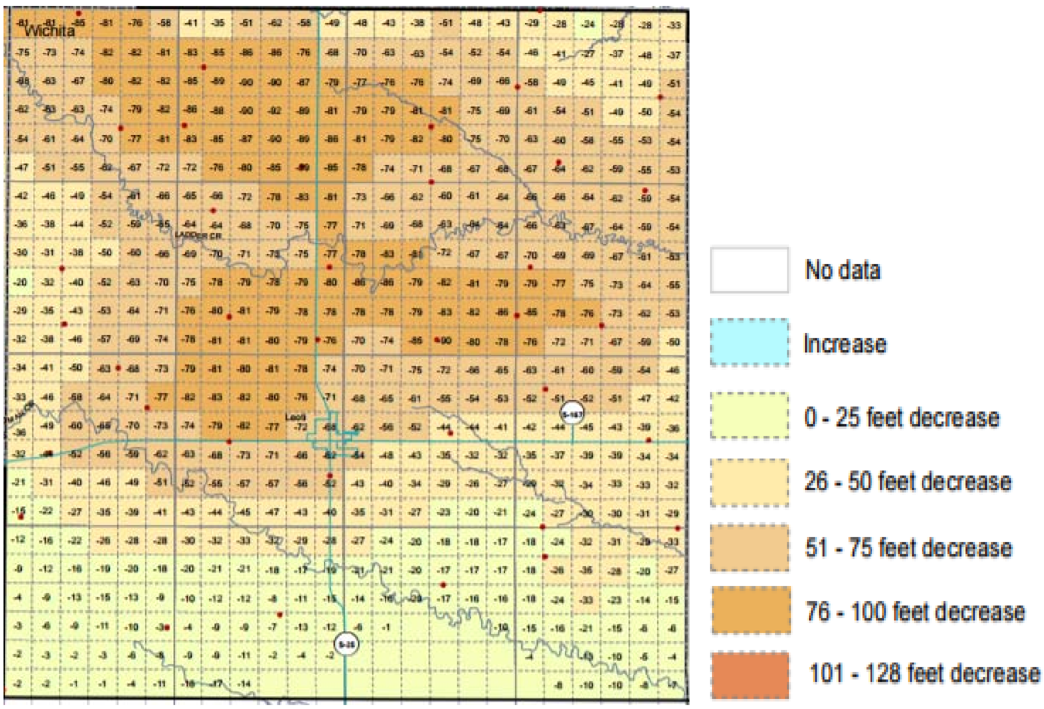
Figure 1.1 Estimated predevelopment of saturated thickness in Wichita, County Kansas, 1940-1950



Source: Kansas Geological Survey 2016

The average saturated thickness for 2014-2016 in the same regions, northern and central Wichita County, showed a decrease of between 76 to 100 feet (dark beige). Surrounding these sectors, the saturated thickness decreased from 51 to 75 feet (light beige). The remainder of the county experienced a 20 to 50 feet decrease with no areas showing an increase in saturated thickness (Kansas Geological Survey 2016) (Figure 1.2).

Figure 1.2 Estimated changes in saturated thickness in Wichita County, Kansas, 2014-2016



Source: Kansas Geological Survey 2016

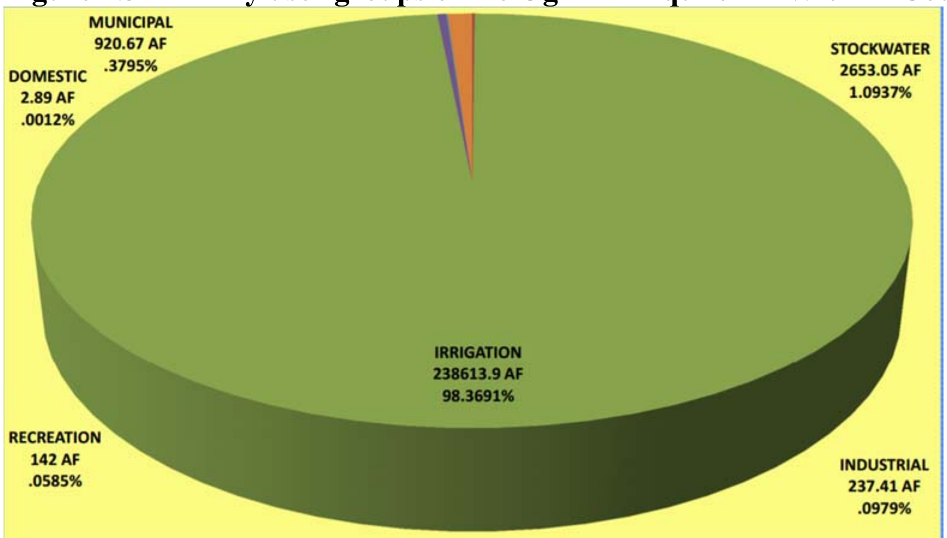
The history of the decline in saturated thickness of the Ogallala Aquifer in Wichita County, Kansas dates back to predevelopment of irrigation. Predevelopment is considered the time period before the aquifer was mined for fresh water in the 1940s and 1950s. A study conducted in 1954 showed there was no aquifer depletion concerns because precipitation, recharge, and withdrawal were virtually in balance, and there was little danger of lowering the water table (Prescott et al. 1954). Twenty-two years later, in 1976, a report declared the water level had declined to a level that dryland production would once again become the prominent method of farming (Slagle and Weekly 1976).

Subsequently in 1980, it was reported the Ogallala had declined by 30% to 50% in sections of Wichita County (Dunlap 2000). It was determined in 2000 that some areas overlying the aquifer in Wichita County had been completely depleted (Buchanan and Buddemeir 2001).

Data presented at the Wichita County Water Conservation Area Annual Meeting (2017) showed 65% of the Ogallala Aquifer is depleted in Wichita County. On March 27, 2017, a consent agreement was signed between the State of Kansas before the Division of Water Resources Kansas Department of Agriculture and the Wichita County Water Conservation Area, a voluntary group of water right owners. This Water Conservation Area has set goals to conserve the aquifer "by decreasing 29% of water usage in seven years (2017-2023), which increases to 36% over the next seven years (2024-2030). That's followed by a 43% reduction (2031-2037) and a 50% reduction (2038-2044)."

Figure 1.3 shows primary users of water from the Ogallala Aquifer in Wichita County, Kansas. According to the Western Kansas Groundwater Management District No. 1 Informational meeting in 2012, 242,428 acre-feet (ac-ft) are used by Wichita County, Kansas annually. The five user groups are as follows: domestic at 2.89 (ac-ft.) or 0.001%, municipal at 920.67 ac-ft. or 0.38%, stockwater at 2,653.05 ac-ft. or 1.09%, industrial at 237.41 ac-ft. or 0.09%, recreation at 142.00 ac-ft. or 0.05%, and irrigation at 238,613.90 ac-ft. or 98.36%.

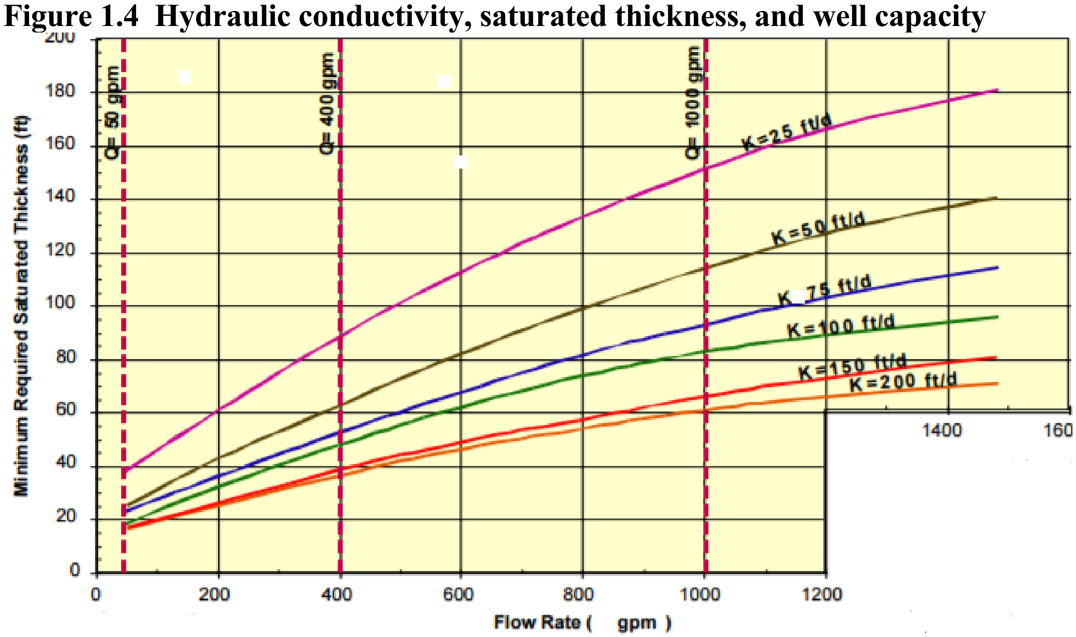
Figure 1.3 Primary user groups of the Ogallala Aquifer in Wichita County, Kansas



Source: Kansas Geological Survey 2012

Figure 1.4 developed by the Kansas Geological Survey (2002) describes irrigation well capacity in relation to Ogallala Aquifer saturated thickness. It indicates that with a saturated thickness of 70 feet, the pumping flow rate would be 600 GPM. If the saturated thickness decreases to 50 feet, then the flow rate decreases to 300 GPM.

Figure 1.4 Hydraulic conductivity, saturated thickness, and well capacity



Source: Kansas Geological Survey 2002

1.2 Thesis Outline

Chapter II of this thesis addresses current literature relevant to irrigation and the depletion and its effects on saturated thickness on the Ogallala Aquifer. It discusses maximizing net returns, maximizing average yield per unit of water, and maximizing yield. This chapter also discusses risk aversion behavior of producers when choosing irrigation strategies for corn and wheat in Wichita County, Kansas. Chapter III examines portfolio theory, average net returns, and three risk measures: Value at Risk (VaR), expected shortfall, and standard deviation. Chapter IV explains the data sources and the methods used to develop the average net returns for each irrigation strategy and their corresponding risk measures. Chapter V presents the 10 highest average net returns on irrigation strategies at 300 GPM and 600 GPM and portfolios including full irrigated corn, moderately irrigated corn, deficit irrigated corn, dryland corn, full irrigated wheat, moderately irrigated wheat, deficit irrigated wheat, and dryland wheat. Chapter VI summarizes the key findings from the research.

CHAPTER II: LITERATURE REVIEW

There are many studies that concentrate on the depletion and saturated thickness of the Ogallala Aquifer. There are also studies that examine how irrigation strategies affect the producer's average net returns. However, the following review of the literature discusses producer risk when saturated thickness declines causing the depth to the water table to increase. When this occurs, pumping costs increase because well capacity decreases thereby limiting the water supply (Ding and Peterson 2012).

Boggess et al. (1983) used a process simulation model to determine a producer's response to irrigation strategies for soybeans when subjected to risk and uncertainty. Risk assessment used two measures: (1) amount of water applied per application and (2) level of soil moisture at which irrigation is applied, known as irrigation threshold. The objectives targeted were maximizing net returns, maximizing average yield per unit of water, and maximizing yield. Different irrigation strategies optimized each of these objectives. It was determined that net returns were maximized with soil moisture at 70% and applying 1 centimeter (cm) of water per application yielding an expected return of $553.36/hectare. The maximum yield was attained with a 90% irrigation threshold and application of 1 cm of water resulting in net returns of $235.38/hectare, a decrease of $58/hectare as compared to the maximum net returns ($553.36-$295.38). The maximum yield response per unit of irrigation water was a 50% irrigation threshold and 2 cm-application. This strategy used only 40% as much irrigation water as the maximum returns strategy. However, the expected yield was approximately 505 kg lower and the expected net returns were $57.81/hectare lower that the maximum returns simulation ($553.36-$495.55). Boggess found a different optimal irrigation strategy for alternative objectives.

Peterson and Ding (2005) developed a risk-programming translog model for corn based on irrigation timing and the influence of risk-averting behavior on irrigation choices. An engineering formula was used to develop the irrigation constraints for the four growth stages: preplant, vegetative, flowering, and ripening. Three irrigation efficiency systems, flood, sprinkler, and drip were used with well capacities at 300 GPM and 500 GPM.

Using a sprinkler system at 300 GPM, the engineering formula calculated the upper irrigation at 5.80 inches/acre for the preplant stage. The risk neutral producer applied 2.89 inches/acre; whereas, the risk averse individual applied 1.90 inches/acre. While the overall seasonal irrigation constraint was limited to 24.00 inches/acre, the risk neutral producer applied a total of 19.28 inches/acre, and the risk adverse producer applied a total of 18.07 inches/acre. Producers were constrained by the low-capacity well of 300 GPM and not the legal limit of 24.00 inches/acre.

Using a sprinkler system at 500 GPM, the engineering formula constrained the irrigation application rate at 12.61 inches/acre for the vegetative growth stage. At this stage, the risk neutral producer applied 11.10 inches/acre; whereas, the risk averse producer applied 7.51 inches/acre. Risk aversion leads a producer to restrict water application during the production phase (Peterson and Ding 2005).

Wilbowo et al. (2017) studied optimal irrigation management by risk adverse producers when faced with limited water availability. AquaCrop, a daily specific crop model, is used to simulate corn yield under alternative irrigation scenarios with historical weather data (1986-2015) in Southwest Kansas. This study maximized of expected utility analyzing the optimal irrigation for a specific risk aversion coefficient.

The optimal water application use is dependent on the risk premium a producer is assigned. Results show greater risk aversion results in more water use. A moderate well capacity of 138 m^3/hr causes a producer with a 20% risk premium to increase water use by 30%. With a 20% risk premium and 207 m^3/hr, the producer increases water use by 15%. Models that do not consider risk may be underestimating water use causing greater depletion to the aquifer (Wilbowo et al. 2017).

CHAPTER III: THEORY

3.1 Decision Making Process

Boggess et al. (1983) best describe the decision making process in three steps: (1) "an objective or decision criterion, (2) a set of alternative choices, and (3) a set of costs, constraints, and benefits which limit the choice set." A producer's objective is often thought of as earning the highest average net returns by growing crops with constraints such as weather, availability of water, and precipitation.

3.2 Portfolio Theory

For this study, the decision making process begins with building an understanding of portfolio theory that was developed in the 1950s by Harry Markowiwtz as a tool for evaluating and investing in a group of assets (Markowitz 1952). The concept is used for the diversification of assets with the goal of maximizing return while minimizing risk. While this method is used predominantly in finance, the system has been applied to irrigation management. Investment and water managers face similar dilemmas - quantifying a finite resource – money or water. In the finance world, portfolio theory reduces risk by developing a set of diversified investments. This study applies portfolio theory to select a portfolio of crops and irrigation strategies to earn the highest average net returns given a level of producer risk (Paydar and Quershi 2011).

3.3 Average Net Returns

The model in this thesis simulates annual average net returns to land for corn and wheat, dryland and irrigated on a 125-acre center pivot field. This is done to determine the optimum portfolio crop mix and irrigation strategies using 30 years of historical weather (1986-2015) (Kansas Mesonet 2016).

3.4 Risk Measures

The next step involved building an understanding of risk measures (assigning values) to evaluate a portfolio of crops (corn and wheat) and irrigation strategies simulated for 300 and 600 gallon per minute wells. Three measures applied to the average net returns are standard deviation, Value at Risk (VaR), and expected shortfall.

3.5 Standard Deviation

Standard deviation is a measure of the dispersion of average net returns from the mean. With a large standard deviation, the values are widely dispersed from the mean. According to the New York University Stern School of Business (2001), with a small standard deviation, the values are concentrated or focused closer to the mean. Advantages of this tool are that it takes into account all values and is a good measure for a normal distribution. The disadvantages are upside deviations are weighted equally as downside, but what matters most to producers are the downside risks. In a non-normal distribution, the large downside risk may not be fully represented using standard deviation.

3.6 Value at Risk (VaR)

Markowitz's (1952) portfolio theory is the mathematics behind "Value at Risk" (VaR). Damodaran (2007) states "this measure was used in 1980 when the Securities and Exchange tied the financial service firms to the losses that would be incurred, with 95% confidence over a thirty-day interval. In the financial world, this (1) measures the potential loss in value of an asset, (2) over a defined period, and (3) for given confidence level."

According to Jorion (2001), "Value at Risk measures the worst expected loss over a given horizon at a given level of confidence." In this study, Value at Risk is a (1) measure of the potential gain or loss in the value of a crop, (2) representing the sequence of 30 years

(1986-2015) of net returns by using different outcomes for the past precipitation, and (3) at a selected confidence levels.

Historical simulation, variance-covariance, and Monte Carlo simulation are three methods to measure VaR. In this study, historical simulation is used based on the following criteria:

(1) Calculated using 30 years of rainfall data (1986-2015), where no "underlying assumptions of normality are driving the conclusion,"

(2) "Each year was equally weighted; however, reliance on past data may cause a potential problem if there is a trend in the underlying distribution of weather."

(3) Analyses were based on history repeating itself forward" (Damordaran 2007).

(4) The advantage of this historical simulation is the weather data are available for Wichita County, Kansas. On the other hand, a disadvantage is that there are only 30 years of data available (1986-2015).

(5) Value at Risk captures the downside risk that is not taken into account using standard deviation.

3.7 Beyond Value at Risk: Expected Shortfall

One important measure of risk, Value at Risk (VaR), answers the question "What is the return such that potential returns will only be worse $p \times 100\%$ of the time in all potential weather scenarios?" The limitation of VaR is that it does not indicate the magnitude of losses exceeding the VaR. (An example of magnitude of losses exceeding the VaR is presented in Chapter V: Results.) For example, it could be that all potential returns "less than VaR would be close to the VaR or if there is a fat tail to the distribution, there could be a non-negligible probability of much more severe losses." The expected shortfall is an alternative measure of risk that addresses this limitation. Expected shortfall measures the expected return conditional on returns less than the VaR (Christoffersen 2003) and is simply an average of the three VaR values.

CHAPTER IV: DATA AND METHODS

This study's primary objective is to develop a method to identify, quantify, and evaluate the producer's risk of implementing a portfolio of alternative irrigation strategies for corn and wheat in Wichita County, Kansas. It was accomplished by simulating average annual net returns for each strategy. Three risk measures were applied to the average net returns: Value at Risk (VaR), expected shortfall, and standard deviation.

4.1 Alternative Irrigation Strategies

To determine alternative irrigation strategies and their average net returns, an annual crop simulation model was developed from data based on Wichita County, Kansas. To determine the crop portfolios, planted irrigated acres of corn for grain, sorghum, soybeans, and wheat were obtained from the *Census of Agriculture* for 2012 (USDA NASS 2012). Of the total 2,129 planted soybean acres, there were 779 irrigated acres with 1,350 dryland acres in 2012. There were 3,477 planted irrigated sorghum areas with 35,629 planted dryland sorghum acres. Because of the small number of irrigated acres for soybeans and sorghum, these crops were not used in the study (USDA NASS 2012) (Table 4.1).

Corn for grain and wheat were used in this report because these crops represented a majority of the irrigated acres in 2012. Of the total 40,630 planted corn for grain acres, 25,423 acres were irrigated corn acres with 15,207 planted dryland acres. Of the total 135,947 planted wheat acres, 31,452 were irrigated acres with 104,495 planted dryland acres (USDA NASS 2012) (Table 4.1).

Table 4.1 Irrigated and dryland acres for Wichita County, Kansas, 2012

Crop	Year	Total Acres	Irrigated Acres	Dryland Acres
Corn for Grain	2012	40,630	25,423	15,207
Sorghum	2012	39,106	3,477	35,629
Soybeans	2012	2,129	779	1,350
Wheat	2012	135,947	31,452	104,495

Two sources were utilized to determine three levels of irrigation, full, moderate, and deficit. The first source was the *Farm Management Guides* developed by Kansas State University Agricultural Experiment Station and Cooperative Extension for the 2015 growing season (Ibendahl et al. 2015) (Table 4.3). The second source, Peterson and Ding (2005), reported "…24 inches of irrigation is a typical authorized use in a groundwater right in western Kansas for corn." Based on these sources, full, moderate, and deficit irrigated corn were 24 inches/acre, 18 inches/acre (24*75%), and 12 inches/acre (24*50%), respectively. Irrigation application rates of 12 inches/acre, 9 inches/acre (12*75%), and 6 inches/acre (12*50%) were used for full, moderate, and deficit irrigated wheat, respectively (Table 4.2).

Table 4.2 Parameters for crop model simulation for Wichita County, Kansas

Crop	Irrigation Quantity, in	Projected Yield, bu/ac	Price/ bushel	Production Costs ($/ac)	Pumping Cost/acin	300 GPM	500 GPM
Full Irrigated Corn[1]	24	250	$4.25	$817.99	$5.26	12.73	25.45
Moderate Irrigated Corn[1]	18	210	$4.25	$739.84	$5.26	12.73	25.45
Deficit Irrigated Corn[1]	12	173	$4.25	$649.98	$5.26	12.73	25.45
Dryland Corn[2]	-	77	$4.25	$310.30	-	-	-
Full Irrigated Wheat[1]	12	80	$5.72	$388.33	$5.26	12.73	25.45
Moderate Irrigated Wheat[1]	9	65	$5.72	$358.01	$5.26	12.73	25.45
Deficit Irrigated Wheat[1]	6	50	$5.72	$330.75	$5.26	12.73	25.45
Dryland Wheat[2]	-	51	$5.72	$258.61	-	-	-

[1]Production costs exclude land rent and natural gas cost
[2] Production costs exclude cash rent
Source: Ibendahl et al. 2015

Two well capacities were used in this study, 300 gallons per minute (GPM) or 12.73 inches and 600 GPM or 25.45 inches (Table 4.2). At a well capacity of 300 GPM, 12.73 inches is the maximum amount of water that is applied in a growing season. This calculation is as follows:

$$inches/acre = ((GPM * time/(27{,}154/125)),$$

where, GPM is gallons per minute. The calculation assumes 27,154 gallons equal an acre-inch and water is pumped for 2,400 hours during the growing season.

This analysis is based on a 125-acre center pivot field producing corn and/or wheat with four possible land use combinations including: 100%, 50%/50%, 25%/75%, and 75%/25% (Table 4.3). The land uses are full irrigated corn, moderately irrigated corn, deficit irrigated corn, dryland corn, full irrigated wheat, moderately irrigated wheat, deficit irrigated wheat, and dryland wheat.

Possible land use option examples follow. One land use (100%) is to plant one crop over the entire field with a single irrigation strategy (e.g., 125 acres of full irrigated corn). Another possible land use is planting 25% of the field with one crop and irrigation strategy (e.g., 31.25 acres of moderately irrigated corn) and 75% to another crop and irrigation strategy (e.g., 93.75 acres of deficit irrigated wheat). A third land choice is to plant 50% of the field in one crop and irrigation strategy (e.g., 62.50 acres to full irrigated wheat) and 50% to another crop and irrigation strategy (e.g., 62.50 acres of moderately irrigated wheat). The final strategy example is planting 75% of the field to dryland corn and 25% of the field to deficit irrigated corn (Table 4.3).

Table 4.3 Land use options in percentages

Land Uses (%)	Land Use 1 (%)	Land Use (2%)
100	100	0
100	0	100
25/75	25	75
50/50	50	50
75/25	75	25

Howell et al. (2012) described land uses in irrigation allocation as spreading and concentrating water. Spreading signifies stretching the water source over a large number of acres with the thought being that precipitation will be plentiful enough to make up the difference. In this study, the best examples of this would be 100% irrigated corn or 100% irrigated wheat. Concentrating water means allocating the water over a smaller number of acres. An example in this study is 50% irrigated corn at 300 GPM and 50% dryland corn. The 12.73 inches of irrigated water would be applied to half of the circle with the remaining acres dependent on precipitation only.

4.2 Calculation of Net Returns

To determine the portfolio of optimum irrigation strategies for corn and wheat, net returns to land were calculated for 30 years of historical weather (1986-2015). The following formula was used to calculate net returns for a given crop with a particular year of historical weather:

$$NR_{jt} \ = p_j \ f_j\left(nirr_{jt}, prec_t\right) - w \cdot airr_{jt} - k_j(airr_j),$$

where, NR_{jt} is the net returns for crop j with historical weather from year t, p_j is the price of crop j, $f(\cdot)$ is the production function that determines yield, $nirr_{jt}$ is the net irrigation for crop j in year t, $prec_t$ is the precipitation in inches in year t, w is the cost per acre of applied water, $airr_{jt}$ is applied inches of irrigation for crop j in year t, and k_j is the production costs for crop j.

Based on the *Farm Management Guides* for 2015, crop prices (p_j) of $4.25 per bushel for corn and $5.72 per bushel for wheat were used (Ibendahl et al. 2015) (Table 4.3). These prices were based on "expected harvest price" in western and southwestern Kansas. Price forecasts were the futures market adjusted to the historical basis, "where basis equals cash price minus futures price" (Ibendahl et al. 2015).

Dr. Nathan Hendricks developed crop production functions using Stata Statistical Software to determine predicted yield for corn and wheat. These functions were based on the interaction of yield and annual precipitation between 7 and 27 inches in no specified increments. The production function for corn ($f_{corn}(\cdot)$) is:

$$y = \max(\min(-157.9887 + 20.73612nirr - 0.2900359\,nirr^2 + 1.977787prec^2 - 0.4966157 * In(prec) * prec^2 - 0.0000205 * (nirr * prec)^3 + 0.0000309 * In(nirr * prec) * (nirr * prec)^3, 211) * 1.19), 0),$$

where, $nirr$ is net irrigation and $prec$ is the precipitation in inches. The predicted yield is constrained, so that it does not exceed 211*1.19 bushels per acre (bu/ac) and so that yield cannot be negative. These constraints are incorporated into the production function to prevent implausible yield values at the extremes resulting from the nonlinearity of the function. The production function for wheat ($f_{wheat}(\cdot)$) is:

$$y = \max(\min(-58.10471 + 8.075576nirr - 0.1041257nirr^2 + 0.9682407prec^2 - 0.2498325 * In(prec) * prec^2 - 0.0009477 * (nirr * prec)^2 + 0.00000121 * (nirr * prec)^3, 75), * 1.30), 0).$$

The predicted yield does not exceed 75*1.30 bu/ac and is constrained to be non-negative.

These crop production functions were estimated using simulations of net irrigation, precipitation, and crop yields reported by Stone et al. (2005). The production functions were estimated using a flexible econometric model because the original Stone data only reported predicted yields for precipitation between 11 and 21 inches in one inch increments, but precipitation in this study was sometimes outside this range. The production functions also provide estimates of predicted yield for different levels of precipitation.

The Stone et al. (2005) simulations attributed to data obtained from the *Farm Management Guides* at 250 bu/ac; therefore, the corn function in this model was multiplied by 1.19 (250 bu 2015 yield / 211 bu 2005 yield) to update for increased yields in the past decade. For wheat, the Stone et al. (2005) simulations were also based on 2005 data with wheat yields at 60 bu/ac. The 2015 wheat yields were also coming from data obtained from the *Farm Management Guides* at 80 bu/ac; therefore, the wheat function was also updated by multiplying by 1.30 (80 bu 2015 yield / 60 bu 2005 yield (Ibendahl et al. 2015).

The Stone crop production functions, developed by Kansas State University in 2005, are research based yield functions for irrigated crops in western Kansas and are used in the Crop Water Allocator (CWA). The CWA calculates average net returns attributed to "iterations of all possible combinations of the water allocations by 10% increments from 11 to 21 inches of irrigation over possible crop combinations and chosen land divisions" (Klocke 2006). The average net return results are based on average rainfall with no consideration for risk.

Thirty years of simulations were completed using annual precipitation ($prec_{jt}$) for Wichita County, Kansas obtained from the weather data library at Kansas Mesonet for 1986-2015, where *prec* is precipitation of crop *j* in year *t*. Average annual rainfall was

18.61 inches with the maximum of 27.10 inches occurring in 1993 and a minimum of 8.26 inches in 2012. Details of rainfall data are in Appendix A.

Applied irrigation varied depending on the amount of precipitation in a given year. The 30 years of rainfall data (1986-2015) were incorporated into the following applied irrigation formula:

$$airr_{jt} = \overline{airr_j} - 0.5(\text{prec}_t - \overline{\text{prec}}),$$

where, $airr_{jt}$ is applied irrigation for crop *j* in year *t*, $prec_t$ is precipitation in year *t*, and $\overline{prec}$ is average precipitation for 30 years. Average applied irrigation ($\overline{airr_j}$) is based on the alternative irrigation strategies being simulated, full, moderate, or deficit irrigation for corn for grain or wheat (Table 4.2). The value of -0.50 means for every additional inch of precipitation, the producer applies -0.50 inches less water. Using the parameter value of -0.50 is based on the econometric estimates of Mieno (2014).

Irrigation application efficiency rates vary by system type. For this study, 90% efficiency was assumed for a system with heads positioned within the crop canopy (Klocke 2006) and used in the following net irrigation formula below:

$$nirr_{jt} = airr_{jt} * 0.90,$$

where, $nirr_{jt}$ is the net irrigation for crop *j* in year *t*, $airr_{jt}$ is applied inches of irrigation for crop *j* in time *t*, and 0.90 is 90% efficiency for the irrigation system. Note that the production function depends on net irrigation, whereas, production costs depend on applied irrigation.

In the model, well capacity is constrained at 300 GPM and 600 GPM. Three hundred gallons per minute allows the irrigator to pump 12.73 inches during the growing season. Therefore, when there is a single land use (for example, moderate corn), the water applied is the smallest of the applied irrigation calculation or the limited well capacity. For two land uses, water is applied to the first land use with excess water remaining applied to the second land use.

Production costs (k_j) were obtained from *Farm Management Guides* for the 2015 growing season (Ibendahl et al. 2015) (Table 4.2). These costs consisted of seed, herbicide, insecticide/fungicide, fertilizer and lime, crop insurance, crop consulting, drying, miscellaneous, custom hire/machinery expense (repair, maintenance, and interest), non-machinery labor, irrigation labor, and non-land interest cost. Cash rent and natural gas costs were excluded from the budget.

Production costs (k_j) varied depending on projected crop yield and water application. Under full irrigation (24 inches) for corn, these costs were estimated at $817.99/acre. Under moderately irrigated corn (18 inches), the production costs were estimated at $739.84/acre. Deficit irrigation (12 inches) resulted in a decrease of production costs to $649.98/acre. Dryland corn had production costs of $310.30/acre (Table 4.2).

Full irrigated wheat (12 inches) production costs were estimated at $388.30/acre. Wheat under moderate irrigation (9 inches) had production costs of $358.01/acre. Deficit irrigation (6 inches) resulted in production costs of $330.75/acre. Dryland wheat production costs were predicted at $258.61/acre (Table 4.2).

Pumping costs (*w*) were assumed at $5.26/acre-inch and obtained from the *Farm Management Guides* for the 2015 growing season (Ibendahl 2015). When the constraint of 300 GPM is binding, 12.73 inches are applied during the growing season at a cost of

$66.69. When the constraint of 600 GPM is binding, 25.45 inches are applied during the growing season at a cost of $133.87 inches.

4.3 Risk Measures

After average net returns for 30 years were calculated, Value at Risk (VaR), expected shortfall, and standard deviation were determined across the 30 different average net returns to measure risk for each land use portfolio. The three VaR measures were 1/30 VaR as the lowest average net return, 2/30 VaR as the second lowest average net return, and 3/30 VaR as the third lowest average net return. Expected shortfall was calculated as the average of the three VaR values. Standard deviation was determined across all 30 estimates of average net returns to determine variation.

CHAPTER V: RESULTS

5.1 Introduction

Evaluation of producer's risk of implementing alternative irrigation strategies for corn for grain and wheat in Wichita County, Kansas is the major objective in this thesis. It is accomplished by simulating average annual net returns for each portfolio. Three risk measures are applied to the average net returns: Value at Risk (VaR), expected shortfall, and standard deviation.

The full set of results for the 172 irrigation strategies analyzed are located in Appendices D (300 GPM) and E (600 GPM). This chapter reports tables with key subsets of these findings for Wichita County, Kansas. These include the following: Irrigation Strategies at 300 GPM and Alternative Land Uses, Irrigation Strategies at 600 GPM and Alternative Land Uses, Irrigation Strategies at 300 GPM and 100% Land Use, Irrigation Strategies at 600 GPM and 100% Land Use, and Dryland Corn and Wheat Production at 100% Land Use.

5.2 Irrigation Strategies at 300 GPM and Alternative Land Uses in Wichita County, Kansas

Table 5.1 shows the results for irrigation strategies with the 10 highest average net returns given a well capacity of 300 GPM (i.e., 12.73 inches/acre). An interpretation of the table columns is presented for the first row. The irrigation strategy is deficit irrigated corn. One hundred percent land use signifies only corn is grown and results in average net returns over 30 years of $166.99/acre. The estimated Value at Risk (VaR) amounts are as follow: -$213.95/acre for 1/30 VaR indicating the worst year in average net returns, -$47.79/acre for 2/30 VaR signifying the second worst year in average net returns, and -$17.84/acre for 3/30 VaR meaning the third worst year in average net returns. Expected shortfall, average of 1/30, 2/30, 3/30 VaR values, is -$93.19/acre. The standard deviation is $117.73/acre (Table 5.1).

Based on ranking the portfolios only on average net returns, the optimum irrigation strategy in this group is deficit irrigated corn (100%). However, the producer needs to evaluate risk measures to identify and analyze the potential of reduced average net returns, or the risk/reward factor. The first two lines in Table 5.1 demonstrate this scenario. The second strategy is deficit irrigated corn / deficit irrigated wheat (75%/25%) and has lower estimated average net returns of $147.93/acre, but less exposure to risk at -$93.42/acre for 1/30 VaR, -$3.37/acre for 2/30 VaR, -$25.25/acre for expected shortfall, and standard deviation at $80.00/acre. Less risk is accompanied by earning less average net returns of $19.06/acre in the second portfolio ($166.99-$147.93) (Table 5.1).

Even though moderately irrigated corn / deficit irrigated corn (25%/75%) has reasonable average net returns at $139.41/acre, it may not be a preferred strategy based on risk measures. Of the 10 portfolios studied, it has the lowest 1/30 VaR at -$290.87/acre, the lowest 2/30 VaR at -$115.59/acre, the lowest 3/30 VaR at -$83.65/acre, the worst expected shortfall at -$163.37/acre, and highest standard deviation at $141.38/acre (Table 5.1).

There are instances where the risk measures do not agree. When there is not an obvious preferred strategy, the producer may need to use intuition. This is demonstrated in Table 5.1. Deficit irrigated corn / dryland wheat (75%/25%) yields the most favorable 1/30 VaR at -$75.24/acre, and deficit irrigated corn / deficit irrigated wheat (50%/50%) has the most satisfactory 2/30 VaR at -$0.72/acre. Deficit irrigated corn / deficit irrigated wheat (75%/25%) has the most acceptable 3/30 VaR at $21.03/acre and expected shortfall at -$25.25/acre. Deficit irrigated corn / deficit irrigated wheat (50%/50%) projects the smallest standard deviation at $69.91/acre (Table 5.1).

In Chapter III, it was noted that a limitation of VaR is that it does not indicate the magnitude of losses exceeding the Value at Risk (VaR). An example is warranted to explain this statement. In Table 5.1, moderately irrigated corn / deficit irrigated corn (25%/75%) shows a 3/30 VaR of -$83.65/acre. If only examining this one risk factor, the producer does not have information that the worst outcome in average net returns (1/30) is -$290.87/acre and the second worst outcome (2/30) in average net returns is -$115.59/acre. The expected shortfall for this portfolio takes those values into consideration and shows the extent or average magnitude of the loss being -$163.37/acre (Table 5.1).

Table 5.1 Ten irrigation portfolio strategies and land uses (%) ranked highest to lowest in average net returns with their corresponding risk measures, Value at Risk (VaR), expected shortfall, and standard deviation ($/acre) for 300 GPM, 12.73 inches, of water applied for Wichita County, Kansas

Irrigation Strategy	Land Use (%)	Average Net Returns ($/ac)	1/30 VaR ($/ac)	2/30 VaR ($/ac)	3/30 VaR ($/ac)	Expected Shortfall ($/ac)	Standard Deviation ($/ac)
Deficit Irrigated Corn	100	166.99	-213.95	-47.79	-17.84	-93.19	117.73
Deficit Irrigated Corn / Deficit Irrigated Wheat	75/25	147.93	-93.42	-3.37	21.03	-25.25	80.00
Deficit Irrigated Corn / Moderately Irrigated Wheat	75/25	147.43	-100.24	-10.18	14.21	-32.07	82.86
Moderately Irrigated Corn / Deficit Irrigated Corn	25/75	139.41	-290.87	-115.59	-83.65	-163.37	141.38
Deficit Irrigated Corn / Full Irrigated Wheat	75/25	135.49	-107.82	-17.76	6.63	-39.65	79.88
Deficit Irrigated Corn / Dryland Wheat	75/25	122.36	-75.24	-15.85	-5.63	-32.24	82.41
Deficit Irrigated Corn / Moderately Irrigated Wheat	50/50	114.77	-118.88	-8.25	9.98	-39.05	72.34
Deficit Irrigated Corn / Deficit Irrigated Wheat	50/50	113.08	-105.25	-0.72	11.57	-31.47	69.91
Moderately Irrigated Corn / Dryland Wheat	75/25	108.98	-142.63	-44.51	-28.03	-71.72	86.75
Deficit Irrigated Corn / Dryland Corn	75/25	105.17	-88.31	-28.92	-18.71	-45.31	87.76

5.3 Irrigation Strategies at 600 GPM and Alternative Land Uses in Wichita County, Kansas

There is a large spread in average net returns of the 10 irrigation strategies analyzed at 600 GPM (i.e., 25.45 inches/acre) (Table 5.2). In this study, moderately irrigated corn (100%) has the highest average net returns at $198.38/acre. Located midway within this group is deficit irrigated corn (100%) at $191.12/acre. Growing full irrigated corn / moderately irrigated corn (50%/50%) is at the lowest end of the spectrum with average net returns of $155.69/acre.

Moderately irrigated corn (100%) is the preferred irrigation strategy based on a majority of the evaluation components, average net returns and risk measures. This strategy yields the highest average net returns at $198.38/acre. The 1/30, 2/30, and 3/30 Value at Risk (VaR) values signify the least risky irrigation strategy at $90.49/acre, $131.49/acre, and $138.89/acre, respectively, with an expected shortfall of $120.29/acre. Standard deviation is the third smallest at $38.36/acre of the 10 portfolios studied (Table 5.2).

Producers making planting choices based on standard deviation alone may select an option with lower average net returns. Full irrigated corn / moderately irrigated corn (50%/50%) estimates the lowest standard deviation, $28.40/acre, but also the lowest average net returns, $155.69/acre, of the 10 portfolios studied. The second lowest standard deviation is $32.51/acre growing full irrigated corn / moderately irrigated corn (25%/75%) with average net returns of $177.33/acre (Table 5.2).

In this study, the five irrigation strategies based on largest average net returns vary by $7.26/acre ($198.38/acre to $191.12/acre) growing corn. These strategies are some combination of moderate irrigation at 18 inches/acre of water applied and deficit irrigation at 12 inches/acre of water applied, or 100% moderately irrigated corn, or 100% deficit irrigated corn (Table 5.2).

Even though the five irrigation portfolios differ minimally in terms of average net returns, the Value at Risk (VaR) and expected shortfall amounts vary significantly and in a stair-step fashion from each portfolio demonstrating additional risk. Moderately irrigated corn (100%) represents the least risk with an expected shortfall of $120.29/acre. Midway within this group is moderately irrigated corn / deficit irrigated corn (50%/50%) with an expected shortfall of $83.02/acre. At the bottom of this range, deficit irrigated corn (100%) demonstrates the highest risk at $45.76/acre.

Table 5.2 Ten irrigation portfolio strategies and land uses (%) ranked highest to lowest in average net returns with their corresponding risk measures, Value at Risk (VaR), expected shortfall, and standard deviations ($/acre) for 600 GPM, 25.45 inches, of water applied for Wichita County, Kansas

Irrigation Strategy	Land Use (%)	Average Net Returns ($/ac)	1/30 VaR ($/ac)	2/30 VaR ($/ac)	3/30 VaR ($/ac)	Expected Shortfall ($/ac)	Standard Deviation ($/ac)
Moderately Irrigated Corn	100	198.38	90.49	131.49	138.89	120.29	38.36
Moderately Irrigated Corn / Deficit Irrigated Corn	75/25	196.56	66.35	114.83	123.79	101.66	46.95
Moderately Irrigated Corn / Deficit Irrigated Corn	50/50	194.75	42.20	98.18	108.69	83.02	55.57
Moderately Irrigated Corn / Deficit Irrigated Corn	25/75	192.93	18.06	81.53	93.59	64.39	64.19
Deficit Irrigated Corn	100	191.12	-6.08	64.87	78.49	45.76	72.83
Full Irrigated Corn / Moderately Irrigated Corn	25/75	177.33	90.98	121.76	127.31	113.35	32.51
Full Irrigated Corn / Deficit Irrigated Corn	25/75	171.88	18.55	71.80	82.02	57.46	58.41
Moderately Irrigated Corn / Moderately Irrigated Wheat	75/25	160.52	48.66	88.86	96.40	77.97	41.40
Moderately Irrigated Corn / Deficit Irrigated Wheat	75 25	158.25	37.92	82.04	90.33	70.09	43.41
Full Irrigated Corn / Moderately Irrigated Corn	50/50	155.69	73.81	112.03	115.74	100.53	28.40

5.4 Irrigation Strategies at 300 GPM at 100% Land Use in Wichita County, Kansas

In this study, there is a large disparity in the eight irrigation strategies based on average net returns at 300 GPM (i.e.,12.73 inches/acre) and 100% land use (Table 5.3). (As a reminder, 100% land use means only one crop is grown on the 125-acre center pivot field.) Deficit irrigated corn ranks largest at $166.99/acre. Located midway within this group in average net returns is deficit irrigated wheat at $37.85/acre with dryland corn yielding a significant loss in average net returns of -$151.88/acre.

Planting choices based on evaluating risk measures may not provide the largest average net returns, but the producer may avoid some huge losses. Moderately irrigated wheat estimates lower average net returns at $45.88/acre. However, a majority of this irrigation strategy's risk measures project a much more favorable degree of risk than other portfolios in this group including: the highest 1/30 VaR at -$108.49/acre, the largest 2/30 at -$39.01/acre, and the largest 3/30 VaR at -$31.06/acre resulting in the most favorable expected shortfall of -$59.52/acre. This irrigation strategy also estimates the second lowest standard deviation at $53.76/acre (Table 5.3).

Evaluating risk measures can be used as an instrument in estimating significant losses. In this study, even though full irrigated corn projects positive average net returns at $23.65/acre, risk measures may lead to reconsidering this cropping practice. Without taking into account dryland corn and wheat production, this irrigation strategy estimates the most negative risk measures including: the lowest 1/30 VaR at -$381.96/acre, the lowest 2/30 VaR at -$215.80/acre, the lowest 3/30 VaR at -$185.85/acre, the lowest expected shortfall at -$261.20/acre, and the second largest standard deviation at $134.91/acre (Table 5.3).

Table 5.3 Eight irrigation portfolio strategies and 100% land use ranked from highest to lowest in average net returns with corresponding risk measures, Value at Risk (VaR), expected shortfall, and standard deviations ($/acre) for 300 GPM, 12.73 inches, of water applied for Wichita County, Kansas

Irrigation Strategy	Land Use (%)	Average Net Returns ($/ac)	1/30 VaR ($/ac)	2/30 VaR ($/ac)	3/30 VaR ($/ac)	Expected Shortfall ($/ac)	Standard Deviation ($/ac)
Deficit Irrigated Corn	100	166.99	-213.95	-47.79	-17.84	-93.19	117.73
Moderately Irrigated Corn	100	101.80	-303.81	-137.65	-107.70	-183.05	134.91
Moderately Irrigated Wheat	100	45.88	-108.49	-39.01	-31.06	-59.52	53.76
Deficit Irrigated Wheat	100	37.85	-119.79	-66.30	-55.35	-80.48	58.61
Full Irrigated Corn	100	23.65	-381.96	-215.80	-185.85	-261.20	134.91
Full Irrigated Wheat	100	-0.24	-138.81	-65.48	-54.17	-86.15	39.76
Dryland Wheat	100	-83.71	-258.61	-258.61	-258.61	-258.61	111.78
Dryland Corn	100	-151.88	-310.30	-310.30	-310.30	-310.30	141.30

5.5 Irrigation Strategies at 600 GPM and 100% Land Use in Wichita County, Kansas

In this study, there is a large spread in the eight irrigation strategies based on average net returns at 600 GPM (i.e., 25.45 inches/acre) and 100% land use (Table 5.4). Moderately irrigated corn ranks largest in net returns at $198.38/acre. Located midway within this group in average net returns is moderately irrigated wheat at $46.94/acre with dryland corn yielding a significant loss in average net returns of -$151.88/acre.

When reviewing production options in this study based on expected shortfall, there appears to be three primary options. As previously stated, moderately irrigated corn has the highest average net returns at $198.38/acre with the least degree of risk based on expected shortfall at $120.29/acre. The second strategy is full irrigated corn with average net returns at $113.40/acre and an expected shortfall at $80.36/acre. Even though the third choice, deficit irrigated corn, yields higher average net returns, $191.12/acre, it has a larger degree of risk at $45.76/acre (Table 5.4).

In this study, these results reveal irrigated corn as the preferred crop choice based on average net returns and risk measures. When reviewing the 1/30, 2/30, and 3/30 Value at Risk (VaR), and expect shortfall values for full, moderate, and deficit irrigated corn, there is only one negative value being -$6.09/acre (deficit irrigated corn). Wheat VaR values, 1/30, 2/30, and 3/30, yield all negative results from -$119.79/acre (deficit irrigated wheat) to -$31.06/acre (moderately irrigated wheat). The expected shortfall values range from -$43.51/acre (full irrigated wheat) to -$80.48/acre (deficit irrigated wheat) (Table 5.4).

Table 5.4 Eight irrigation portfolio strategies and 100% land use ranked highest to lowest in average net returns with their corresponding risk measures, Value at Risk

(VaR), expected shortfall, and standard deviations ($/acre) for 600 GPM, 25.45 inches, of water applied for Wichita County, Kansas

Irrigation Strategy	Land Use (%)	Average Net Returns ($/ac)	1/30 VaR ($/ac)	2/30 VaR ($/ac)	3/30 VaR ($/ac)	Expected Shortfall ($/ac)	Standard Deviation ($/ac)
Moderately Irrigated Corn	100	198.38	90.49	131.49	138.89	120.29	38.36
Deficit Irrigated Corn	100	191.12	-6.08	64.87	78.49	45.76	72.83
Full Irrigated Corn	100	113.40	55.03	91.56	94.48	80.36	18.68
Moderately Irrigated Wheat	100	46.94	-76.83	-39.01	-31.06	-48.97	50.85
Deficit Irrigated Wheat	100	37.85	-119.79	-66.30	-55.35	-80.48	58.61
Full Irrigated Wheat	100	4.55	-54.61	-39.64	-36.30	-43.51	28.10
Dryland Wheat	100	-83.71	-258.61	-258.61	-258.61	-258.61	111.78
Dryland Corn	100	-151.88	-310.30	-310.30	-310.30	-310.30	141.30

5.6 Dryland Corn and Wheat Production and 100% Land Use for Wichita County, Kansas

In this study, 100% land use for dryland corn and wheat production is significantly low in average net returns with high risk measure values. Corn has average net returns of -$151.88/acre with the 1/30, 2/30, and 3/30 Value at Risk (VaR), expected shortfall, and standard deviation values identical at -$310.30/acre. Average net returns for dryland wheat production are low at -$83.71/acre with the 1/30, 2/30, and 3/30 VaR, expected shortfall, and standard deviation values the same at -$258.61/acre (Table 5.5).

Low average net returns and large risk measures for dryland corn and wheat production is likely due to the low annual precipitation in four years out of the 30 years (1986-2015) in this study including: 1986 at 12.43 inches, 2010 at 12.37 inches, 2012 at 8.26 inches, and 2013 at 11.72 inches. In these cases, the yield was 0.00 bushels/acre that resulted in risk measures reflecting production costs, -$310.30/acre for corn and -$258.61/acre for wheat.

Table 5.5 Dryland corn and wheat production at 100% land use showing average net returns and their corresponding risk measures, Value at Risk (VaR), expected shortfall, and standard deviation ($/acre) during 4 years of low precipitation, 1986, 2010, 2012, and 2013 for Wichita County, Kansas

Year	Precipitation	Land Use (%)	Yield (bu/acre)	Production Costs ($/ac)	Average Net Returns ($/ac)	1/30 VaR ($/ac)	2/30 VaR ($/ac)	3/30 VaR ($/ac)	Expected Shortfall ($/ac)	Standard Deviation ($/ac)
Dryland Corn										
1986	12.43	100%	0.00	310.30	-151.88	310.30	310.30	310.30	310.30	310.30
2010	12.37	100%	0.00	310.30	-151.88	310.30	310.30	310.30	310.30	310.30
2012	8.26	100%	0.00	310.30	-151.88	310.30	310.30	310.30	310.30	310.30
2013	11.72	100%	0.00	310.30	-151.88	310.30	310.30	310.30	310.30	310.30
Dryland Wheat										
1986	12.43	100%	0.00	-258.61	-83.71	-258.61	-258.61	-258.61	-258.61	-258.61
2010	12.37	100%	0.00	-258.61	-83.71	-258.61	-258.61	-258.61	-258.61	-258.61
2012	8.26	100%	0.00	-258.61	-83.71	-258.61	-258.61	-258.61	-258.61	-258.61
2013	11.72	100%	0.00	-258.61	-83.71	-258.61	-258.61	-258.61	-258.61	-258.61

CHAPTER VI: CONCLUSION

This study's objective was to develop a method to assist producers in comparing alternative irrigation management strategies in the face of risk due to a limited well capacity. The objective simulated average net returns for 172 different irrigation strategies across 30 years (1986-2015) of historical weather (Kansas Mesonet 2016). Irrigation strategies included different combinations of corn and wheat production with full irrigation, moderate irrigation, deficit irrigation, and dryland production. Three risk measures were applied to the average net returns: Value at Risk (VaR), expected shortfall, and standard deviation. Calculating these risk measures can help producers better evaluate the optimal irrigation strategy compared to the approach of only equating average net returns.

When comparing irrigation strategies in this study, well capacity is varied at 300 gallons per minute (GPM) and 600 GPM. This has a dramatic impact on risk measures for 300 GPM; thus, exposing the producer to higher risk. Specifically, Value at Risk (VaR) measures are predominantly negative with the most significant being a 1/30 VaR value of -$290.78/acre planting moderately irrigated corn / deficit irrigated corn (25%/75%) (Table 5.1). At 600 GPM, the 1/30 VaR value for deficit irrigated corn (100%) was -$6.08/acre reflecting the only negative amount with all other values positive demonstrating much less uncertainty (Table 5.2). Comparing expected shortfall values in turn shows financial drawbacks at 300 GPM with the lowest value of -$163.37/acre, moderately irrigated corn / deficit irrigated corn (25%/75%) (Table 5.1). Significant risk improvement with the largest expected shortfall at $120.29/acre, moderately irrigated corn (100%) at 600 GPM demonstrates a more optimistic view (Table 5.2).

Simulation results for 100% land use shows crop-specific analyses may be warranted when evaluating irrigation strategies because all average net returns for corn are larger than those for wheat in this study. At 600 GPM, corn has the largest average net return as compared to wheat. Average net returns for moderately irrigated corn are $198.38/acre, $191.12/acre for deficit irrigated corn, and $113.40/acre for full irrigated corn with primarily positive risk measures (Table 5.4). On the other hand for wheat, moderately irrigated wheat has the highest average net returns at $46.94/acre, $37.85/acre for deficit irrigated wheat, and $4.55/acre for full irrigated wheat (Table 5.4). Their corresponding risk measures are all negative varying from -$119.79/acre growing deficit irrigated wheat to -$31.06/acre growing moderately irrigated wheat.

In this study, 100% land use for dryland corn and wheat production are significantly low in average net returns with high risk measure values likely due to the low annual precipitation in four years out of the 30 years (1986-2015) including: 1986 at 12.43 inches, 2010 at 12.37 inches, 2012 at 8.26 inches, and 2013 at 11.72 inches. In all cases, the yield was 0.00 bushels/acre that resulted in all risk measures reflecting production costs of -$310.30/acre for corn and -$258.61/acre for wheat.

Further research could entail modeling all Kansas counties that overlie the Ogallala Aquifer taking into consideration additional crops to analyze. The research could also include different well capacities, using different input and output prices, and simulating a model with daily specific data. It appears that knowing what is the most productive crop in terms of average net returns is not enough, especially with limited well capacities. The producer also needs to understand the risk of each irrigation strategy to make a well-informed decision. Ideally, a risk measure could be incorporated into a decision tool like

Crop Water Allocator to help producers have more complete information on alternative management strategies.

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APPENDIX A

Annual precipitation (inches) for Wichita County, Kansas, 1986 –2015

Year	Annual Precipitation	Year	Annual Precipitation
1986	12.43	2001	18.08
1987	20.79	2002	14.66
1988	14.36	2003	21.51
1989	15.92	2004	20.08
1990	19.37	2005	22.61
1991	15.58	2006	22.97
1992	23.35	2007	22.65
1993	27.10	2008	13.72
1994	19.34	2009	20.85
1995	19.17	2010	12.37
1996	19.13	2011	16.81
1997	27.02	2012	8.26
1998	18.96	2013	11.72
1999	21.64	2014	20.03
2000	19.86	2015	18.10

Source: Kansas Mesonet 2016

APPENDIX B

Parameters for irrigated corn and wheat budgets for full irrigation, moderate irrigation, and deficit irrigation in western Kansas in 2015

Items	Deficit	Moderate	Full	Items	Deficit	Moderate	Full
Acres	125	125	125	Acres	125	125	125
Yield per acre	170	210	250	Yield per acre	50	65	80
Price per Bushel	$4.25	$4.25	$4.25	Price per Bushel	$5.72	$5.72	$5.72
Cost per Acre				Cost per Acre			
Seed	$102.96	$126.72	$145.56	Seed	$12.00	$14.40	$19.20
Herbicide	$51.00	$51.00	$51.00	Herbicide	$9.38	$9.38	$9.38
Insecticide/Fungicide	$16.54	$19.07	$19.07	Insecticide/Fungicide	$10.56	$10.56	$10.56
Fertilizer & Lime	$117.52	$144.96	$169.50	Fertilizer & Lime	$55.52	$69.48	$88.00
Crop Consulting	$6.50	$6.50	$6.50	Crop Consulting	$6.00	$6.00	$6.00
Crop Insurance	$13.68	$20.23	$26.78	Crop Insurance			
Drying	$22.10	$27.30	$32.09	Drying			
Miscellaneous	$10.00	$10.00	$10.00	Miscellaneous	$10.00	$10.00	$10.00
Custom Hire/Machinery Expense	$149.39	$168.14	$186.39	Custom Hire/Machinery Expense	$78.34	$87.39	$92.44
Non-machinery Labor	$18.00	$18.00	$18.00	Non-machinery Labor	$18.00	$18.00	$18.00
Irrigation				Irrigation			
Labor	$7.50	$7.50	$7.50	Labor	$7.50	$7.50	$7.50
Repairs & Maintenance	$3.96	$5.94	$7.92	Repairs & Maintenance	$2.64	$3.30	$3.96
Depreciation, Equipment & Well	$64.26	$64.26	$64.26	Depreciation, Equipment & Well	$64.26	$64.26	$64.26
Interest, Equipment & Well	$48.36	$48.36	$48.26	Interest, Equipment & Well	$48.36	$48.36	$48.36
Interest on ½ Nonland Costs	$18.21	$21.86	$25.16	Interest on ½ Nonland Costs	$8.19	$9.38	$10.67
Total Costs	$649.98	$739.84	$817.99	Total Costs	$330.75	$358.01	$388.33

Source: Ibenthal 2015

Source: Ibenthal 2015

APPENDIX C

Parameters for dryland corn and wheat budgets for southwest Kansas in 2015

Items	Dryland	Items	Dryland
Acres	125	Acres	125
Yield per acre	77	Yield per acre	51
Price per Bushel	$4.25	Price per Bushel	$5.72
Cost per Acre		Cost per Acre	
Seed	$53.28	Seed	$12.80
Herbicide	$67.47	Herbicide	$22.33
Fertilizer & Lime	$51.40	Insecticide/Fungicide	4.73
Crop Insurance	$6.48	Fertilizer & Lime	$64.60
Miscellaneous	$5.50	Crop Insurance	$1.36
Custom Hire/Machinery Expense	$93.91	Miscellaneous	$5.50
Non-machinery Labor	$22.50	Custom Hire/Machinery Expense	$116.65
Interest on ½ Nonland Costs	$9.77	Non-machinery Labor	$22.50
Total Costs	$310.31	Interest on ½ Nonland Costs	$8.14
		Total Costs	$258.61

Source: Ibendahl 2015 Source: Ibendahl 2015

APPENDIX D

Eighty-six irrigation portfolio strategies and land uses (%) ranked highest to lowest in average net returns with their corresponding risk measures, Value at Risk (VaR), expected shortfall, and standard deviations ($/acre) for 300 GPM, 12.73 inches, of water applied for Wichita County, Kansas

Irrigation Strategy	Land Use (%)	Average Net Returns ($/ac)	1/30 VaR ($/ac)	2/30 VaR ($/ac)	3/30 VaR ($/ac)	Expected Shortfall ($/ac)	Standard Deviation ($/ac)
Deficit Irrigated Corn	100	166.99	-213.95	-47.79	-17.84	-93.19	117.73
Deficit Irrigated Corn / Deficit Irrigated Wheat	75/25	147.93	-93.42	-3.37	21.03	-25.25	80.00
Deficit Irrigated Corn / Moderately Irrigated Wheat	75/25	147.43	-100.24	-10.18	14.21	-32.07	82.86
Moderately Irrigated Corn / Deficit Irrigated Corn	25/75	139.41	-290.87	-115.59	-83.65	-163.37	141.38
Deficit Irrigated Corn / Full Irrigated Wheat	75/25	135.49	-107.82	-17.76	6.63	-39.65	79.88
Deficit Irrigated Corn / Dryland Wheat	75/25	122.36	-75.24	-15.85	-5.63	-32.24	82.41
Deficit Irrigated Corn / Moderately Irrigated Wheat	50/50	114.77	-118.88	-8.25	9.98	-39.05	72.34
Deficit Irrigated Corn / Deficit Irrigated Wheat	50/50	113.08	-105.25	-0.72	11.57	-31.47	69.91
Moderately Irrigated Corn / Dryland Wheat	75/25	108.98	-142.63	-44.51	-28.03	-71.72	86.75
Deficit Irrigated Corn / Dryland Corn	75/25	105.17	-88.31	-28.92	-18.71	-45.31	87.76
Moderately Irrigated Corn / Deficit Irrigated Wheat	50/50	102.41	-126.13	-48.68	-26.90	-67.24	76.71
Moderately Irrigated Corn	100	101.80	-303.81	-137.65	-107.70	-183.05	134.91
Moderately Irrigated Corn / Moderately Irrigated Wheat	50/50	98.30	-139.76	-62.31	-40.53	-80.87	83.11
Moderately Irrigated Corn / Deficit Irrigated Wheat	75/25	97.17	-160.82	-62.69	-46.21	-89.91	93.10
Moderately Irrigated Corn / Dryland Corn	75/25	91.79	-155.71	-57.58	-41.10	-84.80	90.59
Moderately Irrigated Corn / Moderately Irrigated Wheat	75/25	91.28	-167.63	-69.51	-53.03	-96.72	94.24
Deficit Irrigated Corn / Full Irrigated Wheat	50/50	91.06	-134.04	-23.41	-5.18	-54.21	66.32
Moderately Irrigated Corn / Full Irrigated Wheat	75/25	83.13	-175.21	-77.09	-60.61	-104.30	93.52
Moderately Irrigated Corn / Deficit Irrigated Corn	50/50	81.89	-285.75	-228.81	-193.42	-235.99	161.88
Deficit Irrigated Corn / Moderately Irrigated Wheat	25/75	80.93	-110.42	-20.00	-5.53	-45.32	61.86
Moderately Irrigated Corn / Full Irrigated Wheat	50/50	79.81	-154.92	-77.47	-55.69	-96.03	80.28
Moderately Irrigated Corn / Moderately Irrigated Wheat	25/75	78.00	-128.59	-31.13	-14.83	-58.19	62.72
Moderately Irrigated Corn / Deficit Irrigated Wheat	25/75	76.62	-108.15	-16.86	-6.79	-43.93	57.72
Deficit Irrigated Corn / Deficit Irrigated Wheat	25/75	76.17	-91.36	-33.51	-21.89	-48.92	62.11
Full Irrigated Corn / Deficit Irrigated Corn	25/75	67.51	-390.37	-216.18	-183.90	-263.48	162.10
Moderately Irrigated Corn / Dryland Wheat	50/50	57.63	-83.76	-63.26	-59.56	-68.86	74.39
Deficit Irrigated Corn / Dryland Wheat	50/50	54.01	-132.05	-96.57	-89.76	-106.12	91.52
Full Irrigated Corn / Deficit Irrigated Wheat	25/75	51.45	-155.93	-56.52	-39.22	-83.89	61.16
Full Irrigated Corn / Dryland Wheat	75/25	48.97	-201.25	-103.12	-86.64	-130.34	85.33
Full Irrigated Corn / Moderately Irrigated Wheat	25/75	48.25	-176.38	-76.97	-59.67	-104.34	70.31
Moderately Irrigated Wheat	100	45.88	-108.49	-39.01	-31.06	-59.52	53.76
Deficit Irrigated Corn / Full Irrigated Wheat	25/75	45.74	-133.16	-42.74	-28.27	-68.06	52.33
Moderately Irrigated Corn / Full Irrigated Wheat	25/75	43.98	-151.33	-53.87	-37.57	-80.93	54.74
Moderately Irrigated Wheat / Deficit Irrigated Wheat	25/75	42.40	-98.31	-52.66	-43.21	-64.73	54.58
Moderately Irrigated Wheat / Deficit Irrigated Wheat	50/50	42.40	-98.31	-52.66	-43.21	-64.73	54.58
Moderately Irrigated Wheat / Deficit Irrigated Wheat	75/25	41.04	-138.94	-52.66	-43.21	-78.27	58.55
Deficit Irrigated Wheat	100	37.85	-119.79	-66.30	-55.35	-80.48	58.61
Full Irrigated Corn / Dryland Corn	75/25	31.78	-214.32	-116.19	-99.71	-143.41	88.79
Full Irrigated Corn / Deficit Irrigated Wheat	75/25	30.79	-219.43	-121.30	-104.83	-148.52	85.33
Moderately Irrigated Corn / Deficit Irrigated Corn	75/25	26.12	-240.63	-142.50	-126.02	-169.72	116.25
Full Irrigated Wheat / Moderately Irrigated Wheat	25/75	24.38	-99.91	-43.97	-34.92	-59.60	42.86
Full Irrigated Corn / Moderately Irrigated Wheat	75/25	23.97	-226.25	-128.12	-111.64	-155.34	85.33

APPENDIX D

Eighty-six irrigation portfolio strategies and land uses (%) ranked highest to lowest in average net returns with their corresponding risk measures, Value at Risk (VaR), expected shortfall, and standard deviations ($/acre) for 300 GPM, 12.73 inches, of

water applied for Wichita County, Kansas (continued)

Irrigation Strategy	Land Use (%)	Average Net Returns ($/ac)	1/30 VaR ($/ac)	2/30 VaR ($/ac)	3/30 VaR ($/ac)	Expected Shortfall ($/ac)	Standard Deviation ($/ac)
Full Irrigated Wheat / Deficit Irrigated Wheat	50/50	19.79	-129.51	-52.97	-45.83	-76.10	47.15
Full Irrigated Corn / Full Irrigated Wheat	25/75	19.65	-199.12	-99.71	-82.41	-127.08	65.43
Deficit Irrigated Corn / Dryland Corn	50/50	19.62	-158.19	-122.71	-115.90	-132.27	104.10
Full Irrigated Corn / Full Irrigated Wheat	75/25	16.39	-233.83	-135.70	-119.22	-162.92	85.33
Full Irrigated Corn / Dryland Wheat	50/50	15.15	-101.41	-83.21	-81.76	-88.79	64.64
Full Irrigated Wheat / Deficit Irrigated Wheat	75/25	11.83	-194.19	-123.86	-93.83	-137.29	64.10
Full Irrigated Wheat / Moderately Irrigated Wheat	50/50	10.82	-207.82	-137.49	-107.46	-150.92	69.88
Full Irrigated Wheat / Moderately Irrigated Wheat	75/25	10.82	-207.82	-137.49	-107.46	-150.92	69.88
Full Irrigated Corn / Deficit Irrigated Wheat	50/50	10.33	-137.78	-119.58	-118.13	-125.16	86.72
Full Irrigated Corn / Moderately Irrigated Corn	25/75	2.46	-457.76	-283.58	-251.29	-330.88	165.01
Full Irrigated Wheat	100	-0.24	-138.81	-65.48	-54.17	-86.15	39.76
Full Irrigated Corn / Moderately Irrigated Wheat	50/50	-1.50	-151.41	-133.21	-131.76	-138.79	89.24
Dryland Corn / Moderately Irrigated Wheat	25/75	-2.76	-135.20	-106.84	-100.87	-114.30	71.85
Dryland Corn / Deficit Irrigated Wheat	25/75	-9.58	-167.42	-127.30	-119.09	-137.94	76.28
Moderately Irrigated Corn / Dryland Wheat	25/75	-12.74	-170.89	-160.64	-158.79	-163.44	93.02
Deficit Irrigated Corn / Dryland Wheat	25/75	-14.55	-195.03	-177.29	-173.88	-182.07	101.51
Full Irrigated Corn / Full Irrigated Wheat	50/50	-16.70	-166.57	-148.37	-146.92	-153.95	89.18
Moderately Irrigated Wheat / Dryland Wheat	25/75	-18.38	-167.72	-148.81	-144.83	-153.79	80.98
Moderately Irrigated Wheat / Dryland Wheat	50/50	-18.38	-167.72	-148.81	-144.83	-153.79	80.98
Moderately Irrigated Wheat / Dryland Wheat	75/25	-18.38	-167.72	-148.81	-144.83	-153.79	80.98
Full Irrigated Corn / Dryland Corn	50/50	-19.24	-127.56	-109.35	-107.91	-114.94	79.19
Full Irrigated Corn / Dryland Wheat	25/75	-33.79	-170.39	-170.36	-170.36	-170.37	87.83
Dryland Corn / Full Irrigated Wheat	25/75	-34.63	-120.79	-107.30	-104.80	-110.96	55.93
Full Irrigated Wheat / Dryland Wheat	25/75	-39.58	-156.61	-149.12	-147.46	-151.06	69.82
Full Irrigated Wheat / Dryland Wheat	50/50	-39.58	-156.61	-149.12	-147.46	-151.06	69.82
Full Irrigated Wheat / Dryland Wheat	75/25	-39.63	-158.12	-149.12	-147.46	-151.56	69.90
Dryland Corn / Moderately Irrigated Wheat	50/50	-52.47	-193.57	-174.66	-170.68	-179.63	94.43
Full Irrigated Corn / Deficit Irrigated Corn	75/25	-53.14	-299.24	-201.11	-184.63	-228.33	88.79
Dryland Corn / Deficit Irrigated Wheat	50/50	-57.01	-215.05	-188.30	-182.83	-195.39	96.80
Moderately Irrigated Corn / Dryland Corn	25/75	-64.31	-210.10	-199.85	-198.00	-202.65	114.26
Deficit Irrigated Corn / Dryland Corn	25/75	-66.13	-234.25	-216.51	-213.10	-221.28	122.28
Dryland Corn / Full Irrigated Wheat	50/50	-73.66	-182.45	-174.97	-173.30	-176.91	84.18
Full Irrigated Corn / Moderately Irrigated Corn	75/25	-75.60	-321.70	-223.58	-207.10	-250.79	88.79
Dryland Wheat	100	-83.71	-258.61	-258.61	-258.61	-258.61	111.78
Full Irrigated Corn / Dryland Corn	25/75	-85.36	-209.61	-209.58	-209.58	-209.59	109.97
Dryland Corn / Moderately Irrigated Wheat	75/25	-102.17	-251.93	-242.48	-240.49	-244.97	117.69
Dryland Corn / Deficit Irrigated Wheat	75/25	-104.44	-262.67	-249.30	-246.56	-252.85	118.68
Dryland Corn / Full Irrigated Wheat	75/25	-112.77	-246.38	-242.63	-241.80	-243.60	112.71
Full Irrigated Corn / Deficit Irrigated Corn	50/50	-115.09	-297.40	-279.19	-277.75	-284.78	141.29
Dryland Corn	100	-151.88	-310.30	-310.30	-310.30	-310.30	141.30
Full Irrigated Corn / Moderately Irrigated Corn	50/50	-160.02	-342.33	-324.12	-322.68	-329.71	141.29

APPENDIX E

Eighty-six irrigation portfolio strategies and land uses (%) ranked highest to lowest in average net returns with their corresponding risk measures, Value at Risk (VaR), expected shortfall, and standard deviations ($/acre) for 600 GPM, 25.45 inches, of water applied for Wichita County, Kansas

Irrigation Strategy	Land Split/Use (%)	Average Net Return ($/ac)	1/30 VaR ($/ac)	2/30 VaR ($/ac)	3/30 VaR ($/ac)	Expected Shortfall ($/ac)	Standard Deviation ($/ac)
Moderately Irrigated Corn	100	198.38	90.49	131.49	138.89	120.29	38.36
Moderately Irrigated Corn / Deficit Irrigated Corn	75/25	196.56	66.35	114.83	123.79	101.66	46.95
Moderately Irrigated Corn / Deficit Irrigated Corn	50/50	194.75	42.20	98.18	108.69	83.02	55.57
Moderately Irrigated Corn / Deficit Irrigated Corn	25/75	192.93	18.06	81.53	93.59	64.39	64.19
Deficit Irrigated Corn	100	191.12	-6.08	64.87	78.49	45.76	72.83
Full Irrigated Corn / Moderately Irrigated Corn	25/75	177.33	90.98	121.76	127.31	113.35	32.51
Full Irrigated Corn / Deficit Irrigated Corn	25/75	171.88	18.55	71.80	82.02	57.46	58.41
Moderately Irrigated Corn / Moderately Irrigated Wheat	75/25	160.52	48.66	88.86	96.40	77.97	41.40
Moderately Irrigated Corn / Deficit Irrigated Wheat	75/25	158.25	37.92	82.04	90.33	70.09	43.41
Full Irrigated Corn / Moderately Irrigated Corn	50/50	155.69	73.81	112.03	115.74	100.53	28.40
Deficit Irrigated Corn / Moderately Irrigated Wheat	75/25	155.08	-23.77	38.90	51.10	22.08	67.30
Deficit Irrigated Corn / Deficit Irrigated Wheat	75/25	152.80	-34.51	32.08	45.03	14.20	69.23
Full Irrigated Corn / Deficit Irrigated Corn	50/50	152.65	43.19	78.73	85.54	69.15	44.05
Moderately Irrigated Corn / Full Irrigated Wheat	75/25	149.92	54.22	88.71	95.09	79.34	35.59
Deficit Irrigated Corn / Full Irrigated Wheat	75/25	144.48	-18.21	38.75	49.79	23.44	61.51
Full Irrigated Corn / Deficit Irrigated Corn	75/25	132.34	35.50	85.65	89.06	70.07	32.74
Full Irrigated Corn / Moderately Irrigated Corn	75/25	132.11	13.04	92.76	101.44	69.08	30.48
Moderately Irrigated Corn / Dryland Wheat	75/25	128.01	3.36	34.11	39.66	25.71	56.03
Moderately Irrigated Corn / Moderately Irrigated Wheat	50/50	122.66	6.83	46.24	53.91	35.66	44.51
Deficit Irrigated Corn / Dryland Wheat	75/25	122.56	-69.06	-15.85	-5.63	-30.18	81.91
Deficit Irrigated Corn / Moderately Irrigated Wheat	50/50	119.03	-41.46	12.93	23.72	-1.60	61.79
Moderately Irrigated Corn / Deficit Irrigated Wheat	50/50	118.12	-14.65	32.59	41.77	19.90	48.47
Deficit Irrigated Corn / Deficit Irrigated Wheat	50/50	114.49	-62.94	-0.72	11.57	-17.36	65.65
Full Irrigated Corn	100	113.40	55.03	91.56	94.48	80.36	18.68
Moderately Irrigated Corn / Dryland Corn	75/25	110.81	-9.71	21.04	26.59	12.64	61.72
Deficit Irrigated Corn / Dryland Corn	75/25	105.37	-82.14	-28.92	-18.71	-43.25	87.30
Moderately Irrigated Corn / Full Irrigated Wheat	50/50	101.46	17.94	45.93	51.29	38.39	32.94
Deficit Irrigated Corn / Full Irrigated Wheat	50/50	97.84	-30.34	12.62	21.10	1.12	50.24
Full Irrigated Corn / Moderately Irrigated Wheat	75/25	97.37	50.13	59.68	61.68	57.16	24.60
Full Irrigated Corn / Deficit Irrigated Wheat	75/25	95.10	39.39	52.86	55.60	49.29	26.24
Full Irrigated Corn / Full Irrigated Wheat	75/25	86.35	43.01	59.53	60.37	54.30	19.93
Moderately Irrigated Corn / Moderately Irrigated Wheat	25/75	84.80	-35.00	3.61	11.43	-6.65	47.66
Deficit Irrigated Corn / Moderately Irrigated Wheat	25/75	82.99	-59.14	-13.04	-3.67	-25.29	56.31
Full Irrigated Corn / Moderately Irrigated Wheat	50/50	80.56	7.81	26.78	30.76	21.79	33.26
Moderately Irrigated Corn / Deficit Irrigated Wheat	25/75	77.99	-67.22	-16.86	-6.79	-30.29	53.54
Deficit Irrigated Corn / Deficit Irrigated Wheat	25/75	76.17	-91.36	-33.51	-21.89	-48.92	62.11
Full Irrigated Corn / Deficit Irrigated Wheat	50/50	76.02	-13.67	13.14	18.62	6.03	36.86
Full Irrigated Corn / Dryland Wheat	75/25	64.85	4.84	4.93	4.94	4.90	39.98
Full Irrigated Corn / Moderately Irrigated Wheat	25/75	63.75	-34.51	-6.12	-0.15	-13.59	42.03
Full Irrigated Corn / Full Irrigated Wheat	50/50	59.36	18.92	26.47	28.14	24.51	22.05
Moderately Irrigated Corn / Dryland Wheat	50/50	57.63	-83.76	-63.26	-59.56	-68.86	74.39
Full Irrigated Corn / Deficit Irrigated Wheat	25/75	56.94	-66.73	-26.58	-18.37	-37.23	47.69

APPENDIX E

Eighty-six irrigation portfolio strategies and land uses (%) ranked highest to lowest in average net returns with their corresponding risk measures, Value at Risk (VaR), expected shortfall, and standard deviations ($/acre) for 600 GPM, 25.45 inches, of

water applied for Wichita County, Kansas (continued)

Irrigation Strategy	Land Split/Use (%)	Average Net Return ($/ac)	1/30 VaR ($/ac)	2/30 VaR ($/ac)	3/30 VaR ($/ac)	Expected Shortfall ($/ac)	Standard Deviation ($/ac)
Deficit Irrigated Corn / Dryland Wheat	50/50	54.01	-132.05	-96.57	-89.76	-106.12	91.52
Moderately Irrigated Corn / Full Irrigated Wheat	25/75	53.01	-18.33	3.14	7.50	-2.56	30.43
Deficit Irrigated Corn / Full Wheat	25/75	51.19	-42.47	-13.51	-7.60	-21.20	39.07
Full Irrigated Corn / Dryland Corn	75/25	47.66	-8.24	-8.14	-8.13	-8.17	47.36
Moderately Irrigated Wheat	100	46.94	-76.83	-39.01	-31.06	-48.97	50.85
Moderately Irrigated Wheat / Deficit Irrigated Wheat	25/75	42.40	-98.31	-52.66	-43.21	-64.73	54.58
Moderately Irrigated Wheat / Deficit Irrigated Wheat	50/50	42.40	-98.31	-52.66	-43.21	-64.73	54.58
Moderately Irrigated Wheat / Deficit Irrigated Wheat	75/25	42.40	-98.31	-52.66	-43.21	-64.73	54.58
Deficit Irrigated Wheat	100	37.85	-119.79	-66.30	-55.35	-80.48	58.61
Full Irrigated Corn / Full Irrigated Wheat	25/75	31.96	-17.84	-6.58	-4.08	-9.50	25.06
Full Irrigated Wheat / Moderately Irrigated Wheat	25/75	25.75	-65.72	-39.32	-33.68	-46.24	39.40
Full Irrigated Wheat / Moderately Irrigated Wheat	50/50	25.75	-65.72	-39.32	-33.68	-46.24	39.40
Full Irrigated Wheat / Moderately Irrigated Wheat	75/25	25.75	-65.72	-39.32	-33.68	-46.24	39.40
Moderately Irrigated Corn / Dryland Corn	50/50	23.25	-109.91	-89.41	-85.71	-95.01	87.58
Full Irrigated Wheat / Deficit Irrigated Wheat	25/75	21.20	-87.20	-52.97	-45.83	-62.00	42.98
Full Irrigated Wheat / Deficit Irrigated Wheat	50/50	21.20	-87.20	-52.97	-45.83	-62.00	42.98
Full Irrigated Wheat / Deficit Irrigated Wheat	75/25	21.20	-87.20	-52.97	-45.83	-62.00	42.98
Deficit Irrigated Corn / Dryland Corn	50/50	19.62	-158.19	-122.71	-115.90	-132.27	104.10
Full Irrigated Corn / Dryland Wheat	50/50	15.53	-82.78	-82.71	-82.71	-82.73	63.89
Full Irrigated Wheat	100	4.55	-54.61	-39.64	-36.30	-43.51	28.10
Dryland Corn / Moderately Irrigated Wheat	25/75	-2.76	-135.20	-106.84	-100.87	-114.30	71.85
Dryland Corn / Deficit Irrigated Wheat	25/75	-9.58	-167.42	-127.30	-119.09	-137.94	76.28
Moderately Irrigated Corn / Dryland Wheat	25/75	-12.74	-170.89	-160.64	-158.79	-163.44	93.02
Deficit Irrigated Corn / Dryland Wheat	25/75	-14.55	-195.03	-177.29	-173.88	-182.07	101.51
Moderately Irrigated Wheat / Dryland Wheat	25/75	-18.38	-167.72	-148.81	-144.83	-153.79	80.98
Moderately Irrigated Wheat / Dryland Wheat	50/50	-18.38	-167.72	-148.81	-144.83	-153.79	80.98
Moderately Irrigated Wheat / Dryland Wheat	75/25	-18.38	-167.72	-148.81	-144.83	-153.79	80.98
Full Irrigated Corn / Dryland Corn	50/50	-18.85	-108.92	-108.86	-108.86	-108.88	78.66
Full Irrigated Corn / Dryland Wheat	25/75	-33.79	-170.39	-170.36	-170.36	-170.37	87.83
Dryland Corn / Full Irrigated Wheat	25/75	-34.56	-118.53	-107.30	-104.80	-110.21	55.81
Full Irrigated Wheat / Dryland Wheat	25/75	-39.58	-156.61	-149.12	-147.46	-151.06	69.82
Full Irrigated Wheat / Dryland Wheat	50/50	-39.58	-156.61	-149.12	-147.46	-151.06	69.82
Full Irrigated Wheat / Dryland Wheat	75/25	-39.58	-156.61	-149.12	-147.46	-151.06	69.82
Dryland Corn / Moderately Irrigated Wheat	50/50	-52.47	-193.57	-174.66	-170.68	-179.63	94.43
Dryland Corn / Deficit Irrigated Wheat	50/50	-57.01	-215.05	-188.30	-182.83	-195.39	96.80
Moderately Irrigated Corn / Dryland Corn	25/75	-64.31	-210.10	-199.85	-198.00	-202.65	114.26
Deficit Irrigated Corn / Dryland Corn	25/75	-66.13	-234.25	-216.51	-213.10	-221.28	122.28
Dryland Corn / Full Irrigated Wheat	50/50	-73.66	-182.45	-174.97	-173.30	-176.91	84.18
Dryland Wheat	100	-83.71	-258.61	-258.61	-258.61	-258.61	111.78
Full Irrigated Corn / Dryland Corn	25/75	-85.36	-209.61	-209.58	-209.58	-209.59	109.97
Dryland Corn / Moderately Irrigated Wheat	75/25	-102.17	-251.93	-242.48	-240.49	-244.97	117.69
Dryland Corn / Deficit Irrigated Wheat	75/25	-104.44	-262.67	-249.30	-246.56	-252.85	118.68
Dryland Corn / Full Irrigated Wheat	75/25	-112.77	-246.38	-242.63	-241.80	-243.60	112.71
Dryland Corn	100	-151.88	-310.30	-310.30	-310.30	-310.30	141.30