Table of Contents

List of Figures

List of Tables

Abstract

Currently, the Ogallala Aquifer is a huge water source used for mainly for irrigation purposes across eight different states. Depletion of this water resource is being to increase at a rapid rate due to the increased amount of water pumped from it and a low recharge rate; therefore, the following research papers discusses major factors that influence current issues with the depletion of the Ogallala Aquifer. Some main points discussed include current conditions and issues, best management practices used currently, water laws, and economics. All of these factors play a role in how the Ogallala Aquifer is currently being used. With these factors considered, recommendations were made that would help decrease the amount of water used in the Ogallala Aquifer, and help the aquifer recharge as much as possible.

1. Introduction

The Ogallala Water Aquifer spans across eight states with an area of about 174,000 square miles (The Ogallala Aquifer, 2012). Western Kansas is a region that depends heavily on the aquifer as the dominant source of water. The majority of the water is used for irrigation in agricultural processes. With such a high demand for the Ogallala's water in businesses, residential, and rural communities, the supply will not be able to accommodate everyone's needs forever. The depletion and low recharge rate of the Ogallala Water Aquifer is a pressing issue that affects not only the residents of Western Kansas, but everyone reliant on food products from the United States. There are current laws and regulations that govern the usage of water from the aquifer. However, these laws and regulations must be reviewed, compared with others, and adjusted to increase water use efficiency and protect the future of water use from the Ogallala. Management practices in agriculture, storm water routing, and on the individual level should be developed that will maximize the efficiency of every gallon of water used. The recharge rate of the groundwater in the aquifer is currently less than total usage. If more water is being taken out than what is being put back then the water volume of the aquifer will decline over time. If a stable rate of input versus output is not reached then an economic tragedy would occur. The region that uses the majority of water from the Ogallala aquifer is also a region on the globe where agricultural food products are generated. A fall in the agricultural productivity of this region would lead to a loss in a major U.S. export, but more importantly, food availability across the globe would diminish. Starvation, higher food prices, and loss of jobs and homes are all possible outcomes for this world if adjustments are not made to improve the current conditions in the Ogallala Water Aquifer in Western Kansas.

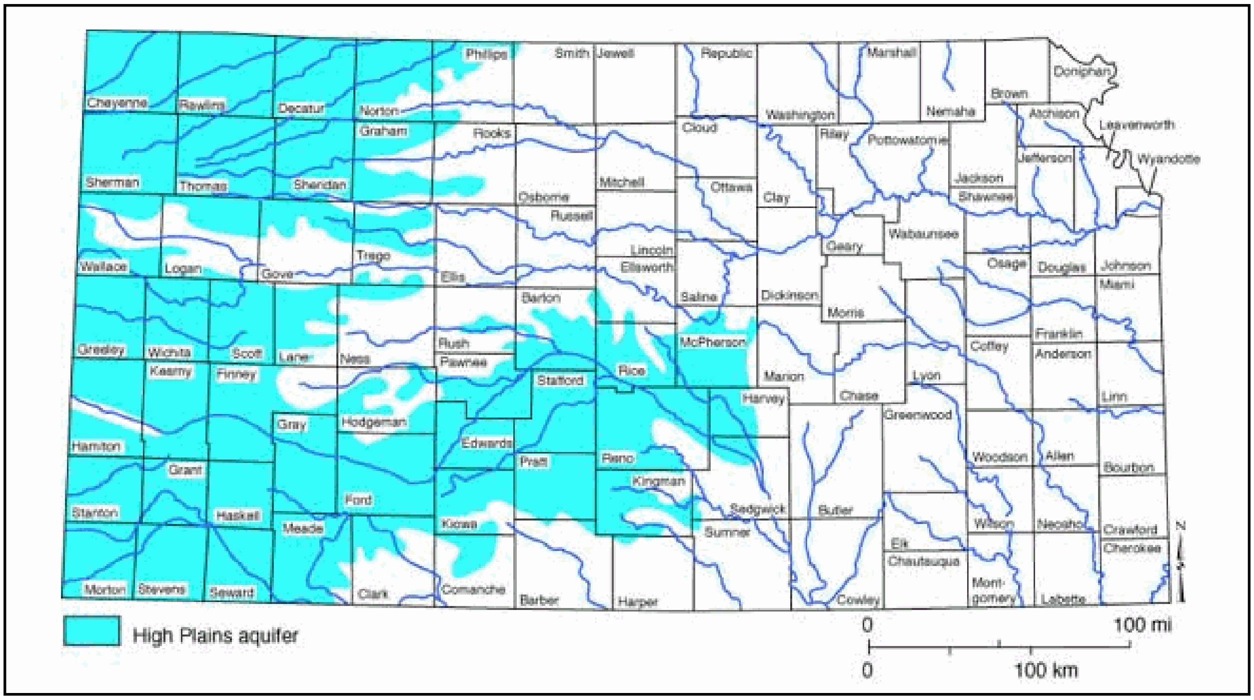

Figure 1. An overlay of the Kansas Ogallala Aquifer's water table as it exists under Kansas land.

2. Current Conditions and Issues

2.1 Current Water Use

Understanding how water is currently being allocated throughout the state is important for realizing how much is being taken out of the aquifer as well as what is being used for recharge. In a region with little precipitation, the majority of the water supply is drawn up from the underground aquifer. Monitoring this information has improved throughout the years. More accurate instruments allow for precise measurements on water flow meters and better efficiency in water allocation. Improvements in technology have helped reduce the waste of water; reductions in water use also rely on human efforts. The water laws and rights that are appropriated across the Kansas groundwater management districts (GMDs) require an annual water use report to be submitted to the Division of Water Resources. These water reports give the data needed to calculate annual averages, depletion, and usage.

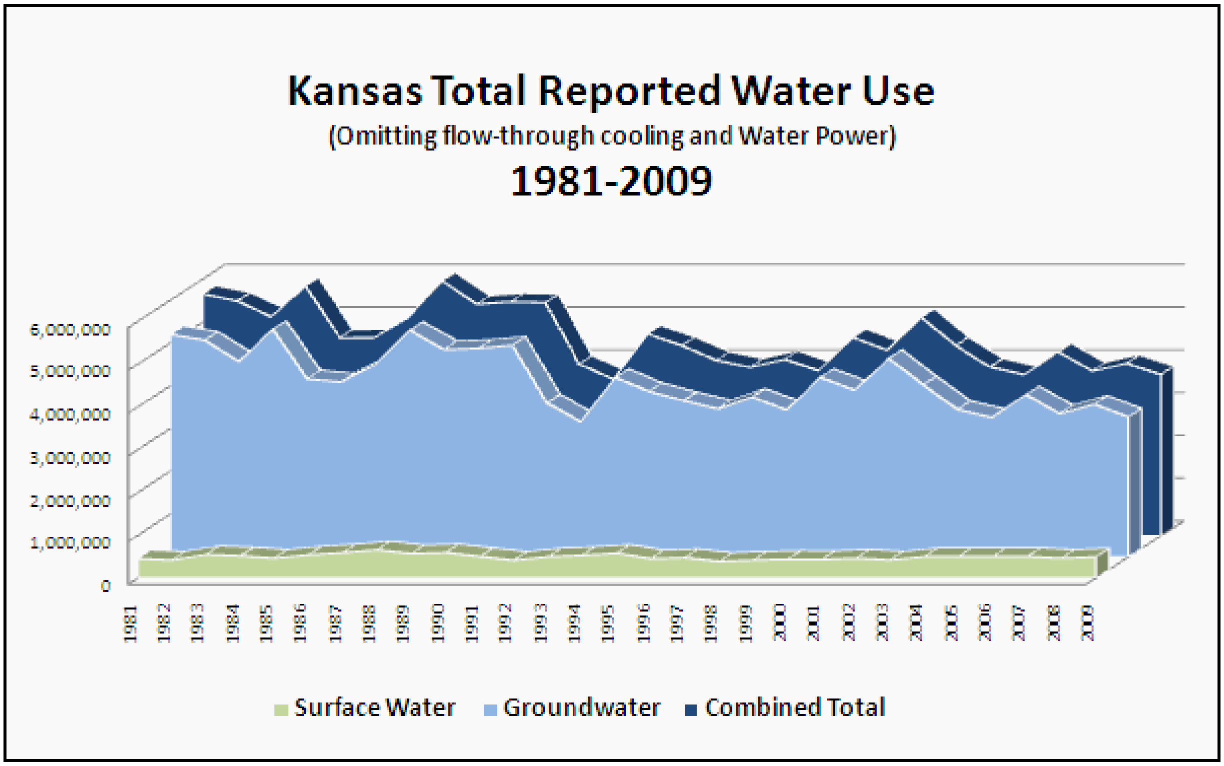

Figure 2. Average Kansas water use over 29 years taken for both groundwater and surface water use.

Over a 29 year period, the average water usage in Kansas was 4,611,108 acre-feet per year. Figure 2 shows the general trend in surface water, groundwater, and the combined total. The reassuring characteristic of this graph is the trend of a negative slope for water usage; the negative slope shows that our efficiencies and practices are improving to use and monitor water. Table 1 shows the data for Figure 2. The percentage of this water that is used for consumptive usage (not to be recirculated back into the supply) is about 90% (Kansas Department of Agriculture, 2012). Of this 90% of consumptive water, 85% is used for irrigation and about 10% is used in municipal areas. The 10% of water used for non-consumptive uses is allocated to hydroelectric power or power plant cooling systems. This water is replaced back into the stream or aquifer from which is derived from so the water balance is zero (input equals output). Irrigation is the largest area that needs to be reviewed and managed. Efficient practices in irrigation can be the turn-around point in which groundwater recharge is not losing water to poor irrigation water use.

Table 1. Water use over time for Kansas. This table is the data presented in Figure 2.

Reported Water Use by Source

All quantities in acre-feet

Year	Surface water	Ground-water	Total for Year
1981	453,355	5,198,268	5,651,624
1982	419,749	5,063,560	5,483,310
1983	548,664	4,569,537	5,118,196
1984	517,757	5,320,064	5,837,821
1985	463,420	4,158,023	4,621,443
1986	540,433	4,083,407	4,623,841
1987	590,171	4,511,662	5,101,597
1988	658,551	5,298,483	5,956,785
1989	568,414	4,842,120	5,410,272
1990	593,150	4,872,735	5,465,885
1991	501,422	4,946,114	5,447,269
1992	415,105	3,598,768	4,013,873
1993	497,198	3,156,207	3,653,405
1994	529,281	4,190,010	4,719,291
1995	579,416	3,865,227	4,444,643
1996	450,036	3,650,992	4,101,028
1997	477,463	3,459,009	3,936,472
1998	388,802	3,732,916	4,121,718
1999	419,851	3,436,877	3,856,728
2000	439,629	4,192,105	4,631,734
2001	432,284	3,897,976	4,330,260
2002	463,648	4,641,898	5,105,546
2003	420,942	4,022,566	4,443,508
2004	500,689	3,443,697	3,944,386
2005	503,907	3,258,577	3,762,484
2006	504,469	3,792,242	4,296,711
2007	504,224	3,344,930	3,849,154
2008	462,690	3,566,088	4,028,778
2009	494,892	3,269,473	3,764,365
29 year AVG	494,469	4,116,673	4,611,108

(As reported to the Division of Water Resources)

2.1.1 Irrigation

Municipal water and non-consumptive water will not be focused on in this paper due to the majority of water usage being allocated to irrigation practices. Figure 3 was taken from the Kansas Department of Agriculture. It shows the partitioning of water over 18 years. 85% was used for irrigation. Figure 4 can also be a reference to show how much water is being used in the western part of Kansas for irrigation. The efficiency of irrigation relies on weather patterns, types of crop, and management practices. The amount of irrigation needed depends on the area of planting and water tolerances of the type of crop planted. About one-half of all irrigated acres in Kansas are represented by corn production (Rogers, 2008). Crop selection and best management practices will be discussed in a later section. Weather patterns and precipitation is a factor that contributes to the variability in irrigation water usage for the year. Naturally, irrigation would be minimized if precipitation is taking care of providing water to the crops. However, recent trends in weather have shown an increase in the severity and abundance of droughts in the region. Figure 4 shows the total irrigation water diverted from surface and groundwater sources. The general trend shows that the irrigation water efficiency is improving. Less water is being needed each year to acquire an acceptable crop yield. The average of irrigation water usages is still around 3.5 to 4 million acre-feet per year. There is another issue with availability of the aquifer's water. Pumping water from underground is required to collect water from the Ogallala.

Kansas Reported Water Use

1990 - 2008 Averaged

As reported to the Division of Water Resources, Kansas Department of Agriculture
All quantities in acre-feet
Ditch Rights and Districts included

1990-2008 Averaged Water Use by Use Made of Water		
Irrigation	3,690,611	84.53%
Municipal	416,535	9.54%
Industrial	139,983	3.21%
Recreation	47,067	1.08%
Stockwater	33,626	0.77%
Other	38,359	0.88%
Total	4,366,180	100.00%

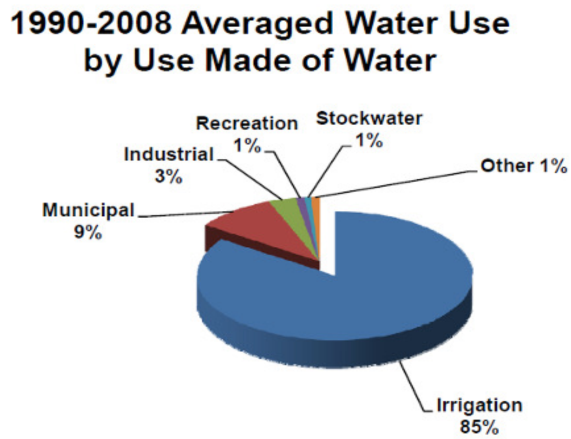

Figure 3. Table and pie chart showing how Kansas water use is dispersed over 18 years.

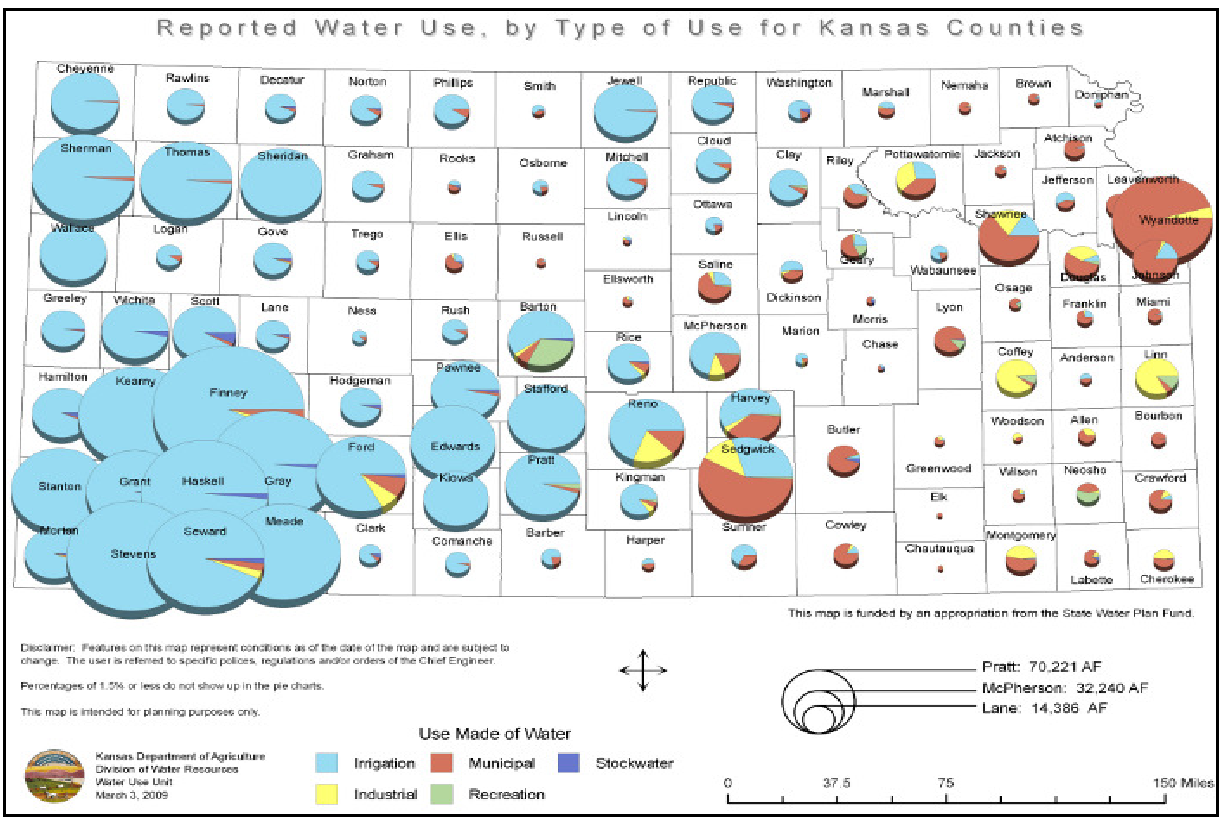

Figure 4. Kansas water use by county in 2009

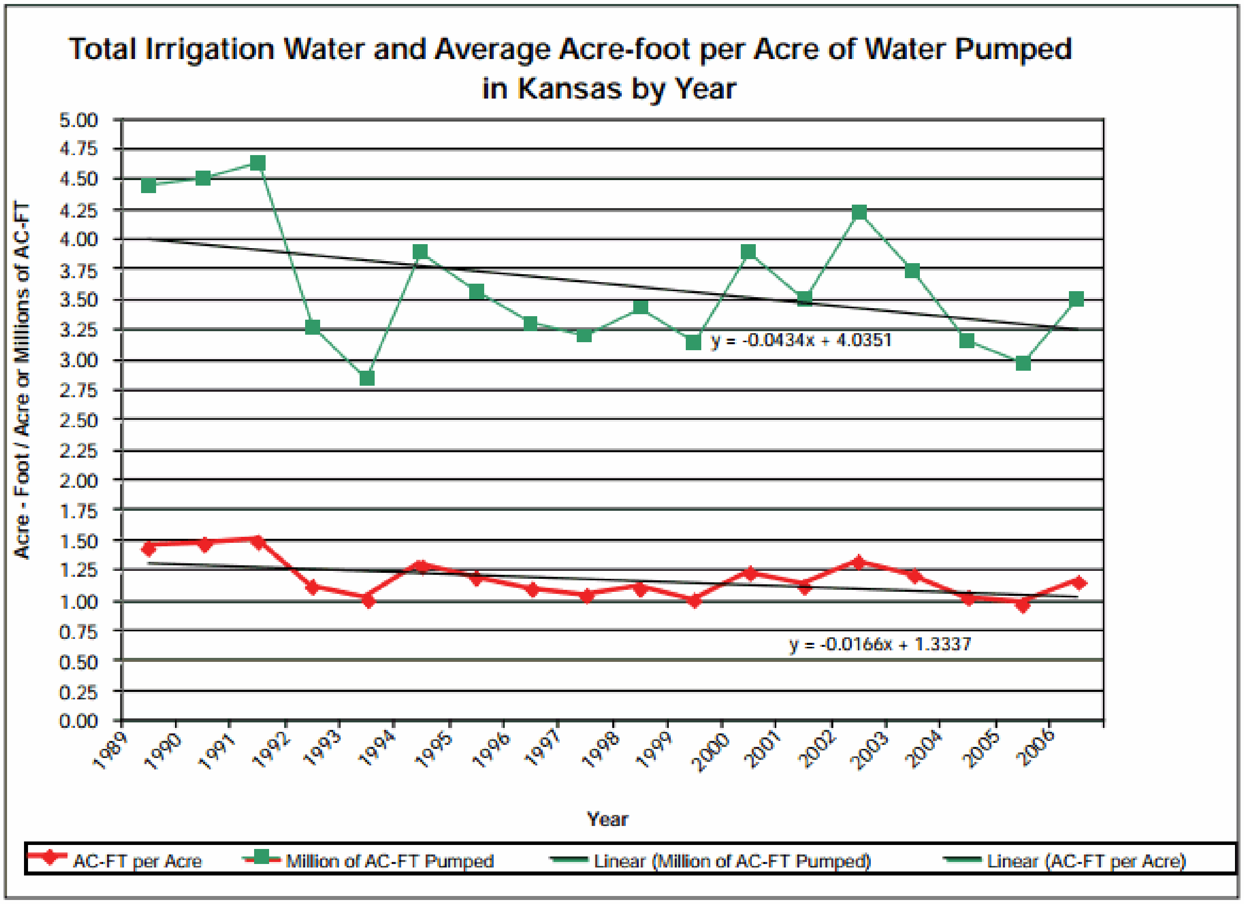

Figure 5. 10 year trend of total water pumped for irrigation and an average of water pumped per acre for Kansas.

2.1.2 Pumping

As more water is used from the Ogallala Aquifer, and the balance of water stays in a deficit, then the water table level will continue to decrease. Water used in irrigation requires pumps to extract the water from depths below the surface. Pumping equations use pressure differences to calculate flow rates, efficiencies, and power requirements. As the water level decreases in the water table, more energy is required to lift the water to the surface. A higher pressure difference and energy requirement will lead to greater expectation out of pumping systems. Materials of the pump system will need to be retrofitted to provide the system with the correct dimensions and stress resistance for desired flow patterns. Deeper wells may have to be drilled to find more water. Pumping can be seen as a factor that is only a detriment to water levels in the Ogallala due to the fact that pumping for irrigation is in excess of water recharge (KGS—Kansas Ground Water—Use, 2012). Natural conditions are disturbed when one pump is placed. The groundwater recharge tendencies are altered with human invasion, but humans can choose the best practices on the surface that will lead to more efficient water usage. Groundwater and recharge will be discussed later in this report.

2.2 Precipitation and Weather Patterns

The amount of irrigation used in a year is highly dependent on what the weather has done for that year. Precipitation and weather patterns are used as a reference to compare how much water would be expected for a growing season. Annual precipitation data for one hundred years is depicted in Figure 5. 45 precipitation stations were used to calculate annual averages in Northwest Kansas. The average annual precipitation for NW Kansas is calculated to be about 20.3 inches (Ogallala-High Plains Fringe

Area, 2011). Altering management practices to expect about 20.3 inches in Western Kansas (a little less in the Southwest) could influence water use efficiencies to improve. A knowledge of how the climate the percolation of this precipitation (after an amount has been absorbed or evaporated) is the recharge input for groundwater (KGS—Kansas Ground Water—Use, 2012). Factors such as amount of precipitation, evaporation, and transpiration affect the rate of which water percolate through the soil profile.

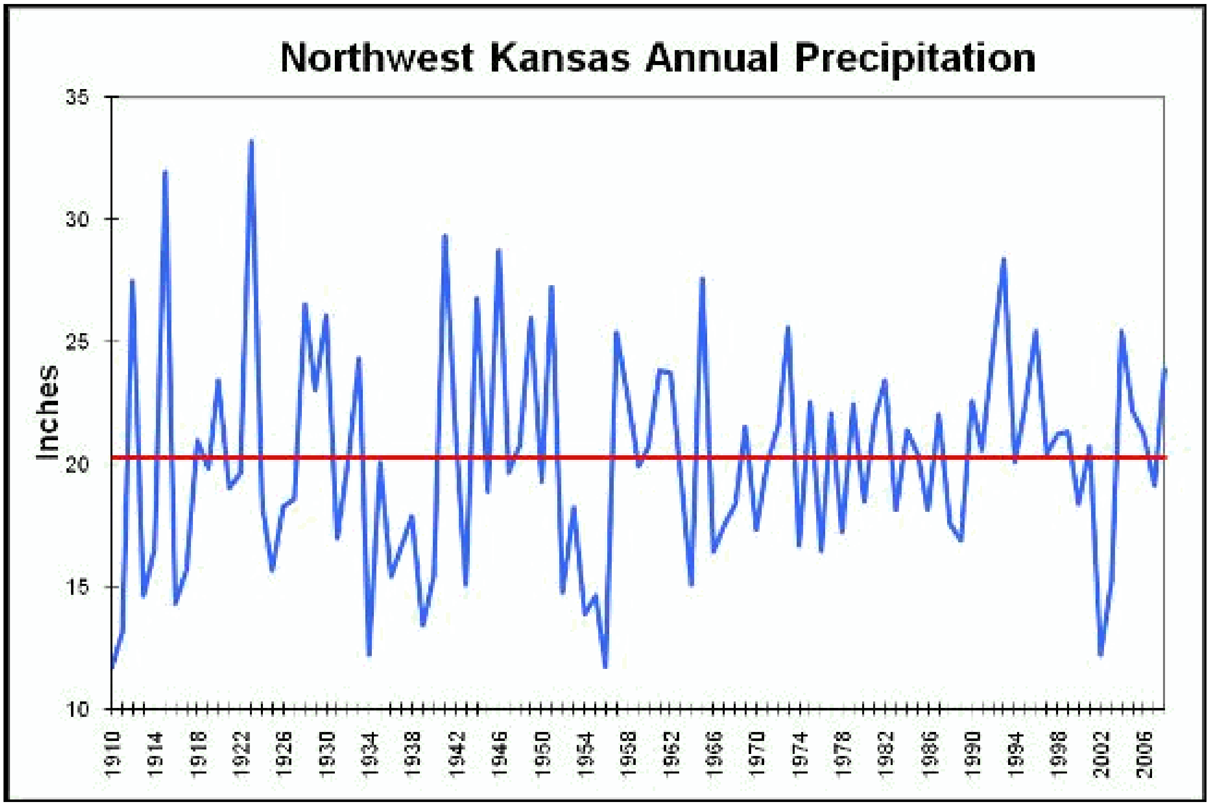

Figure 6. Northwest Kansas precipitation fluctuations compared to the average precipitation (red line) over the past 100 years.

The temperature patterns of this region can be used to adjust for foreseen drought, frost, or storms. With Global Warming becoming a major reality for increased global average temperatures, more droughts and severe weather are likely to happen. Recharge rates rely on how much precipitation makes it through the soil to percolate through to the groundwater. Warmer weather will alter the rates at which water is consumed by the plant, evaporated into the atmosphere, and surface runoff rates. The vegetation in the region relies on temperature to achieve optimal growing conditions. Temperature effects how plants maintain a healthy level by altering evapotranspiration rates and growth rates. Choosing plants/crops that are resilient to temperature fluctuations is a management practice that will be discussed later in this report. Average annual temperature for Kansas is around 55 degrees Fahrenheit (Climate of Kansas, 2012). This is a fairly mild average for the region. However, low precipitation with higher than average temperatures will press the Ogallala water aquifer by demanding more water to be pumped out for stressed crops and people. Severe weather conditions for prolonged periods will need to expect for yearly water allocations. Using trends in precipitation and temperature will allow for better management practices for all people with water rights.

2.3 Groundwater Depletion

The number of streams in western Kansas are diminishing at an increased rate, over the past 40 years. But this reduction of surface water in the western Kansas has lead to pumping of ground water from the aquifer to increase. Secondarily, the diversion of water into the agricultural farmland and also the best management conservation practices, on irrigation have helped to reduce the surface run off (Perlman, 2012). Also, dry land farming practices (conservation tillage), ponds and terraces have reduced stream runoff. But the development of the high plain aquifer in Kansas started in 1940s, but large scale drilling of water commence fully in 1960s.

Since then, parts of the state have experience reduction in the saturated thickness, and these changes are pronounced in west-central and southwestern Kansas. Although there is still water in the aquifer in these regions, is just the yield product is very low, when compare to the cost of pumping, it is not worth it. But according to Kansas geological survey, they believe that the high plains aquifer in the western Kansas is exhausted by frequent mining of the aquifer (Playa Lakes Joint Venture, 2003). But the eastern part of the Arkansas River Lowlands declines, but little when compare to the west of Kansas. This is as a result of the pumping rate in the east is lower, compare to the west, and the amount of rainfall is more in the east than the west of Kansas, therefore the recharge rate is less in the western Kansas. The concern of the aquifer in the western Kansas has led to water management districts to require the installation of water meters on wells to record the water that is been used for that particular period.

The high plain aquifer stretches from South Dakota to Texas and supplies up to 30 percent of water that is been used for irrigation in the United States. But this distribution of the water is not even, when viewing the high plain aquifer; places like Nebraska hold 60 percent of the waters in the aquifer, while Texas and Kansas hold about 12 and 10 percent each of waters in the aquifer respectively. But majority of the counties in western Kansas depend on the aquifer for water source.

2.3.1 Causes of Groundwater Depletion

The cause of ground water mining, is as a result of human activities for the purpose of crop irrigation, but it looks as if the rate at which human are pumping from the aquifer is faster than the recharge of the aquifer by natural process. According to NASA reporters, they believe that all the ground water, which is pump, is either evaporated into the atmosphere or run into the sea, so they believe this is one of the factors that is causing sea level to rise beyond is usual place. The question is that many believe that the sea raising is as a result of the melting glacier, if it is the melting glacier, what is then the pathway of this water to the sea? Is it through ground water, and if it is, the question is, why there is still depletion of groundwater. If measures are not taking to control how this groundwater is been drill, the western part of Kansas will or may experience the collapse of agricultural output and potable water.

But according to NASA report, they carried out an experiment in India, and found out how groundwater is been declining at an average years. They were able to see that at this region, groundwater level decline at one meter every three years, more than 109 cubic km (26 cubic miles) of groundwater disappeared between 2002 to 2008, If will compare India to western Kansas, were they rely primary on groundwater for nearly everything, it indicates that if a proper water management practices is not done, they may end up really experiencing water problem in the next generation to come. Now due to much pumping of the aquifer, most of the wells are drying up, and in some places, one have to drill up to nearly 40 miles, if not more than to get water, which increases the cost of pumping. Why those that rear goats and sheep have to drive miles just to get water for the animals and if the cost is more than profit, one will run out of business. The problem with these is that the cost of pumping is high, because the elevation of the water table is down beyond normal the water is slowly recharging, and when there is no water to grow the crop, then there is a great problem because it will affect the market value of western Kansas.

But we can see that irrigation (agriculture) is not the only factor that leads to depletion of groundwater; most of the land is now cover by either construction of roads or buildings (urbanization). The construction of roads and buildings are preventing waters to move into the ground, and this is preventing the recharge of the aquifer, instead this constructions of roads or buildings are causing flash flood and allowing waters to run into the steam and rivers, when this water are prevented from recharge the aquifer, this problem to farmer, because they spending much of the water budget with little or nothing to enter into the water. However, change in land cover from agriculture to urbanization does not a pose a huge effect on western Kansas.

The loss of wetlands is another factor causing the depletion of groundwater. Evidence have point to playa lakes as the primary source of natural recharge for the Ogallala aquifer, these playas are shallow, seasonal wetlands, which are located across the grassland in the western great plains. They are the most numerous wetlands in the region, which are more than 60,000 in this area of the Great Plains. Studies have shown that the recharge of the Ogallala aquifer when the rainfalls into this playa region, the water found its way into the aquifer through the cracks in the clays. But 70 percent of these playas are now altered from their natural state by tilling, pitting, and the filling of this area by sedimentation.

Sedimentation is actually the threat to Playa lakes (wetland) when it comes to the recharge of ground water. Sedimentation occurs in Playa area that is been surrounds by tilled lands. Water from precipitation and irrigation carry soil into Playa areas whereby covering these wetlands, as this process continue, sediment start building up, which reduces the ability of Playa to hold water, and water is loss to the atmosphere by evaporation. The losses of this wetland, not only affect the recharge of groundwater, but also affect wild lives that habit this region. The PLJV are now working with landowners in Colorado, Kansas, Nebraska, New Mexico, whereby providing technical and financial assistance to conserve playas in agricultural lands and range lands, about the sum of $50 million have been spent by joint venture partners just to preserve this wetlands (Playas).

3. Best Management Practices

3.1 Irrigation

Crop production in western Kansas comes from both dry land and irrigation, in which the water used in irrigation, comes mainly from groundwater resources, such as the Ogallala Aquifer. There are several types of irrigation systems used, including flood, center-pivot, and subsurface drip irrigation. With these three irrigation systems, each system differs in water efficiency; therefore, by switching from one system to another can increase the water efficiency from the current irrigation system, decreasing the amount of water removed from the Ogallala.

3.1.1 Flood Irrigation

Flood irrigation, similar to surface irrigation, in which water is distributed overt the soil surface by gravity flow. Flood irrigation was the dominating irrigation system back around the 1970’s before sprinkler irrigation systems became more popular; however, today, flood irrigation is less used compared to other irrigation systems, like sprinkler irrigation systems (Rogers, 2008). Compared to sprinkler irrigation systems flood irrigation systems tend to use more water in order to apply a uniform water distribution across the field. Flood irrigation systems typically apply 3 to 4 inches per irrigation event, while a typical sprinkler irrigation system only applies a depth of one inch (Rogers, 2008). Also, the amount of time it takes to complete an irrigation cycle is much larger with flood irrigation systems, taking about 10 to 14 days, while a sprinkler irrigation system takes only 3 to 5 days (Rogers, 2008). Flood irrigation systems operate around 65% irrigation efficiency, allowing 65% of the applied water to enter the root zone of the crop and the remaining 35% to either run off and/or return to the soil through deep percolation.

3.1.2 Center-Pivot Irrigation

Sprinkler irrigation systems in the 1970's were not as popular as flood irrigation systems, in which only 18% of 1.8 million irrigated acres in Kansas were irrigated using sprinklers (Rogers, 2008). The use of sprinkler irrigation systems increased over the next 20 years, in which the adoption of center-pivot irrigation increased and about half of all the acres irrigated in Kansas where through center-pivot irrigation. Today, nearly 90 percent of all irrigated land in Kansas use center-pivot irrigation.

Center-pivot irrigation systems have several different types of high efficiency irrigation systems that allow control of irrigation application amounts, including low energy precision application (LEPA), low elevation spray application (LESA), low pressure in canopy (LPIC), and mid-elevation spray application (MESA). These types of high efficiency irrigation systems conserve more energy and water compared to just a standard center-pivot irrigation system.

Low Energy Precision Application (LEPA)

Low Energy Precision Application (LEPA) irrigation was developed for mainly arid and semi-arid regions to help maximize the use of limited water resources and increase irrigation efficiency. A LEPA system was also developed for areas that were experiencing dropping water tables, such as the Ogallala aquifer.

LEPA irrigation system is a "moving truss system with water conveyance tubes extending from the system mainline to near the soil surface, where correctly sized orifices control deposition of water to individual soil furrows" (Low Energy Precision Application, LEPA, 2012). LEPA systems are used for crops that are planted with furrows, which use circular rows for center-pivot systems and straight rows for linear systems. The slope of the land being irrigated cannot not exceed 1 percent or more than 50 percent of the field in order to use a LEPA system. With LEPA, water can either be discharged to the surface through a drag sock or hose, or through a nozzle that is equipped with a bubble shield or pad (Utilizing Center Pivot Sprinkler Irrigation Systems to Maximize Water Saving, 2012). Depending on which method used to discharge the water will help determine the nozzle height. If drag hoses are used, no nozzle height is required, because the hose discharges water directly to the surface; however, for a nozzle equipped with a bubble shield or pad, the nozzle height must be less than 18 inches to the surface. For a nozzle that is equipped with a bubble shield or pad, the nozzle height must be less than 18 inches to the surface (Utilizing Center Pivot Sprinkler Irrigation Systems to Maximize Water Saving, 2012).

LEPA systems have two main advantages compared to other irrigation systems, like low pressure irrigation systems, including: (1) evaporation losses are reduced, increasing water application efficiency to around 98% and (2) the amount of end pressure need is around 5 to 10 pounds, instead of other low pressure irrigation systems that require at least 15 to 30 pounds (Hill, 1990). By decreasing evaporation loss and increasing water application efficiency, more crop production can occur, increasing profit; therefore, converting to a LEPA irrigation system would be an economically feasible decision.

Low Elevation Spray Application (LESA), Low Pressure in Canopy (LPIC), and Mid-Elevation Spray Application (MESA) irrigation systems are similar to LEPA systems, but have declining water application efficiency with respect to increased nozzle height; therefore, these systems will not be discussed in this paper.

3.1.3 Subsurface Drip Irrigation

Subsurface Drip Irrigation (SDI) "is an adaptation of micro-irrigation technology for field crop irrigation", in which the system consists of "permanently-installed below-ground plastic tubes that slowly discharge water into the root zone of a crop through emitters" (Rogers, 2008). Compared to other irrigation systems, like flood and sprinkler irrigation systems, subsurface drip irrigation has the ability to produce equal or better crop yields. Typically, when an irrigation system is converted from flood irrigation system to SDI, there is an increase in crop yield, usually around a 20% increase (Camp, 1998). With a conversion from sprinkler irrigation systems to SDI, the same amount of crop yield is normally achieved; however, the amount of water required for an SDI system is 30% less than for sprinkler irrigation systems and 40% less than for flood irrigation systems (Camp, 1998).

Even though the amount of water saved by using SDI systems over flood and sprinkler irrigation systems is huge, SDI systems are still not as popular. For example, in Kansas, SDI systems represent about one percent of the total Kansas irrigation amount (Rogers, 2008). This small percentage is a result of several limitations SDI systems have compared to other irrigation systems. The greatest limitation for SDI systems is the fact it is buried below the soil surface, making it difficult to observe water flow from individual emitters and operation and maintenance difficult (Camp, 1998). Also, SDI systems have a higher initial cost compared to other irrigation systems. With a declining water table in the Ogallala Aquifer, SDI systems would be a better option for reducing the amount of water used for irrigation.

3.2 Crop Selection

Current crop selection conditions are causing a large amount of water to be extracted from the Ogallala aquifer, in order to grow these crops and make a profit off them; however, due to a declining water table in the Ogallala aquifer, change in the current crop selection conditions are needing to change to a more water efficient system.

3.2.1 Alternative Crops for Sustainable Water Use

Currently, the four major crops grown in Kansas include corn, cotton, sorghum, and wheat, with corn being the main income crop; however, corn requires a lot of water to grow. According to K-State Research and Extension, corn requires about 22 inches of water, or about 594,000 gallons of water per acre (Corn, Water Requirements, 2012). For example, if there is a corn yield of 200 bu, then around 3,000 gallons of water was used for each bushel of yield (Corn, Water Requirements, 2012). Because of this high amount of water used, it is suggested that cotton should become one of the main crops grown in Kansas primarily to help reduce the amount of water used.

Due to the declining water table in the Ogallala aquifer, more drought tolerant and economically viable crops, like cotton, are being considered. Cotton requires around 647 mm of water, which is less than other major crops such as corn (835 mm), sorghum (688 mm), and soybeans (681mm) (Gowda et al., 2007). A study was conducted to "assess the feasibility of growing cotton and estimate the cotton yield potential and the potential reduction in Ogallala Aquifer withdrawals by producing cotton as an alternative to corn (Gowda et al., 2007). This study was conducted for 30 years and included 131 counties in the Ogallala Aquifer Region, which includes all of the Southern and central High Plains and part of the Northern High Plains (Gowda et al., 2007). A potential cotton yield was determined for each county, which was based off of the total heat units accumulated (THU).

Of the 131 counties in the study, over half of the counties experienced a THU greater than 1000 degrees C; therefore, these counties were removed from the study, because it is known that cotton can be well grown in an area with a THU of 1000 degrees C or greater (Gowda et al., 2007). The remaining 26 counties that experienced either a THU between 800 to 999 degrees C or below 800 degrees C were still researched to determine if cotton was a suitable alternative to corn. For counties that experience a THU of less than 800 degrees C, the potential cotton yield is ultimately zero, because it would not be economic to grow cotton instead of another crop; however, the counties that experience a THU between 800 degrees C to 999 degrees C can still grow cotton (Gowda et al., 2007). Based on just THU, one can determine if growing cotton is economically sound.

Potential cotton yield was determined based on THU, and determined that "the average PCY varied from 569 to 2518 kg ha^{-1} for counties with 1000 degrees C or more heat units" (Gowda et al., 2007). Table 2 shows the number of counties in each yield group based on a 30 year average potential cotton yield and three different growing scenarios. This table shows P, which is exceedance probability, meaning a higher P will result in a lower yield risk and vice-versa; therefore, this study shows that as PCYs increase, the P value decreases, indicating that higher cotton yields are associated with higher risks.

Table 2. Number of counties in each yield group based on a 30-yr average potential cotton yield and three different scenarios.

	Number of counties			
PCY	$P = 0.99$ (every year)	$P = 0.8$ (4 of 5 yr)	$P = 0.75$ (3 of 4 yr)	Based on 30-yr average PCY
kg ha^{-1}				
0	55	21	18	4
1–500	25	26	23	22
501–1000	33	44	39	41
>1000	18	40	51	64

† *P*, exceedance probability; PCY, potential cotton yield.

Figure 6 depicts "the county-wide potential reduction in crop water use if producers were to convert 50% of their total irrigated corn area to cotton in counties that had a yield of at least 500 kg ha^{-1} lint in 3 out of 4 years" (Gowda et al., 2007). By doing this, there is 73% reduction in water use in Kansas counties, because most of the area in Kansas irrigates corn, not cotton. Overall, it was found that Southern and Central High Plains provide suitable climatic conditions to grow cotton; therefore, cotton is a suitable alternative crop for the Central High Plains of the Ogallala Aquifer Region. Even by converting 50% of the land from corn to cotton, doing this, a significant reduction in water withdrawals from the Ogallala Aquifer for irrigation is probable if producers were to convert 50% of their irrigated corn to cotton.

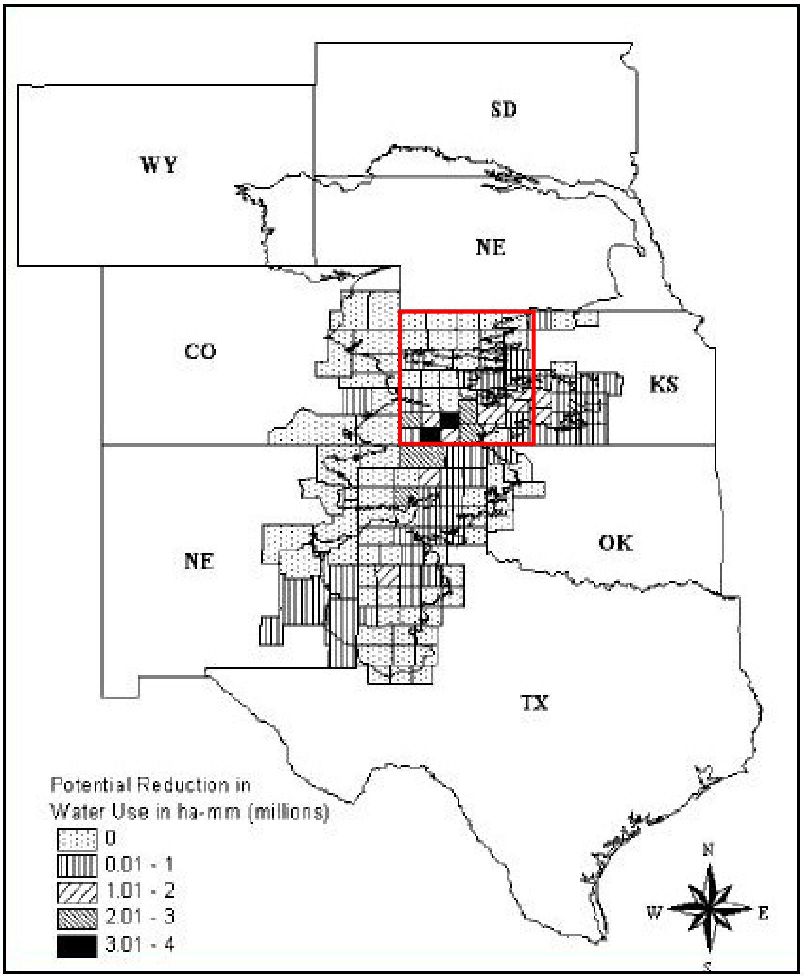

Figure 7. Potential reduction in crop water use if 50% irrigated corn area was switched to cotton. Kansas area is shown in the red square.

3.2.2 Integrated Crop-Livestock Systems

"Integrated crop-livestock systems can improve soil quality, interrupt pest cycles, and spread economic risk through diversification", according to Allen (Allen, 2005); however, little research has been conducted on integrated systems. In Allen's paper, *Integrating Cotton and Beef Production to Reduce Water Withdrawal from the Ogallala Aquifer in the Southern High Plains,* research was initiated in 1997 to compare a continuous cotton monoculture system with an integrated cotton-forage-livestock system in Lubbock County (Allen, 2005). The research was replicated three times in a random block design, in which the monoculture cotton systems was 0.25 ha in area and the integrated crop-livestock system comprised of 4 ha, for a total of 12.75 ha in the entire experimental area. Both systems were irrigated by an underground drip system, with a water meter attached to measure the total water applied. For this research, the cotton monoculture system consisted of a single enclosure with monoculture cotton planted into terminated wheat, no cattle were a part of this system; however, the integrated cotton-livestock system consisted of about 53.6% perennial warm-season grass, providing grazing for steers between January to July, and the remaining 46.4% was divided into two encasement's in which cotton was grown in alternate rotation between the two (Allen, 2005). Cotton was in rotation with rye, fallow, and wheat between the two encasements.

These systems were run for 5 years, in which during the first year was an establishment year and the amount of water used was not accounted for in the overall analysis. Through years 2-5, the amount of irrigation water used on the monoculture system and the integrated system was 481 mm and 372 mm, respectively; therefore, the monoculture system used 23% more water per hectare annually compared to the integrated system (Allen, 2005). It was found that during the first year, cotton produced by the monoculture system produced more yield than the integrated system; however, this only occurred for the first year (Figure 7). The average production over years 2-5 for the monoculture system and the integrated system was 1036 and 1062 kg ha^{-1}, respectively (Allen, 2005).

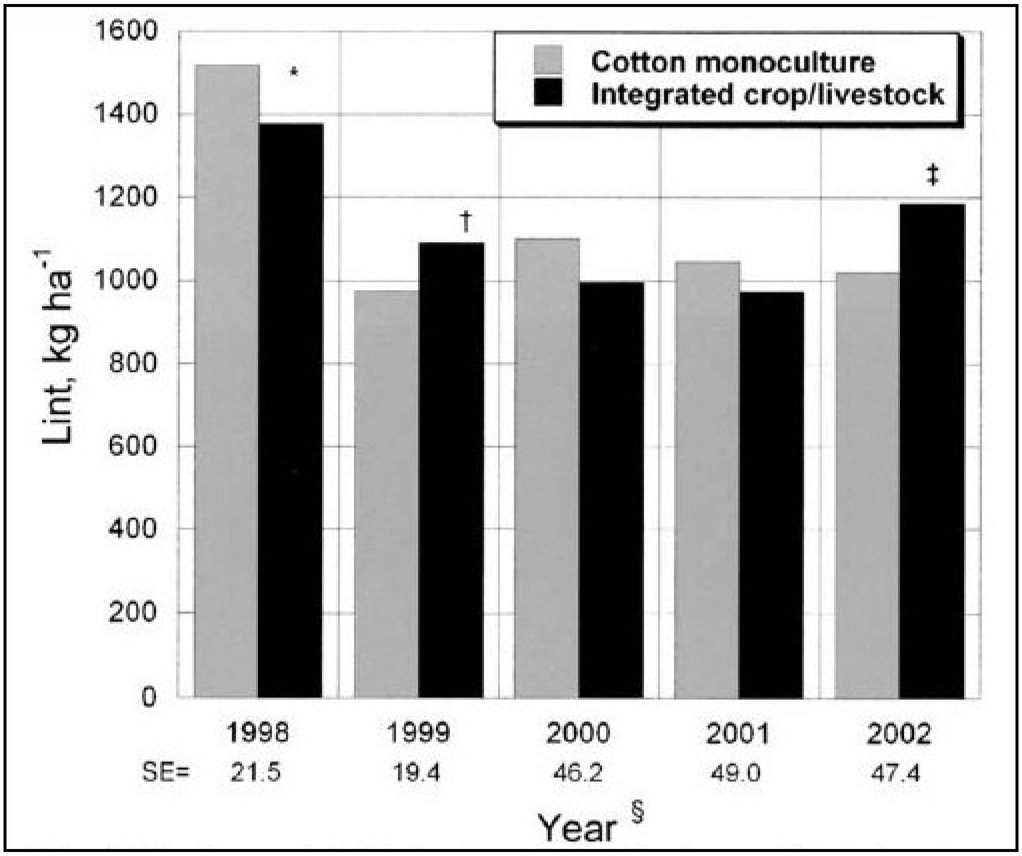

Figure 8. Total annual yield of cotton during 5 years for a cultivated cotton monoculture and no-till cotton grown in a two-paddock rotation with rye and wheat within an integrated cotton—forage—livestock system.

Overall, it was proved that the integrated system is more profitable than the monoculture system with respect to pumping depth, increasing as depth to water increases (Table 3). Because of this, the more scarce water becomes in the Ogallala aquifer, the greater the chance of conversion from a monoculture system to an integrated system.

Table 3. Net returns above variable costs of production of a cotton monoculture system and an integrated cotton—forage—livestock system averaged over Years 2 through 5.

Irrigation water pumping lift	Net returns per hectare for two systems	
	Monoculture cotton‡	Integrated cotton–forage–livestock‡§¶
m	net returns above variable cost of production, $ ha^{-1}	
45	310.38	453.33
60	272.75	424.62
75	231.83	393.41
90#	190.91	362.17

† Returns do not include any government payments due to variability of benefits received by producers.
‡ Price used for cotton lint was $1.21 kg^{-1}.
§ Price used for old world bluestem seed was $39.60 kg^{-1}.
¶ Price used for steers was $1.92 kg^{-1}.
# Actual pumping lift at the research site.

3.3 Individual Management

Besides irrigation and crop selection, there are other individual management techniques that can be done to help reduce the amount of water used from the Ogallala Aquifer, including conservation tillage and computer tools and programs.

3.3.1 Conservation Tillage

Conservation tillage systems are methods of soil tillage that leave a minimum of 30% of crop residue on the soil surface, or at least 1,000 lb/ac (1,100 kg/ha) of small grain residue on the surface during the critical soil erosion period (Conservation Tillage, 2012). Types of conservation tillage includes: no-till, strip till, mulch-till, rotational till, and ridge till. In order to help reduce the amount of water drawn from the Ogallala aquifer, any one of these conversational tillage methods would be appropriate to use; however, no-till is one of the best options to reduce the most amount water drawn from the aquifer.

No-till is “a farming system in which the seeds are directly deposited into untilled soil which has retained the previous crop residues” (No-Till, 2012). In order to achieve no-till, special seeding equipment with discs or narrow tine coulters are needed in order to open a narrow slot into the residue covered soil to put the seeds in and recover with soil. By using no-till, erosion is controlled and reduced, while water infiltration, soil moisture, and soil organic matter is increased.

Overall, by using conservation tillage, there are many environmental and practical benefits, including: 60 to 90% reduction in soil erosion, improved soil and water quality due to increased organic matter, conservation of water through reduced evaporation at the soil surface, and conservation of energy due to fewer trips across the field (Conservation Tillage, 2012).

3.3.2 Computer Tools and Programs

Crop Water Allocator

The Crop Water Allocator (CWA) is part of the Mobile Irrigation Lab presented by Kansas State University Research and Extension and is a “seasonal planning tool to find the optimum net return from all of the combinations of crops, irrigation amounts, and land allocations that the program user wants to examine” (Mobile Irrigation Lab, 2012). Some general inputs for the CWA model including: water iteration “water split factor”, total land area, irrigation application efficiency, annual rainfall, season gross irrigation or water allocation, calculated gross water volume, land split, select the crops to evaluate, price per unit, and maximum yield (Klocke, 2006). Other inputs, such as pumping discharge, hours of pumping, pumping lift, system operating pressure, fuel type, labor, and repair and maintenance, help determine irrigation costs that combine to estimate energy use (Klocke, 2006). Crop production costs can also be determined by inputting general input costs, land usage returns, operational costs, and other miscellaneous costs. With all of these inputs, the CWA calculates the net economic return for each combination of inputs, in which the results are ranked so the user can evaluate their options.

Crop Yield Predictor

The Crop Yield Predictor (CYP) is also part of the Mobile Irrigation Lab presented by Kansas State University Research and Extension; however, this tool "was designed as an interactive decision tool to predict crop yields and economic returns for deficit irrigated crops" (Mobile Irrigation Lab, 2012). With this program, users can input different irrigation schedules to optimize yields and net returns. The different irrigation schedules can be tested using a range of annual precipitation to find yield and income risks based on wet, average, and/or dry years (Mobile Irrigation Lab, 2012).

4. Water Laws

4.1 Kansas

By Kansas law, water is a public resource that is dedicated to the use of the people of the state. Individuals, companies, municipalities, and other entities can obtain permission to use water for beneficial purposes by obtaining a water right, either new or existing. In general, all beneficial uses of water, except most domestic use, require a water right. Responsibility for managing water use in Kansas is spread over several agencies. The Division of Water Resources (DWR) of the Kansas Department of Agriculture is responsible for administering water rights, and thus is primarily responsible for regulation related to the quantity of water used (Buchanan et al, 2009).

Kansas is a "prior appropriation state" in regard to water rights. This means that all the water is owned by the state and dedicated to the use of the citizens subject to the conditions and caveats spelled out in the state's water appropriation act (KSA 82a-701). This act operates under the general principal of "first in time-first in right", which means in times of shortage, the last people to obtain water rights are the first to be affected by whatever remedy(s) is prescribed. However, statutory amendments now provide powers to the DWR to establish special management areas called Intensive Groundwater Use Control Areas (IGUCAs) where additional tools besides the strict response of reverse order of priority can be utilized.

Although the state is obviously the lead entity in water rights, there are other entities also involved. Local groundwater management districts (GMDs) have also been authorized in special areas of the state to develop regulations for the management of local groundwater supplies - so long as they are not inconsistent with the water appropriation act (KSA 82a-1020). There are 5 GMDs that have formed to date. Within a GMD, the local board may develop specific regulations which when properly adopted, become the regulations of the DWR for that local district, see Figure 9 (www.kswatercongress.org, 2011).

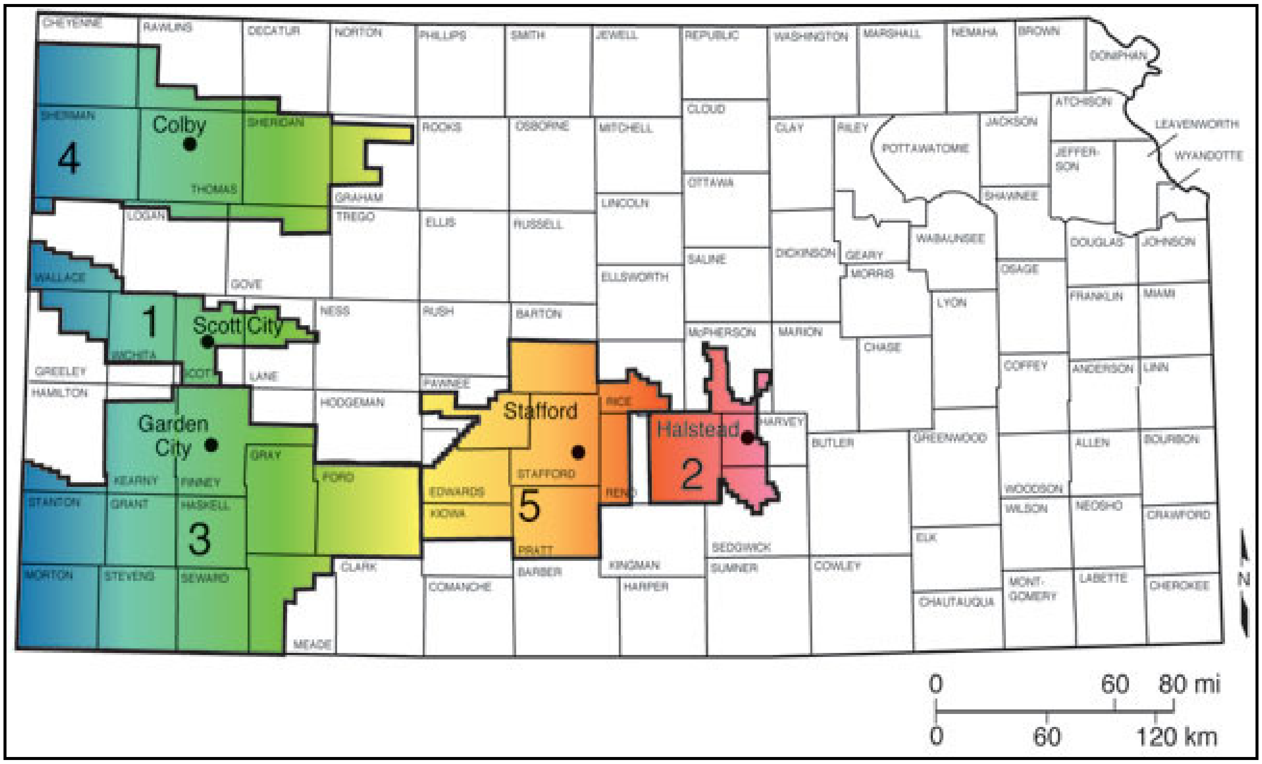

Figure 9. Kansas groundwater management districts

The GMDs are currently working 7 new issues for eventual inclusion into the revised Management Program. These are: Installing a Management Program as the expression of "public interest" for Kansas GMD members; The viability of obtaining variable assessment rates for both land assessments and water user charges; A possible economic development component for processing future water rights; A public water rights ownership program to promote reduced water use and simultaneously increased economic returns; A possible water rights allocation regulation for irrigation in high priority areas; The limitation of impairment complaints in active management areas; and additional restrictions on adding acres to existing water rights (Buchanan et al, 2009).

There are also other state agencies which have water responsibilities, including: (1) The Kansas Department of Health and Environment (KDHE) deals with water quality (pollution, etc.) and the effects on health and the environment, (2) The Kansas Water Office (KWO) is the planning agency in the state and is responsible for the State Water Plan, and (3) The Kansas Geological Survey has data collection and research responsibilities.

4.1.1 Current Legislation

Because many of the water rights in the High Plains aquifer were established long ago and thus have priority, the implementation of sustainable development approaches to water resources has serious legal implications. Other methods for dealing with the High Plains aquifer are being proposed, discussed, and implemented. All are aimed at extending the life of this crucial resource. Among the more far-reaching proposals for extending the life of the aquifer is the idea of sustainable development. This is the concept of limiting the amount of water taken from the aquifer to no more than the amount of recharge, and perhaps less, depending on the impact on water quality and minimum stream flows.

Kansas Governor, Sam Brownback, recently signed a new bill to repeal the 1945 law which required water-right holders to pump a the maximum amount of water each year or they would lose the right to pump that amount of water for the next year. The so-called “use-it-or-lose-it” doctrine didn’t allow farmers to use more water in dry years and then less water in wet years with keeping an eye on conservation. This bill gives water-right holders more flexibility in how they use their water each year.

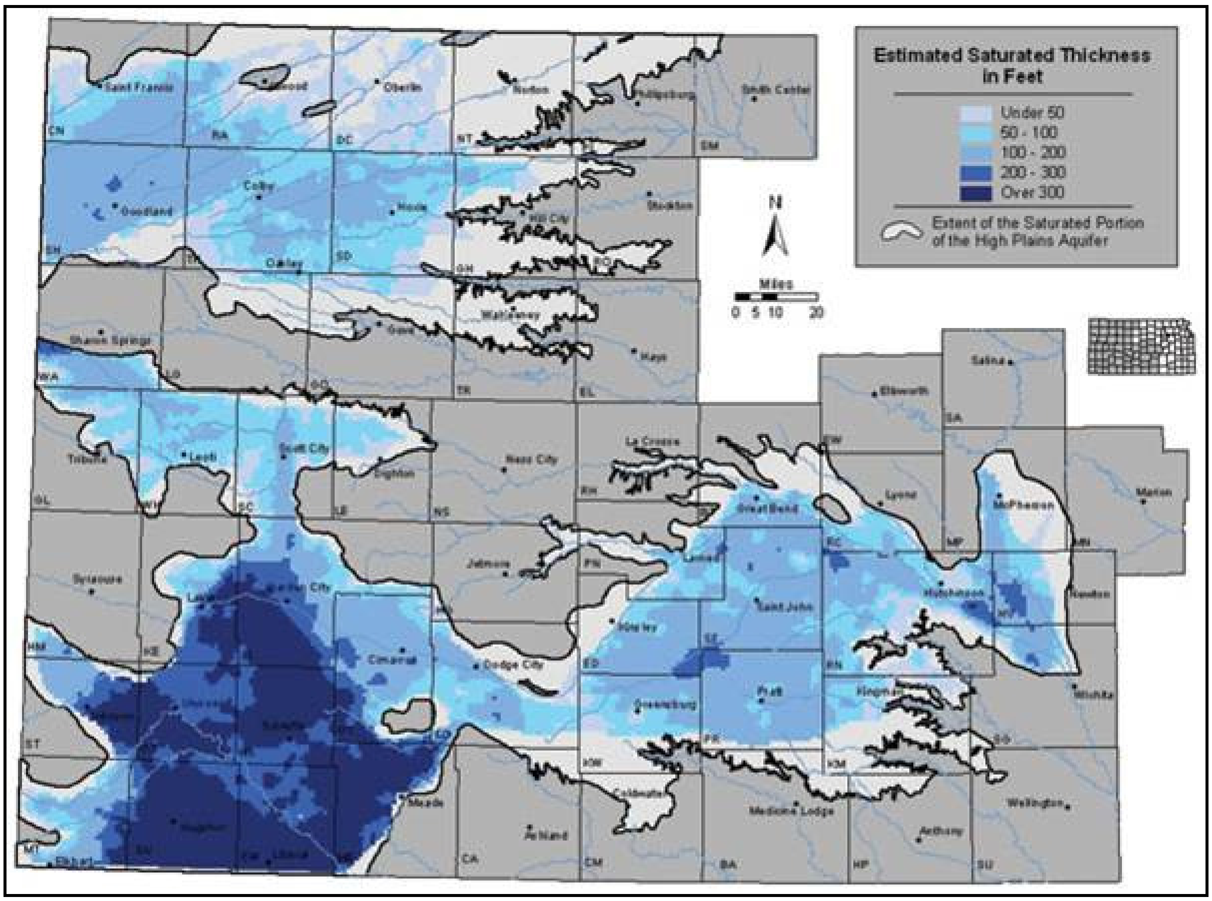

Figure 10. Kansas groundwater pre-development saturated thickness

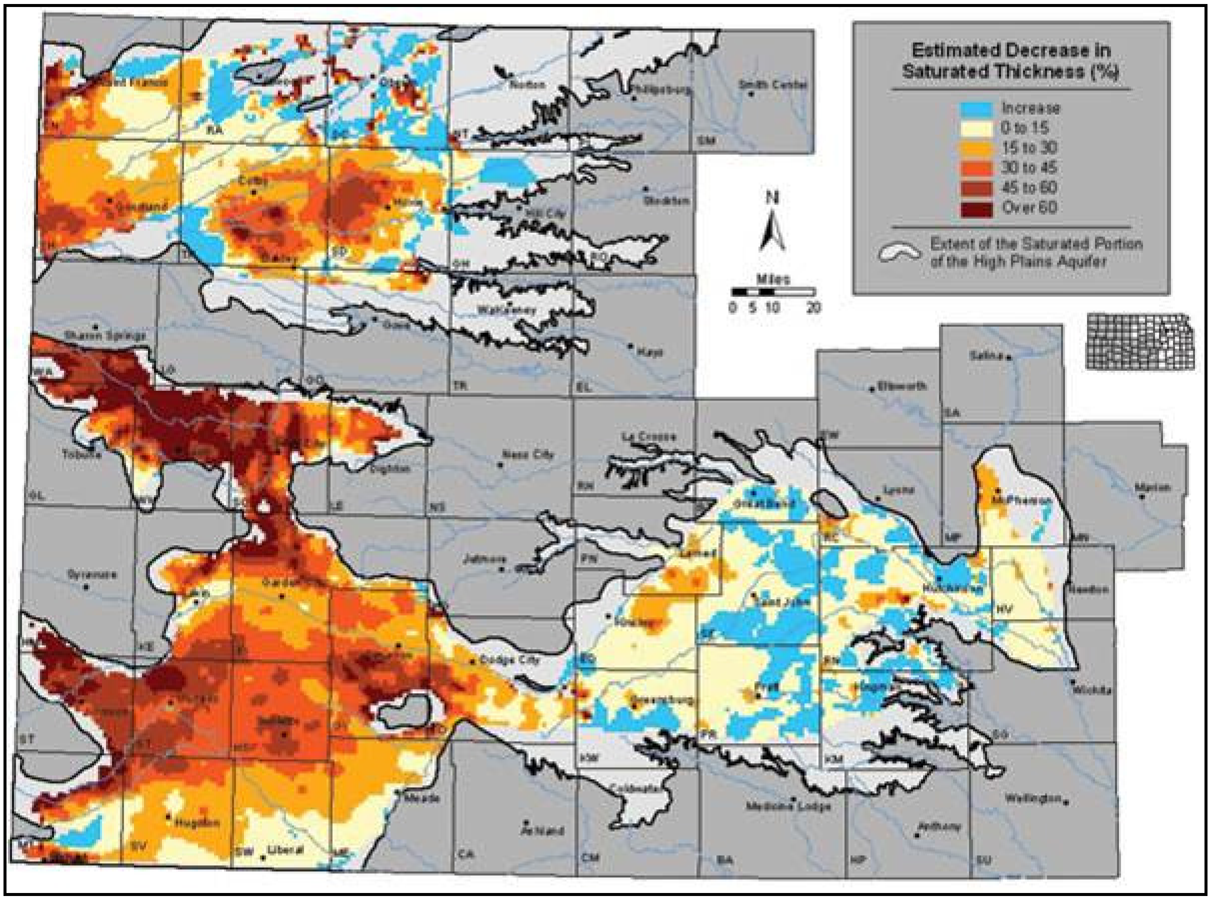

Figure 11. Kansas groundwater pre-development to 2007-2009 saturated thickness

4.1.2 Amendments to Legislation

SB 310: Establishes a process through groundwater management districts (GMDs) that allows local communities of producers to collectively decide their future by initiating the implementation of conservation plans that meet their local goals. The GMDs are to develop Local Enhanced Management Areas (LEMAs). The LEMA process is an alternative to the existing Intensive Groundwater Use Control Area (IGUCA) process, to allow GMDs to craft specific corrective controls in specific areas to conserve and extend the useful life of the Ogallala aquifer. The new process allows GMD's and stakeholders to propose to the chief engineer their own specific corrective controls.

SB 272: Provides expanded flexibility in managing water use. A Multi-Year Flex Account allows water right holders to obtain a 5-year term permit that temporarily replaces their water right. This term permit allows the water right holder to exceed their annual authorized quantity in any year but restricts total pumping over the 5-year period. Pumping for the five-year period is limited to a maximum of five times the larger of the water right's average water use or the water right's maximum reported acres times the county's net irrigation requirement for corn. This program is voluntary and does not permanently change the underlying water right. At the end of the 5-year period, if not extended by filing a new Multi-Year Flex Account application, the operation of the water right returns back to the original water right conditions.

SB 214: Redefining “person” in the groundwater management district act. The Bill purpose is to further define who/what entities have a right to vote in GMD related matters. The bill was requested by GMD#5 and was supported by all five GMDs. The current Bill status, the bill was passed as amended by the Senate Natural Resources committee and the full Senate. The bill was referred to the House Committee on Ag & Natural Resources and was amended to include HB 2272 (stream obstruction) and to make a technical change to clarify GMD voting procedures. The conference committee report was adopted by the House on April 1, 2011 by a vote of 120-0 and was acted upon by the Senate after they returned to Topeka on April 27 (http://www.ksda.gov, 2012).

4.2 Surrounding States

Nine surrounding states were taken into consideration to research and develop a broader understanding of how they handle groundwater and surface water. The following states were researched: Arkansas, Colorado, Iowa, Missouri, Nebraska, New Mexico, Oklahoma, Texas, and Wyoming.

4.2.1 Differentiations in Laws between States

The following states are grouped in the Rocky Mountain Region and follow the Western Water Law: Colorado, New Mexico, and Wyoming. Each state has their own unique set of rules but they all follow the same rule, prior appropriation system. Water rights are treated similarly to rights to real property, can be conveyed, mortgaged, and encumbered in the same manner, all independently of the land on which the water originates, or on which it is used. The essence of the doctrine of prior appropriation is that, while no one may own the water in a stream, all persons, corporations, and municipalities have the right to use the water for beneficial purposes. In order to obtain water from any of these places they must apply for a permit, through the current state Engineer. The states that are along the Rocky Mountain region may also follow the riparian system as they have many streams and rivers that run off of the mountains. In Colorado for example, there are seven different water districts. These districts are based under different river basins. Regardless if they follow both prior appropriation and riparian system or just prior appropriation they must follow the following rules in order to obtain their water right permit. 1.) they must have enough water available for beneficial use, 2.) they do not go against water conservation, and 3.) they do not go against public welfare.

The state of Arkansas’ legal water rights are based on a regulated riparian system. Riparian systems are very common in the eastern states of the United States. In the late fifty’s the Arkansas Natural Resources Commission (ANRC) was established to help maintain water resources and management. Riparianism attaches a water right to land adjacent to a water course; however the landowner cannot unreasonably diminish the quality or quantity of water to neighboring landowners. The ANRC has the authority to investigate and assist in the resolution of water rights complaints that deal with surface water availability and use. In order to further investigate in situation, one must submit a written request to ANRC. They then review that request to determine whether or not they can assist in that situation. If the ANRC can conduct an investigation, the person with the request may be charged a fee to follow through with results. Furthermore, if that person is not satisfied, they may file for a lawsuit.

The state of Iowa in 1987, adopted the Groundwater Protection Act (GPA). This act permits the taking-up of health-related groundwater standards. This is to ensure that owners of water restore contaminated water or prevent it from happening. Also within this state they must obtain a permit issued by the state or the county board of supervisors; in order to construct, drill, reconstruct, or replace a particular water well. These wells include domestic wells, livestock, irrigation, recreation, monitoring wells, heat pump wells, and dewatering wells. One must also obtain a permit if they withdraw or divert more than 25,000 gallons of water per day from either a surface or groundwater source. All agricultural drainage wells must be registered as well.

The state of Missouri Department of Natural Resources (MDNR) bases their water quality off of the current quality of surface water and groundwater. They have developed data that address the chemical, bacteriological, and radiological quality of water, natural and man-induced water quality changes, and as well as the effects of waste disposal on water. The main use of water in Missouri is for the following: commercial, industrious, residential, livestock use, irrigation, thermoelectric, in-stream flows, hydropower uses, recreation, fish and wildlife, and waterbourne transport on the Missouri and Mississippi River. As you can see, water use in Missouri is stretched thin and because of its many uses it must be monitored and regulated closely. Surface water in Missouri is contained by basin-by-basin assessment; they are grouped in six different tributaries. The six basins include: 1) Upper Mississippi River tributary, 2) Missouri River tributary north of the river, 3) Missouri River tributary south of the river, 4) Lower Mississippi River tributary, 5) White River tributary, and 6) Arkansas River tributary. All reservoirs are owned by the Missouri Department of Conservation and Department of Natural Resources. Surface water use by the public is to be identified and permitted by the departments listed above. Groundwater in Missouri is divided into seven groundwater provinces. The provinces are as the following: 1) the Ozarks (Salem Plateau); 2) the Ozarks (Springfield Plateau); 3) Southeastern Missouri (the Bootheel), Mississippi River alluvium, and Missouri River alluvium; 4) St. Francois Mountains; 5) Northwestern Missouri; 6) Northeastern Missouri, and 7) the Osage Plains of West-Central Missouri. Since before Missouri became a state it has been the custom and tradition that riparian water law is developed within the domain of the judicial branch. Riparian water law is published in judicial holdings (court records) and prior appropriation water law is commonly legislated (statutory, or required). Also, Missouri riparian water law is what is commonly referred to as restrictive. This means a person is legally allowed to use the water in any way for any legal and reasonable purpose until a court restricts that use. Under permissive laws only that activity that is clearly provided for in a statute, judicial holding, or some other legally binding policy is allowed and all uses that are not provided for are prohibited. Prior appropriation water law is typically permissive.

The state of Nebraska has their own Department of Natural Resources (DNR) and has authority over all matters related to surface water, rights for storage, irrigation, power, manufacturing, in-stream flows and other beneficial uses. This all pertains to the available supply of water each year or at the certain time, as there can be a shortage and they must be aware of already established rights. They have a permit system and one must attain one to gain the right to use the water, this pertains to surface water and groundwater. In receiving a permit, there very well might be a formal hearing. At these said hearings, they may be subject to the Nebraska court of Appeals. Any one user of these water rights that doesn’t follow the provisions found on the permit will be called in for a review at court. Any wells permitted can be used for any of the following: domestic, geothermal, industrial, injection, irrigation, monitoring, observation, public use (protected or unprotected), and a test hole. Any of these wells all have to go through a similar process to get a permit. A plan must be made and presented with a detailed description of each proposed well, setting forth the intended depth, screen type and casing size, and pump capacity. All pipelines, pumping stations, treatment plants, location of use, location of injection wells or discharge, and other facilities must be depicted. After that plan is presented, one must attend a conference where they will learn of all the requirements and from there they will receive notice of a hearing. At the end of the hearing a decision will be made by the director, and if a decision was made without a hearing, one can appeal for a hearing. From there an annotation is made and the permission for a well to be constructed is enabled.

The State of Oklahoma regulates groundwater rights by the allocations system, which ties groundwater ownerships to surface water ownership. All of this is determined by the amount of acres of land that overlays the basin the water right holder owns. The Oklahoma Water Resources Board (OWRB) regulates the use of groundwater, and a permit is required for use of water. The permit application has more information needed than surface water application. The OWRB must determine if the holder owns or leases the land, if the land is above water basins, if the use will be beneficial, and to ensure that the water won't be wasted. Also they must figure if the requested amount of water is present, is there a present or future need for the water and is the intended use beneficial, does it interfere with existing uses, and if the transportation of water must not interfere with current uses or needs of the area's water users. Surface water, including streams, is considered to be water that is owned by the public and is subject to appropriation. Or in other words, "First in time, first in right." Beneficial use is required to establish and maintain the right. Say if the water is not used at least once during any consecutive seven-year period the right of the unused amount is lost. Any time water is to be diverted out of a stream, it must be used for domestic use if no permit is filed. Domestic use can be described as water used by individuals, families, or households for household purposes. Groundwater is regulated by OWRB, even if the groundwater is considered private property. A permit is required for non-domestic use of water; however, even domestic users are prohibited from wasting groundwater pumped from a well. In times of severe drought, all beneficial uses may be affected, and even public water suppliers cannot demand that water use for other purposes cease.

The state of Texas' water rights depend greatly if it is groundwater or surface water. Ground water is overseen by the rule of capture, this means the owner is entitled to the rights of the water beneath their property. In other words, all property owners may own the right to the water beneath them, but until that water is pumped out of the ground they don't own the water. The groundwater is regulated by water conservation districts. These districts have a say in promoting the rules that stand for conserving, protecting, recharging, and preventing the waste of underground water. All of the surface water in Texas is owned by the state. Owners may use the water as long as they have permission from the state. This also goes towards riparian laws, as long as they own the land adjacent to the water they are permitted to use it. All of the rules that implemented by the state are to prevent over usage or pumping of groundwater and the usage of surface water. Texas water law has often been referred to as "law of the biggest pump." The practical effect of Texas groundwater law is that one landowner can dry up an adjoining landowner's well and the landowner with the dry well is without a legal remedy. The exceptions to Absolute Owner Rules include five situations in which a Texas landowner can take legal action for interference with his groundwater rights. First, if an adjoining neighbor trespasses on the land to remove water either by drilling a well directly on the land owner's property or by drilling a "slant" well on adjoining property so that it crosses the subterranean property line, the injured landowner can sue for trespass. Second, if there is malicious conduct in pumping water for the sole purpose of injuring an adjoining landowner. Third, landowners waste artesian well water by allowing it to run off their land or to percolate back into the water table. Fourth, there is contamination of water in a landowner's well. Not a single person is allowed to unlawfully pollute groundwater. And lastly, the land subsidence and surface injury result from negligent over pumping from adjoining lands. Currently the legislation is responding by attempting to strengthen the laws enabling citizens to manage this problem locally through groundwater conservation districts.

The eastern states that were researched, referring to Iowa and Missouri, have more annual rainfall than the western states and focus more on water quality along with water rights. With more flooding occurrence, it is necessary to apply laws that require people to hold regular inspections, and monitor for discharges; these states follow a riparian system. The western states place their focus more on prior appropriation, just as described above, making it a first come first serve approach. Prior appropriation is typically what you'll find in the western states. As the annual rainfall has a smaller average of rainfall, the main focus is groundwater. Urban cities do get priority over many wells, especially junior wells. However, if the well has been there before urbanization, then that well gets priority. Groundwater's in the western states have been the main source for beneficial water use.

4.2.2 Similarities in the Laws

The states west of Missouri and Iowa, not including Texas, all follow the prior appropriation system. As they all have similar environmental locations and weather patterns. They all seemed to put this system into effect all around the same time and therefore have been keeping the system updated ever since. All have experienced aquifer depletion and face the same challenges in keeping up with water uses but conserving it at the same time. It is a hard task that is a constant issue that is to be solved. But will it ever be solved? No state has come up with a system that would ultimately conserve and stop depletion. The weather patterns play a key role in the changes in the total amount of water that remains. But efforts had been made to conserve and positive results have protruded from it. The pumping of water and use of it has been more sustainable and continues to improve.

4.3 Different Countries

The countries in the Middle East and northern Africa have the scarcest water resources in the world. Those countries also have a long history of demand management, farming systems, and pricing polices implemented in regards to groundwater depletion. Water allocation law is undergoing changes all over the world. Surface water is being redistributed toward a more public and environmental purpose and groundwater allocation law is being redeveloped bas needs change. It is important to review the governmental controls that have been in practice for decades in these countries to gain a better understanding of the options available and to see what options are successful.

4.3.1 Egypt - Nubian Sandstone Aquifer

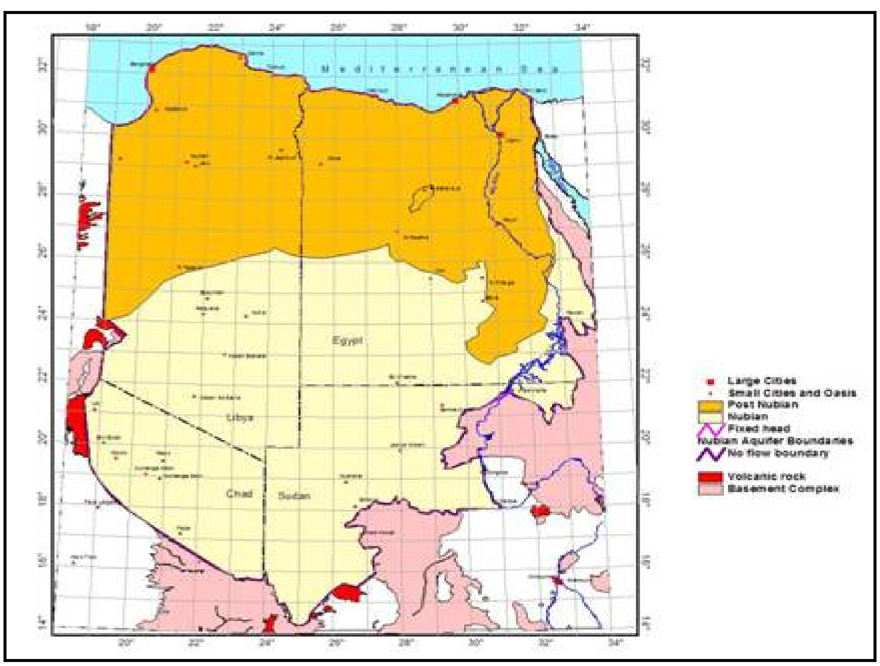

Figure 12. Nubian Sandstone Aquifer System

The Nubian Sandstone Aquifer System (NSAS) is the world's largest "fossil" water aquifer system and many countries rely on it for their livelihoods. The aquifer lies beneath four key African countries; Chad, Egypt, Libya, and Sudan and covers a little over two million square kilometers. The primary use of the groundwater in Libya is for irrigation for mixed farming of cereals and sheep and the production costs are much higher than the world price for these goods. They have been using central-pivot-sprinkler systems for irrigation leaving huge evaporation losses behind (Foster et al, 2006).

There is a growing demand on the NSAS for the development goals of each of these countries and other human pressures with major population increases in those countries. Over abstraction has already occurred in many areas and led to desertification. The International Atomic Energy Agency (IAEA) has partnered with these countries in hopes to establish long-term goals of equitable management, sustainable socioeconomic development, and protection of land resources. For many years, the IAEA has been working with NSAS countries through national and regional projects to try and understand the complexities of the aquifer (http://www-naweb.iaea.org, 2010).

Globally groundwater science, management, and law are still in the infancy stages and this is the first international water project for a transboundry aquifer. Several objectives were outlined after a national meeting was held in February 2010 in Tripoli, Libya. There was much data collection and modeling efforts taken before the meeting to access the priority of threats to the aquifer. Each country included a national shared aquifer diagnostic analysis (SADA) and understands that "adaptive management" will be required.

The project goals included: identify priority transboundry threats and root causes, fill key gaps, prepare strategic action programs, and establish the framework to implement the strategic action program (SAP). The main challenge is in developing an agreed legal and institutional structure for joint four party management. Considerable challenges lie ahead with relation to legal frameworks for groundwater regulation. The UN watercourse Convention in 1997 even noted that groundwater is considered only when there is an interaction or relation to surface water, which makes this endeavor a major legal challenge without much legal framework and very little precedent set.

4.3.2 Jordan - Azraq Oasis in the Lower Jordan River Basin

In the country of Jordan agriculture is the main user of water, as is the situation in most arid developing countries. In the early 1990's, Jordan's officials began measures for the coming water crisis caused by an absence of controls in groundwater abstraction. When the groundwater drilling began in the Azraq oasis back in the 1930's it just met the needs of the local agriculture demand and the water needs of the city of Amman. Since then the groundwater abstraction rate has reached 215% of the annual recharge which has resulted in increased salinity and a decline in the water quality (Venot & Molle, 2008).

Pricing policies of irrigation water has been the primary instrument to reduce the demand for water. The pricing policies that were to assist in controlling groundwater abstraction resulted in a shift toward higher-value crops. A shift towards high-valued crops would only raise the water productivity making essential for negative incentives to be accompanied by positive measures with attractive alternatives. In Jordan, prices are unlikely to enable regulation of groundwater abstraction and significant reduction will only be achieved through policies that reduce the number of wells in use. The government is currently promoting the buying-out of wells.

3.3.3 Saudi Arabia - Damman, Neogene, Umm Er Radhuma Aquifers

The Kingdom of Saudi Arabia has one of the scarcest water resources in the world and relies on three types of water resources; renewable, non-renewable groundwater and desalinated seawater. Only a small section of land on the Arabian Shield receives enough precipitation to enable a renewable water supply and the remainder of the country relies on the subdivided fossil aquifer systems. Currently this country faces significant population growth due to a rapid economic development. In 2009, 73% of the total water consumption was from non-renewable groundwater resources and the recharge rate of these aquifers does not come close to the abstraction rate (Al-Saud et al, 2011).

The country is currently improving outdated extraction methods which have wasted as much as 30% of the groundwater pumped. Once the new technology is implemented in the pumping methods it could almost double the lifetime of the aquifers. The government has also started reducing wheat production and abandoned their 30-year program to grow wheat and achieve self-sufficiency. They began reducing purchases from farmers by 12.5% each year beginning in 2008 and aims to rely solely on imports by 2016 (Khanfar, 2008).

5. Economics

5.1 Depletion Effects on Producer Energy Costs

The United States Geological Survey (USGS) estimated that in 2011 the Ogallala aquifer has declined by 274 million acre-feet since the 1950's, with most of the decline occurring in the 1980's. Estimated land value premiums capitalized the Ogallala's peak value at $26 billion in the 1970's and, as extraction rates remained high and water levels declined, the Ogallala's estimated value fell to $9 billion in 2002 (Keskin, 2011). This raises concerns about the long-term viability of the irrigation based economy which accounts for 20% of the area economy to include $300 million in farm production and $380 million in value added agriculture (Bertrand, 2011). Water has been neglected to be viewed as a natural resource like fossil fuels, forest, and mined minerals, which each have a dynamic economic value. Costs associated with the use of water for agricultural irrigation is centered on the amount of money required to allocate the resource rather than placing a value on the resource. Recognizing that water is an economic good would place a market value of utilizing the source and promote an understanding that it is not limitless, and that demand scarcity developed by not adopting conservation practices will lead to an increased economic cost of use, and a lower net profit for producers of irrigated agriculture.

The Ogallala aquifer has been historically seen as a common property, or a common pool resource that is uniformly distributed. The reality is that specific yield and storage vary significantly over the entire formation, with thickness of the saturation zone ranging from 50 feet to more than 300ft. The disparity in water levels affects available water use by geographic location (Brajer et al, 1989). Given the idea of common property, no one user must bear the full consequences of increased pumping costs due to declining water levels. Allocation of groundwater from an aquifer through well pumping results in a drawdown of the water table level where homogenous aquifer properties with isotropic permeability will form a hydraulic formation known as a cone of depression. This is characteristically a drawdown curve that superficially further reduces the water table level along the line of the curve. The outer limit of the cone of depression defines the area of influence of the pumping well. The aquifer water levels take on more of an "egg carton" water level surface profile when many wells are pumping from the aquifer in one area (Brajer et al, 1989). The area of influence from a well is dependent on the pumping rate and available saturated thickness of the aquifer, which can affect the neighboring well water table levels and the depressions in the water table and lead to higher pump suction heads which induces increased pumping costs. This action then causes individual users to bear the costs imposed by the action of their neighbors and therefore contradicts the idea of a common property resource.

5.1.1 Energy cost associated with increased pump lift

As the total dynamic head of the pump (lift head on the suction side and discharge head on the discharge side) increases, the amount of time and energy required for the pump to deliver equal amounts of water at a higher lift distance will also increase. It is estimated that a one to one ratio of foot decrease in thickness to foot increase in lift exists. Translating this relationship into increased pumping costs, the total water output (WHP) is a measurement of power (in units of horsepower) required to lift water from the aquifer to the irrigation surface. The following equations are used to show the relationship between increased pump lift, discharge, energy requirements, and cost,

$$WHP = \frac{Q * L_e}{3960} \quad \text{(Equation 1)}$$

$$Pumping\ cost = WHP\ (hp) * \frac{1.341\ kW}{hp} * (hours\ of\ pump\ operation) \frac{*(\$)}{kWhr} \quad \text{(Equation 2)}$$

where, (WHP) is water horse power, or the amount of horse power the pump is generating , (Le)is the pump lift distance in (ft) plus the assumed output pressure of (30 psi)(2.31 ft/psi) , (Q) is the pumping rate of discharge in (gpm), and the value 3960 is a horsepower conversion factor (Smajstrala et al, 1999). Utilities cost also varies across the western regions. Energy cost increases with 100 ft increments of pump lift are shown in Table 4 for two energy supplies: natural gas and electricity. Cost variations for natural gas range from $4.00-$12.00 per million cubic feet and for electricity from $0.06-$0.14 per kilowatt-hour and total pumping cost is presented in dollars per acre-inch.

Table 4. Data retrieved from Farm Management Guide, MF-836. Kansas State Research and Extension. Department of Agricultural Economics, 2011. Retrieved from www.agmanager.info, 4/17/2011.

Energy Pumping Cost Per Acre-Inch

	Total Lift (ft)					
	100	200	300	400	500	600
Natural Gas ($/mcf)						
$4.00	$1.40	$2.22	$3.04	$3.87	$4.69	$5.52
$6.00	$2.09	$3.33	$4.56	$5.80	$7.04	$8.27
$8.00	$2.79	$4.44	$6.09	$7.73	$9.38	$11.03
$10.00	$3.49	$5.55	$7.61	$9.67	$11.73	$13.79
$12.00	$4.19	$6.66	$9.13	$11.60	$14.07	$16.55
	Total Lift (ft)					
	100	200	300	400	500	600
Electricity ($/kWhr)						
$0.06	$1.46	$2.32	$3.18	$4.04	$4.91	$5.77
$0.08	$1.95	$3.09	$4.24	$5.39	$6.54	$7.69
$0.10	$2.43	$3.87	$5.30	$6.74	$8.18	$9.61
$0.12	$2.92	$4.64	$6.37	$8.09	$9.81	$11.54
$0.14	$3.40	$5.42	$7.43	$9.44	$11.45	$13.46

From (Equations 1, 2), a relationship between total water output, the pump lift (L_e) and pump yield (Q) shows that an increase in pump lift will result in a lower pump yield to maintain the desired water output. Declining well yield as the aquifer is dewatered, in conjunction with increasing lift, serves to increase pumping costs per acre inch of water (Lacewell & Pearce, 1973). When pumping cost increase to the point of providing net returns of dry-land farming equal to net returns of irrigated land farming for any crop choice, effective economic exhaustion of the water supply has been reached. Remaining available water may be present in the aquifer, but the cost of allocating the resource exceeds the economic return of use for irrigated crop production.

5.2 Commodities Prices and Cropping Patterns of Corn Production

Commodities prices are the driving factor for crop choices by producers. Each year a producer must make decisions based on constraints such as crop to plant, available acreage, and available water. Ideally in areas where water is not a constraint and is abundant enough to neglect in making crop choices, a crop with the highest potential revenues will be chosen regardless of the water demand. Producers overlying the Ogallala aquifer have tended to adopt the idea that water is not a binding constraint and continue to choose water intensive crops such as corn due to their high commodity price which delivers the largest return revenue. The increased demand for allocation of groundwater by choosing a water intensive crop decreases the water table, induces cones of depression, and impacts availability for neighboring producers in addition to reducing future water availability.

5.2.1 Production trends and revenues from 2008-2011

Crop prices for the years 2008-2011 were compiled to compare the changes in developed irrigation land devoted to corn in relationship to the changing market price of corn yield in bushels per acre planted (Table 5). Western Kansas corn production areas of influence were divided into three regions with different characteristic remaining aquifer saturated thickness levels including: Northwest Kansas (NW) having intermediate saturated thickness remaining, West Central Kansas (WC) having areas of near effective depletion, and Southwest Kansas (SW) having an abundant supply of saturated thickness remaining (Clark, 2007). These yields are specific to center-pivot irrigated corn versus dry-land corn and shows data for gross revenues of corn production based off of the annual commodities prices established by Kansas Department of Agriculture, Kansas Agricultural statistics for each year of production compared.

Table 5. Production data retrieved from Kansas Agricultural Statistics, Kansas Department of Agriculture and crop prices retrieved from National Agricultural Statistics Service.

NW	Year	Irrigated Acres planted	Yield bushels/acre	Production, bushels	Non-irrigated Acres planted	Yield bushels/acre	Production, bushels	Prices Received, April $/bushel
	2008	245,000	184	45,120,000	405,000	64	25,900,000	5.67
	2009	240,000	190	45,700,000	440,000	108	47,300,000	3.85
	2010	265,000	198.1	50,515,000	665,000	84	55,891,000	3.41
	2011	265,000	183.4	48,600,000	595,000	78	46,400,000	6.48

WC	Year	Irrigated Acres planted	Yield bushels/acre	Production, bushels	Non-irrigated Acres planted	Yield bushels/acre	Production, bushels	Prices Received, April $/bushel
	2008	127,000	169	21,440,000	185,000	49	9,100,000	5.67
	2009	122,000	202	24,700,000	193,000	108	20,800,000	3.85
	2010	135,000	184.8	23,291,000	329,000	76.4	25,152,000	3.41
	2011	120,000	184.2	22,100,000	260,000	64.8	16,850,000	6.48

SW	Year	Irrigated Acres planted	Yield bushels/acre	Production, bushels	Non-irrigated Acres planted	Yield bushels/acre	Production, bushels	Prices Received, April $/bushel
	2008	710,000	193	137,300,000	68,000	30	2,070,000	5.67
	2009	675,000	215	145,000,000	75,000	71	5,300,000	3.85
	2010	770,000	196.7	144,600,000	150,000	51.5	7,721,000	3.41
	2011	655,000	156	102,170,000	35,000	28	980,000	6.48

5.2.2 Observed response to changing commodities prices and cropping patterns

In the years from 2008-2011, the year with the lowest projected crop price per bushel was $3.41 in 2010. Each of the three regions responded by increasing acres planted by 25,000 acres in the Northwest region, 13,000 acres in the West Central region, and 115,000 acres in the Southwest region to attempt to recover the maximum gross profits of previous years at higher commodity pricing. A similar response is observed between years 2008 and 2009 when a crop price per bushel decreased by $1.82 dollars per bushel, and dedicated irrigated acres to corn increased in each region. This evidence supports the cropping decisions by producers to maintain gross revenues from year to year in response to changes in market commodities prices. Increased irrigated land devoted to water-intense corn production is directly related to decreasing aquifer water table levels as the demand for water allocation increases to support the increase in planted acreage. This relationship is particularly important in the West Central region where the average saturated thickness levels are 46 ft remaining, 16 feet from a 30 ft saturated thickness level which considered effective depletion.

A higher commodities price of $6.48 per bushel from 2011 provides the availability to reach gross revenues expected without dedicating the same amount of acreage to corn production. The Northwest region was the only region that did not decrease irrigated acreage in response to the $3.07 increase per bushel between years 2010-2011, but rather reduced the amount of dry-land corn production by 70,000 acres. However, given the high commodity price, overall gross revenue from both irrigated and dry-land production far exceeded revenues from the previous year despite less overall acres planted. The following compiled table compares the gross revenues for each region from the years 2008-2011, corresponding to acres of irrigated corn planted and dry-land corn planted.

Table 6. Production data retrieved from Kansas Agricultural Statistics, Kansas Department of Agriculture and crop prices retrieved from National Agricultural Statics Services.

		Irrigated		Non-Irrigated					
NW	Year	Acres planted	Production, bushels	Acres planted	Production, bushels	Prices Received, April $/bushel	Revenue Irrigated	Revenue non-irrigated	Change from previous year
	2008	245,000	45,120,000	405,000	25,900,000	5.67	$255,830,400	$146,853,000	
	2009	240,000	45,700,000	440,000	47,300,000	3.85	$175,945,000	$182,105,000	($44,633,400)
	2010	265,000	50,515,000	665,000	55,891,000	3.41	$172,256,150	$190,588,310	$4,794,460
	2011	265,000	48,600,000	595,000	46,400,000	6.48	$314,928,000	$300,672,000	$252,755,540

		Irrigated		Non-Irrigated					
WC	Year	Acres planted	Production, bushels	Acres planted	Production, bushels	Prices Received, April $/bushel	Revenue Irrigated	Revenue non-irrigated	Change from previous year
	2008	127,000	21,440,000	185,000	9,100,000	5.67	$121,564,800	$51,597,000	
	2009	122,000	24,700,000	193,000	20,800,000	3.85	$95,095,000	$80,080,000	$2,013,200
	2010	135,000	23,291,000	329,000	25,152,000	3.41	$79,422,310	$85,768,320	($9,984,370)
	2011	120,000	22,100,000	260,000	16,850,000	6.48	$143,208,000	$109,188,000	$87,205,370

		Irrigated		Non-Irrigated					
SW	Year	Acres planted	Production, bushels	Acres planted	Production, bushels	Prices Received, April $/bushel	Revenue Irrigated	Revenue non-irrigated	Change from previous year
	2008	710,000	137,300,000	68,000	2,070,000	5.67	$778,491,000		
	2009	675,000	145,000,000	75,000	5,300,000	3.85	$558,250,000	$20,405,000	($199,836,000)
	2010	770,000	144,600,000	150,000	7,721,000	3.41	$493,086,000	$26,328,610	($59,240,390)
	2011	655,000	102,170,000	35,000	980,000	6.48	$662,061,600	$6,350,400	$148,997,390

5.3 Conversion of Irrigated Farming to Dry-Land Farming

5.3.1 Replacing 50% irrigated corn acreage with dry-land corn acreage

These results lead to estimating the effects of converting 50% of the current irrigated acreage in each region to dry-land farming, using the same yield in bushels per acre planted as the 2011 yields. The desired results would show an effective alternative to crop water use resulting in reduced aquifer withdrawals by irrigation pumping while maintaining the lowest possible economic impacts in gross annual revenues (Table 7).

Table 7. Yield in bushels/acre were kept constant from 2011 reported yields. The irrigated land acres were reduced by 50%, and the quantity of that land was added to 2011 reported dry-land acres in production. Commodities prices projected for 2011 were used to determine revenues from both production of irrigated acres and dry-land acres.

Conversion to 50% irrigated to dry-land (non-irrigated) estimates, Year 2011

	Irrigated				Non-Irrigated			
Region	Acres planted	Yield bushels/acre	Production, bushels	Revenue at $6.48/bushel	Acres planted	Yield bushels/acre	Production, bushels	Revenue at $6.48/bushel
NW	132,500	183.4	24,300,000	$157,464,000	727,500	78	56,745,000	$367,707,600
WC	60,000	184.2	11,052,000	$71,616,960	320,000	64.8	20,736,000	$134,369,280
SW	327,500	156	51,090,000	$331,063,200	362,500	28	52,070,000	$337,413,600

In the Southwest region (SW) gross revenue loss in conversion of 50% irrigated land to dry-land corn production was $64800, with a total reduction of 327,000 acres of irrigated land. The Southwest region has the highest available saturated thickness, ranging from 100ft to over 300ft, which decreases overhead pumping costs due to reduced pump lift. However, due to this area having the greatest supply of available groundwater, rates of depletion are also higher than the West Central and Northwest regions, at an average decline of 30 feet from 2008 to 2011 as compared to an average decline of 5 to 15 feet from the years 1996 to 2006, respectively (Clark, 2007). Relative to the $668,476,800 in total revenue from 50% conversion to dry-land production, a $68,000 per year loss has relatively low negative economic impact for an average potential groundwater withdrawal savings of 412,650 acre-feet per year[12] (Hutson et al, 2000). Conversion of 50% irrigated to dry-land production resulted in a potential revenue loss of $90,428,400 for the Northwestern region, and $37,409,760 for the West Central region.

These losses are much more significant than losses for the Southwestern region, and show negative impact the economic gains in those regions. These estimations are also highly dependent on the environmental factors effecting crop yields, but commodity price fluctuations applied to the reduced irrigated acreage scenario will vary in gross revenue loss amounts though annual percentages of loss will vary little between regions. Total revenue losses from conversion to dry-land production does not take into account the overhead costs saved by reduced pump energy savings, reduced maintenance cost related to irrigation machinery, and reduced labor costs related to irrigation production. These cost savings could be significant in areas were pump lift requirements are high, such as the conditions predominant in the West Central region and portions of the Northwestern region.

[1] Estimated use of water in the United States in 2000, from USGS Circular 1268, designates an irrigation water use application rate of 1.26 acre-feet per acre, from annual withdrawals in thousands of 3840 acre-feet per year for the state of Kansas. Irrigation accounts for 83.65% of all groundwater withdrawals. (USGS, 2011)

[2] Irrigation water use as defined in USGS Circular 1268 is water that is applied by an irrigation system to assist in the growing of crops and pastures or to maintain vegetative growth in recreational lands such as parks and golf courses. (USGS, 2011)

5.4 Alternative Crops for Sustained Revenue with Irrigation Reduction

5.4.1 Replacing 50% irrigated corn acreage with irrigated cotton acreage

Water conservative crop choices for sustained economic sustainability can be explored for areas where water intensive corn production must be abandoned due to declining water availability. This would require choosing a crop that is has competitive yield and commodities prices, while requiring less annual irrigation withdrawals. One such alternative crop that is not grown in high quantities currently in Kansas is cotton. The success of cotton production in the Northern High Plains of Texas has proven profitable for areas of declined Ogallala aquifer levels, and though it requires less annual water application (of 647mm annually in comparison to 835mm annually for corn), a specific number of growing degree days (heat units) during the growing season much be reached to produce yields sufficient enough to match corn yields (Gowda et al., 2007). Most of the countries cotton has traditionally been grown in what is known as the "cotton belt" (below the 37° N lat), regarded as having the best climatic conditions for maximum cotton production. Cotton requires approximately 1440°C heating units during the entire growing season, but Texas Panhandle farmers have shown that economically viable cotton can be grown with approximately one-third fewer heat units (Howell et al., 2004). Heating units of approximately 1000°C, or one-third of typical requirements provides the possibility that cotton could be a suitable crop alternative in Western Kansas. A study conducted in 2005 explored the possibility of cotton production over the entire Western portion of the state, including the Northwest, West Central, and Southwest regions. It was determined that the conversion of 50% of the current acreage used for irrigated corn production could result in significant cotton production with reduced water allocation from the Ogallala. Potential production was analyzed for four years of 50% conversion, and it was found that converting 3 out of every 4 years would result in the highest production yields (Figure 14).

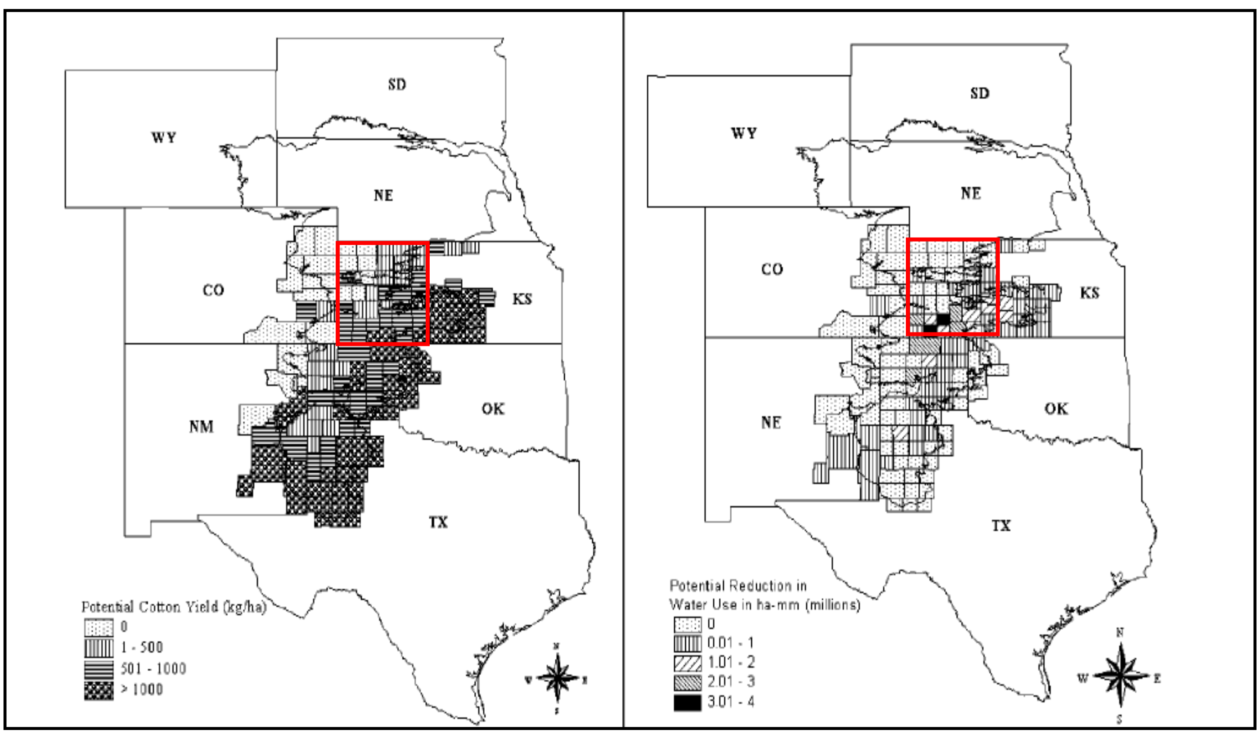

Figure 13. Spatial distribution of county-wide potential cotton yield (PCY) in P=0.75, 3 out of 4 years conversion of 50% corn production to cotton production. (Gowda et al., 2007)

Nineteen counties in Kansas returned annual heating units between 800 and 999°C where cotton can be grown economically where yields varied between 500 and 1000 for seventeen counties, and greater than 1000 (kg/ha) for two counties. A potential reduction resulted of about 339,450 ml (11.98 ft^3) of water in Kansas alone which was applied to the approximate 250,000 hectares (617,763 acres) that were presently under irrigated corn for the whole Ogallala region during the 2005 study (Gowda et al., 2007). Estimations for increased cotton production were forecasted for the returns reported in 2011 to show advantages and disadvantages of converting 50% of the 2011 irrigated corn acreage with cotton acreage (Table 8).

Table 8. Estimates of cotton and corn production revenues if 50% of 2011 irrigated corn production acreage is converted to cotton production acreage at recorded 2011 commodities prices (KAS, 2012).

Total Acres for Corn and Cotton Production from NASS 2011

Year	Practice	Acres planted	Production	Avg Yield	Prices Received, April $/Yield	Production Revenue
2011	Irrigated	655,000	137,300,000 bu	156 bu/acre	6.48	$662,061,600
	Non-Irrigated	35,000	980,000 bu	28 bu/acre	6.48	$6,350,400
Total						**$668,412,000**

Total Estimated Production for 50% Irrigated Cotton acres and 50% Irrigated Corn acres

Year	Practice	Acres Planted	Production	Avg Yield	Prices Received, April $/Yield	Production Revenue
2011	Cotton	327,500	257,742,500 lbs	787 lb/acre	0.903/lb	$245,178,045
	Irr Corn	327,500	51090000 bu	156 bu/acre	$6.48/bu	$348,753,600
	Non-Irr Corn	35,000	980,000 bu	28 bu/acre	$6.48/bu	$6,350,400
Total						**$600,282,045**

Actual cotton production in 2011 was reported as being 50,000 acres planted at 787.0 lbs per acre, accounting for 82,000 bales at $0.903/lb, for a total returned revenue of $34,675,000. It is estimated that conversion of 50% irrigated corn to cotton will save 6.35 ft3 annually, based off of (Gowda et al.,2007) returned water savings estimates. Cotton seed costs about $80 per acre, which is comparable to corn. Herbicide and insecticide costs are also about equal. The advantage that corn has for farmers is after it's harvested, the farmer has only winter field preparation left. Harvested cotton still has to be ginned upon harvest, a costly step in taking produced yield to market (Sorenson, 2011). The estimated $68,000 in revenue lost compared to water saved may not be persuasive enough for a producer to incorporate cotton production into their cropping patters.

5.5 Planned Depletion Strategies

Developments of groundwater pumping systems were encouraged to stimulate economic growth in Western Kansas, significantly increasing in the early 1970's. Decades later, without significant policy enforcement or changes to prior appropriate and the "use it or lose it" doctrine, an unintended consequence of over allocation has led to facing an economic crisis when the groundwater levels reach effective depletion. One of the greatest challenges of implementing changes to current groundwater depletion management is how to effectively induce technological advancement of water conservation strategies while maintaining economic viability. Many policy amendments include incentive based programs that include some level of voluntary participation with lack of state and local enforcement (Bertrand, 2011). In order for voluntary participation, economic incentives must meet the needs of the producers' economic viability as moral persuasion is not considered an equal replacement for monetary incentives.

5.5.1 The value of water rights

There is currently no well-defined market for water. Approximately 36 million acre-feet are extracted each year from the Ogallala where approximately 85% is applied directly towards irrigation. Development of economic tools to predict the value of water held within a water right are being developed by researchers at Kansas State University to provide models capable of estimating fair market values[1] of water rights. This research suggests that the value of water for agricultural purposes depends upon the spatially fixed, site-specific characteristics of the land on which the water is used. Factors include water source, soil type, crop type, depth to water, saturated thickness of the aquifer, the seniority level of the water right, average annual water usage, and local precipitation (Golden et al., 2006).

5.5.2 Water conservation policy effects on economic viability

Water Rights Buyout Programs

The Water Plan Storage Act of 1974 provides the State of Kansas with the authority to purchase a "conservation water supply". This plan did not allow a provision that would allow the State to purchase groundwater rights however. A proposed the Irrigation Transition Assistance Program to be introduced into the Kansas Water Plan includes the voluntary relinquishment of water rights compensated by government payments. The rights purchased will be permanently retired. Kansas State House bill HB-2620, now in legislature, offers to pay an amount not to exceed the difference between the fair market value of converted irrigated acres to similar non-irrigated land. Kansas Governor, Sam Brownback, has a current budget of approximately $2,000,000 to purchase 2,500 acres of water rights (Golden et al., 2006).

Long term versus short term water rights buyout policies have been examined to determine economic viability in implemented regions. These policies were evaluated based on the amount of acre-feet of water saved per the cost of the present value of the forgone net income. The long term policy would be in place for 60 years was found to save the most saturated thickness, but at a higher cost to the economy. The short term policy would be in place for 15 years and save much less saturated thickness at a lower cost to the economy, but the cost per saturated thickness is still lower with the long term policy (Wheeler et al., 2008). Funding for this policy was assumed to be derived from government entities, but was not defined in the study.

Another alternative is the Environmental Quality Incentives Program (EQIP), which is a voluntary conservation program for producers to suspend irrigation production for a four year planning horizon. This would be considered a short term water rights buyout where funds would come from the natural Resources Conservation Service (Wheeler et al., 2008). This program is currently being implemented to suspend irrigation for 14 to 15 years in Nebraska and Idaho.

[1] Fair market value it to be determined by an independent appraiser or by appraisal processes.

Cost Share Program

Continuing the treatment of the Ogallala aquifer as a "common pool" resource each groundwater consumer would be responsible for paying an increase of an implemented regional tax which would cover reimbursements to the cost of producers adopting advanced water conservation technologies for irrigation. The incentives of this program would provide greater water use efficiency, leading to lower groundwater withdrawals while maintaining consistent cropping patterns of previous year's maximum yields. Since 90% of all irrigated land in Kansas uses center pivot technology, the most common cost share funds are expected to be applied to expanding center pivot technology to low pressure systems with drops. The success of this program is highly dependent on maintaining current crop patterns. Increasing irrigated acres to take advantage of advanced irrigation efficiency to water intensive crops such as corn will lead to higher crop yields and higher producer revenues, but will not provide reduced aquifer withdrawals. This policy change would only be an advantage to producers increasing irrigated acreage with greater revenues while negatively impacting neighboring producers who pay the increased tax and do not increase irrigated acreage. Adopting this policy change would therefore not change withdrawal rates or provide water conservation at an increased communal tax if policy enforcement is not maintained.

Conservation reserve enhancement program

This program is based on voluntary actions of producers over ten counties in the Kansas Upper Arkansas River basin, comprising the cooperation of 10 Kansas counties. The basis of this program is to provide government payouts to producers to convert currently irrigated agriculture to planted grass acres for fifteen years, where then the land can be converted to dry-land farming only. The Conservation reserve enhancement program (CREP) was analyzed by researchers at Kansas State University to better understand the economic impact on the entire ten county regions if adopted as a water conservation program.

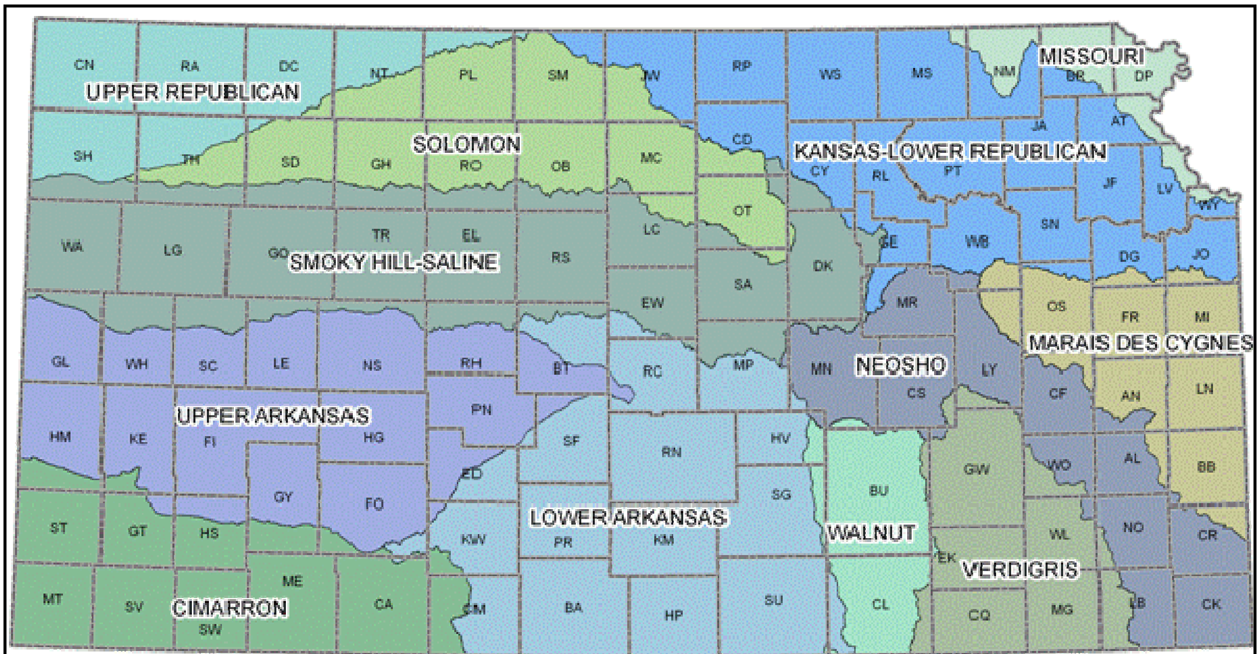

Figure 14. Upper Arkansas River basin is managed in portions by GWD1 and GWD 3. This West Central region has the lowest saturated thickness levels remaining since pre-development. Picture retrieved from KWO (www.kwo.org, 2012)

A total retirement of water rights over 85,000 acres was found to positively impact the reduction of water and extending the economic life of the aquifer, however a negative impact to the regional economy was determined to amount to $14.8 million dollars annually. This reduction in gross revenues is far less than the consequences related to effective depletion and dry-land production, as stated in the conversion to 50% dry-land farming analysis portion of this paper in corn production alone.

Companion Policies

The evaluation of conservation policies separately has returned similar negative impacts on the economy. The challenge is to develop a multifaceted planned depletion policy to counteract the "law of unintended consequences", resulting from the lack of appropriate management practices during the focus of economic stimulation via increased irrigated production (Golden et al., 2006). One suggestion would be to provide several combinations of the various elements presented in each of the proposed policy changes and have the producer chose a management strategy that will have the best possible outcome for their particular production demands. A uniformly adopted policy for the entire Ogallala region has not seemed possible to meet the needs of each individual producer; some plans impact certain producers more than others on both positive and negative sides of the spectrum. Elements from the CERP program may be effective if coupled with a cost share program in smaller regions where the producers are facing similar conservation and economic challenges. This is to suggest that a tailored conservation program to be adopted by producers in West Central Kansas that match their unique conditions wouldn't necessarily be beneficial for producers with unique regional conditions in the Southwest, and vice versa. The success of these tailored regional policies could be effective, but would require increases local enforcements to support the specific adopted and regionally agreed upon policy.

6. Recommendations

The sections below discuss recommendations for slowing down the depletion of the Ogallala Aquifer, including best management practices that can be conducted by farmers to ensure the highest water use efficiency and laws that amend for a sustainable use of the Ogallala Aquifer.

6.1 Best Management Practices

In order to ensure the highest water use efficiency possible, the following recommendations have been made to farmers, including irrigation, crop selection, and individual management.
The two main types of irrigation that should be used in order to reduce the amount of water being drawn from the Ogallala Aquifer include: center-pivot irrigation, with a LEPA low-pressure system and subsurface drip irrigation (SDI). If flood irrigation is currently being used, the conversion to either a LEPA center-pivot irrigation system or SDI system is necessary to increase the irrigation efficiency from 65% to 85% and higher. Between LEPA center-pivot irrigation system and SDI system, the decision to choose either one of these systems is up to the farmer/irrigator. There are pros and cons for both systems, and more research would need to be conducted by the farmer/irrigator to determine which system is better for their situation.

Besides irrigation, crop selection is also key to reduce the amount of water drawn from the Ogallala Aquifer. Conversion from all corn systems to 50% cotton and 50% corn is one recommendation to reduce water use in the Ogallala Aquifer, reducing up to 73% of water used in the state of Kansas. Also, it is recommended that farms that are monoculture systems (grow only one crop), integrate their systems into crop and livestock systems in order to reduce water use and also economic risk.

Individual management is another key factor that reduces water with drawl from the Ogallala Aquifer. Important individual management that is recommended includes conservation tillage and computer tools/programs such as the crop water allocator (CWA) and the crop yield predictor (CYP). By using conservation tillage, soil moisture is increased, allowing for less water being applied to the crops. With computer tools/programs such as the CWA and CYP, these resources allow for feedback on how select inputs, like irrigation water, crops, and land size, will affect the growth of the crop and economics.

6.2 Laws

Due to recently passed legislation in the State of Kansas, planned depletion strategies are being implemented by the Groundwater Management Districts. These new laws allow for greater flexibility in meeting the specific water demands of the producers and stakeholders. The 5-year flex plan replaces the "use-it-or-lose-it" doctrine so that water is being put to beneficial use conservatively and gives producers more incentive to adopt sustainable practices.

SB 310 increases the authority of the Groundwater Management Districts to apply specific groundwater controls that meet the precise needs for each district. This further applies water conservation management practices for planned depletion.

6.2.1 Proposed Beneficial Amendments to Current Kansas Laws

Government incentive programs based on voluntarily retiring productive acreage are not always perceived as beneficial to accumulate enough participation to make a large impact on reduced groundwater withdrawals. The State of Kansas currently budgets about two million dollars a year to purchase and retire water rights as conservative practice, and may be more effective if coupled with a tax credit for producers who provide evidence of water use reduction. This tax credit amount could be assessed by a determination of crop production, crop production revenues, and total water conservation, recorded and submitted by the producer. The efforts for management of accurate production/water use recordings would be coordinated by the GMD's of that region to avoid inflated or inaccurate reported production and water use. This coupled incentive may seem attractive enough to producers to adopt, and allow a greater understanding of the increasing water scarcity in certain regions.

6.2.2 Our Proposed Law

The new legislation is a huge step forward in the sustainable development of the Ogallala Aquifer. It is extremely important to allow for the GMDs to have more authority and specific controls for their specific area. We feel that the new legislation is making great progress in conserving and monitoring the water used. However, we do recommend that more education be required on Best Management Practices and an emphasis on individual management before the producer obtains the 5-Year permit. Perhaps the state could provide stakeholders and producers with BMP seminars in their area throughout the year. The seminars would provide information on new technologies and irrigation practices in managing their water use. The continuing education would also give producers the information needed on crop selection and the current market prices for those crops. All of this information would allow the producers to make better informed decisions in the sustainable development of the Ogallala Aquifer.

7. Conclusion

Overall, the depletion in the Ogallala Aquifer will continue unless the major factors discussed above are taken into consideration. Best management practices, including irrigation systems, crop selection, and individual management, need to be increased and changed accordingly in order to increase water use efficiency. Also, laws must be changed in order to accommodate the decreases water table in the Ogallala Aquifer, as well as find a more sustainable way to allow water to be pumped from the Ogallala Aquifer. Use of the Ogallala Aquifer must become more sustainable in order to ensure its existence for generations to come.

Work Cited

Abderragman, Walid (2006). Future of Saudi Arabian Water Aquifers: Groundwater Resource Management in Saudi Arabian http://www.sawea.org/pdf/FutureOfSaudiArabianWaterAquifers.pdf. Downloaded February 28, 2012.

Al-saud, M., Teutsch, G., & Rausch, R. (2011). Challenges for an Integrated Groundwater Management in the Kingdom of Saudi Arabia. *Water Resources*, *1*(1), 65-70.

Allen, V.G. (2005). "Integrating Cotton and Beef Production to Reduce Water Withdrawal from the Ogallala Aquifer in the Southern High Plains." *Agronomy Journal*, 97(2), 556-567.

Bedessem, M. E., Casey, B., Frederick, K., & Nibbelink, N. (2005). Aquifer prioritization for ambient ground water monitoring. *Ground Water Monitoring & Remediation*, *25*(1), 150-158. doi:10.1111/j.1745-6592.2005.0010.x

Brookshire, Cynthia. M. 1997. Water Quality Assessment of Missouri. http://www.dnr.mo.gov/env/wrc/statewaterplanphase1.htm.

Buchanan, R. C., Buddemeier, R. R., & Wilson, B. B. (2009). Kansas Geological Survey the High Plains Aquifer, 1-6.

Camp, C.R. (1998). "Subsurface Drip Irrigation: A Review." Transactions of the ASAE, 41(5), 1353-1367.

"Climate of Kansas." *K-State Research and Extension*. Web. 04 May 2012. <http://www.ksre.ksu.edu/wdl/climate/cok/index.asp?page=4>.

"Conservation Tillage." *Welcome to the Minnesota Department of Agriculture*. Web. 30 Apr. 2012. <http://www.mda.state.mn.us/protecting/conservation/practices/constillage.aspx>.

DuCharme, Charles and Miller, Todd. 1996. Water use of Missouri. http://www.dnr.mo.gov/env/wrc/statewaterplanphase1.htm.

Foster, Stephan, Loucks, D. P. (2006) UNESCO Non-renewable Groundwater Resource guidebook on socially-sustainable management for water-policy makers. http://unesdoc.unesco.org/images/0014/001469/146997e.pdf. Downloaded February 28, 2012.

Gleeson, T., Alley, W. M., Allen, D. M., Sophocleous, M. a, Zhou, Y., Taniguchi, M., & Vandersteen, J. (2011). Towards Sustainable Groundwater Use: Setting Long-Term Goals, Backcasting, and Managing Adaptively. *Ground water*, *50*(1), 19-26. doi:10.1111/j.1745-6584.2011.00825.x

Golden, B. , Kastens, T., Dhvyuether, K., and Peterson, J. "Developing an Economic Tool to Predict the Value of Water Rights". Posted to www.agmanager.info. 2006.

Gowda, Prasanna H., R. Louis Baumhardt, Allison M. Esparza, Thomas H. Marek, and Terry A.

Hellegers, P. J. G. J., Perry, C. J., & Al-aulaqi, N. (2011). INCENTIVES TO REDUCE GROUNDWATER CONSUMPTION IN YEMEN y , z. *Irrigation and Drainage*, *102*(November 2009), 93-102. doi:10.1002/ird

Hollands and Hart. 2007. Western Water Law. Colorado. http://www.westernwaterlaw.com/colorado.html

Hollands and Hart. 2007. Western Water Law. New Mexico. http://www.westernwaterlaw.com/newmexico.html

Hollands and Hart. 2007. Western Water Law. Wyoming. http://www.westernwaterlaw.com/wyoming.html

Howell. "Suitability of Cotton as an Alternative Crop in the Ogallala Aquifer Region." Agronomy Journal 99 (2007): 1397-403.

Hill, Kenneth, Eduardo Segarra, R. Terry Ervin, and William M. Lyle. "Low Energy Precision Application Irrigation for Cotton Production in the Texas Southern High Plains." *Texas Journal of Agriculture and Natural Resources* 4 (1990).

Howell, T. A., Evett, S. R., Tolk, J. A., & Schneider, A. D. (2004). Evapotranspiration of full-, deficit-irrigated and dryland cotton on the northern texas high plains. *Journal of Irrigation and Drainage Engineering*, *130*, 270-285.

Kansas Data Access & Support Center (DASC). 2012 http://www.kansasgis.org/. Downloaded February 28, 2012.

"Kansas Department of Agriculture." *:: Home Page*. Web. 04 May 2012. <http://www.ksda.gov>.

Kansas Department of Water Resources (DWR). 2012 http://www.ksda.gov/dwr/ Downloaded April 3, 2012.

"KGS--Kansas Ground Water--Use." *Welcome to the Kansas Geological Survey*. Web. 01 May 2012. <http://www.kgs.ku.edu/Publications/Bulletins/ED10/04_occur.html>.

Khanfar, A. R. (2008). Groundwater Investigation in Bel-Ahmar , Assir , Kingdom of Saudi Arabia. *Journal of Biological Sciences*, *15*(2), 289-296.

Klocke, N.L., L. R. Stone, G. A. Clark, T. J. Dumler, and S. Briggeman. "WATER ALLOCATION MODEL FOR LIMITED IRRIGATION." American Society of Agricultural and Biological Engineers 22.3 (2006): 381-89

Kooten, G.C. and A. Schmitz. " Preserving Waterfowl Habitat on the Canadian Prairies: Economic Incentives Versus Moral Suasion." *American Journal of Agricultural Economics*. 74(1992): 79-89

Lacewell, R. D., & Pearce, J. C. (1973). Model to evaluate alternative irrigation distribution systems with an exhaustible water supply. *Southern Journal of Agricultural Economics*, (Dec), 15-21.

Leader, Jessica. "Sam Brownback, Kansas Governor, Signs Water Conservation Laws." *The Huffington Post*. TheHuffingtonPost.com, 05 Mar. 2012. Web. 04 May 2012. <http://www.huffingtonpost.com/2012/03/05/sam-brownback-kansas-water-laws_n_1321511.html>

"Low Energy Precision Application, LEPA." *Low Energy Precision Application LEPA: Irrigation Technology*. Web. 30 Apr. 2012. <http://www.traxcoirrigation.com/low-energy-precision-application-lepa>.

"Mobile Irrigation Lab." *Welcome to the Mobile Irrigation Lab*. Web. 01 May 2012. <http://mobileirrigationlab.com/>.

NASDA. 1998. State Environmental Laws Affecting Iowa Agriculture. http://www.nasda.gov/nasda/foundation/state/Iowa.pdf

"No- till." *Index*. Web. 30 Apr. 2012. <http://www.rolf-derpsch.com/notill.htm>.

OCWP. Oklahoma Water Law. http://environ.okstate.edu/OWRRI/waterplan/files/information_sheets/wrb_info_sheet2.pdf

Official Nebraska Government Website. 2012. Department of Natural Resources Surface Water. http://www.dnr.ne.gov/docs/surface.html

Official Nebraska Government Website. 2008. Department of Natural Resources Groundwater Rules. http://www.dnr.ne.gov/docs/GWrules.html

"Ogallala-High Plains Fringe Area." Divison of Water Resources. Kansas Department of Agriculture. 20 May 2011. <http://www.ksda.gov/includes/document_center/subbasin/Ogallala/Ogallala_2010_Field_Summary.pdf>

Peck, J. C. (2006). An Agricultural Law Research Article Groundwater Management in Kansas : A Brief History and Assessment by, *441*(479).

Qureshi, A. S., Eshmuratov, D., & Bezborodov, G. (2011). Determining optimal groundwater table depth for maximizing cotton production in the Sardarya province of Uzbekistan. *Irrigation and Drainage*, *60*(2), 241-252. doi:10.1002/ird.568

Rogers, Danny H., Mahbub Alam, and L. Kent Shaw. "Kansas Irrigation Trends." Irrigation Management Series (2008).

Ronen, D., Sorek, S., & Gilron, J. (2011). Rationales Behind Irrationality of Decision Making in Groundwater QualiRonen, D., Sorek, S., & Gilron, J. (2011). Rationales Behind Irrationality of Decision Making in Groundwater Quality Management. Ground water, 50(1), 27-36. doi:10.1111/j.1745-6584.201. *Ground water*, *50*(1), 27-36. doi:10.1111/j.1745-6584.2011.00823.x

Sorenson, L. (2011, September 21). *Kansas Cotton: A drought tolerant crop*. Retrieved from http://www.midwestproducer.com/news/special-section/kansas-cotton-a-drought-tolerant-crop/article_30644d1a-e45b-11e0-9209-001cc4c002e0.html. Accessed: 05/03/12

The Nubian Aquifer Project : A Joint Initiative of the IAEA/UNDP/GEF (March 11, 2010) http://www-naweb.iaea.org/napc/ih/IHS_projects_nubian.html. Downloaded February 28, 2012.

The Ogallala Aquifer. (2012). Retrieved 2/28, 2012, from http://www.hpwd.com/the_ogallala.asp

Torell, L. A., Libben, J. D., & Miller, M. D. (1990). The market value of water in the Ogallala aquifer. *Land Economics*, *66*(2), 163-175.

Unger, Paul W. 2006. The Haworth Press, Inc., Binghamton, NY. Soil and Water Conservation Handbook. Policies, Practices, Conditions, and Terms.

University of Arkansas. 1993. Arkansas Water Primer Series: Water Rights in Arkansas. http://www.uaex.edu/other_areas/publications/PDF/FSPPC101.pdf

"Utilizing Center Pivot Sprinkler Irrigation Systems to Maximize Water Savings." Natural Resources Conservation Service. United States Department of Agriculture. 30 Apr. 2012. <http://www.extension.org/mediawiki/files/a/ab/NRCS_Center_Pivot_Irrigation.pdf>

Venot, Jean-Philippe & Francois Molle (2008). Groundwater Depletion in the Jordan Highlands: Can Pricing Policies Regulate Irrigation Water Use?, *Water Resource Management.* 22:1925-1941. DOI: 10.1007/s11269-008-9260-x

Water Legislation Update. Western Kansas Groundwater Management District #1. 18 April 2011. Web. <http://www.kswatercongress.org/Water%20Legislation%20Update%204-8-11%20_3_.pdf>

Wheeler, E., Golden, B., Johnson, J., & Peterson, J. (2008). Economic efficiency of short-term versus long-term water rights buyouts. *Journal of Agriculture and Applied Economics*, *40*(2), 493-501