REGIONAL ECONOMIC IMPACTS OF CONSTRAINED GROUNDWATER AVAILABILITY UNDER A ZERO DEPLETION MANAGEMENT SCENARIO

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Introduction

Depletion of the Ogallala Aquifer is a growing concern among planners and farm managers in the High Plains region. Recent patterns of water use in many areas overlying the aquifer indicate that groundwater withdrawals for irrigation continue to occur at rates that are producing an irreversible overdraft of aquifer water in storage. Consequently, the Ogallala's declining water table has been given a high priority among those concerned with management of water resources in the region.

In the early 1980s, Congress appropriated $6 million to study the problem of declining Ogallala reserves in the High Plains region. The study, which was funded by the Economic Development Administration of the U.S. Department of Commerce, analyzes future impacts of the region's groundwater depletion and includes various scenarios related to voluntary and *mandatory conservation* of aquifer resources (High Plains Study Council, 1982). *Voluntary conservation* is defined as the use of conservation techniques such as improved soil moisture monitoring, improved irrigation scheduling, increased adoption of water efficiency improvement technology, and increased irrigation application efficiency. The objective of *mandatory conservation*, on the other hand, is to limit the quantity of water that can be pumped annually while users continue to apply the most efficient irrigation methods. For the latter case, the study assumes that withdrawals will be limited to a percent of the estimated quantity withdrawn under the voluntary conservation scenario for any given production season, with withdrawals gradually declining 30 percent between 1977 and 2020.

The study concludes that voluntary conservation efforts will result in a relatively small change in water use by 2020 in most states because most water-saving technologies will be adopted without added incentive programs. Increased water-use efficiency would lead to a 5 percent increase in irrigated acreage over the baseline. If mandatory conserva-

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The authors wish to thank Harry Manges, Dan Rogers, Orlan Buller, and two anonymous referees for their comments on an earlier draft of this paper.

The views expressed in this paper are solely those of the authors and do not necessarily reflect those of the U.S. EPA.

tion were enacted, it is projected that irrigated acreage will be less than in a baseline scenario in early years, but it will be only 0.1 percent less than the baseline case by 2020. The High Plains study did not anticipate, however, the substantial impact of a natural regulatory process—well yield declines, increased water costs, and well abandonment—on the area's crop production. This study therefore focuses on comparison of the impacts of this process on a small region characterized by diverse hydrologic conditions, as opposed to the imposition of a mandatory conservation policy designed to replicate, but accelerate, this process. Large initial economic losses to the region will ensue under the most restrictive policy scenario, followed by a leveling of production at low levels, a condition similar to that already existing where groundwater is scarce.

Objectives, Procedures, and the Study Area

The general objective of this study is to design a model that will assess the short-run and long-run regional economic effects of constrained groundwater usage on direct users of irrigation water and to assess any subsequent multiplier effects on sectors linked to the irrigated crop production sector. The study's modeling approach reflects this objective through the creation of a regional impact model rather than a model constructed to assess individual farm-level impacts, including those related to farm size and to management of mixed farming situations in which livestock as well as crops are produced. Groundwater availability constraints include those related to the self-regulatory process that results from diminishing groundwater supplies as well as artificial constraints imposed by a regulatory body to promote groundwater conservation.

The study involves three components: a water budget which estimates each county's water table decline given irrigation withdrawals; a linear program which forecasts the direct impacts of increasing water costs, declining well yields, well abandonment, and artificial water availability constraints on total county crop production; and input-output analysis which forecasts the indirect impacts or multiplier effects of declining irrigated crop production.

Regional impacts of Ogallala depletion are particularly relevant to Kansas because most of the state's western portion overlies the aquifer. As a consequence of the imbalance between aquifer recharge and discharge, groundwater declines in some areas of northwest Kansas have reached a maximum of 3.7 feet per year, with a regional average decline of 0.6 foot per year. In response to appeals to forestall these declines, Northwest Kansas Groundwater Management District No. 4 has proposed a policy designed to gradually limit withdrawals until a zero depletion state in which groundwater discharge equals recharge occurs. The district's policy is unique—it is designed to simulate, in an accelerated fashion, the natural hydrologic and economic processes of an unrestricted environment.

This study focuses on declining aquifer resources within Northwest Kansas Groundwater Management District No. 4, which encompasses a wide range of hydrologic conditions. Northwest Kansas Groundwater Management District No. 4 was established following the adoption of the Kansas Groundwater Management Act of 1972 and is the second largest groundwater management district in the state. The district's boundaries lie within the boundaries of the Ogallala Aquifer and include ten counties: Sherman, Thomas, and Sheridan counties and portions of Cheyenne, Rawlins, Decatur, Graham, Wallace, Logan, and Gove counties. Saturated thicknesses in the area range from 0 feet to 226 feet, with Sherman and Thomas counties exhibiting the greatest thicknesses. On average, saturated thickness is 150 feet in the western counties and as little as 30 feet in the eastern counties. The depth to the water table from the area's land surface is highly variable. In the late 1970s, O'Connor and McClain estimated that depth to water in nonalluvial sections of the region ranged from 100 to 200 feet, reaching a maximum of more than 200 feet in areas of Cheyenne and Rawlins counties (O'Connor and McClain, 1982). Discharge rates (maximum gallons of water per minute that a well can yield) of the 3483 permitted Ogallala wells in the district currently range from 50 gallons per minute to 2000 gallons per minute, with a district average of 600 gallons per minute.

Three scenarios are devised to forecast regional impacts of a declining water table and of artificial pumping constraints imposed by Northwest Kansas Groundwater Management District No. 4. A linear program is designed for each of the six major counties in the groundwater management district (Cheyenne, Graham, Rawlins, Sheridan, Sherman, Thomas). A planning horizon of 50 years is deemed suitable to assess immediate and longer term impacts of Northwest Kansas Groundwater Management District No. 4's zero depletion policy. The model is recursive; a separate linear program is calibrated for each county in each five year period between the years 1989 and 2039.

The Economic Impact Model

The general framework of this analysis is inspired by a study designed by Bredehoeft and Young (1970) who developed a procedure for determining the optimal temporal withdrawal policy given the interdependent nature of aquifer and water user behavior. The authors incorporate two fundamental aspects of groundwater usage in their model. First, withdrawals may occur at greater than socially optimal rates because externalities arise when individual users cause additional drawdown in nearby wells to occur. Second, drawdowns in response to withdrawals may not be distributed uniformly throughout the groundwater basin, necessitating a linkage between hydrologic models and economic demand models.

In the absence of a calibrated hydrologic model for the Northwest Kansas region, a water budget is employed to approximate hydrologic changes due to pumping groundwater for irrigation purposes. The water budget designed for this model employs initial county hydrologic data on regional aquifer area (total county acres overlying the Ogallala), total water in storage, and annual recharge to estimate changes in water in storage and water table declines for each period. The water budget and the direct impact model are temporally interactive; water table declines in a given period are calculated in the water budget based on the previous period's forecasts of crop acreage and subsequent required water withdrawals derived by the direct impact model. That period's water table declines are used in the next period's linear program in conjunction with the model's water availability constraints.

County-level water table declines for each time period are derived in the following manner:

(1) New Water in Storage (WIS) = WIS + Annual Recharge - Withdrawals

(2) ΔWIS = Annual Recharge - Withdrawals

(3) Average Decline per Acre (AD) = DWIS/Regional Aquifer Area

(4) Water Table Decline = AD/Specific Yield.

The water table decline is a key element in the direct impact model, a linear programming model in which total regional net revenue of irrigated and dryland crop production is maximized. The water table decline is used to estimate changes in county ranges of average saturated thicknesses to quantify how the hydrology of the region will affect declining well yields, well abandonment, and shifts between alternative crops. The water table decline is also crucial to Northwest Kansas Groundwater Management District No. 4's policy constraints, as these are based on maximum depletable reservoirs of saturated thickness, which allow only a specified water table decline to occur before withdrawals must be curtailed.

Two types of decisions are incorporated in the direct impact model: an agricultural firm using groundwater will be faced with short-run land and water allocation decisions related to alternative irrigated crop production and also with the longer-run decision to shift from irrigated to dryland production. A general assumption of the model is that water availability is the major factor influencing both types of decisions.

The general form of the direct impact model is:

$$(5)\ \text{Max } Z = \sum_{i,s,e,r} X^{I}_{iser}\left(n^{I}_{ir} - c_{iser}w_{isr} - L^{I}_{is}\right) + \sum_{d} X^{D}_{d}\left(n^{D}_{d} - L^{D}_{d}\right)$$

subject to the linear constraints

$$(6)\ a^{I}_{iserk} X^{I}_{iser} \leq b^{I}_{k}$$

$$(7)\ a^{D}_{dk} X^{D}_{d} \leq b^{D}_{k}$$

and the restrictions that

$$(8,9)\ X^{I}_{iser} \geq 0 \quad X^{D}_{d} \geq 0.$$

where:

X^{I}_{iser} = Acreage of the ith irrigated crop using irrigation system s and energy source e under irrigation regime r;

n^{I}_{ir} = Net revenue over variable operating costs other than water and labor for producing one acre of the ith irrigated crop under regime r (net return per bushel times yield for each regime);

c_{iser} = Per inch cost of water for the ith irrigated crop using irrigation system s and energy source e under irrigation regime r;

w_{isr} = Gross water requirement of the ith irrigated crop for each system s and regime r;

L^{I}_{is} = Per acre labor costs of the ith irrigated crop using system s;

X^{D}_{d} = Acreage of the dth dryland crop, including those acres resulting from a shift from irrigated to dryland production;

n^{D}_{d} = Per acre net revenue over variable operating costs other than labor for producing the dth dryland crop;

L^{D}_{d} = Per acre labor costs of the dth dryland crop;

a^{I}_{iserk} = Elements of the matrix of input-output coefficients for irrigated crops (the quantity of the kth resource required to produce a unit of crop activity);

b^{I}_{k} = kth resource constraint for irrigated crops;

a^{D}_{dk} = Elements of the matrix of input-output coefficients for dryland crops;

b^{D}_{k} = kth resource constraint for dryland crops.

The net returns of both irrigated and dryland crops (n^{I}_{ir} and n^{D}_{d}, respectively) are maximized in equation (5), with the explicit subtraction of per acre water and labor costs. It is assumed that competitive conditions exist in both the resource and product markets, so that demand curves for all commodities are perfectly elastic and prices are treated as constants. The model therefore does not capture the complex feedback process on rates of returns to resources that could affect regional income, nor does it capture the more dynamic influences of changing farm size and technology over time as previous models have attempted (Burt, 1964; Martin, Burdak, and Young, 1969; Swanson and Heady, 1983). Considering the relatively small size of the region, however, the loss of output price effects should not alter the study results significantly.

Resource constraints (equations (6) and (7)) include those relating to total irrigable acres, maximum attainable crop production, crop acreage limits of government programs, dryland transition acreage, energy source limitations, and water rights in addition to water availability and policy constraints. Irrigated crops (i) included in the model are wheat, corn, grain sorghum, soybeans, alfalfa, corn silage, and sorghum silage. Dryland crops (d) include wheat (summer fallow), grain sorghum, and soybeans. As wells are abandoned, water costs rise, and pumpage becomes constrained to minimal levels due to pumping limits imposed by the zero depletion policy, irrigated acres will decline and will be replaced by dryland farming. The effect of this shift is determined in the objective function by the use of a dryland transition variable.

When groundwater is depleted, well yields decline, and less water is available for the crop's consumptive use. Farm managers may respond to this condition by decreasing the acre-inches applied to a given crop, by shifting to crops that require less irrigation, or by reducing total irrigated acres and shifting to dryland cropping. The linear program approximates this decision-making process by selecting various irrigation regimes (r) devised in a previous study by Buller and Williams (1990) to maximize net returns given changing water costs and water availability. For each irrigated crop, the per acre parameter n^{I}_{ir} represents net returns per bushel times a yield chosen by the linear program from a selection of yields based on irrigation regimes.

To estimate yields for wheat, corn, and grain sorghum, irrigation regimes based on the gross water requirement (actual water delivered to the plant after accounting for system efficiency) of the crop at various crop stages are utilized, as shown in Table 1. Crop yields for which no irrigation regimes are available are estimated from data on county average yields from 1980 to 1989.

Initial 1989 water costs (c_{iser}) are computed with a software program (ICEASE) designed by Williams *et al.* (1988). Energy sources (e) used by irrigation systems that are relevant to water costs include natural gas, electricity, and diesel fuel. To estimate the effect of increasing lifts and declining well yields on water costs over time, the estimated percentage change in water costs per foot of water table decline is incorporated into the Direct Impact Model. Water costs increase for each period according to changes in average saturated thicknesses, which are the basis for determining changes in well yields.

Under the baseline scenario with no policy constraints, the Ogallala's stock resource nature is captured in three limiting factors pertaining to water: increasing water costs, declining well yields, and well abandonment. The water availability constraint is the most operative constraint in the linear program in terms of the latter two effects of limited water supplies on crop production decisions. This constraint and the policy constraints (where applicable) determine the allocation of scarce water resources, given the amount of groundwater remaining in the Ogallala, the number of wells and systems left in place, and well yields based on average saturated thicknesses of various ranges in each county.

The water availability constraint is:

$$(10)\ \sum_{i,e,r} w_{isr} X^{I}_{iser} \leq \frac{o_s g_s}{v} h$$

where:

w_{isr} = Gross water requirement of the ith irrigated crop for each system s and regime r;

o_s = Irrigation wells by system s;

g_s = Average well yield (g.p.m. = drawdown times specific capacity) by system s;

v = Conversion factor (452.6);

h = Average seasonal hours.

For a 50 percent maximum depletable reservoir, if WTD > $MDR1_{RNG}$ for any of the six ranges of saturated thickness, then the policy constraint derived from the water availability constraint is:

$$(11)\ \sum_{i,e,r} w_{isr}X^{I}_{iser} \leq \sum_{RNG}\left(\left(\frac{RES10_{sRNG}g_s}{v}\right)h\right)^{*}.5 + \left(\frac{RES10_{sRNG}g_s}{v}\right)h$$

For a 100 percent maximum depletable reservoir, if WTD > $MDR2_{RNG}$ for any of the six ranges of saturated thickness, then the policy constraint derived from the water availability constraint is:

$$(12)\ \sum_{i,e,r} w_{isr}X^{I}_{iser} \leq \sum_{RNG} RCH_{RNG} + \sum_{RNG}\left(\frac{URES20_{sRNG}g_s}{v}\right)h$$

where:

WTD = Water table decline;

MDR1 = 50 percent maximum depletable reservoir;

RNG = Six ranges of saturated thickness;

w_{isr} = Gross water requirement of the ith irrigated crop for each system s and regime r;

$RES1O_{sRNG}$ = Number of wells using system s located in restricted range RNG where WTD > MDR1;

g_s = Average well yield (g.p.m. = drawdown times specific capacity) by system s;

v = Conversion factor (452.6);

h = Average seasonal hours;

$URES1O_{sRNG}$ = Number of wells using system s located in unrestricted range RNG where WTD < MDR1;

MDR2 = 100 percent maximum depletable reservoir;

RCH_{RNG} = Recharge in acre-inches by range of saturated thickness;

$URES2O_{sRNG}$ = Number of wells using system s located in unrestricted range RNG where WTD < MDR2.

The left side of the water availability constraint represents the amount of water in acre-inches required by all irrigated crops in a given time period. The right side of the equation represents the total amount of water available for irrigation purposes in acre-inches. The amount of water available for pumping by each system type is determined by the total number of wells allocated to each system, the average system gallons per minute determined by the linear program, and the mean seasonal hours pumped for each county. In addition, it is necessary to use a conversion factor (452.6) to convert gallons per minute into acre-inches.

Average gallons per minute for each system are computed internally by the linear program to capture the effect of water table declines on well yields. First, each county is divided into six hydrological ranges (RNGs) which initially are demarcated based on median values of saturated thickness (ST). Northwest Kansas Groundwater Management District No. 4 well data are used to estimate average saturated thickness (AVST) for each range in each county. For the initial 1989 period, the following equation is used to estimate gallons per minute for each range:

(13) Average Gallons per Minute = Drawdown * Specific Capacity

where:

(14) Drawdown = AVST * 0.667

For subsequent periods, new well yields are computed using new average saturated thicknesses or the initial average saturated thicknesses of the ranges minus the water table decline. Thus, as depth to water increases, well yields decline proportionately.

Water availability also is affected by well reinvestment and abandonment. Wells in a given range are abandoned in the direct impact model if the average saturated thickness of that range is less than 25 feet. It is assumed that farm managers will continue to reinvest in wells until it is no longer feasible from a hydrologic standpoint to irrigate. This behavior, which is supported by casual observation and anecdotal evidence, may be attributed in part to mixed farming situations in which irrigated grains and silage are required as feed for livestock.

Under the baseline scenario, the water availability constraint is the primary constraint to irrigated production in the region. The policy constraints, which are based on district conservation goals outlined in Northwest Kansas Groundwater Management District No. 4's 1991 policy proposal, form the basis for two additional policy scenarios. Two important components of the district's proposal are the division of the district into related management areas according to the hydrology of each area and the establishment of maximum depletable reservoirs (MDRs) for each well or cluster of wells based on actual water table measurements.

Related management areas are accounted for in the direct impact model by the separation of each county into ranges based on saturated thickness, as outlined above. Maximum depletable reservoirs are included explicitly in the policy constraints; these represent the amount of water that can be withdrawn before regulation occurs and were devised by the Northwest Kansas Groundwater Management District No. 4 with two possible conservation goals to be achieved. Policy Goal I is the least aggressive conservation goal, setting the preservation of 58 percent of remaining water as its target, while Policy Goal II is to conserve 78 percent of remaining water. These goals are embodied in the calculation of maximum depletable reservoirs as follows:

(15) Policy Goal I: $MDR = ST^2 (0.004)$

(16) Policy Goal II: $MDR = ST^2 (0.002)$

Northwest Kansas Groundwater Management District No. 4 proposes that when 50 percent of a maximum depletable reservoir is pumped, withdrawals must be restricted by 50 percent. To constrain water availability according to the 50 percent maximum depletable reservoir criterion, maximum depletable reservoirs for both policy scenarios are calculated for 1994 based on the 1989 average saturated thicknesses of each range. If in a given period the cumulative water table decline for all preceding years is greater than a range's maximum depletable reservoir, the percent of wells in that range is restricted to 50 percent of the water available to that range, given the county's average gallons per minute and mean seasonal hours. Once a range reaches its maximum depletable reservoir, it will be constrained in all ensuing periods.

When 100 percent of the maximum depletable reservoir has been pumped, Northwest Kansas Groundwater Management District No. 4 proposes to limit withdrawals to safe yield, which is equivalent to annual recharge. To reflect the proposed policy, the 100 percent maximum depletable reservoir constraint restricts the amount of water available in the entire county to the acre-inches of water that unrestricted wells can pump plus the allowance of annual recharge for restricted wells. This results in virtually no pumping for restricted wells because annual recharge is negligible.

The managers of Northwest Kansas Groundwater Management District No. 4 recognize that their policy will create incentives that support water use efficiency. The economics of these incentives are captured in the direct impact model because the nature of linear programming is to allocate production based on the best use of scarce resources. As water is constrained, there are shifts between irrigation regimes of a given crop and shifts between crops based on their water requirements. Therefore, an implicit assumption of the model is that farm managers maximize water use efficiency.

After the total dollar value of irrigated and dryland crop production for each period is forecast by the direct impact model, the indirect impact model forecasts the indirect economic effects of diminishing groundwater supplies and restricted withdrawals on sectors linked to the irrigated and dryland crop sectors. When the total value of regional crop production changes, the economic ramifications of this change will be felt in sectors linked to the crop-producing sector. If irrigated crop production dwindles, industries supplying farm managers with inputs related to irrigated production will experience less demand for their products. Likewise, industries buying from the irrigated crop-producing sector will face shortages of inputs purchased locally, forcing them to purchase outside the region or to leave. These negative impacts will have a ripple effect throughout the regional economy as demand for its products diminishes.

To capture these multiplier effects, fixed price input-output (I/O) analysis is employed. A survey-based 1985 Kansas I/O model constructed by Emerson (1989) is compressed from 68 to 19 industry sectors, including ten sectors related to agriculture, for the current study. This compressed table is adjusted by two nonsurvey adjustment techniques to simulate the economic activity of the Northwest Kansas region: the simple location quotient method and the supply-demand pool technique. Direct and indirect impacts form the basis for deliberation of the economic efficacy of Northwest Kansas Groundwater Management District No. 4's current zero depletion policy proposal.

Results

The three components of the model described above—the water budget model, the direct impact model, and the indirect impact model—together produce a variety of empirical results representing forecasts of the hydrologic and economic conditions arising in the 50 year period between 1989 and 2039. Estimated withdrawals decline over the long run under all scenarios for the region as a whole, as presented in Table 2. Total regional withdrawals in 2039 under the baseline scenario are reduced slightly over one-half of initial 1989 withdrawals through the natural process of increasing water costs, well abandonment, and declining well yields. Imposing Policy I restrictions forces regional withdrawals to decline an additional 20 percent over baseline declines. Under the most restrictive conditions of Policy II, an additional 28 percent reduction occurs.

As total regional withdrawals decline, a saving of regional water in storage naturally occurs. Table 2 shows that by the end of the 50 year period, total regional water in storage declines approximately 22 million acre-feet under the baseline scenario, slightly over 16 million acre-feet under the Policy I scenario, and approximately 12 million acre-feet under the Policy II scenario. Thus, approximately one quarter of water that would have been used with no conservation policy for the region is retained by implementing Policy I, while approximately 44 percent of the water that would have been used without imposing a zero depletion policy is saved under Policy II conditions.

Figure 1 illustrates the long-run shrinkage in regional water in storage for all scenarios. Total water in storage declines in an almost linear fashion in the case where no artificial restrictions are imposed on withdrawals. As expected, the rate of decline in water in storage is slowed by both policy proposals. The absolute saving in water in storage ensuing from a zero depletion policy is not obvious until after 1999, when both the 50 percent and 100 percent maximum depletable reservoir restrictions take effect.

The initial forecasted five year average water table decline for the region (Table 2) is slightly above the rule-of-thumb average of one foot of decline per year for the region. Under the baseline scenario, this five year average decline is reduced after 50 years by over one half, while under the two policy scenarios it decreases over baseline reductions an additional 17.2 percent and 26.3 percent, respectively.

Estimated increases in water costs, which traditionally have been considered to play an important self-regulatory function in user behavior (Swanson and Heady, 1983), are relatively small. Fifty year percentage changes in water costs range from 2 percent for electric center pivot systems in Graham County under the Policy II scenario to 16.1 percent for natural gas and diesel-fueled flood systems in Sherman County under the baseline scenario, assuming relative energy prices remain constant. The range of water costs does reflect, however, the variety of hydrologic conditions within the region as illustrated by the county-level distribution of wells and by water availability within the model's six ranges of average saturated thickness (Table 3). For example, Graham County contained 120 wells in 1989, the fewest initial total number of wells in the region, and an average saturated thickness of 74 feet, the smallest in the region. On the opposite end of the spectrum, Sherman County contained 918 initial total wells and an average saturated thickness of 128 feet. Due to this wide variety, hydrologic impacts will not occur uniformly over time throughout the six county region.

Because hydrologic conditions vary greatly, there will be a variance in county-level direct economic impacts, which are affected additionally by the county's crop mix, the predominance of either center pivot or flood irrigation systems, the distribution of wells, and the average saturated thickness of each range. Table 4 shows that Graham and Sheridan counties are affected most by these conditions, with more than a 17 percent reduction in their total crop value by the end of the 50 year period. Although Sheridan has a greater number of wells and a higher average saturated thickness than Graham, Rawlins, and Cheyenne counties, impacts are felt sooner in Sheridan because its average saturated thicknesses are distributed in the four lowest ranges. Sheridan begins with more initial acres in soybeans and sorghum silage than other counties; these crops are the first to experience acreage reductions when groundwater is constrained.

Two counties with well distributions skewed to the upper ranges of average saturated thickness undergo relatively small economic impacts under baseline conditions. Sherman County, with 85 percent of its wells distributed in the upper two ranges, experiences a 6.8 percent decline in total crop value. Cheyenne County is the least affected of all counties under the baseline scenario, with a mere 3.1 percent reduction in total crop value at the end of the 50 year period; 68 percent of its wells are distributed in the upper three ranges of average saturated thickness. These results indicate that, as one would expect, the long-run economic impacts of unrestricted withdrawals may be most severe for areas with relatively less current water availability, while areas overlying more abundant water supplies remain relatively unaffected from an economic standpoint in the 50 year period. An exception to this is Rawlins County, with the greatest concentration of its wells in the third and fourth ranges, but with only a 5.1 percent decline in total crop value. At the end of the 50 year period, however, wells in the third range remain unaffected by declines in saturated thickness. The model shows that only 14 percent, or 22 wells, will be abandoned in Rawlins.

With the pumping restrictions imposed by Policy I, the decline in total value for all crops nearly doubles for most counties by 2039, with Graham as a notable exception. This county experiences an increase in production over that of the baseline case because after 2029 well abandonment is forestalled, allowing irrigators to continue pumping longer than would be the case with no zero depletion policy in place. Hence, the county with the least amount of water today may receive positive long-run economic benefits from curtailed pumping. For the remaining counties, the additional effects of implementing the more severe restrictions of Policy II are relatively minor, except in Cheyenne County, which undergoes an additional 5.9 percent decline in total crop value.

While counties with relatively small current water availability may benefit economically from restricted withdrawals, counties with more abundant groundwater supplies may receive greater hydrologic benefits from a zero depletion policy. The estimated ending saturated thicknesses for the baseline scenario are consistent with actual observations on rates of change in average saturated thicknesses. Sheridan, Thomas, and Sherman exhibit the greatest percentage change (with declines of more than 50 percent), while Graham, Cheyenne, and Rawlins' average saturated thicknesses decline 2 percent, 23 percent, and 28 percent, respectively. These data also show that a zero depletion policy may have a much greater effect on the preservation of saturated thickness in counties with the largest number of wells and which are the heaviest water users. Graham, with the fewest number of wells and the smallest average saturated thickness, preserves only an additional 1 percent of its saturated thickness under both policy scenarios, while Sheridan County saves as much as 27 percent more of its saturated thickness under the Policy II scenario than under baseline conditions. Sherman benefits the most by the additional restrictions of Policy II, saving 13 percent more of its average saturated thickness over Policy I savings.

In spite of the positive economic and hydrologic benefits received by individual counties, the region as a whole experiences negative long-run economic impacts under all scenarios, with reductions in irrigated production partially offset by increases in dryland production. Regional direct economic impacts for all scenarios are illustrated in Figure 2.[1] With no conservation policy enacted, the model indicates that total irrigated crop production will decline an estimated 7 percent in the next 25 years and an estimated 31 percent in 50 years. The increase in dryland production is less than 1 percent by 2014 and approximately 5 percent by the end of 50 years. This eventuates a baseline reduction in the value of all crop production of 10 percent by 2039.

With withdrawals curtailed by Policy I restrictions, the downturn in the total value of irrigated crop production and the subsequent shift to dryland production occur sooner and are greater in absolute terms; the policy doubles the negative impact on the total dollar value of irrigated production. The reduction occurring in 50 years in the baseline scenario occurs in just 25 years in the Policy I scenario. By 2014, the value of

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[1] Crop value has not been discounted and is presented in 1989 dollars. The time value of money thus has not been accounted for in the current research.

irrigated crop production declines 30 percent but is balanced by a 5 percent increase in dryland production (a result similar to the overall result of the baseline scenario). At the end of 50 years of pursuing policy I goals, additional dryland crop production is twice that of the baseline case, while final irrigated crop value remains at 64 percent of baseline final value. The final Policy I value of all regional crop production is only 8 percent less than that of the baseline scenario.

The Policy II scenario presents an additional acceleration of irrigated crop value decline, with a 25 year reduction nearly equal to the overall decline resulting from implementation of Policy I. Although by 2039 dryland crop value increases 2 percent over the Policy I value, the decline in irrigated production slows considerably after 2014. After 50 years the total value of all crop production is only 4 percent less than that of Policy I or 12 percent less than that of the baseline. This reflects a leveling of county withdrawals and production precipitated by the 100 percent maximum depletable reservoir constraint's effect on pumping.

Before results for the three scenarios are contrasted more fully, one must consider an additional source of economic loss to the region: indirect impacts on those economic activities connected to the irrigated agriculture sector. Indirect or multiplier effects have been assessed by the use of output multipliers derived by adjusting the 1985 Kansas Input-Output Table to reflect differences in technology and trade coefficients as well as differences in size of industry output and income in the regional economy.

Regional output multipliers for the relevant crop sectors are presented in Table 5. These multipliers, which have been derived by summing the values in the columns of the direct, indirect, and induced requirements matrix, represent the total output changes of all Northwest Kansas industries as a result of a $1 change in the relevant crop sector. This increment in output includes induced effects related to the additional household income and spending that ensues from a crop sector's increased output, as well as the indirect impacts from industry purchases within the region. These multipliers are relatively small because leakages in the local economy are great. Many industries in the area buy inputs from outside the region; imports to the region are large, which dampens internal multiplier effects.

Figure 3 indicates the total regional direct and indirect impacts on the value of regional crop production in 1989 dollars under the three scenarios. Under baseline conditions regional irrigated crop production remains fairly constant until 2004, after which it declines by an average of 1.3 percent per five year period. Whereas baseline total regional value remains highest in absolute terms and continues to decline over the long run at a fairly steady rate, total regional value under the Policy I scenario declines the greatest relative amount between 2009 and 2014, with the rate of decline slowing somewhat thereafter. In the last five year period, regional value declines a mere 0.3 percent. Finally, for the Policy II scenario, total regional value initially declines at a relatively rapid rate until 2014, when the effect of the 100 percent maximum depletable reservoir criterion becomes obvious. Although production continues to decline in ensuing years, the rate of this decline evens between 2014 and 2034, after which an additional downturn of 1.6 percent occurs in the final period.

Conclusion

Results of this study indicate that Ogallala groundwater withdrawals and related irrigated crop production will continue to decline, even in the absence of mandatory conservation efforts. The study focuses on a small Northwest Kansas region that includes areas with relative groundwater scarcity as well as those in which groundwater is relatively abundant. The region may be representative of the overall situation in the High Plains, where hydrologic conditions may ensure a steady decline in groundwater usage over the next 50 years.

The overall effect of the Northwest Kansas region's proposed zero depletion policy is to accelerate the process of declining withdrawals and irrigated production, with adverse direct economic impacts occurring sooner and more severely. Indirect impacts are relatively small because leakages in the local economy are great, dampening multiplier effects in sectors linked to irrigated agriculture. But although total direct and indirect impacts of Policy II implementation are only 4 percent less than those of Policy I, the long-run pattern of Policy II's economic impacts, which initially decline dramatically and then level, may support policy makers' theory that if pumping is restricted immediately, more water will be retained in the long run so that irrigators can continue to pump indefinitely at decelerated rates.

If this is true, then over an expanded planning horizon, economic benefits theoretically could outweigh the costs imposed by conservation. Unfortunately, the relatively short time frame of 50 years is not adequate to address this theory. Although zero depletion has occurred for some county ranges in the model, other ranges remain unrestricted, and pumping there continues beyond 2039. While the model can demonstrate more immediate outcomes of policy imposition, it would be necessary to know when regional zero depletion occurs for all scenarios in order to analyze whether any stability gained from active groundwater management would lead to greater long-run economic gains for the region.

Results produced on the county level indicate that over the 50 year period, positive economic benefits accrue to areas with relatively little current groundwater availability, while areas with relative groundwater abundance and rapid rates of current withdrawals receive positive hydrologic benefits. Actual variations in impacts on the subareas of the region will be more dispersed than this study indicates, for the results presented here are based on data provided on the county level rather than on the level of townships corresponding to each range of average saturated thickness. Because impacts on these ranges and the competing interests represented therein will present an additional complexity to the proposition of mandated withdrawal levels, further research efforts should be directed toward models that include more detailed hydrologic and economic data.

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Table 1—Irrigation Regimes

Regime	Gross Requirement (Acre-Inches) Flood	Center Pivot	Estimated Yield (Bushels per Acre)
Corn			
1) PP	11.12	8.50	50
2) PP+PT	20.85	15.94	93
3) PP+SK	20.66	15.80	107
4) PP+BL	20.45	15.19	96
5) 18+BL	19.95	15.26	118
6) PP+PT+BL	28.74	21.98	132
7) PP+PT+SK+BL	35.02	26.78	144
8) 18+PT+BL+DT	32.75	25.64	143
9) PP+18+PT+BL+DT	42.74	32.68	151
Grain Sorghum			
1) PP	10.21	7.74	106
2) PP+BT	18.46	14.12	117
3) PP+BL	18.34	14.02	115
4) PP+SD	18.22	13.93	114
5) PP+BT+BL	27.20	20.80	121
5) PP+BT+BL+SD	30.21	23.11	126
7) PP+BT+SD	27.09	20.71	127
8) PP+GD	18.48	14.13	128
9) PP+GD+BL	27.57	21.08	134
Wheat			
1) PP	13.60	10.40	55
2) PP+WI	17.06	13.05	53
3) PP+MI	17.91	13.64	55
4) PP+HD	19.45	14.87	49
5) PP+BT	20.83	15.93	60
5) PP+JT	21.43	16.39	60
7) PP+WI+HD	20.95	16.02	62

Crop Stages
PP=Preplant
BL=Blister (corn), One-Half Bloom (Grain Sorghum)
PT=Pretassel
18=18-Inch Plant Height
Sk=Silk
DT=Dent
SD=Soft Dough
BT=Boot
GD=Growing Point Differentiation
BL=One-Half Bloom
HD=Heading
WI=Winter
MI=Milk
JT=Jointing

Source: Orlan Buller and Jeffrey Williams, "Effects of Energy and Commodity Prices on Irrigation in the Kansas High Plains," Agricultural Experiment Station, Kansas State University, Report of Progress 611, Contribution No. 91-167-5, December 1990

Table 2—Forecast Total Regional Hydrologic Impacts

Year	Total Withdrawals (acre feet)	Percent Change From 1989	Total Water in Storage (acre feet)	Percent Change From 1989	Average Water Table Decline (feet)	Percent Change From 1989
1989						
Baseline	2,871,341		38,003,136		-5.70	
1999						
Baseline	2,785,447	-3.0	32,561,717	-14.3	-5.43	-4.8
Policy I	2,468,374	-14.0	32,612,313	-14.2	-4.69	-17.7
Policy II	1,958,031	-31.8	32,787,610	-13.7	-3.68	-35.4
2009						
Baseline	2,394,170	-16.6	27,366,547	-28.0	-4.65	-18.4
Policy I	1,883,075	-34.4	28,273,912	-25.6	-3.54	-37.9
Policy II	1,186,619	-58.7	29,549,496	-22.2	-2.26	-60.4
2019						
Baseline	2,158,948	-24.8	22,952,878	-39.6	-4.18	-26.7
Policy I	1,206,190	-58.0	25,279,024	-33.5	-2.29	-59.9
Policy II	750,738	-73.9	27,870,587	-26.7	-1.39	-75.6
2029						
Baseline	1,811,239	-36.9	19,096,113	-49.8	-3.29	-42.3
Policy I	933,433	-67.5	23,230,483	-38.9	-1.74	-69.4
Policy II	658,992	-77.0	26,683,594	-29.8	-1.19	-79.2
2039						
Baseline	1,369,328	-52.3	16,086,369	-57.7	-2.49	-56.3
Policy I	800,013	-72.1	21,741,679	-42.8	-1.51	-73.5
Policy II	561,182	-80.5	25,637,941	-32.5	-0.99	-82.6

Table 3—Well Distribution by County and Estimated 1989 Average Saturated Thickness by Range of Saturated Thickness

Range	Graham: Average Saturated Thickness (feet)	Graham: Wells	Graham: Percent of Total Wells	Rawlins: Average Saturated Thickness (feet)	Rawlins: Wells	Rawlins: Percent of Total Wells	Cheyenne: Average Saturated Thickness (feet)	Cheyenne: Wells	Cheyenne: Percent of Total Wells
RNG 1	26	28	23	30	6	4	29	77	18
RNG 2	43	7	6	53	16	10	44	30	7
RNG 3	76	43	36	79	55	35	73	34	8
RNG 4	94	20	17	101	61	39	93	90	21
RNG 5	120	22	18	131	19	12	128	116	27
RNG 6	0	0	0	0	0	0	154	86	20
County	74	120		89	156		99	430	

Range	Sheridan: Average Saturated Thickness (feet)	Sheridan: Wells	Sheridan: Percent of Total Wells	Thomas: Average Saturated Thickness (feet)	Thomas: Wells	Thomas: Percent of Total Wells	Sherman: Average Saturated Thickness (feet)	Sherman: Wells	Sherman: Percent of Total Wells
RNG 1	21	7	1	33	8	1	20	28	3
RNG 2	54	140	20	52	41	5	55	18	2
RNG 3	79	294	42	80	264	32	83	28	3
RNG 4	98	259	37	98	314	38	105	64	7
RNG 5	0	0	0	124	207	25	126	532	58
RNG 6	0	0	0	0	0	0	159	248	27
County	80	701		97	826		128	918	

Table 4—Hydrologic and Direct Economic Impacts by County

	County					
	Graham	Rawlins	Cheyenne	Sheridan	Thomas	Sherman
Beginning						
Total Wells	120	156	430	701	826	918'
AVST (Ft.)	73.50	89.25	99.03	80.45	96.77	127.55
Total Crop Value ($1989)	18,090,324	24,814,596	35,858,873	52,552,209	76,393,815	68,621,250
Baseline Ending						
Total Wells	85	134	323	554	513	844
AVST (Ft.)	72.28	64.01	75.35	34.72	45.65	64.08
Total Crop Value ($1989)	14,994,173	23,556,567	34,744,897	43,322,573	68,667,694	63,925,276
Percent Change in Value	-17.1	-5.1	-3.1	-17.6	-10.1	-6.8
Policy I Ending						
Total Wells	85	150	323	554	777	872
AVST (Ft.)	72.93	66.04	86.06	54.93	56.20	75.39
Total Crop Value ($1989)	16,285,009	22,324,406	32,730,911	38,311,821	61,717,495	57,439,479
Percent Change in Value	-10	-10	-8.7	-27.1	-19.2	-16.3
Policy II Ending						
Total Wells	92	150	323	694	777	872
AVST (Ft.)	72.44	70.89	92.35	56.57	67.09	91.54
Total Crop Value ($1989)	15,713,391	22,015,483	30,607,524	37,953,467	59,273,456	54,030,909
Percent Change in Value	-13.1	-11.3	-14.6	-27.8	-22.4	-21.3

*Weighted average of six county ranges of saturated thickness; ending averages exclude ranges with saturated thicknesses of less than 25 feet

Table 5—Regional Output Multipliers

Wheat	1.49
Corn	1.43
Sorghum	1.45
Alfalfa	1.46
Soybeans	1.35

Figure 1—Total Regional Water in Storage (Acre-Feet)

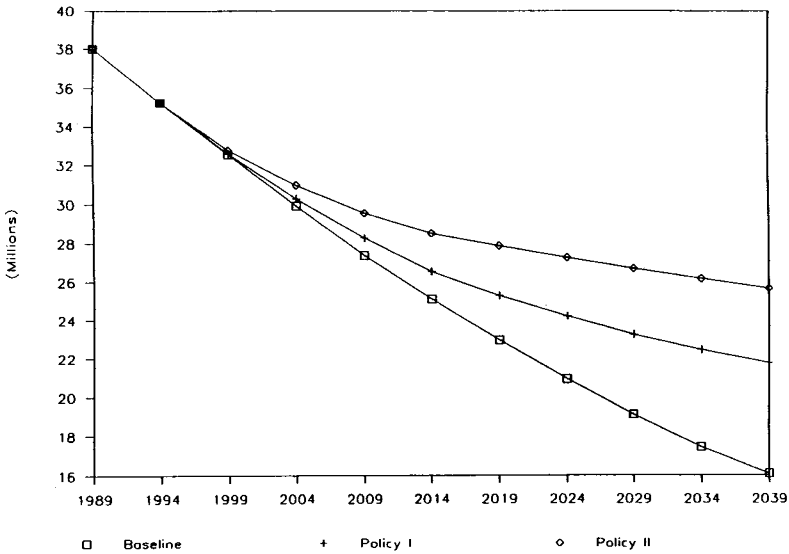

Figure 2—Direct Economic Impacts on Crop Value (Total Regional Value in 1989 Dollars)

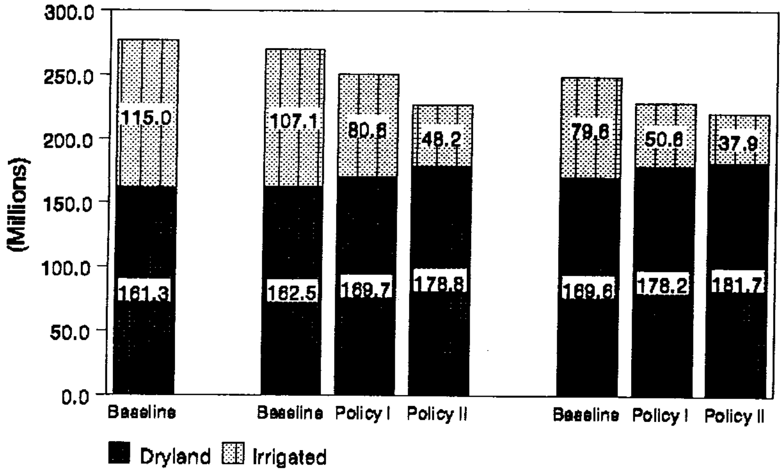

Figure 3—Direct and Indirect Impacts on Total Regional Crop Value