The Value of Ogallala Aquifer Water in Southwest Kansas

DOCKING INSTITUTE Of Public Affairs

Fort Hays State University

Prepared for
Southwest Kansas Groundwater Management District

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Executive Summary

This report presents the findings of the Docking Institute of Public Affair's study of the economic impact of an acre-foot of water on the economy of Southwest Kansas. The funding for this research came from the Southwest Kansas Groundwater Management District (No. 3) (SWKGMD) and the Docking Institute of Public Affairs. The four primary goals of the study are to:

- Develop current ranges of values for an acre-foot of groundwater from the Ogallala Aquifer in Southwest Kansas given its current uses.
- Derive an estimate of the total value of Ogallala Aquifer water over the next 20 years.
- Develop feasible scenarios that will extend the life of the aquifer, based on available technologies.
- Estimate the impact of conservation measures on users and the economy.

To achieve these goals, this study develops a hydroeconomic model for the water based economy in southwest Kansas. This model integrates climatological and hydrological considerations with an irrigation/crop component and a finance component. This integrated model is then used to estimate depletion rates, cash flows, and economic impact over the twenty-year period of the study.

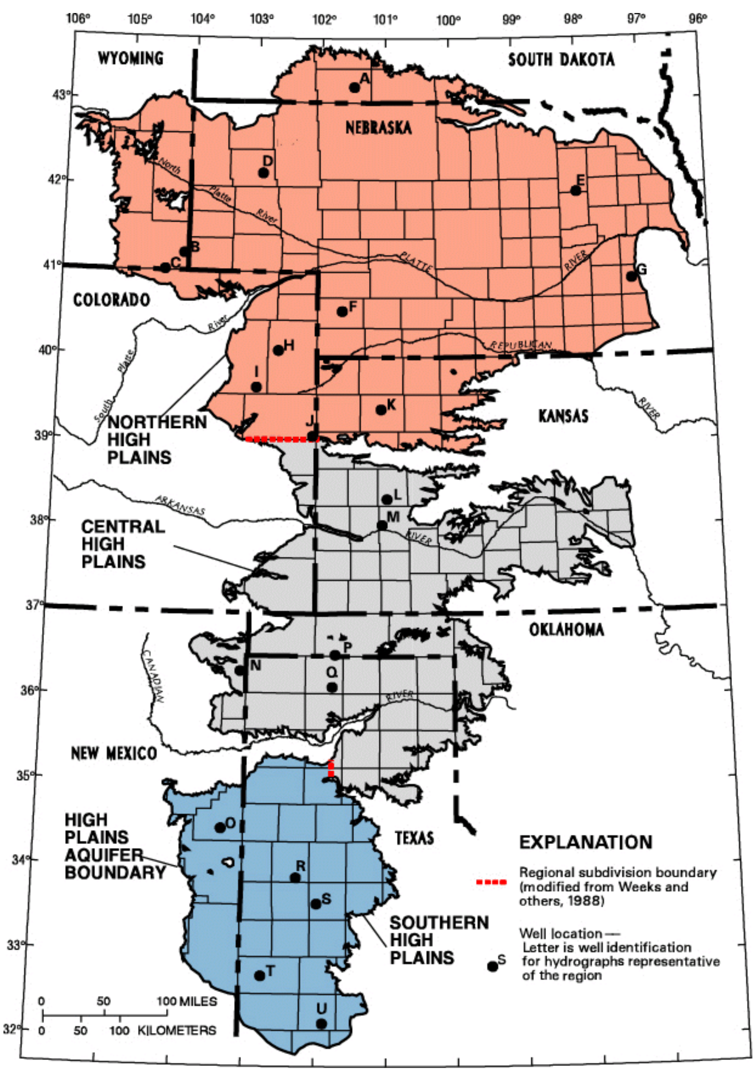
Five scenarios of water utilization and economic impact are developed and analyzed. The first scenario models the current farming and water utilization practices. This scenario finds that excluding government subsidies, the average net present value per section over 20 years is $ -150,000, while the saturated thickness of the aquifer will decrease by about 30%. Including subsidies from external sources, the study finds that on an annual basis, the total economic impact on the SWKGMD area from irrigation is estimated at $188,496,000 in current dollars. This equals about $80 per acre foot. Over the course of the 20 year period of the study, the net present value of this impact in current dollars is estimated at $3,769,920,000.

In the remaining four scenarios, the study explores the impact of changing irrigation methods and water requirements (and thus yields) for irrigated crops on depletion and the net present value for irrigators. The study finds that the most viable scenario for achieving near zero depletion is one that changes all flood irrigation to center pivot and reduces the water utilization for corn by 50%. Significant, the reduced water for corn will only result in a 10% reduction in yield. However, the cost to the irrigator of these changes have a net present value per section of -$4,200 annually, or -$84,000 over the course of the 20 year study. The total cost of this near zero depletion scenario to the collective membership of SWKGMD would be about $11 million (1998 dollars) annually ($4,200 X 2618 sections). Of course, government subsidies and low interest loans will substantially lower the cost to members of the SWKGMD and the cost for individual irrigators will vary by specific circumstances related to their operations.

Chapter 1
The Value of Ogallala Aquifer Water in Southwest Kansas

What is the value of an acre-foot of Ogallala Aquifer water in southwest Kansas? This question has important implications for the region, state, and nation because Ogallala water provides the life blood for the agricultural-based economy of southwestern Kansas. The Ogallala Aquifer not only gives life to the economy of southwest Kansas, but it helps sustain agricultural production from west Texas and eastern New Mexico, through the panhandles of Texas and Oklahoma, much of western Kansas and eastern Colorado, and almost all of Nebraska. Figure 1 depicts the range of the aquifer.

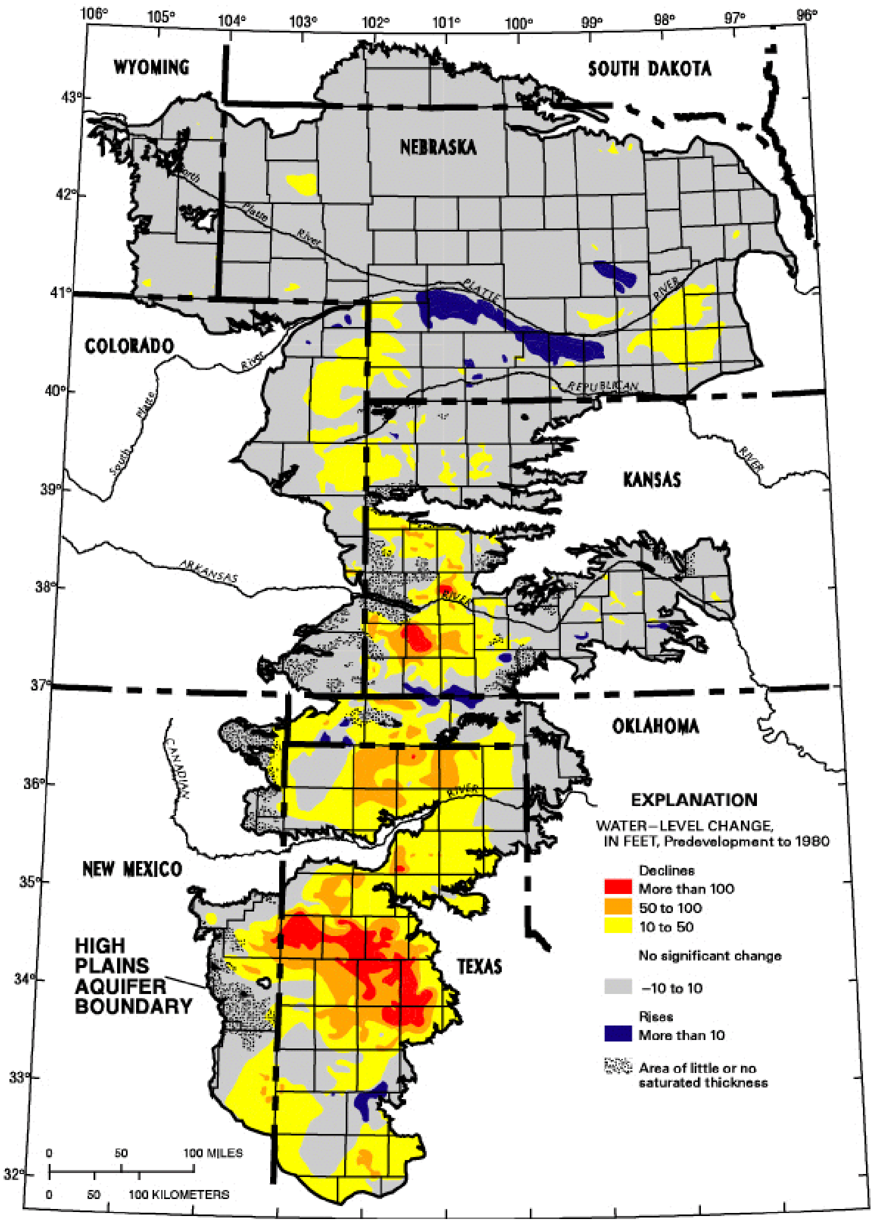
Figure 1: Ogallala Aquifer



Current water management practices across the Ogallala Aquifer extract more water than is recharged into the aquifer. In Kansas, about 3.6 million acre feet of Ogallala water are extracted each year, but only about 1.5 million acre feet are recharged (Hansen 1991). Depending on the saturated thickness of the aquifer, rock formations and location, aquifer depletion rates in Southwest Kansas range from 10% (where the saturated thickness is high) to 70% (where the saturated thickness is low) (Fund 1993, 5).

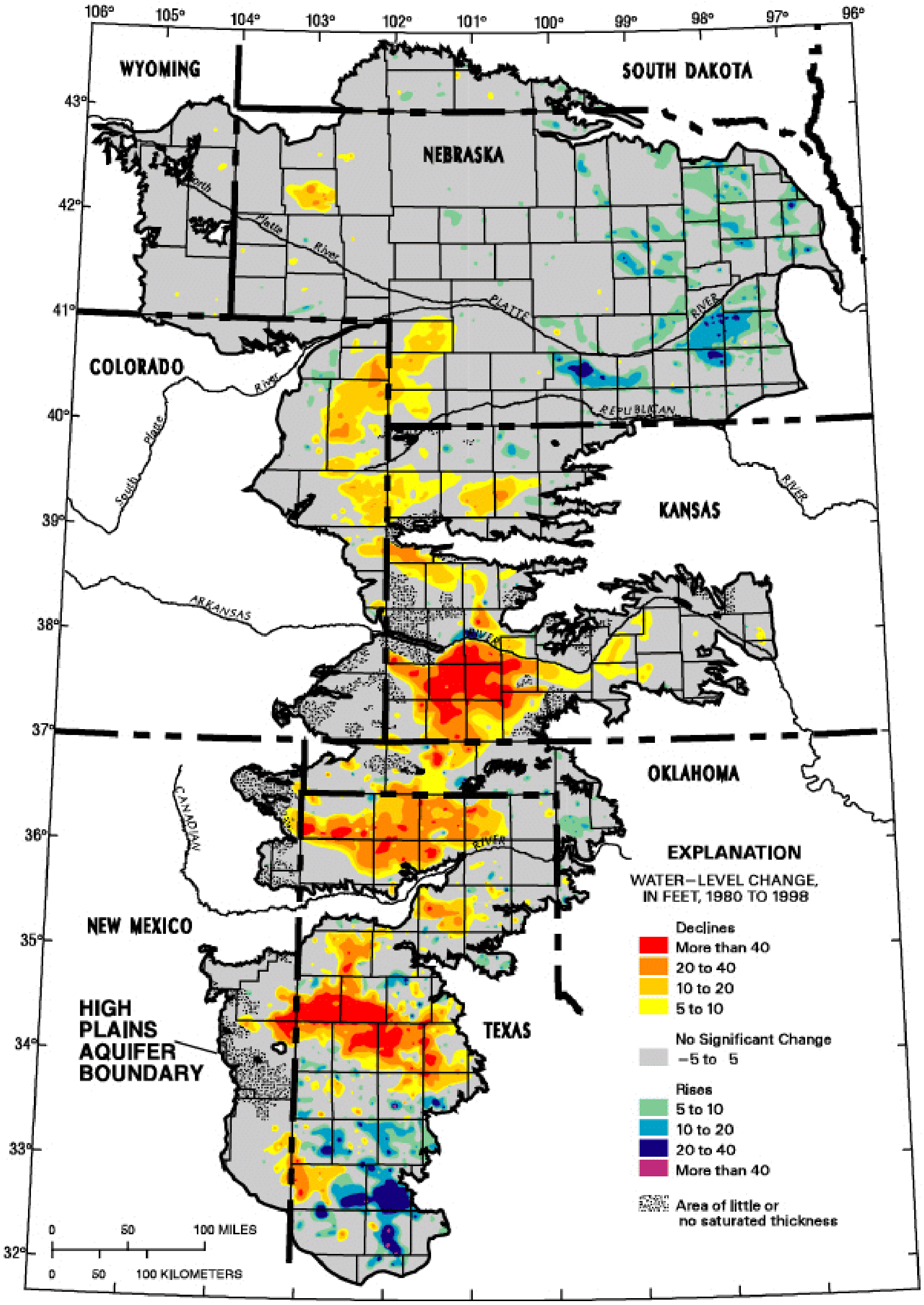
Figures 2 and 3 show the past and recent rates of depletion for the aquifer. As the figures indicate, parts of southwest Kansas have experienced declines in saturated thickness of over 100 feet when compared to the predevelopment of the aquifer, and more than 40 feet from 1980 to 1987.

Figure 2: Depletion of the Aquifer Predevelopment to 1980



Source: V.L. McGuire and B.C. Fischer, USGS, 2000

Figure 3: Depletion of the Aquifer 1980 to 1997



Source: V.L. McGuire and B.C. Fischer, USGS, 2000

Figure 4:

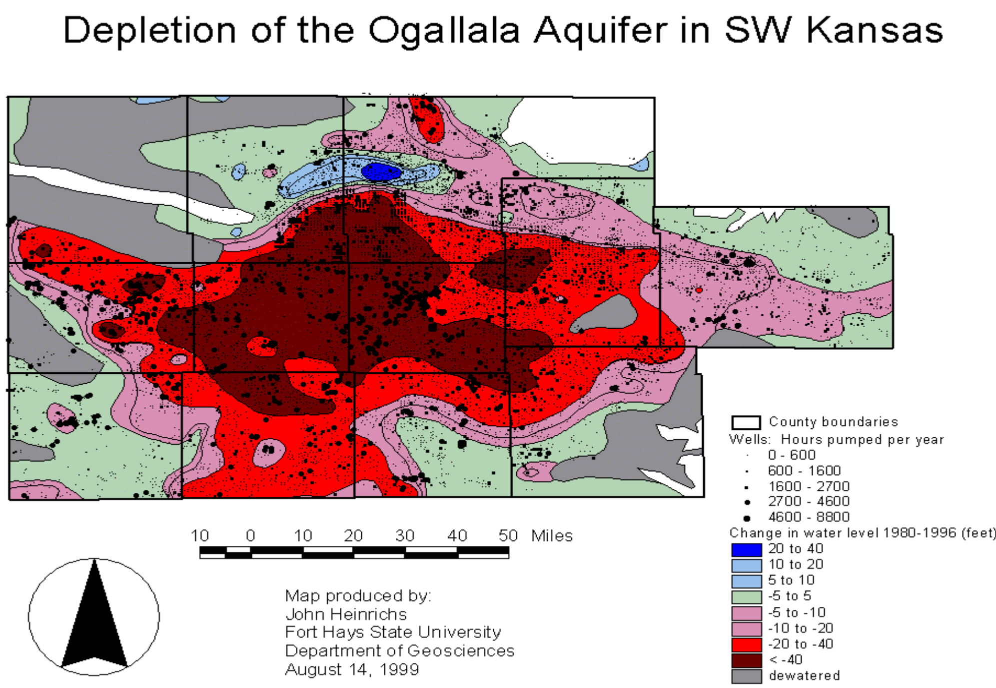


Figure 4 focuses on the level of depletion of the Ogallala Aquifer from 1980 to 1996 in the counties comprising the Southwest Kansas Groundwater Management District. This data confirms the data presented in figure 3, and indicates that the region has experienced a decline in water levels, in some parts of more than 40 feet in 16 years.

What conclusions can be drawn from these facts? Some researches suggest that when the water becomes too expensive the extract, either because of well depth or because the saturated thickness does not yield enough water for irrigation, the economy of southwest Kansas--which blossomed with the rise of irrigated crops in its semi-arid climate and sandy soils in the 1950s and 1960s--will eventually wither and die in the hot summer sun.

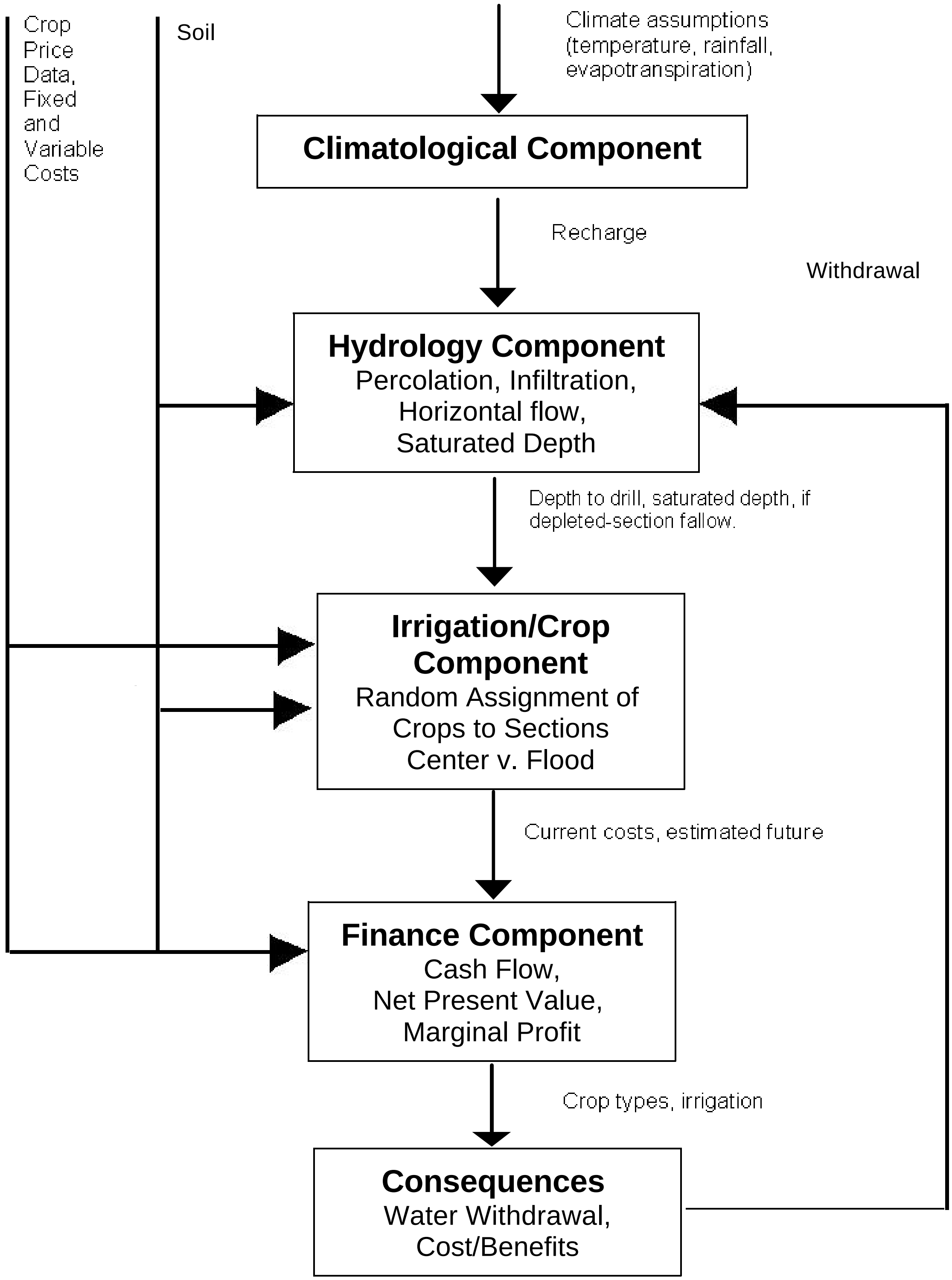
Many studies have focused primarily on remaining water resources and current levels of water usage to suggest that this is the inevitable future of the Ogallala value-added agricultural economy (Fund 1993; Opie 1993). Other studies have focused on the maintenance of current economic activity, asserting that purely economic costs and benefits will lead to individuals making decisions that will ultimately save the aquifer (High Plains Council 1982; Buller and Williams 1990). This study, described here, differs from those approaches because it uses a unified hydroeconomic model for understanding the connections among the major variables affecting the aquifer-based economic structure of southwest Kansas.

Figure 5 (next page) shows this hydroeconomic model, developed and presented for the first time in this report, depicting the dynamic interaction between the hydrology of southwest Kansas and its aquifer-based economy. The model integrates climatological and hydrological considerations with an irrigation/crop component and a finance model to estimate depletion rates, cash flows, and economic impact over a twenty-year period. A more complete description of this hydoeconomic model can be found in Chapter 3 of this study.

Using this unique model, this study develops five scenarios of water utilization and economic impact (present value, depletion rates, and changes in saturated depth) starting in 1998 and spanning the next 20 years. The first scenario models the current farming and water utilization practices. In this scenario, two-thirds of irrigation is by center-pivot methods and one-third is by flood irrigation methods. This scenario provides the lynch-pin of this analysis because it describes current conditions and water utilization and economic patterns that are likely occur in the next 20 years, assuming no major alteration in water management policies and no major regional economic changes. This first scenario, modeling current conditions, is used to contrast the implications of possible policy alternatives. These possible policy alternatives–termed here as scenarios–have been mentioned by various policy makers as probable solutions to the depletion of the aquifer or represent hybrid policy alternatives derived by the authors of this report.

The second scenario simply changes the water irrigation to all center-pivot methods, switching the sections that use the more water-intensive flood irrigation techniques to the more efficient center pivot. Analysis of this second scenario focuses on the evaluation of possible impacts on cash flow and depletion rates with the

Figure 5:
Hydroeconomic Model for Ogallala Depletion Study



replacement of flood irrigation systems by center pivot irrigation systems.

The third and fourth scenarios build on the second scenario. While both scenarios assume that all irrigation is by center-pivot, the third scenario reduces the amount of water to all crops by 50% of the full irrigation level, and the fourth scenario reduces water usage to all crops such that each crop produces 90% of its current yield. In both scenarios, yields and water usage are adjusted to reflect the parameters of the scenario and cash flows are reduced to reflect the decreased production. The purposes of these two scenarios are two-fold: First, to underscore the tradeoffs between these types of policy alternatives and recharging of the aquifer; and second, to highlight the economic impacts as the capacity of the aquifer for irrigation declines.

The fifth model assumes that all irrigation is by center-pivot and that irrigation for corn is reduced by 50% (reducing corn yield by 10%). This scenario, derived by the Docking Institute, represents a hybrid policy alternative based on the findings from the previous four scenarios. The purpose of this scenario is to provide a policy direction that is economically feasible and achieves the major policy goal of extending the life of the aquifer.

We believe this information is of vital importance if irrigators, the SWKGMD, other water users, and policy making bodies are to develop and advocate politically acceptable water management strategies that promote the economic well being of citizens in the region.

Chapter 2
Historical Development of the Ogallala Aquifer Region

A succinct historical review of the region is imperative for understanding the contemporary conditions in the region. As illustrated in Figure 1 in Chapter 1, the Ogallala Aquifer underlies many states. The largest part of the aquifer in saturated thickness lies under the central portion of Nebraska, while the portion with the most dynamic human-environment relationship underlies southwest Kansas, and the Texas/Oklahoma panhandles. Not coincidentally, these regions have experienced the most serious levels of water depletion.

Settlement of the High Plains region[1] began in the 1850s with the establishment of cattle ranching operations, and farming settlement increased in the 1860s with the passage of the Homestead Act in 1862 (Opie 1993; Riebsame 1990; Worster 1979). The region offered flat, open expanses with fertile soil – attractive features for farmers from the East familiar with hilly, forested, and rocky land. Much "boosterism" was undertaken by several interests to lure farmers to this region, two of the most prominent being the U.S. government and the railroads (Opie 1993; Lockeretz 1978). Railroad companies were interested in populating the relatively empty region as they extended their lines through the area. Railroad expansion also facilitated migration throughout the High Plains. Easterners were told that the region had "most favorable" topography and soil conditions, and railroad companies offered travelers free one-way tickets in an effort to lure them to the region (Opie 1993).

Farmers found a region that was much drier than the sub-humid and humid areas of the East. Yet, a belief that gained common acceptance, and which was promoted by pseudo-scientists of the time, involved the notion that "rain will follow the plow." As such, farmers were encouraged to plant crops in efforts to bring on more rain, which in turn, would allow more crops to be planted, which would encourage additional precipitation. Settlers were also charged with a sense of duty to turn the region into a garden for the betterment of other farmers and the nation as a whole (Lockeretz 1978;

[1] We use High Plains and Ogallala Aquifer region interchangeably as they correspond very closely, particularly for the portions of the three state referred to above.

Opie 1993; Worster 1979).

Agricultural practices and ideas from the humid East were transplanted to the arid High Plains with disastrous results. The region soon experienced its first mass exodus in the late 1880s to due crop failures spurred on by drought (Porter 1989; Opie 1993). During this time, “first wave of homesteaders to leave the great plains, abandoning homes, schools, and churches" (Porter 1989).

Farmers moved back into the Great Plains during the late 1890s and the population grew "until 1924, which was a very dry year" (Porter 1989). Population declined slowly for about a decade when the "dust bowl" began after a serious drought in 1934, forcing another wave of farmers to leave the plains. In 1936, a U.S. Congressional session was interrupted by the "fall-out" of High Plains soil from a dust storm carried by the jet stream to the East Coast and on into the Atlantic (Worster 1979). The most severe erosion was centered in the western section of Kansas, the Oklahoma panhandle, and the northern end of the Texas panhandle. Many who lived through this period, including relatives of all the members of this research team, can recall instances in which residents of the area could barely see the distance to their hand when caught outside during a "black blizzard," and wet sheets were hung across windows in futile efforts to keep the fine dust out of houses. Thousands of tons of rich topsoil were transported by wind to areas east of the region.

Disagreement exists regarding the extent to which the dust bowl phenomenon was attributable to drought or farming practices. However, there is little doubt that the severity of the problem was exacerbated by tractor driven dry-land farming practices at a scale unprecedented in the region. Such practices entailed pulverizing the top few inches of soil to a fine texture and keeping fallowed fields clean of all weeds, therefore removing anything that might have held the soil in place (Opie 1993; Worster 1979). It was an outcome of this and the Great Depression (which Worster 1979 argues were intimately linked) that the Soil Conservation Service (SCS) was created. The purpose of the CSC was to implement programs that would avert the future occurrence of such an event. This, in combination with direct "relief" payments, marks the beginning of government aid to this region. In spite of government efforts, many farmers lacked the capital and/or the will to remain in the area. Mass out-migration from the region commenced, hence, the "exodusters" or "Okies" made famous in John Steinbeck's The Grapes of Wrath[2] (Opie 1993; Worster 1979).

Extra-local factors have often served as the catalyst for significant “plow-ups” of the prairie (Lockeretz 1978; Opie 1993; Riebsame 1990; Worster 1979). During WWI, farmers of the region were increasingly gearing their farming practices toward meeting extra-local market demand for commodities. In addition, a post-WWI international demand for grains drove up the price of wheat, providing a strong impetus to bring more High Plains sod into wheat production. A similar situation marked the Post-WWII period, and again large tracts of the land were submitted to massive cultivation as prices of grains rose significantly. In the early 1970s, the U.S. Secretary of Agriculture beseeched farmers to "plant fence row to fence row" in order to meet high international demand, and again the price of wheat skyrocketed for a time, to over $4 per bushel (Lockeretz 1978).

More importantly, the 1970s were also marked by widespread mining of the aquifer for irrigation. Water manipulation of this sort allowed for successful crop growth in the face of ongoing drought (Opie 1993, Worster 1993).

Irrigation on the High Plains

In the early 1800s, the High Plains were often referred to as the “Great American Desert” (Porter 1989). A decade and a half later, however, the region became known as the “breadbasket of the world.” It was only the extensive, regular use of water from the Ogallala aquifer for irrigation that ended the black blizzards and periodic exoduses associated with periods of drought.

Irrigation technology allowed for predictable environmental conditions for growing crops, and, in turn, led to a more stable population growth. Early attempts at irrigation employed methods widely used throughout history, and they proved of limited success for the region. Namely, diversion of rivers for irrigation was extremely problematic as river flows are very erratic, there is a high evaporation rate from canals, and there is a lack of good dam sites due to the absence of any deep canyons (Opie 1993). The

[2] Also see Worster 1979 who points out that many of the "Okies" were not necessarily from Oklahoma and were not necessarily moving as a direct result of Dust Bowl conditions but depressed economic conditions -- no cash flow and high debt.

riverbeds of the Arkansas, the Cimarron, and other southwest Kansas rivers are wide and the waters are relatively shallow. In the late 19th and early 20th century, extensive diversion projects were undertaken on the Arkansas around Garden City, Kansas (Opie 1993; White 1994). With increasing settlement and diversion along the Arkansas River in Colorado, water became increasingly less available for irrigation in Kansas. However, farmers came to realize that irrigation of crops was necessary for raising crops in a region that averages only about 15 inches of rainfall per year and that experiences tremendous rainfall variation from year to year.

Extensive, intensive, and regular irrigation appeared with the advent of the centrifugal pumps in combination with the availability of relatively cheap pump-driving engines (Green 1973; Musick and Stewart 1992; Opie 1993). Use of this technology first took hold on a widespread basis in the Texas panhandle in the early 1940s (Green 1973) and in southwest Kansas in the 1950s (Musick and Stewart 1992; White 1994; Opie 1993). Now crops requiring high levels of water (e.g., corn and alfalfa) could successfully be grown first through flood irrigation and more recently through circular sprinkler irrigation made possible by tapping the waters of the Ogallala. Farmers of the region came to rely on Ogallala water for regular irrigation of their fields rather than as supplemental irrigation in times of drought.

An irrigated cornfield in this region produces an average of 115 bushels/acre (in the 1970s and 1980s) compared to 48 bushels/acre with dry-land farming and 89 bushels/acre in the Eastern humid-land farms (Opie 1993). Indeed, as water intensive crops were increasingly used (corn and hybrids of wheat, designed to produce maximum yields under optimum conditions), supplemental irrigation was no longer a viable option. Additionally, thousands of acres of sand-hills were brought into production in Kansas and Nebraska with the advent of circular pivot sprinklers which spread an even, soaking "rain" on the sandy soil.

The total number of irrigated acres in the Ogallala region peaked in the early 1980s at almost 15 million, sustained by over 170,000 irrigation wells pumping from 18 to 21 million acre-feet of water annually (Kromm and White 1992; White 1994). By 1987, however, there was decrease of over 20% in the irrigated acreage to 10,395,000 (Kromm and White 1992).

The U.S. Geological Survey estimates that the total amount of drainable water in the Ogallala formation is about 3.25 billion acre feet (Kromm and White 1992). Kromm and White suggest that an estimate of 15 percent of that amount is more feasible given current technological levels. As shown in Figures 2 and 3 in Chapter 1, estimates of depletion levels show much variation from place to place. The average level of depletion of the entire Ogallala aquifer is about ten feet, but some areas of Texas have had water tables fall by as much as 100 feet since the onset of water mining (Kromm and White 1992; Zwigle 1993). In fact, in some areas of Texas irrigation has already been discontinued (Opie 1993)[3].

Particularly important for understanding the feasibility of heavy groundwater irrigation, is the relatively low cost of fuels in general and natural gas in particular. The Hugoton-Guymon natural gas field, the largest in the world, underlies southwest Kansas and the Oklahoma panhandle (Opie 1993). The availability of local natural gas helps to keep pumping costs relatively low in southwest Kansas.

Population, the Economy, and the Aquifer

Population of the region has grown with the increase in secondary and tertiary sectors of employment that were established primarily on the agricultural sector. Some towns of the Texas panhandle (Lubbock and Amarillo), the Oklahoma panhandle (Guymon), and southwest Kansas (Garden City, Liberal, and Dodge City) grew rapidly throughout the 1960s, 1970s, and 1980s, and are now the major urban centers of this region. Census population figures for these urban areas for 1990 were as follows: Garden City 24,097; Dodge City 21,129; Liberal 16,573; Guymon 7,803; Amarillo 157,605; and Lubbock 222,636. Table 1 shows the change in Kansas Ogallala region population between 1960 and 1990. In general, there has been an increase in population from 184,427 in 1960 to 194,873 in 1990 (Kromm and White 1992). In the Oklahoma Ogallala region, population increased from 91,793 in 1960 to 100,551 in 1980, but dropped back to 90,892 by 1990 (Kromm and White 1992). Table 1 also shows the change in Texas Ogallala region population for the same years. There was a

[3] A discontinuation of the mining of aquifer water does not necessarily mean that water has been depleted. Rather, it may be that the costs for pumping the water have become prohibitive, as wells must be sunk deeper and deeper. Alternatively, the amount of water that can be lifted from a well may be lower than the minimal capacity necessary to sustain an irrigated crop.

slight increase from a population of 994,291 in 1960 to 1,097,559 in 1990 (Kromm and White 1992).

In attempting to identify a relationship between the existence of groundwater and population change, White (1994) conducted a study in southwest Kansas counties. He examined county-to-county data, and intra-county data to identify the extent to which availability of groundwater effects population size. He concluded that of those places over 500 in population, proximity to groundwater has a positive influence on population size. While as noted in Table 1, the region has not grown much in population since 1980, the population has migrated to larger areas that are close in proximity to groundwater.

Table 1:
Population in the High Plains Aquifer Region

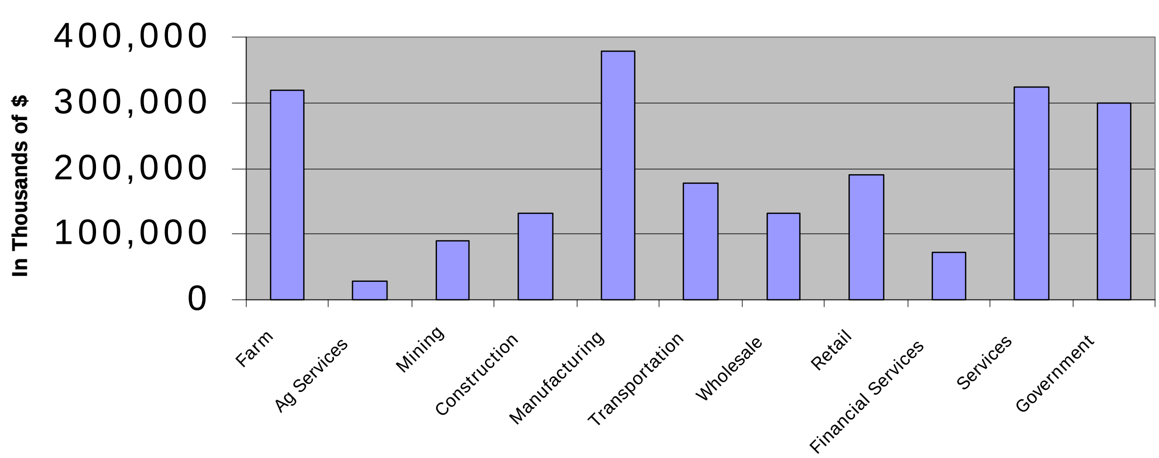
	1960	1970	1980	1990
Colorado	81,608	76,205	77,434	71,869
Kansas	184,427	183,141	188,462	194,873
Nebraska	636,226	621,296	647,477	612,105
New Mexico	122,539	122,726	130,099	130,608
Oklahoma	91,793	90,378	100,551	90,892
Texas	994,291	961,334	1,080,042	1,097,559
High Plains Aquifer Region	2,110,884	2,055,080	2,224,065	2,197,906

Source: Kromm and White 1992, 8

Smaller urban areas such as Garden City, Liberal, and Dodge City may be more susceptible to a diminishing agricultural sector as the Ogallala is depleted. A significant agribusiness industry has developed in southwest Kansas based on farming that has utilized Ogallala water. The area around and between Garden City and Dodge City is home to some of the largest feedlots in the nation and the largest beef packing plant in the world: IBP (Opie 1993; Zwigle 1993). Several other packing houses exist in the area, and 30% of U.S. livestock is processed by plants in Dodge City and Holcomb (8 miles west of Garden City). The abundance of good cattle feeds (corn, alfalfa, sorghums) made possible by irrigation technology and the mining of the aquifer results in a source of relatively cheap inputs for feedlots in the area. In turn, packing plants benefit from an abundance of local beef, keeping transportation costs down for the plants.

The importance of farming, ranching, and meat packing manufacturing for the southwest Kansas economy can be seen in Figure 6. Farming, ranching, and feedlots ("Farm") produce earnings in excess of $300 million on an annual basis. Production agriculture is the third largest source of earnings in southwest Kansas, topped only by the service sector ($325 million) and manufacturing ($380 million), which is largely defined by the meat packing and value-added agricultural industries.

Figure 6: Earnings by Industry in Southwest Kansas



The Policy Problem

There have been numerous efforts to study the use and depletion of Ogallala Aquifer water. If one were to succinctly summarize these findings, it would be that the region's long-term future does not look bright. Study after study, conference after conference, report after report, all note that the useful life expectancy of the Aquifer ranges between 15 and 50 years, depending on the saturated thickness of the aquifer under each section of land (Kromm and White 1992; Opie 1993; V.L. McGuire and B.C. Fischer 2000; USGS 1991; Fund 1993; Buller and Williams 1990; The Great Plains Symposiums 1995a, 1995b, 1996, 1997; Southwest Kansas Groundwater Management District 1999; High Plains Council 1982; Conserving the High Plains Aquifer 2000).

While most researchers agree with this conclusion, most disagree on the solutions to the problem. Some promote an ecologically based solution to resolve the long-term viability of the aquifer, and suggest that the best approach is to move away from irrigated corn, milo, wheat, and alfalfa, to crops that are more ecologically “in-tune” with the dry climate of the High Plains. Opie writes:

> Sustainable agriculture needs to be seen more clearly not as a throwback to less complicated agriculture of fifty to one hundred years ago; instead it requires of the farmer more knowledge of his farm’s ecosystem and its place in his life and society’s. In most cases, alternative farming implies diversification rather than specialization (1993, 16).

Others from the ecological school of thought suggest that part of this transformation away from a water-intensive approach should include the reestablishment of the American bison and other native species and the develop of eco-tourist attractions (see Buffalo Commons Thesis, Popper and Popper 1987; 1999). Still others see farmers and ranchers coming together to form next generation cooperatives to market niche and branded value-added, organically produced products (Fund 1993).

In either case, the future will see another mass exodus of farmers out of the High Plains. This time, however, the exodus will be permanent, as most center pivot irrigation circles, packing houses, confined feedlot operations, and other water-intensive value-added agricultural production activities will move out of the region. As a consequence, so will the jobs associated with these economic activities.

Other researchers promote a “free hand of the marketplace” approach to address the depletion of the aquifer. The combination of market prices for grain, water level declines, and energy costs will eventual cause the demise of most irrigation operations (High Plains Study 1982). From this perspective, water represents just another input into the production process. As the fixed (equipment and land) and variable cost (lift and energy) for water increase, the cost of producing irrigated crops will outweigh its benefits (Buller and Williams 1990), thus leading farmers to adopt other dryland cropping practices or to reconvert fields to grazing land (Kromm and White 1992). In other words, the value of water is defined by its economic uses. Given that the only explicit costs for using aquifer water are energy and pumping and distribution equipment, historically the costs of water are relatively low cost compared to the gains in crop yields.

Much like one would pump an oil well dry to extract the economic benefits, this perspective has given rise to phrases like "planned depletion." The idea of planned depletion is an explicit admission that sometime in the future, it will no longer be economically viable (or in some areas, hydrologically possible) to pump large volumes of water for irrigation (SWKGMD 1999). The market approach tends to hold out hope for a technological solution to the problem, and assumes that better methods of irrigation and/or higher yielding, water-conserving crop hybrids will be developed to reduce the amount of water needed to irrigate crops (Conserving the High Plains Aquifer 2000).

Conclusion

The development of the High Plains Aquifer has been, and will continue to be, the key to economic future of southwest Kansas. The corollary of this is that without water, the economic future of southwest Kansas is rather bleak. While the transformation of the irrigation economy to dryland practices may save some farmers, and the development of jobs in the "new information economy" may help some people in urban centers (Center for the New West 1992; Docking Institute of Public Affairs 1998), these developments will not be enough to off-set the loss of value-added agriculture. The questions addressed in the next chapters are what is the current and future value of the water for various economic activities, and what are some of the available alternatives for conserving water and the associated costs for conservation.

Chapter 3
Theory, Data, and Methodology

The historical development of the High Plains Aquifer frame the theoretical model used in this study to assess the value of an acre foot of Ogallala water. This chapter shifts gears away from this history to outline the components of the hydroeconomic model and the model's data and methodological considerations. By its very nature, this discussion is technical in nature.

Previous Research on the Value of Water

This study is not the first nor is it likely to be the last analytical effort to estimate the value of an acre foot of water. Indeed, there have been numerous studies estimating the economic value of an acre foot of water over the past few years.

- In California during the 1991 drought, an acre foot of water was estimated at $25 for agricultural uses and $400 for urban/industrial uses (Phillips 1998).
- Irrigation water in Colorado typically ranges between $9 to $103 depending on the irrigated crop (Boggess, Lacewell, and Zilberman 1993)
- In the Texas High Plains in the early to mid 1990s, an acre foot of water went for between $30 to $40 for agricultural uses, and up to $160 for industrial uses, and up to $400 for municipal uses (Lacewell 1998, 14).
- In the 1980s and 1990s, recreational water was valued at between $3 and $17 per acre foot (Boggess, Lacewell, and Zilberman 1993).
- Water supplied through the Big Thompson project in Colorado is being transferred from "underutilized" farm uses, estimated to be worth about $40 per acre foot, to urban uses estimated at $1,200 per acre foot.
- Surface water for irrigation in Nebraska was valued at $83 to $115 per acre foot in 1977.

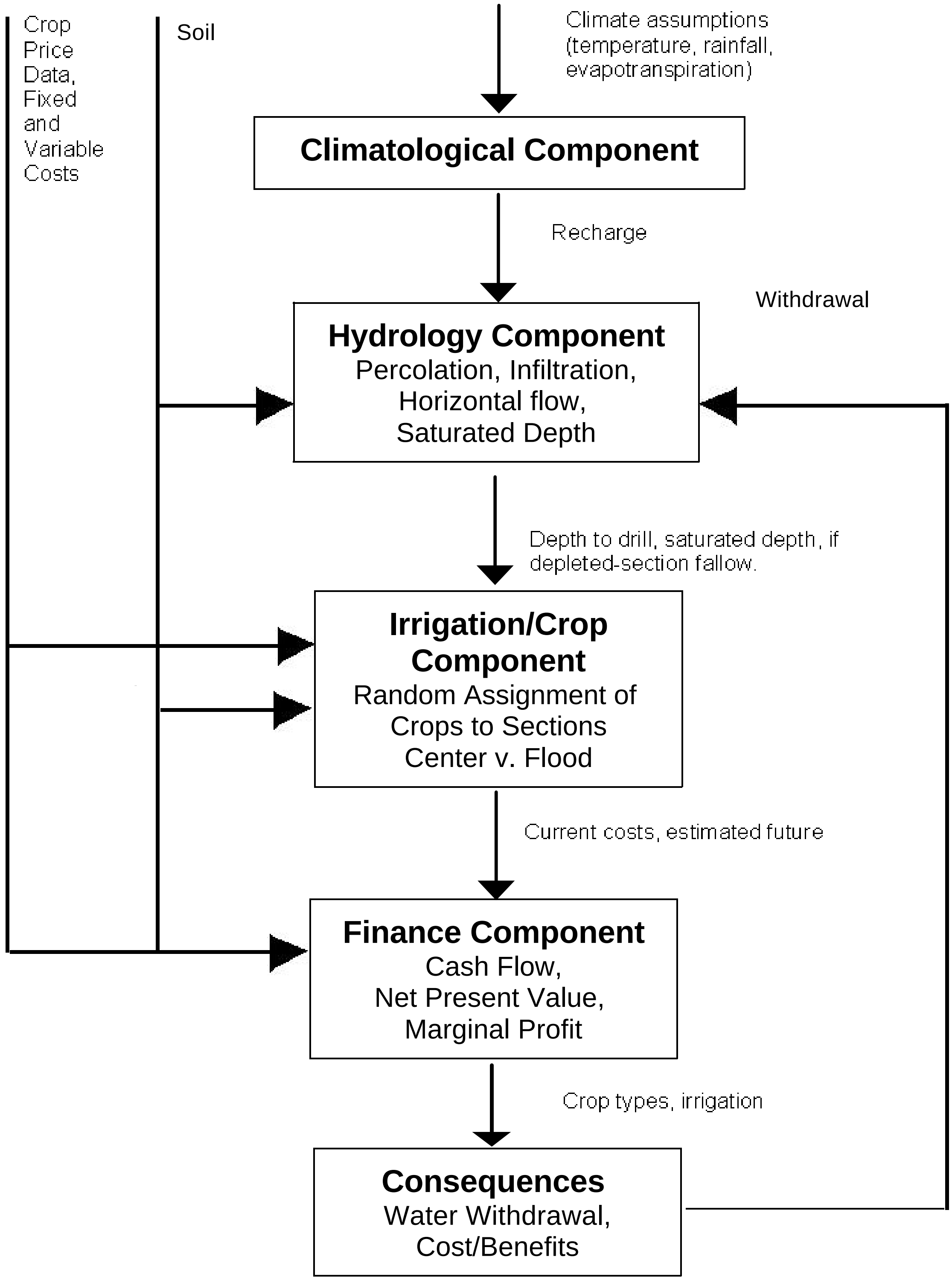
Of the many studies of the economic value of water, the most comparable to this study is the "Kansas' Expert Reports in Support of its Claim for Money Damages for Colorado's Violations of the Arkansas River Compact 1950-94" (1998). Using classic cost-benefit analysis, the experts found that the value of Arkansas River water in 1998 dollars was an average $514 per acre foot for all uses (agriculture, manufacturing, municipal).

Previous research suggests that the value of an acre foot of water varies considerably depending on its use. Agricultural uses tend to have a lower economic value when compared to municipal and industrial uses. The reason for this is straightforward: 1,000 acre feet of water can grow 480 acres of corn or support the recreational and economic activities of 5,000 people. Irrigators, for example, in Finney County in 1996 used about 338,000 acre feet of water on their crops, but municipalities in Finney County used 5,200 acre feet, and value-added processing activities used about 11,900 acre feet of water that same year (Analysis of Kansas Water Office data). The lower economic value of water for agricultural uses also reflects the low prices that farmers receive for their commodities. Taken together, previous research finds that the value of water for general agricultural irrigation varies between about $25 and $40 per acre foot.

Theoretical Approach

This study uses an integrated theoretical perspective – the hydroeconomic model – to describe the current economic situation in southwestern Kansas and a number of possible scenarios relating to how these current conditions may be changed based on the uniform application of four possible policy directives. Figure 7 (also shown as Figure 5) illustrates the hydroeconomic model. For each section of irrigated land, the model inputs data on climatic conditions, represented by variables like *temperature, rainfall, evapotranspiration*; hydrology, represented by variables like *saturated depth, maximum saturated depth, and recharge*; irrigated crop, represented by variables like *crop type (i.e., corn, alfalfa, beans, milo, wheat or fallow), irrigation method (i.e., flood vs center pivot), and yields;* and finances, represented by *fixed and variable costs, lift, cash flow, net present value, and profit*. Additional inputs into the model are soil types (good, fair, and poor) and crop prices.

Figure 7:
Hydroeconomic Model for Ogallala Depletion Study

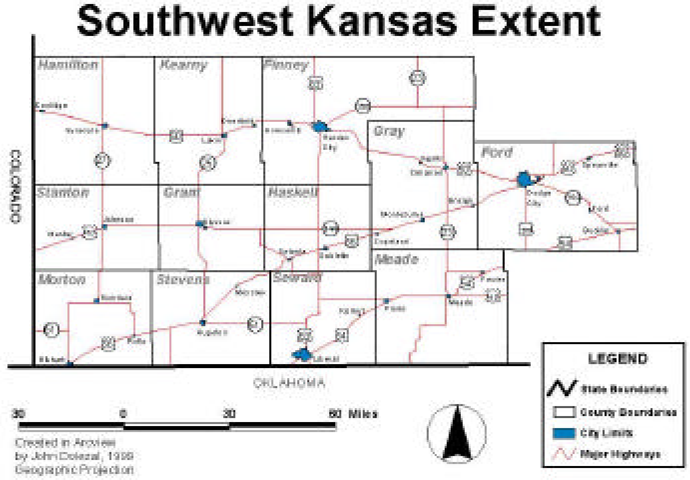


The hydroeconomic model operates in the following manner. In any given section, in any given year, the model first examines whether the water necessary for planting an irrigated crop is present. If so, an irrigated crop is assigned to that section. The amount of water used to irrigate that crop is determined by the crop type, soil type, and method of irrigation. Similarly, the fixed and variable costs associated with raising that crop are largely determined by the irrigation method, lift costs, crop type, and soil type. The cash flow generated from the crop is a function of subtracting the fixed and variable costs (taxes, mortgages, equipment, seed, fertilizer, etc) from the revenues generated from the sale of the crop. Revenues from the crop are determined by multiplying together the yield per section (which is a function of soil type and crop type) and the market price. The information regarding water withdrawal is then applied to the next year and this process is repeated for each section, each year, for 20 years. The model can also be used to calculate depletion rates, changes in saturated depth, cash flows, and the net present value of the agricultural activities.

Study Area, Sections, and Data

The study area for these analyses are the 12 counties that are wholly or partly within the Southwest Kansas Groundwater Management District (SWKGMD). Figure 8 shows these 12 counties.

Figure 8:
Ogallala Aquifer Study: Southwest Kansas Extent



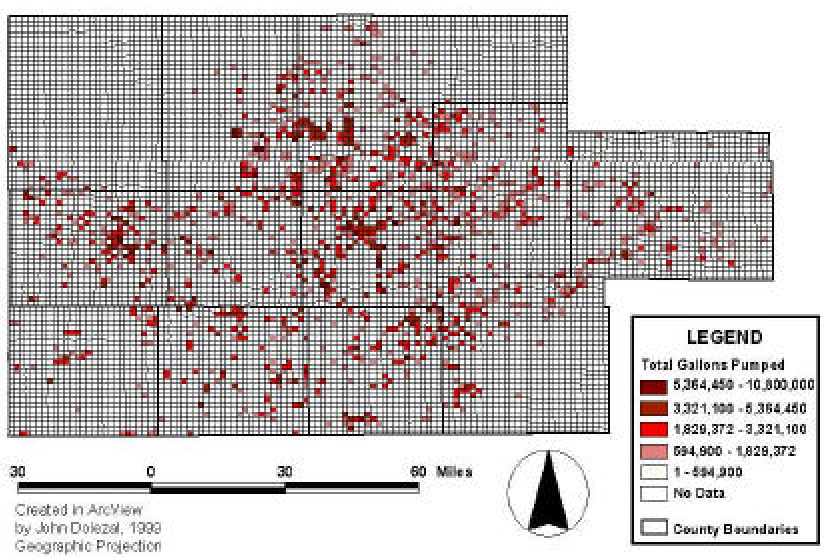
According to the 1997 Agriculture Census, these 12 counties contain 5,958,160 acres of farmland. 4,611,732 acres are classified as crop land and, of these, 2,855,073 were harvested. Of these cropland acres, 1,361,511 are irrigated cropland (USGS 1998).

Due to data limitations (privacy rights), square mile sections are the unit of analysis for this study. We realize that fields do not often conform to these one mile squares. However, for purposes of this model, defining the exact location of each field is less important than defining the amount of irrigated acreage in production and the general location of these irrigated acres. Wellhead data is used to help identify the general location of the irrigated acres. Once this determination has been made, the soil suitability and permeability classes for each section are matched to the irrigated sections as well as other types of information.

The wellhead data suggests that there are 2,657 sections that were irrigated. Thirty-nine sections were eliminated from the study because the well data was inconclusive, leaving 2,618 valid irrigated sections. By dividing the 1,361,511 irrigated acres by the 2,618 irrigated sections, the model assumes that about 520 acres per section are irrigated through flood or center pivot irrigation systems. This seems like a reasonable average given that four quarter section center pivot systems cover about 480 acres of a 640 acre section while flood irrigation covers most of the section. Figure 9 shows wellhead data from the Kansas Water Office aggregated to the section level.

Table 2 summarizes the data and sources that are used in these analyses. For each variable, the data were either aggregated to the

Figure 9:
Gallons of Water Pumped per Section in Southwest Kansas, 1995



section level, or in the case of county agricultural data, disaggregated from the county level to the section level. The method of aggregation used for each source of data are discussed below.

Table 2:
Data and Sources

Data Set	**Data Items**	**Sources**
Aquifer data	Extent Upper surface height Lower surface height Historical depletion	U.S. Geological Survey
Soil Data	Suitability class Permeability	U.S. Geological Survey (STATSGO)
Well data	Location Pumping (gal/hr) Pumping time (hrs/yr)	Kansas Water Office
Other Climatological and Hydrology data	Precipitation Precipitation minus evapotranspiration Runoff	National Oceanic and Atmosphere Administration Environmental Protection Agency
Agricultural data	Acres harvested Yields per acre Production methods Production costs Irrigation requirements Irrigated acres	USDA Agriculture Census USDA NASS USDA Extension Publications Kansas State University Extension
Economic data	Crop prices Demographics Government Crop Subsidies	USDA NASS Kansas Statistical Abstract Kansas State University Agricultural Experiment Station and Cooperative
Fixed Costs Per Acre	Real estate taxes Interest on land and well Rent Interest and depreciation on machinery Interest and depreciation on irrigation equipment Insurance	Kansas State University Agricultural Experiment Station and Cooperative
Variable Costs Per Acre	Labor, Seed, Herbicide, Insecticide, Fertilizers, Fuel and Oil, Repairs, Crop Insurance, Drying, Miscellaneous	Kansas State University Agricultural Experiment Station and Cooperative

The Climatic and Hydrological Components: Methods and Data

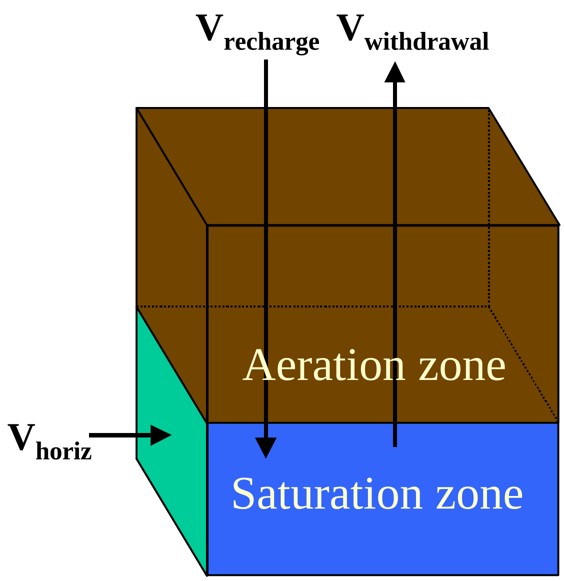
The hydrological component is a recharge model, which uses climatic, water withdrawal, hydraulic head, conductivity, and porosity data to calculate the recharge of the aquifer (see Figure 10). Water withdrawal is based on the water requirements for each crop planted on a section, rather than reported pumping data. Based on this, the model derives estimates for the saturated depth at time t+1 as function of saturated depth at time t, aquifer porosity, and net volumetric balance ($V_{recharge} + V_{withdrawal} + V_{horiz}$), where:

$V_{recharge}$ = f(precipitation, evapotranspiration, runoff)

$V_{withdrawal}$ = f(crop type, irrigation type, population)

V_{horiz} = f(hydraulic head, hydraulic conductivity).

Figure 10: Hydrological Component



This model assumes steady-state saturation flow in the saturation zone and is based on a simple equation of continuity (Freeze and Cherry 1979). The volume of water entering each cell from the side is balanced by the recharge or withdrawal. The formula used to compute the level of depletion in this component is:

Depl =SatDep + ((100 / porosity) * (.1337 * crop water - ((5280 * hhead * conduct * 365.25 * 30 / 2500) + prechrge * (recharge / 12) * 5280 * 5280)) / (5280 *5280)).

where:

Depl =Depletion in feet
Satdep = Saturated depth
crop water = Crop water used
porosity = Porosity and is a constant = 29
hhead = Hydraulic head and is a constant=10
conduct = Hydraulic conductivity and is a constant=100
prechrge = Proportion recharge and is a constant =.02
recharge = Inches of recharge annually

The values for hydraulic conductivity and porosity were chosen from the range of values observed in the Ogallala Aquifer (Gutentag et al. 1984) and adjusted within that range to produce reasonable depletion rates given current climate inputs. The value for hydraulic head is based on the change in elevation of the saturated depth over the study region. The proportion of recharge is the fraction of surface recharge that enters the saturation zone based on typical surfaces and soils in the study region. The other constants in the formula are unit and time conversion factors. Significantly, the hydrological components of the model estimates water use only, it makes no assumptions regarding water quality.

As Table 2 shows, data for the hydrological component of the hydroeconomic model come largely from the USGS and the Kansas Water Office. These data include geospatial identifiers that allow them to be integrated into a Geographic Information System (GIS) program (ArcView). For purposes of these analyses, these data are aggregated to the section level using algorithms in ArcView. Figures 11 through 14 show maps of the climatic and hydrological data aggregated to the section level in the study region.

Figure 11:
Lowest Elevation of Water in the Ogallala Aquifer, Normalized by Section

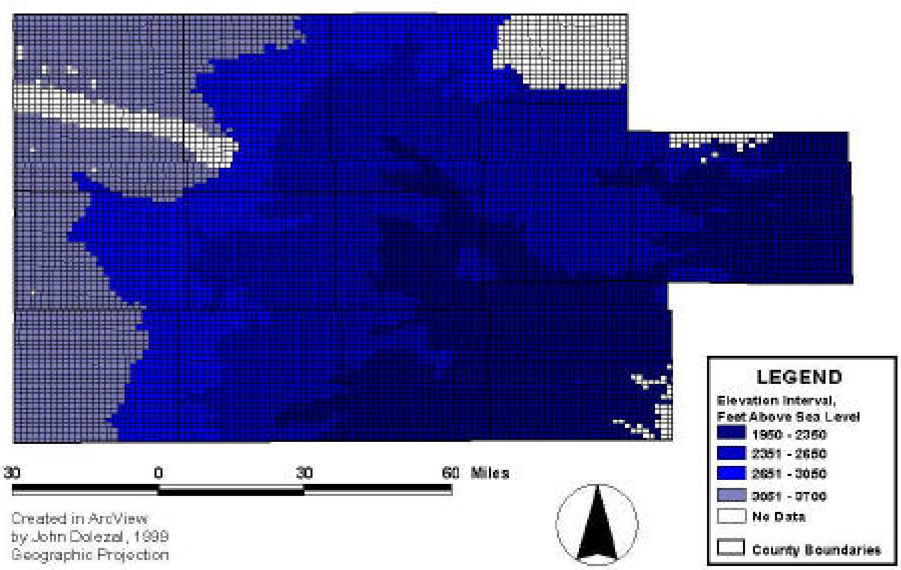


Figure 12:
Highest Level of Water in the Ogallala Aquifer, Normalized by Section

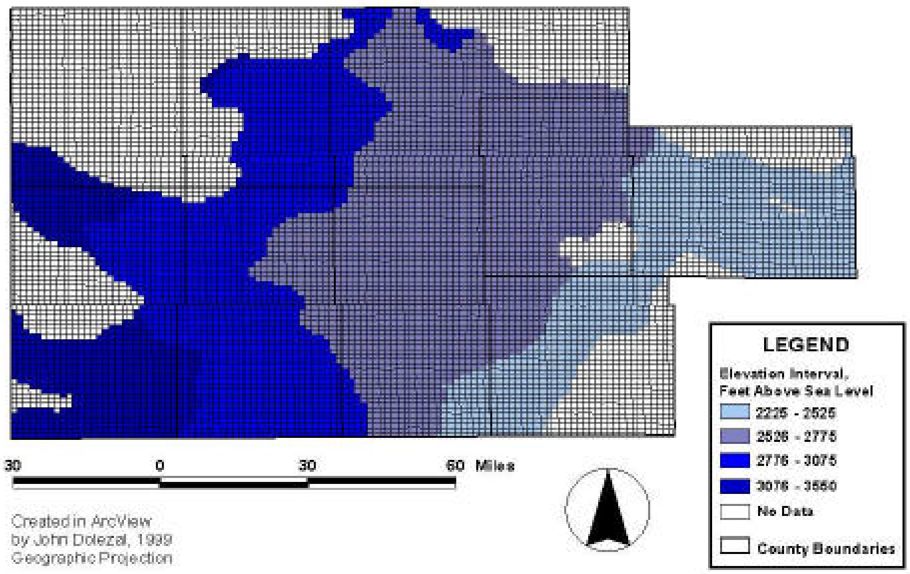
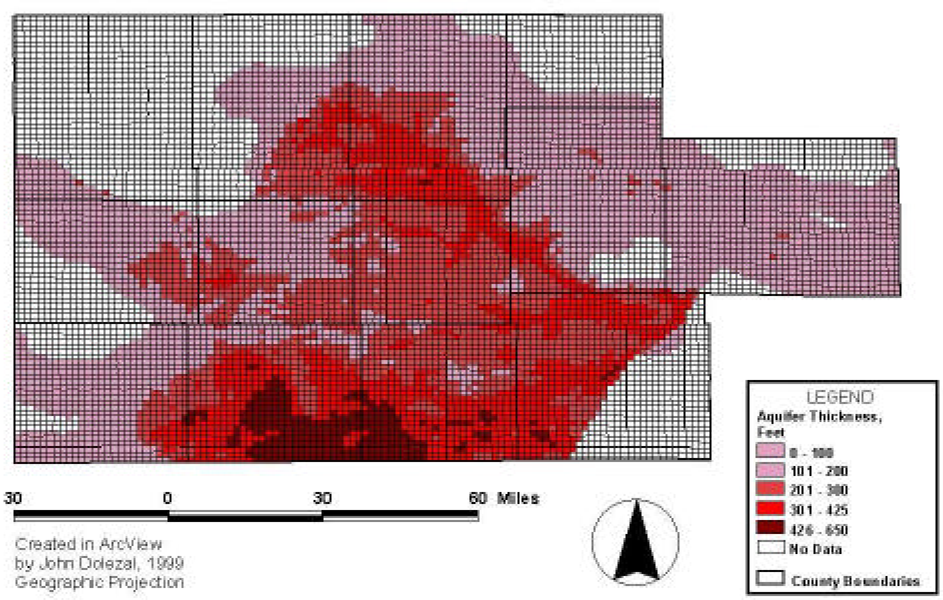


Figure 13:
Ogallala Aquifer Thickness, Normalized by Section



Soils Data

Soils data represent an important set of variables in this analysis. As noted in Figure 7, the quality of the soil affects hydrology, irrigation considerations, and crop yields. Data representing various suitability classes and permeability were obtained from the USGS. These data were then imported into ArcView and aggregated to the section level. Figure 15 shows the soil capability classes based on these data. The best soils for cultivation have a classification of 1, while the worst soils for farming are classified 6. The soil types were grouped into three groups: types 1 and 2, the best types of soil, types 3 and 4, moderate soil, and types 5 and 6, poor soil.

Figure 14:
Net Rainfall for Southwest Kansas (Precipitation minus Evapotranspiration)

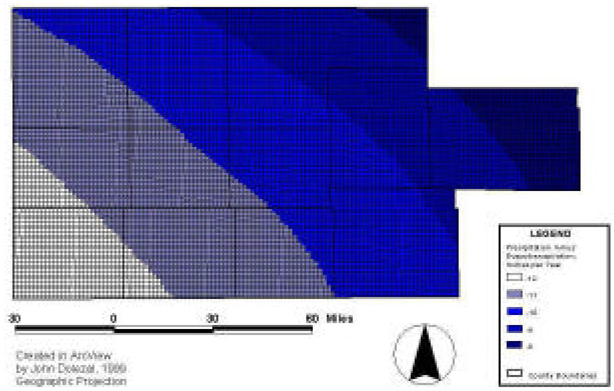
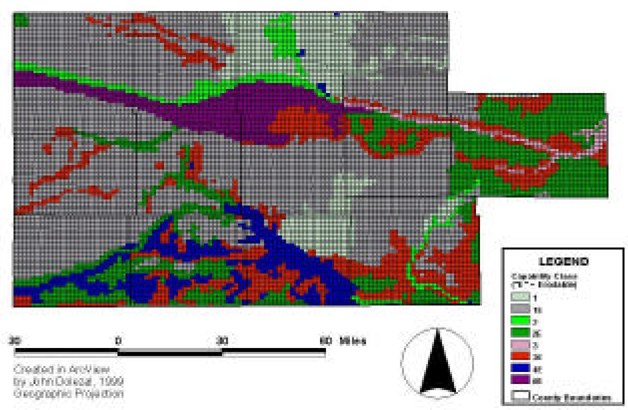


Figure 15:
Soil Capability Class, Normalized by Section



Irrigation/Crop Component: Methods and Data

Data regarding cropping practices on specific acres are considered confidential by the USDA. This presented a number of problems for the analysis because there was no practical way to identify which crops are planted on each irrigated section. Moreover, because this study projects 20 years into the future, confidential cropping practices presented additional problems for predicting future crop planting practices. To resolve this issue, the study uses USDA crop survey data for each county for 1998 (USDA 1999) regarding the percentage of irrigated land that was planted in corn, beans, milo, wheat, alfalfa, and fallow. Next, the study uses a uniform random number generation algorithm to randomly assign the crops to each section in each county in each of the 20 years. This random selection process is then weighted by the percentage of crops types that were planted in 1998 in each county. Table 3 shows the crop assignments for each county in the first year. Because we use a random process to generate the crop assignments, the percentages of crop types in each county vary slightly from year to year. However, this type of yearly variation can also be seen in the crop survey data (1986-1996).

Table 3

Percentage of Irrigated Sections by Crop Type

			Crop Assignment in Year 1						
			Corn	Soybeans	Milo	Wheat	Alfalfa	Fallow	Total
COUNTY	Finney	Sections	160	11	18	105	38	0	332
		% within COUNTY	48.2%	3.3%	5.4%	31.6%	11.4%	0%	100.0%
	Ford	Sections	87	3	16	24	30	105	265
		% within COUNTY	32.8%	1.1%	6.0%	9.1%	11.3%	39.6%	100.0%
	Grant	Sections	74	2	24	82	15	10	207
		% within COUNTY	35.7%	1.0%	11.6%	39.6%	7.2%	4.8%	100.0%
	Gray	Sections	173	6	19	82	23	48	351
		% within COUNTY	49.3%	1.7%	5.4%	23.4%	6.6%	13.7%	100.0%
	Hamilton	Sections	20	1	3	7	6	0	37
		% within COUNTY	54.1%	2.7%	8.1%	18.9%	16.2%	0%	100.0%
	Haskell	Sections	202	6	8	109	4	0	329
		% within COUNTY	61.4%	1.8%	2.4%	33.1%	1.2%	0%	100.0%
	Kearny	Sections	92	0	4	22	26	9	153
		% within COUNTY	60.1%	0%	2.6%	14.4%	17.0%	5.9%	100.0%
	Meade	Sections	57	2	21	83	11	55	229
		% within COUNTY	24.9%	.9%	9.2%	36.2%	4.8%	24.0%	100.0%
	Morton	Sections	28	1	8	33	4	45	119
		% within COUNTY	23.5%	.8%	6.7%	27.7%	3.4%	37.8%	100.0%
	Seward	Sections	87	7	33	39	14	1	181
		% within COUNTY	48.1%	3.9%	18.2%	21.5%	7.7%	.6%	100.0%
	Stanton	Sections	109	1	9	87	2	25	233
		% within COUNTY	46.8%	.4%	3.9%	37.3%	.9%	10.7%	100.0%
	Stevens	Sections	98	1	27	82	13	0	221
		% within COUNTY	44.3%	.5%	12.2%	37.1%	5.9%	0%	100.0%
Total		Sections	1187	41	190	755	186	298	2657
		% within COUNTY	44.7%	1.5%	7.2%	28.4%	7.0%	11.2%	100.0%

These data show that corn is the most prevalent crop type, in most counties, followed by wheat, fallow, milo, alfalfa, milo, and soybeans.

It is important to note that common crop rotation methods are not reflected in the these random crop assignments. For example, alfalfa is generally grown in fields for up to five years before rotating to another crop. Under this model, alfalfa may be replaced in the next year. The model compensates for this problem by adjusting fixed and variable costs to reflect the average costs for the field of alfalfa over multiple years as opposed to only the first year (when the costs are higher due to cultivating, seeding and other high cost production procedures).

Additionally, it was not possible to determine from the aggregated data the type of irrigation system used in each section. To resolve this problem, we once again used a random assignment method. According to Kansas State University Agricultural Experiment Station and Cooperative personnel, about one-third of irrigated acres use flood irrigation, while the other two-thirds use some form of drop-head, center pivot irrigation. Given this, each section is randomly assigned an irrigation method weighted so that one-third of the sections are flood irrigation and the remaining sections are drop head, low pressure center pivot irrigation. Based on the crop type water requirements (Kansas State University Cooperative Extension Service crop "Production Handbooks"), climatic conditions, soil conditions, and the irrigation method, the model then computes the gallons of water withdrawn to irrigate each section. These estimates are then converted to acre feet.

Finance Component: Data and Methods

The finance component is a standard net present value analysis of the relevant cash flows associated with the crop, irrigation method, and lift distance for each section. Standard financial valuation techniques involve estimating the timing and magnitude of expected future cash flows and then discounting them to the present using the opportunity cost of capital appropriate for the risk associated with the project. The finance component uses the following data and methods to derive the estimates. The analysis begins in 1998 and all cash flows are discounted back to 1998 constant dollars.

<u>Price Series</u>

The model uses monthly Kansas prices from 1984 - 1996 to determine the mean (average) price. A regression of the price series indicated there was no strong trend in prices over the long term. In fact, after adjusting for inflation, corn and wheat were essentially flat over the thirteen-year interval. Crop prices were the average Kansas monthly price series for 1984 - 1996 (USDA NASS Prices Received by Farmers, by Commodity, Monthly, by State, 1984-1996). Table 4 shows the series mean price and standard deviation for each crop.

Table 4:
Price Series

Crop	Mean Price per Unit	Standard Deviation
Corn	$2.465	.677
Alfalfa	$66.583	16.394
Milo	$3.808	1.107
Soybeans	$5.836	1.230
Wheat	$3.218	.884

<u>Yields</u>

The analysis uses yield estimates from KSU farm management publications (Kansas State University Farm Management Guides). These publications provide conservative yield estimates for center and flood irrigation methods controlling for the quality of the soil. These estimated average yields were then compared with the yields reported in the 1997 Ag Census and the 1992 Ag Census for each county. For example, average corn yields for irrigated land ranged from a high of over 206 bushels an acre for excellent soil in Haskell County to a low of 123 bushels an acre for poor soil in Morton County. Similarly, the average milo yields for irrigated land ranged from 113 bushels an acre for excellent soil in Finney County to less than 70 bushels an acre for average to poor soil in the far western counties.

Significantly, the model does not include estimates for higher yields that may result from improved hybrid crop varieties. While we feel confident that these higher yielding crops will emerge, it is difficult to assess the increase in yields that will result. It is also difficult to assess an increase in the costs of seed, fertilizers, and other inputs. Recent history suggests that increases in yields are usually accompanied by higher variable costs, thus offsetting any real gains for farmers' bottom line. For this reason, the estimates produced by the model will accurately reflect the net cash flow, even with the emergence of higher yielding crop varieties.

<u>Fixed and Variable Costs</u>

The finance component uses fixed and variable cost estimates from Kansas State University Agricultural Experiment Station and Cooperative "Farm Management Guide" series. Table 5 details the fixed and variable costs included in the model.

Table 5:
Fixed and Variable Costs

Expenses	Expense Items
Fixed Costs Per Acre	Real estate taxes, Interest on land and well, Rent, Interest and depreciation on machinery, Interest and depreciation on irrigation equipment, Insurance
Variable Costs Per Acre	Labor, Seed, Herbicide, Insecticide, Fertilizers, Fuel and Oil, Repairs, Crop Insurance, Drying, Marginal lift expense, Miscellaneous

Fixed costs include all those costs that do not change as the quantity produced changes. For example, the cost of drilling a well, installing a pump and motor, and installing an irrigation system are all fixed costs whether a crop is planted or not. Variable costs, on the other hand, increase with an increase in output. The energy costs and other operational costs of a well and irrigation system increase as the system is operated for longer periods of time. The finance component controls for the lower fixed costs associated with flood irrigation compared with center pivot irrigation. It also compensates for the lower variable costs associated with center pivot irrigation.

The variable costs are those expenses that change by crop, soil type, and depth to water. Marginal lift expenses are calculated from the water level at the first time point (t). As water is withdrawn in successive years (t+1, t+2) the saturated depth of the aquifer declines, causing additional lift costs to be incurred by the irrigator. The additional lift costs include both the variable costs of increased operation, the incremental fixed costs of more rapid wear and tear on the pumping equipment, and both maintenance and replacement of pumps and irrigation equipment.

<u>Cash Flow and Net Present Value</u>

Because of the high levels of variability from one farm and farmer to another in capital structure, income taxes, and individual income, the analysis focuses on the irrigated land as a production enterprise. This means that on the income statement the model only considers earnings before taxes (EBT). For purposes of the analyses, a farmer's cash flow at time t is defined by his EBT_t. A farmer's revenue is computed:

$$\text{Revenue} = (\text{Price} * \text{Yield})$$

Cash Flow (CF_t) is computed by subtracting a farmer's expenses from his revenues.

$$CF_t = R_t - (FPC_t + VPC_t + MLC_t)$$

Where:

R_t = Revenue at time t.

FPC_t = Fixed Production Costs at time t.

VPC_t = Variable Production Costs at time t.

MLC_t = Marginal Lift Costs at time t.

Significantly, as every farmer knows, it is possible for CF_t to have a negative, as well as, a positive value.

The finance component of the model uses standard financial procedures to calculate the net present value for each irrigated section. Standard financial valuation techniques involve estimating the timing and magnitude of expected future cash flows and then discounting them to the present using the opportunity cost of capital appropriate for the risk associated with the project. This can be expressed in the following relationship: $NPV = \sum(CF_t * (1 + k_t))^{-t}$.

Where:

NPV = Net Present Value of the irrigated section in today's dollars.

CF_t = Cash flow at time t.

k_t = The risk adjusted opportunity cost associated with the project at time t, also termed the discount rate.

$\sum$ = Sum of time t, t+1, t+2, . . t+20.

This microeconomic approach uses discounted expected cash flows to estimate the Net Present Value of water. The discount rate (k_t) is set at 12%. This is average long term rate of return from equity investments in the United States and thus, represents a reasonable alternative investment for a capital holder. A lower rate of return would have the effect of making the value of the water for irrigation more negative.

The study is limited to a twenty year time frame starting in 1998 and all dollar values are placed in 1998 constant dollars. Thus, the time subscript has values ranging between 1 and 20. A simple reflection on the changes that have occurred over the past twenty years shows that forecasting beyond twenty years is of limited value.

This model excludes income taxes, government transfer payments, and profit. The model, in its initial stages, focuses exclusively on the value of water to the production process. Later, when examining the consequences for the larger southwest Kansas economy, the analysis addresses issues relevant to the importance of transfer payments for economic impact.

Consequences

The hydroeconomic model produces a number of consequences that are of primary importance for this study. Two consequences are especially important for the economy of southwest Kansas. The first is the effects of irrigation practices on the rates of depletion. As noted previously, the rate of depletion is based on the crop water requirements, climatic conditions, soil conditions, and the irrigation method. Using a feedback loop, this data is then inputted into the next year's model. If the saturated depth equals or exceeds the maximum saturated depth, the section is set at fallow. This simply reflects the reality that an irrigated crop cannot be planted unless water levels are sufficient for irrigation.

The second consequence is the economic impact of the use of an acre foot of water. Based on estimated cash flows and expenditures, the model estimates the total direct economic impact of an acre foot of water on the region of southwest Kansas.

The analysis then estimates the multiplier effects. These multiplier effects include the indirect and induced economic impacts. Indirect effects are defined as additional goods or services that are bought or produced regionally to support the direct effects. Induced economic impacts represent income received by regional businesses that are a result of direct effects. This income is recycled to regional residents through wages and purchases. In short, the total annualized economic impact of an acre foot of water are derived by adding together the direct, indirect, and induced economic impacts.

Chapter 4
The Economic Value of an Acre Foot of Water
Scenario 1: Modeling Current Practices

This chapter reports the findings for scenario 1. This scenario models the current farming and water utilization practices in southwest Kansas over a 20 year time frame. In reporting the findings from this application of the hydroeconomic model, the analysis focuses on net present value, depletion rates, and changes in saturated depth. After reporting these findings, the analysis then reports the direct, and secondary (indirect and induced) economic impacts on southwest Kansas economy, including the value of an acre foot of water. Chapter 5 reports the findings by applying the other four scenarios of water utilization over the same twenty-year time frame.

Hydroeconomic Model in Brief

The hydroeconomic model has three major components. These are hydrology, irrigation/crop, and finances. The hydrology component is a recharge model. It uses climatic, water withdrawal, hydraulic head conductivity, and porosity data to calculate recharge of the aquifer. Water withdrawal is based on the water requirements of each crop planted on a section, rather than reported pumping data. From the well data we identified 2,618 irrigated sections (39 sections were eliminated from the study because of unreliable well data). The water model focuses on water quantity, and issues of water quality are not addressed in this study. In addition, none of the findings make assumptions about the ownership of the irrigated land.[4]

The irrigation/crop component maintains the current distribution of crops that are randomly assigned to each irrigated section for each year of the 20 year study, subject to the constraint that the well(s) assigned to the section produced sufficient water to irrigate that crop. The crop model does not increase the number of sections of the particular crop over the twenty-year study period.

The finance component estimates cash flows for each section for each year. Because there is considerable variation between farming operations, the finance component does not consider the cash flows that arise from non-irrigated operations, nor does it initially consider the government transfer payments that might be associated

[4] So the model might assign corn to a particular section while the actual owner of that section might not raise any corn. However, the individual decisions that owners have made with regard to wells, irrigation methods, and crops have been used as initial conditions and parameters.

with a particular section of irrigated farmland. Rather, the finance component focuses on the cash flows arising from the use of the irrigated land as an independent production enterprise. These cash flows are simply the revenues for each irrigated section minus the expenses for that section.

The finance component calculates the revenues by multiplying the crop price by the crop yield. The crop price is the average Kansas market crop price for that crop from 1984 to 1996. The crop yield is the average county yield for that crop on irrigated land. This crop yield is adjusted for soil type and irrigation practice. The expenses for each section consist of fixed production costs, variable production costs, and marginal lift costs. The fixed production costs are specific to the irrigation practice, either flood or center pivot, and vary according to the soil type. The fixed production costs include: real estate taxes, interest, rent, depreciation, and insurance for land, machinery, and irrigation equipment. The variable production costs include: labor, seed, chemicals, fuels, repairs and maintenance, and crop insurance. The fixed and variable production costs are from Kansas State University Farm Management Guides for 2000. It is important to note that although variable production costs are zero for land that is fallow, fixed production costs remain even for fallow land. The marginal lift costs are calculated from the water level for the first time period, and include both the variable costs of increased operation, and the incremental fixed costs of more rapid wear and tear on the pumping equipment and both maintenance and replacement of pumps and irrigation equipment. All dollar calculations are done using 1998 dollars.

Scenario 1: Initial Conditions

Scenario 1 models the current farming and water utilization practices. In this model, two-thirds of irrigation is by center-pivot methods, with one-third flood irrigation methods. Table 6 summarizes the findings for this scenario based on crop type and cash flow for the twenty-year period.

Table 6:
Scenario 1, Average Cash Flow by Crop

Crop	Percent of Sections	Average cash flow per section, per year
Corn	44.6	$-10,103.62
Soybeans	1.5	$-17,781.82
Milo	7.2	$13,397.18
Wheat	28.4	$-42,389.49
Alfalfa	7.0	$2,397.72
Fallow	11.3	$-44,786.70

It is important to note that corn is the dominant irrigated crop with nearly 45% of the total irrigated acres. Together, corn and wheat account for almost 75% of the irrigated acres. Whereas, milo and alfalfa account for less than 15% of the irrigated acres. The table shows that milo and alfalfa are the only two crops that have an average positive cash flow over the twenty year period.

Significantly, there was no soil type or county that generated positive cash flows over the twenty-year period. Annual cash flows per section by soil type ranged from $-13,625 to $-26,106. Annual cash flows per section by county ranged from $-2,801 to $-47,197. When we examined irrigated sections through time we found less than 10% of the sections had a positive net present value for the 20 years estimated.

Table 7:
Scenario 1, Net Present Value and Depletion

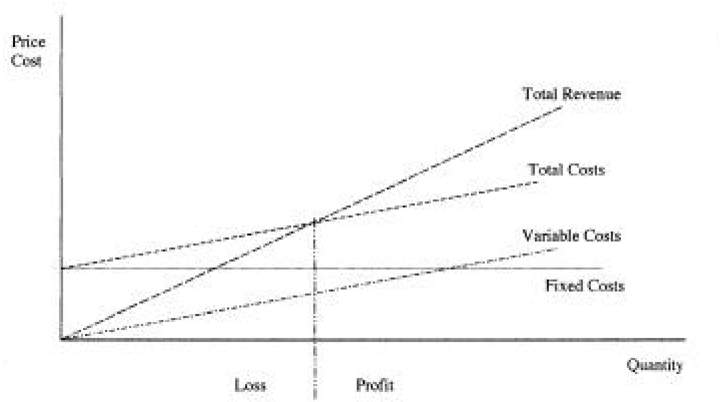
Scenario	Average Net Present Value per Section	Standard Deviation – NPV	Average Depletion Rate	Average Change In Saturated Depth
Initial Conditions	$-150,000	$124,000	30.6%	-53.9 feet

Table 7 shows that on average, irrigated land had a negative Net Present Value (NPV) of $-150,000 per section (1998 dollars) over the twenty year study period. The standard deviation was about $124,000 per section, suggesting that there is much variation in the NPV by section dependent on soil type, crop, and yield. Significantly, for more than 90 percent of the irrigated sections, the income from crop production was negative. The average depletion rate for the study area was 30.6% for the twenty-year period. The average change in saturated depth was -54 feet.

Economic Impact of Irrigation Agriculture

Because the value of Ogallala Aquifer water for irrigation, on average, is negative for the irrigator, it is hard to see how the water can have a positive economic impact on the region. The answer lies in understanding that government subsidies, tax policies, and farmer subsidies from other agricultural operations (dryland, confined feeding, livestock) were not included in the finance component. These additional cash inflows must be large enough to make irrigated farming profitable. Figure 16 depicts a breakeven model for irrigators in southwest Kansas. Without subsidies, irrigators are in the loss region and over the long term will not survive. With subsidies, irrigators have sufficient revenues to pay the bills and at least, breakeven.

Figure 16
Breakeven Point for Irrigators



Direct Economic Impact

The direct economic impact measures the first round of spending for locally provided goods and services. From the perspective of the larger regional economy all of the irrigator's costs for locally purchased goods or services adds to the size of that economy. As discussed above, the revenues that allow the irrigator to make these expenditures come from sale of crops, subsidies from other farm operations (for some), and government subsides. Thus:

$E = R_{crops} + R_{farm\ operations} + R_{government\ subsidies}$

Where:
E = Expenditures
R = Revenues

From the perspective of regional economic impact, revenues that come from outside the local economy are a net gain to that economy because these revenues allow irrigators to expend monies to remain in business. In order to understand the impact of these different sources of revenue on the economy, this analysis deconstructs the direct impact expenditures in terms of the two major revenue streams: crops and subsidies (both government and farm operations).

When examining the entire region for the twenty-year study period, the average net present value per section under the current conditions is $ -150,000 (standard deviation = $124,000).[1] This means that for the region the average net present value of the subsidies to irrigators should be close to $150,000 per section for the twenty-year study period. Because the analysis involves 2,618 irrigated sections, it suggests that the direct economic benefit to the local economy from external subsidies for the twenty-year study period are about $392,700,000 in current dollars. On an annual basis this is approximately $19,635,000. Additionally, there are the revenues that the irrigator receives for the crops. We estimate that the average net present value of the revenue per section for the twenty-year study period under the initial conditions is $170,000 (standard deviation = $89,500). Multiplied by the 2,618 irrigated sections, the direct economic benefit to the local economy is about $445,060,000 for the twenty-year study period. On an annual basis this is approximately $22,253,000. Adding the direct benefit from the sale of commodities and the direct benefit from subsidies provides an annual total direct benefit from irrigation of $41,888,000 in 1998 dollars (see Table 8).

Table 8:
Direct Economic Impact

Source	Annual Amount
Direct Impact from Subsidies	$19,635,000
Direct Impact from Crop Revenues	$22,253,000
Total Direct Impact	$41,888,000

[1] This average value does not mean that all irrigated sections will have this value. Rather, it means that a typical (or average) section will have this value. In fact, more than 1,738 of the 2,618 sections have values between $ -26,000 and $ - 274,000.

Secondary Economic Impacts

In addition to the direct economic benefits to the local economy from the activities of irrigators, there are secondary (induced and indirect) economic benefits generated through the "multiplier effect". The indirect impact can be explained as follows: because of the local sales that occurred as a result of the direct impact, business establishments in the twelve county area purchased additional goods and services from other local sources in order to support the direct impact. The induced impact arises from the income received by local business establishments as a result of the direct expenditures of irrigators. A portion of these receipts received by local businesses will in turn be distributed to local residents in the form of wages, salaries, commission fees, and profits. A part of this distribution will in turn be used to make "second round" local purchases, which in turn becomes additional income to local residents and thus sets off a "third round" of expenditures, *et cetera*. The data did not allow us to estimate these secondary effects individually.

The question is what the multiplier effect should be for irrigation? Some have argued for a multiplier effect from agriculture of 2.3 times ("Determining the value of water" The Great Plains Symposium 1998: The Ogallala Aquifer). However, we know that without irrigated farming most of the additional economic development in the past thirty years would not have occurred in southwestern Kansas. An analysis of the total economy for agriculture in southwest Kansas counties suggests that the total economic multiplier for agriculture ranges from 12.5 to .3 depending upon the county. This variation reflects the fact that some counties have very little economic activity beyond agriculture, while others have a much larger value-added agricultural economy that relies on agriculture. This analysis suggests that the multiplier for agriculture in the entire region of about 3.5. This estimated multiplier is somewhat higher because of the rather isolated nature of the southwest Kansas economy and the degree to which it is vertically integrated.[2]

With an estimated multiplier effect of 3.5, for every dollar of direct spending by farmers and ranchers, $3.50 of additional business activity will ultimately be generated

[2]The data do not allow us to estimate a multiplier for just irrigated agriculture. Clearly, this multiplier is larger than the overall agricultural multiplier (3.5) that we estimated.

in the SWKGMD area. These secondary effects approach $3 billion over the twenty-year study period, or $146,608,000 annually.

Table 9:
Secondary Impacts of Irrigation Agriculture

Economic Impact	Annualized	20 Year Study Period
Direct	$41,888,000	$837,760,000
Secondary	$146,608,000	$2,932,160,000
Total	$188,496,000	$3,769,920,000

The total economic benefit to the SWKGMD area economy is the sum of the direct impact and the secondary (induced and indirect) impacts. For the twenty-year period of this study those benefits are estimated at $837,760,000 and $2,932,160,000 respectively. Thus, the total economic benefit from irrigation in 1998 dollars is estimated at $3,769,920,000 for the twenty-year study period. On an annual basis the total economic impact on the SWKGMD area from irrigation is estimated at $188,496,000 in 1998 dollars. The size of the total annual economy in the SWKGMD is about $2.18 billion. Thus, approximately 9 percent of this economic activity can be attributed to irrigated farming. It is likely that if more accurate data existed we would find the impact of irrigation on the economy of SWKGMD is considerably more than 9 percent.

Table 10 summarizes these findings and shows the regional economic value of an acre foot of Ogallala Aquifer water used for irrigation. While the direct impact is about $18 per acre foot, once secondary economic impacts are calculated, the value of an acre foot of water is over $80.

Table 10: Value of Acre Foot of Water for Irrigation

Economic Impact	Acre Feet	Annualized Impact	Economic Impact Per Acre Foot
Direct	2,345,353	$41,888,000	$17.86
Secondary	2,345,353	$146,608,000	$62.51
Total	2,345,353	$188,496,000	$80.37

Finally, there is the question of economic impact beyond the present study area. Clearly, irrigated farming and the subsequent economic activity in the SWKGMD have an economic impact on the State of Kansas. Leatherman and Howard (2001, 3) suggest that on an aggregate, statewide basis "a reasonable economic multiplier to use would be about 2.0." If one uses their multiplier, then the economic impact from irrigated farming in the SWKGMD on the State of Kansas is probably around $375 million dollars on an annual basis.

Economic Impact of Other Sectors

An important question is what is the value of an acre foot of water for other economic sectors in the region. Two of the largest users of water in the region are livestock operations and municipalities. We estimated the economic value of an acre-foot of water for livestock operations by first calculating the amount of water needed for the livestock industry in the district.

$Water_{livestock}$ = Number of animals * Daily water requirement * Days to slaughter

After calculating the water required for livestock (almost 72,000 acre feet), we estimate the amount of economic revenues associated with the sale of livestock. On an annualized basis (1998 dollars), the amount of revenue generated in the region from the sale of livestock is about $35.7 million (see Table 11).

To examine the impact of municipal use, we first calculated the amount of water used by the major cities in the region (Garden City, Dodge City, and Liberal). Second, we calculated the amount of revenues generated from the sales of the water by the cities.

Table 11:
Value of Acre Foot, Municipal, and Livestock Operations, and Agriculture

Source	Acre Feet	Annualized Impact	Direct Economic Impact Per Acre Foot
Livestock Operations	71,669	$35,704,779	$498.19
Municipal (Garden City, Dodge City, and Liberal)	16,312	$7,483,456	$458.77
Agriculture	2,345,353	$41,888,000	$17.86

Table 11 shows the findings from this analysis in comparison to irrigation agriculture. Livestock operations generate a direct impact of about $500 per acre foot, while municipalities generate over $450 per acre foot. By comparison, the direct impact of an acre foot of water for irrigation is almost $18. Even adding together direct and secondary impact for agriculture, the value is approximately $80 per acre foot (see Table 10). This reflects the reality that it takes much water to support the economic benefits of irrigation agriculture. Moreover, it also shows that not all uses of water have equal economic value.