ECONOMICS OF IRRIGATED CROP CHOICES USING CENTER PIVOT SYSTEM IN OKLAHOMA PANHANDLE

By

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ECONOMICS OF IRRIGATED
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IN OKLAHOMA PANHANDLE

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Abstract: The study seeks to maximize the net benefits through extraction of groundwater from Ogallala aquifer in the Oklahoma Panhandle. In recent decades in most parts of the southern Great Plains overlying Ogallala, the water table level decline has been significant. The continuous decline of the Ogallala water table results in reduced well capacity, increased pumping cost, and reduced crop yields. Producers with limited well capacity will choose to irrigate fewer acres, implement dry land practices, apply less water to existing acres, or choose an alternative crop that requires less water. As the present-day pumping rate declines, the producer can make choices to irrigate corn or grain sorghum that will derive maximum net benefit. Research in the Oklahoma Panhandle has shown 150 bushels of grain sorghum [Sorghum bicolor (L.) Moench] can be produced with 9.4 inches of irrigation, while 22 inches are required to produce 190 bushels of corn [Zea mays L.]. Corn has higher profits over variable cost per irrigated acre. However, grain sorghum provides higher returns per acre-foot of water. ‘EPIC’ was used to simulate crop yields for corn and grain sorghum corresponding to 120-acre pivot circles with various well capacities under irrigation stress triggers between 30 and 90 percent of soil moisture. The well capacity and number of acres determined the frequency between irrigations. Pumping cost for well operations and water supply during well capacity transitions were determined using Cooper-Jacob well drawdown calculations. Expected water use, present value of crop production, capital investment of the irrigation system, land constraint and water supply for each annual combination were then incorporated into a 50-year (CPLEX) Mixed Integer Linear Programming (MIP) model to obtain long term profit maximizing benefits. To compare the long-term results with short-term profit maximization, a simple recursive optimization was developed to determine the series of annual profits that will give the maximum Net Present Value (NPV) over the pivot purchases. The results show that Long-Term Profit Maximizing (LTPM) producer with high saturated sand makes greater profits than the Annual Profit Maximizing (APM) producer. However, with shorter saturated sand results do not show difference in their overall benefits between APM and LTPM.

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CHAPTER I

INTRODUCTION

1.1 Background

In the United States, there are ample supplies of fresh water, however, the water is not always available at the desired place and time. In most parts of the Great Plains, water-level in the Ogallala formation has declined over the past few decades (McGuire, 2014). Oklahoma Panhandle producers, like others in the southern Great Plains, suffer from depleting ground water and ravaging droughts. Groundwater levels in the Oklahoma Panhandle portion of the Ogallala began falling rapidly in the mid-1960s. The number of acres under irrigation increased from 49,648 in 1964 to 217,009 by 2012 (Census of Agriculture, 1964-2012). During the same period, the number of irrigation wells in the Oklahoma Panhandle increased from 975 to 2,818 (USGS, 1976 and OWRB, 2016). Inexpensive water in the past years has been suggested as leading to excessive irrigation in some parts of the United States (Harris and Mapp, 1986). Water use is no longer inexpensive in Ogallala portion of Oklahoma Panhandle. The available fresh ground water supply in the Panhandle is limited, that is zero to very little recharge. The Oklahoma Panhandle's sole source of irrigation is the Ogallala aquifer, and irrigation is the largest use of groundwater from the Ogallala in Oklahoma, which accounted for 93 percent of all use in 1997 (Luckey and Becker, 1999).

1.2 Geographical Area of Ogallala in Oklahoma Panhandle

The Ogallala aquifer stretches across parts of eight states, which are New Mexico, Texas, Oklahoma, Colorado, Kansas, Wyoming, Nebraska, and South Dakota as shown in Figure 1. The High Plains is a major agricultural area, which spreads about 174,000 square miles, while the Oklahoma Panhandle Counties (OPC) Cimarron, Texas and Beaver cover about 5,700 square miles.

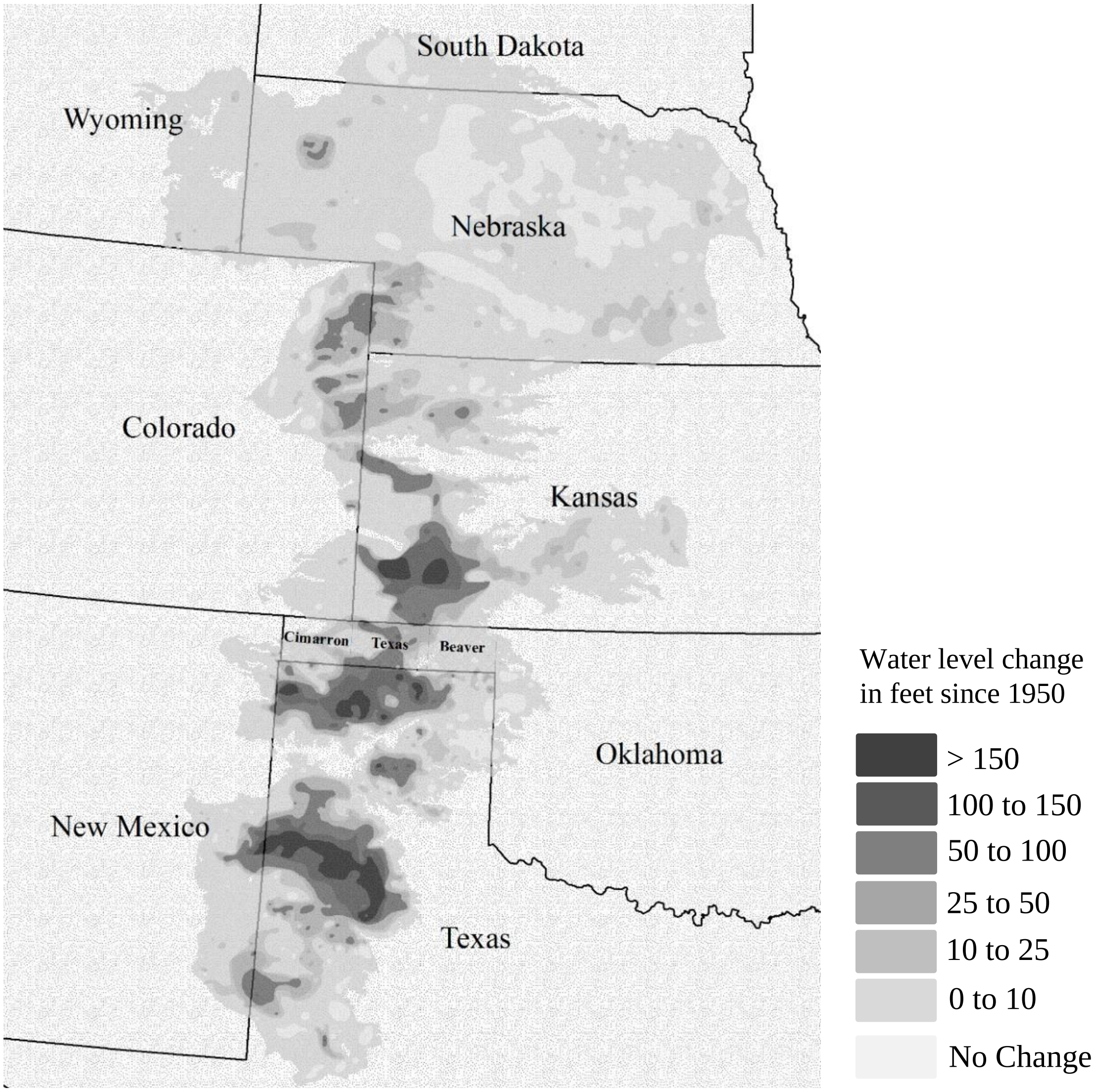


Figure 1. Water level change in the High Plains Aquifer with state boundaries overlaying the aquifer
Source: United States Geological Survey (USGS) Scientific Investigation Report 2014-5218

1.3 Irrigation in the Oklahoma Panhandle

The semi-arid Oklahoma Panhandle, like most of the High Plains, has middle latitude, dry-continental climate with abundant sunshine, low precipitation (less than 20 inches), frequent high speed winds, low humidity, and high evaporation (Weeks et al. 1988). Much of the OPC area is covered by Gruver clay loam soil, and agricultural production benefits from groundwater resources.

Irrigation in OPC began in 1930s. Data from the Census of Agriculture shown in Table 1 indicates there was very rapid growth in irrigated acres in the OPC between 1959 and 1969. From 1972, irrigated acres increased steadily and reached a peak in 1992 of 239,623 acres. The 2012 census shows a 22,616 acre decline in irrigated acres for the OPC since 1992.

Table 1. Irrigated Acres in the Oklahoma Panhandle Counties between 1959-2012

	County			OPC
Year	Beaver	Cimarron	Texas	Total
1959	5,857	12,416	31,675	49,948
1964	6,417	31,416	60,336	98,169
1969	22,873	83,986	158,712	265,571
1974	21,557	63,212	168,141	252,910
1978	32,940	95,382	155,938	284,260
1982	24,335	45,275	151,711	221,321
1987	22,489	46,840	157,645	226,974
1992	28,377	50,642	160,604	239,623
1997	22,082	68,941	137,898	228,921
2002	22,898	50,056	161,569	234,523
2007	28,512	45,513	156,026	230,051
2012	24,597	39,430	152,982	217,009

Source: Census of Agriculture, Various Years

The irrigated acres of the major crops (corn, grain sorghum, and wheat) planted in the OPC from 1959 to 2012 given by the Census of Agriculture are shown in Table 2. Grain sorghum was the major irrigated crop planted between 1964 and 1969. Irrigated wheat became the major crop in Beaver and Cimarron counties from 1974 through 2007. Wheat became the major irrigated crop in Texas County from 1978 through 1997. Irrigated corn then became the major crop in Texas County from 2002 through 2012. By 2012, the total acres of irrigated corn, grain sorghum, and wheat planted in the OPC were 106,236, 19,457, and 64,671 acres respectively. Irrigated corn has been the major crop or near major irrigated crop in the OPC since 2002.

National Agricultural Statistics Service (NASS) in 2012 reported that 129,325 acres of irrigated corn and 22,999 acres of irrigated sorghum were planted in Oklahoma. Within the OPC, irrigated corn and irrigated sorghum were planted on 80,731 and 13,259 acres respectively, in Texas County.

Table 2. Planted Acres of Irrigated Corn, Grain Sorghum, and Wheat in Beaver, Cimarron, and Texas Counties for Census Years from 1964 through 2012

	Beaver			Cimarron			Texas		
Year	Corn	Sorghum	Wheat	Corn	Sorghum	Wheat	Corn	Sorghum	Wheat
1964	2,176	9,781	4,739	10,188	44,190	13,951	27,064	73,564	43,456
1969	2,176	9,781	4,739	10,188	44,190	13,951	27,064	73,564	43,456
1974	1,644	6,825	8,094	7,614	25,033	18,213	55,587	35,234	57,373
1978	1,034	11,088	11,769	3,855	25,047	22,215	19,053	43,174	62,283
1982	d	7,418	11,196	2,140	16,107	19,969	13,508	49,401	74,913
1987	406	6,708	10,364	3,908	13,050	20,088	30,468	31,891	79,513
1992	1,456	6,680	13,299	10,180	11,242	21,240	50,875	17,626	80,207
1997	2,628	4,171	8,209	17,966	7,497	27,162	51,547	11,748	53,170
2002	3,075	3,806	7,831	17,728	2,910	13,311	65,741	16,569	46,251
2007	4,390	2,547	11,236	13,018	1,038	16,550	66,291	9,847	61,009
2012	4,971	4,059	9,591	20,534	2,139	10,044	80,731	13,259	45,036

Note: Source: Census of Agriculture, Various Years. “d” indicates data withheld due to disclosure rules

The irrigation wells in the OPC have increased along with the irrigated acreage. The drilling of wells increased steady until 1965, when numbered 975. After 1965, the irrigation wells have increased very rapidly through 1971 to 1,846 within the OPC area.

Since 1971, a steady growth in irrigation wells is seen Figure 2 shows the distribution of 2,818 irrigation wells recorded by OWRB within OPC in 2016.

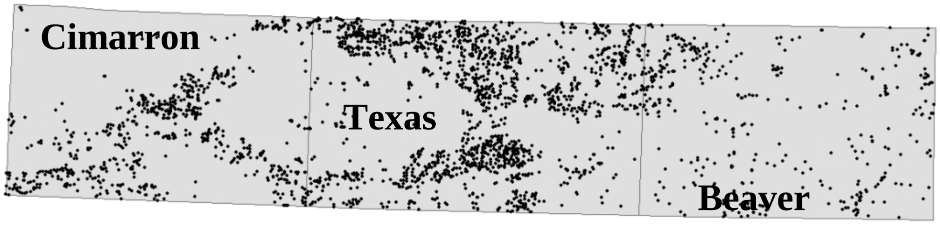


Figure 2. Location of 2818 irrigation wells as reported by the OWRB in 2015

Increase in the total number of wells (irrigation, domestic, agricultural, municipal, and industrial) between 1930 and 1999 in Oklahoma Panhandle Counties is shown in the Figure 3. In 2000, Texas County had the greatest number of wells with 1,100, followed by Beaver and Cimarron Counties, with 350 wells each. United States Geological Survey (USGS) and Oklahoma Water Resources Board (OWRB) reported the well pumping rates as 216.00, 278.78 and 301.54 Mgal/day (million gallons per day) in 1990, 2000 and 2010 respectively in Texas County, Oklahoma.

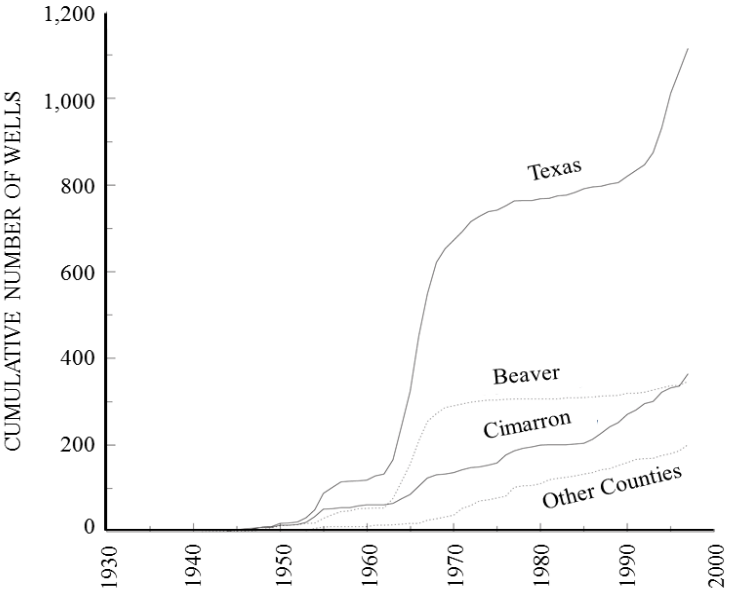


Figure 3. Increase in number of wells in OPC between 1930 and 1999
Source: USGS Water-Resources Investigations Report 99-4104

1.4 Ground Water Measurements

The increase in irrigated acres throughout the high plains brought reports of water table declines in the High Plains Aquifer (HPA). The USGS, in cooperation with numerous federal, state, and local water resources agencies began periodic water-level measurements wells in before 1950 (McGuire, 2000). In response to water level declines in HPA, the USGS began monitoring more than 7,000 wells in eight states overlaying HPA in 1988.

In Oklahoma, the USGS in cooperation with the OWRB began a program of locating and monitoring wells pumping from the Ogallala in the Oklahoma Panhandle and northwestern Oklahoma in late 1930s. The objective was to estimate changes in groundwater storage levels and the effects of intensive pumping in Oklahoma to assess annual water level changes (Hart et al. 1976). In 1975, approximately 500 wells have been measured annually throughout the Oklahoma Panhandle, however, the current number of monitoring wells is approximately 150 (McGuire, 2012). The locations of these monitoring wells in Texas County, Oklahoma in 2015 are shown in Figure 4.

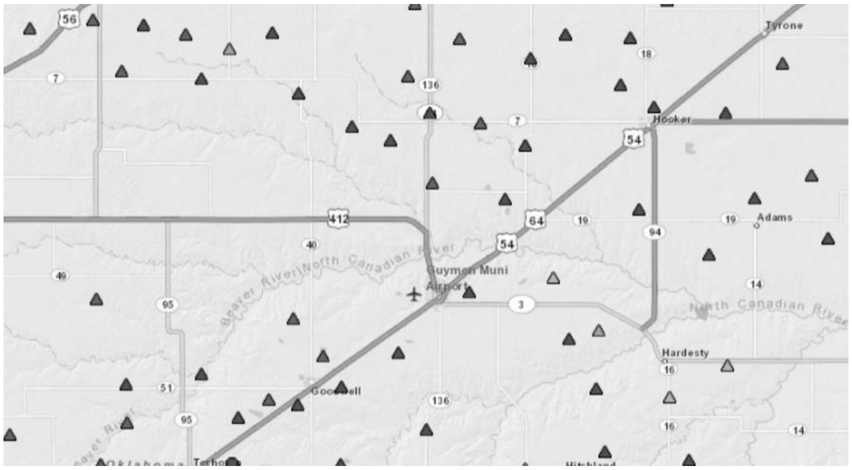


Figure 4. USGS monitoring wells in Texas County, Oklahoma in 2015

Luckey and Becker (1999) calibrated a simulation model to estimate the water level changes from 1988 to 2020 using 1996 and 1997 mean pumping rates. They found that, the largest simulated water-level change in Oklahoma may occur in Texas County where the water levels may decline about 20 to 50 feet. This would be approximately one foot per year. Guru (2000) estimated that some wells in Texas County have caused 200 feet to decline in the water table from the Ogallala formation. In a 2014, McGuire (2014) found that most of the static water levels in the Panhandle had declined from 10 to 150 feet between 1940 and 2014. Figure 5 shows the average decline in Static Water Levels (SWL) from monitored wells in the OPC from 1995 to 2013. (Stoecker et al. 2015) estimated historical average water table decline in OPC and found that the average decline in OPC varies between 1 and 3 feet per year as shown in Table 3.

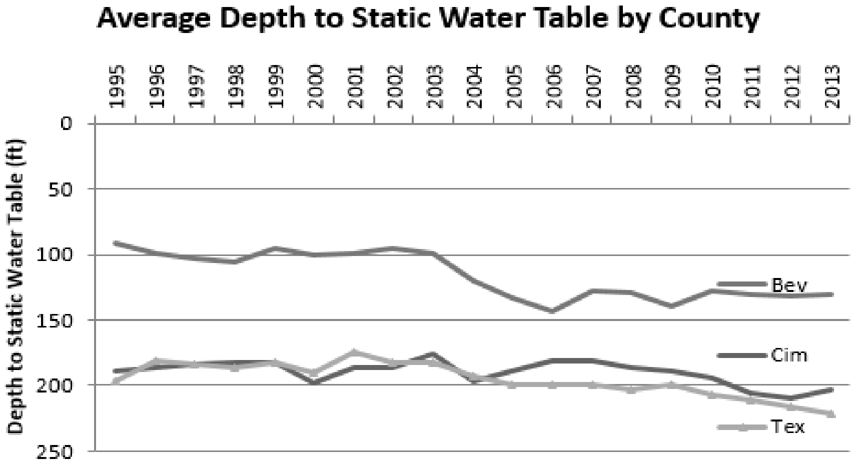


Figure 5. Graph of water table declines in Beaver, Cimarron and Texas County, Oklahoma from 1995 to 2013

Table 3. Average Table Decline Recorded in Oklahoma Panhandle Counties from 1995 to 2013

County	Water Level Decline (feet/year)
Beaver	2.6
Texas	1.9
Cimarron	0.9

1.5 Physical Characteristics of the Ogallala in Oklahoma

The state's largest source of fresh water is the HPA, which consists of the saturated part to the Ogallala formation of the Great Plains that is hydraulically connected with the Ogallala aquifer. In this study, the HPA and the Ogallala aquifer are treated as being the same entity. The Ogallala aquifer is an unconfined aquifer, which covers about 7,100 square miles in the northwestern Oklahoma, and the saturated thickness ranges from more than 400 feet to less than 50 feet.

In unconfined aquifers, total available water supply and extraction rates are sensitive to the coefficient of transmissivity (hydraulic conductivity multiplied by aquifer thickness) and coefficient of storage (specific yield). The USGS published maps of Hydraulic Conductivity (commonly denoted by letter K) in the Texas County portion of the HPA are shown in Figure 6. The range of K for the Texas County varies from 25 to 100 feet per day, and for the same region Specific Yield (commonly denoted by letter S) ranges between 18 and 28 percent (USGS and OWRB). However, K and S vary by location.

The geospatial data provided by USGS gives detailed information about aquifer characteristics and groundwater levels. Information of well depth and water level changes determines the remaining saturated thickness and static water level. Key aquifer characteristics such as K and S are highly important in quantitative studies for estimating possible drawdown for a given well yield and saturated thickness. For definition and explanations of Hydraulic Conductivity (K) and Specific Yield (S) refer to Driscoll, (1986).

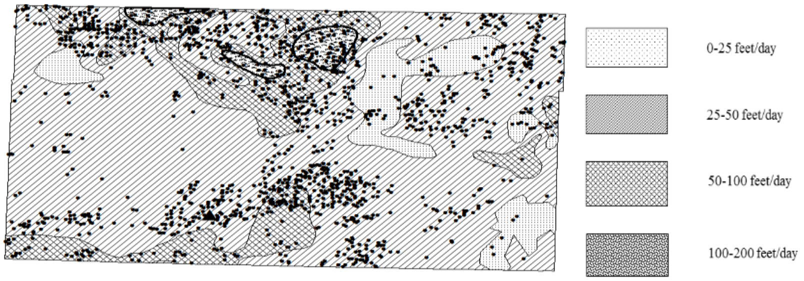


Figure 6. Irrigation well clusters on a Hydraulic Conductivity map for Texas County, Oklahoma. ▲Goodwell, OK

1.6 Groundwater and Recharge

In Oklahoma, the irrigation accounts for 86% of the withdrawal of water from the Ogallala aquifer (OWRB, 2012). The Ogallala aquifer is in a state of disequilibrium because natural recharge to the aquifer is much less than the withdrawals. The Ogallala aquifer is an unconfined aquifer. Under normal conditions in an unconfined aquifer, water percolation from the land surface is expected to flow to the saturated zone. The Panhandle's saturated stratum has a relatively very low permeability, which is the ultimate reason for low recharge and water table decline. Luckey and Becker (1999) Estimated recharge in Oklahoma High Plains is between 0.2 to 0.50 inches per year. In this study, well recharge is zero, as a result, the water supply is limited and water level drops during the pumping process.

In 1998, over a noticeable area in northern Texas County, the saturated thickness exceeded over 400 feet, and southwestern Texas County saturated thickness was less than 50 feet. The mean saturated thickness of HPA in Texas County was 200 feet in the year 1998. The maximum and minimum depth to water (or SWL) in the year 2000 was 329 feet and 65 feet respectively. However, the total well depth, SWL, saturated thickness and water level decline rates are fairly varying throughout the Texas County.

1.7 Experimental Research on Irrigated Crop Yield and Water Use

In 1976, Mapp and Dobbins analyzed the escalating energy cost for irrigated farms in the Oklahoma Panhandle. Using previous input and output prices, Mapp and Dobbins (1976) estimated the expected net return per acre of irrigated corn and grain sorghum as $193.51 and $155.97 respectively. The authors observed that the producers tended to choose irrigated crop that gave maximum expected current returns per acre or unit of land. When large quantities of groundwater supplies were suitable for irrigation, land tends to be a more limiting resource than water. This is especially true with favorable input and output prices. Since 2002, corn is grown on more irrigated acres than any other crop in the OPC because of its high economic value in the Oklahoma Panhandle. This value occurs in part because of the presence of a large confined animal feeding industry. The OPC area is actually a grain deficit area.

Grain sorghum is very competitive with corn on a feed value basis. A unit of grain sorghum contains about 95 percent of the feed value of a unit of corn. This is reflected in the cash prices (Oklahoma Agricultural Statistics, NASS, 2013). In addition, Warren (2015) and Stoecker (2015) found that present-day major cash crop corn requires more water than grain sorghum. Thus, there are questions as whether grain sorghum can be competitive with corn in terms of profit per unit of remaining groundwater and if so, under what circumstances.

Comparisons of the water-use efficiency between irrigated corn and grain sorghum in the OPC are available through irrigated variety trials and irrigation research conducted at the Oklahoma Panhandle Research and Extension Center (OPREC), Goodwell, Texas County, Oklahoma. The results of variety trials in Table 4 show that irrigated grain sorghum has lower yields per acre than corn. However, grain sorghum consistently produces more grain per acre inch of irrigation than irrigated corn.

The variety trials are generally designed to produce maximum yields per acre. The data in Table 4 shows that maximum grain sorghum yields are produced with approximately 60 percent of the irrigation water required for corn. These results indicate that more total grain per unit of water could be produced by growing grain sorghum than corn. Since less water is used annually per acre, with a constant number of irrigated acres, the remaining life of the aquifer could be extended by switching from irrigated corn to irrigated grain sorghum.

Table 4. Recent OPREC Field Research Experiments on Corn and Grain Sorghum from 2005 to 2014

	Yield (bushels/acre)		Irrigation (acre-inch)		Water Efficiency (bushels/acre-inch)	
Year	Corn	Sorghum	Corn	Sorghum	Corn	Sorghum
2005	186.2	149.4	15.5	9.8	12.0	15.2
2006	179.2	142.5	19.4	11.8	9.2	12.1
2007	170.9	92.3	19.4	5.7	8.8	16.2
2008	216.8	122.7	19.3	12.2	11.2	10.1
2009	226.0	152.0	21.0	6.7	10.8	22.7
2010	179.0	145.0	18.0	12.6	9.9	11.5
2011	98.5	166.0	22.5	4.9	4.4	33.9
2012	177.5	152.0	20.3	8.7	8.7	17.5
2013	217.5	145.0	22.1	9.1	9.8	15.9
2014	147.0	159.0	13.8	12.7	10.7	12.5
Average	179.9	142.6	19.1	9.4	9.4	15.1

Note: Corn variety trials were executed in Goodwell, OK and Guymon, OK

Research and field experiments conducted at the OPREC between 2009 and 2012 in Goodwell, Texas County, Oklahoma demonstrated that 150 bushels of grain sorghum can be produced with 9.4 inches of irrigation, while 22 inches are required to produce

190 bushels of corn. Following 2012 trials, (Warren et al. 2015) conducted simulated experimental trials on corn and sorghum in the year 2013 and 2014 using various well capacities. Four treatments with well capacities of 800, 600, 400, 200, and 100 GPM (assuming a 125 acre irrigated area) were conducted on randomized blocks for corn and sorghum as shown in the Table 5.

The outcome of the trials suggests that as the well capacity declines, sorghum shows a tendency to give more bushels per acre-inch of water. Results and outcomes of these trial experiments available from 2005 to 2014 are supporting this current study to simulate and validate the crop yields and water use. The annual average (2005-2013) crop prices in Oklahoma Panhandle for corn and sorghum are $4.48 and $4.16 per bushel respectively (Oklahoma-NASS). Refer APPENDIX Table A1 for annual average prices.

Table 5. Experimental Trials Performed in Goodwell, Oklahoma with Various Well Capacities for the Years 2013 and 2014

2013

Well Capacity (gallons/minute)	Irrigation (acre-inch)		Yield (bushels/acre)		Water Use Efficiency (bushels/acre-inch)	
GPM	Corn	Sorghum	Corn	Sorghum	Corn	Sorghum
800	12.9		166.5		12.9	
600	11.4	10.2	156.2	141.2	13.7	13.8
400	8.6	7.7	148.7	130.9	17.3	17.0
200	6.1	5.8	112.2	128.1	18.4	22.1
100		3.9		107.5		27.6

2014

Well Capacity (gallons/minute)	Irrigation (acre-inch)		Yield (bushels/acre)		Water Use Efficiency (bushels/acre-inch)	
GPM	Corn	Sorghum	Corn	Sorghum	Corn	Sorghum
800	21.7		180.6		8.3	
600	17.7	13.3	171.3	139.5	9.7	10.5
400	14.7	11.8	149.7	131.0	10.2	11.1
200	8.7	7.3	104.1	86.5	12.0	11.9
100		5.3		96.0		18.1

1.8 Economic Impacts and Analysis

The continuous decline in the water table increases vertical pumping lift, as a result well capacity reduces and increases pumping duration, hence, additional energy is required to discharge a unit of water. Additional energy raises the fuel cost causing diminishing returns and reduced well yields cannot meet the crop water requirement, which eventually leads to reduced profits and yields. Under constant natural gas prices, cost of pumping irrigation water in Oklahoma Panhandle has increased since 1969 (Mapp and Dobbins, 1976) (Sloggett and Mapp, 1984) (Mapp, 1988). As the pumping cost increases, it can create a gradual shift in the farming practices from irrigation to dry land, because it could create a circumstance where producing crops using one more additional unit of water is no more economically viable.

This study is an extension of an earlier study (Stoecker et al. 2015) submitted in completion of an OSU OWRRI grant. This report examines implications of spatial Ogallala aquifer parameters related to aquifer depth, hydraulic conductivity and specific yield. This thesis does contain results of the EPIC simulations from the 2015 OWRRI report, which were done by the current author.

CHAPTER II

THEORY

2.1 Lagrangian Multipliers for Land and Water

(Bryant, 1991) used a theoretical analysis to optimally allocate irrigation water through time with stochastic dominance and Neo-Classical Production theory. Here, we use a different approach to show how an optimal crop mix is allocated under limited water supply. This theory will explain situations where two products are produced from one variable input using the product-product model. Multi-product production can generally be appropriately viewed as production of several products. However, the products are linked through resource constraints, non-allocable factors of production, and/or through joint-ness in production (Beattie and Taylor, 2009). The first part of the theory will address multi-product production linked through a land resource constraint. Beattie and Taylor present the framework to maximize the revenue subject to a fixed amount of a variable factor in the input. The production function for each crop can be expressed as,

$$y_i = f_i(\cdot) = f(r_i)x_i \tag{2.1}$$

where y_i is the yield for the crop i, x_i is the amount of the variable factor, r_i is a vector of variable inputs applied to x_i to produce y_i, and $f_i(\cdot)$ represents the production function of crop i.

Assuming the producer is a price-taker (under perfect competition), the profit function can be given by equation (2.2). Net Returns (NR) received in one period is entirely independent and does not affect the preceding or successive production process.

$$NR = p_1 y_1(r_1) + p_2 y_2(r_2) - C_1 r_1 - C_2 r_2 \tag{2.2}$$

where p_1 and p_2 are assumed to be exogenous crop output prices, where producer does not have any market power. The objective is to maximize profit (net returns) subject to a land constraint $x_1 + x_2 = x^0$, where x^0 is the fixed/limited amount of land.

The constraint Lagrangian can be written as,

$$L(r_1, r_2, x_1, x_2) = (p_1 y_1(r_1) - C_1 r_1)x_1 + (p_2 y_2(r_2) - C_2 r_2)x_2 + \lambda(x^0 - x_1 - x_2) \tag{2.3}$$

where $r_1, r_2, x_1, x_2 \geq 0$, because the input variables are required to be non-negative, the first order Karush-Kuhn-Tucker (KKT) conditions can be expressed as,

$$\frac{\partial L(\cdot)}{dr_1} = (p_1 y_1'(r_1) - C_1)\, x_1 \leq 0, \tag{2.4}$$

$$\frac{\partial L(\cdot)}{dr_2} = (p_2 y_2'(r_2) - C_2)\, x_2 \leq 0, \tag{2.5}$$

and,

$$\frac{\partial L(\cdot)}{dx_1} = p_1 y_1(r_1) - C_1 r_1 - \lambda \leq 0, \tag{2.6}$$

$$\frac{\partial L(\cdot)}{dx_2} = p_2 y_2(r_2) - C_2 r_2 - \lambda \leq 0, \tag{2.7}$$

$$r_1^*(p_1 y_1'(r_1^*) - C_1) = 0, \tag{2.8}$$

$$r_2^*(p_2 y_2'(r_2^*) - C_2) = 0, \tag{2.9}$$

and,

$$(p_1 y_1(r_1^*) - C_1 r_1^* - \lambda^*)x_1^* = 0, \tag{2.10}$$

$$(p_2 y_2(r_2^*) - C_2 r_2^* - \lambda^*)x_2^* = 0, \tag{2.11}$$

$$\lambda^*(x^0 - x_1^* - x_2^*) = 0, \tag{2.12}$$

Expressions (2.8) – (2.11) require the product of the optimal value of each variable multiplied by the value of its derivative of the Lagrangian (at the optimal solution), be zero. For each of the input variables $r_i, i = 1{,}2$, equations (2.4) and (2.5) are multiplied by $1/x_i$, the derivative are set to zero and solved for r_i^*. If r_i^* is non-negative then, $f_i(r_i^*) - C_i = 0$ ($\mathrm{VMP}_{r_i} = \mathrm{MFC}_{r_i}$). If either r_i^* be negative, then r_i^* is set equal to zero. In either case,

$$r_i^*[p_i y_i'(r_i^*) - C_i] = 0. \tag{2.13}$$

In equations (2.10) and (2.11), the maximum returns to land (i.e., profit per acre) for crop i is given by the terms $p_i y_i(r_i^*) - C_i r_i^*$. The $\lambda^*$is determined as $\lambda^* = \max[(p_i y_i(r_i^*) - C_i r_i^*), 0]$. λ^* is set equal to the net return to land. In this example if y_1 was the most profitable, $x_1^* = x^0$ and $x_2^* = 0$. If should both crops be unprofitable then x_1^* and $x_2^* = 0$. The result will satisfy equations (2.10), (2.11) and (2.12). The results show how higher returns crop dominates lower returns crops and use more available land.

Above theory behaves well only when land x^0 is a constraint and water is unlimited. When water is assumed to be a non-binding constraint, its absence does not affect the results. However, when the supply of water is limited, its limitation should be considered along with land. In the following theory, it is assumed that total available water supply is a limited and land area irrigated is fixed. By following the previous theory steps, equation (2.1) can be rewritten as,

$$y_i = f_i(\cdot) = f(r_{it}, w_{it}), \tag{2.14}$$

where y_{it} is the yield obtained for the crop i in any year t, $i = \{1{,}2\}$, and $f_i(\cdot)$ represents the production function of variable inputs r_{it} plus water extracted w_{it} in year $t = 1, \dots, T$.

Assuming there is a well, which has a fixed/limited water stock S_1 and the expected price p_i per each bushel for crop i, which is constant each year. Groundwater is a resource that is subject to increasing extraction cost. This is because the pumping lift increases as the remaining supply declines. A pumping cost function is exclusively a function of output that reflects the pumping of a unit of water in time period t is,

$$V_i = aw_{it} + bw_{it}^2 - dw_{it}S_t, \tag{2.15}$$

where a and b are constants and S_t is the remaining supply of water. The constant d reflects the additional cost as the remaining supply of water declines. Over a period of time the discounted total net returns (Net Present Value (NPV)) for producing a single crop at time period $(t = 1, \dots, T)$ using a Lagrange multiplier can be written as,

$$\begin{aligned} \max \mathrm{NPV} \\ &= \sum_{t=1}^{T} \beta^{-t} \{[p_1 y_1(r_{1t}, w_{1t}) - C_1 r_{1t} - V_1(w_{1t})] \\ &+ [p_1 y_1(r_{1t}, w_{1t}) - C_2 r_{2t} - V_2(w_{2t})] \\ &+ \lambda_t(x^0 - x_{1t} - x_{2t}) + \lambda_t(S_t - x_{1t}w_{1t} - x_{2t}w_{2t})\} \end{aligned} \tag{2.16}$$

where the value of S_1 is known and x_{it} is the amount of land allocated to crop i to produce y_i at time period t.

The above expression maximizes the Net Present Value (NPV) from the remaining fixed water stock S_1. Note the stock and land constraints are also discounted in equation (2.17). The constrained long-term profit maximization is solved for the optimum by taking the first order conditions, w.r.t. to each w_t, S_t and λ_t.

Assuming all $w_t, S_t,$ and $\lambda_t \geq 0$, first order optimum conditions for maximum profit are,

$$\text{for all } w_t, \frac{\partial \text{NPV}}{\partial w_t} = p\left(\frac{dy_t}{dw_t}\right) - a - 2bw_t + dS_t - \lambda_t = 0 \tag{2.17}$$

$$\text{for all } S_t, \frac{\partial \text{NPV}}{\partial S_t} = \frac{dw_t + \lambda_t}{(1+i)^t} - \frac{\lambda_{t-1}}{(1+i)^{t-1}} = 0 \tag{2.18}$$

$$\frac{\partial \text{NPV}}{\partial S_t} = dw_t + \lambda_t - (1+i)\,\lambda_{t-1} = 0 \tag{2.19}$$

$$\lambda_t = (1+i)\,\lambda_{t-1} - dw_t \tag{2.20}$$

The expression 2.20 means, the value of the opportunity cost of foregone rent in the current period is equal to its value in the previous period times one plus the rate of discount less the decline due to stock decline. That is, price of the resource λ,changes over period of time, and the changes must affected by the discount rate and marginal extraction costs according to the change in the stock. Otherwise, the extraction rate is not optimal. The water supply in each period is equal to than in the previous period less withdrawals,

$$\text{w.r.t } \lambda_t, \quad \frac{\partial \text{NPV}}{\partial \lambda_t} = S_t - w_t - S_{t+1} = 0. \tag{2.21}$$

The interpretation in this theory makes a valid point to say that optimal water extraction declines ($w_t > w_{t+1} > w_{t+2}, \dots, w_T$), over time when water is limited and the discount rate is positive. Therefore, over a period of time, crops may receive smaller amounts of water. This study follows theoretical methods explained above; the MIP model decides pivot investments over the long-run, with constraints of land and available water supply.

2.2 Irrigation System Purchases with Mixed Integer Programming

In this section, the structure of Mixed Integer Programming (MIP) algorithm is explained for choosing the pivot purchases during the transformation period. In a general MIP problem, where some variables take integer values, but the rest are ordinary continuous variables. These ordinary continuous variables are the amount of cropland allocated to each crop activity. The general form of the Linear Program (LP) problem can be seen as,

$$\max\{cx: Ax \leq b, x \geq 0\} \tag{2.22}$$

where c is the objective function as a n-dimensional row vector with and x is the n-dimensional column vector with decision variables unknown, A is the m by n matrix and b is an m-dimensional column vector. The objective values are set as row vector of expected net returns of crop per acre, and decision variables set of column vector is the amount of land allocated for each crop are calculated from the LP model. Exogenous crop activities were computed using crop yield model EPIC and Microsoft® VBA, explained in Chapter 3.

Assume existing four wells can irrigate up to 480 acres using four pivots. The producer will make this land allocation decision depending on the maximum net present value that will be obtained through crop choices and investment decision over the life of the pivots. The list of feasible irrigation activities also varies with the number of pivots selected. This is because (as shown later in Chapter 3), if for example two pivots were selected, the producer with four wells could use two wells to supply each pivot. This affects the variable pumping cost and net returns. The variables such as pumping cost and crop responses to water stress are linearized because the nonlinear mixed-integer approach has more computational problems.

The choice between one, two, three or four pivot selection decision variable for each 15-year period was assumed to be an integer variable, which sums up to one. The purchase variables take binary integer variables $y \epsilon \{0,1\}$. Since, restriction added for the pivot selection take integer values, but not all variables are integers, the model for (Linear) Mixed Inter Program (MIP) can be written as,

$$\max cx + hy \tag{2.23}$$

$$Ax + Gy \leq b, \tag{2.24}$$

$$x \geq 0, y \epsilon \{0,1\}^n . \tag{2.25}$$

where again A is the m by n matrix, G is the m by p matrix, h is a p-dimensional row-vector, and y is a p-dimensional column vector of integers.

2.3 Shadow Price Validation

Euler's Theorem [Chiang and Wainwright (2005)]

If $Q = f(K, L)$ is linearly homogeneous, then,

$$K \frac{\partial Q}{\partial K} + L \frac{\partial Q}{\partial L} = Q \tag{2.26}$$

This is valid for any values of K and L.

Mathematically, Euler theorem for this study can be developed as,

$$L\Delta l + W\Delta w + I\Delta i = PV \tag{2.27}$$

where, L is the total land used or one acre, W is the acre feet water used per irrigated acre, and I is one irrigated acres supplied by the pivots, Δl unit shadow price of land, Δw unit shadow price of water and Δi is per unit area shadow price of pivot size investment.

CHAPTER III

OBJECTIVES, METHODS AND PROCEDURES

The overall objective of this research is to maximize the agricultural benefits from the remaining limited groundwater supply in Oklahoma Panhandle. The overall objective can be divided into sub objectives as,

1. Extend available but limited crop research on irrigated corn and sorghum yields and water use to be more representative of long term weather conditions in the Oklahoma Panhandle.
2. Estimate the impacts of recent USGS published Ogallala parameters on pumping cost considering pumping drawdown and well interference on various levels of pumping as the water table declines.
3. Determine the optimal irrigation level and choice between irrigated corn and grain sorghum that maximizes the net benefits from the remaining groundwater supply.
4. Determine the optimal most profitable sequence of pivot investments over the remaining life of the aquifer.
5. Determine the difference in discounted profits earned by producers who maximizes long-term NPV from the remaining groundwater and the producer who chooses the crop with the highest current returns to land until the aquifer is exhausted.

To accomplish the above objectives, the concept of a representative irrigated section of land in Texas County, Oklahoma is visualized. An outline of the representative field is shown in Figure 7.

The irrigation characteristics assumed for this study are,

1. Producer’s field is a 640-acre square section with four irrigation wells.
2. The wells are located at the edge of the field, and pivots rotate from the center of the circle.
3. Center pivots are connected using underground pipelines. *Note*: Underground pipelines are in existence before the start of the project.
4. The water table is split into eight layers, and wells can produce 800 GPM at the top level.

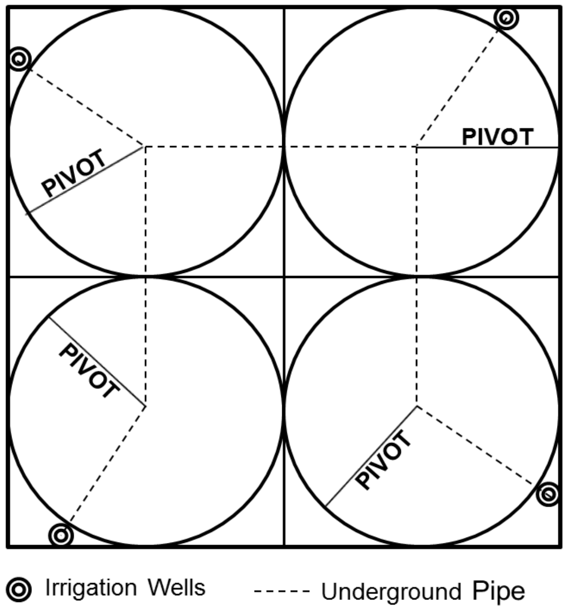


Figure 7. Well locations and pipelines connecting wells and pivots are shown on a representative farm land

A multi-period mathematical programming model is used to determine the optimal crop choice and groundwater use. A sample of planned crop activities is shown in Table 6. Construction of the model requires estimates of crop yields that are likely to result from the long-term weather conditions while experimental research is conducted for only few years. The weather observed during the experimental period may not be representative of the highly variable weather in the Oklahoma Panhandle.

The activities are the expected crop net returns per acre calculated by subtracting expected revenue over the variable costs, and then discounted at four percent to the base year. In short, the activities give the net present value of the crop net revenue over variable cost per acre. Oklahoma average market prices received by corn and sorghum are used as the crop output price for each year (Oklahoma-NASS). Center-Pivot System (CPS) investment costs are collected from local Oklahoma irrigation dealers. The crop activities are discounted using federal water-supply project discount rates, based on PL 99-662.

Table 6. The Planned Crop Activities for the Programming Model

Activity Name	Ch90138, Sf41046, Sz060
Crop	C = Corn, and S = Sorghum
GPM Supplied to Operating Pivots	h = 800 GPM, g = 700 GPM, f = 600 GPM, e = 500 GPM, d = 400 GPM, c = 300 GPM, b = 200 GPM and a = 100 GPM. z is dryland.
Irrigation Stress Level	9 = 90%, 8 = 80%, 7 =70%, 6 = 60%, 5 = 50%, 4 = 40% and 3 = 30%. 0 = Dryland.
Year	1,…,60
Number of Operating Pivots	1, 2, 3 or 4
Saturated Layer	8,…,1

Note: The activities are sample in year 1, complete set of one year activities are presented in APPENDIX Table A5.

3.1 Objective 1:

To accomplish objective 1, the Environmental Policy Integrated Climate (EPIC) simulation model (Williams et al. 1989) was set up for the conditions prevailing at OPREC in Goodwell, Oklahoma. The purpose was to calibrate the model yields and water use against the weather and experimental yields obtained from 2005 to 2014. After calibration, the EPIC model is used to estimate crop yields with various levels of irrigation and irrigation stress using daily weather conditions that were observed from 1965 through 2014 at Goodwell, Oklahoma.

3.1.1 Simulation Design Irrigated Yields and Water Use

An outline of the research or yield estimation plan with EPIC is shown in Figure 8. The specific irrigation simulations conducted with each crop (corn and grain sorghum) were designed to estimate yields from 120-acre using center pivot irrigation at 800, 700, 600, 500, 400, 300, 200 and 100 GPM. The effects of irrigation stress were simulated by delaying an irrigation application until the soil moisture content declined to 90, 80, 70, 60, 50, 40 or 30 percent from the soil moisture threshold. EPIC results are calibrated for 56 combinations (GPM and Stress) for corn and sorghum over a 50-year period.

The field experiments results in Oklahoma Panhandle, Texas Panhandle and southwestern Kansas for corn and sorghum are available from 1989 to 2014. The simulation results were compared with the existing experimental results. The objective to compare the EPIC results was to validate the simulated yield and water use with the experimental yields. Once the simulation results match the experimental results, the calibration was extended to represent the long-term weather conditions.

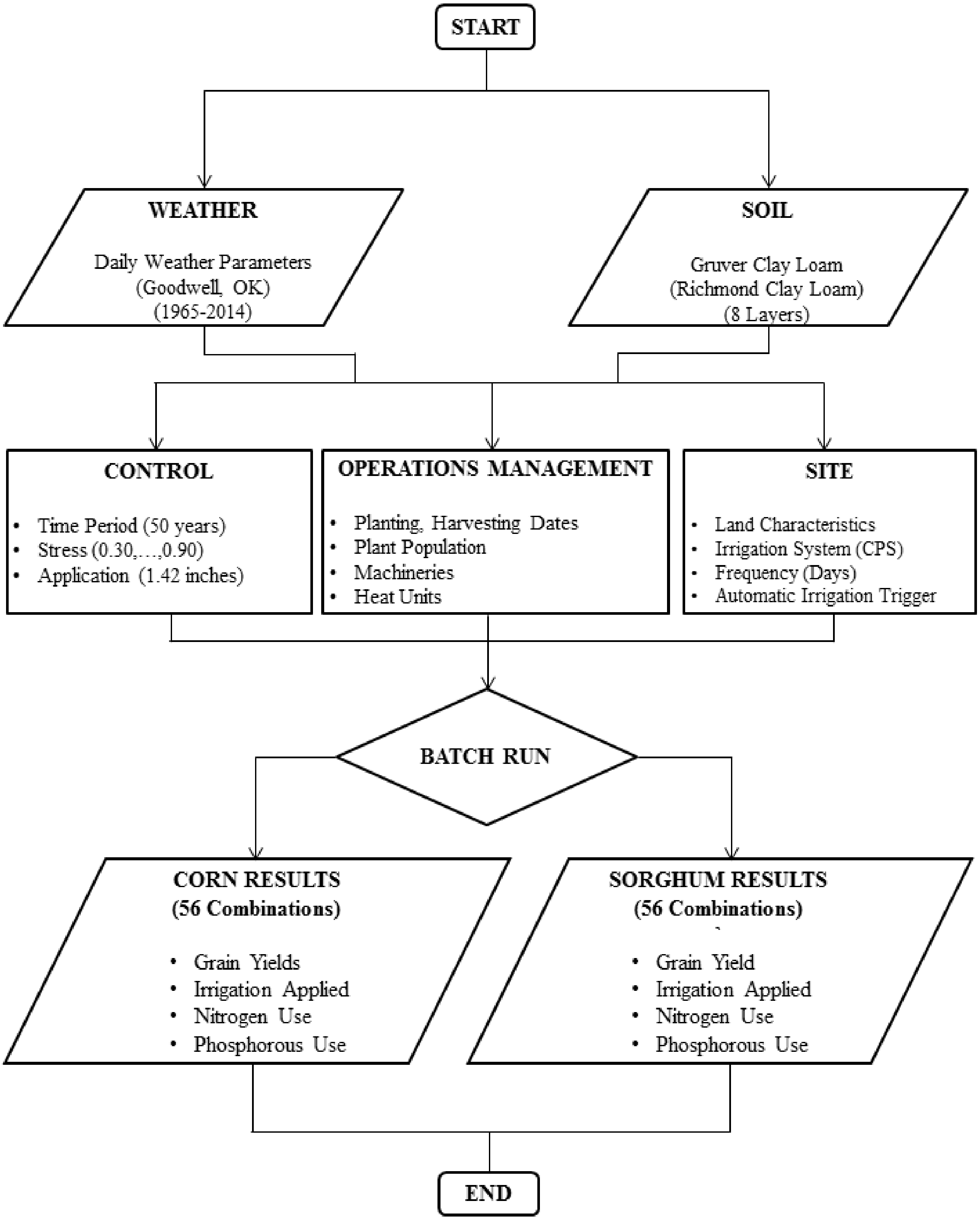


Figure 8. Flow chart showing the structure of EPIC simulation for Center Pivot System

3.1.2 Daily Weather Data

For the simulation, EPIC utilizes daily weather data, such as air temperature, precipitation, solar radiation, relative humidity and wind speed. Although EPIC can operate with daily precipitation and temperature data, for a better estimate and to obtain accurate results from the simulation, actual available weather data was collected from nearby locations to predict the Goodwell, Oklahoma weather variables. To construct a 50 year (1965-2014) daily weather file, Stoecker (2015) developed a series of multiple regressions for each weather parameter using the available data from the surrounding weather stations and MESONET stations. Twenty-year available daily weather data from 1994 to 2014 were collected for Goodwell, Oklahoma from the Oklahoma MESONET. Unfortunately, temperature data were not recorded by the MESONET until 1997 at Goodwell, Oklahoma. For missing Goodwell temperature values between 1994 and 1997, temperature data were collected from Hooker and Boise City, Oklahoma, Liberal and Elkhart, Kansas, and Amarillo and Perryton, Texas.

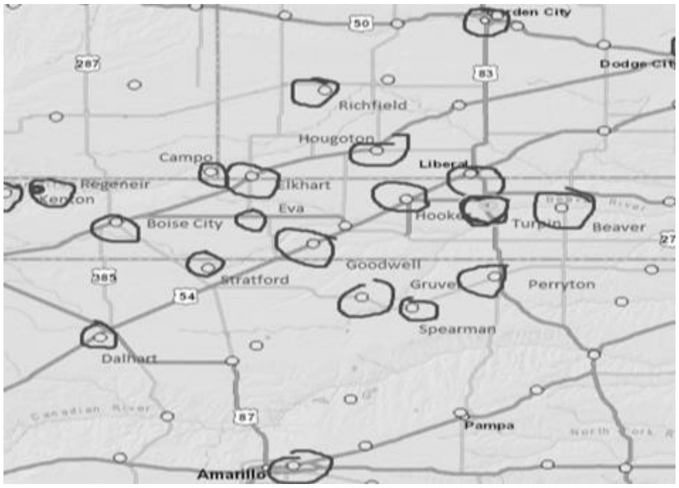


Figure 9. Locations around Goodwell, Oklahoma from where weather variables were obtained to estimate missing Goodwell Weather values. *Source*: Stoecker (2015)

Other missing daily weather variables between 1965 and 2014 were predicted using OLS regression process using more surrounding weather station values (see Figure 9). Goodwell objective weather parameter was set as a dependent variable and regressed against reported values from the surrounding stations. To predict Goodwell missing daily weather variables, 1) daily precipitation was used from Eva, Oklahoma, Elkhart, Richfield and Hugoton, Kansas, Gruver and Spearman and Stratford, Texas, 2) daily relative humidity were used from Liberal and Elkhart, Kansas, Dalhart, Texas, and Clayton, New Mexico, 3) daily wind speed were used from Clayton, New Mexico, Amrillo and Dalhart, Texas, and Garden City, Dodge City and Liberal, Kansas, 4) daily solar radiation was regressed against MESONET values in Beaver County and Boise City, Oklahoma for the period 1964 through 2014. Estimated average monthly weather parameters for Goodwell, Oklahoma are shown in the Table 7.

Table 7. 50-Year (1965-2014) Monthly Average Weather Data Represented Annually

	Max. Daily Temperature (°C)	Min. Daily Temperature (°C)	Monthly Precipitation (mm)	Daily Relative Humidity (%)	Daily Wind Speed (m/s)	Daily Solar Radiation (W/m^2)
Jan	9.1	-7.0	7.6	60	9.1	10.8
Feb	11.3	-5.3	10.3	60	9.5	13.7
Mar	15.9	-1.2	25.4	60	10.6	17.8
Apr	21.1	4.0	34.1	60	11.1	24.5
May	25.9	9.5	67.8	60	9.9	26.4
Jun	31.4	15.2	64.2	60	9.7	25.4
Jul	34.1	18.0	58.8	60	8.9	22.2
Aug	32.8	17.1	58.4	60	8.4	19.3
Sep	28.5	12.4	36.9	60	8.9	15.2
Oct	22.4	5.3	32.4	60	9.1	11.6
Nov	15.0	-1.3	14.8	60	9.1	9.9
Dec	9.6	-5.9	11.3	60	9.2	18.3
Year	21.5	5.1	34.7	60	9.5	22.2

Note: °C is degree Celsius, mm is millimeter, % is percentage, m/s is meter per second and W/m^2 watt per square meter. *Source*: Stoecker (2015)

3.1.3 Additional EPIC Data

Goodwell, Oklahoma, according to USGS is approximately located at N 36º 60', W 101º 62', and has average elevation of about 3300 feet above the sea level. The major soil type found in the Goodwell and Texas County, Oklahoma is Gruver series (formerly Richmond). The Gruver series consists of very deep, well drained, moderately slowly permeable soils that formed in calcareous Eolian sediments of Pleistocene age (USGS, 2007). The soil series is ideally clay loam, with a nearly level plain of 0.5 percent slope. The Gruver clay loam has an albedo of 14% and falls under hydrologic group 3 or C. Total soil depth of 84 inches was split into eight layers for modeling. Each layer has a different depth, bulk density, pH, conductivity, and other organic and inorganic concentrations. The soil is assumed to be static profile and there is no soil erosion affecting the crop productivity.

The Land use number is 9 (USDA Soil Conservation Service 1972). Each model run used the Penman method (FAO) to calculate the evapotranspiration. Runoff is found to be 0 to 1%, which is neglected in the model. Furthermore, atmospheric CO_2 was kept constant at average 330 ppm to avoid the climate-change effects, which are unknown for the location. Since water irrigated to the crops is fresh groundwater, the salt concentration was set to zero. Also USGS reports, nitrate aquifer vulnerability is low in the study area, which makes the groundwater in Goodwell, Oklahoma risk-free from contamination. The fertilizer was set as automatic. It means whenever the crop requires nutrients, the crop is supplied with the nitrogen and phosphorous. In addition, the pesticides, insecticides and herbicides were set automatic whenever necessary in the operation's scheduling.

Plant population (PP) for corn or sorghum is adjusted accordingly to attain the desired yield for each well capacity. The average PP for corn and sorghum was 32,000 plants acre^{-1} and 64,000 plants acre^{-1} respectively. The reason to adjust the PP could be seen as, too high planting can cause lodging problems and yield loss, and too low planting may not maximize the productivity which could have been achieved in that period. After several iterations, precise PP is determined for each well capacity, to avoid loss of water use and crop productivity. Usually, PP is determined by seeding rate and germination date. However, due to lack of information on the history of the project, PP was held constant throughout the model.

The planting and harvesting dates for corn and grain sorghum were held constant. In the EPIC modeling, grain sorghum was planted on May 28 and harvested on October 31. For grain sorghum, the previous studies and experiments from Bushland, Texas, Goodwell and Guymon, Oklahoma, and Tribune and Garden City, Kansas suggest that the reasonable planting date is during the end of May or beginning of June, and harvested in the end of October. Corn is commonly planted a month or two weeks before sorghum in the United States and harvested during the end of September. In EPIC modeling, corn planting date was set on April 15, and harvest date was set as September 30.

EPIC has the potential to automate its harvest date when the desired heat units are reached. For the given maximum and minimum temperatures, long-term predicted Potential Heat Units (PHU) from planting to maturity for corn and sorghum is 2,100 and 1,700 respectively. Therefore, the harvest dates are automated to attain the most optimal yields in any season.

3.1.4 Yield, Well Capacity, and Soil Moisture

The EPIC model allows a specification of the minimum number of days between successive irrigations. The minimum number of days the pivot takes to complete a circle for applying 1.4 acre-inches of water with 100 to 800 GPM well capacities is shown below at the left of Table 8. To evaluate the effects of deficit irrigation, initiation of subsequent irrigation could be delayed until the available soil moisture reached a stress level of 90, 80, 70, 60, 50, 40, or 30 percent, which is related to the soil moisture threshold. This was done in order to take advantage of any rainfall received during the previous pivot rotation. The 90 percent trigger represents almost continuous irrigation while the 30 percent level represents extreme deficit irrigation.

An 800 GPM well supplying to a center-pivot system with an application efficiency of 85 percent can apply 42.4 acre-inches per day (154,000 cubic feet per day). At this rate, 1.4 inches of water can be applied to 33.3 acres in one day. Therefore, with an 800 GPM well, for applying 1.4 acre-inches it takes about four days to complete a 120-acre quarter section with a CPS.

Table 8. Irrigation Frequency for Single Well Operated on a 120-acre Quarter Section Using CPS

Well Capacity	Single Day Application Rate	Single Day Application Rate	Irrigation Frequency
GPM	inches (in)	millimeter (mm)	days
800	1.4	36	4
700	1.4	36	5
600	1.4	36	6
500	1.4	36	7
400	1.4	36	8
300	1.4	36	11
200	1.4	36	16
100	1.4	36	32

Note: Application rate design features of experimental irrigation research at OPREC

3.2 Objective 2:

Objective two is concerned with the pumping cost from a declining aquifer in the presence of well interference and when two or more wells are linked together through an underground pipe to supply a single pivot.

3.2.1 Pumping Estimates

What diminishes irrigated crop net returns when the water table is continuously declining? One answer is an increase in pumping cost. So, it is essential to understand the long-term effects on the water supply that affect the producer’s profits.

During continuous pumping, producers face a gradual decline in the water table and increase in the vertical pump lift. Under this condition, if groundwater is the only source of cropland water use, it is all-important to evaluate the irrigation cost estimates as there is a steady decline in the water table.

As shown in the Figure 7 each section of land is equipped with four irrigation wells at the edge of the field. When it is time for pivot replacement, a producer with a limited water supply can purchase one, two, or three pivots but continue to use all four wells. Producers can connect the wells together to irrigate one, two, or three quarter sections with an ideal discharge rate that will give the maximum benefit. When the wells are to be connected in various combinations, the number of wells pumped at a certain pumping rate influences the total drawdown and also additional head is required to move the water from a remote well to an operating pivot, all of these factors influence the pumping cost.

3.2.2 Drawdown Estimates

In this study, there are two scenarios where the drawdown has to be calculated. First, when a producer's discharging wells are not influenced by any surrounding wells assuming the neighboring wells are located far away. Second, when adjacent wells cause a lowering of the water table at the producer's well. If multiple-well drawdowns are significantly different from single-well drawdowns, then a detailed study would be necessary, otherwise the well interference could be avoided and use the calculations for the future studies when interference problems increase.

In this study, we are assuming that when a producer is surrounded by other producers, only water beneath the irrigated section is available, when producers are not surrounded by other producers, it is assumed that 40% of the surrounding area was irrigated. When only 40% of land in the irrigated area is irrigated, the producers pumping wells were assumed to not to be affected by the surrounding wells. To avoid the externality issue, we assume two wells are never located on the same edge of the field.

3.2.2.1 Single-Well Drawdown

In the single-well approach, the water table is assumed to be not affected by the surrounding wells. The amount of water pumped from the water table depends on the depth of the saturated thickness, duration of pumping, and hydraulic conductivity and specific yield. When extracting groundwater from an unconfined aquifer, a cone of depression is formed as shown in the Figure 10, the depth of the cone of depression from SWL is called as the drawdown. The cone of depression varies with the discharge rates. The drawdowns are used to estimate the total head and cost of pumping per unit of water.

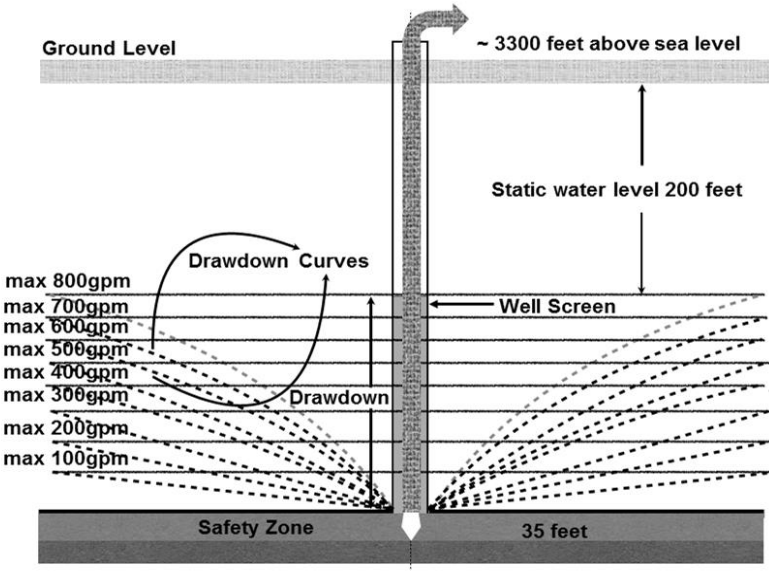


Figure 10. Illustration of Cone of Depression for various well capacities after 90 days of pumping

The well-known and most widely used modified radial flow equation developed by Cooper and Jacob (1946) is used to estimate the drawdowns for single well and multiple wells. Using Cooper and Jacob (1946) equation, the well drawdown occurring at the aquifer is calculated as,

$$s_{nw} = \frac{Q}{4\pi T} W(u) \tag{3.1}$$

$$s_{nw} = \frac{Q}{4\pi T}\left[-0.577216 - \ln(u) + u - \frac{u^2}{2\times 2!} + \frac{u^3}{3\times 3!} - \cdots\right] \tag{3.2}$$

$$\text{here, } u = \frac{r^2 S}{4Tt} \tag{3.3}$$

where s_{nw} is the drawdown in feet from nw number of wells, Q is the discharge rate in gallons per day, $T(K, b)$ is called as coefficient of transmissivity ft^2/d which is a function of hydraulic conductivity K in ft/d and saturated thickness b in feet, r is the distance from the pumping well in feet, S is the specific yield, t is the duration of pumping in days.

For single well drawdown, the drawdowns are calculated at $r = 1$ foot. When $r = 1$ foot, $u < 0.01$, hence the series following the first two terms in $W(u)$ can be neglected from the equation 3.2 (Hecox et al. 2002). Therefore, the equation (3.2) is written in the form of equation (3.4) for calculating the single well drawdown ($s_{1\mathrm{w}}$),

$$s_{1w} = \frac{Q}{4\pi T}[-0.577216 - \ln(u)] \tag{3.4}$$

The amount of drawdown can also increase with the number of days pumped or length of the irrigation season. *Note*: while estimating the variables outside the brackets *T* should be used in terms of gallons day^{-1} ft^{-1} to obtain the drawdown in feet.

3.2.2.2 Drawdown with Multiple Wells

In multiple wells approach, the well discharge is influenced by the surrounding wells because the surrounding wells drawdown cone extend to the well in question, which reduces the saturated thickness. For multiple wells case in this study, it is assumed that each discharging well in a quarter-section is surrounded by four wells, each well drawdown influences the discharging well (well in question), which causes a drop in the static water level as shown in the Figure 11.

The drop in the static level reduces the vertical length of the saturated thickness, in effect well capacity declines in the discharging well. Therefore, single and multiple well discharge rates are different for a given saturated thickness. This effect is shown in Figure 11. The situation can also be seen as four wells are located around a center well at equal distance of 402 meter (1320 feet). When five wells extract groundwater during the same period, drawdowns of four wells at $r = 1320$ feet are calculated and added to the single well drawdown to estimate the total drawdown.

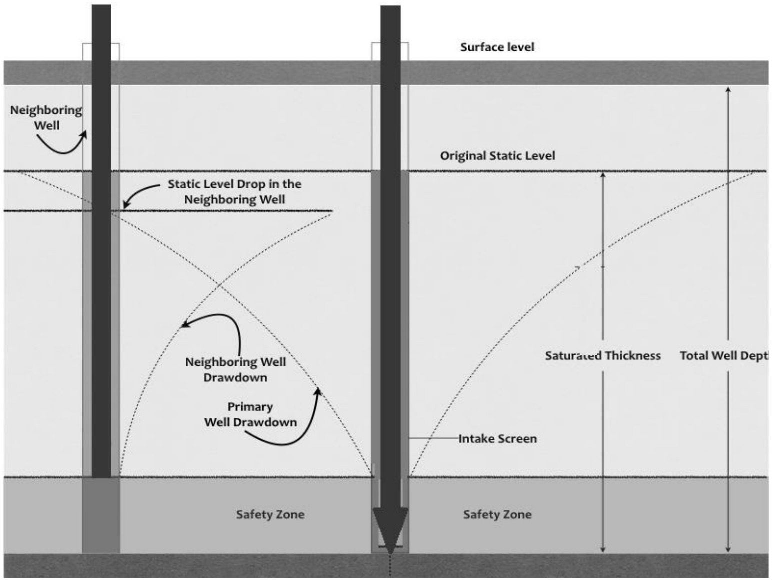


Figure 11. Illustrating the drawdown interference and drop in the Static Water Level

When $r = 1320$, $u > 0.01$. To approximate the equation 3.2, Mount (1969) developed a method to estimate the drawdown at a given point from *n* surrounding wells. Using the example, assuming there *n* wells in a field and each well is pumped at a same discharge rate of Q, then the drawdown (s_{nw}) of the point located r_i can be written as,

$$s_{\mathrm{nw}} = \frac{Q}{4\pi T}\left[n\left(-0.577216 - \ln\left(\frac{4Tt}{S}\right)\right) - 2\sum_{i=1}^{n}\ln(r_i)\right] \qquad (3.5)$$

The equation can be rewritten when the wells are located at identical distances (r_e),

$$s_{\mathrm{nw}} = \frac{Q}{4\pi T}\left[n\left(-0.577216 - \ln\left(\frac{4Tt}{S}\right)\right) - 2\,n\ln(r_e)\right] \qquad (3.6)$$

$$s_{\mathrm{nw}} = n\left(\frac{Q}{4\pi T}\left[-0.577216 - \ln\left(\frac{{r_e}^2 S}{4Tt}\right)\right]\right) \qquad (3.7)$$

Since $u \geq 0.01$, the additional terms cannot be neglected, here $u_e = \frac{{r_e}^2 S}{4Tt}$ (3.8)

$$s_{\mathrm{nw}} = \frac{Q}{4\pi T}\left[-0.577216 - \ln(u_e) + u_e - \frac{{u_e}^2}{2\times 2!} + \frac{{u_e}^3}{3\times 3!} - \cdots\right] \qquad (3.9)$$

When $n = 4$, the additional four well drawdowns ($s_{4\mathrm{w}}$) can be added to the single well drawdown (s_{1w}) to obtain the total drawdown (s_{5w}) for pumping five wells. The theoretical equation for calculating the total drawdown developed in this study is as follows,

$$s_{5w} = s_{1w} + s_{4w} \tag{3.10}$$

$$s_{5w} = \frac{Q}{4\pi T}\left[-0.577216 - \ln\left(\frac{r^2 S}{4Tt}\right)\right] + n\left(\frac{Q}{4\pi T}W(u_e)\right) \tag{3.11}$$

$$s_{5w} = \frac{Q}{4\pi T}\left[-0.577216 - \ln\left(\frac{r^2 S}{4Tt}\right) + n\left(-0.577216 - \ln\left(\frac{{r_e}^2 S}{4Tt}\right) + u_e - \frac{{u_e}^2}{2\times 2!} + \frac{{u_e}^3}{3\times 3!} - \cdots\right)\right] \tag{3.12}$$

$$s_{5w} = \frac{Q}{4\pi T}\left[-0.577216\,(n+1) - \ln\left(\frac{r^2 S}{4Tt}\right) - n\ln\left(\frac{{r_e}^2 S}{4Tt}\right) + n\sum_{k=1}^{\infty}(-1)^{k-1}\frac{{u_e}^k}{k\times k!}\right] \tag{3.13}$$

$$s_{5\mathrm{w}} = \frac{Q}{4\pi T}\left[-0.577216\,(n+1) - \ln\left(\frac{r^2}{{r_e}^{2n}}\right) - (n-1)\ln\left(\frac{4Tt}{S}\right) + n\sum_{k=1}^{\infty}(-1)^{k-1}\frac{{u_e}^k}{k\times k!}\right] \tag{3.14}$$

Therefore, the total drawdown occurring at the center well for multiple wells is estimated using the expressions (3.11) and (3.14). The time period for the irrigation season was assumed to be 90 days, and the aquifer parameters of hydraulic conductivity and specific yield were 25 feet per day and 18 percent respectively. The drawdowns were calculated for wells pumping 800, 700, 600, 500, 400, 300, 200 and 100 GPM.

One side of drawdown curves extending from the center of the well when multiple wells are pumping are shown in the Figure 12. The figure, illustrates the drop of static water level along the distance from the center of the well. The results of single well and multiple drawdown case are discussed in Chapter 4.1 Groundwater Modeling.

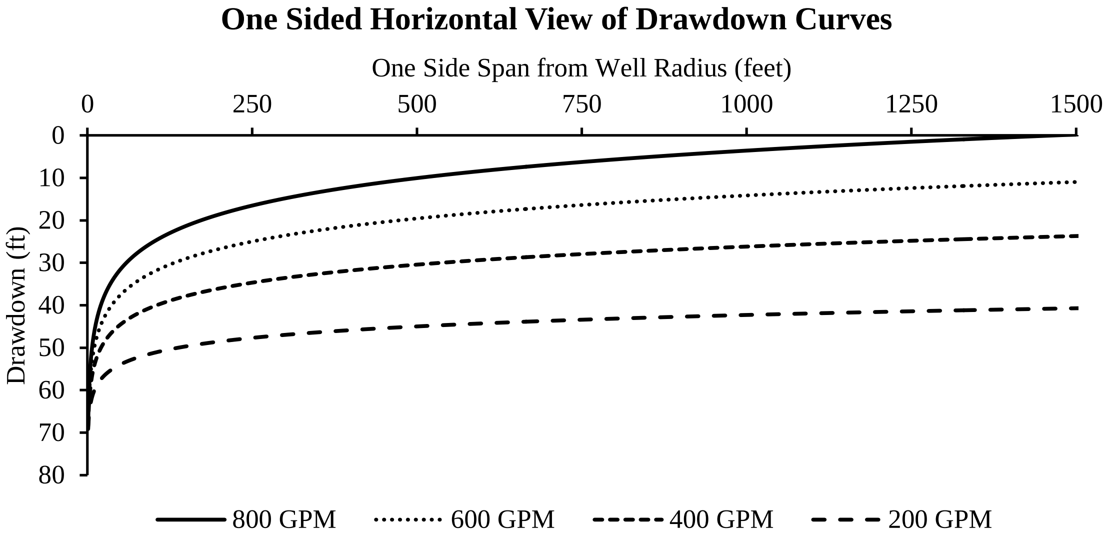


Figure 12. Illustration of drawdown curves for a center well operated at various well capacities when surrounded by four other simultaneously operating wells for a 90 day period

3.2.3 Total Estimated Head

In order to calculate the pumping cost, the total head of each activity is required. This is complicated by the fact that the cost of pumping 600 GPM for a single well and pivot will differ from the case where two 300 GPM wells are combined to supply 600 GPM to a pivot. In situations where wells are being connected, the total heads are estimated to obtain 35psi at the emitters of pivot. In general (Driscoll, 1986), the total dynamic head for a variable displacement pumping rate is determined by considering the vertical pumping lift and minor head loss.

Calculating the total head for each scenario was fairly complicated. One must think from a producer's perspective to understand the following calculations. As the water table declines, wells become dysfunctional to obtain previous maximum GPM. Once all the four wells become unsustainable to pump 800 GPM and are only capable of pumping 700 GPM, the producers could combine the wells to irrigate to a maximum of three pivots, each with 800 GPM. However, there is an Additional Head (AH) to move the water from pumping wells to operating pivots. This process of combining wells and delivering higher GPM to fewer pivots continues until the water table is exhausted. For example, when four wells are restricted to the maximum of 100 GPM, four wells are connected to pump 400 GPM and operate one pivot, or operate two pivots with 200 GPM each. This means that the pumping costs are different when two or more wells are combined to supply a pivot than when each pivot is supplied by a single well.

Typical section of well locations and connecting pipeline skeleton diagram are shown in Figure 13. In this diagram, W1, W2, W3 and W4 are the wells serving pivots P1, P2, P3 and P4 respectively. The wells are located near the edge of the field, and connected to pivots using 1,320 feet pipes, and the pivots are connected using 2640 feet pipeline. Pipes used are 8 inches in diameter with roughness coefficient of 100.

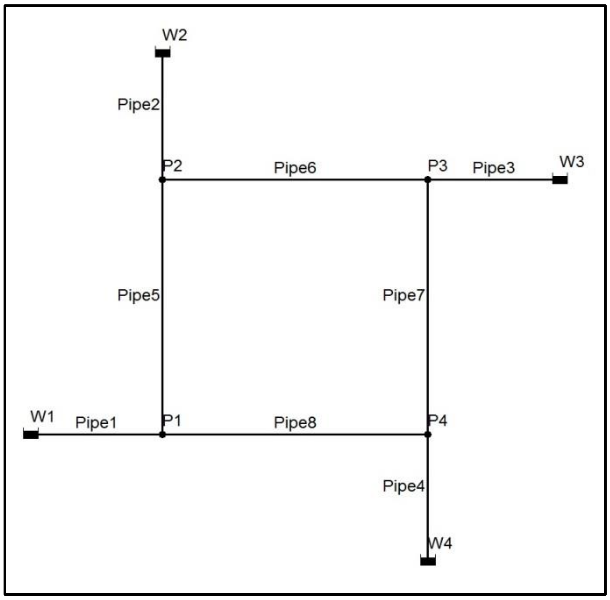


Figure 13. Well locations and pipe network used in EPANET 2.0

AH is the energy required to move the water from wells through the pipelines to the operating pivots. AH is calculated in feet by determining value changes in elevation, pressure, velocity, plus the friction. The AH for this study is calculated as,

$$\mathrm{AH} = \Delta \mathrm{H}_{\mathrm{elevation}} + \Delta \mathrm{H}_{\mathrm{pressure}} + \Delta \mathrm{H}_{\mathrm{velocity}} + \Delta \mathrm{H}_{\mathrm{friction}} \qquad (3.15)$$

where $\Delta \mathrm{H}_{\mathrm{elevation}}$ is the length between land surface and pivot head in feet, $\Delta \mathrm{H}_{\mathrm{pressure}}$ is the pressure required at each pivot nozzle [35 psi (1 psi = 2.31 ft)], $\Delta \mathrm{H}_{\mathrm{velocity}}$ is the speed of the water movement in feet per second, and $\Delta \mathrm{H}_{\mathrm{friction}}$ is the minor loss between the pipelines during the water movement.

Hazen-Williams equation was used to calculate the friction loss through the underground pipes using the equation, $V = 1.318\ C\ (R)^{0.63} S^{0.54}$, where V is the friction, C is the roughness coefficient, R is the radius of the pipeline, and S is the slope along the energy grade line (Driscoll, 1986). Considering well capacity and number of operating pivots, AH to move water through the pipelines is calculated using EPANET 2.0. Calculated total AH requirements to move water from corner wells to operating pivots are listed in Table 9.

Table 9. Additional Head to Transfer Water from Wells to Operating Pivots

	Pivot (s)			
	1	2	3	4
GPM at Each Pivot	Head (feet)			
100	81	81	81	82
200	81	81	82	83
300	82	82	83	85
400	83	84	85	88
500	85	86	87	92
600	87	88	91	96
700	88	90	96	101
800	88	92	103	110

Note: Additional feet of head required at each of four irrigation wells to supply the indicated GPM to one, two, three or four operating pivots. EPANET 2.0 is a program by US EPA for modeling water distribution piping systems.

Additional head is added to the drawdown and static water level to calculate the Total Dynamic Head (*TDH*) for each pumping scenario. It is assumed that the producer always uses all four wells. Therefore, the *TDH* for each irrigation activity is written as,

$$TDH_{wpg} = SWL_w + DD_{wg} + AH_{pg} \tag{3.16}$$

where, w is the water level, p is the number of operating pivots and g is the GPM pumped from each well, $TDH_{wpg}$is the total dynamic head required to irrigate p pivots from water level w using g GPM wells, SWL_w is the static water level at level w, DD_{wg} is the drawdown from level w for pumping g GPM, and AH_{pg} is the additional head require to move the water through pipelines to p pivots using four wells with g GPM.

As an example, assume the current static water level is 200 feet below the land surface where all the four wells are able to pump 800 GPM. While extracting 800 GPM from 200 feet from ground surface and remaining saturated thickness of 105 (35 feet left inaccessible layer at the well bottom), it creates a drawdown of 69.55 feet. Additional head is calculated to move 800 GPM from four well to number of operating pivots. For example, when $w = 200$ feet, $p = 4$ pivots, $g = 800$ GPM, the TDH for operating four pivots at 35 psi is,

$$\mathrm{TDH}_{200,4,800} = 200 + 69.55 + 110 = 379.5 \text{ feet},$$

3.2.4 Pumping Cost Estimation

Once the drawdown, AH, and TDH are estimated, the next operation is to calculate the pumping cost for each scenario. As the water table declines, pumping cost for each individual scenario depends on SWL, maximum well capacity and amount of water delivered at the operating pivots. Estimated pumping cost is used in the static crop budgets for each irrigated crop activity. However, since the GPM of the well is usually limited by the base of the drawdown cone and the 35-foot safety margin, the calculated pumping lift for a given well capacity does not increase as the water table declines. Using the total head calculations, Pumping Cost (*PC*) per acre foot for each activity is calculated as,

$$PC_{\ wpc}(\$) = \frac{BHP_{wpc} \times D_c \times \rho}{61.7} \tag{3.17}$$

where $PC_{\ wpc}$ is the pumping cost per acre foot to pump from water level w and deliver c GPM to the p operating pivots, BHP_{wpc} is the Brake Horse-Power for pumping from water level w and delivering c GPM at p operating pivots, , D_c is the duration of pumping to irrigate the one acre foot with c GPM pivots, 61.7 is the WHP-hr/mcf, and the cost of natural gas is ρ = $6/1,000 cubic feet (mcf). APPENDIX Table A4 lists the pumping cost estimates per acre feet. The Brake Horse-Power (*BHP*) is calculated using,

$$BHP_{wpc} = \frac{WHP_{wpc}}{PE \times ME \times DE} \tag{3.18}$$

where $\mathrm{WHP}_{\mathrm{wpc}}$ is the Water Horse-Power for pumping from water level w and delivering c GPM at p operating pivots,, and PE, ME and DE are the Pump Efficiency, Motor Efficiency, and Drive Efficiency respectively. PE is 70%, ME is 18%, DE is 95% and overall efficiency is 12%.

The Water Horse-Power (WHP) is calculated as,

$$WHP_{wpc} = \frac{TDH_{wpg} \times W_c}{3960} \tag{3.19}$$

where TDH_{wpg} is the total dynamic head required to irrigate p pivots from water level w using g GPM wells, W_c is the water delivered from pivot at g GPM.

3.3 Budgets for Irrigated Corn and Grain Sorghum

So far, in the methods section the procedures of modeling to obtain yield, water use, pumping cost, have been discussed. This section discusses the variable cost and static budgets that will be used in the objective function of the model. A static budget per acre (without irrigation system cost) gives the expected net returns at each level of the aquifer.

The net returns calculated for this study is expressed as,

$$NR_{iwsp} = p_i \times Y_{iws} - OVC_{iws} - PC_{iwsp} \tag{3.20}$$

where NR_{iwsp} is the Net Return per acre for the crop i with well capacity w under irrigation stress s when p pivots are operated, $p_i$is the price of crop i, Y_{iws} is the yield of crop i with well capacity w under irrigation stress s, OVC_{iws} is the yield of crop i with well capacity w under irrigation stress s, and PC_{iwsp} is the pumping cost for irrigating crop i with well capacity w under stress s when p pivots are operated.

The crop yield, and other variable costs depend on the well capacity (GPM) and stress levels (delayed irrigations), but do not vary with aquifer depth. This is because the bottom of the drawdown cone is always assumed to be at the top of the safety zone. Pumping costs are calculated for use of 1 to 4 pivots, from each layer. Example, if one pivot irrigates 600 GPM, then four 150gpm wells combine and serve one pivot, or when two pivots irrigate with 600 GPM then four 300 GPM wells combine and serve two pivots, or when three pivots irrigated with 600 GPM then four 450gpm wells combine and serve three pivots. Final case is when four pivots operated at 600 GPM each latter is possible if each well yields 600 GPM. The yields and OVC are extracted from 600 GPM and respective stress factor, what makes the difference with these situations is the pumping cost, since each situation is pumped from different SWL.

Other variable costs for corn and grain sorghum are calculated using enterprise input prices from OSU budgets and the Kansas State University Agricultural Experimental Station. Seeding rates are assumed as EPIC inputs levels. Note: Seeding cost, Corn = $3.5/1,000 seeds, Sorghum = $0.25/1,000 seeds. Market price for corn is assumed as $4.48 per bushel and grain sorghum is assumed as $4.16 per bushel respectively. Each irrigated corn and sorghum generates 546 activities and 1 dryland activity each year. Therefore, 63,000 activities are generated for the MIP and recursive optimization models, after eliminating the negative returns crop activities.

3.4 Water Supply Estimation

Before we estimate the amount of water that can be pumped in a given season, it is very important to analyze the amount of supply available in the water-bearing formation. The total water supplies available in each layer are the initial constraint. Each aquifer location has its own water capacity, which depends on the specific yield and remaining saturated thickness and percent of area irrigated. The specific yield indicates the volume of water per unit volume that can be removed by pumping (Driscoll, 1986).

Warren (2016) recent field studies indicate that sufficient well pumping capacity in the Oklahoma Panhandle to produce maximum yields on average is 800 GPM. With maximum well capacity as 800 GPM and USGS aquifer parameters, minimum saturated thickness required to produce steady discharge over a pumping period is estimated.

For an aquifer with $K = 25$ feet per day and $S = 18$ percent, maximum possible drawdown to sustain 90 days pumping for well capacities 800,…,100 are calculated. Intermediate well capacity drawdowns are also calculated for the combined well extraction. Remaining saturated thickness and maximum possible drawdown decides the steady discharge rate over the season. The minimum required saturated thickness for a given well capacity is achieved by a trial-and-error method to obtain saturated thickness equal to the vertical distance of drawdown plus the safety zone. Table 10 shows the saturated thickness and drawdowns for each well capacity.

Table 10. Single Well Drawdown for Existing Saturated Thickness for 90 days of Pumping with an Hydraulic Conductivity ($\boldsymbol{K = 25}$)

Well Capacity (GPM)	Minimum Saturated Thickness (feet)	Drawdown (feet)	Thickness of each Layer (feet)
900	110.1	75.1	
800	104.7	69.7	5.4
700	99.1	64.1	5.6
600	93.2	58.2	5.9
500	86.80	51.8	6.4
400	79.9	44.9	6.9
300	72.0	37.0	7.9
200	63.3	28.3	8.7
100	51.5	16.5	11.8

Note: The assumed safety zone for calculating drawdowns was 35 feet. Hydraulic conductivity and specific yield are 25 feet per day and 18 percent respectively. This drawdown estimates does not consider well interferences.

For each well capacity, the difference in the saturated thickness is the layer thickness. Layer thickness or vertical depth is used to estimate the total water supply for a section of the land by using the porosity of the aquifer. Porosity is closely related to specific yield and it is important in estimating the total water storage (or Volume). Therefore, the initial volume at each layer is calculated as,

$$\text{Volume} = \text{Land Area} \times \text{Saturated Thickness} \times \text{Specific yield} \qquad (3.21)$$

For example, if only 40% of the area is irrigated, then water beneath the land area of 1,600 acres supplies water to the representative 640 acres. In other words, section of land is irrigated with not just the water beneath the 640 acres, but also from the surrounding area that are not irrigated. Assuming this, volume that could be pumped at 700 GPM is calculated from Table 11 as,

$$\text{Volume}_{700} = \frac{640 \times 5 \times .175}{.40} = 1400 \text{ acre} - \text{feet}$$

Table 11. Water Supply Calculation and Layer Depth

Water Table Level	Static Water Level (feet)	Drawdown (feet)	Layer Thickness (feet)	Volume (ac-feet)	Total Well Depth (feet)
Level 8	200	70	15	4,200	305
Level 7	205	65	5	1,400	305
Level 6	211	59	6	1,680	305
Level 5	218	52	7	1,960	305
Level 4	225	45	7	1,960	305
Level 3	232	38	7	1,960	305
Level 2	241	29	9	2,520	305
Level 1	253	17	29	8,120	305

3.5 Mathematical Programming Models

To accomplish objectives three, four, and five, both Mixed-Integer (MIP) and recursive optimization programming models are constructed. First the structure of the MIP model is discussed, and then the recursive optimization is discussed.

3.5.1 Mixed-Integer Programming

Irrigation decisions for a specific period of time are dynamic, especially when water is limited and the water table is declining. The irrigations occurring in stage one affect the future investment and allocation. For this reason, dynamic linear programming is needed to determine the optimal long term profit maximizing crop choice, water use, and investment in pivot systems over the remaining life of the aquifer. The MIP model maximizes the net present values of the expected returns, choice variables are crop and irrigation levels. The pivot purchases every 15 years are treated as integer variables, which necessitate the use of an MIP model. The purchase of one, two, three, or four pivots allows the producer to irrigate up to 120, 240, 260, or 480 acres respectively for 15 years. The task of the programming model is to determine if the increases in net returns from irrigation are sufficient to warrant the cost of one or more pivots.

The first step of developing the MIP is to consider the constraints and construct the activities that go into a model to decide the best possible solution. To achieve a precise model, one has to set up mathematical equations to abstract the situations that attempt to obtain valid solutions for the real problem.

NPV maximization over a 60 year using MIP is expressed as,

$$\max \text{NPV} = \sum_{r=1}^{4}\left[\sum_{t=1}^{15}\left[\left(\sum_{g=1}^{8}\sum_{j=1}^{n}\left(C_{tgj}I_{tgj}\right) + d_tD_t\right) - K_rP_r\right]\right] \tag{3.22}$$

Subject to:

Total Land: $\sum_g \sum_j I_{tgj} + D_t \leq 640$ for all t, (3.23)

Irrigated Land: $\sum_g \sum_j I_{tgj} - 120 \times P_r \leq 0, P_r \in \{0,4\}$ integer for all t, g, r, (3.24)

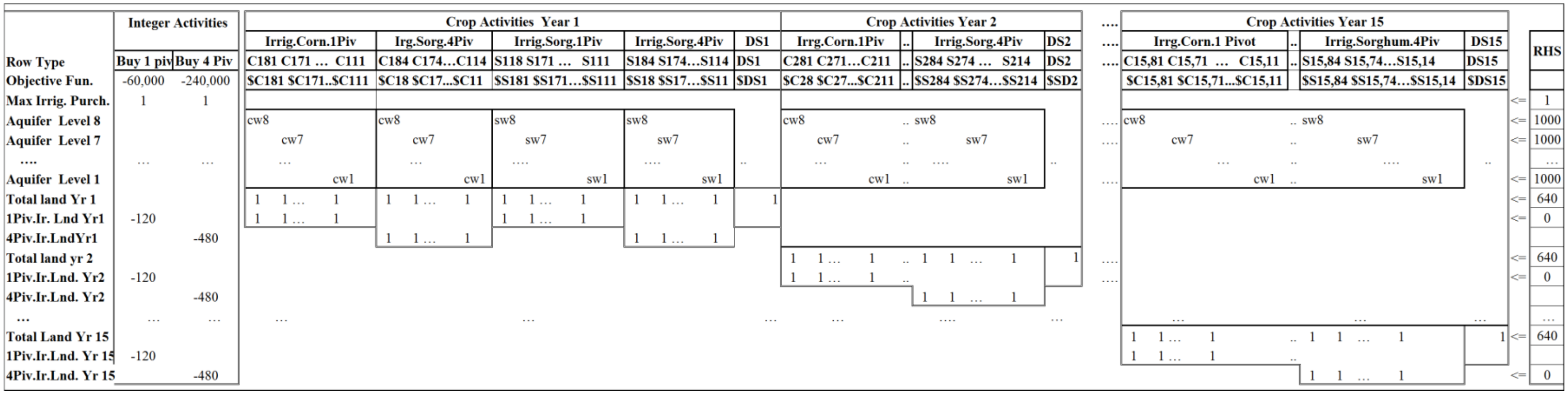
and, Water Supply: $\sum_r \sum_t \sum_g \sum_j W_{tgj} I_{rgj} \leq WS_g$ for all t, (3.25) where j is the index of irrigated corn and sorghum activities at alternative stress levels, g is the index of aquifer level and well capacity, t is the index of crop land allocation time period, r is the index of irrigation purchase period 0-15, 15-30, 30-45 and 45-60, C_{tgj} is the present value of net revenue from irrigation in year t, I_{tgj} is the acres irrigated at aquifer level g with GPM in year t, d_t is the present value of dryland production per acre at year t, D_t is the land allocated for dryland production, K_r is the present value of pivot investment in period r, P_r is the pivots investment in period r.

The MIP model will decide long term profitable choice of crops or acreage allocation for both crops to be irrigated with respect to the remaining water and actual rate possible to extract. The MIP also decides the optimal number of pivots and number of wells to be tied to using the existing pivots. A schematic diagram of the MIP model used for the study is shown in Figure 14. The schematic represents just one of the several possible 15 year periods. The integer pivot purchases are at the left of the models. These variables represent purchase of zero, one, two, three or four pivots.

<u>Constraints</u>: The RHS constraint on the “Max Irrig.Purch.” restricts the sum of these variables to be less than or equal one. Since the purchase variables are declared as integer, then only the integer variable representing the most profitable of the possible pivot purchases can enter the solution. In the cases all irrigation is unprofitable or the aquifer lacks sufficient water to justify the purchases of a pivot, then the purchase level can be zero since an inequality constraint is used. As shown in the pivot purchase columns, the purchase of a single pivot will cost $60,000 and allow up to 120 acres of land to be irrigated over the next 15 years. The maximum amount of irrigated land each

year is indicated in the “1Piv.Ir.Lnd Yr1” row of the designated year. The model allows the planting of a row “Total land Yr 1” indicates that up to 640 acres of dryland and irrigated crops is grown each in the designated year. The quantities of available water for irrigation are shown in the RHS column by level. In the schematic, the producer has 1,000 acre-feet of water that is pumped at the rate of 800 GPM. When this level is exhausted, the producer is shown as having another 1,000 acre-feet that is pumped from level 7 at 700 GPM.

Activities: Years 1, 2, and 15 year sample activities are shown. For example, first year’s one and four pivots are shown under the column “Crop activities Year 1”. The activity, “C184” is read as, at year 1, 480 acres of corn is irrigated when well are operating at 800 GPM with four pivots and its discount net return per acre is the coefficient (parameter) in the “Objective Fun” as “$C184”. The activities are bounded with the operating aquifer level constraint, for this example the activity extracts “cw8” acre-foot of water from “Aquifer Level 8” to irrigate 480 corn acres allocated on year 1. Similarly, DS2 and $DS2 are the dryland sorghum’s activity name and discounted net returns respectively at year 2.



	Integer Activities		Crop Activities Year 1					Crop Activities Year 2				….	Crop Activities Year 15					
			Irrig.Corn.1Piv	Irg.Sorg.4Piv	Irrig.Sorg.1Piv	Irrig.Sorg.4Piv	DS1	Irrg.Corn.1Piv	..	Irrig.Sorg.4Piv	DS2	….	Irrg.Corn.1 Pivot	..	Irrig.Sorghum.4Piv	DS15		RHS
Row Type	Buy 1 piv	Buy 4 Piv	C181 C171 … C111	C184 C174…C114	S118 S171 … S111	S184 S174…S114	DS1	C281 C271…C211	..	S284 S274 … S214	DS2	….	C15,81 C15,71 … C15,11	..	S15,84 S15,74…S15,14	DS15		
Objective Fun.	-60,000	-240,000	$C181 $C171..$C111	$C18 $C17...$C11	$S181 $S171…$S111	$S18 $S17…$S11	$DS1	$C28 $C27...$C211	..	$S284 $S274…$S214	$SD2		$C15,81 $C15,71...$C15,11		$S15,84 $S15,74…$S15,14	$DS15		
Max Irrig. Purch.	1	1															<=	1
Aquifer Level 8			cw8	cw8	sw8	sw8		cw8	..	sw8		….	cw8	..	sw8		<=	1000
Aquifer Level 7			cw7	cw7	sw7	sw7		cw7	..	sw7		….	cw7	..	sw7		<=	1000
….	…	…	…	…	….	….	..	…	..	….	..		…	..	….	..		…
Aquifer Level 1			cw1	cw1	sw1	sw1		cw1	..	sw1		….	cw1	..	sw1		<=	1000
Total land Yr 1			1 1… 1	1 1… 1	1 1… 1	1 1… 1	1										<=	640
1Piv.Ir. Lnd Yr1	-120		1 1… 1		1 1… 1												<=	0
4Piv.Ir.LndYr1		-480		1 1… 1		1 1… 1												
Total land yr 2								1 1… 1	..	1 1 … 1	1	….					<=	640
1Piv.Ir.Lnd. Yr2	-120							1 1… 1	..			….					<=	0
4Piv.Ir.Lnd. Yr2		-480								1 1 … 1								
…	…	…	…		…		…	…		….	…		…		…	…		…
Total Land Yr 15													1 1… 1	..	1 1 … 1	1	<=	640
1Piv.Ir.Lnd. Yr 15	-120												1 1… 1	..				
4Piv.Ir.Lnd. Yr 15		-480													1 1 … 1		<=	0

Figure 14. Partial Schematic diagram of multiperiod Mixed Integer Programming model showing integer purchase activities and irrigated corn and sorghum activities.

Note: Abbreviations Used: Buy 1 Piv is an interget activity representing the purchase of a single pivot which allows up to 120 acres to be irrigated annually for 15 years, C281 stand for 120 acres of corn is irrigated with 800 GPM in year 2.

3.5.2 Recursive Optimization

To achieve objective five, it was necessary to construct a recursive optimization model. The recursive model developed in this study is to determine net returns and aquifer if the producer follows simple annual profit maximization. The recursive procedure chooses the crop and irrigation treatment that gives maximum net returns each year. As the pumping progresses, highest net return activity is chosen.

The feasible activities for irrigated corn and grain sorghum at any point in time depend on the aquifer level and the number of operating pivots. The aquifer level determines the GPM output of each of the four operating irrigation wells. The number of operating pivots determines the number of acres to be irrigated. The number of operating pivots also determines the number of wells supplying each operating pivot. This in turn determines the maximum GPM supplied to each pivot. This permits estimation of the net revenue from irrigation from each feasible irrigated corn or sorghum activity.

The activity chosen then for the current aquifer level L and with p operating pivots is the activity with the highest current net revenue. Given a list of feasible activities with index *i*, net revenue is expressed as, $R^* = \frac{\text{Max}}{i}[\text{RC}_i(L,p), RS_i(L,p)]$. The activity R^* is the *i*th activity that has the highest irrigated net revenue from corn $\text{RC}_i(L,p)$ or grain sorghum $RS_i(L,p)$ at aquifer level *L* and *p* pivots. With activity R^* chosen in year *t*, the net revenue for the 640-acre field is,

$$NR_t = R^* \times p \times 120 + (640 - p \times 120) \times RS_d\ , \tag{3.26}$$

where NR_t is the net returns in year t, RS_d is the net revenue per acre of dryland sorghum. Each pivot is assumed to irrigate 120 acres. With a given number of pivots, R^*

declines with the level of the aquifer L. From year t to year $t+1$, the aquifer level decline is a function of the irrigation water used in year t, so $L_{t+1} = GW(L_t - R^*(iw_t) \times p \times 120)$, iw_t is the acre feet of irrigation water used by R^* and $GW(iw_t)$ is a function relating the remaining groundwater volume to the GPM level.

The discounted revenue over each 15-year period when irrigation with p pivots is,

$$\mathrm{NPV}(p) = \sum_{t=1}^{15} \left[\frac{NR_t}{(1+i)^t}\right] - p \times PC \tag{3.27}$$

where t is the index for year, i is the discount rate, p is the number of pivot invested, and PC is the undiscounted cost of each pivot. The same method is repeated for every 15 years (life of the pivot) for a 60 year planning horizon.

CHAPTER IV

RESULTS

4.0 Outline of Results

This chapter discusses the results obtained from groundwater modeling, annual profit maximization, and 60-year optimal long-term profit maximization. Researchers have long known that, under limited resources, an optimal extraction rate gains more profit in the long run (Hotelling, 1931). Therefore, showing the results of series of annual profit maximization and long-term optimal allocation validates the whole purpose of this project. In other words, results of recursive optimization and linear mixed-integer programming optimization are compared.

The first part (Section 4.1) presents the EPIC simulation results. Results were produced using 50 years of daily weather (1965-2014) to simulate corn and grain sorghum yields and water use in Oklahoma Panhandle. Calibrated results were compared with the published crop yield and water use results to validate the EPIC output. Section 4.2 covers the well interference effects between drawdown of single and multiple wells. It also explains the impacts of hydraulic conductivities and specific yields. Superimposed well locations on hydrogeological maps provided the major hydraulic conductivity and specific yields. Hydraulic conductivity and specific yield are the two most important constants always involved in quantitative groundwater studies (Cooper and Jacob, 1946). Since 1946, several quantitative methods to calculate the drawdowns have been available. However, hydraulic conductivity and specific yield have always been the necessary constants.

The crop yields and inputs from EPIC, and the pumping cost calculated from groundwater modeling were used to develop the site-specific crop budgets shown in Section 4.3. The present enterprise budgets from OSU and KSU were used as basics to calculate the expected crop budgets for corn and sorghum under alternative irrigation levels. The calculated expected net returns were discounted at 4 percent and used in the programming models.

In Section 4.4, crop choices, irrigation decisions, and net returns for producers who maximize annual profits are presented. When producers make higher profits each year with intensive irrigation, high-water use in the beginning could exhaust the aquifer more quickly and reduce potential profits that could be obtained in the long-run. The MIP results are explained in Section 4.5. In this section, the producer seeks to maximize long-term profits by choosing crops and irrigation levels that gives the highest NPV over the remaining life of the aquifer. Groundwater serves as a production input. It is important to find the production possibilities that will use the limited water wisely and generate higher benefits in the long run. (Ciriacy-Wantrup, 1963) The theory in the field of resource economics states that long-term profit maximization gives more benefit over short term maximization. However, the question about the difference in the benefits in this study is addressed in the section 4.6.

In both programming models, three levels of the aquifer are considered. 1. Wells with high saturated thickness are assumed to produce 800 GPM, 2. Wells with medium saturated thickness are assumed to produce 600 GPM, and 3. Wells with low saturated thickness are assumed to produce 400 GPM. In the final section 4.6, similarities and differences between the programming model results are discussed. The results show that producers with saturated thickness above 105 feet and hydraulic conductivity 25 feet per day make considerably higher profits in the long run than the producers with less saturated thickness.

4.1 EPIC Validation and Yield Simulation Results

4.1.1 EPIC Validation

It was necessary to validate the EPIC simulations with the research at the OPREC. Variety trial results for irrigated corn and sorghum are available for 10 years from 2005 to 2014. The corn trials were executed at Goodwell and Guymon, Oklahoma. A weighted average was used when both data were available, otherwise only the recorded data was used. Goodwell corn trial yields were not reported during 2009 and 2010, and 2014 corn yields were not reported in Guymon. The 10-year average corn yield was 180 bushels per acre with average water use of 19 inches. Average grain sorghum yield was 143 bushels per acre and water use was 9 inches. The simulated full irrigation corn and sorghum yields were compared with variety trial results as shown in Figure 15 and 16 respectively. The simulated corn yields under 10 percent soil moisture stress matched nearly all the points except in 2014. Grain sorghum yields under 10 percent stress also matched nearly all the points but miss the downturn in 2011. To note, simulated model planting dates and harvest periods were not same as the field experiments. Simulation results were further compared with the published experimental results from Oklahoma, Kansas and Texas.

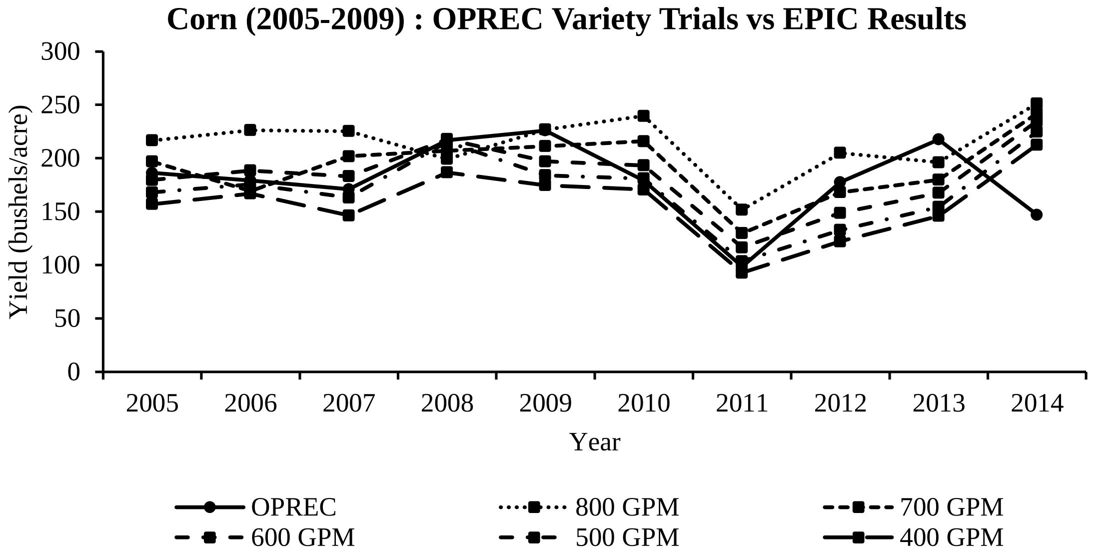


Figure 15. Simulated EPIC Corn yields 10 percent are compared with OPREC field study results. *Note*: Corn planted in the mid-April and harvested in late September.

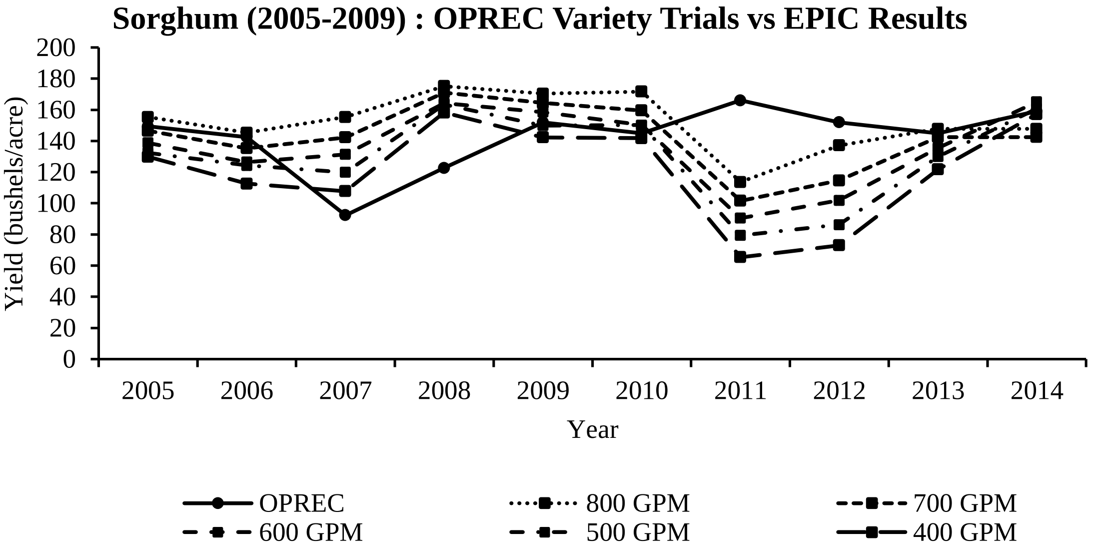


Figure 16. Simulated EPIC Sorghum yields at 10 percent stress are compared with OPREC field study results. *Note*: Sorghum Planted in early June and harvested in end of October.

Agronomists from OSU conduct experiments and publish results based on the variety trial outcomes in Oklahoma Panhandle (Warren et al. 2016). Warren studies were used to validate the yields of EPIC simulation for the years 2013 and 2014. Furthermore, to extend the validation, EPIC results were compared with experiment results from Garden City, Kansas and Bushland, Texas.

In 2012, Klocke, Currie, Tomsicek and Koehn published results of irrigation treatments imposed on sorghum for the period 2005 to 2009 at Garden City, Kansas (Southwest Kansas). There were six irrigation treatments each applying 25 mm every 6 to 26 days. Each year irrigation treatments were 100%, 80%, 70%, 50%, 40%, and 25% of full irrigation. The maximum irrigation and yield were assumed to be 100 percent and lower treatments are assumed as a relative ratio to the maximum levels of yield and irrigation. To match the sorghum simulations with Garden City, Kansas, which is located north of the Oklahoma Panhandle, it is expected to have somewhat lower crop evapotranspiration (ETc). At Garden City, treatment 1 ET_c was reported as 527 mm, whereas simulated EPIC full irrigation treatment ET_c was 663 mm. The verification can be seen below in Figure 17.

In the same article (Klocke et al. 2012), the authors compared the 4 field studies with 11 site-years of irrigated sorghum data from Bushland, Texas between 1989 and 2002. During this study, irrigation treatments were based on a percentage of the irrigation replacement relative to full irrigation. Following this principle, maximum irrigations (800 GPM) with delayed irrigation (irrigation trigger) results from EPIC are compared with studies conducted in the Bushland, Texas located 125 miles from Goodwell, Oklahoma. (Allen and Musick, 1993; Schneider and Howell, 1995; Bordovsky and Lyle,1996; Colaizzi et al. 2004) Report that Texas location ET_c was 260 mm higher than at the Garden City location. This shows that Texas location has higher ET_c than Goodwell, Oklahoma. The comparison and validation of sorghum EPIC results is shown in Figure 18.

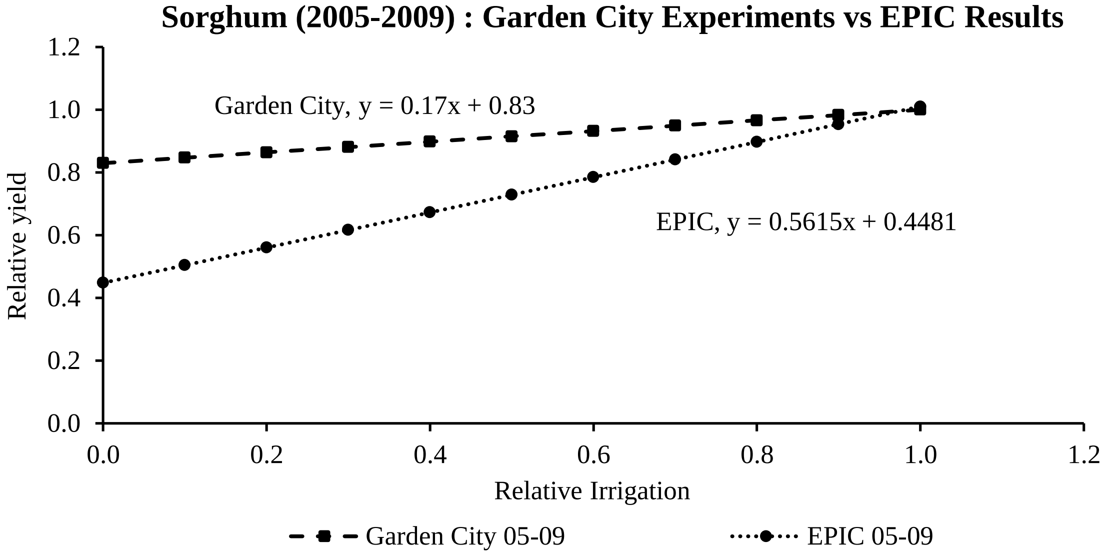


Figure 17. Simulated EPIC relative Sorghum Yields versus Relative Irrigation between 2005-2009 is compared with field study results in Garden City, Kansas

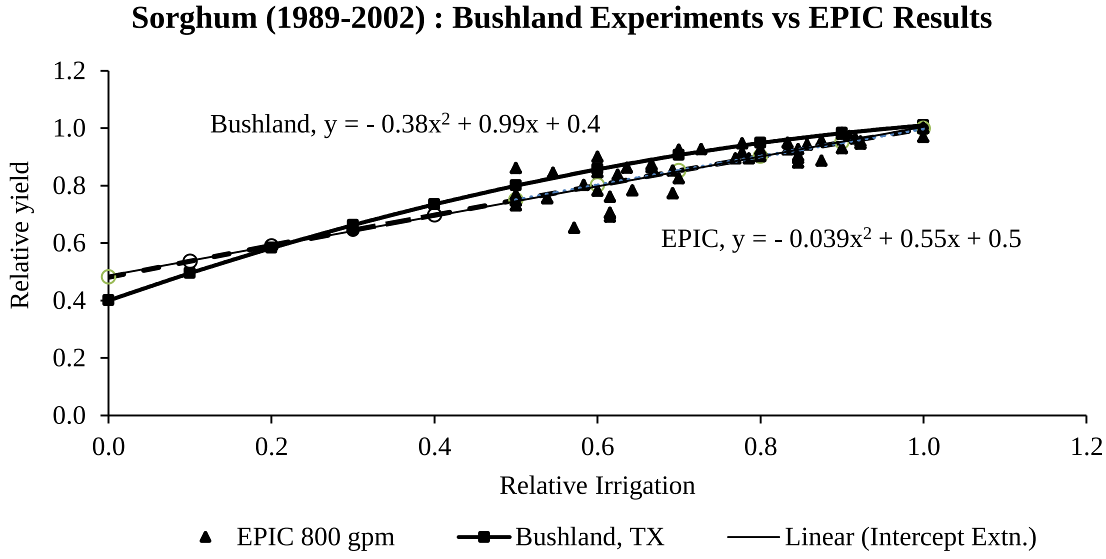


Figure 18. Simulated EPIC Sorghum Relative Yields versus Relative Irrigation between 1989 and 2002 are compared with Bushland, Texas field study result

In 2011, the same authors (Klock et al. 2011) conducted a series of studies to determine the relative yield response of corn to net irrigation for six irrigation treatments applying 25 mm of irrigation for every 5 to 17 days in Garden City, Kansas,. The validation results were obtained by matching the EPIC simulated irrigation amounts and frequencies output to the Garden City experimental frequencies and amounts results. Results were compared from 500 GPM (7 days, 36 mm) to 150 GPM (average of 100 and 200 GPM, 24 days, 36 mm). As it can be seen from Figure 19, the Garden City irrigations required relatively less water to produce maximum possible yields than at Goodwell, Oklahoma.

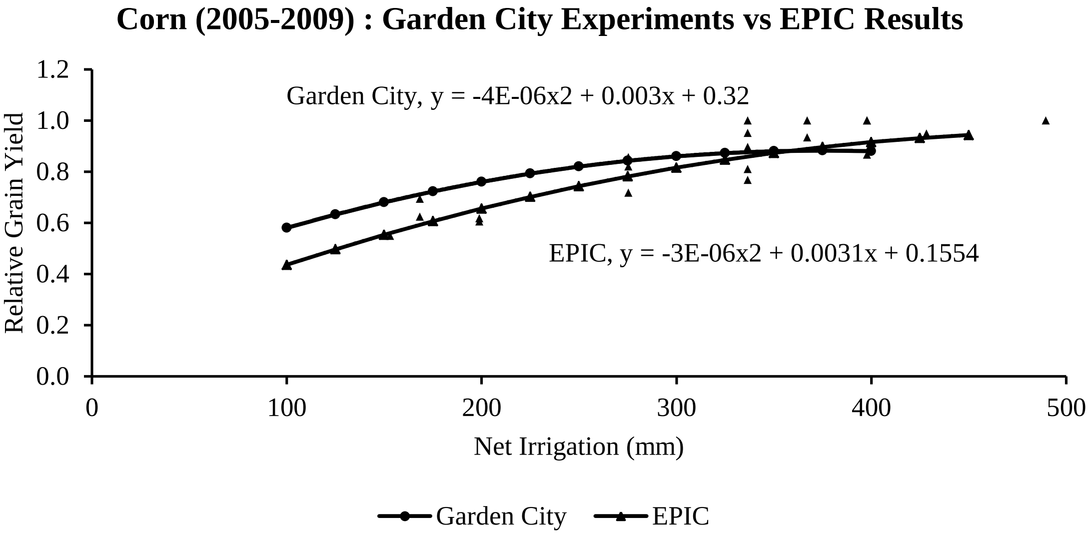


Figure 19. A comparison of simulated relative EPIC Corn yields to reported relative Corn yields to Net Irrigation at Garden City, Kansas for the years 2005 to 2009

4.1.2 EPIC Simulation Results

EPIC results were simulated for 56 combinations of eight GPM and seven stress levels. The results shown below are average over the 50-year period (1965-2014) of each individual simulation. Since the field experiments in Oklahoma Panhandle and surrounding locations (Kansas and Texas) for corn and sorghum are limited, the simulated results are only validated with the existing results for those years.

4.1.2.1 Corn CPS Output

The results of corn yields and water use are shown in Table 12 and 13. The average yields obtained with the 800 GPM and 100 GPM wells with a 0.90 stress trigger were 213.4 bushels/acre with 19.1 inches and 99.1 bushels/acre with 5.2 inches respectively. Similarly, yields obtained with 800 GPM and 100 GPM with a 0.30 stress trigger were 159.3 bushels/acre with 12.4 inches and 96.8 bushels/acre with 4.6 inches respectively. The irrigation trigger had more effect with higher well capacities than with lower well capacities, because the pivot completes the circle more quickly (fewer days) with the higher GPM well. The next irrigation does not begin until the soil moisture level declines to the set trigger. With the lower GPMs it takes more days to complete the entire circle, by which time the soil moisture has already declined, and the pivot remains in motion.

With an 800 GPM well, it takes 4 days to complete an entire circle. When the irrigation trigger is set at 0.60, there is a chance the soil moisture may not have declined to the trigger for several more days. Conversely, with a 200 GPM well, it takes 16 days to complete the entire circle. After this time, the soil moisture level has likely declined to the trigger level. The longer time span increases the likelihood of the soil moisture target which would have been reached before the circle is completed. With the lower capacity well, the pivot is more likely to remain in motion and the moisture stress trigger becomes less effective. In APPENDIX, relative yield and irrigation can be found in the Table A2 and A3.

Table 12. EPIC Simulated Corn Yields by Well Capacities and Irrigation Trigger with Center Pivot System on a 120-acre Field

	Corn Yields (bushels/acre)						
Well Capacity	Plant Water Stress Factor						
GPM	0.30	0.40	0.50	0.60	0.70	0.80	0.90
800	159.3	163.4	166.9	180.8	193.9	206.3	213.4
700	158.4	161.9	165.1	176.0	186.3	194.6	198.9
600	156.9	159.8	163.0	170.7	177.2	182.9	186.9
500	153.8	156.1	158.3	162.2	168.4	172.4	175.0
400	148.5	150.1	152.1	154.7	157.7	161.2	164.4
300	133.7	134.9	136.9	138.4	139.3	141.2	142.6
200	117.5	117.7	118.9	119.2	120.1	121.2	122.2
100	96.8	97.7	98.1	98.1	98.4	98.9	99.1

Table 13. EPIC Simulated Corn Net Water Use by Well Capacity and Irrigation Trigger with Center Pivot System on a 120-acre Field

	Corn Net Irrigation (acre-inches)						
Well Capacity	Plant Water Stress Factor						
GPM	0.30	0.4	0.50	0.6	0.70	0.8	0.90
800	12.4	13.0	13.8	16.0	18.3	19.1	19.6
700	12.4	13.0	13.7	15.3	17.3	18.8	19.1
600	12.4	12.7	13.5	14.6	16.2	17.3	18.3
500	12.0	12.4	13.0	13.6	14.8	15.8	16.5
400	11.5	11.8	12.3	12.7	13.5	14.5	15.0
300	9.4	9.6	10.0	10.4	10.9	11.4	11.8
200	7.4	7.5	7.7	8.0	8.3	8.6	8.8
100	4.6	4.7	4.8	5.0	5.0	5.1	5.2

Note: Net water use (net irrigation = gross application - water loss during delivery), the sprinkler efficiency is assumed as 85%, as 15 % is lost during the delivery

4.1.2.2 Sorghum CPS Output

The yields obtained with the 800 GPM and 100 GPM simulations with a 0.90 stress trigger were 162.8 bushels/acre with 13.3 inches and 88.5 bushels/acre with 2.4 inches respectively. Similarly, the yields obtained with the 800 GPM and 100 GPM with a 0.30 stress trigger were 122.1 bushels/acre with 7.1 inches and 87.5 bushels/acre with 1.9 inches respectively. An identical trend of irrigation trigger effects can be seen in sorghum results as well. The irrigation trigger did not affect yields and water use with the lower well capacity much as with the higher well capacities. Table 14 and Table 15, show the water use and crop productivity with grain sorghum were less sensitive to moisture stress than corn at lower well capacities. With higher well capacity corn and sorghum, water-use efficiency was close. With 800 GPM and 0.90 stress corn and sorghum produced at 11.2 bushels and 12.3 bushels per unit of water respectively. However, with lower well capacity and higher stress, sorghum had much greater water-use efficiency than corn. With 200 GPM and 0.30 stress corn and sorghum are produced at 15.9 bushels and 35.5 bushels per unit of water.

Table 14. EPIC Simulated Sorghum Yields by Well Capacity and Irrigation trigger with Center Pivot System on a 120-acre Field

	Sorghum Yields (bushels/acre)						
Well Capacity	Plant Water Stress Factor						
GPM	0.30	0.40	0.50	0.60	0.70	0.80	0.90
800	122.1	124.9	129.0	138.6	148.7	156.5	162.8
700	122.4	125.3	129.1	137.3	145.3	150.9	155.7
600	122.3	125.2	128.5	134.0	139.6	144.6	148.4
500	120.5	123.5	126.0	129.6	134.1	137.5	141.1
400	116.9	119.7	122.4	124.6	128.6	131.4	133.8
300	104.8	107.0	108.7	110.4	112.3	115.0	117.2
200	88.4	89.1	89.6	90.1	90.5	91.1	92.0
100	87.5	87.8	87.9	88.1	88.2	88.3	88.5

Table 15. EPIC Simulated Sorghum Net Water Use by Well Capacity and Irrigation Trigger with Center Pivot System on 120-acre Field

	Sorghum Net Irrigation (acre-inches)						
Well Capacity	Plant Water Stress Factor						
GPM	0.30	0.40	0.50	0.60	0.70	0.80	0.90
800	7.1	7.3	7.8	7.8	10.7	12.0	13.3
700	7.0	7.2	7.7	8.8	10.0	11.1	12.0
600	7.0	7.2	7.7	8.5	9.1	10.1	10.7
500	6.8	7.1	7.5	7.9	8.4	9.2	9.6
400	6.5	6.8	7.0	7.3	8.0	8.4	8.8
300	5.5	5.8	6.0	6.2	6.5	6.6	7.0
200	2.5	2.6	2.7	2.8	2.9	3.0	3.5
100	1.9	2.0	2.0	2.1	2.1	2.2	2.4

The Figure 20 and 21 represents the water use efficiency of the EPIC model results at 0.90 stress levels. Outcome of the results show that sorghum producers more bushels per acre inch than corn. However, corn has a higher market price, which makes corn competitive with grain sorghum. These questions will be answered in the LP model.

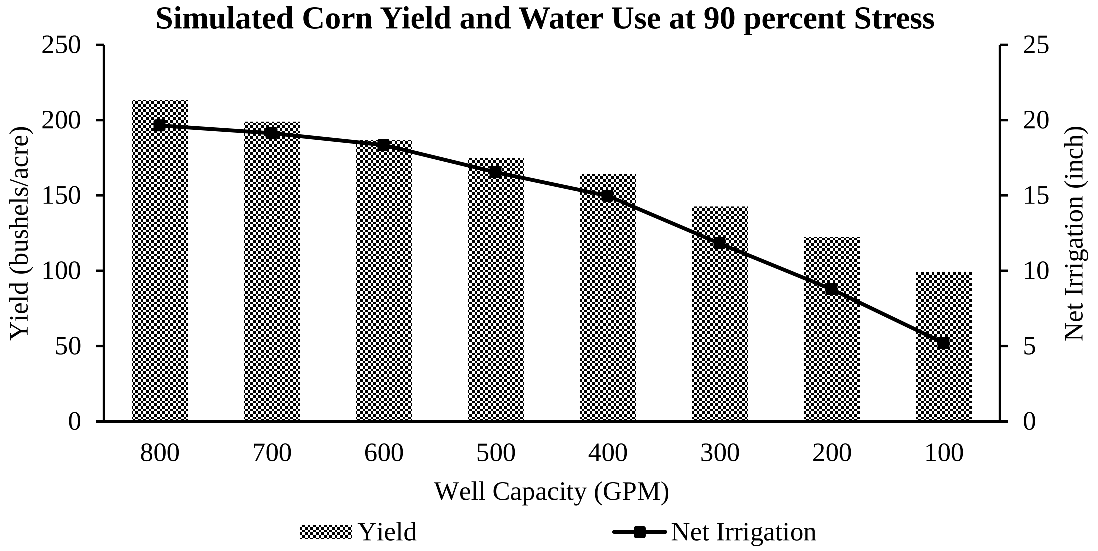


Figure 20. EPIC simulated irrigated Corn Yields and Water Use with a 0.90 irrigation trigger from a 120-acre pivot served by a single well with pumping capacities from 100 to 800 GPM

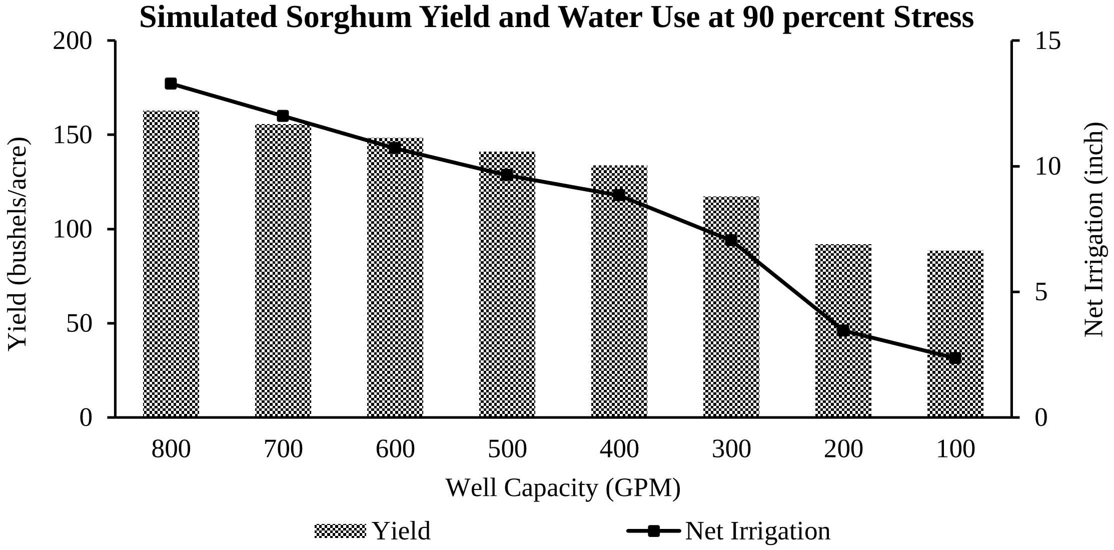


Figure 21. EPIC simulated irrigated sorghum yields and water use with a 0.90 irrigation trigger from a 120-acre pivot served by a single well with pumping capacities from 100 to 800 GPM

4.2 Groundwater Modeling

Groundwater modeling was used to re-estimate pumping costs following published (USGS 2014) results on the High Plains aquifer. The drawdown curves were used to determine the minimum saturated thickness that would support each 100 GPM for 90 days of pumping with a hydraulic conductivity of 25 feet per day. In this analysis, the aquifer was always assumed to be unconfined.

The effects of differences in the Specific Yield (S) on drawdown after 90 days of pumping at rates from 100 to 900 GPM from an aquifer with a Hydraulic Conductivity (K) of 25 feet per day were minimal as shown in Table 16 and Figure 22. Other words, the drawdowns for 18 and 28 percent specific yield did not show any major difference. However, differences in hydraulic conductivity did have a major effect on drawdown as shown in Figure 22.

Table 16. Drawdown Values for Two Sets of Specific Yield in Combinations with Four Values of Hydraulic Conductivity Assuming 35 feet Safety Margin at the Bottom of the Aquifer

Well Capacity (GPM)	Drawdown (feet)							
	$S = 18\%$				$S = 28\%$			
	$K = 25$	$K = 50$	$K = 75$	$K = 100$	$K = 25$	$K = 50$	$K = 75$	$K = 100$
900	74.9	49.9	38.9	32.4	72.9	48.6	37.9	31.5
800	69.7	46.2	35.9	29.8	67.8	45.0	35.0	29.1
700	64.1	42.3	32.8	27.2	62.4	41.2	31.9	26.5
600	58.2	38.2	29.5	24.3	56.6	37.2	28.7	23.7
500	51.8	33.8	25.9	21.3	50.4	32.9	25.2	20.8
400	44.9	28.9	22.0	18.0	43.6	28.1	21.4	17.5
300	37.0	23.5	17.8	14.4	36.0	22.9	17.3	14.0
200	28.0	17.4	12.9	10.4	27.2	16.9	12.6	10.1
100	16.5	10.0	7.3	5.8	16.1	9.7	7.1	5.6

Note: Duration of Pumping is 90 days, S is Specific Yield, K is Hydraulic Conductivity (ft/day)

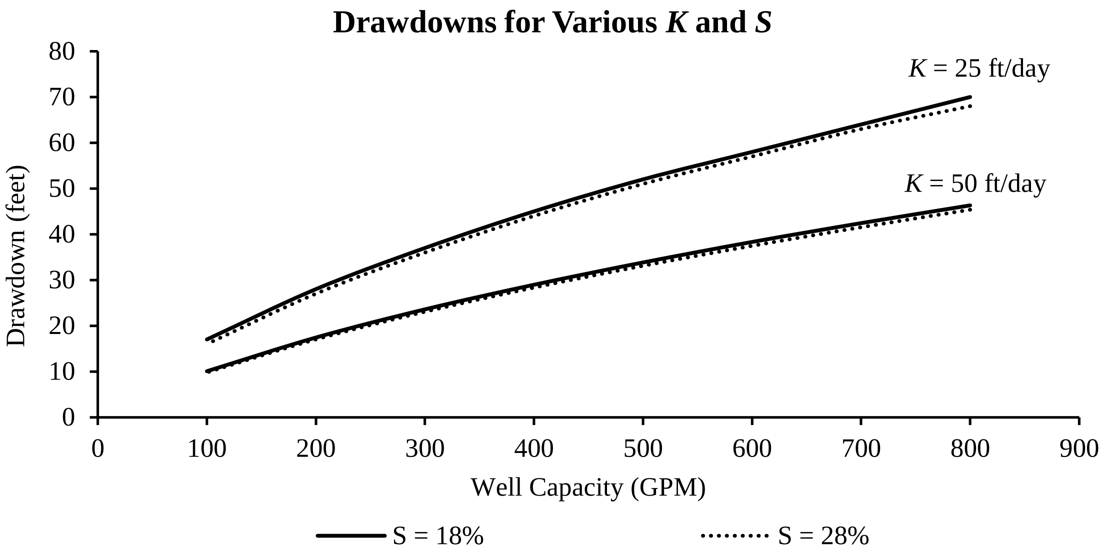


Figure 22. Effect of Specific Yield (*S*) and Hydraulic Conductivity (*K*) on drawdown size for 90 days of pumping on a single well

In the single well approach, the single well was assumed not to be affected by surrounding wells. In the multiple-well case, the well discharge influenced by surrounding wells located at 1,320 feet distance was measured. This is because the drawdown cone from the surrounding wells extends to the discharge well which reduces the saturated thickness.

The drop in the static level reduces the saturated thickness, thus the maximum discharge rate for single well and multiple-well case are different for a given saturated thickness. Table 17 compares the expected drawdown for the single and multiple-well case after 90 days of pumping when the *K* and *S* of the unconfined aquifer are 25 feet per day and 18 percent respectively.

Table 17. Expected Drawdown for the Single Well and Multiple Wells

Well Capacity (GPM)	Single Well Drawdown (feet)	Multiple Well Drawdown (feet)
800	69.7	71.4
700	64.1	65.7
600	58.2	59.4
500	51.8	52.5
400	44.9	45.7

Table 17 (continued)

Well Capacity (GPM)	Single Well Drawdown (feet)	Multiple Well Drawdown (feet)
300	37.0	37.6
200	28.0	28.3
100	16.5	16.8

Note: The duration of pumping is 90 days. Hydraulic conductivity and specific yield are 25 feet per day and 18% respectively. For the multiple well drawdown calculation, four wells are surrounded at a distance of 1320 feet from the discharging well.

The drawdown (DD) cones are graphed in Figure 23. The top curve (solid line) is the 800 GPM DD curve, and bottom curve (dotted line) is the 100 GPM curve. The lines in between from the top represent 700 GPM to 200 GPM DD curves. For pumping 800 GPM well for a 90-day period is expected to produce a drawdown of 69.7 feet. Rounding to 70 feet with a safety zone of 35 feet meant the minimum saturated thickness at the beginning of the season to be 105 feet to support an 800 GPM well. A series of drawdown iterations was required to determine the minimum required saturated thickness for each 100 GPM. If the saturated thickness declines below 105 feet, the producer was assumed to pump at 700 GPM. The 700 GPM could be sustainable for next 6 feet until the saturated thickness declines to 99 feet. Table 17 shows that pumping 200 GPM for 90 days produce 28 feet of drawdown. The drawdown plus a 35 feet safety zone yields a minimum of 63 feet of saturated thickness to support 200 GPM for 90 days pumping. To pump at 100 GPM, the well requires 16 feet DD, which does not exhaust the entire water storage. The remaining water from the very bottom of the aquifer could be extracted using lower well yields such as 75 GPM, 50 GPM and 25 GPM. For example, four 25 GPM wells could combine and produce 100 GPM and irrigate one quarter section, but this was not considered in this study.

These results differ from those in an earlier version of this study where it was assumed the drawdown was constant at 10 feet for 100 GPM. The results here indicate that at a constant annual rate of pumping, the well capacity would decline more rapidly from the top layers (600 to 800 GPM) and less rapidly in the 100-200 GPM range. This is because the top layers are narrower, and the bottom layer is thicker than assumed previously.

Orthographic Projection of Drawdown (Horizontal View)

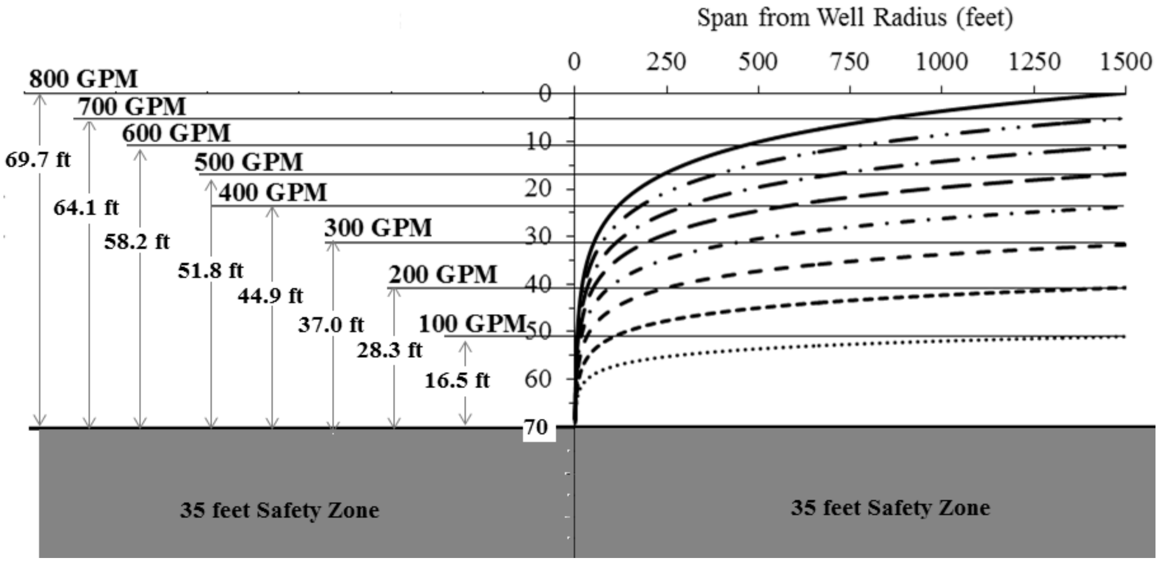


Figure 23. Approximate Single Well Drawdown Curves and minimum beginning of season saturated thickness to sustain 90 days of pumping from an aquifer with a hydraulic conductivity of 25 feet per day with a predetermined discrete set of well capacities

4.3 Crop Budgets

The expected net return (without pumping cost) for each irrigation treatment for corn and grain sorghum was computed from enterprise budgets of the Oklahoma State University (OSU) and Kansas State University (KSU). The expected output prices for crops were assumed to be constant. 10-year (2005-2013) Oklahoma average prices for corn were $4.48 per bushel and for grain sorghum $4.16 per bushel according to data from the Oklahoma Agricultural Statistics (2013).

Crop budgets were prepared for each possible irrigation treatment. Below in Table 18 and 19 are the detailed budgets for Corn and Sorghum irrigated with single well serving one pivot under 10 percent (irrigation trigger 0.90) of soil moisture stress. The net returns are calculated considering a 120-acre field irrigated by one pivot. Producers have choices to irrigate at a slower rate, which was analyzed using the irrigation triggers. The net returns from corn and grain sorghum at 30 percent stress level for alternative well capacities are shown in the Tables 20 and 21. The results suggest that irrigating sorghum begins to become more profitable than corn as the well capacity declines to 500 GPM and 0.90 irrigation trigger, and irrigating sorghum becomes profitable as the well capacities declines to 600 GPM and 0.30 irrigation trigger. The net returns information from Table 18 and 19, and Table 20 and 21 are graphed in Figure 24 and Figure 25 respectively. The net return override by irrigating sorghum is shown as a graph presentation in Figure 24 and 25.

As the water level declines over a period of time, irrigating with four pivots is not profitable due to its capital investment. Therefore, crop budgets for irrigating corn and sorghum under one and two pivots with possible well capacities are shown in the Table 22 and 23. The summary table of net returns for reduced pivot sizes shows that the expected net returns for producing corn stay above sorghum when the corner wells are connected and provide 600 GPM to each of 2 pivots. As the well output becomes reduced to 400 GPM, irrigating sorghum with 1 or 2 pivots becomes more profitable than corn. However, the crop choice to gain profit in a long-run for a myopic producer depends on each year’s remaining water supply, and pivot purchasing decisions. All the crop activities that were developed in this study are listed in APPENDIX Table A5.

Table 18. Budgets for Center Pivot Irrigated Corn with a 0.90 Irrigation Trigger from a Single Well with Alternative Pumping Capacities

		Well Capacity (GPM)							
	Units	800	700	600	500	400	300	200	100
PRODUCTION									
Yield	(bu/acre)	213	199	187	175	164	143	122	99
Nitrogen	(lbs/acre)	197	183	172	161	151	131	112	91
Phosphorus	(lbs/acre)	29	27	25	23	22	19	16	13
Irrigation	(acre-inch)	22	23	22	19	18	14	10	6
Revenue		**$956**	**$891**	**$837**	**$784**	**$736**	**$639**	**$548**	**$444**
OPRERATING INPUTS COSTS									
Nitrogen Cost	($/acre)	108	101	95	88	83	72	62	50
Phosphorus Cost	($/acre)	15	14	13	12	11	10	8	7
Seed Cost	($/acre)	113	113	113	113	113	113	113	113
Herbicide Cost	($/acre)	61	61	61	61	61	61	61	61
Insecticide Cost	($/acre)	16	16	15	15	15	15	14	14
Crop Consulting Cost	($/acre)	7	7	7	7	7	7	7	7
Drying Cost	($/acre)	28	26	24	23	21	19	16	13
Miscellaneous Cost	($/acre)	10	10	10	10	10	10	10	10
Custom Hire Cost	($/acre)	162	155	150	145	140	130	122	111
Non Machinery Labor Cost	($/acre)	18	18	18	18	18	18	18	18
Interest Cost	($/acre)	20	19	18	17	16	15	13	12
Irrigation Cost[a]	($/acre)	127	124	112	97	84	64	46	26
Sub Total Operating Cost		**$683**	**$662**	**$635**	**$606**	**$580**	**$533**	**$489**	**$441**
Crop Insurance[b]	($/acre)	33	32	30	29	28	26	23	21
Total Operating Costs		**$716**	**$694**	**$665**	**$635**	**$608**	**$558**	**$513**	**$462**
Net Returns Above Operating Costs		**$240**	**$197**	**$172**	**$149**	**$129**	**$81**	**$35**	**-$18**

[a] Irrigation cost are calculated using single well drawdown assumptions

[b] Crop Insurance was calculated at 4.8% of the variable cost

Table 19. Budgets for Center Pivot Irrigated Grain Sorghum with a 0.90 Irrigation Trigger from a Single Well with Alternative Pumping Capacities

		Well Capacity (GPM)							
	Units	800	700	600	500	400	300	200	100
PRODUCTION									
Yield	(bu/acre)	163	156	148	141	134	117	92	89
Nitrogen	(lbs/acre)	182	174	165	157	149	131	103	99
Phosphorus	(lbs/acre)	29	28	27	25	24	21	17	16
Irrigation	(acre-inch)	16	14	13	11	10	8	4	3
Revenue		**$677**	**$648**	**$617**	**$587**	**$556**	**$488**	**$383**	**$368**
OPRERATING INPUTS COSTS									
Nitrogen Cost	($/acre)	100	95	91	87	82	72	56	54
Phosphorus Cost	($/acre)	15	15	14	13	13	11	9	8
Seed Cost	($/acre)	16	16	16	16	16	16	16	16
Herbicide Cost	($/acre)	52	52	52	52	52	52	52	52
Insecticide Cost	($/acre)	0	0	0	0	0	0	0	0
Crop Consulting Cost	($/acre)	6	6	6	6	6	6	6	6
Drying Cost	($/acre)	21	20	19	18	17	15	12	12
Miscellaneous Cost	($/acre)	10	10	10	10	10	10	10	10
Custom Hire Cost	($/acre)	133	129	126	123	120	112	101	100
Non Machinery Labor Cost	($/acre)	18	18	18	18	18	18	18	18
Interest Cost	($/acre)	16	15	14	14	13	12	9	9
Irrigation Cost[a]		88	76	65	56	50	38	18	12
Sub Total Operating Cost		**$475**	**$453**	**$433**	**$414**	**$397**	**$363**	**$309**	**$298**
Crop Insurance[b]	($/acre)	23	22	21	20	19	17	15	14
Total Operating Costs		**$498**	**$475**	**$453**	**$434**	**$416**	**$381**	**$323**	**$312**
Net Returns Above Operating Costs		**$179**	**$173**	**$164**	**$153**	**$140**	**$107**	**$59**	**$56**

[a] Irrigation cost are calculated using single well drawdown assumptions
[b] Crop Insurance was calculated at 4.8% of the variable cost

Table 20. Budgets for Center Pivot Irrigated Corn with a 0.30 Irrigation Trigger from a Single Well with Alternative Pumping Capacities

		Well Capacities (GPM)							
	Units	800	700	600	500	400	300	200	100
PRODUCTION									
Yield	(bu/acre)	159	158	157	154	148	134	117	97
Nitrogen	(lbs/acre)	147	146	144	141	136	123	108	89
Phosphorus	(lbs/acre)	21	21	21	21	20	18	16	13
Irrigation	(acre-inch)	15	15	15	14	14	11	9	5
Revenue		**$714**	**$710**	**$703**	**$689**	**$665**	**$599**	**$526**	**$434**
OPRERATING INPUTS COSTS									
Nitrogen Cost	($/acre)	81	80	79	78	75	67	59	49
Phosphorus Cost	($/acre)	11	11	11	11	10	9	8	7
Seed Cost	($/acre)	113	113	113	113	113	113	113	113
Herbicide Cost	($/acre)	61	61	61	61	61	61	61	61
Insecticide Cost	($/acre)	15	15	15	15	15	14	14	14
Crop Consulting Cost	($/acre)	7	7	7	7	7	7	7	7
Drying Cost	($/acre)	21	21	20	20	19	17	15	13
Miscellaneous Cost	($/acre)	10	10	10	10	10	10	10	10
Custom Hire Cost	($/acre)	138	137	137	135	133	127	119	110
Non Machinery Labor Cost	($/acre)	18	18	18	18	18	18	18	18
Interest Cost	($/acre)	16	16	16	16	15	14	13	12
Irrigation Cost[a]	($/acre)	83	79	76	70	65	51	39	23
Sub Total Operating Cost		**$572**	**$567**	**$562**	**$553**	**$540**	**$508**	**$476**	**$435**
Crop Insurance[b]	($/acre)	27	27	27	27	26	24	23	21
Total Operating Costs		**$599**	**$594**	**$589**	**$579**	**$566**	**$533**	**$499**	**$456**
Net Returns Above Operating Costs		**$114**	**$116**	**$114**	**$110**	**$99**	**$66**	**$28**	**-$22**

[a] Irrigation cost are calculated using single well drawdown assumptions

[b] Crop Insurance was calculated at 4.8% of the variable cost

Table 21. Budgets for Center Pivot Irrigated Grain Sorghum with a 0.30 Irrigation Trigger from a Single Well with Alternative Pumping Capacities

		Well Capacities (GPM)							
	Units	800	700	600	500	400	300	200	100
PRODUCTION									
Yield	(bu/acre)	122	122	122	121	117	105	88	88
Nitrogen	(lbs/acre)	136	137	136	134	130	117	99	98
Phosphorus	(lbs/acre)	22	22	22	22	21	19	16	16
Irrigation	(acre-inch)	8	8	8	8	8	7	3	2
Revenue		**$508**	**$509**	**$509**	**$501**	**$486**	**$436**	**$368**	**$364**
OPRERATING INPUTS COSTS									
Nitrogen Cost	($/acre)	75	75	75	74	72	64	54	54
Phosphorus Cost	($/acre)	11	11	11	11	11	10	8	8
Seed Cost	($/acre)	16	16	16	16	16	16	16	16
Herbicide Cost	($/acre)	52	52	52	52	52	52	52	52
Insecticide Cost	($/acre)	0	0	0	0	0	0	0	0
Crop Consulting Cost	($/acre)	6	6	6	6	6	6	6	6
Drying Cost	($/acre)	16	16	16	16	15	14	11	11
Miscellaneous Cost	($/acre)	10	10	10	10	10	10	10	10
Custom Hire Cost	($/acre)	115	115	115	114	112	107	100	99
Non Machinery Labor Cost	($/acre)	18	18	18	18	18	18	18	18
Interest Cost	($/acre)	12	12	12	12	12	11	9	9
Irrigation Cost[a]	($/acre)	47	44	43	40	37	30	13	9
Sub Total Operating Cost		**$379**	**$376**	**$374**	**$369**	**$361**	**$338**	**$299**	**$294**
Crop Insurance[b]	($/acre)	18	18	18	18	17	16	14	14
Total Operating Costs		**$397**	**$394**	**$392**	**$387**	**$379**	**$354**	**$313**	**$308**
Net Returns Above Operating Costs		**$111**	**$115**	**$116**	**$114**	**$108**	**$82**	**$55**	**$56**

[a] Irrigation cost are calculated using single well drawdown assumptions
[b] Crop Insurance was calculated at 4.8% of the variable cost

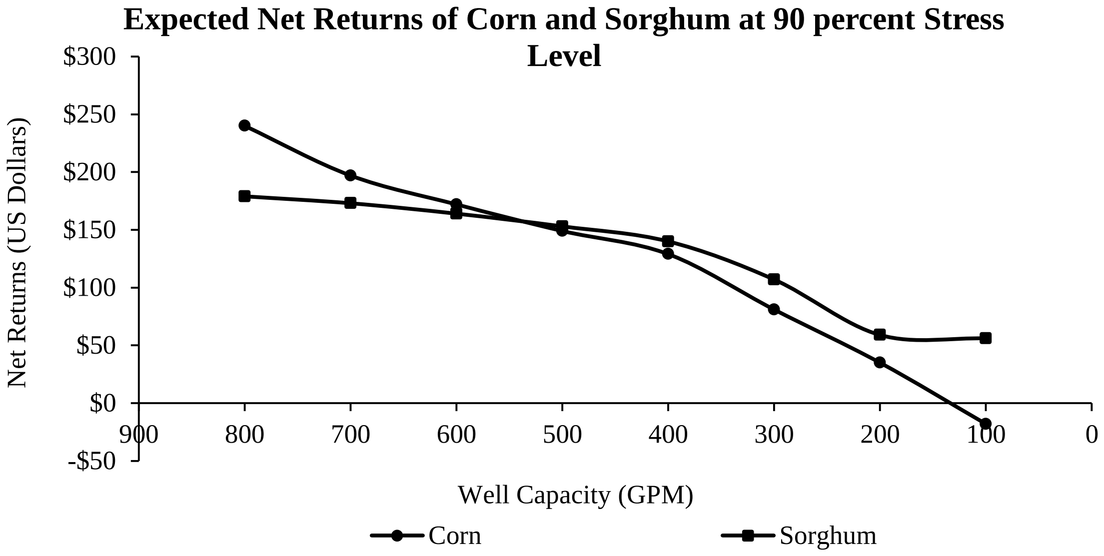


Figure 24. Expected Net Returns of corn and sorghum under 0.90 stress level for single-well pumping case

Note: The the pumping costs are calculated for operating one pivot which is served by one well.

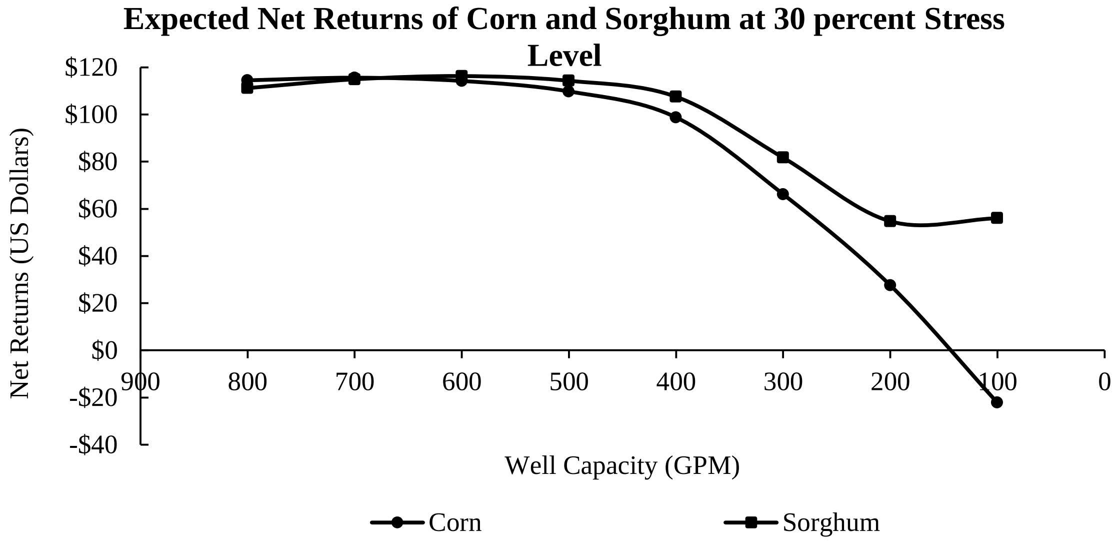


Figure 25. Expected Net Returns of corn and sorghum under 0.30 stress level for single-well pumping case

Note: The the pumping costs are calculated for operating one pivot which is served by one well.

Table 22. Budgets for Center Pivot Irrigated Corn Under 0.90 Stress with one and two Pivots Irrigated with Four Wells

	Units	Well Capacities (GPM)			
Max GPM Per Well		400	300	200	100
No of Pivots		2	2	2	1
GPM per pivot		800	600	400	400
Irrigated Activity Names		Ch90124	Cf90123	Cd90112	Cd90111
PRODUCTION					
Yield	(bu/ac)	213	187	164	164
Nitrogen	(lbs/ac	197	172	151	151
Phosphorus	(lbs/ac)	29	25	22	22
Irrigation	(ac-in)	22	22	18	18
Revenue		**$956**	**$837**	**$736**	**$736**
OPERATING INPUT COSTS					
Nitrogen cost	($/ac)	108	95	83	83
Phosphorus cost	($/ac)	15	13	11	11
Seed cost	($/ac)	113	113	113	113
Herbicide cost	($/ac)	61	61	61	61
Insecticide cost	($/ac)	16	15	15	15
Crop Consulting	($/ac)	7	7	7	7
Drying cost	($/ac)	28	24	21	21
Miscellaneous	($/ac)	10	10	10	10
Custom Hire	($/ac)	162	150	140	140
Non Machinery Labor	($/ac)	18	18	18	18
Interest cost	($/ac)	20	18	16	16
Irrigation Cost	($/ac)	121	114	92	92
Sub Total Operating Cost		**$677**	**$638**	**$588**	**$588**
Crop Insurance	($/ac)	33	31	28	28
Total Operating Costs		**$710**	**$668**	**$616**	**$616**
Net Returns Above Operating Costs		**$246**	**$169**	**$121**	**$121**

Table 23. Budgets for Center Pivot Irrigated Sorghum under 0.90 Stress with One and Two Pivots Irrigated With Four wells

	Units	Well Capacities (GPM)			
Max GPM Per Well		400	300	200	100
No of Pivots		2	2	2	1
GPM per pivot		800	600	400	400
Irrigated Activity Names		Sh90124	Sf90123	Sd90112	Sd90111
PRODUCTION					
Yield		163	148	134	134
Nitrogen	(bu/ac)	182	165	149	149
Phosphorus	(lbs/ac	29	27	24	24
Irrigation	(lbs/ac)	16	13	10	10
Revenue	(ac-in)	**$677**	**$617**	**$556**	**$556**
OPERATING INPUT COSTS					
Nitrogen cost		100	91	82	82
Phosphorus cost	($/ac)	15	14	13	13
Seed cost	($/ac)	16	16	16	16
Herbicide cost	($/ac)	52	52	52	52
Insecticide cost	($/ac)	0	0	0	0
Crop Consulting	($/ac)	6	6	6	6
Drying cost	($/ac)	21	19	17	17
Miscellaneous	($/ac)	10	10	10	10
Custom Hire	($/ac)	133	126	120	120
Non Machinery Labor	($/ac)	18	18	18	18
Interest cost	($/ac)	16	14	13	13
Irrigation Cost	($/ac)	84	67	54	54
Sub Total Operating Cost	($/ac)	**$471**	**$434**	**$402**	**$402**
Crop Insurance		23	21	19	19
Total Operating Costs	($/ac)	**$494**	**$455**	**$421**	**$421**
Net Returns Above Operating Costs		**$184**	**$162**	**$135**	**$135**

4.4 Recursive or Annual Profit Maximizer (APM)

A recursive model was developed to find the crop choices, aquifer life and discounted earnings for a myopic producer who selects the crop with the highest annual return each year. The results for this section were determined iteratively by 15 year periods. In each 15-year period the producers tests returns with one, two, three or four pivots. For example, a producer with four pivots selects the crop with higher net returns per acre. After each year crop selection, the water use of the previous year was deducted, and the process was repeated for 15 years. The same process was conducted with three, two and only one pivot. The NPV of returns from the four cases were compared. The producer was assumed to select the number of pivots that gave the highest NPV. For years 16 to 30 the process was repeated beginning with the remaining water supply from highest NPV number of pivots. The entire process was then repeated for years 31 to 45 and years 46 to 60 or until either economic or physical exhaustion of the aquifer occurred.

4.4.1 Recursive Optimization Results for a Producer with Four Initial 800 GPM Wells

The producer began each 15-year period with one, two, three or four pivots. In each of the following 15 years, the producer selects the crop and irrigation level that gave the highest net returns per acre. The number of pivots that gave the highest NPV was selected, and the amount of remaining groundwater was carried to the next 15-year period beginning water supply. Results in Figure 26 and Table 24 indicate that producers with 105 feet 23,800 acre-ft of water supply should purchase 4 pivots in the year 0. Figure 26 depicts the cumulative net present value by pivot investment numbers. A summary of crop choice and water pumped with NPV for first 15 years are listed in Table 24.

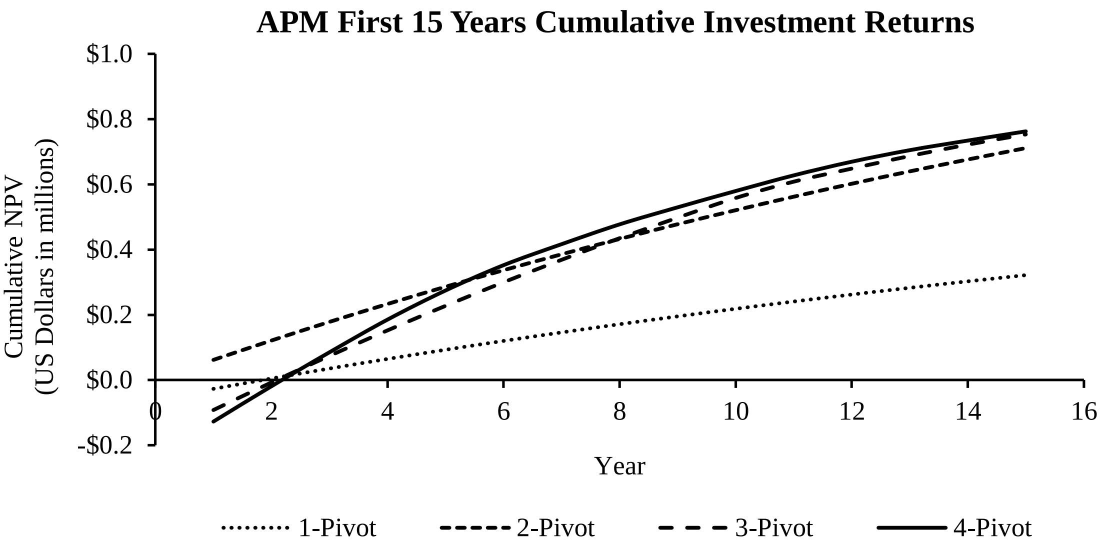


Figure 26. Cumulative Net Present Value for Myopic producer for first 15 years beginning with four initial 800 GPM wells

Table 24. NPV for First 15-Year Period for Myopic Producer with Four Initial 800 GPM Wells

No of Pivots	Years of Corn	Years of Sorghum	Acre-Ft Pumped	NPV @ 4%
1-Pivot	15	-	3,463	$321,709
2-Pivot	15	-	6,926	$711,294
3-Pivot	13	2	9,737	$753,391
4-Pivot	9	6	10,068	$762,652

The model begins by irrigating corn at level 8 with 800 GPM, which gives an annual profit of $117,163 while sorghum at the top level would return only $90,176. Once the water table falls below level 6, the decrease in well capacity affects corn profits. As the water table drops to level 5, irrigated corn requires 779 acre-ft/year to irrigate 480 acres, while irrigating sorghum it requires only 454 acre-ft/yr. At the 500 GPM level, growing 480 acres of sorghum becomes more profitable on an annual basis. Hence, at the year 9, annual profit-maximizing producer switches to grain sorghum when well capacity declines to 500 GPM with an annual return of $73,930. Corn would have returned only $71,595 each year by irrigating 480 acres with 500 GPM wells. Grain sorghum is grown continuously until the end of the 15-year period. By year 16, the wells would have declined to the 300 GPM range with 1,132 acre-ft of unused water.

In year 16, with 300 GPM wells, investing in 4 pivots was no longer the most profitable. This is because 10,068 acre-ft of water was used in the first 15 years and water and water has become more limiting. If the producer invested in 4 pivots and his NPV over the phase from year 16 to year 30 would be only $86,403. If the producer combined the four wells and irrigated with 1-pivot, the discounted earnings would be $168,047. Therefore, producer was assumed to purchase 1-pivot and uses the underground pipe to move water from the four wells to one pivot. At level 3, four wells are combined to irrigate with corn at 800 GPM. This is because irrigated corn with 1-pivot gives $268/acre for total returns of $36,477 for a section of land while irrigating sorghum gave only $28,577. Corn was grown continuously until year 31. The Figure 27 shows that the cumulative profit by one pivot investment stayed above all the other investment decisions during years 16 to 30.

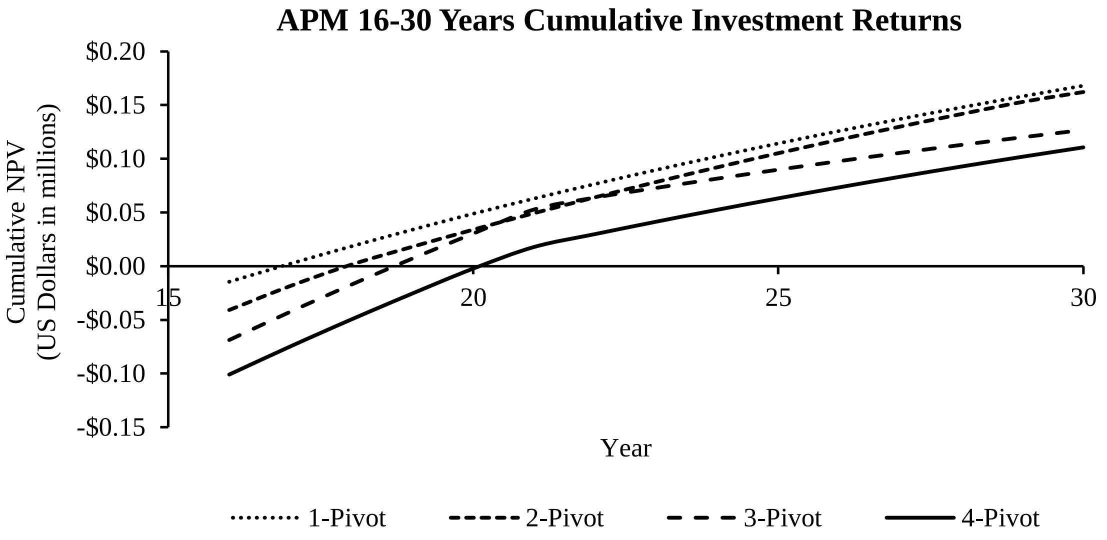


Figure 27. Cumulative Net Present Value for Myopic producer for years 16 to 30 beginning with four initial 800 GPM wells

By year 31, the water level had dropped to level 1 (100 GPM) or 28 feet of saturated sand. The four wells tied to one pivot are capable of supplying 400 GPM to a single pivot. As shown by the budgets, corn was no longer the most profitable, therefore, sorghum was produced until year 60. A single pivot used to irrigate 120 acres at 400 GPM was expected to have a net return of $139 per acre from sorghum while the expected net return from corn was $125 per acre.

For the years 31-45 and 46-60, crop activities and pivot purchases produced similar results. The optimal investment was to use four wells, purchase one pivot, and irrigate grain sorghum. Similar to Phase 2 (years 16-30), the single pivot cumulative NPVs for Phase 3 (years 31-45) and Phase 4 (years 46-60) was above all other investment decision. Table 25 shows the best NPV values, crop choice, along with the water use for the project life.

Table 25. Optimal Investment Sequence, Discounted Returns, Crop Choice, and Resulting Water Use for Recursive Producer with Four Initial 800 GPM Wells

Year	1-15	16-30	31-45	46-60	Total
Pivots	4	1	1	1	
Years of Corn	8	15	1	-	
Years of Sorghum	7	-	14	15	
Water Use (ac-ft)	10,068	3,463	1,663	1,559	16,753
Discounted Net Ret	$762,652	$168,047	$50,032	$25,983	$1,006,714

Note: Net Returns and Pivot Investments are discounted at 4 percent annually

The discounted net revenue each year minus the pivot investment cost each 15 years was summed to give the cumulative NPV for 60 years. Dryland sorghum was grown on the non-irrigated acres each year. The cumulative NPV $1,006,714 for a recursive optimizing producer with 800 GPM wells is shown in Figure 28. The remaining water supply at the end of each year is shown in Figure 29. By year 60, the water table has declined to a point where the maximum GPM per well was in the 100 GPM range.

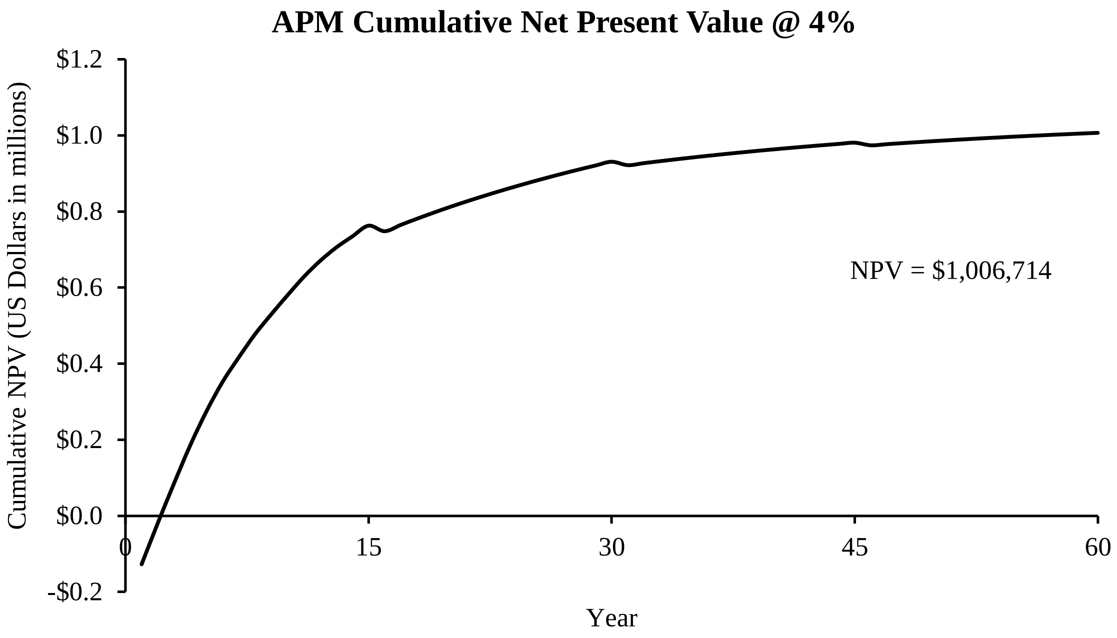


Figure 28. Cumulative Net Present Value for Recursive producer with four initial 800 GPM well over a 60-year period

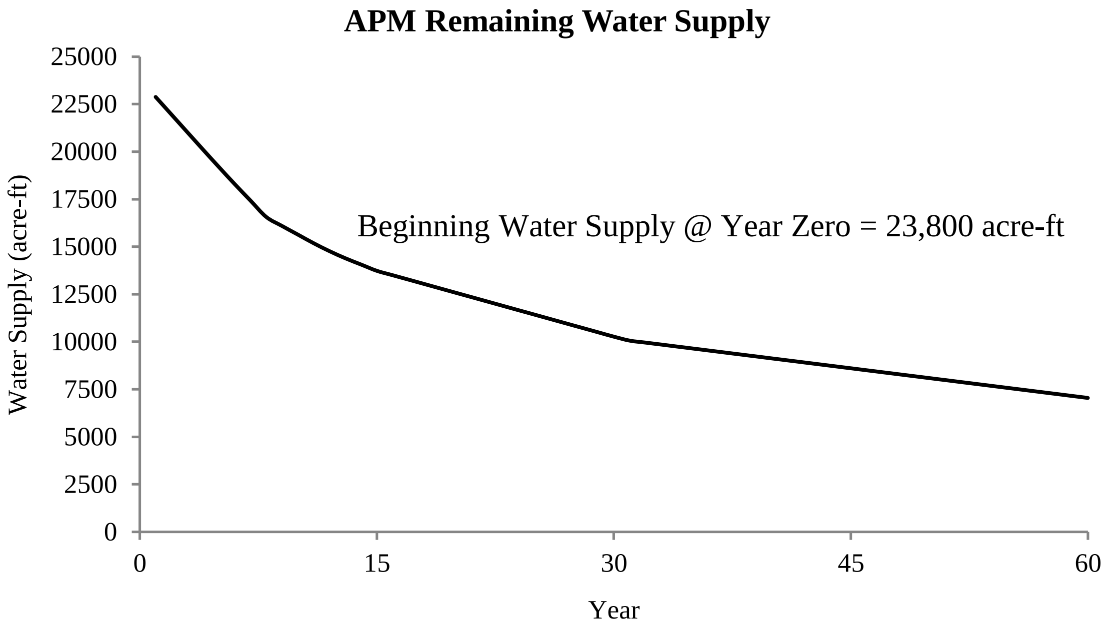


Figure 29. Remaining Water Supply Decline rate for Recursive producer with four initial 800 GPM wells over a 60-year period

4.4.2 Recursive Optimization Results for a Producer with Four Initial 600 GPM Wells

The initial capacity of the producer's wells was assumed to be 600 GPM, with 74 feet of water-saturated sand and 20,720 acre-ft of total water supply. The results show that the producer would purchase three pivots in the year 0, reduce to two pivots at year 16 and then use only one pivot from year 31until the end of the project life. Figure 30 shows the cumulative NPV for pivot investments for Phase 1. The crop choice, water use and NPV results for the first 15 years are shown in Table 26.

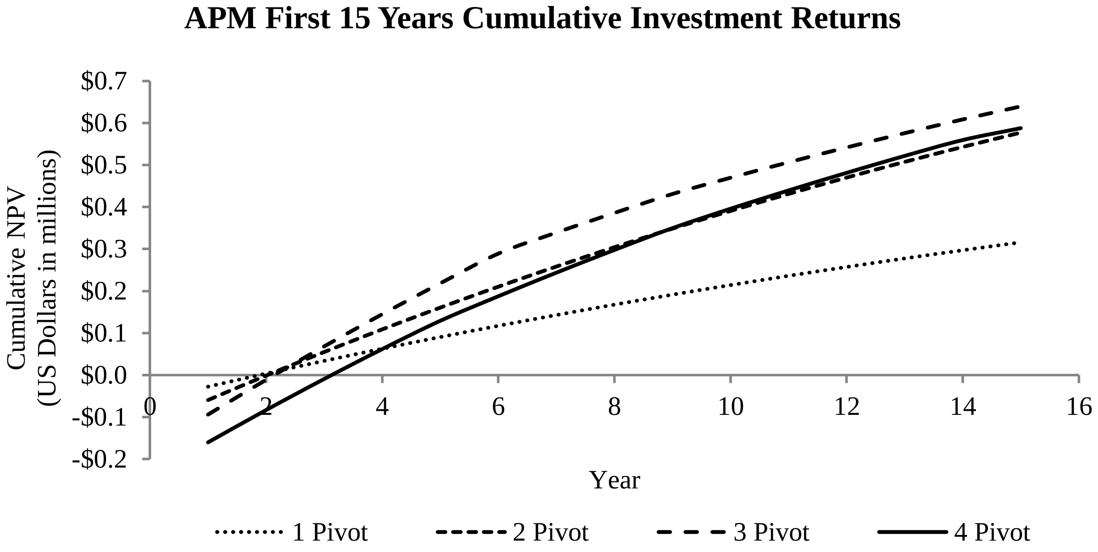


Figure 30. Cumulative Net Present Value for Myopic producer for first 15 years beginning with four initial 600 GPM wells

Table 26. NPV for First 15-Year Period for Myopic Producer with Four Initial 600 GPM Wells

No of Pivots	Years of Corn	Years of Sorghum	Acre-Ft Pumped	NPV @ 4%
1-Pivot	15	-	3,463	$315,841
2-Pivot	15	-	6,926	$576,980
3-Pivot	9	6	8,165	$639,310
4-Pivot	5	10	8,484	$587,582

The method used in the producer with initial 600 GPM wells is similar to the case where the producer began with 800 GPM wells. The optimal recursive choice for a producer with 600 GPM well capacities is to purchase three pivots in the year 0, and irrigate corn through the 600 and 500 GPM range. At level 6, corn gains $89,466 each year, where sorghum could make only $68,428. Irrigating sorghum with three pivots gave net return of $187 per acre while irrigating corn gave $245. Corn continued to have higher returns per acre than sorghum through 500 GPM range until year 9. The respective net returns with the 500 GPM on 120 acres were $175 and $167 for corn and sorghum. With 400 GPM well capacities and three pivots, irrigated corn net returns began to diminish, and sorghum achieved $5 ($154 minus $149) more profit per acre in level 4. At the end of year 15, level 4 was exhausted. The producer then purchased two pivots, and switched back to corn using 600 GPM (with four 300 GPM wells and two pivots) in each pivot.

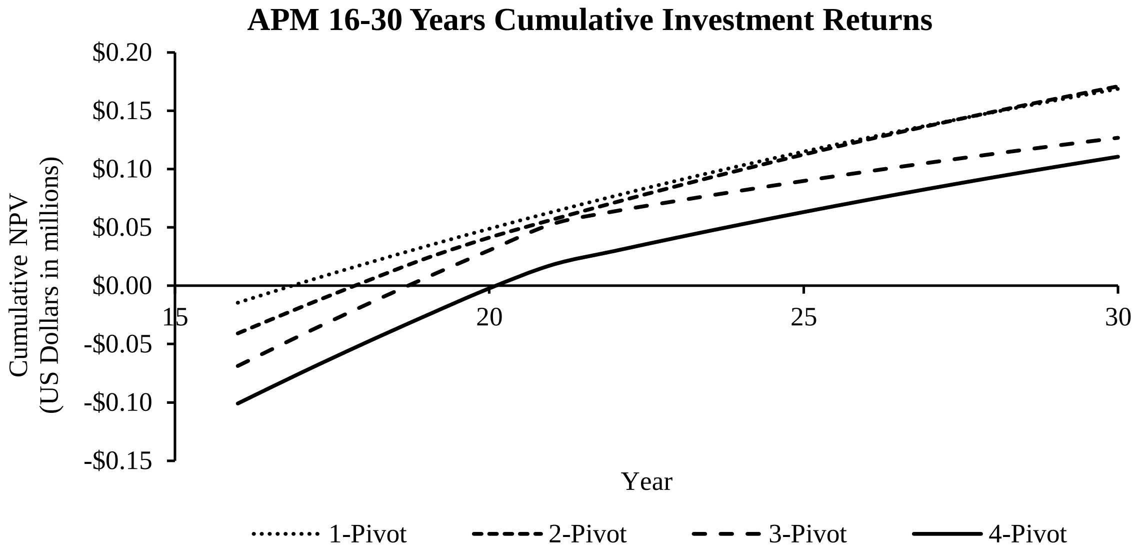


Figure 31. Cumulative Net Present Value for Myopic producer for years 16 to 30 beginning with four initial 600 GPM wells

As the water table dropped to level 2 in the year 20, irrigated sorghum with 400 GPM at each pivot became more profitable than irrigating corn. Irrigating sorghum using 400 GPM in each pivot (with four 200 GPM wells and two pivots) and distributing the remaining 400 acres to dryland sorghum gave $35,035. A similar allocation for corn would return only $31,644. The results are shown in Figure 31.

The water table reached the 100 GPM level by year 31. At this stage, investing in only one pivot was the most profitable. Similar to the previous case (section 4.4.1), irrigating sorghum with 400 GPM with one pivot always gives maximum annual profit at the 100 GPM level. The cumulative investments return for the year 31 through 45 is shown in Figure 32. The crop choice, water use and NPV results are shown in Table 27. The NPV growth and remaining water supply are shown in Figures 33 and 34.

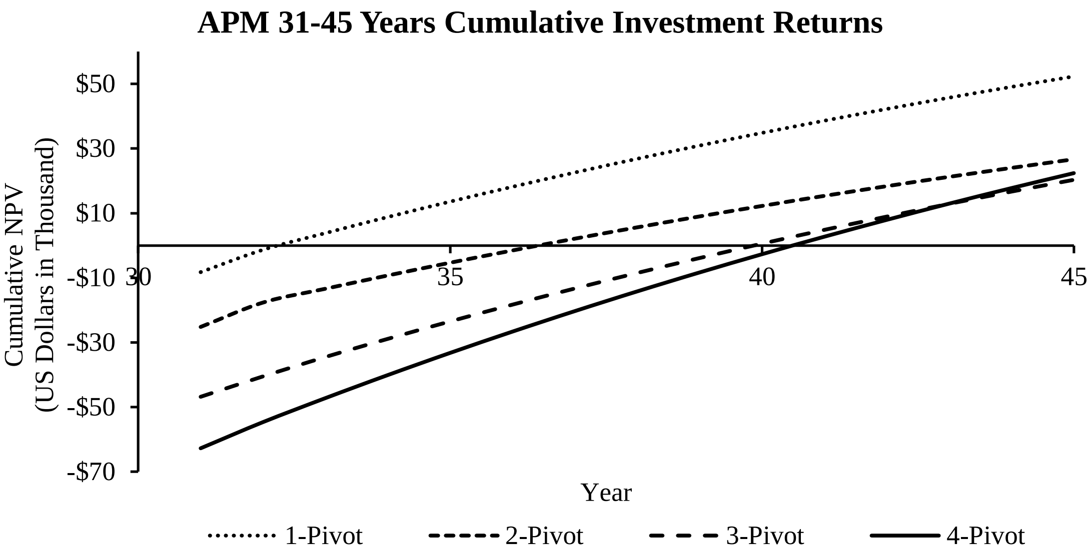


Figure 32. Cumulative Net Present Value for Myopic producer for years 31 to 45 beginning with four initial 600 GPM wells

Table 27. Optimal Investment Sequence, Discounted Returns, Crop Choice, and Resulting Water Use for Recursive Producer with Four Initial 600 GPM Wells

Year	1-15	16-30	31-45	46-60	Total
Pivots	3	1	1	1	
Years of Corn	9	15	1	-	
Years of Sorghum	6	-	14	15	
Water Use (ac-ft)	8,165	3,463	1,737	1,559	14,925
Discounted Net Ret	$639,310	$168,780	$52,299	$25,983	$886,373

Note: Net Returns and Pivot Investments are discounted at 4 percent annually

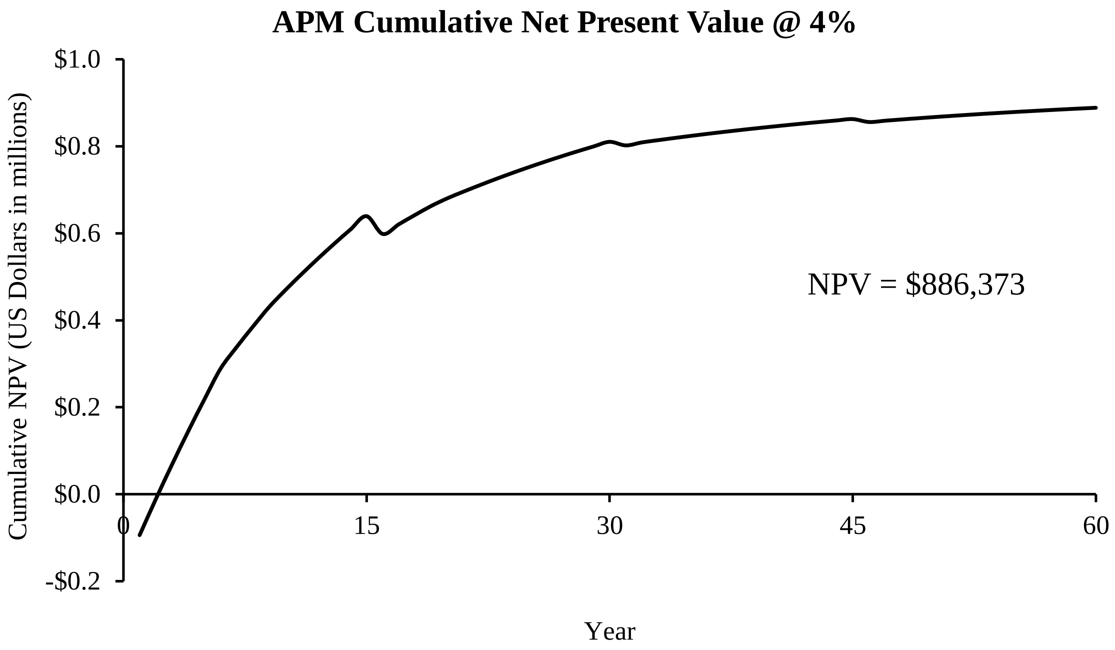


Figure 33. Cumulative Net Present Value for Recursive producer with four initial 600 GPM well over a 60-year period

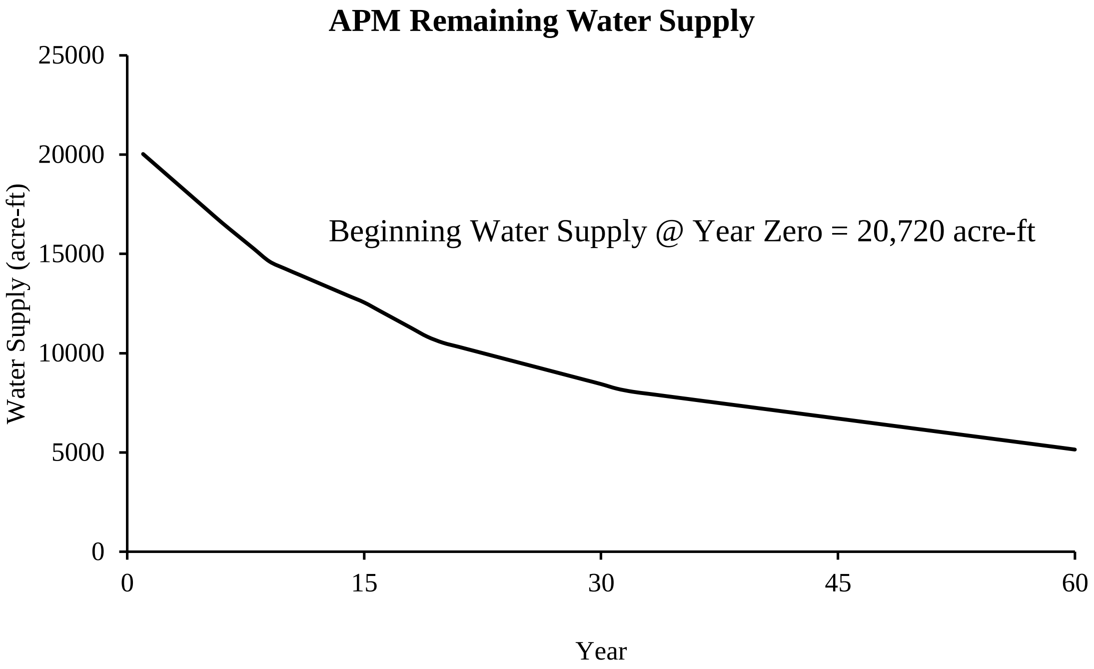


Figure 34. Remaining Water Supply Decline rate for Recursive producers with four initial 600 GPM wells over a 60-year period

4.4.3 Recursive Optimization Results for a Producer with Four Initial 400 GPM Wells

Recursive results point out that the producer who practices annual profit maximization crop production on a 640 acre with four 400 GPM wells would invest in two pivots and irrigate corn at 800 GPM. The comparison between using four wells to irrigate corn on 240 acres and irrigating 480 acres with four pivots or 360 acres with three pivots shows it was slightly more profitable to irrigate 240 acres of corn with two pivots is shown in Table 28. In year 10, the well capacities drop to 200 GPM, and irrigating sorghum was profitable until next pivot purchase. At year 16, well capacities were at 200 GPM. Figure 35 depicts the cumulative present value growth for the first 15 years.

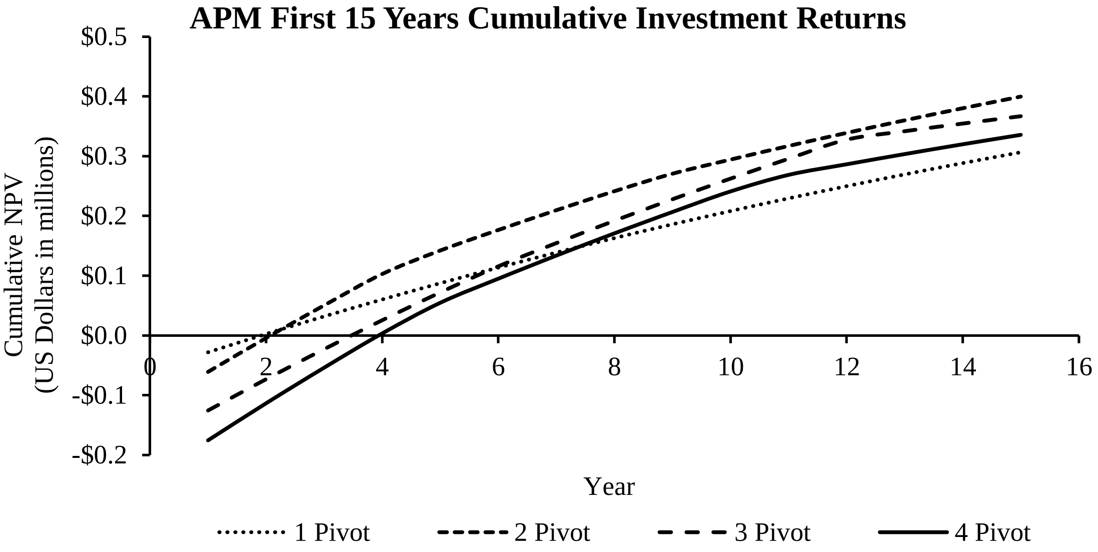


Figure 35. Cumulative Net Present Value for Myopic producer for first 15 years beginning with four initial 400 GPM wells

Table 28. NPV for First 15-Year Period for Myopic Producer with Four Initial 400 GPM Wells

No of Pivots	Years of Corn	Years of Sorghum	Acre-Ft Pumped	NPV @ 4%
1-Pivot	15	-	3,463	$306,487
2-Pivot	9	6	5,211	$399,635
3-Pivot	-	15	4,235	$366,810
4-Pivot	-	15	4,630	$335,645

Beginning with 200 GPM wells at year 16, the second phase of investment for years 16 through 30, the producer would purchase one pivot and irrigate corn for five years before switching to sorghum at year 21 with one pivot that gave higher NPV among the other investment decisions. This is because when the well capacity dropped to the 100 GPM by year 21, irrigating sorghum (Sd90111: $18,838) at 400 GPM was more profitable than irrigating corn (Cd90111: $17,142).

Results of phase 3 (years 31 through 45) and 4 (years through 46 to 60) are similar with the results obtained in the previous parts (producer with level 8 and 6). Hence, one could easily identify that investing in one pivot for rest of the project life would be most profitable investment. The discounted net returns in phase 3 and phase 4 are 46,795 and $25,983 respectively, and NPV of the project is $591,615. Sequences of investment decision and crop choices are shown in Table 29. Cumulative present value growth is shown in Figure 36 and remaining water supply is shown in Figure 37.

Table 29. Optimal Investment Sequence, Discounted Returns, Crop Choice, and Resulting Water Use for Recursive Producer with Four Initial 400 GPM Wells

Year	1-15	16-30	31-45	46-60	Total
Pivots	2	1	1	1	
Years of Corn	9	5	-	-	
Years of Sorghum	6	10	15	15	
Water Use (ac-ft)	5,211	2,234	1,559	1,559	10,564
Discounted Net Ret	$399,635	$119,203	$46,795	$25,983	$591,615

Note: Net Returns and Pivot Investments are discounted at 4 percent annually

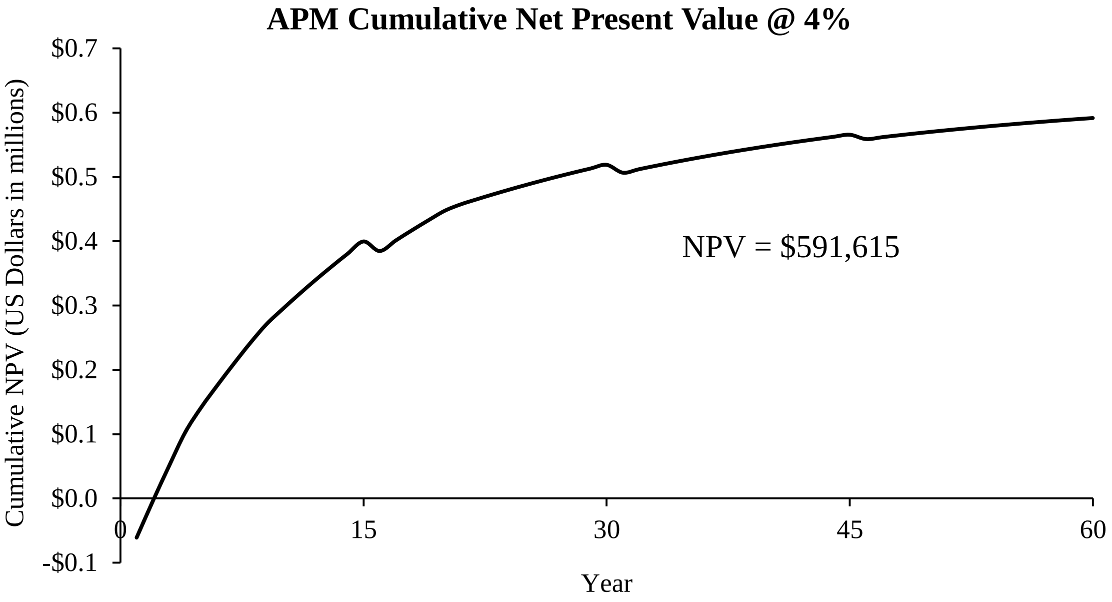


Figure 36. Cumulative Net Present Value for Recursive producer with four initial 400 GPM well over a 60-year period

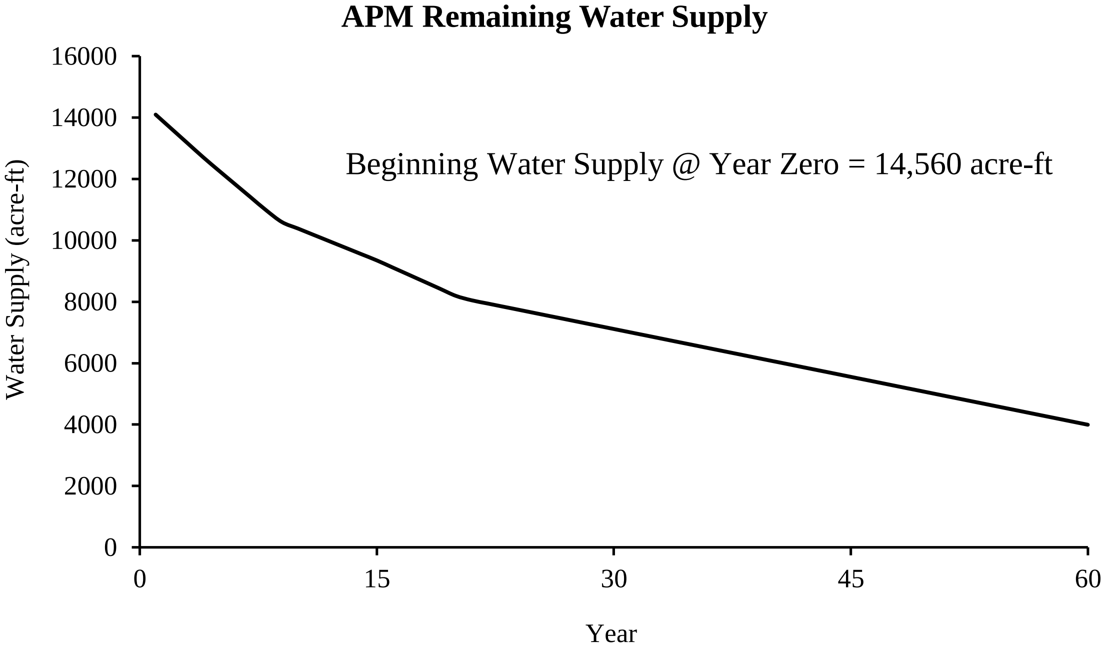


Figure 37. Remaining Water Supply Decline rate for Recursive producers with four initial 400 GPM wells over a 60-year period

4.5 Mixed Integer Programming Results or Long-Term Profit Maximization (LTPM)

One of the main objectives of this research was to determine use of the remaining groundwater that yielded maximum discounted net returns. The results in this section address the objective of deciding the crop and irrigation choice to determine maximum discounted net returns from remaining groundwater. These details are total net present value, optimal crop and irrigation choice, investment in the optimal irrigated area, and dryland area (area not covered by the pivot system). The dryland area produces sorghum, which is assumed to be the marginal value or opportunity costs of the land.

Crop budget results indicate that irrigated crops give diminishing returns by increasing irrigation water each acre. This would imply it will be optimal to spread water supplies over more acres with grain sorghum. However, spreading the water requires more capital investment. If spreading (investing in more pivots) is more expensive respective to remaining water supply, dryland becomes competitive and remaining groundwater is applied to fewer acres. This is clearly obeyed and satisfied by the model results.

4.5.1 Long-Term Profit Maximization Results for a Producer with Four 800 GPM wells

The results show that the producer would initially purchase four pivots in the beginning of the project and irrigate the entire 480 acres with the most profitable and high-water use crop corn, and leave the remaining non-irrigable land (corners) with dryland sorghum. The reason to begin with corn is because corn had a higher return when land is more limiting and when water is not scarce. Figure 38 shows the optimal crop choice from the MIP model.

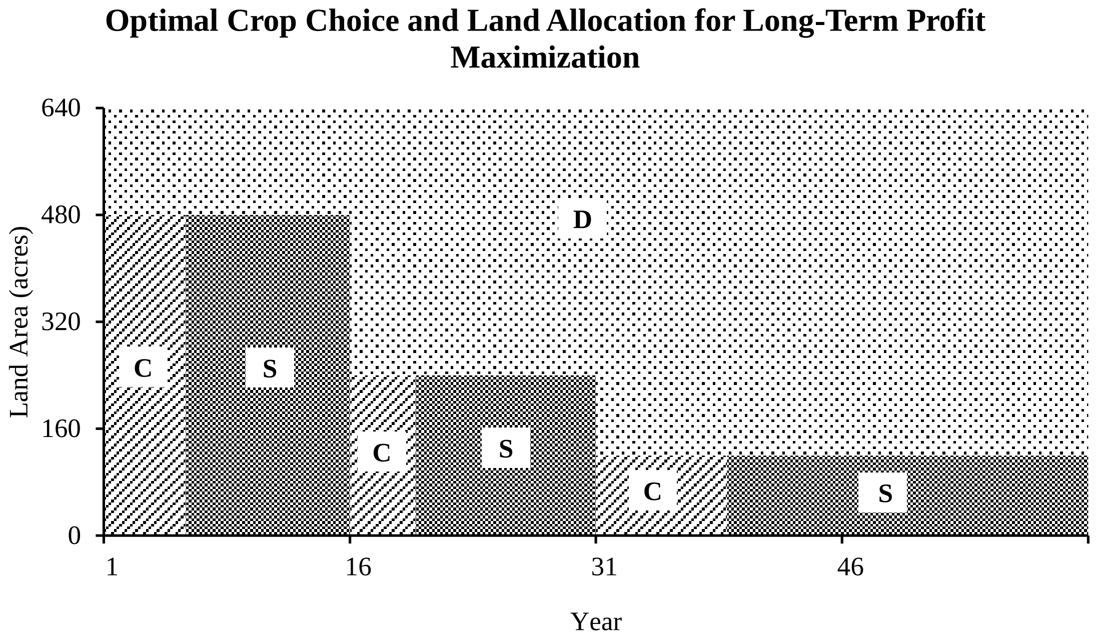


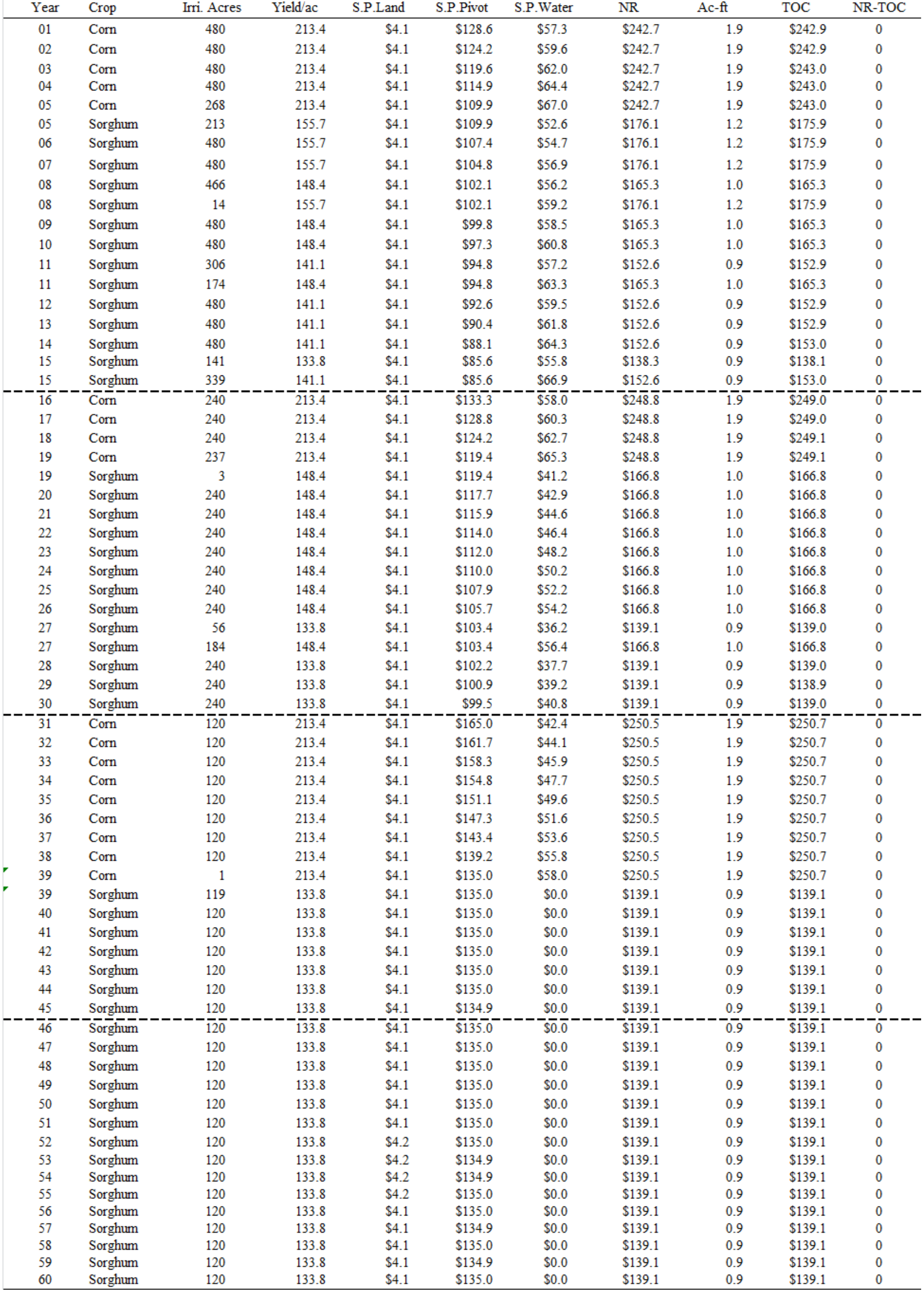
Figure 38. Optimal cropland allocation to irrigated and dryland crops for a 60-year period

Note: C refers Irrigated Corn, S refers Irrigated Grain Sorghum and D refers Dryland Grain Sorghum

The aquifer declines 15 feet in 5 years (which is 2.5 feet decline year), which is close to the annual actual decline (1.9 feet per year) in Texas County water (USGS). Table 30 shows the optimal land allocation results.

At the 800 GPM level, the producer could to irrigate each quarter section with its own well. However, the wells become unable to pump 800 GPM and drop to 700 GPM range in the year 6. Sorghum is selected at year 6 even though the net returns per acre from sorghum are lower than corn (Table 30). Sorghum is then irrigated until next irrigation purchase. The wells capacity declines to 400 GPM by year 16. The crop activities with shadow prices are listed in Table 30. The reasons are discussed below in Table 31.

Table 30. Results of Long Term Profit Maximization with Annual Lagrangian Multipliers Undiscounted Values



Year	Crop	Irri. Acres	Yield/ac	S.P.Land	S.P.Pivot	S.P.Water	NR	Ac-ft	TOC	NR-TOC
01	Corn	480	213.4	$4.1	$128.6	$57.3	$242.7	1.9	$242.9	0
02	Corn	480	213.4	$4.1	$124.2	$59.6	$242.7	1.9	$242.9	0
03	Corn	480	213.4	$4.1	$119.6	$62.0	$242.7	1.9	$243.0	0
04	Corn	480	213.4	$4.1	$114.9	$64.4	$242.7	1.9	$243.0	0
05	Corn	268	213.4	$4.1	$109.9	$67.0	$242.7	1.9	$243.0	0
05	Sorghum	213	155.7	$4.1	$109.9	$52.6	$176.1	1.2	$175.9	0
06	Sorghum	480	155.7	$4.1	$107.4	$54.7	$176.1	1.2	$175.9	0
07	Sorghum	480	155.7	$4.1	$104.8	$56.9	$176.1	1.2	$175.9	0
08	Sorghum	466	148.4	$4.1	$102.1	$56.2	$165.3	1.0	$165.3	0
08	Sorghum	14	155.7	$4.1	$102.1	$59.2	$176.1	1.2	$175.9	0
09	Sorghum	480	148.4	$4.1	$99.8	$58.5	$165.3	1.0	$165.3	0
10	Sorghum	480	148.4	$4.1	$97.3	$60.8	$165.3	1.0	$165.3	0
11	Sorghum	306	141.1	$4.1	$94.8	$57.2	$152.6	0.9	$152.9	0
11	Sorghum	174	148.4	$4.1	$94.8	$63.3	$165.3	1.0	$165.3	0
12	Sorghum	480	141.1	$4.1	$92.6	$59.5	$152.6	0.9	$152.9	0
13	Sorghum	480	141.1	$4.1	$90.4	$61.8	$152.6	0.9	$152.9	0
14	Sorghum	480	141.1	$4.1	$88.1	$64.3	$152.6	0.9	$153.0	0
15	Sorghum	141	133.8	$4.1	$85.6	$55.8	$138.3	0.9	$138.1	0
15	Sorghum	339	141.1	$4.1	$85.6	$66.9	$152.6	0.9	$153.0	0
16	Corn	240	213.4	$4.1	$133.3	$58.0	$248.8	1.9	$249.0	0
17	Corn	240	213.4	$4.1	$128.8	$60.3	$248.8	1.9	$249.0	0
18	Corn	240	213.4	$4.1	$124.2	$62.7	$248.8	1.9	$249.1	0
19	Corn	237	213.4	$4.1	$119.4	$65.3	$248.8	1.9	$249.1	0
19	Sorghum	3	148.4	$4.1	$119.4	$41.2	$166.8	1.0	$166.8	0
20	Sorghum	240	148.4	$4.1	$117.7	$42.9	$166.8	1.0	$166.8	0
21	Sorghum	240	148.4	$4.1	$115.9	$44.6	$166.8	1.0	$166.8	0
22	Sorghum	240	148.4	$4.1	$114.0	$46.4	$166.8	1.0	$166.8	0
23	Sorghum	240	148.4	$4.1	$112.0	$48.2	$166.8	1.0	$166.8	0
24	Sorghum	240	148.4	$4.1	$110.0	$50.2	$166.8	1.0	$166.8	0
25	Sorghum	240	148.4	$4.1	$107.9	$52.2	$166.8	1.0	$166.8	0
26	Sorghum	240	148.4	$4.1	$105.7	$54.2	$166.8	1.0	$166.8	0
27	Sorghum	56	133.8	$4.1	$103.4	$36.2	$139.1	0.9	$139.0	0
27	Sorghum	184	148.4	$4.1	$103.4	$56.4	$166.8	1.0	$166.8	0
28	Sorghum	240	133.8	$4.1	$102.2	$37.7	$139.1	0.9	$139.0	0
29	Sorghum	240	133.8	$4.1	$100.9	$39.2	$139.1	0.9	$138.9	0
30	Sorghum	240	133.8	$4.1	$99.5	$40.8	$139.1	0.9	$139.0	0
31	Corn	120	213.4	$4.1	$165.0	$42.4	$250.5	1.9	$250.7	0
32	Corn	120	213.4	$4.1	$161.7	$44.1	$250.5	1.9	$250.7	0
33	Corn	120	213.4	$4.1	$158.3	$45.9	$250.5	1.9	$250.7	0
34	Corn	120	213.4	$4.1	$154.8	$47.7	$250.5	1.9	$250.7	0
35	Corn	120	213.4	$4.1	$151.1	$49.6	$250.5	1.9	$250.7	0
36	Corn	120	213.4	$4.1	$147.3	$51.6	$250.5	1.9	$250.7	0
37	Corn	120	213.4	$4.1	$143.4	$53.6	$250.5	1.9	$250.7	0
38	Corn	120	213.4	$4.1	$139.2	$55.8	$250.5	1.9	$250.7	0
39	Corn	1	213.4	$4.1	$135.0	$58.0	$250.5	1.9	$250.7	0
39	Sorghum	119	133.8	$4.1	$135.0	$0.0	$139.1	0.9	$139.1	0
40	Sorghum	120	133.8	$4.1	$135.0	$0.0	$139.1	0.9	$139.1	0
41	Sorghum	120	133.8	$4.1	$135.0	$0.0	$139.1	0.9	$139.1	0
42	Sorghum	120	133.8	$4.1	$135.0	$0.0	$139.1	0.9	$139.1	0
43	Sorghum	120	133.8	$4.1	$135.0	$0.0	$139.1	0.9	$139.1	0
44	Sorghum	120	133.8	$4.1	$135.0	$0.0	$139.1	0.9	$139.1	0
45	Sorghum	120	133.8	$4.1	$134.9	$0.0	$139.1	0.9	$139.1	0
46	Sorghum	120	133.8	$4.1	$135.0	$0.0	$139.1	0.9	$139.1	0
47	Sorghum	120	133.8	$4.1	$135.0	$0.0	$139.1	0.9	$139.1	0
48	Sorghum	120	133.8	$4.1	$135.0	$0.0	$139.1	0.9	$139.1	0
49	Sorghum	120	133.8	$4.1	$135.0	$0.0	$139.1	0.9	$139.1	0
50	Sorghum	120	133.8	$4.1	$135.0	$0.0	$139.1	0.9	$139.1	0
51	Sorghum	120	133.8	$4.1	$135.0	$0.0	$139.1	0.9	$139.1	0
52	Sorghum	120	133.8	$4.2	$135.0	$0.0	$139.1	0.9	$139.1	0
53	Sorghum	120	133.8	$4.2	$134.9	$0.0	$139.1	0.9	$139.1	0
54	Sorghum	120	133.8	$4.2	$134.9	$0.0	$139.1	0.9	$139.1	0
55	Sorghum	120	133.8	$4.2	$135.0	$0.0	$139.1	0.9	$139.1	0
56	Sorghum	120	133.8	$4.1	$135.0	$0.0	$139.1	0.9	$139.1	0
57	Sorghum	120	133.8	$4.1	$134.9	$0.0	$139.1	0.9	$139.1	0
58	Sorghum	120	133.8	$4.1	$135.0	$0.0	$139.1	0.9	$139.1	0
59	Sorghum	120	133.8	$4.1	$134.9	$0.0	$139.1	0.9	$139.1	0
60	Sorghum	120	133.8	$4.1	$135.0	$0.0	$139.1	0.9	$139.1	0

Note: Irri.Acres is the irrigated acres, S.P. is the shadow price, NR is the Net Returns, Ac-ft refers acre-foot, TOC is the Total Oppurtunity Cost. All values are based on per acre.

The objective value depending on groundwater, total land, and irrigated land can be expressed as $f(x_w, x_l, x_i)$, where x_w is the water, x_l land, and x_i is the irrigated area available, where the inequality constraints can be considered as $g_w(x_w, x_l, x_i) \leq d_w$, $g_l(x_w, x_l, x_i) \leq d_l$ and $g_i(x_w, x_l, x_i) \leq d_i$ where d_w is the water supply, d_l is total land, and d_i is the irrigated area constraint. Generally the arguments f and g need not be linear assumptions, however our model consists of strictly simultaneous piecewise linear equations.

The role of the Lagrange Multipliers in selecting the optimal activity for these constraints expressions is shown in Table 31. The net revenue of sorghum in the year 7 at 700 GPM level fully replaces corn, and continues each year until next pivot purchase. The value of the Lagrangian Multipliers reflects the scarcity of the limiting resources. While reducing the pivot size with less water-use crop sorghum, the discounted profit must be always greater than profit of higher return and high-water use crop corn. Spreading the irrigated corn acres may give higher returns per acre. However, while the water level is declining, net returns per acre foot of water are higher for sorghum than corn. Consequently, water table declines faster and water becomes more limiting. The increased shadow price of water makes corn less profitable between years 6 and 15. This is shown in Tables 31 and 32 where sorghum activity can able to pay resource rents while the corn activity is relatively increasing. Similar results are associated with downsizing the irrigated area while switching back from grain sorghum to corn. The effect of reducing the irrigated acres from 480 acres in the year 15, to 240 acres in the year 16 increases the relative value of irrigated land to groundwater or cause water to be less limiting. This is reflected in an increase in the VMP of irrigated land in the year 16. By reducing the irrigated area from 480 to 240 acres, the producer can supply 800 GPM to each of the two pivots. Since corn (at 800 GPM) had higher returns to land than sorghum, the increase was sufficient for corn to become selected over grain sorghum as shown in Table 33.

Table 31. Illustration of Effect of the Shadow Price (SP) of Groundwater on Choice of Grain Sorghum for LTPM producers with 700 GPM wells

	(1)	(2)	(3)	(4)	(5)	(6)	1-2-3-6
Activity	Annual Net Returns	Land Shadow Price	Pivot Shadow Price	Water Shadow Price	Annual Water Use	Value of Water	NR-OC[c]
Name	($/ac)	($/ac)	($/irrigated ac)	($/ac-ft)	(ac-ft/ac)	($)	($)
Sg90647[a]	$176.1	$4.1	$107.4	$54.7	1.18	$64.3	$0
Cg90647[b]	$203.4	$4.1	$107.4	$54.7	1.87	$102.4	-$11

[a] Sg90647 is the activity for sorghum irrigating with maximum of 700 GPM wells under 90 percent stress in year 06 with 4 pivots, [b] Cg90647 is the activity for corn irrigating with maximum of 700 GPM wells under 90 percent stress in year 06 with 4 pivots, [c] NR is the Net Returns and OC is the Opportunity Cost

Table 32. Illustration of Effect of the Shadow Price (SP) Groundwater on Choice of Grain Sorghum and Corn on Year 15

	(1)	(2)	(3)	(4)	(5)	(6)	1-2-3-6
Activity	Net Returns	Land Shadow Price	Pivot Shadow Price	Water Shadow Price	Water Use	Value of Water	NR-OC[c]
Name	($/ac)	($/ac)	($/irrigated ac)	($/ac-ft)	(ac-ft/ac)	($)	($)
Se91545[a]	$152.6	$4.1	$88.1	$64.3	0.94	$60.8	$0
Ce91545[b]	$146.4	$4.1	$88.1	$64.3	1.62	$104.3	-$50

[a] Se91545 is the activity for sorghum irrigating with maximum of 500 GPM wells under 90 percent stress at year 15 with 4 pivots, [b] Ce91545 is the activity for corn irrigating with maximum of 500 GPM wells under 90 percent stress at year 15 with 4 pivots, [c] NR is the Net Returns and OC is the Opportunity Cost

Table 33. Illustration of Effect of the Shadow Price (SP)of Groundwater on Choice of Grain Sorghum and Corn on Year 16

	(1)	(2)	(3)	(4)	(5)	(6)	1-2-3-6
Activity	Net Returns	Land Shadow Price	Pivot Shadow Price	Water Shadow Price	Water Use	Value of Water	NR-OC[c]
Names	($/ac)	($/ac)	($/irrigated ac)	($/ac-ft)	(ac-ft/ac)	($)	($)
Sh91624[a]	$189.2	$4.1	$133.3	$58.0	1.30	$75.5	-$24
Ch91624[b]	$248.8	$4.1	$133.3	$58.0	1.92	$111.6	$0

[a] Sh91624 is the activity for sorghum irrigating with maximum of 400 GPM wells under 90 percent stress at year 16 with 2 pivots, [b] Ch91624 is the activity for corn irrigating with maximum of 400 GPM wells under 90 percent stress at year 16 with 2 pivots, [c] NR is the Net Returns and OC is the Opportunity Cost

Finally, it was worthwhile to check whether the land allocated is optimal and profitable. This check was validated using the classic Euler Theorem, which was illustrated in Chapter 2. Euler theorem states that if the marginal value is paid to the input of the optimal output, the profit from the output is equal to the distributed shares from the input. The last column in the Table 30 illustrates that for the optimal activity each year, the shadow prices for the optimal activity listed each year satisfy the Euler conditions. Theoretically, if all resources (land, irrigated land and water) are paid their VMP, all the net revenue would be exhausted. The Figure 39 shows the trend of undiscounted shadow prices falling over the 60 year period where land remains constant. The undiscounted VMP of land is given by the net returns of dryland sorghum.

So what limits extracting the water from deeper wells? Also, what limits the producer investing in producing higher returns crop and purchasing more pivots? Beginning in the year 40, the water constraint became non-binding, because there was enough water supply to irrigate one pivot with 400 GPM for rest of the project life. After 60 years, there was groundwater remaining in the 100 GPM level. Therefore, the shadow price of water becomes zero starting in year 40. A limitation of the study is there were no simulation results for well capacities less than 100 GPM, which could irrigate one pivot with less than 400 GPM. Increasing dryland sorghum becomes profitable when extracting one more unit of water and investing in pivots is not profitable. When new pivot life begins, irrigated acres value becomes very high; however, this is not seen throughout the life of the pivot after year 40. Therefore, producing sorghum with higher value per unit of water on 120 acres with 400 GPM became the only choice and continues to irrigate at the pivot size towards the end of the project.

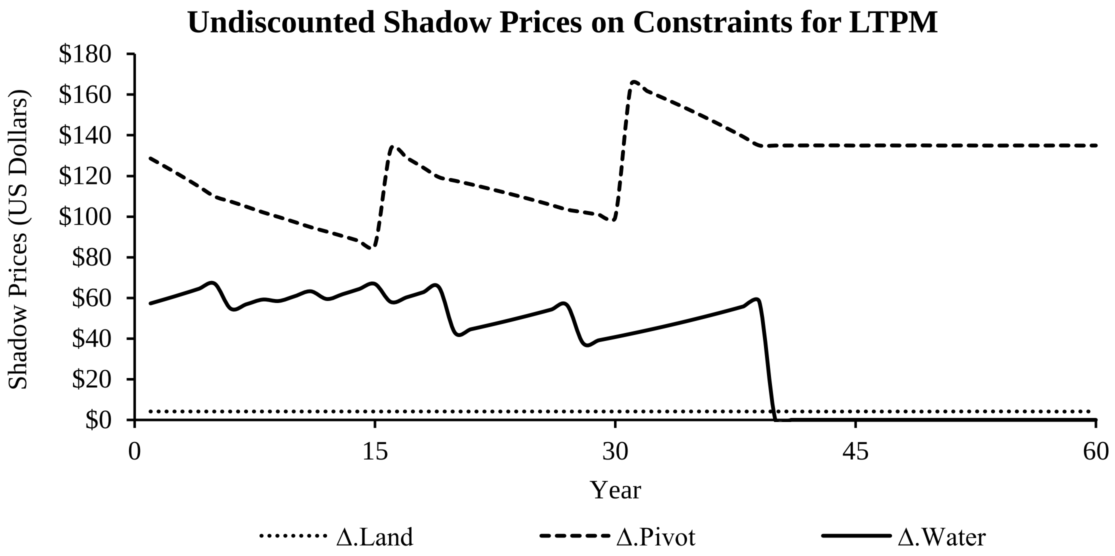


Figure 39. Undiscounted Shadow Price trend of constrained resources for long-term profit maximization

4.6 Annual Profit Maximizer vs Long-Term NPV Maximizer

In this section, results of Annual Profit Maximization (APM) and Long-Term Profit Maximization (LTPM) results are compared. Results show that producers' operating on long-term profit maximization generated higher profits than the APM producer who followed annual profit maximization. The LTPM producer who begins with 800 GPM well capacities generated $113,255 more NPV than the APM producer at the 4 percent discount rate. However, the LTPM producer beginning with 600 GPM wells generated only about $20,000 more NPV than the APM producer as shown in Table 34. Results from Figure 40 show that long term profit maximizer pulls ahead of annual profit maximizer at year 13 and continue to make better profits than annual profit maximizer. In addition, the LTPM producer uses more water from the aquifer as shown in Figure 41, and produces 133,000 more bushels of grain than the APM producer.

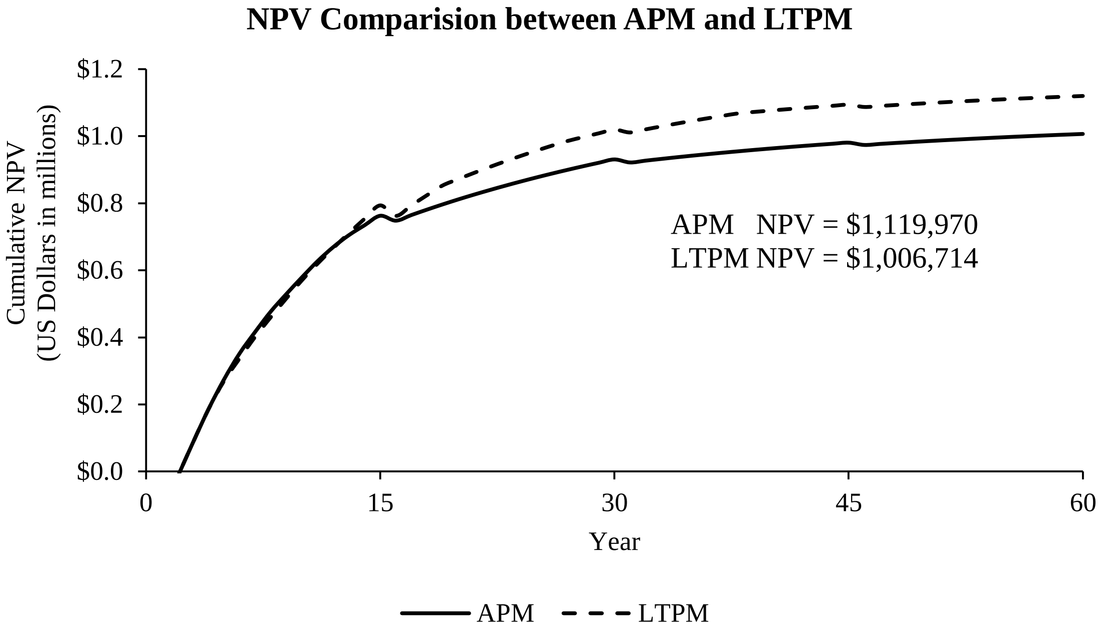


Figure 40. Cumulative Net Present Value between APM and LTPM with four initial 800 GPM well capacities

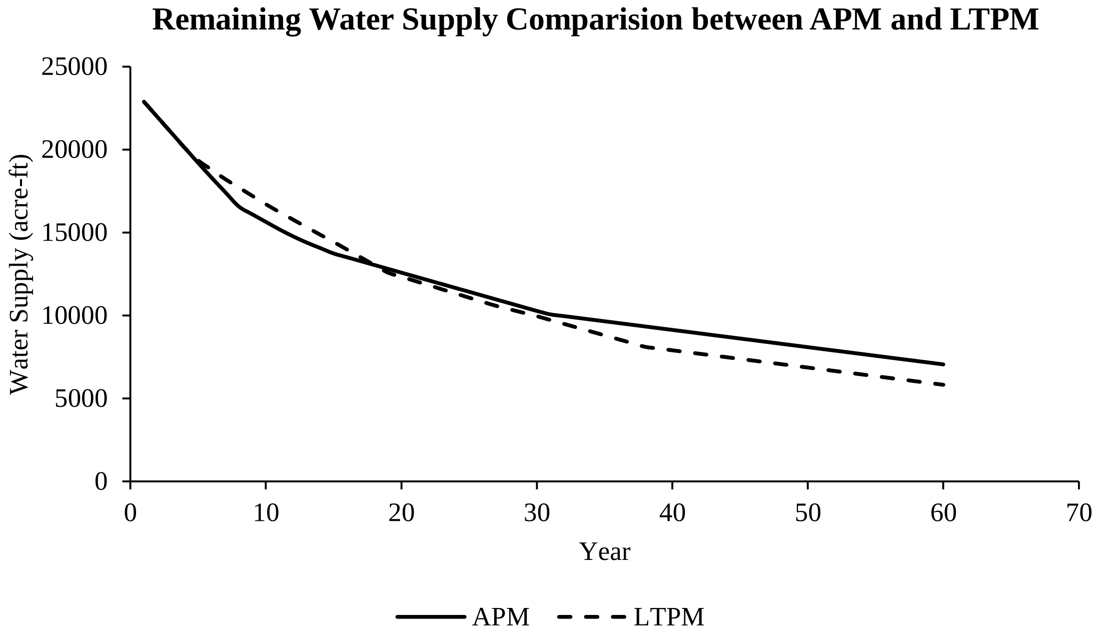


Figure 41. Image showing Water Supply Decline Rate between producers with four initial 800 GPM wells and selects series of Annual Profits and maximizes Long-Term Profits over a period of 60 years

Unlike producers with 800 GPM well capacities, producers with 600 GPM wells did not show a large difference in the NPV between APM and LTPM as shown in Figure 42.

Therefore, precise alternative irrigation is necessary to make higher long-term returns. The following Tables 35 through 38 compare crop activities, well yield restriction, well capacities per pivot, and irrigated and non-irrigated land allocation between APM and LTPM producer. Tables 35 and 36 list the summary activities for both APM and LTPM with 800 GPM well capacities. Similarly, summary tables of activities for producers with 600 GPM are listed in Tables 37 and 38. One main difference is the LTPM producer changes from corn to sorghum two to three years sooner than the APM producer. As shown previously in Table 31, this is because consideration of the opportunity cost of groundwater in the LTPM model indicated that sorghum is the better choice. This information is not available to the APM producer.

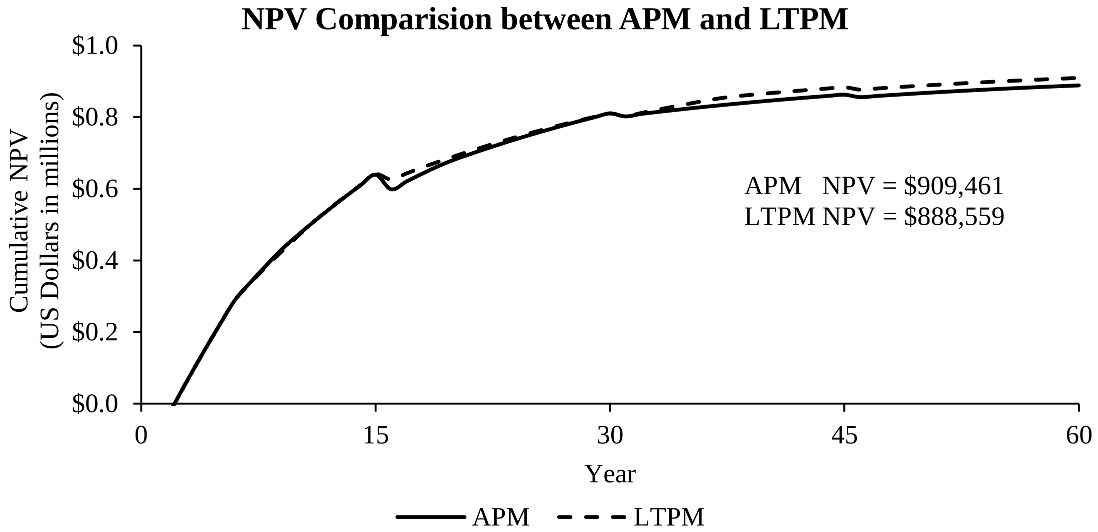


Figure 42. Cumulative Net Present Value between APM and LPTM producers with four initial 600 GPM well capacities

Table 34. 60-year NPV of APM and LTPM producers with Different Well Capacities

	Maximum Well Capacities		
Producer's Choice	800 GPM	600 GPM	400 GPM
NPV of Long Term Maximization	$1,119,970	$909,461	$615,906
NPV of Annual Profit Maximization	$1,006,714	$888,559	$591,615

Table 35. 60-year Crop Activities which gave Maximum Annual Profits for Producers with 800 GPM Well Capacities

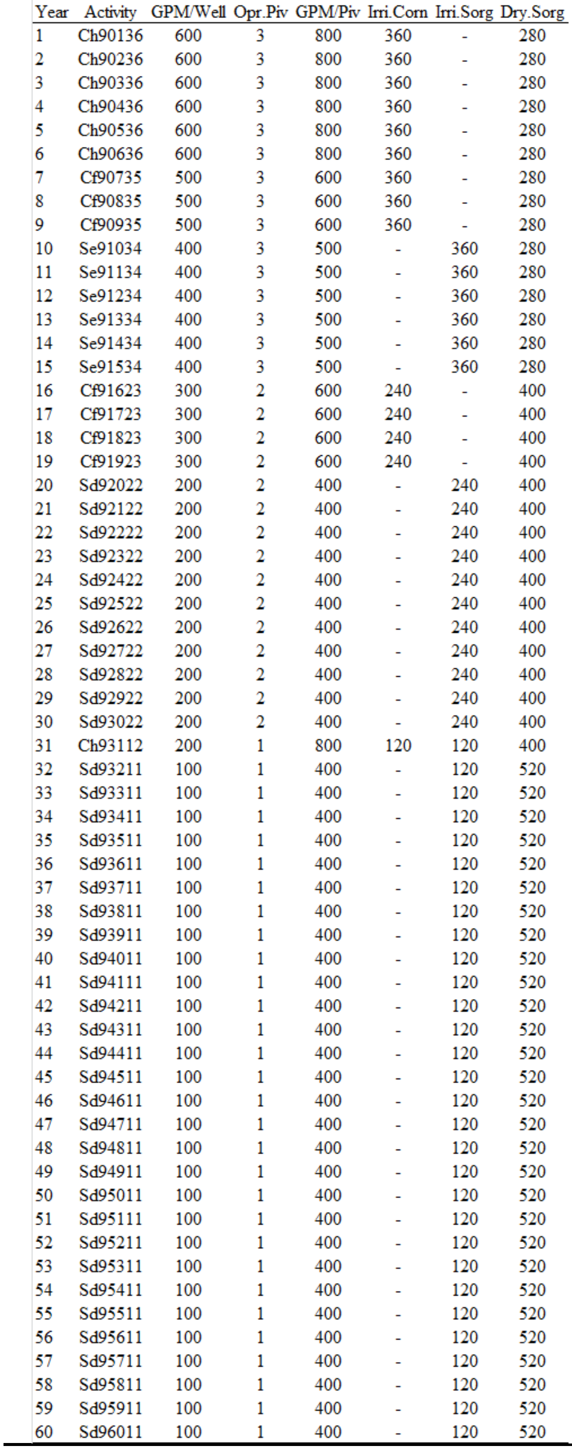
Year	Activity	GPM/Well	Opr.Piv	GPM/Piv	Irri.Corn	Irri.Sorg	Dry.Sorg
1	Ch90148	800	4	800	480	-	160
2	Ch90248	800	4	800	480	-	160
3	Ch90348	800	4	800	480	-	160
4	Ch90448	800	4	800	480	-	160
5	Ch90548	800	4	800	480	-	160
6	Cg90647	700	4	700	480	-	160
7	Cf90746	600	4	600	480	-	160
8	Cf90846	600	4	600	480	-	160
9	Se90945	500	4	500	-	480	160
10	Se91045	500	4	500	-	480	160
11	Se91145	500	4	500	-	480	160
12	Sd91244	400	4	400	-	480	160
13	Sd91344	400	4	400	-	480	160
14	Sc91443	300	4	300	-	480	160
15	Sc91543	300	4	300	-	480	160
16	Ch91613	300	1	800	120	-	520
17	Ch91713	300	1	800	120	-	520
18	Ch91813	300	1	800	120	-	520
19	Ch91913	300	1	800	120	-	520
20	Ch92013	300	1	800	120	-	520
21	Ch92112	200	1	800	120	-	520
22	Ch92212	200	1	800	120	-	520
23	Ch92312	200	1	800	120	-	520
24	Ch92412	200	1	800	120	-	520
25	Ch92512	200	1	800	120	-	520
26	Ch92612	200	1	800	120	-	520
27	Ch92712	200	1	800	120	-	520
28	Ch92812	200	1	800	120	-	520
29	Ch92912	200	1	800	120	-	520
30	Ch93012	200	1	800	120	-	520
31	Ch93112	200	1	800	120	-	520
32	Sd93211	100	1	400	-	120	520
33	Sd93311	100	1	400	-	120	520
34	Sd93411	100	1	400	-	120	520
35	Sd93511	100	1	400	-	120	520
36	Sd93611	100	1	400	-	120	520
37	Sd93711	100	1	400	-	120	520
38	Sd93811	100	1	400	-	120	520
39	Sd93911	100	1	400	-	120	520
40	Sd94011	100	1	400	-	120	520
41	Sd94111	100	1	400	-	120	520
42	Sd94211	100	1	400	-	120	520
43	Sd94311	100	1	400	-	120	520
44	Sd94411	100	1	400	-	120	520
45	Sd94511	100	1	400	-	120	520
46	Sd94611	100	1	400	-	120	520
47	Sd94711	100	1	400	-	120	520
48	Sd94811	100	1	400	-	120	520
49	Sd94911	100	1	400	-	120	520
50	Sd95011	100	1	400	-	120	520
51	Sd95111	100	1	400	-	120	520
52	Sd95211	100	1	400	-	120	520
53	Sd95311	100	1	400	-	120	520
54	Sd95411	100	1	400	-	120	520
55	Sd95511	100	1	400	-	120	520
56	Sd95611	100	1	400	-	120	520
57	Sd95711	100	1	400	-	120	520
58	Sd95811	100	1	400	-	120	520
59	Sd95911	100	1	400	-	120	520
60	Sd96011	100	1	400	-	120	520

Table 36. 60-year Crop Activities which gave Maximum Long Term NPV for Producers with 800 GPM Well Capacities

Year	Activity	GPM/Well	Opr.Piv	GPM/Piv	Irri.Corn	Irri.Sorg	Dry.Sorg
1	Ch90148	800	4	800	480	-	160
2	Ch90248	800	4	800	480	-	160
3	Ch90348	800	4	800	480	-	160
4	Ch90448	800	4	800	480	-	160
5	Ch90548	800	4	800	480	-	160
6	Sg90647	700	4	700	-	480	160
7	Sg90747	700	4	700	-	480	160
8	Sf90846	600	4	600	-	480	160
9	Sf90946	600	4	600	-	480	160
10	Sf91046	600	4	600	-	480	160
11	Se91145	500	4	500	-	480	160
12	Se91245	500	4	500	-	480	160
13	Se91345	500	4	500	-	480	160
14	Se91445	500	4	500	-	480	160
15	Se91545	500	4	500	-	480	160
16	Ch91624	400	2	800	240	-	400
17	Ch91724	400	2	800	240	-	400
18	Ch91824	400	2	800	240	-	400
19	Ch91924	400	2	800	240	-	400
20	Sf92023	300	2	600	-	240	400
21	Sf92123	300	2	600	-	240	400
22	Sf92223	300	2	600	-	240	400
23	Sf92323	300	2	600	-	240	400
24	Sf92423	300	2	600	-	240	400
25	Sf92523	300	2	600	-	240	400
26	Sf92623	300	2	600	-	240	400
27	Sf92723	300	2	600	-	240	400
28	Sd92822	200	2	400	-	240	400
29	Sd92922	200	2	400	-	240	400
30	Sd93022	200	2	400	-	240	400
31	Ch93112	200	1	800	120		520
32	Ch93212	200	1	800	120		520
33	Ch93312	200	1	800	120		520
34	Ch93412	200	1	800	120		520
35	Ch93512	200	1	800	120		520
36	Ch93612	200	1	800	120		520
37	Ch93712	200	1	800	120		520
38	Ch93812	200	1	800	120		520
39	Sd93911	100	1	400		120	520
40	Sd94011	100	1	400		120	520
41	Sd94111	100	1	400		120	520
42	Sd94211	100	1	400		120	520
43	Sd94311	100	1	400		120	520
44	Sd94411	100	1	400		120	520
45	Sd94511	100	1	400		120	520
46	Sd94611	100	1	400		120	520
47	Sd94711	100	1	400		120	520
48	Sd94811	100	1	400		120	520
49	Sd94911	100	1	400		120	520
50	Sd95011	100	1	400		120	520
51	Sd95111	100	1	400		120	520
52	Sd95211	100	1	400		120	520
53	Sd95311	100	1	400		120	520
54	Sd95411	100	1	400		120	520
55	Sd95511	100	1	400		120	520
56	Sd95611	100	1	400		120	520
57	Sd95711	100	1	400		120	520
58	Sd95811	100	1	400		120	520
59	Sd95911	100	1	400		120	520
60	Sd96012	200	1	400		120	520

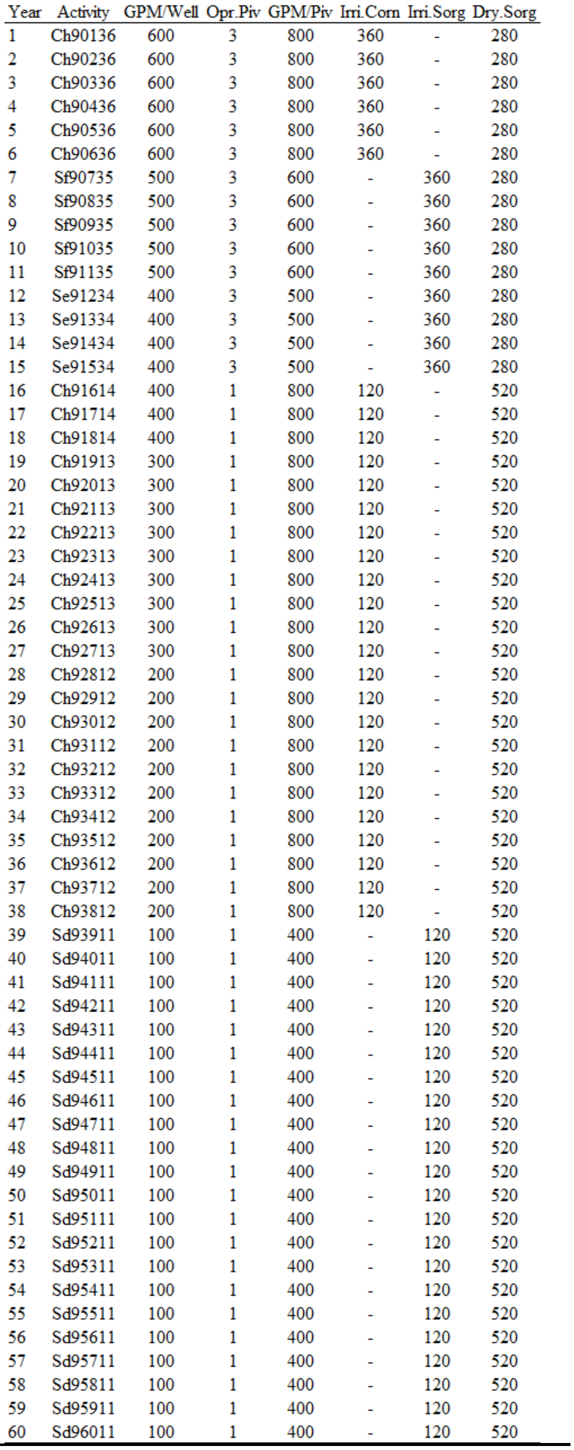
Note: GPM/Well is the well capacity of each well, Opr.Piv is the no of Operating Pivots, GPM/Piv is the total GPM delivered through each pivot head, Irri.Corn is the total irrigated acres, Irri.Sorg is the total irrigated Sorghum and Dry.Sorg is the dryland area. Land are measured in acres and well capacities are measured in Gallons Per Minute.

Table 37. 60-year Crop Activities which gave Maximum Annual Profits for Producers with 600 GPM Well Capacities



Year	Activity	GPM/Well	Opr.Piv	GPM/Piv	Irri.Corn	Irri.Sorg	Dry.Sorg
1	Ch90136	600	3	800	360	-	280
2	Ch90236	600	3	800	360	-	280
3	Ch90336	600	3	800	360	-	280
4	Ch90436	600	3	800	360	-	280
5	Ch90536	600	3	800	360	-	280
6	Ch90636	600	3	800	360	-	280
7	Cf90735	500	3	600	360	-	280
8	Cf90835	500	3	600	360	-	280
9	Cf90935	500	3	600	360	-	280
10	Se91034	400	3	500	-	360	280
11	Se91134	400	3	500	-	360	280
12	Se91234	400	3	500	-	360	280
13	Se91334	400	3	500	-	360	280
14	Se91434	400	3	500	-	360	280
15	Se91534	400	3	500	-	360	280
16	Cf91623	300	2	600	240	-	400
17	Cf91723	300	2	600	240	-	400
18	Cf91823	300	2	600	240	-	400
19	Cf91923	300	2	600	240	-	400
20	Sd92022	200	2	400	-	240	400
21	Sd92122	200	2	400	-	240	400
22	Sd92222	200	2	400	-	240	400
23	Sd92322	200	2	400	-	240	400
24	Sd92422	200	2	400	-	240	400
25	Sd92522	200	2	400	-	240	400
26	Sd92622	200	2	400	-	240	400
27	Sd92722	200	2	400	-	240	400
28	Sd92822	200	2	400	-	240	400
29	Sd92922	200	2	400	-	240	400
30	Sd93022	200	2	400	-	240	400
31	Ch93112	200	1	800	120	120	400
32	Sd93211	100	1	400	-	120	520
33	Sd93311	100	1	400	-	120	520
34	Sd93411	100	1	400	-	120	520
35	Sd93511	100	1	400	-	120	520
36	Sd93611	100	1	400	-	120	520
37	Sd93711	100	1	400	-	120	520
38	Sd93811	100	1	400	-	120	520
39	Sd93911	100	1	400	-	120	520
40	Sd94011	100	1	400	-	120	520
41	Sd94111	100	1	400	-	120	520
42	Sd94211	100	1	400	-	120	520
43	Sd94311	100	1	400	-	120	520
44	Sd94411	100	1	400	-	120	520
45	Sd94511	100	1	400	-	120	520
46	Sd94611	100	1	400	-	120	520
47	Sd94711	100	1	400	-	120	520
48	Sd94811	100	1	400	-	120	520
49	Sd94911	100	1	400	-	120	520
50	Sd95011	100	1	400	-	120	520
51	Sd95111	100	1	400	-	120	520
52	Sd95211	100	1	400	-	120	520
53	Sd95311	100	1	400	-	120	520
54	Sd95411	100	1	400	-	120	520
55	Sd95511	100	1	400	-	120	520
56	Sd95611	100	1	400	-	120	520
57	Sd95711	100	1	400	-	120	520
58	Sd95811	100	1	400	-	120	520
59	Sd95911	100	1	400	-	120	520
60	Sd96011	100	1	400	-	120	520

Table 38. 60-year Crop Activities which gave Maximum Long Term NPV for Producers with 600 GPM Well Capacities



Year	Activity	GPM/Well	Opr.Piv	GPM/Piv	Irri.Corn	Irri.Sorg	Dry.Sorg
1	Ch90136	600	3	800	360	-	280
2	Ch90236	600	3	800	360	-	280
3	Ch90336	600	3	800	360	-	280
4	Ch90436	600	3	800	360	-	280
5	Ch90536	600	3	800	360	-	280
6	Ch90636	600	3	800	360	-	280
7	Sf90735	500	3	600	-	360	280
8	Sf90835	500	3	600	-	360	280
9	Sf90935	500	3	600	-	360	280
10	Sf91035	500	3	600	-	360	280
11	Sf91135	500	3	600	-	360	280
12	Se91234	400	3	500	-	360	280
13	Se91334	400	3	500	-	360	280
14	Se91434	400	3	500	-	360	280
15	Se91534	400	3	500	-	360	280
16	Ch91614	400	1	800	120	-	520
17	Ch91714	400	1	800	120	-	520
18	Ch91814	400	1	800	120	-	520
19	Ch91913	300	1	800	120	-	520
20	Ch92013	300	1	800	120	-	520
21	Ch92113	300	1	800	120	-	520
22	Ch92213	300	1	800	120	-	520
23	Ch92313	300	1	800	120	-	520
24	Ch92413	300	1	800	120	-	520
25	Ch92513	300	1	800	120	-	520
26	Ch92613	300	1	800	120	-	520
27	Ch92713	300	1	800	120	-	520
28	Ch92812	200	1	800	120	-	520
29	Ch92912	200	1	800	120	-	520
30	Ch93012	200	1	800	120	-	520
31	Ch93112	200	1	800	120	-	520
32	Ch93212	200	1	800	120	-	520
33	Ch93312	200	1	800	120	-	520
34	Ch93412	200	1	800	120	-	520
35	Ch93512	200	1	800	120	-	520
36	Ch93612	200	1	800	120	-	520
37	Ch93712	200	1	800	120	-	520
38	Ch93812	200	1	800	120	-	520
39	Sd93911	100	1	400	-	120	520
40	Sd94011	100	1	400	-	120	520
41	Sd94111	100	1	400	-	120	520
42	Sd94211	100	1	400	-	120	520
43	Sd94311	100	1	400	-	120	520
44	Sd94411	100	1	400	-	120	520
45	Sd94511	100	1	400	-	120	520
46	Sd94611	100	1	400	-	120	520
47	Sd94711	100	1	400	-	120	520
48	Sd94811	100	1	400	-	120	520
49	Sd94911	100	1	400	-	120	520
50	Sd95011	100	1	400	-	120	520
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58	Sd95811	100	1	400	-	120	520
59	Sd95911	100	1	400	-	120	520
60	Sd96011	100	1	400	-	120	520

Note: GPM/Well is the well capacity of each well, Opr.Piv is the no of Operating Pivots, GPM/Piv is the total GPM delivered through each pivot head, Irri.Corn is the total irrigated acres, Irri.Sorg is the total irrigated Sorghum and Dry.Sorg is the dryland area. Land are measured in acres and well capacities are measured in Gallons Per Minute.

CHAPTER V

SUMMARY and CONCLUSIONS

The objective of the study was to determine the optimal choice between irrigated corn and grain sorghum in Oklahoma Panhandle as determined the capacity and properties of the aquifer. A representative farm was presented, and water supply was estimated to determine the water constraints as the water table declined. Mathematical models were developed to allocate the resources for short-term and long-term benefits using a dynamic framework.

The study shows that under current prices and technology, grain sorghum returns higher profits per unit of water as the water table declines. Under the single well assumption, static budget analysis shows sorghum begins to generate higher net returns than corn when the well capacity per quarter section pivot declines to 500 GPM or less. However, LTPM producers would switch from corn to grain sorghum before the aquifer declined to the 500 GPM per pivot level. The net returns per acre of corn became negative as the well capacity declined below 200 GPM. The delayed irrigation strategies used in the study did not enter any of the model solutions. With this model, the producer would lose profits when adopting delayed irrigation. However, several other irrigation strategies are possible using agronomic studies, which are not used in this study.

The groundwater modeling shows that some well interference was possible when farms adjacent to a producer are irrigating simultaneously. Therefore, additional groundwater study is needed to determine the effect of well interference. Moreover, only one level of hydraulic conductivity and specific yield was used in the study. Pumping costs are sensitive to alternative hydraulic conductivities and well spacing. Two profit maximization approaches were utilized to determine the cropland allocation for the representative farm.

Annual profit maximization and long-term profit maximization with less saturated sand do not show a large difference in their overall benefits while under taking the project. This impact is because the study assumes only 40 percent of the land was irrigated, and producers can combine wells and irrigate fewer pivots with higher return crops. This is seen in both methods of profit maximization. However, when groundwater is only available beneath the producer's land, long term profit maximization may make much higher long-term profits than annual profit maximizing producers.

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APPENDIX

Table A1. Corn and Sorghum: Market Year Average Prices Received, Oklahoma, 2005-2014

Units Year	($/cwt) Sorghum	($/bu) Sorghum	($/bu) Corn
2005	3.32	1.86	2.39
2006	5.87	3.29	3.17
2007	7.00	3.92	4.07
2008	5.89	3.30	4.46
2009	5.68	3.18	3.71
2010	9.00	5.04	4.66
2011	10.8	6.05	6.22
2012	12.6	7.06	6.95
2013	7.49	4.19	5.09
2014	6.65	3.72	4.10
Mean	7.43	4.16	4.48

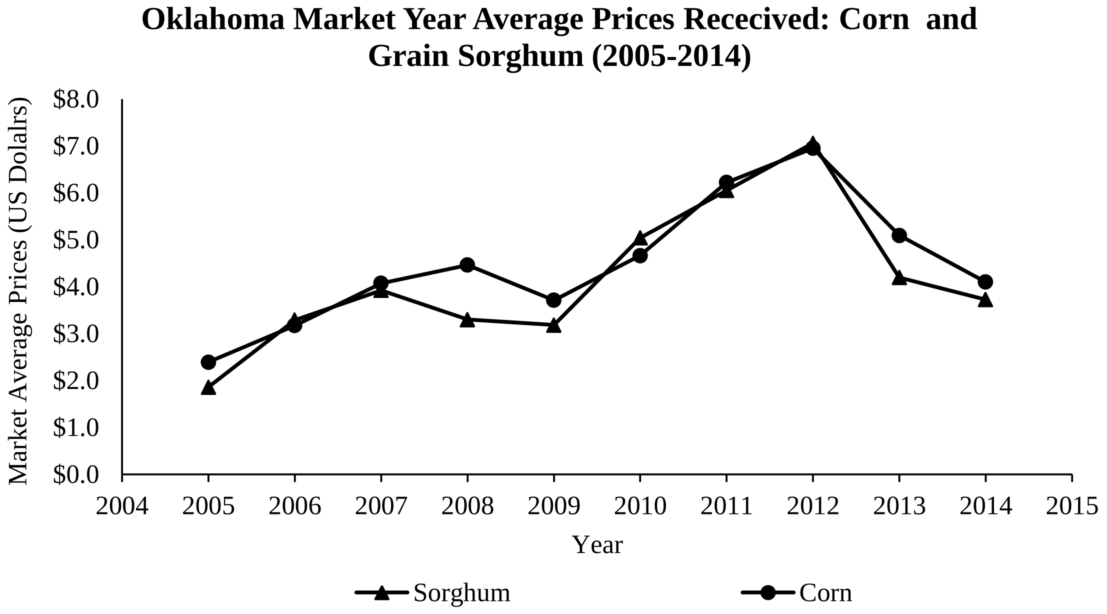


Figure A1. Oklahoma Corn and Grain Sorghum average price trends between 2005 and 2014

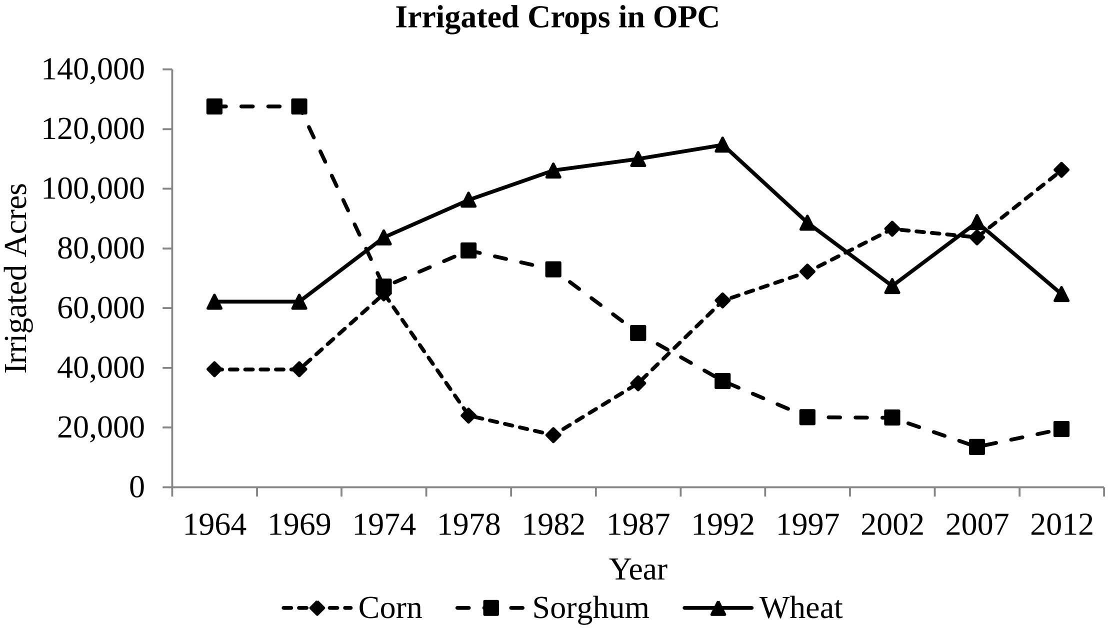


Figure A2. Irrigated crops in Oklahoma Panhandle Counties (OPC) from 1964 and 2012

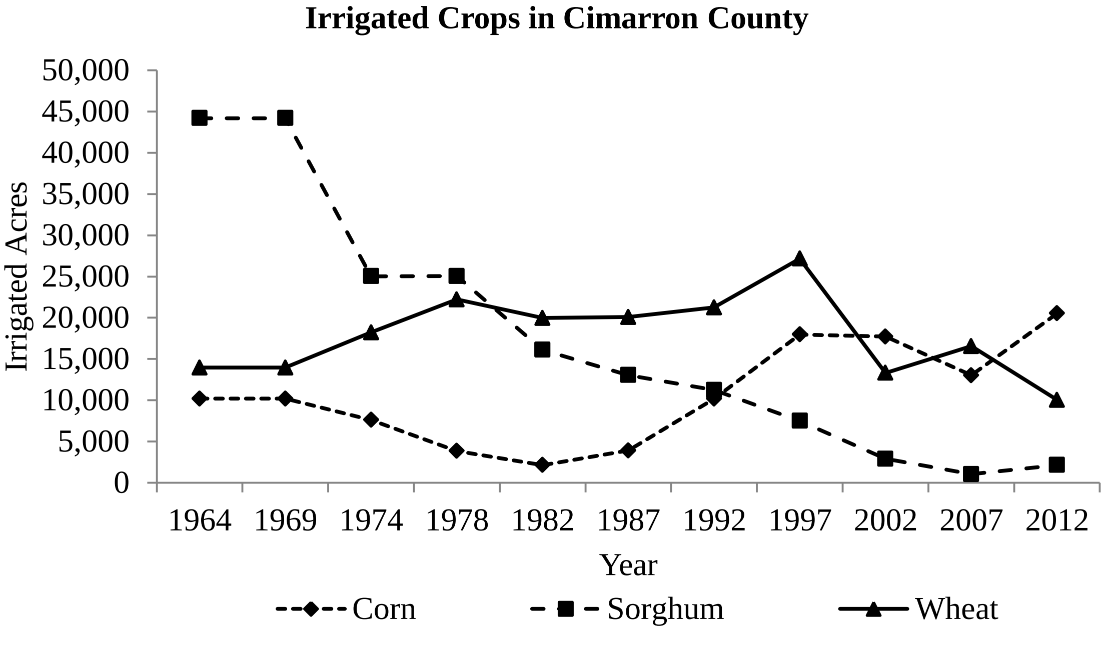


Figure A3. Irrigated crops in Cimarron County, Oklahoma from 1964 and 2012

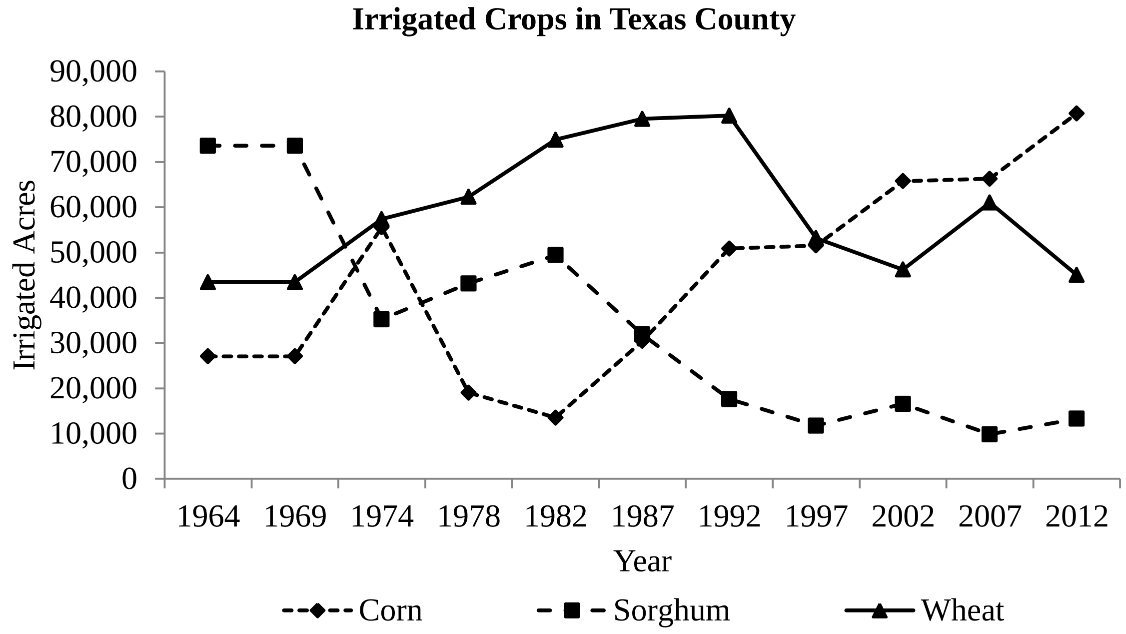


Figure A4. Irrigated crops in Texas County, Oklahoma from 1964 and 2012

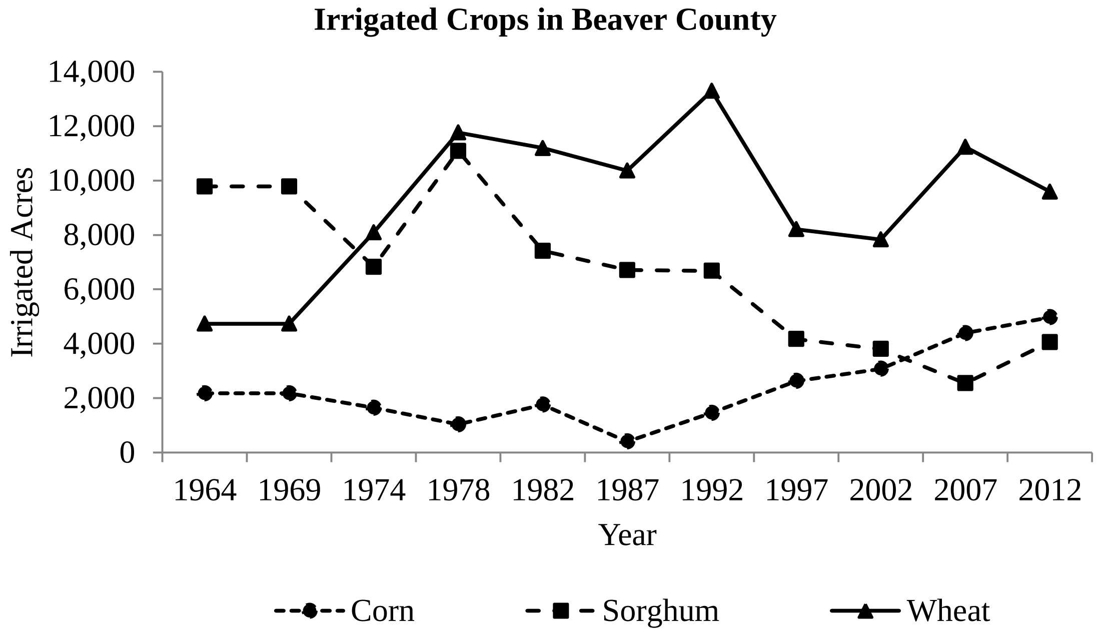


Figure A5. Irrigated crops in Beaver County, Oklahoma from 1964 and 2012

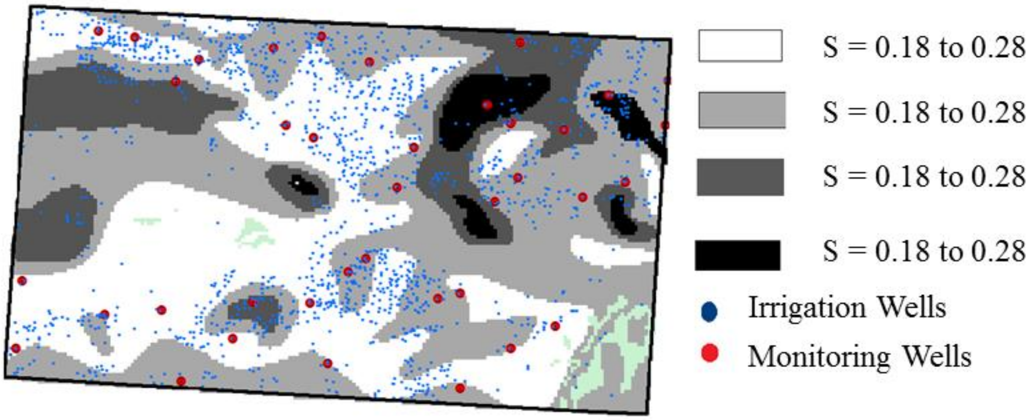


Figure A6. Specific Yield map for Texas County, Oklahoma and locations of irrigation and monitoring wells in 2015

Table A2. Sorghum Relative Yields and Sorghum Obtained from EPIC Crop Data

	0.30	0.40	0.50	0.6	0.70	0.80	0.90	0.30	0.40	0.50	0.6	0.70	0.80	0.90
800	0.75	0.77	0.79	0.85	0.91	0.96	1.00	0.53	0.55	0.59	0.59	0.80	0.91	1.00
700	0.75	0.77	0.79	0.84	0.89	0.93	0.96	0.53	0.54	0.58	0.66	0.76	0.83	0.90
600	0.75	0.77	0.79	0.82	0.86	0.89	0.91	0.53	0.54	0.58	0.64	0.69	0.76	0.81
500	0.74	0.76	0.77	0.80	0.82	0.84	0.87	0.51	0.53	0.56	0.60	0.63	0.69	0.73
400	0.72	0.74	0.75	0.77	0.79	0.81	0.82	0.49	0.51	0.53	0.55	0.60	0.63	0.67
300	0.64	0.66	0.67	0.68	0.69	0.71	0.72	0.42	0.43	0.45	0.47	0.49	0.50	0.53
200	0.54	0.55	0.55	0.55	0.56	0.56	0.56	0.19	0.20	0.21	0.21	0.22	0.23	0.26
100	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.14	0.15	0.15	0.16	0.16	0.17	0.18

Table A3. Corn Relative Yields and Sorghum Obtained from EPIC Crop Data

	Stress Factors													
	Corn Relative Yield							Corn Relative Irrigation						
	0.30	0.40	0.50	0.6	0.70	0.80	0.90	0.30	0.40	0.50	0.6	0.70	0.80	0.90
800	0.75	0.77	0.78	0.85	0.91	0.97	1.00	0.65	0.68	0.72	0.84	0.96	1.00	1.00
700	0.74	0.76	0.77	0.82	0.87	0.91	0.93	0.65	0.68	0.72	0.80	0.91	0.98	1.03
600	0.74	0.75	0.76	0.80	0.83	0.86	0.88	0.65	0.67	0.71	0.77	0.85	0.91	0.96
500	0.72	0.73	0.74	0.76	0.79	0.81	0.82	0.63	0.65	0.68	0.71	0.77	0.83	0.87
400	0.70	0.70	0.71	0.73	0.74	0.76	0.77	0.60	0.62	0.64	0.67	0.71	0.76	0.78
300	0.63	0.63	0.64	0.65	0.65	0.66	0.67	0.49	0.50	0.52	0.55	0.57	0.60	0.62
200	0.55	0.55	0.56	0.56	0.56	0.57	0.57	0.39	0.39	0.40	0.42	0.43	0.45	0.46
100	0.45	0.46	0.46	0.46	0.46	0.46	0.46	0.24	0.25	0.25	0.26	0.26	0.27	0.27

Table A4. Single Well Pumping Cost Estimates per acre foot for Pivot Operating at Various Aquifer Levels with *K* = 25 and *S* = 18

		Aquifer Level							
GPM	Pivots	1	2	3	4	5	6	7	8
800	1	66.6	63.6	61.4	59.7	58.2	56.7	55.4	54.4
800	2	73.3	69.3	66.5	64.5	62.6	60.9	59.4	58.2
800	3	81.1	76.3	72.9	70.4	68.2	66.3	64.6	63.3
800	4	88.3	82.5	78.5	75.7	73.2	71.0	69.2	67.6
700	1	65.9	63.0	60.8	59.2	57.7	56.3	55.1	54.0
700	2	71.4	67.7	65.0	63.1	61.3	59.7	58.3	57.1
700	3	77.6	73.1	69.9	67.7	65.6	63.8	62.2	60.9
700	4	83.7	78.4	74.7	72.1	69.7	67.7	65.9	64.4
600	1	64.9	62.1	60.1	58.5	57.0	55.6	54.5	53.5
600	2	69.6	66.0	63.6	61.7	60.0	58.5	57.0	56.0
600	3	74.6	70.3	67.4	65.3	63.3	61.6	60.0	58.8
600	4	79.9	74.9	71.6	69.2	67.0	65.0	63.4	62.1
500	1	63.9	61.1	59.2	57.7	56.3	54.9	53.6	52.7
500	2	67.7	64.4	62.1	60.4	58.7	57.2	55.9	54.8
500	3	71.6	67.8	65.1	63.0	61.2	59.5	58.1	56.9
500	4	76.1	71.7	68.7	66.5	64.4	62.6	61.1	59.7
400	1	62.8	60.1	58.3	56.9	55.4	54.0	52.9	51.9
400	2	65.9	62.8	60.7	59.0	57.4	56.0	54.7	53.7
400	3	69.0	65.5	63.1	61.2	59.5	57.9	56.5	55.4
400	4	72.6	68.6	65.8	63.8	61.9	60.1	58.7	57.4
300	1	61.9	59.4	57.5	56.1	54.9	53.5	52.4	51.4
300	2	64.1	61.3	59.2	57.7	56.1	54.7	53.6	52.5
300	3	66.4	63.3	61.1	59.4	57.8	56.3	55.0	53.9
300	4	69.1	65.5	63.0	61.3	59.5	57.8	56.6	55.3
200	1	61.0	58.6	56.7	55.6	54.2	52.8	51.8	50.9
200	2	62.4	59.8	57.9	56.5	55.1	53.7	52.5	51.6
200	3	64.0	61.2	59.3	57.7	56.3	54.9	53.5	52.5
200	4	65.6	62.6	60.5	58.8	57.2	55.8	54.6	53.5
100	1	60.0	58.1	56.3	54.9	53.9	52.5	51.1	50.6
100	2	61.0	58.6	56.7	55.3	54.4	53.0	51.6	50.6
100	3	61.9	59.1	57.2	55.8	54.4	53.5	52.0	51.1
100	4	62.8	60.0	58.1	56.7	55.3	53.9	52.5	51.6

[1 HP = 2547 Btu per hour, and 1 mcf = 1,000,000 BTu (1 MMBTU)] and [One cubic foot of natural gas produces approximately 1,000 BTUs. Therefore, 1,000 cu.ft (1 mcf) of gas is comparable to 1 MBTU. MBTU is occasionally expressed as MMBTU, which is intended to represent a thousand thousand BTUs]

Table A5. 63,000 Activities Generated for the Recursive Optimization and MIP Models

Year	Activity	Crop	GPM	Lev	Piv	Yield	PC	NR	ac-in/ac
1	Sa30111	Sorghum	100	1	1	87.5	$11.0	$55.8	2.2
1	Sa40111	Sorghum	100	1	1	87.8	$11.5	$56.1	2.3
1	Sa50111	Sorghum	100	1	1	87.9	$11.8	$56.1	2.4
1	Sa60111	Sorghum	100	1	1	88.1	$12.1	$56.3	2.4
1	Sa70111	Sorghum	100	1	1	88.2	$12.3	$56.4	2.5
1	Sa80111	Sorghum	100	1	1	88.3	$12.9	$55.9	2.6
1	Sa90111	Sorghum	100	1	1	88.5	$13.9	$55.6	2.8
1	Sa30121	Sorghum	100	1	2	87.5	$11.2	$55.6	2.2
1	Sa40121	Sorghum	100	1	2	87.8	$11.7	$55.9	2.3
1	Sa50121	Sorghum	100	1	2	87.9	$12.0	$55.9	2.4
1	Sa60121	Sorghum	100	1	2	88.1	$12.3	$56.1	2.4
1	Sa70121	Sorghum	100	1	2	88.2	$12.5	$56.2	2.5
1	Sa80121	Sorghum	100	1	2	88.3	$13.1	$55.7	2.6
1	Sa90121	Sorghum	100	1	2	88.5	$14.1	$55.4	2.8
1	Sa30131	Sorghum	100	1	3	87.5	$11.4	$55.4	2.2
1	Sa40131	Sorghum	100	1	3	87.8	$11.9	$55.7	2.3
1	Sa50131	Sorghum	100	1	3	87.9	$12.2	$55.7	2.4
1	Sa60131	Sorghum	100	1	3	88.1	$12.5	$55.9	2.4
1	Sa70131	Sorghum	100	1	3	88.2	$12.7	$56.0	2.5
1	Sa80131	Sorghum	100	1	3	88.3	$13.3	$55.5	2.6
1	Sa90131	Sorghum	100	1	3	88.5	$14.3	$55.2	2.8
1	Sa30141	Sorghum	100	1	4	87.5	$11.5	$55.3	2.2
1	Sa40141	Sorghum	100	1	4	87.8	$12.0	$55.5	2.3
1	Sa50141	Sorghum	100	1	4	87.9	$12.4	$55.6	2.4
1	Sa60141	Sorghum	100	1	4	88.1	$12.7	$55.7	2.4
1	Sa70141	Sorghum	100	1	4	88.2	$12.9	$55.8	2.5
1	Sa80141	Sorghum	100	1	4	88.3	$13.5	$55.3	2.6
1	Sa90141	Sorghum	100	1	4	88.5	$14.5	$55.0	2.8
1	Sb30111	Sorghum	200	1	1	88.4	$14.9	$54.4	2.9
1	Sb40111	Sorghum	200	1	1	89.1	$15.7	$55.4	3.1
1	Sb50111	Sorghum	200	1	1	89.6	$16.3	$56.2	3.2
1	Sb60111	Sorghum	200	1	1	90.1	$17.0	$56.8	3.3
1	Sb70111	Sorghum	200	1	1	90.5	$17.4	$57.5	3.4
1	Sb80111	Sorghum	200	1	1	91.1	$18.1	$58.4	3.6
1	Sb90111	Sorghum	200	1	1	92.0	$20.6	$58.4	4.1
1	Sb30121	Sorghum	200	1	2	88.4	$15.2	$54.1	2.9
1	Sb40121	Sorghum	200	1	2	89.1	$16.0	$55.0	3.1
1	Sb50121	Sorghum	200	1	2	89.6	$16.7	$55.8	3.2
1	Sb60121	Sorghum	200	1	2	90.1	$17.4	$56.4	3.3
1	Sb70121	Sorghum	200	1	2	90.5	$17.8	$57.1	3.4
1	Sb80121	Sorghum	200	1	2	91.1	$18.5	$58.0	3.6
1	Sb90121	Sorghum	200	1	2	92.0	$21.1	$57.9	4.1
1	Sc30111	Sorghum	300	1	1	104.8	$33.6	$80.6	6.5

Table A5 (continued)

Year	Activity	Crop	GPM	Lev	Piv	Yield	PC	NR	ac-in/ac
1	Sc40111	Sorghum	300	1	1	107.0	$34.9	$85.2	6.8
1	Sc50111	Sorghum	300	1	1	108.7	$36.6	$88.4	7.1
1	Sc60111	Sorghum	300	1	1	110.4	$37.7	$91.9	7.3
1	Sc70111	Sorghum	300	1	1	112.3	$39.2	$95.7	7.6
1	Sc80111	Sorghum	300	1	1	115.0	$40.3	$101.7	7.8
1	Sc90111	Sorghum	300	1	1	117.2	$42.7	$105.5	8.3
1	Sd30111	Sorghum	400	1	1	116.9	$40.2	$107.0	7.7
1	Sd40111	Sorghum	400	1	1	119.7	$41.9	$113.2	8.0
1	Sd50111	Sorghum	400	1	1	122.4	$43.2	$119.1	8.3
1	Sd60111	Sorghum	400	1	1	124.6	$45.2	$123.3	8.6
1	Sd70111	Sorghum	400	1	1	128.6	$49.0	$130.5	9.4
1	Sd80111	Sorghum	400	1	1	131.4	$51.8	$135.1	9.9
1	Sd90111	Sorghum	400	1	1	133.8	$54.4	$139.1	10.4
1	Sb30112	Sorghum	200	2	1	88.4	$14.3	$55.0	2.9
1	Sb40112	Sorghum	200	2	1	89.1	$15.1	$56.0	3.1
1	Sb50112	Sorghum	200	2	1	89.6	$15.7	$56.8	3.2
1	Sb60112	Sorghum	200	2	1	90.1	$16.3	$57.5	3.3
1	Sb70112	Sorghum	200	2	1	90.5	$16.8	$58.2	3.4
1	Sb80112	Sorghum	200	2	1	91.1	$17.4	$59.1	3.6
1	Sb90112	Sorghum	200	2	1	92.0	$19.8	$59.2	4.1
1	Sb30122	Sorghum	200	2	2	88.4	$14.6	$54.7	2.9
1	Sb40122	Sorghum	200	2	2	89.1	$15.4	$55.7	3.1
1	Sb50122	Sorghum	200	2	2	89.6	$16.0	$56.5	3.2
1	Sb60122	Sorghum	200	2	2	90.1	$16.6	$57.2	3.3
1	Sb70122	Sorghum	200	2	2	90.5	$17.1	$57.9	3.4
1	Sb80122	Sorghum	200	2	2	91.1	$17.7	$58.8	3.6
1	Sb90122	Sorghum	200	2	2	92.0	$20.2	$58.8	4.1
1	Sb30132	Sorghum	200	2	3	88.4	$14.9	$54.3	2.9
1	Sb40132	Sorghum	200	2	3	89.1	$15.7	$55.3	3.1
1	Sb50132	Sorghum	200	2	3	89.6	$16.4	$56.1	3.2
1	Sb60132	Sorghum	200	2	3	90.1	$17.0	$56.8	3.3
1	Sb70132	Sorghum	200	2	3	90.5	$17.5	$57.5	3.4
1	Sb80132	Sorghum	200	2	3	91.1	$18.1	$58.3	3.6
1	Sb90132	Sorghum	200	2	3	92.0	$20.7	$58.3	4.1
1	Sb30142	Sorghum	200	2	4	88.4	$15.3	$54.0	2.9
1	Sb40142	Sorghum	200	2	4	89.1	$16.1	$55.0	3.1
1	Sb50142	Sorghum	200	2	4	89.6	$16.8	$55.7	3.2
1	Sb60142	Sorghum	200	2	4	90.1	$17.4	$56.4	3.3
1	Sb70142	Sorghum	200	2	4	90.5	$17.9	$57.1	3.4
1	Sb80142	Sorghum	200	2	4	91.1	$18.6	$57.9	3.6
1	Sb90142	Sorghum	200	2	4	92.0	$21.2	$57.8	4.1
1	Sc30112	Sorghum	300	2	1	104.8	$32.3	$82.0	6.5
1	Sc40112	Sorghum	300	2	1	107.0	$33.5	$86.6	6.8
1	Sc50112	Sorghum	300	2	1	108.7	$35.1	$89.8	7.1

Table A5 (continued)

Year	Activity	Crop	GPM	Lev	Piv	Yield	PC	NR	ac-in/ac
1	Sc60112	Sorghum	300	2	1	110.4	$36.2	$93.4	7.3
1	Sc70112	Sorghum	300	2	1	112.3	$37.6	$97.2	7.6
1	Sc80112	Sorghum	300	2	1	115.0	$38.7	$103.4	7.8
1	Sc90112	Sorghum	300	2	1	117.2	$41.0	$107.2	8.3
1	Sc30122	Sorghum	300	2	2	104.8	$33.3	$81.0	6.5
1	Sc40122	Sorghum	300	2	2	107.0	$34.6	$85.6	6.8
1	Sc50122	Sorghum	300	2	2	108.7	$36.2	$88.7	7.1
1	Sc60122	Sorghum	300	2	2	110.4	$37.3	$92.3	7.3
1	Sc70122	Sorghum	300	2	2	112.3	$38.8	$96.0	7.6
1	Sc80122	Sorghum	300	2	2	115.0	$39.9	$102.1	7.8
1	Sc90122	Sorghum	300	2	2	117.2	$42.3	$105.9	8.3
1	Sd30112	Sorghum	400	2	1	116.9	$38.5	$108.7	7.7
1	Sd40112	Sorghum	400	2	1	119.7	$40.1	$115.0	8.0
1	Sd50112	Sorghum	400	2	1	122.4	$41.4	$121.0	8.3
1	Sd60112	Sorghum	400	2	1	124.6	$43.2	$125.2	8.6
1	Sd70112	Sorghum	400	2	1	128.6	$46.9	$132.6	9.4
1	Sd80112	Sorghum	400	2	1	131.4	$49.6	$137.3	9.9
1	Sd90112	Sorghum	400	2	1	133.8	$52.1	$141.4	10.4
1	Sd30122	Sorghum	400	2	2	116.9	$40.2	$107.0	7.7
1	Sd40122	Sorghum	400	2	2	119.7	$41.9	$113.2	8.0
1	Sd50122	Sorghum	400	2	2	122.4	$43.2	$119.1	8.3
1	Sd60122	Sorghum	400	2	2	124.6	$45.2	$123.3	8.6
1	Sd70122	Sorghum	400	2	2	128.6	$49.0	$130.5	9.4
1	Sd80122	Sorghum	400	2	2	131.4	$51.8	$135.1	9.9
1	Sd90122	Sorghum	400	2	2	133.8	$54.4	$139.1	10.4
1	Se30112	Sorghum	500	2	1	120.5	$40.8	$116.5	8.0
1	Se40112	Sorghum	500	2	1	123.5	$42.4	$122.9	8.3
1	Se50112	Sorghum	500	2	1	126.0	$44.8	$127.3	8.8
1	Se60112	Sorghum	500	2	1	129.7	$47.5	$134.7	9.3
1	Se70112	Sorghum	500	2	1	134.1	$50.1	$144.4	9.8
1	Se80112	Sorghum	500	2	1	137.5	$55.0	$148.8	10.8
1	Se90112	Sorghum	500	2	1	141.1	$57.8	$155.7	11.3
1	Sf30112	Sorghum	600	2	1	122.3	$42.6	$119.5	8.2
1	Sf40112	Sorghum	600	2	1	125.2	$44.0	$125.9	8.5
1	Sf50112	Sorghum	600	2	1	128.5	$46.8	$132.2	9.0
1	Sf60112	Sorghum	600	2	1	134.0	$51.5	$142.7	10.0
1	Sf70112	Sorghum	600	2	1	139.6	$55.4	$154.1	10.7
1	Sf80112	Sorghum	600	2	1	144.6	$61.5	$161.7	11.9
1	Sf90112	Sorghum	600	2	1	148.4	$65.2	$168.4	12.6
1	Sg30112	Sorghum	700	2	1	122.4	$43.1	$119.3	8.2
1	Sg40112	Sorghum	700	2	1	125.3	$44.6	$125.6	8.5
1	Sg50112	Sorghum	700	2	1	129.1	$47.8	$132.9	9.1
1	Sg60112	Sorghum	700	2	1	137.3	$54.0	$149.3	10.3
1	Sg70112	Sorghum	700	2	1	145.3	$62.0	$163.1	11.8

Table A5 (continued)

Year	Activity	Crop	GPM	Lev	Piv	Yield	PC	NR	ac-in/ac
1	Sg80112	Sorghum	700	2	1	150.9	$68.3	$172.2	13.0
1	Sg90112	Sorghum	700	2	1	155.7	$74.0	$179.6	14.1
1	Sh30112	Sorghum	800	2	1	122.1	$44.0	$117.4	8.3
1	Sh40112	Sorghum	800	2	1	124.9	$45.4	$123.9	8.6
1	Sh50112	Sorghum	800	2	1	129.0	$48.8	$131.5	9.2
1	Sh60112	Sorghum	800	2	1	138.6	$48.8	$165.1	9.2
1	Sh70112	Sorghum	800	2	1	148.7	$66.6	$167.8	12.6
1	Sh80112	Sorghum	800	2	1	156.5	$75.1	$180.6	14.2
1	Sh90112	Sorghum	800	2	1	162.8	$82.8	$190.4	15.6
1	Sc30113	Sorghum	300	3	1	104.8	$31.2	$83.0	6.5
1	Sc40113	Sorghum	300	3	1	107.0	$32.5	$87.7	6.8
1	Sc50113	Sorghum	300	3	1	108.7	$34.0	$91.0	7.1
1	Sc60113	Sorghum	300	3	1	110.4	$35.0	$94.6	7.3
1	Sc70113	Sorghum	300	3	1	112.3	$36.4	$98.4	7.6
1	Sc80113	Sorghum	300	3	1	115.0	$37.4	$104.6	7.8
1	Sc90113	Sorghum	300	3	1	117.2	$39.7	$108.5	8.3
1	Sc30123	Sorghum	300	3	2	104.8	$32.2	$82.1	6.5
1	Sc40123	Sorghum	300	3	2	107.0	$33.4	$86.7	6.8
1	Sc50123	Sorghum	300	3	2	108.7	$35.0	$89.9	7.1
1	Sc60123	Sorghum	300	3	2	110.4	$36.1	$93.5	7.3
1	Sc70123	Sorghum	300	3	2	112.3	$37.5	$97.3	7.6
1	Sc80123	Sorghum	300	3	2	115.0	$38.6	$103.5	7.8
1	Sc90123	Sorghum	300	3	2	117.2	$40.9	$107.3	8.3
1	Sc30133	Sorghum	300	3	3	104.8	$33.2	$81.0	6.5
1	Sc40133	Sorghum	300	3	3	107.0	$34.5	$85.7	6.8
1	Sc50133	Sorghum	300	3	3	108.7	$36.1	$88.8	7.1
1	Sc60133	Sorghum	300	3	3	110.4	$37.2	$92.4	7.3
1	Sc70133	Sorghum	300	3	3	112.3	$38.7	$96.1	7.6
1	Sc80133	Sorghum	300	3	3	115.0	$39.8	$102.2	7.8
1	Sc90133	Sorghum	300	3	3	117.2	$42.2	$106.0	8.3
1	Sc30143	Sorghum	300	3	4	104.8	$34.2	$80.0	6.5
1	Sc40143	Sorghum	300	3	4	107.0	$35.5	$84.6	6.8
1	Sc50143	Sorghum	300	3	4	108.7	$37.2	$87.7	7.1
1	Sc60143	Sorghum	300	3	4	110.4	$38.4	$91.2	7.3
1	Sc70143	Sorghum	300	3	4	112.3	$39.8	$95.0	7.6
1	Sc80143	Sorghum	300	3	4	115.0	$41.0	$101.0	7.8
1	Sc90143	Sorghum	300	3	4	117.2	$43.5	$104.7	8.3
1	Sd30113	Sorghum	400	3	1	116.9	$37.3	$109.9	7.7
1	Sd40113	Sorghum	400	3	1	119.7	$38.8	$116.3	8.0
1	Sd50113	Sorghum	400	3	1	122.4	$40.1	$122.3	8.3
1	Sd60113	Sorghum	400	3	1	124.6	$41.9	$126.5	8.6
1	Sd70113	Sorghum	400	3	1	128.6	$45.4	$134.0	9.4
1	Sd80113	Sorghum	400	3	1	131.4	$48.0	$138.9	9.9
1	Sd90113	Sorghum	400	3	1	133.8	$50.5	$143.1	10.4

Table A5 (continued)

Year	Activity	Crop	GPM	Lev	Piv	Yield	PC	NR	ac-in/ac
1	Sd30123	Sorghum	400	3	2	116.9	$38.9	$108.3	7.7
1	Sd40123	Sorghum	400	3	2	119.7	$40.5	$114.6	8.0
1	Sd50123	Sorghum	400	3	2	122.4	$41.8	$120.6	8.3
1	Sd60123	Sorghum	400	3	2	124.6	$43.7	$124.8	8.6
1	Sd70123	Sorghum	400	3	2	128.6	$47.3	$132.1	9.4
1	Sd80123	Sorghum	400	3	2	131.4	$50.0	$136.8	9.9
1	Sd90123	Sorghum	400	3	2	133.8	$52.6	$140.9	10.4
1	Sd30133	Sorghum	400	3	3	116.9	$40.4	$106.8	7.7
1	Sd40133	Sorghum	400	3	3	119.7	$42.0	$113.0	8.0
1	Sd50133	Sorghum	400	3	3	122.4	$43.4	$119.0	8.3
1	Sd60133	Sorghum	400	3	3	124.6	$45.4	$123.1	8.6
1	Sd70133	Sorghum	400	3	3	128.6	$49.2	$130.3	9.4
1	Sd80133	Sorghum	400	3	3	131.4	$52.0	$134.9	9.9
1	Sd90133	Sorghum	400	3	3	133.8	$54.6	$138.9	10.4
1	Se30113	Sorghum	500	3	1	120.5	$39.4	$117.8	8.0
1	Se40113	Sorghum	500	3	1	123.5	$41.0	$124.3	8.3
1	Se50113	Sorghum	500	3	1	126.0	$43.3	$128.8	8.8
1	Se60113	Sorghum	500	3	1	129.7	$46.0	$136.3	9.3
1	Se70113	Sorghum	500	3	1	134.1	$48.5	$146.1	9.8
1	Se80113	Sorghum	500	3	1	137.5	$53.3	$150.5	10.8
1	Se90113	Sorghum	500	3	1	141.1	$55.9	$157.6	11.3
1	Se30123	Sorghum	500	3	2	120.5	$41.4	$115.9	8.0
1	Se40123	Sorghum	500	3	2	123.5	$43.0	$122.3	8.3
1	Se50123	Sorghum	500	3	2	126.0	$45.5	$126.6	8.8
1	Se60123	Sorghum	500	3	2	129.7	$48.2	$134.0	9.3
1	Se70123	Sorghum	500	3	2	134.1	$50.8	$143.7	9.8
1	Se80123	Sorghum	500	3	2	137.5	$55.9	$147.9	10.8
1	Se90123	Sorghum	500	3	2	141.1	$58.7	$154.9	11.3
1	Sf30113	Sorghum	600	3	1	122.3	$41.2	$120.9	8.2
1	Sf40113	Sorghum	600	3	1	125.2	$42.6	$127.3	8.5
1	Sf50113	Sorghum	600	3	1	128.5	$45.3	$133.8	9.0
1	Sf60113	Sorghum	600	3	1	134.0	$49.8	$144.4	10.0
1	Sf70113	Sorghum	600	3	1	139.6	$53.6	$155.9	10.7
1	Sf80113	Sorghum	600	3	1	144.6	$59.5	$163.7	11.9
1	Sf90113	Sorghum	600	3	1	148.4	$63.1	$170.5	12.6
1	Sf30123	Sorghum	600	3	2	122.3	$43.6	$118.5	8.2
1	Sf40123	Sorghum	600	3	2	125.2	$45.1	$124.8	8.5
1	Sf50123	Sorghum	600	3	2	128.5	$47.9	$131.1	9.0
1	Sf60123	Sorghum	600	3	2	134.0	$52.8	$141.5	10.0
1	Sf70123	Sorghum	600	3	2	139.6	$56.8	$152.8	10.7
1	Sf80123	Sorghum	600	3	2	144.6	$62.9	$160.2	11.9
1	Sf90123	Sorghum	600	3	2	148.4	$66.8	$166.8	12.6
1	Sg30113	Sorghum	700	3	1	122.4	$41.7	$120.7	8.2
1	Sg40113	Sorghum	700	3	1	125.3	$43.1	$127.2	8.5

Table A5 (continued)

Year	Activity	Crop	GPM	Lev	Piv	Yield	PC	NR	ac-in/ac
1	Sg50113	Sorghum	700	3	1	129.1	$46.1	$134.5	9.1
1	Sg60113	Sorghum	700	3	1	137.3	$52.2	$151.1	10.3
1	Sg70113	Sorghum	700	3	1	145.3	$59.9	$165.2	11.8
1	Sg80113	Sorghum	700	3	1	150.9	$66.0	$174.5	13.0
1	Sg90113	Sorghum	700	3	1	155.7	$71.5	$182.1	14.1
1	Sh30113	Sorghum	800	3	1	122.1	$42.5	$119.0	8.3
1	Sh40113	Sorghum	800	3	1	124.9	$43.8	$125.5	8.6
1	Sh50113	Sorghum	800	3	1	129.0	$47.1	$133.2	9.2
1	Sh60113	Sorghum	800	3	1	138.6	$47.1	$166.8	9.2
1	Sh70113	Sorghum	800	3	1	148.7	$64.2	$170.2	12.6
1	Sh80113	Sorghum	800	3	1	156.5	$72.5	$183.3	14.2
1	Sh90113	Sorghum	800	3	1	162.8	$79.9	$193.3	15.6
1	Sd30114	Sorghum	400	4	1	116.9	$36.4	$110.8	7.7
1	Sd40114	Sorghum	400	4	1	119.7	$37.9	$117.2	8.0
1	Sd50114	Sorghum	400	4	1	122.4	$39.1	$123.2	8.3
1	Sd60114	Sorghum	400	4	1	124.6	$40.9	$127.6	8.6
1	Sd70114	Sorghum	400	4	1	128.6	$44.3	$135.1	9.4
1	Sd80114	Sorghum	400	4	1	131.4	$46.9	$140.0	9.9
1	Sd90114	Sorghum	400	4	1	133.8	$49.2	$144.3	10.4
1	Sd30124	Sorghum	400	4	2	116.9	$37.8	$109.5	7.7
1	Sd40124	Sorghum	400	4	2	119.7	$39.3	$115.8	8.0
1	Sd50124	Sorghum	400	4	2	122.4	$40.5	$121.8	8.3
1	Sd60124	Sorghum	400	4	2	124.6	$42.4	$126.0	8.6
1	Sd70124	Sorghum	400	4	2	128.6	$46.0	$133.5	9.4
1	Sd80124	Sorghum	400	4	2	131.4	$48.6	$138.3	9.9
1	Sd90124	Sorghum	400	4	2	133.8	$51.1	$142.5	10.4
1	Sd30134	Sorghum	400	4	3	116.9	$39.2	$108.0	7.7
1	Sd40134	Sorghum	400	4	3	119.7	$40.8	$114.3	8.0
1	Sd50134	Sorghum	400	4	3	122.4	$42.1	$120.3	8.3
1	Sd60134	Sorghum	400	4	3	124.6	$44.0	$124.4	8.6
1	Sd70134	Sorghum	400	4	3	128.6	$47.7	$131.8	9.4
1	Sd80134	Sorghum	400	4	3	131.4	$50.4	$136.5	9.9
1	Sd90134	Sorghum	400	4	3	133.8	$53.0	$140.5	10.4
1	Sd30144	Sorghum	400	4	4	116.9	$40.8	$106.4	7.7
1	Sd40144	Sorghum	400	4	4	119.7	$42.5	$112.6	8.0
1	Sd50144	Sorghum	400	4	4	122.4	$43.9	$118.5	8.3
1	Sd60144	Sorghum	400	4	4	124.6	$45.9	$122.6	8.6
1	Sd70144	Sorghum	400	4	4	128.6	$49.7	$129.8	9.4
1	Sd80144	Sorghum	400	4	4	131.4	$52.6	$134.3	9.9
1	Sd90144	Sorghum	400	4	4	133.8	$55.2	$138.3	10.4
1	Se30114	Sorghum	500	4	1	120.5	$38.4	$118.8	8.0
1	Se40114	Sorghum	500	4	1	123.5	$40.0	$125.3	8.3
1	Se50114	Sorghum	500	4	1	126.0	$42.2	$129.9	8.8
1	Se60114	Sorghum	500	4	1	129.7	$44.8	$137.4	9.3

Table A5 (continued)

Year	Activity	Crop	GPM	Lev	Piv	Yield	PC	NR	ac-in/ac
1	Se70114	Sorghum	500	4	1	134.1	$47.2	$147.3	9.8
1	Se80114	Sorghum	500	4	1	137.5	$51.9	$151.9	10.8
1	Se90114	Sorghum	500	4	1	141.1	$54.5	$159.0	11.3
1	Se30124	Sorghum	500	4	2	120.5	$40.3	$117.0	8.0
1	Se40124	Sorghum	500	4	2	123.5	$41.8	$123.4	8.3
1	Se50124	Sorghum	500	4	2	126.0	$44.2	$127.9	8.8
1	Se60124	Sorghum	500	4	2	129.7	$46.9	$135.3	9.3
1	Se70124	Sorghum	500	4	2	134.1	$49.5	$145.1	9.8
1	Se80124	Sorghum	500	4	2	137.5	$54.4	$149.4	10.8
1	Se90124	Sorghum	500	4	2	141.1	$57.1	$156.5	11.3
1	Se30134	Sorghum	500	4	3	120.5	$42.0	$115.2	8.0
1	Se40134	Sorghum	500	4	3	123.5	$43.7	$121.6	8.3
1	Se50134	Sorghum	500	4	3	126.0	$46.1	$125.9	8.8
1	Se60134	Sorghum	500	4	3	129.7	$49.0	$133.3	9.3
1	Se70134	Sorghum	500	4	3	134.1	$51.6	$142.9	9.8
1	Se80134	Sorghum	500	4	3	137.5	$56.7	$147.1	10.8
1	Se90134	Sorghum	500	4	3	141.1	$59.5	$154.0	11.3
1	Sf30114	Sorghum	600	4	1	122.3	$40.1	$122.0	8.2
1	Sf40114	Sorghum	600	4	1	125.2	$41.5	$128.4	8.5
1	Sf50114	Sorghum	600	4	1	128.5	$44.1	$134.9	9.0
1	Sf60114	Sorghum	600	4	1	134.0	$48.5	$145.7	10.0
1	Sf70114	Sorghum	600	4	1	139.6	$52.2	$157.3	10.7
1	Sf80114	Sorghum	600	4	1	144.6	$57.9	$165.2	11.9
1	Sf90114	Sorghum	600	4	1	148.4	$61.5	$172.1	12.6
1	Sf30124	Sorghum	600	4	2	122.3	$42.3	$119.8	8.2
1	Sf40124	Sorghum	600	4	2	125.2	$43.8	$126.2	8.5
1	Sf50124	Sorghum	600	4	2	128.5	$46.5	$132.5	9.0
1	Sf60124	Sorghum	600	4	2	134.0	$51.2	$143.1	10.0
1	Sf70124	Sorghum	600	4	2	139.6	$55.1	$154.5	10.7
1	Sf80124	Sorghum	600	4	2	144.6	$61.1	$162.1	11.9
1	Sf90124	Sorghum	600	4	2	148.4	$64.8	$168.8	12.6
1	Sg30114	Sorghum	700	4	1	122.4	$40.6	$121.8	8.2
1	Sg40114	Sorghum	700	4	1	125.3	$42.0	$128.3	8.5
1	Sg50114	Sorghum	700	4	1	129.1	$44.9	$135.7	9.1
1	Sg60114	Sorghum	700	4	1	137.3	$50.8	$152.5	10.3
1	Sg70114	Sorghum	700	4	1	145.3	$58.3	$166.8	11.8
1	Sg80114	Sorghum	700	4	1	150.9	$64.2	$176.3	13.0
1	Sg90114	Sorghum	700	4	1	155.7	$69.6	$184.0	14.1
1	Sg30124	Sorghum	700	4	2	122.4	$43.2	$119.2	8.2
1	Sg40124	Sorghum	700	4	2	125.3	$44.7	$125.5	8.5
1	Sg50124	Sorghum	700	4	2	129.1	$47.9	$132.8	9.1
1	Sg60124	Sorghum	700	4	2	137.3	$54.2	$149.1	10.3
1	Sg70124	Sorghum	700	4	2	145.3	$62.2	$163.0	11.8
1	Sg80124	Sorghum	700	4	2	150.9	$68.4	$172.1	13.0

Table A5 (continued)

Year	Activity	Crop	GPM	Lev	Piv	Yield	PC	NR	ac-in/ac
1	Sg90124	Sorghum	700	4	2	155.7	$74.2	$179.4	14.1
1	Sh30114	Sorghum	800	4	1	122.1	$41.4	$120.1	8.3
1	Sh40114	Sorghum	800	4	1	124.9	$42.6	$126.7	8.6
1	Sh50114	Sorghum	800	4	1	129.0	$45.9	$134.5	9.2
1	Sh60114	Sorghum	800	4	1	138.6	$45.9	$168.1	9.2
1	Sh70114	Sorghum	800	4	1	148.7	$62.5	$171.9	12.6
1	Sh80114	Sorghum	800	4	1	156.5	$70.5	$185.2	14.2
1	Sh90114	Sorghum	800	4	1	162.8	$77.8	$195.4	15.6
1	Sh30124	Sorghum	800	4	2	122.1	$44.7	$116.8	8.3
1	Sh40124	Sorghum	800	4	2	124.9	$46.0	$123.3	8.6
1	Sh50124	Sorghum	800	4	2	129.0	$49.5	$130.8	9.2
1	Sh60124	Sorghum	800	4	2	138.6	$49.5	$164.4	9.2
1	Sh70124	Sorghum	800	4	2	148.7	$67.5	$166.9	12.6
1	Sh80124	Sorghum	800	4	2	156.5	$76.1	$179.6	14.2
1	Sh90124	Sorghum	800	4	2	162.8	$83.9	$189.2	15.6
1	Se30115	Sorghum	500	5	1	120.5	$37.5	$119.7	8.0
1	Se40115	Sorghum	500	5	1	123.5	$39.0	$126.3	8.3
1	Se50115	Sorghum	500	5	1	126.0	$41.2	$130.9	8.8
1	Se60115	Sorghum	500	5	1	129.7	$43.7	$138.5	9.3
1	Se70115	Sorghum	500	5	1	134.1	$46.1	$148.4	9.8
1	Se80115	Sorghum	500	5	1	137.5	$50.7	$153.1	10.8
1	Se90115	Sorghum	500	5	1	141.1	$53.2	$160.4	11.3
1	Se30125	Sorghum	500	5	2	120.5	$39.1	$118.1	8.0
1	Se40125	Sorghum	500	5	2	123.5	$40.7	$124.6	8.3
1	Se50125	Sorghum	500	5	2	126.0	$43.0	$129.1	8.8
1	Se60125	Sorghum	500	5	2	129.7	$45.6	$136.6	9.3
1	Se70125	Sorghum	500	5	2	134.1	$48.1	$146.4	9.8
1	Se80125	Sorghum	500	5	2	137.5	$52.9	$151.0	10.8
1	Se90125	Sorghum	500	5	2	141.1	$55.5	$158.1	11.3
1	Se30135	Sorghum	500	5	3	120.5	$40.8	$116.4	8.0
1	Se40135	Sorghum	500	5	3	123.5	$42.4	$122.8	8.3
1	Se50135	Sorghum	500	5	3	126.0	$44.8	$127.3	8.8
1	Se60135	Sorghum	500	5	3	129.7	$47.6	$134.7	9.3
1	Se70135	Sorghum	500	5	3	134.1	$50.1	$144.4	9.8
1	Se80135	Sorghum	500	5	3	137.5	$55.1	$148.7	10.8
1	Se90135	Sorghum	500	5	3	141.1	$57.9	$155.7	11.3
1	Se30145	Sorghum	500	5	4	120.5	$43.0	$114.3	8.0
1	Se40145	Sorghum	500	5	4	123.5	$44.6	$120.6	8.3
1	Se50145	Sorghum	500	5	4	126.0	$47.2	$124.9	8.8
1	Se60145	Sorghum	500	5	4	129.7	$50.1	$132.2	9.3
1	Se70145	Sorghum	500	5	4	134.1	$52.8	$141.8	9.8
1	Se80145	Sorghum	500	5	4	137.5	$58.0	$145.8	10.8
1	Se90145	Sorghum	500	5	4	141.1	$60.9	$152.6	11.3
1	Sf30115	Sorghum	600	5	1	122.3	$39.1	$123.0	8.2

Table A5 (continued)

Year	Activity	Crop	GPM	Lev	Piv	Yield	PC	NR	ac-in/ac
1	Sf40115	Sorghum	600	5	1	125.2	$40.4	$129.5	8.5
1	Sf50115	Sorghum	600	5	1	128.5	$43.0	$136.1	9.0
1	Sf60115	Sorghum	600	5	1	134.0	$47.3	$146.9	10.0
1	Sf70115	Sorghum	600	5	1	139.6	$50.9	$158.7	10.7
1	Sf80115	Sorghum	600	5	1	144.6	$56.4	$166.7	11.9
1	Sf90115	Sorghum	600	5	1	148.4	$59.9	$173.7	12.6
1	Sf30125	Sorghum	600	5	2	122.3	$41.1	$121.0	8.2
1	Sf40125	Sorghum	600	5	2	125.2	$42.5	$127.4	8.5
1	Sf50125	Sorghum	600	5	2	128.5	$45.2	$133.8	9.0
1	Sf60125	Sorghum	600	5	2	134.0	$49.8	$144.5	10.0
1	Sf70125	Sorghum	600	5	2	139.6	$53.6	$156.0	10.7
1	Sf80125	Sorghum	600	5	2	144.6	$59.4	$163.8	11.9
1	Sf90125	Sorghum	600	5	2	148.4	$63.0	$170.6	12.6
1	Sf30135	Sorghum	600	5	3	122.3	$43.4	$118.7	8.2
1	Sf40135	Sorghum	600	5	3	125.2	$44.9	$125.0	8.5
1	Sf50135	Sorghum	600	5	3	128.5	$47.7	$131.3	9.0
1	Sf60135	Sorghum	600	5	3	134.0	$52.5	$141.8	10.0
1	Sf70135	Sorghum	600	5	3	139.6	$56.5	$153.1	10.7
1	Sf80135	Sorghum	600	5	3	144.6	$62.6	$160.5	11.9
1	Sf90135	Sorghum	600	5	3	148.4	$66.5	$167.1	12.6
1	Sg30115	Sorghum	700	5	1	122.4	$39.6	$122.8	8.2
1	Sg40115	Sorghum	700	5	1	125.3	$40.9	$129.3	8.5
1	Sg50115	Sorghum	700	5	1	129.1	$43.8	$136.8	9.1
1	Sg60115	Sorghum	700	5	1	137.3	$49.6	$153.7	10.3
1	Sg70115	Sorghum	700	5	1	145.3	$56.9	$168.2	11.8
1	Sg80115	Sorghum	700	5	1	150.9	$62.6	$177.9	13.0
1	Sg90115	Sorghum	700	5	1	155.7	$67.9	$185.7	14.1
1	Sg30125	Sorghum	700	5	2	122.4	$42.0	$120.4	8.2
1	Sg40125	Sorghum	700	5	2	125.3	$43.4	$126.8	8.5
1	Sg50125	Sorghum	700	5	2	129.1	$46.5	$134.1	9.1
1	Sg60125	Sorghum	700	5	2	137.3	$52.6	$150.7	10.3
1	Sg70125	Sorghum	700	5	2	145.3	$60.4	$164.7	11.8
1	Sg80125	Sorghum	700	5	2	150.9	$66.5	$174.0	13.0
1	Sg90125	Sorghum	700	5	2	155.7	$72.1	$181.6	14.1
1	Sh30115	Sorghum	800	5	1	122.1	$40.3	$121.2	8.3
1	Sh40115	Sorghum	800	5	1	124.9	$41.6	$127.7	8.6
1	Sh50115	Sorghum	800	5	1	129.0	$44.7	$135.6	9.2
1	Sh60115	Sorghum	800	5	1	138.6	$44.7	$169.3	9.2
1	Sh70115	Sorghum	800	5	1	148.7	$60.9	$173.5	12.6
1	Sh80115	Sorghum	800	5	1	156.5	$68.7	$187.0	14.2
1	Sh90115	Sorghum	800	5	1	162.8	$75.8	$197.4	15.6
1	Sh30125	Sorghum	800	5	2	122.1	$43.4	$118.1	8.3
1	Sh40125	Sorghum	800	5	2	124.9	$44.7	$124.6	8.6
1	Sh50125	Sorghum	800	5	2	129.0	$48.1	$132.3	9.2

Table A5 (continued)

Year	Activity	Crop	GPM	Lev	Piv	Yield	PC	NR	ac-in/ac
1	Sh60125	Sorghum	800	5	2	138.6	$48.1	$165.9	9.2
1	Sh70125	Sorghum	800	5	2	148.7	$65.5	$168.9	12.6
1	Sh80125	Sorghum	800	5	2	156.5	$73.9	$181.8	14.2
1	Sh90125	Sorghum	800	5	2	162.8	$81.5	$191.7	15.6
1	Sf30116	Sorghum	600	6	1	122.3	$38.1	$124.0	8.2
1	Sf40116	Sorghum	600	6	1	125.2	$39.4	$130.5	8.5
1	Sf50116	Sorghum	600	6	1	128.5	$41.9	$137.1	9.0
1	Sf60116	Sorghum	600	6	1	134.0	$46.1	$148.1	10.0
1	Sf70116	Sorghum	600	6	1	139.6	$49.7	$159.9	10.7
1	Sf80116	Sorghum	600	6	1	144.6	$55.1	$168.1	11.9
1	Sf90116	Sorghum	600	6	1	148.4	$58.4	$175.2	12.6
1	Sf30126	Sorghum	600	6	2	122.3	$40.0	$122.0	8.2
1	Sf40126	Sorghum	600	6	2	125.2	$41.4	$128.5	8.5
1	Sf50126	Sorghum	600	6	2	128.5	$44.0	$135.0	9.0
1	Sf60126	Sorghum	600	6	2	134.0	$48.5	$145.8	10.0
1	Sf70126	Sorghum	600	6	2	139.6	$52.2	$157.4	10.7
1	Sf80126	Sorghum	600	6	2	144.6	$57.8	$165.3	11.9
1	Sf90126	Sorghum	600	6	2	148.4	$61.4	$172.2	12.6
1	Sf30136	Sorghum	600	6	3	122.3	$42.2	$119.9	8.2
1	Sf40136	Sorghum	600	6	3	125.2	$43.6	$126.3	8.5
1	Sf50136	Sorghum	600	6	3	128.5	$46.4	$132.6	9.0
1	Sf60136	Sorghum	600	6	3	134.0	$51.1	$143.2	10.0
1	Sf70136	Sorghum	600	6	3	139.6	$55.0	$154.6	10.7
1	Sf80136	Sorghum	600	6	3	144.6	$60.9	$162.2	11.9
1	Sf90136	Sorghum	600	6	3	148.4	$64.7	$168.9	12.6
1	Sf30146	Sorghum	600	6	4	122.3	$44.5	$117.5	8.2
1	Sf40146	Sorghum	600	6	4	125.2	$46.1	$123.8	8.5
1	Sf50146	Sorghum	600	6	4	128.5	$49.0	$130.1	9.0
1	Sf60146	Sorghum	600	6	4	134.0	$53.9	$140.3	10.0
1	Sf70146	Sorghum	600	6	4	139.6	$58.0	$151.6	10.7
1	Sf80146	Sorghum	600	6	4	144.6	$64.3	$158.8	11.9
1	Sf90146	Sorghum	600	6	4	148.4	$68.3	$165.3	12.6
1	Sg30116	Sorghum	700	6	1	122.4	$38.5	$123.9	8.2
1	Sg40116	Sorghum	700	6	1	125.3	$39.9	$130.4	8.5
1	Sg50116	Sorghum	700	6	1	129.1	$42.7	$137.9	9.1
1	Sg60116	Sorghum	700	6	1	137.3	$48.3	$155.0	10.3
1	Sg70116	Sorghum	700	6	1	145.3	$55.4	$169.7	11.8
1	Sg80116	Sorghum	700	6	1	150.9	$61.0	$179.5	13.0
1	Sg90116	Sorghum	700	6	1	155.7	$66.2	$187.5	14.1
1	Sg30126	Sorghum	700	6	2	122.4	$40.9	$121.5	8.2
1	Sg40126	Sorghum	700	6	2	125.3	$42.3	$128.0	8.5
1	Sg50126	Sorghum	700	6	2	129.1	$45.3	$135.3	9.1
1	Sg60126	Sorghum	700	6	2	137.3	$51.2	$152.1	10.3
1	Sg70126	Sorghum	700	6	2	145.3	$58.8	$166.3	11.8

Table A5 (continued)

Year	Activity	Crop	GPM	Lev	Piv	Yield	PC	NR	ac-in/ac
1	Sg80126	Sorghum	700	6	2	150.9	$64.7	$175.8	13.0
1	Sg90126	Sorghum	700	6	2	155.7	$70.2	$183.4	14.1
1	Sg30136	Sorghum	700	6	3	122.4	$43.7	$118.7	8.2
1	Sg40136	Sorghum	700	6	3	125.3	$45.2	$125.1	8.5
1	Sg50136	Sorghum	700	6	3	129.1	$48.4	$132.2	9.1
1	Sg60136	Sorghum	700	6	3	137.3	$54.7	$148.6	10.3
1	Sg70136	Sorghum	700	6	3	145.3	$62.8	$162.3	11.8
1	Sg80136	Sorghum	700	6	3	150.9	$69.2	$171.3	13.0
1	Sg90136	Sorghum	700	6	3	155.7	$75.0	$178.6	14.1
1	Sh30116	Sorghum	800	6	1	122.1	$39.3	$122.2	8.3
1	Sh40116	Sorghum	800	6	1	124.9	$40.5	$128.8	8.6
1	Sh50116	Sorghum	800	6	1	129.0	$43.5	$136.8	9.2
1	Sh60116	Sorghum	800	6	1	138.6	$43.5	$170.4	9.2
1	Sh70116	Sorghum	800	6	1	148.7	$59.3	$175.1	12.6
1	Sh80116	Sorghum	800	6	1	156.5	$66.9	$188.8	14.2
1	Sh90116	Sorghum	800	6	1	162.8	$73.8	$199.4	15.6
1	Sh30126	Sorghum	800	6	2	122.1	$42.2	$119.3	8.3
1	Sh40126	Sorghum	800	6	2	124.9	$43.5	$125.8	8.6
1	Sh50126	Sorghum	800	6	2	129.0	$46.8	$133.6	9.2
1	Sh60126	Sorghum	800	6	2	138.6	$46.8	$167.2	9.2
1	Sh70126	Sorghum	800	6	2	148.7	$63.8	$170.6	12.6
1	Sh80126	Sorghum	800	6	2	156.5	$71.9	$183.8	14.2
1	Sh90126	Sorghum	800	6	2	162.8	$79.3	$193.9	15.6
1	Sh30136	Sorghum	800	6	3	122.1	$45.9	$115.6	8.3
1	Sh40136	Sorghum	800	6	3	124.9	$47.3	$122.0	8.6
1	Sh50136	Sorghum	800	6	3	129.0	$50.9	$129.4	9.2
1	Sh60136	Sorghum	800	6	3	138.6	$50.9	$163.0	9.2
1	Sh70136	Sorghum	800	6	3	148.7	$69.4	$165.0	12.6
1	Sh80136	Sorghum	800	6	3	156.5	$78.3	$177.5	14.2
1	Sh90136	Sorghum	800	6	3	162.8	$86.3	$186.9	15.6
1	Sg30117	Sorghum	700	7	1	122.4	$37.7	$124.7	8.2
1	Sg40117	Sorghum	700	7	1	125.3	$39.0	$131.2	8.5
1	Sg50117	Sorghum	700	7	1	129.1	$41.8	$138.9	9.1
1	Sg60117	Sorghum	700	7	1	137.3	$47.3	$156.0	10.3
1	Sg70117	Sorghum	700	7	1	145.3	$54.2	$170.9	11.8
1	Sg80117	Sorghum	700	7	1	150.9	$59.7	$180.8	13.0
1	Sg90117	Sorghum	700	7	1	155.7	$64.7	$188.9	14.1
1	Sg30127	Sorghum	700	7	2	122.4	$39.9	$122.5	8.2
1	Sg40127	Sorghum	700	7	2	125.3	$41.3	$129.0	8.5
1	Sg50127	Sorghum	700	7	2	129.1	$44.2	$136.4	9.1
1	Sg60127	Sorghum	700	7	2	137.3	$50.0	$153.3	10.3
1	Sg70127	Sorghum	700	7	2	145.3	$57.4	$167.7	11.8
1	Sg80127	Sorghum	700	7	2	150.9	$63.2	$177.3	13.0
1	Sg90127	Sorghum	700	7	2	155.7	$68.5	$185.1	14.1

Table A5 (continued)

Year	Activity	Crop	GPM	Lev	Piv	Yield	PC	NR	ac-in/ac
1	Sg30137	Sorghum	700	7	3	122.4	$42.6	$119.8	8.2
1	Sg40137	Sorghum	700	7	3	125.3	$44.1	$126.2	8.5
1	Sg50137	Sorghum	700	7	3	129.1	$47.2	$133.5	9.1
1	Sg60137	Sorghum	700	7	3	137.3	$53.4	$150.0	10.3
1	Sg70137	Sorghum	700	7	3	145.3	$61.2	$163.9	11.8
1	Sg80137	Sorghum	700	7	3	150.9	$67.4	$173.1	13.0
1	Sg90137	Sorghum	700	7	3	155.7	$73.1	$180.5	14.1
1	Sg30147	Sorghum	700	7	4	122.4	$45.2	$117.2	8.2
1	Sg40147	Sorghum	700	7	4	125.3	$46.7	$123.5	8.5
1	Sg50147	Sorghum	700	7	4	129.1	$50.0	$130.6	9.1
1	Sg60147	Sorghum	700	7	4	137.3	$56.6	$146.7	10.3
1	Sg70147	Sorghum	700	7	4	145.3	$64.9	$160.2	11.8
1	Sg80147	Sorghum	700	7	4	150.9	$71.5	$169.0	13.0
1	Sg90147	Sorghum	700	7	4	155.7	$77.5	$176.1	14.1
1	Sh30117	Sorghum	800	7	1	122.1	$38.4	$123.1	8.3
1	Sh40117	Sorghum	800	7	1	124.9	$39.6	$129.7	8.6
1	Sh50117	Sorghum	800	7	1	129.0	$42.6	$137.7	9.2
1	Sh60117	Sorghum	800	7	1	138.6	$42.6	$171.4	9.2
1	Sh70117	Sorghum	800	7	1	148.7	$58.0	$176.4	12.6
1	Sh80117	Sorghum	800	7	1	156.5	$65.5	$190.3	14.2
1	Sh90117	Sorghum	800	7	1	162.8	$72.2	$201.0	15.6
1	Sh30127	Sorghum	800	7	2	122.1	$41.2	$120.3	8.3
1	Sh40127	Sorghum	800	7	2	124.9	$42.4	$126.9	8.6
1	Sh50127	Sorghum	800	7	2	129.0	$45.6	$134.7	9.2
1	Sh60127	Sorghum	800	7	2	138.6	$45.6	$168.3	9.2
1	Sh70127	Sorghum	800	7	2	148.7	$62.2	$172.2	12.6
1	Sh80127	Sorghum	800	7	2	156.5	$70.2	$185.6	14.2
1	Sh90127	Sorghum	800	7	2	162.8	$77.4	$195.8	15.6
1	Sh30137	Sorghum	800	7	3	122.1	$44.8	$116.7	8.3
1	Sh40137	Sorghum	800	7	3	124.9	$46.2	$123.1	8.6
1	Sh50137	Sorghum	800	7	3	129.0	$49.6	$130.7	9.2
1	Sh60137	Sorghum	800	7	3	138.6	$49.6	$164.3	9.2
1	Sh70137	Sorghum	800	7	3	148.7	$67.7	$166.7	12.6
1	Sh80137	Sorghum	800	7	3	156.5	$76.4	$179.4	14.2
1	Sh90137	Sorghum	800	7	3	162.8	$84.2	$189.0	15.6
1	Sh30118	Sorghum	800	8	1	122.1	$37.7	$123.8	8.3
1	Sh40118	Sorghum	800	8	1	124.9	$38.8	$130.5	8.6
1	Sh50118	Sorghum	800	8	1	129.0	$41.8	$138.6	9.2
1	Sh60118	Sorghum	800	8	1	138.6	$41.8	$172.2	9.2
1	Sh70118	Sorghum	800	8	1	148.7	$56.9	$177.5	12.6
1	Sh80118	Sorghum	800	8	1	156.5	$64.2	$191.5	14.2
1	Sh90118	Sorghum	800	8	1	162.8	$70.8	$202.4	15.6
1	Sh30128	Sorghum	800	8	2	122.1	$40.3	$121.2	8.3
1	Sh40128	Sorghum	800	8	2	124.9	$41.6	$127.7	8.6

Table A5 (continued)

Year	Activity	Crop	GPM	Lev	Piv	Yield	PC	NR	ac-in/ac
1	Sh50128	Sorghum	800	8	2	129.0	$44.7	$135.6	9.2
1	Sh60128	Sorghum	800	8	2	138.6	$44.7	$169.3	9.2
1	Sh70128	Sorghum	800	8	2	148.7	$60.9	$173.5	12.6
1	Sh80128	Sorghum	800	8	2	156.5	$68.7	$187.0	14.2
1	Sh90128	Sorghum	800	8	2	162.8	$75.8	$197.4	15.6
1	Sh30138	Sorghum	800	8	3	122.1	$43.8	$117.7	8.3
1	Sh40138	Sorghum	800	8	3	124.9	$45.2	$124.1	8.6
1	Sh50138	Sorghum	800	8	3	129.0	$48.6	$131.7	9.2
1	Sh60138	Sorghum	800	8	3	138.6	$48.6	$165.3	9.2
1	Sh70138	Sorghum	800	8	3	148.7	$66.3	$168.1	12.6
1	Sh80138	Sorghum	800	8	3	156.5	$74.8	$181.0	14.2
1	Sh90138	Sorghum	800	8	3	162.8	$82.4	$190.8	15.6
1	Sh30148	Sorghum	800	8	4	122.1	$46.8	$114.6	8.3
1	Sh40148	Sorghum	800	8	4	124.9	$48.3	$121.0	8.6
1	Sh50148	Sorghum	800	8	4	129.0	$51.9	$128.4	9.2
1	Sh60148	Sorghum	800	8	4	138.6	$51.9	$162.0	9.2
1	Sh70148	Sorghum	800	8	4	148.7	$70.8	$163.6	12.6
1	Sh80148	Sorghum	800	8	4	156.5	$79.9	$175.9	14.2
1	Sh90148	Sorghum	800	8	4	162.8	$88.1	$185.1	15.6
1	Cb30111	Corn	200	1	1	117.5	$44.0	$24.0	8.7
1	Cb40111	Corn	200	1	1	117.7	$44.6	$23.9	8.8
1	Cb50111	Corn	200	1	1	118.9	$46.1	$26.6	9.1
1	Cb60111	Corn	200	1	1	119.2	$47.7	$25.9	9.4
1	Cb70111	Corn	200	1	1	120.1	$49.4	$27.0	9.7
1	Cb80111	Corn	200	1	1	121.2	$51.2	$28.5	10.1
1	Cb90111	Corn	200	1	1	122.2	$52.3	$30.8	10.3
1	Cb30121	Corn	200	1	2	117.5	$45.0	$23.0	8.7
1	Cb40121	Corn	200	1	2	117.7	$45.7	$22.9	8.8
1	Cb50121	Corn	200	1	2	118.9	$47.1	$25.5	9.1
1	Cb60121	Corn	200	1	2	119.2	$48.8	$24.8	9.4
1	Cb70121	Corn	200	1	2	120.1	$50.6	$25.8	9.7
1	Cb80121	Corn	200	1	2	121.2	$52.4	$27.4	10.1
1	Cb90121	Corn	200	1	2	122.2	$53.5	$29.6	10.3
1	Cc30111	Corn	300	1	1	133.7	$56.9	$62.6	11.0
1	Cc40111	Corn	300	1	1	134.9	$58.2	$65.1	11.3
1	Cc50111	Corn	300	1	1	136.9	$60.8	$69.2	11.8
1	Cc60111	Corn	300	1	1	138.4	$63.4	$71.3	12.3
1	Cc70111	Corn	300	1	1	139.3	$66.0	$71.4	12.8
1	Cc80111	Corn	300	1	1	141.2	$69.2	$74.3	13.4
1	Cc90111	Corn	300	1	1	142.6	$71.6	$76.4	13.9
1	Cd30111	Corn	400	1	1	148.5	$70.7	$95.8	13.5
1	Cd40111	Corn	400	1	1	150.1	$72.6	$99.1	13.9
1	Cd50111	Corn	400	1	1	152.1	$75.5	$102.6	14.4
1	Cd60111	Corn	400	1	1	154.7	$78.5	$108.0	15.0

Table A5 (continued)

Year	Activity	Crop	GPM	Lev	Piv	Yield	PC	NR	ac-in/ac
1	Cd70111	Corn	400	1	1	157.7	$83.1	$112.9	15.9
1	Cd80111	Corn	400	1	1	161.2	$89.1	$118.0	17.0
1	Cd90111	Corn	400	1	1	164.4	$92.2	$125.0	17.6
1	Cb30112	Corn	200	2	1	117.5	$42.3	$25.7	8.7
1	Cb40112	Corn	200	2	1	117.7	$42.9	$25.6	8.8
1	Cb50112	Corn	200	2	1	118.9	$44.3	$28.4	9.1
1	Cb60112	Corn	200	2	1	119.2	$45.8	$27.7	9.4
1	Cb70112	Corn	200	2	1	120.1	$47.5	$28.9	9.7
1	Cb80112	Corn	200	2	1	121.2	$49.2	$30.5	10.1
1	Cb90112	Corn	200	2	1	122.2	$50.3	$32.8	10.3
1	Cb30122	Corn	200	2	2	117.5	$43.2	$24.9	8.7
1	Cb40122	Corn	200	2	2	117.7	$43.8	$24.8	8.8
1	Cb50122	Corn	200	2	2	118.9	$45.2	$27.5	9.1
1	Cb60122	Corn	200	2	2	119.2	$46.8	$26.8	9.4
1	Cb70122	Corn	200	2	2	120.1	$48.5	$27.9	9.7
1	Cb80122	Corn	200	2	2	121.2	$50.2	$29.5	10.1
1	Cb90122	Corn	200	2	2	122.2	$51.3	$31.8	10.3
1	Cb30132	Corn	200	2	3	117.5	$44.2	$23.8	8.7
1	Cb40132	Corn	200	2	3	117.7	$44.8	$23.8	8.8
1	Cb50132	Corn	200	2	3	118.9	$46.3	$26.4	9.1
1	Cb60132	Corn	200	2	3	119.2	$47.9	$25.7	9.4
1	Cb70132	Corn	200	2	3	120.1	$49.6	$26.8	9.7
1	Cb80132	Corn	200	2	3	121.2	$51.4	$28.3	10.1
1	Cb90132	Corn	200	2	3	122.2	$52.5	$30.6	10.3
1	Cb30142	Corn	200	2	4	117.5	$45.2	$22.8	8.7
1	Cb40142	Corn	200	2	4	117.7	$45.8	$22.7	8.8
1	Cb50142	Corn	200	2	4	118.9	$47.3	$25.3	9.1
1	Cb60142	Corn	200	2	4	119.2	$49.0	$24.6	9.4
1	Cb70142	Corn	200	2	4	120.1	$50.8	$25.6	9.7
1	Cb80142	Corn	200	2	4	121.2	$52.6	$27.2	10.1
1	Cb90142	Corn	200	2	4	122.2	$53.7	$29.4	10.3
1	Cc30112	Corn	300	2	1	133.7	$54.6	$64.9	11.0
1	Cc40112	Corn	300	2	1	134.9	$55.8	$67.4	11.3
1	Cc50112	Corn	300	2	1	136.9	$58.3	$71.6	11.8
1	Cc60112	Corn	300	2	1	138.4	$60.8	$73.8	12.3
1	Cc70112	Corn	300	2	1	139.3	$63.3	$74.1	12.8
1	Cc80112	Corn	300	2	1	141.2	$66.4	$77.1	13.4
1	Cc90112	Corn	300	2	1	142.6	$68.7	$79.3	13.9
1	Cc30122	Corn	300	2	2	133.7	$56.3	$63.2	11.0
1	Cc40122	Corn	300	2	2	134.9	$57.6	$65.7	11.3
1	Cc50122	Corn	300	2	2	136.9	$60.1	$69.8	11.8
1	Cc60122	Corn	300	2	2	138.4	$62.7	$71.9	12.3
1	Cc70122	Corn	300	2	2	139.3	$65.3	$72.1	12.8
1	Cc80122	Corn	300	2	2	141.2	$68.5	$75.0	13.4

Table A5 (continued)

Year	Activity	Crop	GPM	Lev	Piv	Yield	PC	NR	ac-in/ac
1	Cc90122	Corn	300	2	2	142.6	$70.9	$77.1	13.9
1	Cd30112	Corn	400	2	1	148.5	$67.7	$98.8	13.5
1	Cd40112	Corn	400	2	1	150.1	$69.4	$102.2	13.9
1	Cd50112	Corn	400	2	1	152.1	$72.3	$105.9	14.4
1	Cd60112	Corn	400	2	1	154.7	$75.1	$111.4	15.0
1	Cd70112	Corn	400	2	1	157.7	$79.5	$116.4	15.9
1	Cd80112	Corn	400	2	1	161.2	$85.2	$121.9	17.0
1	Cd90112	Corn	400	2	1	164.4	$88.2	$128.9	17.6
1	Cd30122	Corn	400	2	2	148.5	$70.7	$95.8	13.5
1	Cd40122	Corn	400	2	2	150.1	$72.6	$99.1	13.9
1	Cd50122	Corn	400	2	2	152.1	$75.5	$102.6	14.4
1	Cd60122	Corn	400	2	2	154.7	$78.5	$108.0	15.0
1	Cd70122	Corn	400	2	2	157.7	$83.1	$112.9	15.9
1	Cd80122	Corn	400	2	2	161.2	$89.1	$118.0	17.0
1	Cd90122	Corn	400	2	2	164.4	$92.2	$125.0	17.6
1	Ce30112	Corn	500	2	1	153.8	$72.1	$111.5	14.1
1	Ce40112	Corn	500	2	1	156.1	$74.5	$116.2	14.6
1	Ce50112	Corn	500	2	1	158.3	$77.8	$120.0	15.3
1	Ce60112	Corn	500	2	1	162.2	$81.7	$128.4	16.0
1	Ce70112	Corn	500	2	1	168.4	$88.4	$141.4	17.4
1	Ce80112	Corn	500	2	1	172.4	$94.8	$147.7	18.6
1	Ce90112	Corn	500	2	1	175.0	$99.2	$151.7	19.5
1	Cf30112	Corn	600	2	1	156.9	$75.7	$117.7	14.6
1	Cf40112	Corn	600	2	1	159.8	$77.5	$125.0	15.0
1	Cf50112	Corn	600	2	1	163.0	$82.2	$130.4	15.9
1	Cf60112	Corn	600	2	1	170.7	$89.2	$147.9	17.2
1	Cf70112	Corn	600	2	1	177.2	$98.5	$159.3	19.0
1	Cf80112	Corn	600	2	1	182.9	$105.5	$170.4	20.4
1	Cf90112	Corn	600	2	1	186.9	$111.7	$177.0	21.6
1	Cg30112	Corn	700	2	1	158.4	$76.8	$121.2	14.6
1	Cg40112	Corn	700	2	1	161.9	$80.3	$128.7	15.3
1	Cg50112	Corn	700	2	1	165.1	$84.6	$134.7	16.1
1	Cg60112	Corn	700	2	1	176.0	$94.7	$159.2	18.0
1	Cg70112	Corn	700	2	1	186.3	$106.9	$179.9	20.4
1	Cg80112	Corn	700	2	1	194.6	$116.0	$197.0	22.1
1	Cg90112	Corn	700	2	1	198.9	$117.8	$208.9	22.5
1	Ch30112	Corn	800	2	1	159.3	$77.6	$123.4	14.6
1	Ch40112	Corn	800	2	1	163.4	$81.3	$132.5	15.3
1	Ch50112	Corn	800	2	1	166.9	$86.0	$139.2	16.2
1	Ch60112	Corn	800	2	1	180.8	$99.5	$178.1	18.8
1	Ch70112	Corn	800	2	1	193.9	$114.2	$196.7	21.5
1	Ch80112	Corn	800	2	1	206.3	$119.3	$231.0	22.5
1	Ch90112	Corn	800	2	1	213.4	$122.3	$250.5	23.1
1	Cc30113	Corn	300	3	1	133.7	$52.8	$66.6	11.0

Table A5 (continued)

Year	Activity	Crop	GPM	Lev	Piv	Yield	PC	NR	ac-in/ac
1	Cc40113	Corn	300	3	1	134.9	$54.0	$69.2	11.3
1	Cc50113	Corn	300	3	1	136.9	$56.5	$73.5	11.8
1	Cc60113	Corn	300	3	1	138.4	$58.9	$75.8	12.3
1	Cc70113	Corn	300	3	1	139.3	$61.3	$76.1	12.8
1	Cc80113	Corn	300	3	1	141.2	$64.3	$79.2	13.4
1	Cc90113	Corn	300	3	1	142.6	$66.6	$81.4	13.9
1	Cc30123	Corn	300	3	2	133.7	$54.4	$65.0	11.0
1	Cc40123	Corn	300	3	2	134.9	$55.7	$67.6	11.3
1	Cc50123	Corn	300	3	2	136.9	$58.1	$71.8	11.8
1	Cc60123	Corn	300	3	2	138.4	$60.6	$74.0	12.3
1	Cc70123	Corn	300	3	2	139.3	$63.1	$74.2	12.8
1	Cc80123	Corn	300	3	2	141.2	$66.2	$77.3	13.4
1	Cc90123	Corn	300	3	2	142.6	$68.6	$79.4	13.9
1	Cc30133	Corn	300	3	3	133.7	$56.1	$63.3	11.0
1	Cc40133	Corn	300	3	3	134.9	$57.4	$65.8	11.3
1	Cc50133	Corn	300	3	3	136.9	$60.0	$69.9	11.8
1	Cc60133	Corn	300	3	3	138.4	$62.6	$72.1	12.3
1	Cc70133	Corn	300	3	3	139.3	$65.1	$72.2	12.8
1	Cc80133	Corn	300	3	3	141.2	$68.3	$75.2	13.4
1	Cc90133	Corn	300	3	3	142.6	$70.7	$77.3	13.9
1	Cc30143	Corn	300	3	4	133.7	$57.9	$61.6	11.0
1	Cc40143	Corn	300	3	4	134.9	$59.2	$64.1	11.3
1	Cc50143	Corn	300	3	4	136.9	$61.8	$68.1	11.8
1	Cc60143	Corn	300	3	4	138.4	$64.5	$70.2	12.3
1	Cc70143	Corn	300	3	4	139.3	$67.1	$70.2	12.8
1	Cc80143	Corn	300	3	4	141.2	$70.4	$73.1	13.4
1	Cc90143	Corn	300	3	4	142.6	$72.9	$75.1	13.9
1	Cd30113	Corn	400	3	1	148.5	$65.6	$100.9	13.5
1	Cd40113	Corn	400	3	1	150.1	$67.3	$104.4	13.9
1	Cd50113	Corn	400	3	1	152.1	$70.0	$108.1	14.4
1	Cd60113	Corn	400	3	1	154.7	$72.8	$113.7	15.0
1	Cd70113	Corn	400	3	1	157.7	$77.1	$118.9	15.9
1	Cd80113	Corn	400	3	1	161.2	$82.6	$124.5	17.0
1	Cd90113	Corn	400	3	1	164.4	$85.5	$131.7	17.6
1	Cd30123	Corn	400	3	2	148.5	$68.4	$98.2	13.5
1	Cd40123	Corn	400	3	2	150.1	$70.1	$101.6	13.9
1	Cd50123	Corn	400	3	2	152.1	$73.0	$105.2	14.4
1	Cd60123	Corn	400	3	2	154.7	$75.9	$110.6	15.0
1	Cd70123	Corn	400	3	2	157.7	$80.3	$115.7	15.9
1	Cd80123	Corn	400	3	2	161.2	$86.1	$121.0	17.0
1	Cd90123	Corn	400	3	2	164.4	$89.1	$128.1	17.6
1	Cd30133	Corn	400	3	3	148.5	$71.0	$95.5	13.5
1	Cd40133	Corn	400	3	3	150.1	$72.8	$98.9	13.9
1	Cd50133	Corn	400	3	3	152.1	$75.8	$102.3	14.4

Table A5 (continued)

Year	Activity	Crop	GPM	Lev	Piv	Yield	PC	NR	ac-in/ac
1	Cd60133	Corn	400	3	3	154.7	$78.8	$107.7	15.0
1	Cd70133	Corn	400	3	3	157.7	$83.4	$112.6	15.9
1	Cd80133	Corn	400	3	3	161.2	$89.4	$117.7	17.0
1	Cd90133	Corn	400	3	3	164.4	$92.5	$124.6	17.6
1	Ce30113	Corn	500	3	1	153.8	$69.7	$113.8	14.1
1	Ce40113	Corn	500	3	1	156.1	$72.1	$118.6	14.6
1	Ce50113	Corn	500	3	1	158.3	$75.3	$122.5	15.3
1	Ce60113	Corn	500	3	1	162.2	$79.1	$131.0	16.0
1	Ce70113	Corn	500	3	1	168.4	$85.6	$144.2	17.4
1	Ce80113	Corn	500	3	1	172.4	$91.8	$150.7	18.6
1	Ce90113	Corn	500	3	1	175.0	$96.0	$154.9	19.5
1	Ce30123	Corn	500	3	2	153.8	$73.2	$110.4	14.1
1	Ce40123	Corn	500	3	2	156.1	$75.6	$115.1	14.6
1	Ce50123	Corn	500	3	2	158.3	$79.0	$118.8	15.3
1	Ce60123	Corn	500	3	2	162.2	$82.9	$127.1	16.0
1	Ce70123	Corn	500	3	2	168.4	$89.8	$140.0	17.4
1	Ce80123	Corn	500	3	2	172.4	$96.3	$146.2	18.6
1	Ce90123	Corn	500	3	2	175.0	$100.7	$150.2	19.5
1	Cf30113	Corn	600	3	1	156.9	$73.2	$120.2	14.6
1	Cf40113	Corn	600	3	1	159.8	$74.9	$127.5	15.0
1	Cf50113	Corn	600	3	1	163.0	$79.5	$133.1	15.9
1	Cf60113	Corn	600	3	1	170.7	$86.3	$150.8	17.2
1	Cf70113	Corn	600	3	1	177.2	$95.3	$162.6	19.0
1	Cf80113	Corn	600	3	1	182.9	$102.1	$173.8	20.4
1	Cf90113	Corn	600	3	1	186.9	$108.0	$180.7	21.6
1	Cf30123	Corn	600	3	2	156.9	$77.5	$115.9	14.6
1	Cf40123	Corn	600	3	2	159.8	$79.3	$123.1	15.0
1	Cf50123	Corn	600	3	2	163.0	$84.1	$128.5	15.9
1	Cf60123	Corn	600	3	2	170.7	$91.3	$145.8	17.2
1	Cf70123	Corn	600	3	2	177.2	$100.8	$157.0	19.0
1	Cf80123	Corn	600	3	2	182.9	$108.0	$167.8	20.4
1	Cf90123	Corn	600	3	2	186.9	$114.4	$174.3	21.6
1	Cg30113	Corn	700	3	1	158.4	$74.2	$123.8	14.6
1	Cg40113	Corn	700	3	1	161.9	$77.6	$131.4	15.3
1	Cg50113	Corn	700	3	1	165.1	$81.7	$137.6	16.1
1	Cg60113	Corn	700	3	1	176.0	$91.5	$162.5	18.0
1	Cg70113	Corn	700	3	1	186.3	$103.3	$183.6	20.4
1	Cg80113	Corn	700	3	1	194.6	$112.1	$200.9	22.1
1	Cg90113	Corn	700	3	1	198.9	$113.8	$213.0	22.5
1	Ch30113	Corn	800	3	1	159.3	$74.9	$126.1	14.6
1	Ch40113	Corn	800	3	1	163.4	$78.4	$135.4	15.3
1	Ch50113	Corn	800	3	1	166.9	$82.9	$142.2	16.2
1	Ch60113	Corn	800	3	1	180.8	$96.0	$181.5	18.8
1	Ch70113	Corn	800	3	1	193.9	$110.2	$200.7	21.5

Table A5 (continued)

Year	Activity	Crop	GPM	Lev	Piv	Yield	PC	NR	ac-in/ac
1	Ch80113	Corn	800	3	1	206.3	$115.2	$235.1	22.5
1	Ch90113	Corn	800	3	1	213.4	$118.1	$254.8	23.1
1	Cd30114	Corn	400	4	1	148.5	$64.0	$102.5	13.5
1	Cd40114	Corn	400	4	1	150.1	$65.7	$106.0	13.9
1	Cd50114	Corn	400	4	1	152.1	$68.3	$109.8	14.4
1	Cd60114	Corn	400	4	1	154.7	$71.0	$115.5	15.0
1	Cd70114	Corn	400	4	1	157.7	$75.2	$120.8	15.9
1	Cd80114	Corn	400	4	1	161.2	$80.6	$126.5	17.0
1	Cd90114	Corn	400	4	1	164.4	$83.4	$133.7	17.6
1	Cd30124	Corn	400	4	2	148.5	$66.4	$100.2	13.5
1	Cd40124	Corn	400	4	2	150.1	$68.1	$103.6	13.9
1	Cd50124	Corn	400	4	2	152.1	$70.9	$107.3	14.4
1	Cd60124	Corn	400	4	2	154.7	$73.7	$112.8	15.0
1	Cd70124	Corn	400	4	2	157.7	$78.0	$118.0	15.9
1	Cd80124	Corn	400	4	2	161.2	$83.6	$123.5	17.0
1	Cd90124	Corn	400	4	2	164.4	$86.5	$130.6	17.6
1	Cd30134	Corn	400	4	3	148.5	$68.9	$97.6	13.5
1	Cd40134	Corn	400	4	3	150.1	$70.7	$101.0	13.9
1	Cd50134	Corn	400	4	3	152.1	$73.6	$104.6	14.4
1	Cd60134	Corn	400	4	3	154.7	$76.4	$110.0	15.0
1	Cd70134	Corn	400	4	3	157.7	$80.9	$115.0	15.9
1	Cd80134	Corn	400	4	3	161.2	$86.7	$120.4	17.0
1	Cd90134	Corn	400	4	3	164.4	$89.8	$127.4	17.6
1	Cd30144	Corn	400	4	4	148.5	$71.8	$94.7	13.5
1	Cd40144	Corn	400	4	4	150.1	$73.6	$98.1	13.9
1	Cd50144	Corn	400	4	4	152.1	$76.7	$101.5	14.4
1	Cd60144	Corn	400	4	4	154.7	$79.7	$106.8	15.0
1	Cd70144	Corn	400	4	4	157.7	$84.4	$111.6	15.9
1	Cd80144	Corn	400	4	4	161.2	$90.4	$116.7	17.0
1	Cd90144	Corn	400	4	4	164.4	$93.6	$123.6	17.6
1	Ce30114	Corn	500	4	1	153.8	$68.0	$115.6	14.1
1	Ce40114	Corn	500	4	1	156.1	$70.2	$120.5	14.6
1	Ce50114	Corn	500	4	1	158.3	$73.4	$124.5	15.3
1	Ce60114	Corn	500	4	1	162.2	$77.1	$133.0	16.0
1	Ce70114	Corn	500	4	1	168.4	$83.4	$146.4	17.4
1	Ce80114	Corn	500	4	1	172.4	$89.5	$153.1	18.6
1	Ce90114	Corn	500	4	1	175.0	$93.6	$157.4	19.5
1	Ce30124	Corn	500	4	2	153.8	$71.2	$112.4	14.1
1	Ce40124	Corn	500	4	2	156.1	$73.6	$117.2	14.6
1	Ce50124	Corn	500	4	2	158.3	$76.9	$121.0	15.3
1	Ce60124	Corn	500	4	2	162.2	$80.7	$129.4	16.0
1	Ce70124	Corn	500	4	2	168.4	$87.3	$142.5	17.4
1	Ce80124	Corn	500	4	2	172.4	$93.7	$148.8	18.6
1	Ce90124	Corn	500	4	2	175.0	$98.0	$152.9	19.5

Table A5 (continued)

Year	Activity	Crop	GPM	Lev	Piv	Yield	PC	NR	ac-in/ac
1	Ce30134	Corn	500	4	3	153.8	$74.3	$109.3	14.1
1	Ce40134	Corn	500	4	3	156.1	$76.7	$114.0	14.6
1	Ce50134	Corn	500	4	3	158.3	$80.2	$117.7	15.3
1	Ce60134	Corn	500	4	3	162.2	$84.2	$125.9	16.0
1	Ce70134	Corn	500	4	3	168.4	$91.1	$138.7	17.4
1	Ce80134	Corn	500	4	3	172.4	$97.8	$144.8	18.6
1	Ce90134	Corn	500	4	3	175.0	$102.2	$148.7	19.5
1	Cf30114	Corn	600	4	1	156.9	$71.3	$122.1	14.6
1	Cf40114	Corn	600	4	1	159.8	$73.0	$129.4	15.0
1	Cf50114	Corn	600	4	1	163.0	$77.4	$135.2	15.9
1	Cf60114	Corn	600	4	1	170.7	$84.0	$153.1	17.2
1	Cf70114	Corn	600	4	1	177.2	$92.8	$165.0	19.0
1	Cf80114	Corn	600	4	1	182.9	$99.4	$176.5	20.4
1	Cf90114	Corn	600	4	1	186.9	$105.2	$183.5	21.6
1	Cf30124	Corn	600	4	2	156.9	$75.2	$118.2	14.6
1	Cf40124	Corn	600	4	2	159.8	$77.0	$125.4	15.0
1	Cf50124	Corn	600	4	2	163.0	$81.7	$131.0	15.9
1	Cf60124	Corn	600	4	2	170.7	$88.6	$148.5	17.2
1	Cf70124	Corn	600	4	2	177.2	$97.9	$160.0	19.0
1	Cf80124	Corn	600	4	2	182.9	$104.8	$171.0	20.4
1	Cf90124	Corn	600	4	2	186.9	$111.0	$177.7	21.6
1	Cg30114	Corn	700	4	1	158.4	$72.3	$125.7	14.6
1	Cg40114	Corn	700	4	1	161.9	$75.5	$133.5	15.3
1	Cg50114	Corn	700	4	1	165.1	$79.6	$139.8	16.1
1	Cg60114	Corn	700	4	1	176.0	$89.1	$164.9	18.0
1	Cg70114	Corn	700	4	1	186.3	$100.6	$186.3	20.4
1	Cg80114	Corn	700	4	1	194.6	$109.1	$203.9	22.1
1	Cg90114	Corn	700	4	1	198.9	$110.8	$216.0	22.5
1	Cg30124	Corn	700	4	2	158.4	$77.0	$121.0	14.6
1	Cg40124	Corn	700	4	2	161.9	$80.5	$128.5	15.3
1	Cg50124	Corn	700	4	2	165.1	$84.8	$134.5	16.1
1	Cg60124	Corn	700	4	2	176.0	$94.9	$159.0	18.0
1	Cg70124	Corn	700	4	2	186.3	$107.2	$179.7	20.4
1	Cg80124	Corn	700	4	2	194.6	$116.3	$196.7	22.1
1	Cg90124	Corn	700	4	2	198.9	$118.1	$208.7	22.5
1	Ch30114	Corn	800	4	1	159.3	$72.9	$128.1	14.6
1	Ch40114	Corn	800	4	1	163.4	$76.3	$137.4	15.3
1	Ch50114	Corn	800	4	1	166.9	$80.7	$144.4	16.2
1	Ch60114	Corn	800	4	1	180.8	$93.4	$184.1	18.8
1	Ch70114	Corn	800	4	1	193.9	$107.2	$203.7	21.5
1	Ch80114	Corn	800	4	1	206.3	$112.1	$238.2	22.5
1	Ch90114	Corn	800	4	1	213.4	$114.9	$257.9	23.1
1	Ch30124	Corn	800	4	2	159.3	$78.7	$122.3	14.6
1	Ch40124	Corn	800	4	2	163.4	$82.4	$131.4	15.3

Table A5 (continued)

Year	Activity	Crop	GPM	Lev	Piv	Yield	PC	NR	ac-in/ac
1	Ch50124	Corn	800	4	2	166.9	$87.1	$138.0	16.2
1	Ch60124	Corn	800	4	2	180.8	$100.9	$176.7	18.8
1	Ch70124	Corn	800	4	2	193.9	$115.7	$195.1	21.5
1	Ch80124	Corn	800	4	2	206.3	$121.0	$229.3	22.5
1	Ch90124	Corn	800	4	2	213.4	$124.0	$248.8	23.1
1	Ce30115	Corn	500	5	1	153.8	$66.3	$117.2	14.1
1	Ce40115	Corn	500	5	1	156.1	$68.5	$122.2	14.6
1	Ce50115	Corn	500	5	1	158.3	$71.6	$126.2	15.3
1	Ce60115	Corn	500	5	1	162.2	$75.2	$134.9	16.0
1	Ce70115	Corn	500	5	1	168.4	$81.4	$148.4	17.4
1	Ce80115	Corn	500	5	1	172.4	$87.3	$155.2	18.6
1	Ce90115	Corn	500	5	1	175.0	$91.3	$159.6	19.5
1	Ce30125	Corn	500	5	2	153.8	$69.2	$114.4	14.1
1	Ce40125	Corn	500	5	2	156.1	$71.5	$119.2	14.6
1	Ce50125	Corn	500	5	2	158.3	$74.7	$123.1	15.3
1	Ce60125	Corn	500	5	2	162.2	$78.4	$131.6	16.0
1	Ce70125	Corn	500	5	2	168.4	$84.9	$144.9	17.4
1	Ce80125	Corn	500	5	2	172.4	$91.1	$151.5	18.6
1	Ce90125	Corn	500	5	2	175.0	$95.2	$155.7	19.5
1	Ce30135	Corn	500	5	3	153.8	$72.2	$111.4	14.1
1	Ce40135	Corn	500	5	3	156.1	$74.6	$116.1	14.6
1	Ce50135	Corn	500	5	3	158.3	$78.0	$119.9	15.3
1	Ce60135	Corn	500	5	3	162.2	$81.8	$128.2	16.0
1	Ce70135	Corn	500	5	3	168.4	$88.6	$141.2	17.4
1	Ce80135	Corn	500	5	3	172.4	$95.0	$147.5	18.6
1	Ce90135	Corn	500	5	3	175.0	$99.3	$151.6	19.5
1	Ce30145	Corn	500	5	4	153.8	$75.9	$107.6	14.1
1	Ce40145	Corn	500	5	4	156.1	$78.5	$112.2	14.6
1	Ce50145	Corn	500	5	4	158.3	$82.0	$115.9	15.3
1	Ce60145	Corn	500	5	4	162.2	$86.1	$124.0	16.0
1	Ce70145	Corn	500	5	4	168.4	$93.2	$136.6	17.4
1	Ce80145	Corn	500	5	4	172.4	$99.9	$142.6	18.6
1	Ce90145	Corn	500	5	4	175.0	$104.5	$146.4	19.5
1	Cf30115	Corn	600	5	1	156.9	$69.5	$123.9	14.6
1	Cf40115	Corn	600	5	1	159.8	$71.1	$131.3	15.0
1	Cf50115	Corn	600	5	1	163.0	$75.5	$137.2	15.9
1	Cf60115	Corn	600	5	1	170.7	$81.9	$155.2	17.2
1	Cf70115	Corn	600	5	1	177.2	$90.4	$167.4	19.0
1	Cf80115	Corn	600	5	1	182.9	$96.9	$179.0	20.4
1	Cf90115	Corn	600	5	1	186.9	$102.6	$186.1	21.6
1	Cf30125	Corn	600	5	2	156.9	$73.1	$120.3	14.6
1	Cf40125	Corn	600	5	2	159.8	$74.8	$127.6	15.0
1	Cf50125	Corn	600	5	2	163.0	$79.4	$133.2	15.9
1	Cf60125	Corn	600	5	2	170.7	$86.2	$151.0	17.2

Table A5 (continued)

Year	Activity	Crop	GPM	Lev	Piv	Yield	PC	NR	ac-in/ac
1	Cf70125	Corn	600	5	2	177.2	$95.1	$162.7	19.0
1	Cf80125	Corn	600	5	2	182.9	$101.9	$173.9	20.4
1	Cf90125	Corn	600	5	2	186.9	$107.9	$180.8	21.6
1	Cf30135	Corn	600	5	3	156.9	$77.1	$116.3	14.6
1	Cf40135	Corn	600	5	3	159.8	$78.9	$123.5	15.0
1	Cf50135	Corn	600	5	3	163.0	$83.7	$128.9	15.9
1	Cf60135	Corn	600	5	3	170.7	$90.9	$146.2	17.2
1	Cf70135	Corn	600	5	3	177.2	$100.4	$157.5	19.0
1	Cf80135	Corn	600	5	3	182.9	$107.5	$168.4	20.4
1	Cf90135	Corn	600	5	3	186.9	$113.8	$174.9	21.6
1	Cg30115	Corn	700	5	1	158.4	$70.5	$127.5	14.6
1	Cg40115	Corn	700	5	1	161.9	$73.7	$135.4	15.3
1	Cg50115	Corn	700	5	1	165.1	$77.6	$141.7	16.1
1	Cg60115	Corn	700	5	1	176.0	$86.8	$167.1	18.0
1	Cg70115	Corn	700	5	1	186.3	$98.1	$188.8	20.4
1	Cg80115	Corn	700	5	1	194.6	$106.4	$206.6	22.1
1	Cg90115	Corn	700	5	1	198.9	$108.1	$218.7	22.5
1	Cg30125	Corn	700	5	2	158.4	$74.8	$123.2	14.6
1	Cg40125	Corn	700	5	2	161.9	$78.2	$130.8	15.3
1	Cg50125	Corn	700	5	2	165.1	$82.4	$137.0	16.1
1	Cg60125	Corn	700	5	2	176.0	$92.2	$161.7	18.0
1	Cg70125	Corn	700	5	2	186.3	$104.1	$182.8	20.4
1	Cg80125	Corn	700	5	2	194.6	$112.9	$200.1	22.1
1	Cg90125	Corn	700	5	2	198.9	$114.7	$212.1	22.5
1	Ch30115	Corn	800	5	1	159.3	$71.0	$130.0	14.6
1	Ch40115	Corn	800	5	1	163.4	$74.4	$139.4	15.3
1	Ch50115	Corn	800	5	1	166.9	$78.7	$146.4	16.2
1	Ch60115	Corn	800	5	1	180.8	$91.0	$186.5	18.8
1	Ch70115	Corn	800	5	1	193.9	$104.5	$206.4	21.5
1	Ch80115	Corn	800	5	1	206.3	$109.2	$241.1	22.5
1	Ch90115	Corn	800	5	1	213.4	$112.0	$260.9	23.1
1	Ch30125	Corn	800	5	2	159.3	$76.4	$124.6	14.6
1	Ch40125	Corn	800	5	2	163.4	$80.0	$133.8	15.3
1	Ch50125	Corn	800	5	2	166.9	$84.6	$140.5	16.2
1	Ch60125	Corn	800	5	2	180.8	$97.9	$179.6	18.8
1	Ch70125	Corn	800	5	2	193.9	$112.4	$198.5	21.5
1	Ch80125	Corn	800	5	2	206.3	$117.5	$232.8	22.5
1	Ch90125	Corn	800	5	2	213.4	$120.4	$252.4	23.1
1	Cf30116	Corn	600	6	1	156.9	$67.8	$125.6	14.6
1	Cf40116	Corn	600	6	1	159.8	$69.4	$133.0	15.0
1	Cf50116	Corn	600	6	1	163.0	$73.6	$139.0	15.9
1	Cf60116	Corn	600	6	1	170.7	$79.9	$157.2	17.2
1	Cf70116	Corn	600	6	1	177.2	$88.2	$169.6	19.0
1	Cf80116	Corn	600	6	1	182.9	$94.5	$181.4	20.4

Table A5 (continued)

Year	Activity	Crop	GPM	Lev	Piv	Yield	PC	NR	ac-in/ac
1	Cf90116	Corn	600	6	1	186.9	$100.0	$188.7	21.6
1	Cf30126	Corn	600	6	2	156.9	$71.2	$122.2	14.6
1	Cf40126	Corn	600	6	2	159.8	$72.9	$129.5	15.0
1	Cf50126	Corn	600	6	2	163.0	$77.3	$135.3	15.9
1	Cf60126	Corn	600	6	2	170.7	$83.9	$153.2	17.2
1	Cf70126	Corn	600	6	2	177.2	$92.7	$165.2	19.0
1	Cf80126	Corn	600	6	2	182.9	$99.3	$176.6	20.4
1	Cf90126	Corn	600	6	2	186.9	$105.1	$183.6	21.6
1	Cf30136	Corn	600	6	3	156.9	$75.0	$118.4	14.6
1	Cf40136	Corn	600	6	3	159.8	$76.8	$125.6	15.0
1	Cf50136	Corn	600	6	3	163.0	$81.5	$131.2	15.9
1	Cf60136	Corn	600	6	3	170.7	$88.4	$148.7	17.2
1	Cf70136	Corn	600	6	3	177.2	$97.6	$160.2	19.0
1	Cf80136	Corn	600	6	3	182.9	$104.6	$171.3	20.4
1	Cf90136	Corn	600	6	3	186.9	$110.7	$178.0	21.6
1	Cf30146	Corn	600	6	4	156.9	$79.2	$114.2	14.6
1	Cf40146	Corn	600	6	4	159.8	$81.1	$121.4	15.0
1	Cf50146	Corn	600	6	4	163.0	$86.0	$126.6	15.9
1	Cf60146	Corn	600	6	4	170.7	$93.3	$143.8	17.2
1	Cf70146	Corn	600	6	4	177.2	$103.1	$154.8	19.0
1	Cf80146	Corn	600	6	4	182.9	$110.4	$165.5	20.4
1	Cf90146	Corn	600	6	4	186.9	$116.9	$171.8	21.6
1	Cg30116	Corn	700	6	1	158.4	$68.7	$129.3	14.6
1	Cg40116	Corn	700	6	1	161.9	$71.8	$137.2	15.3
1	Cg50116	Corn	700	6	1	165.1	$75.6	$143.7	16.1
1	Cg60116	Corn	700	6	1	176.0	$84.6	$169.3	18.0
1	Cg70116	Corn	700	6	1	186.3	$95.6	$191.3	20.4
1	Cg80116	Corn	700	6	1	194.6	$103.7	$209.3	22.1
1	Cg90116	Corn	700	6	1	198.9	$105.3	$221.5	22.5
1	Cg30126	Corn	700	6	2	158.4	$72.8	$125.2	14.6
1	Cg40126	Corn	700	6	2	161.9	$76.1	$132.9	15.3
1	Cg50126	Corn	700	6	2	165.1	$80.2	$139.1	16.1
1	Cg60126	Corn	700	6	2	176.0	$89.8	$164.2	18.0
1	Cg70126	Corn	700	6	2	186.3	$101.4	$185.5	20.4
1	Cg80126	Corn	700	6	2	194.6	$110.0	$203.0	22.1
1	Cg90126	Corn	700	6	2	198.9	$111.7	$215.1	22.5
1	Cg30136	Corn	700	6	3	158.4	$77.8	$120.2	14.6
1	Cg40136	Corn	700	6	3	161.9	$81.3	$127.7	15.3
1	Cg50136	Corn	700	6	3	165.1	$85.7	$133.6	16.1
1	Cg60136	Corn	700	6	3	176.0	$95.9	$158.0	18.0
1	Cg70136	Corn	700	6	3	186.3	$108.3	$178.5	20.4
1	Cg80136	Corn	700	6	3	194.6	$117.5	$195.5	22.1
1	Cg90136	Corn	700	6	3	198.9	$119.3	$207.4	22.5
1	Ch30116	Corn	800	6	1	159.3	$69.2	$131.8	14.6

Table A5 (continued)

Year	Activity	Crop	GPM	Lev	Piv	Yield	PC	NR	ac-in/ac
1	Ch40116	Corn	800	6	1	163.4	$72.4	$141.3	15.3
1	Ch50116	Corn	800	6	1	166.9	$76.6	$148.5	16.2
1	Ch60116	Corn	800	6	1	180.8	$88.7	$188.9	18.8
1	Ch70116	Corn	800	6	1	193.9	$101.8	$209.1	21.5
1	Ch80116	Corn	800	6	1	206.3	$106.4	$243.9	22.5
1	Ch90116	Corn	800	6	1	213.4	$109.0	$263.8	23.1
1	Ch30126	Corn	800	6	2	159.3	$74.3	$126.7	14.6
1	Ch40126	Corn	800	6	2	163.4	$77.8	$136.0	15.3
1	Ch50126	Corn	800	6	2	166.9	$82.3	$142.8	16.2
1	Ch60126	Corn	800	6	2	180.8	$95.3	$182.3	18.8
1	Ch70126	Corn	800	6	2	193.9	$109.3	$201.5	21.5
1	Ch80126	Corn	800	6	2	206.3	$114.3	$236.0	22.5
1	Ch90126	Corn	800	6	2	213.4	$117.2	$255.7	23.1
1	Ch30136	Corn	800	6	3	159.3	$80.9	$120.1	14.6
1	Ch40136	Corn	800	6	3	163.4	$84.7	$129.1	15.3
1	Ch50136	Corn	800	6	3	166.9	$89.6	$135.5	16.2
1	Ch60136	Corn	800	6	3	180.8	$103.7	$173.8	18.8
1	Ch70136	Corn	800	6	3	193.9	$119.0	$191.9	21.5
1	Ch80136	Corn	800	6	3	206.3	$124.4	$225.9	22.5
1	Ch90136	Corn	800	6	3	213.4	$127.5	$245.3	23.1
1	Cg30117	Corn	700	7	1	158.4	$67.2	$130.8	14.6
1	Cg40117	Corn	700	7	1	161.9	$70.2	$138.8	15.3
1	Cg50117	Corn	700	7	1	165.1	$74.0	$145.3	16.1
1	Cg60117	Corn	700	7	1	176.0	$82.8	$171.1	18.0
1	Cg70117	Corn	700	7	1	186.3	$93.5	$193.3	20.4
1	Cg80117	Corn	700	7	1	194.6	$101.5	$211.6	22.1
1	Cg90117	Corn	700	7	1	198.9	$103.0	$223.7	22.5
1	Cg30127	Corn	700	7	2	158.4	$71.1	$126.9	14.6
1	Cg40127	Corn	700	7	2	161.9	$74.3	$134.7	15.3
1	Cg50127	Corn	700	7	2	165.1	$78.3	$141.0	16.1
1	Cg60127	Corn	700	7	2	176.0	$87.6	$166.3	18.0
1	Cg70127	Corn	700	7	2	186.3	$99.0	$187.9	20.4
1	Cg80127	Corn	700	7	2	194.6	$107.4	$205.6	22.1
1	Cg90127	Corn	700	7	2	198.9	$109.1	$217.7	22.5
1	Cg30137	Corn	700	7	3	158.4	$75.9	$122.2	14.6
1	Cg40137	Corn	700	7	3	161.9	$79.3	$129.7	15.3
1	Cg50137	Corn	700	7	3	165.1	$83.5	$135.8	16.1
1	Cg60137	Corn	700	7	3	176.0	$93.5	$160.4	18.0
1	Cg70137	Corn	700	7	3	186.3	$105.6	$181.3	20.4
1	Cg80137	Corn	700	7	3	194.6	$114.5	$198.5	22.1
1	Cg90137	Corn	700	7	3	198.9	$116.3	$210.4	22.5
1	Cg30147	Corn	700	7	4	158.4	$80.4	$117.6	14.6
1	Cg40147	Corn	700	7	4	161.9	$84.1	$124.9	15.3
1	Cg50147	Corn	700	7	4	165.1	$88.6	$130.8	16.1

Table A5 (continued)

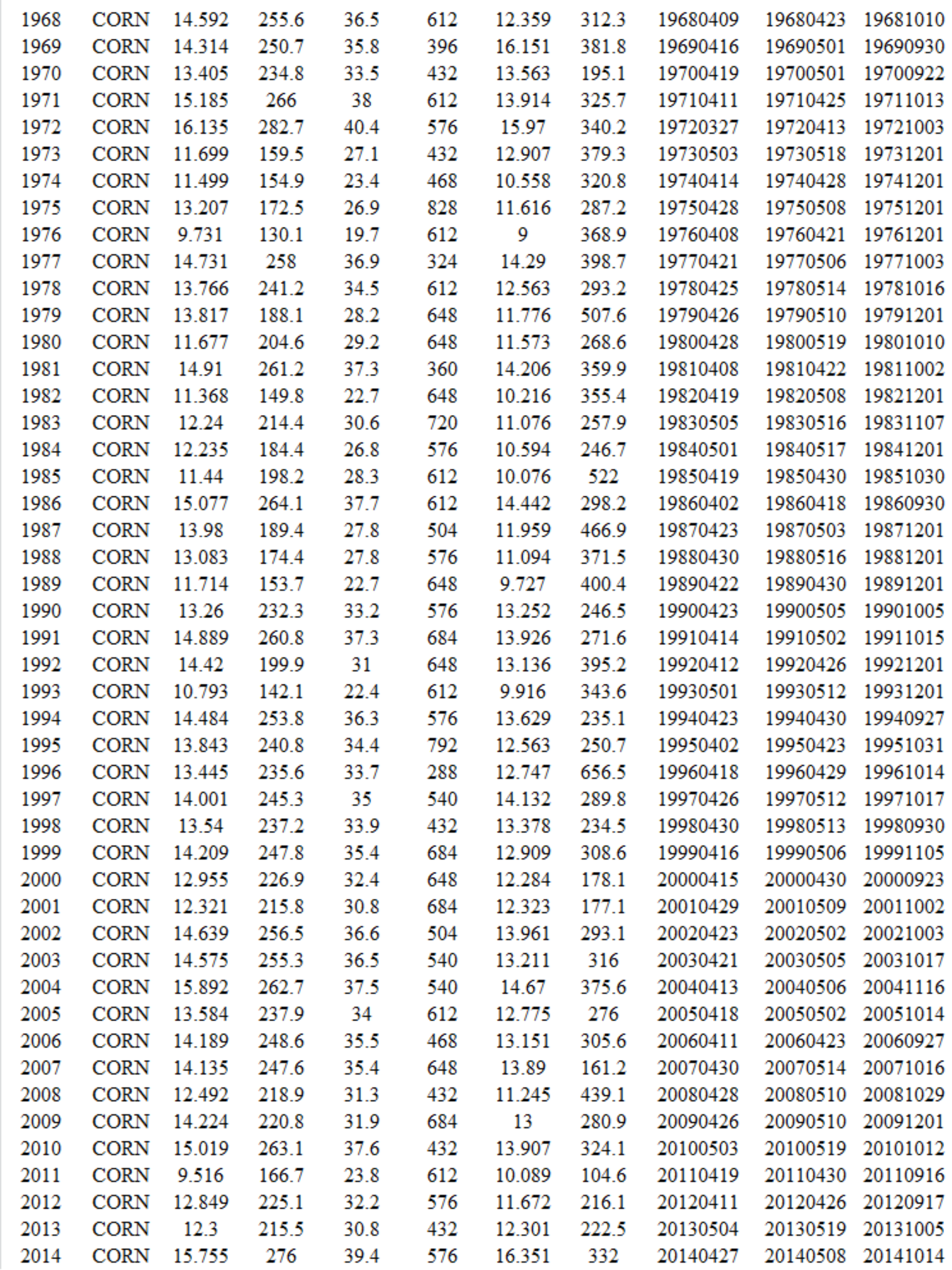
Year	Activity	Crop	GPM	Lev	Piv	Yield	PC	NR	ac-in/ac
1	Cg60147	Corn	700	7	4	176.0	$99.1	$154.8	18.0
1	Cg70147	Corn	700	7	4	186.3	$111.9	$174.9	20.4
1	Cg80147	Corn	700	7	4	194.6	$121.4	$191.6	22.1
1	Cg90147	Corn	700	7	4	198.9	$123.3	$203.4	22.5
1	Ch30117	Corn	800	7	1	159.3	$67.7	$133.3	14.6
1	Ch40117	Corn	800	7	1	163.4	$70.9	$142.9	15.3
1	Ch50117	Corn	800	7	1	166.9	$74.9	$150.2	16.2
1	Ch60117	Corn	800	7	1	180.8	$86.7	$190.8	18.8
1	Ch70117	Corn	800	7	1	193.9	$99.5	$211.3	21.5
1	Ch80117	Corn	800	7	1	206.3	$104.1	$246.3	22.5
1	Ch90117	Corn	800	7	1	213.4	$106.7	$266.2	23.1
1	Ch30127	Corn	800	7	2	159.3	$72.5	$128.5	14.6
1	Ch40127	Corn	800	7	2	163.4	$76.0	$137.8	15.3
1	Ch50127	Corn	800	7	2	166.9	$80.3	$144.8	16.2
1	Ch60127	Corn	800	7	2	180.8	$93.0	$184.6	18.8
1	Ch70127	Corn	800	7	2	193.9	$106.7	$204.2	21.5
1	Ch80127	Corn	800	7	2	206.3	$111.5	$238.8	22.5
1	Ch90127	Corn	800	7	2	213.4	$114.3	$258.5	23.1
1	Ch30137	Corn	800	7	3	159.3	$78.9	$122.1	14.6
1	Ch40137	Corn	800	7	3	163.4	$82.6	$131.2	15.3
1	Ch50137	Corn	800	7	3	166.9	$87.4	$137.7	16.2
1	Ch60137	Corn	800	7	3	180.8	$101.1	$176.4	18.8
1	Ch70137	Corn	800	7	3	193.9	$116.1	$194.8	21.5
1	Ch80137	Corn	800	7	3	206.3	$121.3	$229.0	22.5
1	Ch90137	Corn	800	7	3	213.4	$124.4	$248.5	23.1
1	Ch30118	Corn	800	8	1	159.3	$66.4	$134.6	14.6
1	Ch40118	Corn	800	8	1	163.4	$69.5	$144.3	15.3
1	Ch50118	Corn	800	8	1	166.9	$73.5	$151.6	16.2
1	Ch60118	Corn	800	8	1	180.8	$85.1	$192.4	18.8
1	Ch70118	Corn	800	8	1	193.9	$97.6	$213.2	21.5
1	Ch80118	Corn	800	8	1	206.3	$102.1	$248.2	22.5
1	Ch90118	Corn	800	8	1	213.4	$104.6	$268.2	23.1
1	Ch30128	Corn	800	8	2	159.3	$71.0	$130.0	14.6
1	Ch40128	Corn	800	8	2	163.4	$74.4	$139.4	15.3
1	Ch50128	Corn	800	8	2	166.9	$78.7	$146.4	16.2
1	Ch60128	Corn	800	8	2	180.8	$91.0	$186.5	18.8
1	Ch70128	Corn	800	8	2	193.9	$104.5	$206.4	21.5
1	Ch80128	Corn	800	8	2	206.3	$109.2	$241.1	22.5
1	Ch90128	Corn	800	8	2	213.4	$112.0	$260.9	23.1
1	Ch30138	Corn	800	8	3	159.3	$77.3	$123.7	14.6
1	Ch40138	Corn	800	8	3	163.4	$80.9	$132.9	15.3
1	Ch50138	Corn	800	8	3	166.9	$85.6	$139.6	16.2
1	Ch60138	Corn	800	8	3	180.8	$99.0	$178.5	18.8
1	Ch70138	Corn	800	8	3	193.9	$113.6	$197.2	21.5

Table A5 (continued)

Year	Activity	Crop	GPM	Lev	Piv	Yield	PC	NR	ac-in/ac
1	Ch80138	Corn	800	8	3	206.3	$118.8	$231.5	22.5
1	Ch90138	Corn	800	8	3	213.4	$121.8	$251.1	23.1
1	Ch30148	Corn	800	8	4	159.3	$82.6	$118.4	14.6
1	Ch40148	Corn	800	8	4	163.4	$86.5	$127.3	15.3
1	Ch50148	Corn	800	8	4	166.9	$91.4	$133.7	16.2
1	Ch60148	Corn	800	8	4	180.8	$105.8	$171.7	18.8
1	Ch70148	Corn	800	8	4	193.9	$121.4	$189.4	21.5
1	Ch80148	Corn	800	8	4	206.3	$126.9	$223.4	22.5
1	Ch90148	Corn	800	8	4	213.4	$130.1	$242.7	23.1
1	Sz001	Sorghum	0	0	0	63.1	$0.0	$4.1	0.0

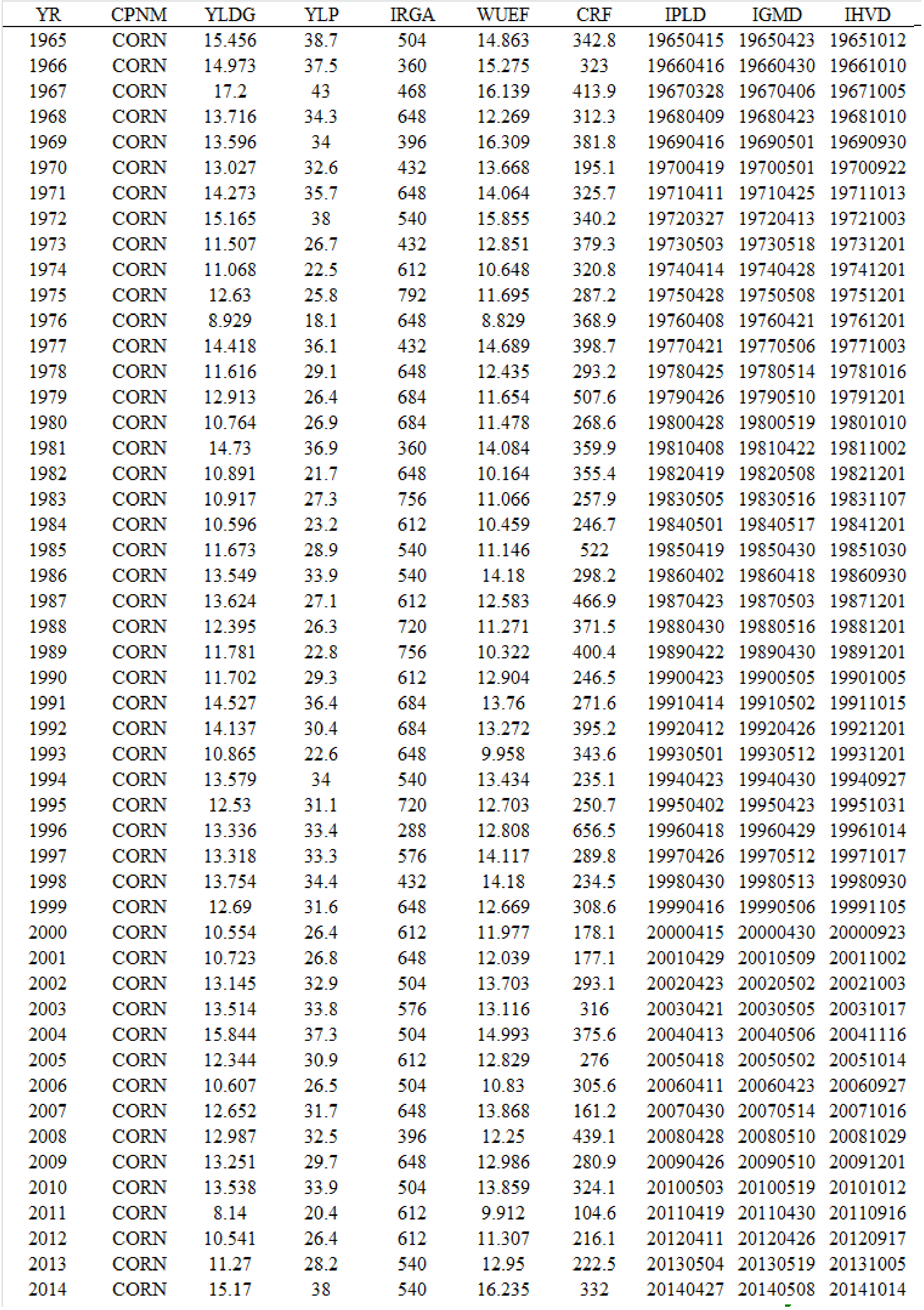
YR= Year, CPNM = Crop Name, YLDG = Yld in kg/ha, YLN = N in Kg/ha, YLP = P in Kg/ha, IRGA = Irrigation applied in mm, WUEF = Water Use efficiency, IPLD = Planting Date, IGMD = Germination Date, and IHVD = Harvest Date

Epic Simulation Results of Corn for 800 Gpm under .90 Stress Trigger



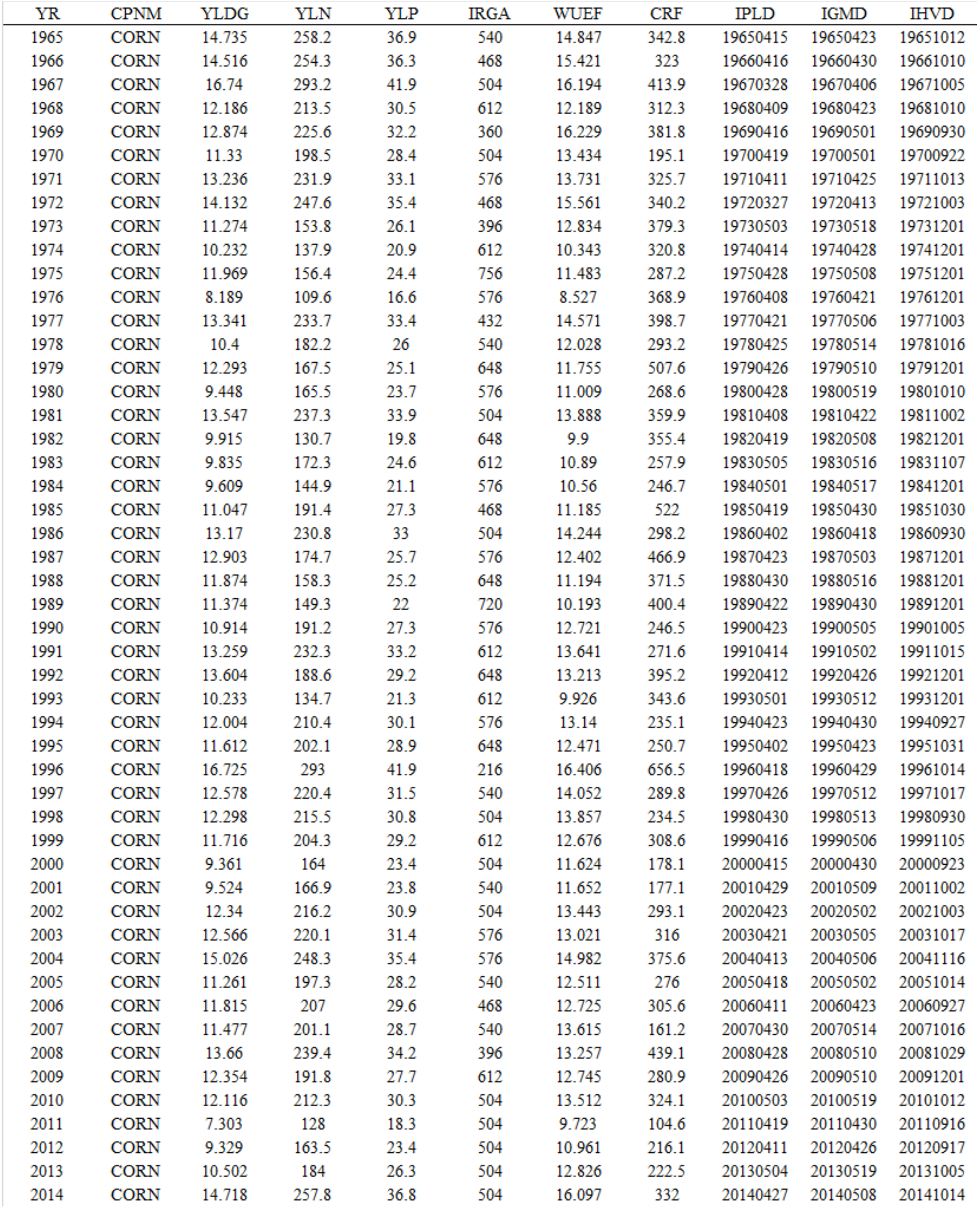
YR	CPNM	YLDG	YLN	YLP	IRGA	WUEF	CRF	IPLD	IGMD	IHVD
1965	CORN	16.469	288.6	41.2	504	15.159	342.8	19650415	19650423	19651012
1966	CORN	15.433	270.4	38.6	360	15.243	323	19660416	19660430	19661010
1967	CORN	17.445	305.6	43.7	504	16.262	413.9	19670328	19670406	19671005
1968	CORN	14.592	255.6	36.5	612	12.359	312.3	19680409	19680423	19681010
1969	CORN	14.314	250.7	35.8	396	16.151	381.8	19690416	19690501	19690930
1970	CORN	13.405	234.8	33.5	432	13.563	195.1	19700419	19700501	19700922
1971	CORN	15.185	266	38	612	13.914	325.7	19710411	19710425	19711013
1972	CORN	16.135	282.7	40.4	576	15.97	340.2	19720327	19720413	19721003
1973	CORN	11.699	159.5	27.1	432	12.907	379.3	19730503	19730518	19731201
1974	CORN	11.499	154.9	23.4	468	10.558	320.8	19740414	19740428	19741201
1975	CORN	13.207	172.5	26.9	828	11.616	287.2	19750428	19750508	19751201
1976	CORN	9.731	130.1	19.7	612	9	368.9	19760408	19760421	19761201
1977	CORN	14.731	258	36.9	324	14.29	398.7	19770421	19770506	19771003
1978	CORN	13.766	241.2	34.5	612	12.563	293.2	19780425	19780514	19781016
1979	CORN	13.817	188.1	28.2	648	11.776	507.6	19790426	19790510	19791201
1980	CORN	11.677	204.6	29.2	648	11.573	268.6	19800428	19800519	19801010
1981	CORN	14.91	261.2	37.3	360	14.206	359.9	19810408	19810422	19811002
1982	CORN	11.368	149.8	22.7	648	10.216	355.4	19820419	19820508	19821201
1983	CORN	12.24	214.4	30.6	720	11.076	257.9	19830505	19830516	19831107
1984	CORN	12.235	184.4	26.8	576	10.594	246.7	19840501	19840517	19841201
1985	CORN	11.44	198.2	28.3	612	10.076	522	19850419	19850430	19851030
1986	CORN	15.077	264.1	37.7	612	14.442	298.2	19860402	19860418	19860930
1987	CORN	13.98	189.4	27.8	504	11.959	466.9	19870423	19870503	19871201
1988	CORN	13.083	174.4	27.8	576	11.094	371.5	19880430	19880516	19881201
1989	CORN	11.714	153.7	22.7	648	9.727	400.4	19890422	19890430	19891201
1990	CORN	13.26	232.3	33.2	576	13.252	246.5	19900423	19900505	19901005
1991	CORN	14.889	260.8	37.3	684	13.926	271.6	19910414	19910502	19911015
1992	CORN	14.42	199.9	31	648	13.136	395.2	19920412	19920426	19921201
1993	CORN	10.793	142.1	22.4	612	9.916	343.6	19930501	19930512	19931201
1994	CORN	14.484	253.8	36.3	576	13.629	235.1	19940423	19940430	19940927
1995	CORN	13.843	240.8	34.4	792	12.563	250.7	19950402	19950423	19951031
1996	CORN	13.445	235.6	33.7	288	12.747	656.5	19960418	19960429	19961014
1997	CORN	14.001	245.3	35	540	14.132	289.8	19970426	19970512	19971017
1998	CORN	13.54	237.2	33.9	432	13.378	234.5	19980430	19980513	19980930
1999	CORN	14.209	247.8	35.4	684	12.909	308.6	19990416	19990506	19991105
2000	CORN	12.955	226.9	32.4	648	12.284	178.1	20000415	20000430	20000923
2001	CORN	12.321	215.8	30.8	684	12.323	177.1	20010429	20010509	20011002
2002	CORN	14.639	256.5	36.6	504	13.961	293.1	20020423	20020502	20021003
2003	CORN	14.575	255.3	36.5	540	13.211	316	20030421	20030505	20031017
2004	CORN	15.892	262.7	37.5	540	14.67	375.6	20040413	20040506	20041116
2005	CORN	13.584	237.9	34	612	12.775	276	20050418	20050502	20051014
2006	CORN	14.189	248.6	35.5	468	13.151	305.6	20060411	20060423	20060927
2007	CORN	14.135	247.6	35.4	648	13.89	161.2	20070430	20070514	20071016
2008	CORN	12.492	218.9	31.3	432	11.245	439.1	20080428	20080510	20081029
2009	CORN	14.224	220.8	31.9	684	13	280.9	20090426	20090510	20091201
2010	CORN	15.019	263.1	37.6	432	13.907	324.1	20100503	20100519	20101012
2011	CORN	9.516	166.7	23.8	612	10.089	104.6	20110419	20110430	20110916
2012	CORN	12.849	225.1	32.2	576	11.672	216.1	20120411	20120426	20120917
2013	CORN	12.3	215.5	30.8	432	12.301	222.5	20130504	20130519	20131005
2014	CORN	15.755	276	39.4	576	16.351	332	20140427	20140508	20141014

Epic Simulation Results of Corn for 700 GPM under .90 Stress Trigger



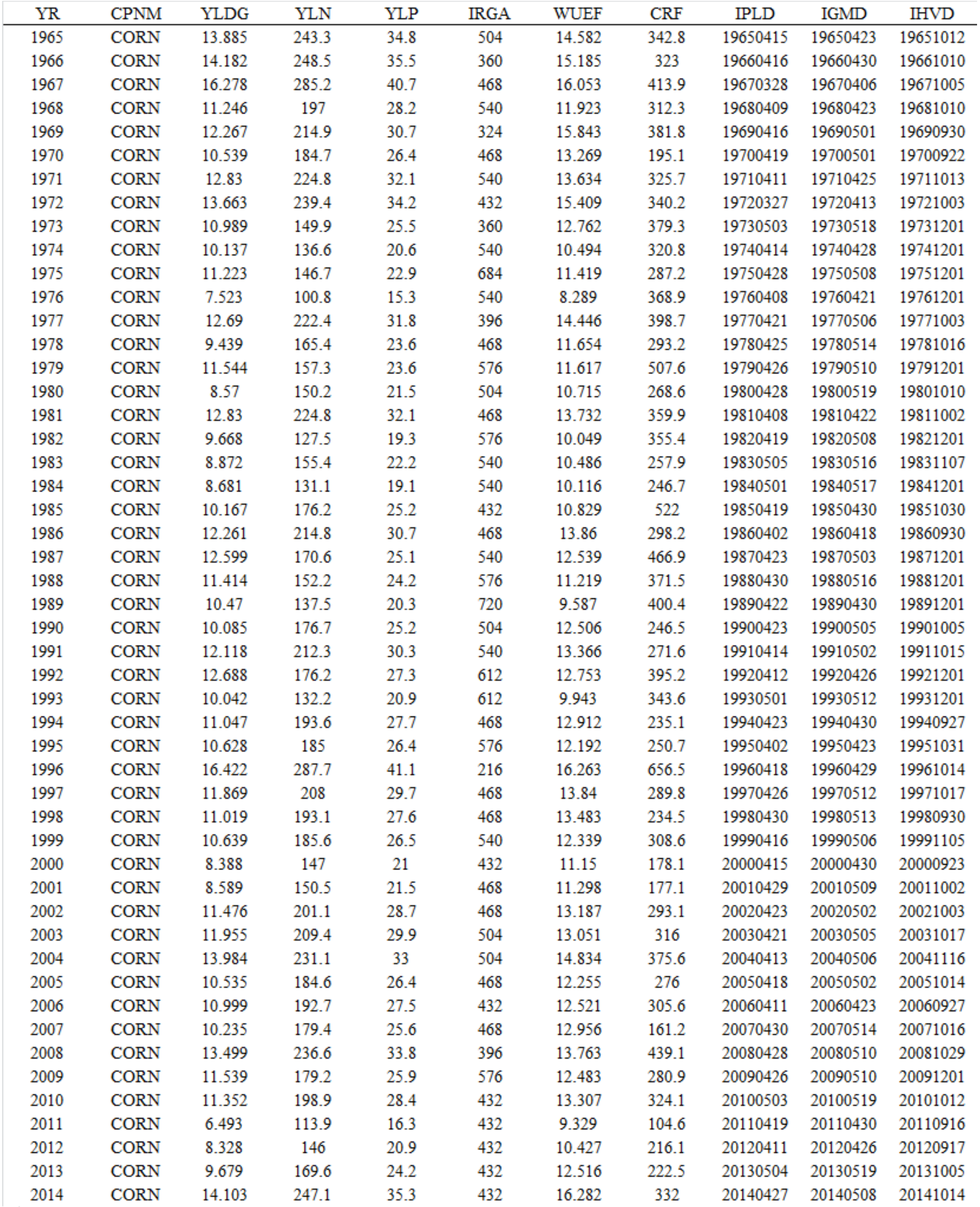
YR	CPNM	YLDG	YLP	IRGA	WUEF	CRF	IPLD	IGMD	IHVD
1965	CORN	15.456	38.7	504	14.863	342.8	19650415	19650423	19651012
1966	CORN	14.973	37.5	360	15.275	323	19660416	19660430	19661010
1967	CORN	17.2	43	468	16.139	413.9	19670328	19670406	19671005
1968	CORN	13.716	34.3	648	12.269	312.3	19680409	19680423	19681010
1969	CORN	13.596	34	396	16.309	381.8	19690416	19690501	19690930
1970	CORN	13.027	32.6	432	13.668	195.1	19700419	19700501	19700922
1971	CORN	14.273	35.7	648	14.064	325.7	19710411	19710425	19711013
1972	CORN	15.165	38	540	15.855	340.2	19720327	19720413	19721003
1973	CORN	11.507	26.7	432	12.851	379.3	19730503	19730518	19731201
1974	CORN	11.068	22.5	612	10.648	320.8	19740414	19740428	19741201
1975	CORN	12.63	25.8	792	11.695	287.2	19750428	19750508	19751201
1976	CORN	8.929	18.1	648	8.829	368.9	19760408	19760421	19761201
1977	CORN	14.418	36.1	432	14.689	398.7	19770421	19770506	19771003
1978	CORN	11.616	29.1	648	12.435	293.2	19780425	19780514	19781016
1979	CORN	12.913	26.4	684	11.654	507.6	19790426	19790510	19791201
1980	CORN	10.764	26.9	684	11.478	268.6	19800428	19800519	19801010
1981	CORN	14.73	36.9	360	14.084	359.9	19810408	19810422	19811002
1982	CORN	10.891	21.7	648	10.164	355.4	19820419	19820508	19821201
1983	CORN	10.917	27.3	756	11.066	257.9	19830505	19830516	19831107
1984	CORN	10.596	23.2	612	10.459	246.7	19840501	19840517	19841201
1985	CORN	11.673	28.9	540	11.146	522	19850419	19850430	19851030
1986	CORN	13.549	33.9	540	14.18	298.2	19860402	19860418	19860930
1987	CORN	13.624	27.1	612	12.583	466.9	19870423	19870503	19871201
1988	CORN	12.395	26.3	720	11.271	371.5	19880430	19880516	19881201
1989	CORN	11.781	22.8	756	10.322	400.4	19890422	19890430	19891201
1990	CORN	11.702	29.3	612	12.904	246.5	19900423	19900505	19901005
1991	CORN	14.527	36.4	684	13.76	271.6	19910414	19910502	19911015
1992	CORN	14.137	30.4	684	13.272	395.2	19920412	19920426	19921201
1993	CORN	10.865	22.6	648	9.958	343.6	19930501	19930512	19931201
1994	CORN	13.579	34	540	13.434	235.1	19940423	19940430	19940927
1995	CORN	12.53	31.1	720	12.703	250.7	19950402	19950423	19951031
1996	CORN	13.336	33.4	288	12.808	656.5	19960418	19960429	19961014
1997	CORN	13.318	33.3	576	14.117	289.8	19970426	19970512	19971017
1998	CORN	13.754	34.4	432	14.18	234.5	19980430	19980513	19980930
1999	CORN	12.69	31.6	648	12.669	308.6	19990416	19990506	19991105
2000	CORN	10.554	26.4	612	11.977	178.1	20000415	20000430	20000923
2001	CORN	10.723	26.8	648	12.039	177.1	20010429	20010509	20011002
2002	CORN	13.145	32.9	504	13.703	293.1	20020423	20020502	20021003
2003	CORN	13.514	33.8	576	13.116	316	20030421	20030505	20031017
2004	CORN	15.844	37.3	504	14.993	375.6	20040413	20040506	20041116
2005	CORN	12.344	30.9	612	12.829	276	20050418	20050502	20051014
2006	CORN	10.607	26.5	504	10.83	305.6	20060411	20060423	20060927
2007	CORN	12.652	31.7	648	13.868	161.2	20070430	20070514	20071016
2008	CORN	12.987	32.5	396	12.25	439.1	20080428	20080510	20081029
2009	CORN	13.251	29.7	648	12.986	280.9	20090426	20090510	20091201
2010	CORN	13.538	33.9	504	13.859	324.1	20100503	20100519	20101012
2011	CORN	8.14	20.4	612	9.912	104.6	20110419	20110430	20110916
2012	CORN	10.541	26.4	612	11.307	216.1	20120411	20120426	20120917
2013	CORN	11.27	28.2	540	12.95	222.5	20130504	20130519	20131005
2014	CORN	15.17	38	540	16.235	332	20140427	20140508	20141014

Epic Simulation Results of Corn for 600 GPM under .90 Stress Trigger



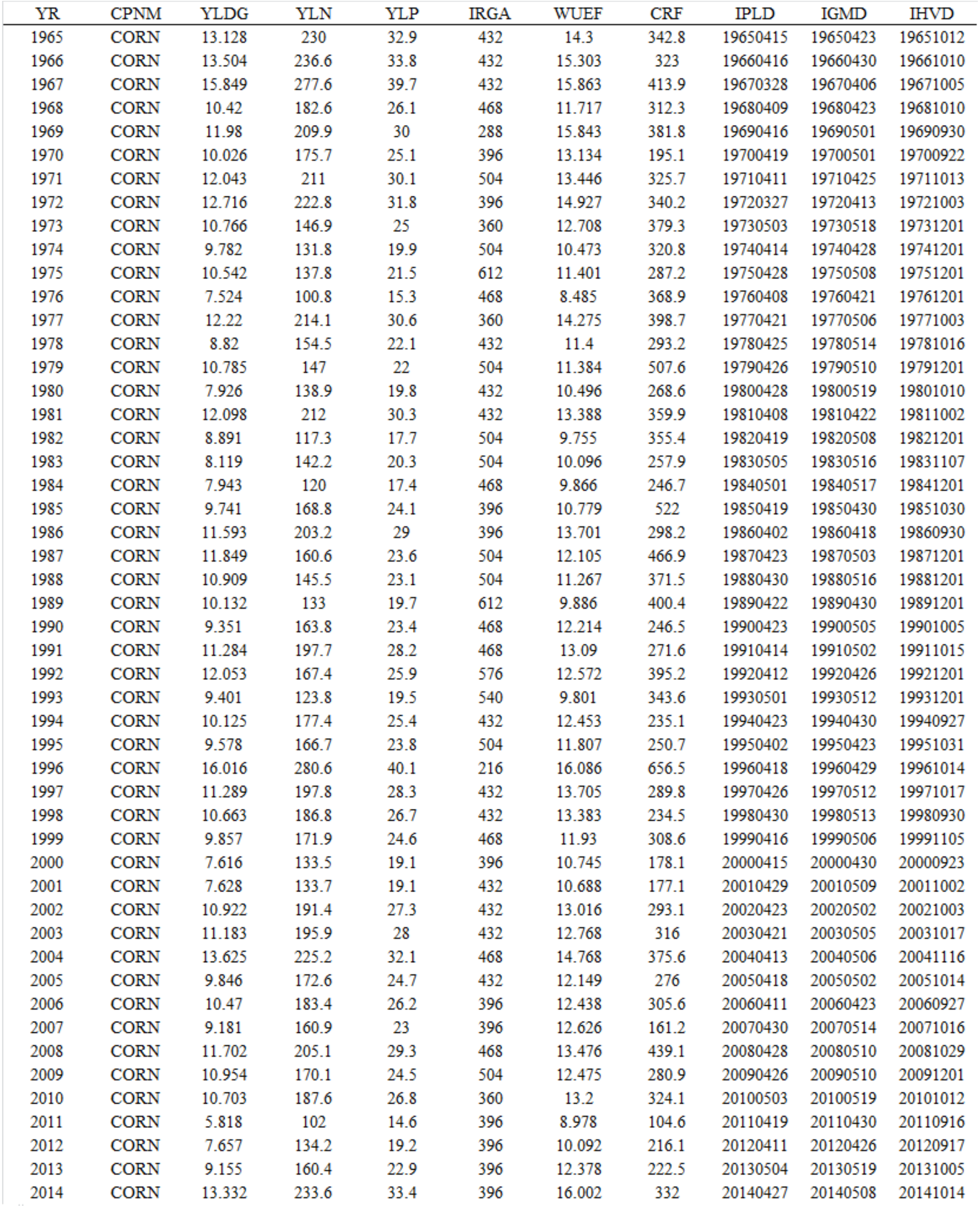
YR	CPNM	YLDG	YLN	YLP	IRGA	WUEF	CRF	IPLD	IGMD	IHVD
1965	CORN	14.735	258.2	36.9	540	14.847	342.8	19650415	19650423	19651012
1966	CORN	14.516	254.3	36.3	468	15.421	323	19660416	19660430	19661010
1967	CORN	16.74	293.2	41.9	504	16.194	413.9	19670328	19670406	19671005
1968	CORN	12.186	213.5	30.5	612	12.189	312.3	19680409	19680423	19681010
1969	CORN	12.874	225.6	32.2	360	16.229	381.8	19690416	19690501	19690930
1970	CORN	11.33	198.5	28.4	504	13.434	195.1	19700419	19700501	19700922
1971	CORN	13.236	231.9	33.1	576	13.731	325.7	19710411	19710425	19711013
1972	CORN	14.132	247.6	35.4	468	15.561	340.2	19720327	19720413	19721003
1973	CORN	11.274	153.8	26.1	396	12.834	379.3	19730503	19730518	19731201
1974	CORN	10.232	137.9	20.9	612	10.343	320.8	19740414	19740428	19741201
1975	CORN	11.969	156.4	24.4	756	11.483	287.2	19750428	19750508	19751201
1976	CORN	8.189	109.6	16.6	576	8.527	368.9	19760408	19760421	19761201
1977	CORN	13.341	233.7	33.4	432	14.571	398.7	19770421	19770506	19771003
1978	CORN	10.4	182.2	26	540	12.028	293.2	19780425	19780514	19781016
1979	CORN	12.293	167.5	25.1	648	11.755	507.6	19790426	19790510	19791201
1980	CORN	9.448	165.5	23.7	576	11.009	268.6	19800428	19800519	19801010
1981	CORN	13.547	237.3	33.9	504	13.888	359.9	19810408	19810422	19811002
1982	CORN	9.915	130.7	19.8	648	9.9	355.4	19820419	19820508	19821201
1983	CORN	9.835	172.3	24.6	612	10.89	257.9	19830505	19830516	19831107
1984	CORN	9.609	144.9	21.1	576	10.56	246.7	19840501	19840517	19841201
1985	CORN	11.047	191.4	27.3	468	11.185	522	19850419	19850430	19851030
1986	CORN	13.17	230.8	33	504	14.244	298.2	19860402	19860418	19860930
1987	CORN	12.903	174.7	25.7	576	12.402	466.9	19870423	19870503	19871201
1988	CORN	11.874	158.3	25.2	648	11.194	371.5	19880430	19880516	19881201
1989	CORN	11.374	149.3	22	720	10.193	400.4	19890422	19890430	19891201
1990	CORN	10.914	191.2	27.3	576	12.721	246.5	19900423	19900505	19901005
1991	CORN	13.259	232.3	33.2	612	13.641	271.6	19910414	19910502	19911015
1992	CORN	13.604	188.6	29.2	648	13.213	395.2	19920412	19920426	19921201
1993	CORN	10.233	134.7	21.3	612	9.926	343.6	19930501	19930512	19931201
1994	CORN	12.004	210.4	30.1	576	13.14	235.1	19940423	19940430	19940927
1995	CORN	11.612	202.1	28.9	648	12.471	250.7	19950402	19950423	19951031
1996	CORN	16.725	293	41.9	216	16.406	656.5	19960418	19960429	19961014
1997	CORN	12.578	220.4	31.5	540	14.052	289.8	19970426	19970512	19971017
1998	CORN	12.298	215.5	30.8	504	13.857	234.5	19980430	19980513	19980930
1999	CORN	11.716	204.3	29.2	612	12.676	308.6	19990416	19990506	19991105
2000	CORN	9.361	164	23.4	504	11.624	178.1	20000415	20000430	20000923
2001	CORN	9.524	166.9	23.8	540	11.652	177.1	20010429	20010509	20011002
2002	CORN	12.34	216.2	30.9	504	13.443	293.1	20020423	20020502	20021003
2003	CORN	12.566	220.1	31.4	576	13.021	316	20030421	20030505	20031017
2004	CORN	15.026	248.3	35.4	576	14.982	375.6	20040413	20040506	20041116
2005	CORN	11.261	197.3	28.2	540	12.511	276	20050418	20050502	20051014
2006	CORN	11.815	207	29.6	468	12.725	305.6	20060411	20060423	20060927
2007	CORN	11.477	201.1	28.7	540	13.615	161.2	20070430	20070514	20071016
2008	CORN	13.66	239.4	34.2	396	13.257	439.1	20080428	20080510	20081029
2009	CORN	12.354	191.8	27.7	612	12.745	280.9	20090426	20090510	20091201
2010	CORN	12.116	212.3	30.3	504	13.512	324.1	20100503	20100519	20101012
2011	CORN	7.303	128	18.3	504	9.723	104.6	20110419	20110430	20110916
2012	CORN	9.329	163.5	23.4	504	10.961	216.1	20120411	20120426	20120917
2013	CORN	10.502	184	26.3	504	12.826	222.5	20130504	20130519	20131005
2014	CORN	14.718	257.8	36.8	504	16.097	332	20140427	20140508	20141014

Epic Simulation Results of Corn for 500 GPM under .90 Stress Trigger



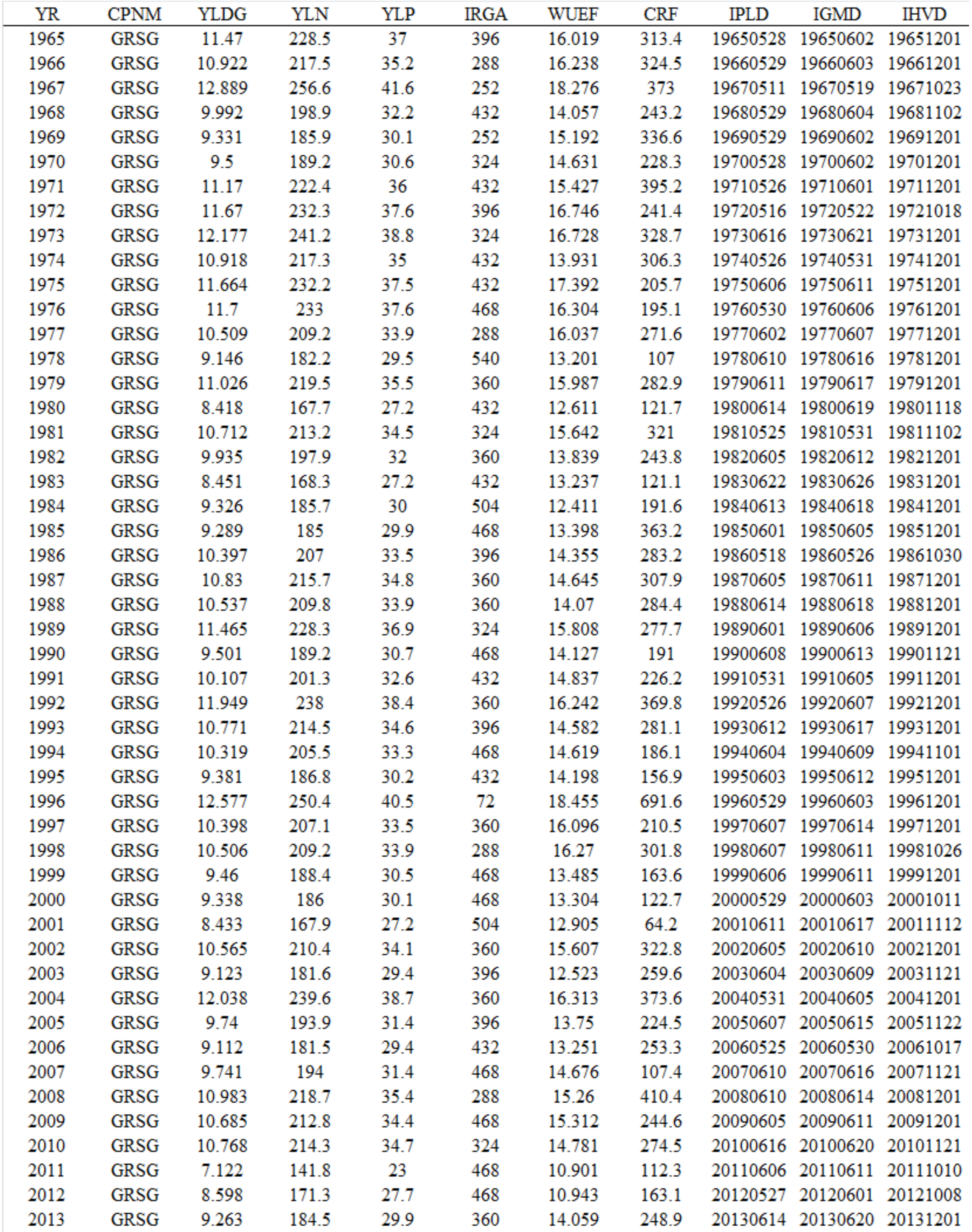
YR	CPNM	YLDG	YLN	YLP	IRGA	WUEF	CRF	IPLD	IGMD	IHVD
1965	CORN	13.885	243.3	34.8	504	14.582	342.8	19650415	19650423	19651012
1966	CORN	14.182	248.5	35.5	360	15.185	323	19660416	19660430	19661010
1967	CORN	16.278	285.2	40.7	468	16.053	413.9	19670328	19670406	19671005
1968	CORN	11.246	197	28.2	540	11.923	312.3	19680409	19680423	19681010
1969	CORN	12.267	214.9	30.7	324	15.843	381.8	19690416	19690501	19690930
1970	CORN	10.539	184.7	26.4	468	13.269	195.1	19700419	19700501	19700922
1971	CORN	12.83	224.8	32.1	540	13.634	325.7	19710411	19710425	19711013
1972	CORN	13.663	239.4	34.2	432	15.409	340.2	19720327	19720413	19721003
1973	CORN	10.989	149.9	25.5	360	12.762	379.3	19730503	19730518	19731201
1974	CORN	10.137	136.6	20.6	540	10.494	320.8	19740414	19740428	19741201
1975	CORN	11.223	146.7	22.9	684	11.419	287.2	19750428	19750508	19751201
1976	CORN	7.523	100.8	15.3	540	8.289	368.9	19760408	19760421	19761201
1977	CORN	12.69	222.4	31.8	396	14.446	398.7	19770421	19770506	19771003
1978	CORN	9.439	165.4	23.6	468	11.654	293.2	19780425	19780514	19781016
1979	CORN	11.544	157.3	23.6	576	11.617	507.6	19790426	19790510	19791201
1980	CORN	8.57	150.2	21.5	504	10.715	268.6	19800428	19800519	19801010
1981	CORN	12.83	224.8	32.1	468	13.732	359.9	19810408	19810422	19811002
1982	CORN	9.668	127.5	19.3	576	10.049	355.4	19820419	19820508	19821201
1983	CORN	8.872	155.4	22.2	540	10.486	257.9	19830505	19830516	19831107
1984	CORN	8.681	131.1	19.1	540	10.116	246.7	19840501	19840517	19841201
1985	CORN	10.167	176.2	25.2	432	10.829	522	19850419	19850430	19851030
1986	CORN	12.261	214.8	30.7	468	13.86	298.2	19860402	19860418	19860930
1987	CORN	12.599	170.6	25.1	540	12.539	466.9	19870423	19870503	19871201
1988	CORN	11.414	152.2	24.2	576	11.219	371.5	19880430	19880516	19881201
1989	CORN	10.47	137.5	20.3	720	9.587	400.4	19890422	19890430	19891201
1990	CORN	10.085	176.7	25.2	504	12.506	246.5	19900423	19900505	19901005
1991	CORN	12.118	212.3	30.3	540	13.366	271.6	19910414	19910502	19911015
1992	CORN	12.688	176.2	27.3	612	12.753	395.2	19920412	19920426	19921201
1993	CORN	10.042	132.2	20.9	612	9.943	343.6	19930501	19930512	19931201
1994	CORN	11.047	193.6	27.7	468	12.912	235.1	19940423	19940430	19940927
1995	CORN	10.628	185	26.4	576	12.192	250.7	19950402	19950423	19951031
1996	CORN	16.422	287.7	41.1	216	16.263	656.5	19960418	19960429	19961014
1997	CORN	11.869	208	29.7	468	13.84	289.8	19970426	19970512	19971017
1998	CORN	11.019	193.1	27.6	468	13.483	234.5	19980430	19980513	19980930
1999	CORN	10.639	185.6	26.5	540	12.339	308.6	19990416	19990506	19991105
2000	CORN	8.388	147	21	432	11.15	178.1	20000415	20000430	20000923
2001	CORN	8.589	150.5	21.5	468	11.298	177.1	20010429	20010509	20011002
2002	CORN	11.476	201.1	28.7	468	13.187	293.1	20020423	20020502	20021003
2003	CORN	11.955	209.4	29.9	504	13.051	316	20030421	20030505	20031017
2004	CORN	13.984	231.1	33	504	14.834	375.6	20040413	20040506	20041116
2005	CORN	10.535	184.6	26.4	468	12.255	276	20050418	20050502	20051014
2006	CORN	10.999	192.7	27.5	432	12.521	305.6	20060411	20060423	20060927
2007	CORN	10.235	179.4	25.6	468	12.956	161.2	20070430	20070514	20071016
2008	CORN	13.499	236.6	33.8	396	13.763	439.1	20080428	20080510	20081029
2009	CORN	11.539	179.2	25.9	576	12.483	280.9	20090426	20090510	20091201
2010	CORN	11.352	198.9	28.4	432	13.307	324.1	20100503	20100519	20101012
2011	CORN	6.493	113.9	16.3	432	9.329	104.6	20110419	20110430	20110916
2012	CORN	8.328	146	20.9	432	10.427	216.1	20120411	20120426	20120917
2013	CORN	9.679	169.6	24.2	432	12.516	222.5	20130504	20130519	20131005
2014	CORN	14.103	247.1	35.3	432	16.282	332	20140427	20140508	20141014

Epic Simulation Results of Corn for 400 GPM under .90 Stress Trigger



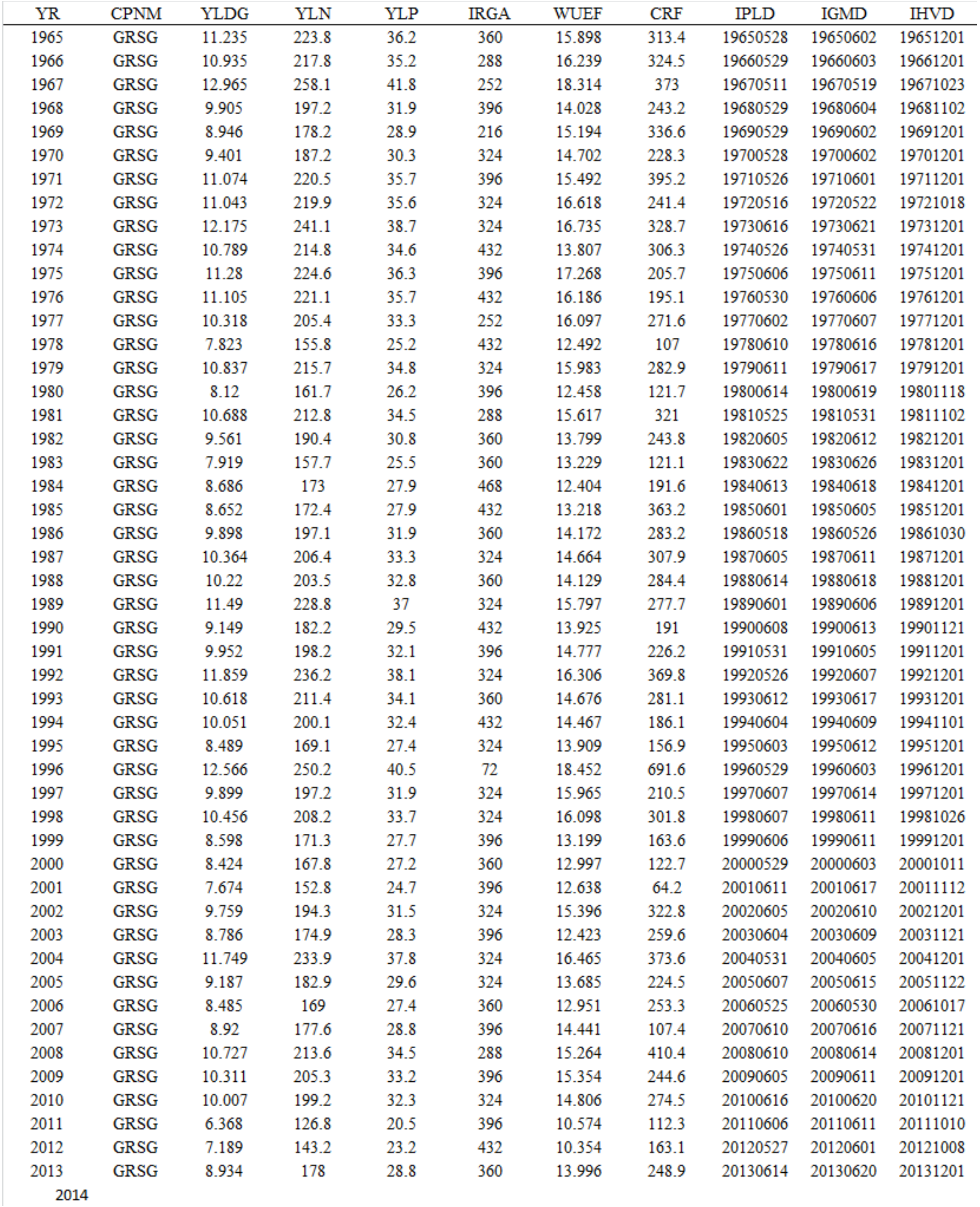
YR	CPNM	YLDG	YLN	YLP	IRGA	WUEF	CRF	IPLD	IGMD	IHVD
1965	CORN	13.128	230	32.9	432	14.3	342.8	19650415	19650423	19651012
1966	CORN	13.504	236.6	33.8	432	15.303	323	19660416	19660430	19661010
1967	CORN	15.849	277.6	39.7	432	15.863	413.9	19670328	19670406	19671005
1968	CORN	10.42	182.6	26.1	468	11.717	312.3	19680409	19680423	19681010
1969	CORN	11.98	209.9	30	288	15.843	381.8	19690416	19690501	19690930
1970	CORN	10.026	175.7	25.1	396	13.134	195.1	19700419	19700501	19700922
1971	CORN	12.043	211	30.1	504	13.446	325.7	19710411	19710425	19711013
1972	CORN	12.716	222.8	31.8	396	14.927	340.2	19720327	19720413	19721003
1973	CORN	10.766	146.9	25	360	12.708	379.3	19730503	19730518	19731201
1974	CORN	9.782	131.8	19.9	504	10.473	320.8	19740414	19740428	19741201
1975	CORN	10.542	137.8	21.5	612	11.401	287.2	19750428	19750508	19751201
1976	CORN	7.524	100.8	15.3	468	8.485	368.9	19760408	19760421	19761201
1977	CORN	12.22	214.1	30.6	360	14.275	398.7	19770421	19770506	19771003
1978	CORN	8.82	154.5	22.1	432	11.4	293.2	19780425	19780514	19781016
1979	CORN	10.785	147	22	504	11.384	507.6	19790426	19790510	19791201
1980	CORN	7.926	138.9	19.8	432	10.496	268.6	19800428	19800519	19801010
1981	CORN	12.098	212	30.3	432	13.388	359.9	19810408	19810422	19811002
1982	CORN	8.891	117.3	17.7	504	9.755	355.4	19820419	19820508	19821201
1983	CORN	8.119	142.2	20.3	504	10.096	257.9	19830505	19830516	19831107
1984	CORN	7.943	120	17.4	468	9.866	246.7	19840501	19840517	19841201
1985	CORN	9.741	168.8	24.1	396	10.779	522	19850419	19850430	19851030
1986	CORN	11.593	203.2	29	396	13.701	298.2	19860402	19860418	19860930
1987	CORN	11.849	160.6	23.6	504	12.105	466.9	19870423	19870503	19871201
1988	CORN	10.909	145.5	23.1	504	11.267	371.5	19880430	19880516	19881201
1989	CORN	10.132	133	19.7	612	9.886	400.4	19890422	19890430	19891201
1990	CORN	9.351	163.8	23.4	468	12.214	246.5	19900423	19900505	19901005
1991	CORN	11.284	197.7	28.2	468	13.09	271.6	19910414	19910502	19911015
1992	CORN	12.053	167.4	25.9	576	12.572	395.2	19920412	19920426	19921201
1993	CORN	9.401	123.8	19.5	540	9.801	343.6	19930501	19930512	19931201
1994	CORN	10.125	177.4	25.4	432	12.453	235.1	19940423	19940430	19940927
1995	CORN	9.578	166.7	23.8	504	11.807	250.7	19950402	19950423	19951031
1996	CORN	16.016	280.6	40.1	216	16.086	656.5	19960418	19960429	19961014
1997	CORN	11.289	197.8	28.3	432	13.705	289.8	19970426	19970512	19971017
1998	CORN	10.663	186.8	26.7	432	13.383	234.5	19980430	19980513	19980930
1999	CORN	9.857	171.9	24.6	468	11.93	308.6	19990416	19990506	19991105
2000	CORN	7.616	133.5	19.1	396	10.745	178.1	20000415	20000430	20000923
2001	CORN	7.628	133.7	19.1	432	10.688	177.1	20010429	20010509	20011002
2002	CORN	10.922	191.4	27.3	432	13.016	293.1	20020423	20020502	20021003
2003	CORN	11.183	195.9	28	432	12.768	316	20030421	20030505	20031017
2004	CORN	13.625	225.2	32.1	468	14.768	375.6	20040413	20040506	20041116
2005	CORN	9.846	172.6	24.7	432	12.149	276	20050418	20050502	20051014
2006	CORN	10.47	183.4	26.2	396	12.438	305.6	20060411	20060423	20060927
2007	CORN	9.181	160.9	23	396	12.626	161.2	20070430	20070514	20071016
2008	CORN	11.702	205.1	29.3	468	13.476	439.1	20080428	20080510	20081029
2009	CORN	10.954	170.1	24.5	504	12.475	280.9	20090426	20090510	20091201
2010	CORN	10.703	187.6	26.8	360	13.2	324.1	20100503	20100519	20101012
2011	CORN	5.818	102	14.6	396	8.978	104.6	20110419	20110430	20110916
2012	CORN	7.657	134.2	19.2	396	10.092	216.1	20120411	20120426	20120917
2013	CORN	9.155	160.4	22.9	396	12.378	222.5	20130504	20130519	20131005
2014	CORN	13.332	233.6	33.4	396	16.002	332	20140427	20140508	20141014

Epic Simulation Results of Sorghum for 800 GPM under .90 Stress Trigger



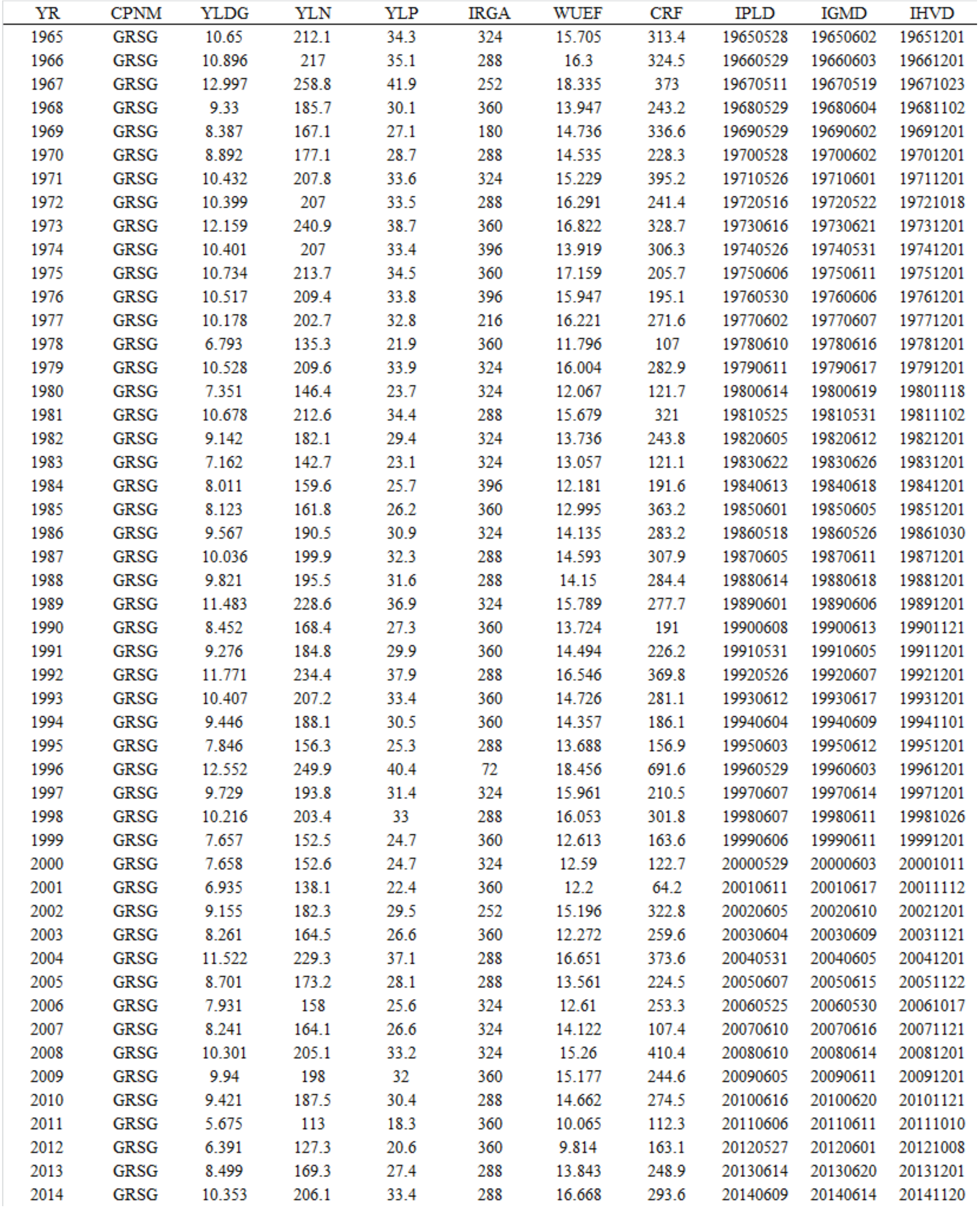
YR	CPNM	YLDG	YLN	YLP	IRGA	WUEF	CRF	IPLD	IGMD	IHVD
1965	GRSG	11.47	228.5	37	396	16.019	313.4	19650528	19650602	19651201
1966	GRSG	10.922	217.5	35.2	288	16.238	324.5	19660529	19660603	19661201
1967	GRSG	12.889	256.6	41.6	252	18.276	373	19670511	19670519	19671023
1968	GRSG	9.992	198.9	32.2	432	14.057	243.2	19680529	19680604	19681102
1969	GRSG	9.331	185.9	30.1	252	15.192	336.6	19690529	19690602	19691201
1970	GRSG	9.5	189.2	30.6	324	14.631	228.3	19700528	19700602	19701201
1971	GRSG	11.17	222.4	36	432	15.427	395.2	19710526	19710601	19711201
1972	GRSG	11.67	232.3	37.6	396	16.746	241.4	19720516	19720522	19721018
1973	GRSG	12.177	241.2	38.8	324	16.728	328.7	19730616	19730621	19731201
1974	GRSG	10.918	217.3	35	432	13.931	306.3	19740526	19740531	19741201
1975	GRSG	11.664	232.2	37.5	432	17.392	205.7	19750606	19750611	19751201
1976	GRSG	11.7	233	37.6	468	16.304	195.1	19760530	19760606	19761201
1977	GRSG	10.509	209.2	33.9	288	16.037	271.6	19770602	19770607	19771201
1978	GRSG	9.146	182.2	29.5	540	13.201	107	19780610	19780616	19781201
1979	GRSG	11.026	219.5	35.5	360	15.987	282.9	19790611	19790617	19791201
1980	GRSG	8.418	167.7	27.2	432	12.611	121.7	19800614	19800619	19801118
1981	GRSG	10.712	213.2	34.5	324	15.642	321	19810525	19810531	19811102
1982	GRSG	9.935	197.9	32	360	13.839	243.8	19820605	19820612	19821201
1983	GRSG	8.451	168.3	27.2	432	13.237	121.1	19830622	19830626	19831201
1984	GRSG	9.326	185.7	30	504	12.411	191.6	19840613	19840618	19841201
1985	GRSG	9.289	185	29.9	468	13.398	363.2	19850601	19850605	19851201
1986	GRSG	10.397	207	33.5	396	14.355	283.2	19860518	19860526	19861030
1987	GRSG	10.83	215.7	34.8	360	14.645	307.9	19870605	19870611	19871201
1988	GRSG	10.537	209.8	33.9	360	14.07	284.4	19880614	19880618	19881201
1989	GRSG	11.465	228.3	36.9	324	15.808	277.7	19890601	19890606	19891201
1990	GRSG	9.501	189.2	30.7	468	14.127	191	19900608	19900613	19901121
1991	GRSG	10.107	201.3	32.6	432	14.837	226.2	19910531	19910605	19911201
1992	GRSG	11.949	238	38.4	360	16.242	369.8	19920526	19920607	19921201
1993	GRSG	10.771	214.5	34.6	396	14.582	281.1	19930612	19930617	19931201
1994	GRSG	10.319	205.5	33.3	468	14.619	186.1	19940604	19940609	19941101
1995	GRSG	9.381	186.8	30.2	432	14.198	156.9	19950603	19950612	19951201
1996	GRSG	12.577	250.4	40.5	72	18.455	691.6	19960529	19960603	19961201
1997	GRSG	10.398	207.1	33.5	360	16.096	210.5	19970607	19970614	19971201
1998	GRSG	10.506	209.2	33.9	288	16.27	301.8	19980607	19980611	19981026
1999	GRSG	9.46	188.4	30.5	468	13.485	163.6	19990606	19990611	19991201
2000	GRSG	9.338	186	30.1	468	13.304	122.7	20000529	20000603	20001011
2001	GRSG	8.433	167.9	27.2	504	12.905	64.2	20010611	20010617	20011112
2002	GRSG	10.565	210.4	34.1	360	15.607	322.8	20020605	20020610	20021201
2003	GRSG	9.123	181.6	29.4	396	12.523	259.6	20030604	20030609	20031121
2004	GRSG	12.038	239.6	38.7	360	16.313	373.6	20040531	20040605	20041201
2005	GRSG	9.74	193.9	31.4	396	13.75	224.5	20050607	20050615	20051122
2006	GRSG	9.112	181.5	29.4	432	13.251	253.3	20060525	20060530	20061017
2007	GRSG	9.741	194	31.4	468	14.676	107.4	20070610	20070616	20071121
2008	GRSG	10.983	218.7	35.4	288	15.26	410.4	20080610	20080614	20081201
2009	GRSG	10.685	212.8	34.4	468	15.312	244.6	20090605	20090611	20091201
2010	GRSG	10.768	214.3	34.7	324	14.781	274.5	20100616	20100620	20101121
2011	GRSG	7.122	141.8	23	468	10.901	112.3	20110606	20110611	20111010
2012	GRSG	8.598	171.3	27.7	468	10.943	163.1	20120527	20120601	20121008
2013	GRSG	9.263	184.5	29.9	360	14.059	248.9	20130614	20130620	20131201

Epic Simulation Results of Sorghum for 700 GPM under .90 Stress Trigger



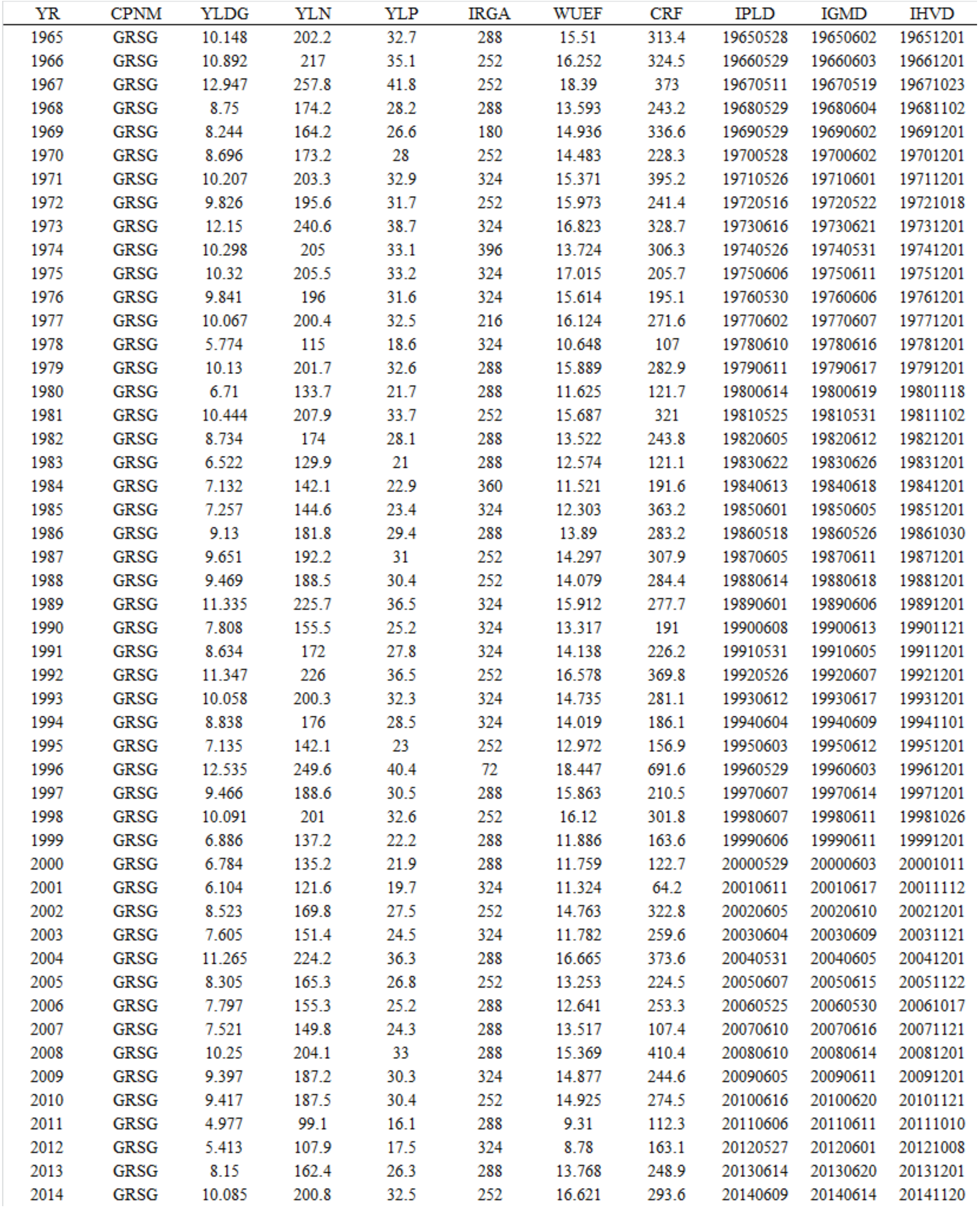
YR	CPNM	YLDG	YLN	YLP	IRGA	WUEF	CRF	IPLD	IGMD	IHVD
1965	GRSG	11.235	223.8	36.2	360	15.898	313.4	19650528	19650602	19651201
1966	GRSG	10.935	217.8	35.2	288	16.239	324.5	19660529	19660603	19661201
1967	GRSG	12.965	258.1	41.8	252	18.314	373	19670511	19670519	19671023
1968	GRSG	9.905	197.2	31.9	396	14.028	243.2	19680529	19680604	19681102
1969	GRSG	8.946	178.2	28.9	216	15.194	336.6	19690529	19690602	19691201
1970	GRSG	9.401	187.2	30.3	324	14.702	228.3	19700528	19700602	19701201
1971	GRSG	11.074	220.5	35.7	396	15.492	395.2	19710526	19710601	19711201
1972	GRSG	11.043	219.9	35.6	324	16.618	241.4	19720516	19720522	19721018
1973	GRSG	12.175	241.1	38.7	324	16.735	328.7	19730616	19730621	19731201
1974	GRSG	10.789	214.8	34.6	432	13.807	306.3	19740526	19740531	19741201
1975	GRSG	11.28	224.6	36.3	396	17.268	205.7	19750606	19750611	19751201
1976	GRSG	11.105	221.1	35.7	432	16.186	195.1	19760530	19760606	19761201
1977	GRSG	10.318	205.4	33.3	252	16.097	271.6	19770602	19770607	19771201
1978	GRSG	7.823	155.8	25.2	432	12.492	107	19780610	19780616	19781201
1979	GRSG	10.837	215.7	34.8	324	15.983	282.9	19790611	19790617	19791201
1980	GRSG	8.12	161.7	26.2	396	12.458	121.7	19800614	19800619	19801118
1981	GRSG	10.688	212.8	34.5	288	15.617	321	19810525	19810531	19811102
1982	GRSG	9.561	190.4	30.8	360	13.799	243.8	19820605	19820612	19821201
1983	GRSG	7.919	157.7	25.5	360	13.229	121.1	19830622	19830626	19831201
1984	GRSG	8.686	173	27.9	468	12.404	191.6	19840613	19840618	19841201
1985	GRSG	8.652	172.4	27.9	432	13.218	363.2	19850601	19850605	19851201
1986	GRSG	9.898	197.1	31.9	360	14.172	283.2	19860518	19860526	19861030
1987	GRSG	10.364	206.4	33.3	324	14.664	307.9	19870605	19870611	19871201
1988	GRSG	10.22	203.5	32.8	360	14.129	284.4	19880614	19880618	19881201
1989	GRSG	11.49	228.8	37	324	15.797	277.7	19890601	19890606	19891201
1990	GRSG	9.149	182.2	29.5	432	13.925	191	19900608	19900613	19901121
1991	GRSG	9.952	198.2	32.1	396	14.777	226.2	19910531	19910605	19911201
1992	GRSG	11.859	236.2	38.1	324	16.306	369.8	19920526	19920607	19921201
1993	GRSG	10.618	211.4	34.1	360	14.676	281.1	19930612	19930617	19931201
1994	GRSG	10.051	200.1	32.4	432	14.467	186.1	19940604	19940609	19941101
1995	GRSG	8.489	169.1	27.4	324	13.909	156.9	19950603	19950612	19951201
1996	GRSG	12.566	250.2	40.5	72	18.452	691.6	19960529	19960603	19961201
1997	GRSG	9.899	197.2	31.9	324	15.965	210.5	19970607	19970614	19971201
1998	GRSG	10.456	208.2	33.7	324	16.098	301.8	19980607	19980611	19981026
1999	GRSG	8.598	171.3	27.7	396	13.199	163.6	19990606	19990611	19991201
2000	GRSG	8.424	167.8	27.2	360	12.997	122.7	20000529	20000603	20001011
2001	GRSG	7.674	152.8	24.7	396	12.638	64.2	20010611	20010617	20011112
2002	GRSG	9.759	194.3	31.5	324	15.396	322.8	20020605	20020610	20021201
2003	GRSG	8.786	174.9	28.3	396	12.423	259.6	20030604	20030609	20031121
2004	GRSG	11.749	233.9	37.8	324	16.465	373.6	20040531	20040605	20041201
2005	GRSG	9.187	182.9	29.6	324	13.685	224.5	20050607	20050615	20051122
2006	GRSG	8.485	169	27.4	360	12.951	253.3	20060525	20060530	20061017
2007	GRSG	8.92	177.6	28.8	396	14.441	107.4	20070610	20070616	20071121
2008	GRSG	10.727	213.6	34.5	288	15.264	410.4	20080610	20080614	20081201
2009	GRSG	10.311	205.3	33.2	396	15.354	244.6	20090605	20090611	20091201
2010	GRSG	10.007	199.2	32.3	324	14.806	274.5	20100616	20100620	20101121
2011	GRSG	6.368	126.8	20.5	396	10.574	112.3	20110606	20110611	20111010
2012	GRSG	7.189	143.2	23.2	432	10.354	163.1	20120527	20120601	20121008
2013	GRSG	8.934	178	28.8	360	13.996	248.9	20130614	20130620	20131201
2014										

Epic Simulation Results of Sorghum for 600 GPM under .90 Stress Trigger



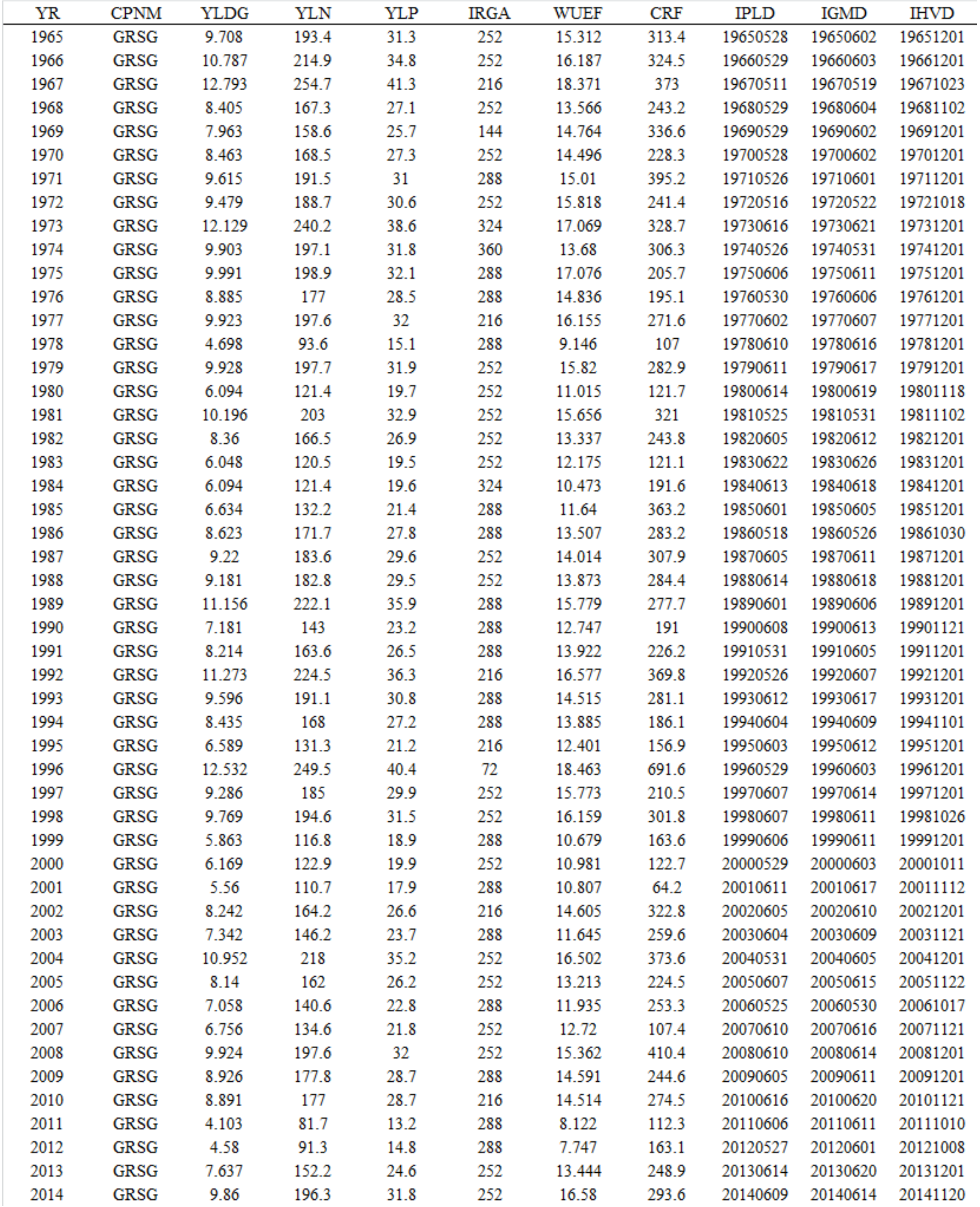
YR	CPNM	YLDG	YLN	YLP	IRGA	WUEF	CRF	IPLD	IGMD	IHVD
1965	GRSG	10.65	212.1	34.3	324	15.705	313.4	19650528	19650602	19651201
1966	GRSG	10.896	217	35.1	288	16.3	324.5	19660529	19660603	19661201
1967	GRSG	12.997	258.8	41.9	252	18.335	373	19670511	19670519	19671023
1968	GRSG	9.33	185.7	30.1	360	13.947	243.2	19680529	19680604	19681102
1969	GRSG	8.387	167.1	27.1	180	14.736	336.6	19690529	19690602	19691201
1970	GRSG	8.892	177.1	28.7	288	14.535	228.3	19700528	19700602	19701201
1971	GRSG	10.432	207.8	33.6	324	15.229	395.2	19710526	19710601	19711201
1972	GRSG	10.399	207	33.5	288	16.291	241.4	19720516	19720522	19721018
1973	GRSG	12.159	240.9	38.7	360	16.822	328.7	19730616	19730621	19731201
1974	GRSG	10.401	207	33.4	396	13.919	306.3	19740526	19740531	19741201
1975	GRSG	10.734	213.7	34.5	360	17.159	205.7	19750606	19750611	19751201
1976	GRSG	10.517	209.4	33.8	396	15.947	195.1	19760530	19760606	19761201
1977	GRSG	10.178	202.7	32.8	216	16.221	271.6	19770602	19770607	19771201
1978	GRSG	6.793	135.3	21.9	360	11.796	107	19780610	19780616	19781201
1979	GRSG	10.528	209.6	33.9	324	16.004	282.9	19790611	19790617	19791201
1980	GRSG	7.351	146.4	23.7	324	12.067	121.7	19800614	19800619	19801118
1981	GRSG	10.678	212.6	34.4	288	15.679	321	19810525	19810531	19811102
1982	GRSG	9.142	182.1	29.4	324	13.736	243.8	19820605	19820612	19821201
1983	GRSG	7.162	142.7	23.1	324	13.057	121.1	19830622	19830626	19831201
1984	GRSG	8.011	159.6	25.7	396	12.181	191.6	19840613	19840618	19841201
1985	GRSG	8.123	161.8	26.2	360	12.995	363.2	19850601	19850605	19851201
1986	GRSG	9.567	190.5	30.9	324	14.135	283.2	19860518	19860526	19861030
1987	GRSG	10.036	199.9	32.3	288	14.593	307.9	19870605	19870611	19871201
1988	GRSG	9.821	195.5	31.6	288	14.15	284.4	19880614	19880618	19881201
1989	GRSG	11.483	228.6	36.9	324	15.789	277.7	19890601	19890606	19891201
1990	GRSG	8.452	168.4	27.3	360	13.724	191	19900608	19900613	19901121
1991	GRSG	9.276	184.8	29.9	360	14.494	226.2	19910531	19910605	19911201
1992	GRSG	11.771	234.4	37.9	288	16.546	369.8	19920526	19920607	19921201
1993	GRSG	10.407	207.2	33.4	360	14.726	281.1	19930612	19930617	19931201
1994	GRSG	9.446	188.1	30.5	360	14.357	186.1	19940604	19940609	19941101
1995	GRSG	7.846	156.3	25.3	288	13.688	156.9	19950603	19950612	19951201
1996	GRSG	12.552	249.9	40.4	72	18.456	691.6	19960529	19960603	19961201
1997	GRSG	9.729	193.8	31.4	324	15.961	210.5	19970607	19970614	19971201
1998	GRSG	10.216	203.4	33	288	16.053	301.8	19980607	19980611	19981026
1999	GRSG	7.657	152.5	24.7	360	12.613	163.6	19990606	19990611	19991201
2000	GRSG	7.658	152.6	24.7	324	12.59	122.7	20000529	20000603	20001011
2001	GRSG	6.935	138.1	22.4	360	12.2	64.2	20010611	20010617	20011112
2002	GRSG	9.155	182.3	29.5	252	15.196	322.8	20020605	20020610	20021201
2003	GRSG	8.261	164.5	26.6	360	12.272	259.6	20030604	20030609	20031121
2004	GRSG	11.522	229.3	37.1	288	16.651	373.6	20040531	20040605	20041201
2005	GRSG	8.701	173.2	28.1	288	13.561	224.5	20050607	20050615	20051122
2006	GRSG	7.931	158	25.6	324	12.61	253.3	20060525	20060530	20061017
2007	GRSG	8.241	164.1	26.6	324	14.122	107.4	20070610	20070616	20071121
2008	GRSG	10.301	205.1	33.2	324	15.26	410.4	20080610	20080614	20081201
2009	GRSG	9.94	198	32	360	15.177	244.6	20090605	20090611	20091201
2010	GRSG	9.421	187.5	30.4	288	14.662	274.5	20100616	20100620	20101121
2011	GRSG	5.675	113	18.3	360	10.065	112.3	20110606	20110611	20111010
2012	GRSG	6.391	127.3	20.6	360	9.814	163.1	20120527	20120601	20121008
2013	GRSG	8.499	169.3	27.4	288	13.843	248.9	20130614	20130620	20131201
2014	GRSG	10.353	206.1	33.4	288	16.668	293.6	20140609	20140614	20141120

Epic Simulation Results of Sorghum for 500 GPM under .90 Stress Trigger



YR	CPNM	YLDG	YLN	YLP	IRGA	WUEF	CRF	IPLD	IGMD	IHVD
1965	GRSG	10.148	202.2	32.7	288	15.51	313.4	19650528	19650602	19651201
1966	GRSG	10.892	217	35.1	252	16.252	324.5	19660529	19660603	19661201
1967	GRSG	12.947	257.8	41.8	252	18.39	373	19670511	19670519	19671023
1968	GRSG	8.75	174.2	28.2	288	13.593	243.2	19680529	19680604	19681102
1969	GRSG	8.244	164.2	26.6	180	14.936	336.6	19690529	19690602	19691201
1970	GRSG	8.696	173.2	28	252	14.483	228.3	19700528	19700602	19701201
1971	GRSG	10.207	203.3	32.9	324	15.371	395.2	19710526	19710601	19711201
1972	GRSG	9.826	195.6	31.7	252	15.973	241.4	19720516	19720522	19721018
1973	GRSG	12.15	240.6	38.7	324	16.823	328.7	19730616	19730621	19731201
1974	GRSG	10.298	205	33.1	396	13.724	306.3	19740526	19740531	19741201
1975	GRSG	10.32	205.5	33.2	324	17.015	205.7	19750606	19750611	19751201
1976	GRSG	9.841	196	31.6	324	15.614	195.1	19760530	19760606	19761201
1977	GRSG	10.067	200.4	32.5	216	16.124	271.6	19770602	19770607	19771201
1978	GRSG	5.774	115	18.6	324	10.648	107	19780610	19780616	19781201
1979	GRSG	10.13	201.7	32.6	288	15.889	282.9	19790611	19790617	19791201
1980	GRSG	6.71	133.7	21.7	288	11.625	121.7	19800614	19800619	19801118
1981	GRSG	10.444	207.9	33.7	252	15.687	321	19810525	19810531	19811102
1982	GRSG	8.734	174	28.1	288	13.522	243.8	19820605	19820612	19821201
1983	GRSG	6.522	129.9	21	288	12.574	121.1	19830622	19830626	19831201
1984	GRSG	7.132	142.1	22.9	360	11.521	191.6	19840613	19840618	19841201
1985	GRSG	7.257	144.6	23.4	324	12.303	363.2	19850601	19850605	19851201
1986	GRSG	9.13	181.8	29.4	288	13.89	283.2	19860518	19860526	19861030
1987	GRSG	9.651	192.2	31	252	14.297	307.9	19870605	19870611	19871201
1988	GRSG	9.469	188.5	30.4	252	14.079	284.4	19880614	19880618	19881201
1989	GRSG	11.335	225.7	36.5	324	15.912	277.7	19890601	19890606	19891201
1990	GRSG	7.808	155.5	25.2	324	13.317	191	19900608	19900613	19901121
1991	GRSG	8.634	172	27.8	324	14.138	226.2	19910531	19910605	19911201
1992	GRSG	11.347	226	36.5	252	16.578	369.8	19920526	19920607	19921201
1993	GRSG	10.058	200.3	32.3	324	14.735	281.1	19930612	19930617	19931201
1994	GRSG	8.838	176	28.5	324	14.019	186.1	19940604	19940609	19941101
1995	GRSG	7.135	142.1	23	252	12.972	156.9	19950603	19950612	19951201
1996	GRSG	12.535	249.6	40.4	72	18.447	691.6	19960529	19960603	19961201
1997	GRSG	9.466	188.6	30.5	288	15.863	210.5	19970607	19970614	19971201
1998	GRSG	10.091	201	32.6	252	16.12	301.8	19980607	19980611	19981026
1999	GRSG	6.886	137.2	22.2	288	11.886	163.6	19990606	19990611	19991201
2000	GRSG	6.784	135.2	21.9	288	11.759	122.7	20000529	20000603	20001011
2001	GRSG	6.104	121.6	19.7	324	11.324	64.2	20010611	20010617	20011112
2002	GRSG	8.523	169.8	27.5	252	14.763	322.8	20020605	20020610	20021201
2003	GRSG	7.605	151.4	24.5	324	11.782	259.6	20030604	20030609	20031121
2004	GRSG	11.265	224.2	36.3	288	16.665	373.6	20040531	20040605	20041201
2005	GRSG	8.305	165.3	26.8	252	13.253	224.5	20050607	20050615	20051122
2006	GRSG	7.797	155.3	25.2	288	12.641	253.3	20060525	20060530	20061017
2007	GRSG	7.521	149.8	24.3	288	13.517	107.4	20070610	20070616	20071121
2008	GRSG	10.25	204.1	33	288	15.369	410.4	20080610	20080614	20081201
2009	GRSG	9.397	187.2	30.3	324	14.877	244.6	20090605	20090611	20091201
2010	GRSG	9.417	187.5	30.4	252	14.925	274.5	20100616	20100620	20101121
2011	GRSG	4.977	99.1	16.1	288	9.31	112.3	20110606	20110611	20111010
2012	GRSG	5.413	107.9	17.5	324	8.78	163.1	20120527	20120601	20121008
2013	GRSG	8.15	162.4	26.3	288	13.768	248.9	20130614	20130620	20131201
2014	GRSG	10.085	200.8	32.5	252	16.621	293.6	20140609	20140614	20141120

Epic Simulation Results of Sorghum for 400 GPM under .90 Stress Trigger



YR	CPNM	YLDG	YLN	YLP	IRGA	WUEF	CRF	IPLD	IGMD	IHVD
1965	GRSG	9.708	193.4	31.3	252	15.312	313.4	19650528	19650602	19651201
1966	GRSG	10.787	214.9	34.8	252	16.187	324.5	19660529	19660603	19661201
1967	GRSG	12.793	254.7	41.3	216	18.371	373	19670511	19670519	19671023
1968	GRSG	8.405	167.3	27.1	252	13.566	243.2	19680529	19680604	19681102
1969	GRSG	7.963	158.6	25.7	144	14.764	336.6	19690529	19690602	19691201
1970	GRSG	8.463	168.5	27.3	252	14.496	228.3	19700528	19700602	19701201
1971	GRSG	9.615	191.5	31	288	15.01	395.2	19710526	19710601	19711201
1972	GRSG	9.479	188.7	30.6	252	15.818	241.4	19720516	19720522	19721018
1973	GRSG	12.129	240.2	38.6	324	17.069	328.7	19730616	19730621	19731201
1974	GRSG	9.903	197.1	31.8	360	13.68	306.3	19740526	19740531	19741201
1975	GRSG	9.991	198.9	32.1	288	17.076	205.7	19750606	19750611	19751201
1976	GRSG	8.885	177	28.5	288	14.836	195.1	19760530	19760606	19761201
1977	GRSG	9.923	197.6	32	216	16.155	271.6	19770602	19770607	19771201
1978	GRSG	4.698	93.6	15.1	288	9.146	107	19780610	19780616	19781201
1979	GRSG	9.928	197.7	31.9	252	15.82	282.9	19790611	19790617	19791201
1980	GRSG	6.094	121.4	19.7	252	11.015	121.7	19800614	19800619	19801118
1981	GRSG	10.196	203	32.9	252	15.656	321	19810525	19810531	19811102
1982	GRSG	8.36	166.5	26.9	252	13.337	243.8	19820605	19820612	19821201
1983	GRSG	6.048	120.5	19.5	252	12.175	121.1	19830622	19830626	19831201
1984	GRSG	6.094	121.4	19.6	324	10.473	191.6	19840613	19840618	19841201
1985	GRSG	6.634	132.2	21.4	288	11.64	363.2	19850601	19850605	19851201
1986	GRSG	8.623	171.7	27.8	288	13.507	283.2	19860518	19860526	19861030
1987	GRSG	9.22	183.6	29.6	252	14.014	307.9	19870605	19870611	19871201
1988	GRSG	9.181	182.8	29.5	252	13.873	284.4	19880614	19880618	19881201
1989	GRSG	11.156	222.1	35.9	288	15.779	277.7	19890601	19890606	19891201
1990	GRSG	7.181	143	23.2	288	12.747	191	19900608	19900613	19901121
1991	GRSG	8.214	163.6	26.5	288	13.922	226.2	19910531	19910605	19911201
1992	GRSG	11.273	224.5	36.3	216	16.577	369.8	19920526	19920607	19921201
1993	GRSG	9.596	191.1	30.8	288	14.515	281.1	19930612	19930617	19931201
1994	GRSG	8.435	168	27.2	288	13.885	186.1	19940604	19940609	19941101
1995	GRSG	6.589	131.3	21.2	216	12.401	156.9	19950603	19950612	19951201
1996	GRSG	12.532	249.5	40.4	72	18.463	691.6	19960529	19960603	19961201
1997	GRSG	9.286	185	29.9	252	15.773	210.5	19970607	19970614	19971201
1998	GRSG	9.769	194.6	31.5	252	16.159	301.8	19980607	19980611	19981026
1999	GRSG	5.863	116.8	18.9	288	10.679	163.6	19990606	19990611	19991201
2000	GRSG	6.169	122.9	19.9	252	10.981	122.7	20000529	20000603	20001011
2001	GRSG	5.56	110.7	17.9	288	10.807	64.2	20010611	20010617	20011112
2002	GRSG	8.242	164.2	26.6	216	14.605	322.8	20020605	20020610	20021201
2003	GRSG	7.342	146.2	23.7	288	11.645	259.6	20030604	20030609	20031121
2004	GRSG	10.952	218	35.2	252	16.502	373.6	20040531	20040605	20041201
2005	GRSG	8.14	162	26.2	252	13.213	224.5	20050607	20050615	20051122
2006	GRSG	7.058	140.6	22.8	288	11.935	253.3	20060525	20060530	20061017
2007	GRSG	6.756	134.6	21.8	252	12.72	107.4	20070610	20070616	20071121
2008	GRSG	9.924	197.6	32	252	15.362	410.4	20080610	20080614	20081201
2009	GRSG	8.926	177.8	28.7	288	14.591	244.6	20090605	20090611	20091201
2010	GRSG	8.891	177	28.7	216	14.514	274.5	20100616	20100620	20101121
2011	GRSG	4.103	81.7	13.2	288	8.122	112.3	20110606	20110611	20111010
2012	GRSG	4.58	91.3	14.8	288	7.747	163.1	20120527	20120601	20121008
2013	GRSG	7.637	152.2	24.6	252	13.444	248.9	20130614	20130620	20131201
2014	GRSG	9.86	196.3	31.8	252	16.58	293.6	20140609	20140614	20141120

VITA

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