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Economic Impact of Zero Depletion and Acre-Inch Restrictions on Irrigated Crop Production and Income in Northwest Kansas

by Orlan Buller

Research Report #24

Department of Agricultural Economics

Kansas State University

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INTRODUCTION AND PROBLEM

Water level changes in the Ogallala Aquifer have been monitored since 1940 in selected irrigation wells in Western Kansas. As the number of irrigated acres increased with a corresponding increase in the number of irrigation wells, the decline in the water table and the concerns raised by the decline also increased. The decline has been well documented and generally understood by the community leaders in the area. Residents of the region overlying the Ogallala Aquifer are aware of the importance of irrigation to the economies of irrigators, towns, and communities. Next to the productive soils of the region, water is important for a viable and productive agriculture.

Continued decline of the aquifer places at risk the sustainability of the western Kansas economy. Thus, community leaders, managers of agribusinesses, and irrigators have discussed and proposed policies to reduce the decline of the aquifer, thereby prolonging the economic base for many farms and businesses in the region.

The region is classified as semi-arid, with much of it receiving 18 inches of rainfall or less per year, of which about 10 inches falls during the growing season. Normal rainfall is much below what corn needs for productive growing and grain production. These conditions have two effects: 1) irrigating 18 to 20 inches greatly enhances agricultural productivity, and 2) very little rainfall is available for natural recharge of the aquifer. For several decades, the water withdrawn from the aquifer greatly has exceeded natural recharge. The problem of depletion and the associated implications stimulated much discussion related to policies and/or incentive to prolong the economic life of the aquifer.

The objectives of this study were to analyze the economic impact of alternative water policies and options on irrigated agriculture in Northwest Kansas. Two options exist. Option 1 limits the depletion of the aquifer, the so-called zero depletion option; and option 2 considers four different per-acre-inch authorizations of the water rights.

WATER POLICY ALTERNATIVES AND INITIATIVES

In 1991, a discussion began on a proposal that, over time, would limit the pumping of water from the aquifer so as not to exceed the amount of natural recharge. The term 'zero depletion' was used to describe this policy. The proposal was to allow irrigators 10 years prior to an implementation of the plan to adjust the crop mix and irrigation regimes in anticipation of the impact of the forthcoming policy. The plan called for a calculation of the maximum amount that saturated thickness could decline before the restriction went into effect. Once the saturated thickness reached the maximum allowable depletion, the irrigator was restricted to pumping no more than natural recharge, thereby stabilizing and stopping the decline of the aquifer. This proposal resulted in a discussion of the impact of such a policy on irrigators, on agriculture in the region, and on the business and economic viability of communities in Northwest Kansas.

A water-resource depletion study committee was formed to evaluate the proposal and oversee an economic impact study. The committee included five officers and representatives of Ground Water Management District No. Four (GMD4) organization; three GMD4 staff; nine Kansas State University staff, including two county extension agents and four Northwest Research-Extension Center faculty; 10 local concerned citizens, including eight irrigator/dryland farmers and two dryland farmers; and two local elected officials. Committee members are listed in Appendix E.

Another policy alternative was to consider the effects of alternative per-acre-inch authorizations. Kansas water law authorizes 24 acre-inches per irrigated acre in western Kansas. The study committee asked for a "what if" approach considering authorizations of 18, 15, and 12 acre-inches compared to 24 acre-inches.

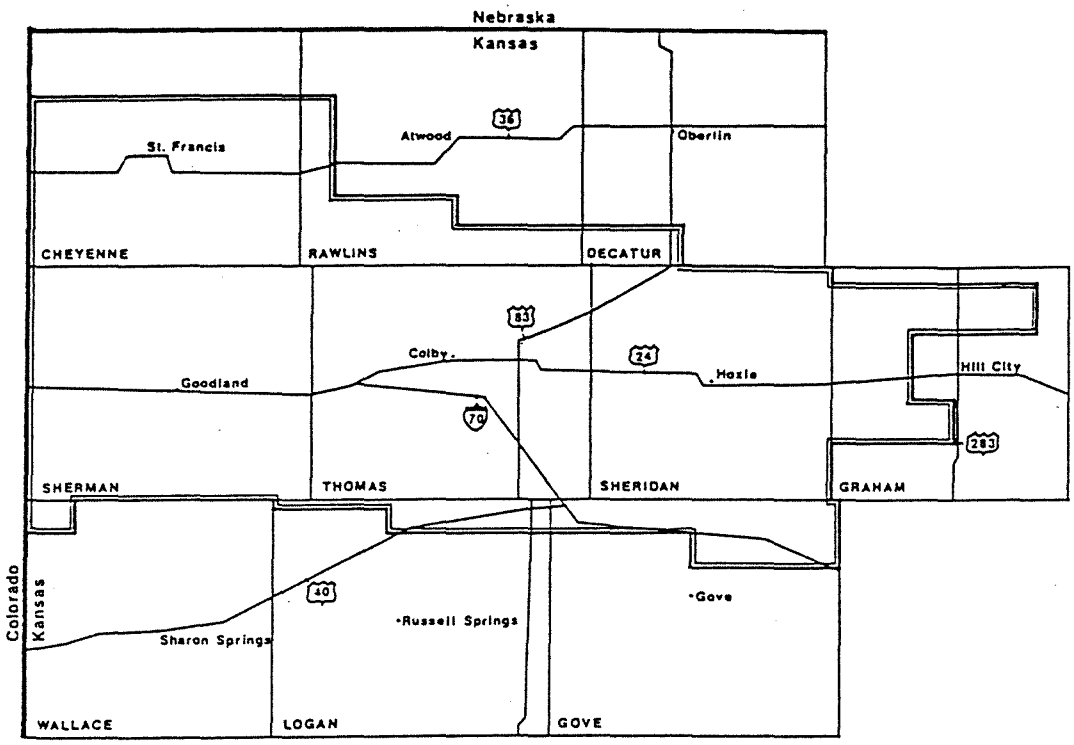
TIME FRAME

The overdraft of the Ogallala Aquifer in Northwest Kansas has created a gradual shift from irrigated to nonirrigated agriculture. Parts of this region have been in a transition back to nonirrigated agriculture for over a decade. The issue is not if agriculture will revert back to rainfed agriculture, but how soon will it happen. To study the possible decline of the aquifer and its impact on agriculture and the region, a 40-year time frame was selected, because the historical database of some of the important variables began in the late 1950's or early 1960's. Determining changes that have occurred regarding the crop mix, irrigation development, and water use provides a valuable base from which to project possible future conditions. This study began with 1991 as the base year from which projections were made.

The 40-year time frame was studied using a model to estimate conditions for 1991, 1996, 2001, 2006, 2011, 2021 and 2031. These 7 years were selected to simplify the study and also to allow reliable estimates of trends. Estimates for saturated thickness, pumping costs, depth to water, crop prices and yields, crop production expenses, available farm operator labor, number and age of wells by irrigation system, and number and type of irrigation system with associated efficiency were estimated for each of the beginning years of each period. The procedure was to use the results of 1991 as the estimated results for 1992, 1993, 1994, and 1995. The model parameters for the variables previously specified were updated to represent 1996 conditions. The model results for 1996 were used as estimates for 1997, 1998, 1999, and 2000. The same process was followed for the remainder of the study period.

Pumping costs were estimated using a variable pumping cost computer program. This model considered the water lift, well yield, acres irrigated, and the type of energy used to power the system in estimating pumping cost. Other sources of data used in this study are cited in the list of references.

Figure 1.



NORTHWEST KANSAS GMD #4
District Boundary

Table 1. Saturated Thickness and Irrigation Well Yield by Group in GMD4 in Northwest Kansas

Group	Range in Sat. Thk.	Average Sat Thk.	Range in GPM	Average GPM	Number of Points of Diver
1A	- 50 ft.	35	0 - 450	287	266
1B	- 50 ft.	39	451 - 1500	636	164
2A	1 - 75 ft.	67	0 - 550	390	304
2B	1 - 75 ft.	66	551 - 1480	679	240
3A	76 - 100 ft.	88	0 - 585	421	396
3B	76 - 100 ft.	88	586 - 1700	742	374
4A	101 - 125 ft.	112	0 - 595	415	448
4B	101 - 125 ft.	113	596 - 2200	776	492
5A	over 125 ft.	147	0 - 604	459	394
5B	over 125 ft.	150	605 - 2900	826	398

Source: Division of Water Resources, 1991, Topeka, KS.

Table 2. Total Acres Irrigated by Crop and Irrigation System by Group in GMD4, Northwest Kansas.

	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	TOTAL
Total Acres Irrigated	13423	19659	21982	28552	34381	49140	39913	62124	36944	51810	357928
Acres Irrigated by Crop											
Corn	4602	8094	8687	12242	16306	22930	16155	24893	9249	16438	139596
Grain Sorghum	1057	994	2356	947	1594	2572	3361	3502	3995	3122	23500
Wheat	717	285	864	1371	2190	1356	2137	1578	2988	2258	15744
Afalfa	456	637	111	524	463	372	481	1369	1274	544	6231
Soybeans	175	88	867	640	984	330	1220	475	520	305	5604
Other	855	190	668	546	1607	1144	1904	1654	2530	1010	12108
Double Crop	497	227	183	802	618	1482	1435	1480	1041	1521	9287
One Crop	4995	9081	8181	11320	10508	18954	13219	27023	15347	26563	145191
Crop Not Identified	69	63	65	160	111	0	0	150	0	49	667
Acres Irrigated by System											
Flood	4793	6160	4892	6834	6999	17610	8998	26598	6889	21478	111251
Sprinkler	7644	13160	17935	20259	27116	30775	31596	33260	29836	28887	240468
Hi Efficiency	848	396	290	608	929	345	687	695	918	710	6426

Source: Division of Water Resources, 1991, Topeka, KS.

STUDY AREA

The area affected by the proposed policy by the GMD4 Board of Directors includes all or parts of 10 counties in Northwest Kansas. (Fig. 1.). The GMD4 region contains 72 percent of the 1991 reported irrigated acres in the 12 county region in Northwest Kansas. This district reported nearly 359,000 irrigated acres in 1991.

STUDY GROUPS

The objective of this study was to estimate the effect of alternative water policies on irrigated agriculture in Northwest Kansas, principally in GMD4. The study committee discussions indicated much variability in well yield capacity, saturated thickness of the aquifer, and depth to water throughout GMD4. To provide reasonably reliable estimates, the irrigators in GMD4 were grouped into somewhat homogenous groups. The criteria for grouping irrigators was based on how each group would be affected by alternative water policies and how they would respond with regard to their crop mix and water use. After consulting with the water study advisory committee, we determined that well yield, as measured by pumping rate in gallons per minute (GPM), was the most important variable affecting crop selection, acres irrigated, and water use. Another hydrologic characteristic, the aquifer saturated thickness, was also important because it influenced GPM and also how long irrigation could continue. The zero depletion policy was based on the decline of the aquifer (the saturated thickness), and so this hydrologic characteristic had to be part of the group-selection criteria.

Well yield is influenced by several geohydrologic characteristics, two of which are saturated thickness and aquifer porosity. The porosity represents how much water can be stored in the saturated material, but the quantity of water that the material will give up is the specific yield of the aquifer. The specific yield and permeability of the aquifer influence how rapidly water will move through the aquifer into the well. Thus, well yield or pumping rate in GPM is influenced by the permeability of the water-bearing material, the saturated thickness of the aquifer before pumping, and depth of water in the well while pumping. Review of data showed great variation in well yield for the same amount of saturated thickness.

All irrigators reporting water use in 1991 to the Division of Water Resources (DWR) provided data for the study. The grouping of irrigators was done first by reported saturated thickness on 5-50 ft., 51-75 ft., 76-100 ft., 101-125 ft., and over 125 foot. Each saturated thickness group next was divided by GPM. Thus, each saturated thickness group had some low- and high-yielding wells. The result was that all irrigators in GMD4 were placed in one of 10 groups; 1A, 1B, 2A, 2B, 3A, 3B, 4A, 4B, 5A, and 5B. (Table 1).

Some irrigators in the group with lowest saturated thickness had well GPM nearly as large as those in the middle saturated-thickness group. Some irrigators in the higher saturated-thickness groups had well GPM as low as those in the lower saturated-thickness group. Well GPM is important because it determines the well's ability to deliver large amounts of water to crops during the plant's critical physiological stages. The saturated thickness influences how long the irrigator will be able to pump water. Group 5A, Table 1, has an average GPM of 177 units less than the average for group 1B. Thus, irrigators in group 5A are not able to irrigate more acres per well than group 1B, but they will be able to irrigate for many years more. Apparently, in the Ogallala Aquifer of Northwest Kansas, the permeability varies greatly among wells in the same region. Thus, it will be difficult to have one water policy that treats all irrigators fairly and equitably.

Crop acreages were different in 1991for the 10 groups, as was the relative emphasis by crop. The B groups, which had the higher GPM within each class, had the larger absolute and larger relative acreages in irrigated corn (Table 2). This was expected, because the need to supply the necessary water during the relatively short silking and tassel stages can be met best with higher GPM wells.

Data reported to DWR and shown in Table 2 indicated more irrigated acreage for double crop (includes the category of more than one crop) than for any specifically identified crop. This presented a problem in the development of the models. We wanted the crop acreage allowed in the models to conform as much as possible to federal government farm program provisions. The problem is that the largest acreage category did not specify which crops were grown, thereby making the specific crop estimates impossible. More corn, grain sorghum, and wheat probably were grown and irrigated in GMD4 than reported in Table 2, but how much more is not known. Therefore, the double crop acreage was distributed to corn, grain sorghum, and wheat by the same percentage as reported for these crops. Specifically, 78% of double crop acreage was allocated to corn, 13% of double crop acreage was allocated to grain sorghum, and 9% of double crop acreage was allocated to wheat.

MODEL

The model was used to determine the farm-level use of water, land, and labor that provided the highest net returns. A separate model was constructed for each of the 10 groups. The differences among the models of the groups were in the number of available acres, both irrigated and nonirrigated, the number of wells, age of wells, well yields, pumping costs, the number and type of irrigation systems and operator labor available, and the saturated thickness and GPM.

Each model had 15 different irrigation regimes for corn with each repeated for flood, center pivot, and high efficiency irrigation systems. Each model had 15 different irrigations regime for grain sorghum with each repeated for flood, center pivot, and high efficiency irrigation systems. Each model had 14 different irrigation regimes for wheat with each repeated for flood, center pivot, and high efficiency irrigation systems. Each model included irrigation regimes for corn silage, soybeans, grain sorghum silage, and sunflowers. Each model included eight irrigation regimes for alfalfa with each repeated for flood, center pivot, and high efficiency irrigation systems.

Irrigation regimes varied by the amount of water applied and the time of application. Regimes were selected based on those frequently used or recommended to irrigators.

The Model SMODET [18] was used to estimate daily water (ET) use by each crop. Crop yields were estimated from the accumulated ET deficit during each of the plant stages.

The irrigation season was divided into 10 periods. Each period had at least one unique crop stage for one of the irrigated crops.

Period 1: until May 20;
Preseason irrigation of corn and grain sorghum, irrigate during wheat flowering stage, and irrigate alfalfa before first cut.

Period 2: from May 20 until June 5;
Irrigate corn during vegetative stage, preseason irrigation of grain sorghum, irrigate wheat during flowering stage, and irrigate alfalfa prior to first cut.

Period 3: from June 5 until July 5;
Irrigate corn in vegetative stage, irrigated grain sorghum in vegetative stage, irrigate wheat in yield formation stage, and irrigate alfalfa prior to second cutting.

Period 4: from July 5 to July 25;
Irrigate corn in vegetative stage, irrigate grain sorghum in vegetative stage, no irrigation of wheat, and irrigate alfalfa prior to second cutting.

Period 5: form July 25 to August 5;
Irrigate corn during flowering stage, irrigate grain sorghum during vegetative stage, preseason irrigation of wheat, and irrigate alfalfa prior to third cutting.

Period 6: from August 5 to August 10;
Irrigate corn during flowering stage, irrigate grain sorghum during flowering stage, preseason irrigation of wheat, and irrigate alfalfa prior to third cutting.

Period 7: from August 10 to August 20;
Irrigate corn during yield formation stage, irrigate grain sorghum during flowering stage, preseason irrigation of wheat, and irrigate alfalfa prior to third cutting.

Period 8: beginning on August 20 to September 5;
Irrigate corn during yield formation stage, irrigate grain sorghum during flowering stage, preseason irrigation of wheat, and irrigate alfalfa prior to fourth cutting.

Period 9: beginning on September 5 to September 15;
Irrigate corn during yield formation stage, irrigate grain sorghum during yield formation stage, preseason irrigation of wheat, and irrigate alfalfa prior to fourth cutting.

Period 10: beginning on September 15 to October 15;
Irrigate corn at mature stage, irrigate grain sorghum during yield formation stage, irrigate wheat during vegetative stage, and irrigate alfalfa after fourth cutting.

Irrigated corn, grain sorghum, and wheat regimes each had five equations that specified the amount of water needed during the preseason, vegetative, flowering, yield formation, and mature stage of crop development. Using the computer Model SMODET, the day irrigation begins and the amount applied were specified as appropriate for each regime. Thus, each regime had a unique amount of water applied during some or all of the stages. SMODET also estimated ET for each day of the growing season, and so daily ET was aggregated into that amount during each stage. From these ET amounts, crop yield for each regime was estimated.

To determine the supply of water available, well GPM and hours of pumping time available during each period were used. The number of hours during each of the 10 periods determined the number of hours of pumping time. The well GPM determined the amount of water that can be pumped during each period. Thus, the supply of water during any stage of any crop must be greater than or equal to the demand for each stage of crop development. The number of acres specified for each crop regime multiplied by the water required by regime selected determined the total water requirement. The model selected the most profitable regime based on the most profitable yield, considering the limitation of water that can be pumped and the cost of pumping the water.

The hourly cost of pumping water was different for each of the 10 models, because the GPM and depth to water were different.

The models tended to fully irrigate corn but reduce acreage as water availability declines; the opposite relationship was used for wheat and grain sorghum.

The computer Model SMODET estimated ET and soil water drainage for each day. The relationship between ET and crop yield was linear, but including soil water drainage established a nonlinear relationship between crop yield and water pumped. [19]

Crop yields for each crop by irrigation regime and total water availability are provided in Appendix F.

Commodity real prices over time in the models declined 1 percent per year, the same as in the last 10 years. Results are reported in real money values (price inflation removed) and not nominal terms.

Crop yields from 1991 through 2031 increased at one-half the rate of yields for the 40 years prior to 1991.

Numbers of farms and farm operators were set to decline 1 percent per year beginning in 1991.

Irrigated acreage for the 10 groups was not allowed to exceed the 1991 authorized amount of 358,674 acres.

Number of wells was not allowed to exceed the number authorized in 1991.

Recharges were assumed to be 1 acre-inch per acre per year on irrigated acres and .5 acre-inch per acre per year on nonirrigated acres.

GPM in a specified year was calculated with the equation:
$GPM_t = (SAT.TAK_t/SAT.THK_{t-1})^{2}*GPM_{t-1}$ where GPM_t is the new GPM, GPM_{t-1} is the GPM of the previous year, $SAT.THK_t$ is new saturated thickness, and $SAT.THK_{t-1}$ is the saturated thickness of the previous year. Saturated thickness in 1991 was taken from the Division of Water Resources data tape [2]. Saturated thickness after 1991 was estimated based on estimated water use.

The models calculated the most profitable crop acreage, crop mix, irrigation regime, the amount of water to pump, water use, and the type of irrigation system.

Coefficients that changed over time and among groups were the per-hour pumping cost (which was influenced by GPM and lift), saturated thickness, GPM, number of farm operators, number and age of wells, and number and age of irrigation systems.

Irrigation system efficiencies were assumed to be 65 percent for gravity flow, 80 percent for traditional center pivots, and 95 percent for high efficiency sprinklers.

Well life was assumed to be 45 years, sprinkler system life 30 years, and engine life 15 years.

Major livestock enterprises were not allowed to exceed 1991 numbers.

Irrigated wheat acreage was not allowed to exceed 10 percent of the total wheat acreage.

Irrigated grain sorghum acreage was not allowed to exceed 20 percent of total grain sorghum acreage.

The study advising committee discussed the structure of the model during several meetings. One of the topics was how to handle the government programs. Because the study covered a period of 40 years beginning in 1991, the decision was made to not model a specific program except not to exceed the wheat, corn, and grain sorghum base acreages. Thus, the baseline and the zero depletion policy options placed a maximum acreage on corn, grain sorghum, and wheat. Acreage was allowed to change between irrigated and dryland within a crop, but not between crops. Two other scenarios allowed more flexibility. The baseline plus flexible option (B+F) and the baseline plus flexible plus high crop yield trend (B+T+F) option increased the upper constraints on corn, grain sorghum, and wheat to allow an increase of 1 percent each year.

Total wheat, corn, and grain sorghum acreages were not allowed to exceed that of 1991 acreage. These acreages represented the government program base for each and were not allowed to increase. Because future prices were based on the previous 10 years, government programs and base acreage representing the same period were used. Prices and production are interdependent and so should be based on a consistent relationship.

Gravity flow systems on irrigated fields of less than 80 acres were not allowed to change to a sprinkler system.

The zero depletion option was based on the idea of a maximum depletable reservoir (MDR). An MDR is the amount by which the saturated thickness of a well or aquifer can be reduced. The formula is:

$$MDR = St^{2} * .002$$, where St is saturated thickness at the base year.

Over the 40-year study period, whenever saturated thickness declined to 20 feet, irrigation was stopped except for use of recharge.

Values for the MDR for each group are provided in Appendix D.

The model in matrix format and description are provided in Appendix A.

The frequencies of reported test dates for wells in GMD4 by group and by system are shown in Appendix B.

RESULTS

ZERO DEPLETION OPTION

The basic assumptions of the baseline and zero depletion situations have been discussed. The same choices were available in both stiuations. The difference was only in the management and implementation of the zero depletion water option, which was based on the draw-down of the aquifer. The specifics of the zero depletion option are reported in Table D.1 in Appendix D.

Net Returns

Net returns by option included net returns from crops and livestock. The crop and livestock enterprises competed for irrigated land to produce grain either for the cash market or for use as feed for livestock or to produce irrigated forages. Figure 2 shows the income relationship over time, and Table 3 shows accumulated return estimates for a 40-year total. The model was used to estimate returns for 1991, 1996, 2001, 2006, 2011, 2021, and 2031. Return estimates for the in-between years were made by interpolating between end points.

Figure 2.

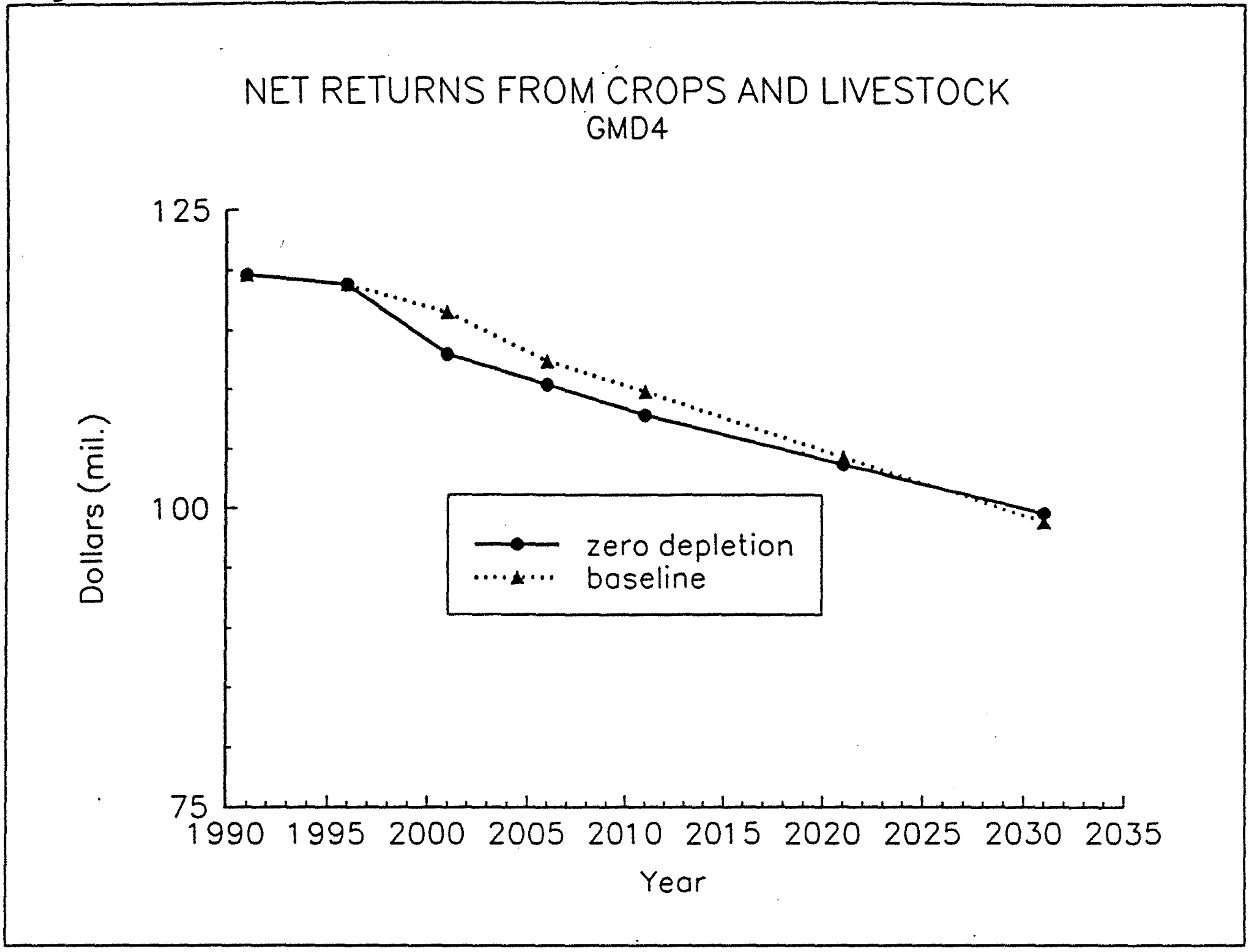


Table 3. Total Returns from Crops & Livestock in GMD4 by Option by Year

Year	Baseline	Zero Depletion	Year	Baseline	Zero Depletion
	(Mil. $)			(Mil. $)	
1991	119.614	119.614	2012	109.252	107.399
1992	119.444	119.444	2013	108.701	106.985
1993	119.274	119.274	2014	108.149	106.571
1994	119.103	119.103	2015	107.598	106.157
1995	118.933	118.933	2016	107.047	105.744
1996	118.763	118.763	2017	106.496	105.330
1997	118.303	117.596	2018	105.945	104.916
1998	117.843	116.429	2019	105.393	104.502
1999	117.383	115.263	2020	104.842	104.088
2000	116.923	114.096	2021	104.291	103.674
2001	116.463	112.929	2022	103.754	103.268
2002	115.642	111.977	2023	103.216	102.862
2003	114.820	111.026	2024	102.679	102.456
2004	113.999	110.074	2025	102.142	102.050
2005	113.177	109.123	2026	101.605	101.645
2006	112.356	108.171	2027	101.067	101.239
2007	111.845	108.099	2028	100.530	100.833
2008	111.335	108.028	2029	99.993	100.427
2009	110.824	107.956	2030	99.455	100.021
2010	110.314	107.885	2031	98.918	99.615
2011	109.803	107.813	**Total**	4507.234	4451.377

The option of maintaining a reservoir by limiting the depletion reduces total returns and the pattern over time (Figure 2). The zero depletion option reduces the estimated net returns of irrigators by $55.9 million over the 1991 to 2031 period (Table 3). This reduction is 1.3 percent from the baseline value.

Figure 2 shows that the effect of the zero depletion option is to reduce net income, compared to baseline immediately after the policy goes into effect in 2001, but then stabilizes after year 2011. Both scenarios show a steady decline after 2001, but the decline is a lesser rate for the zero depletion option.

The long-term impact is that after about 30 years, the annual net returns are nearly the same for both situations, and thereafter the baseline net returns are less than those with zero depletion. From 2001 through 2021, the aquifer is diminished more rapidly under baseline and continues to decline at the end of the study period. The full impact of water policy on the aquifer is realized only in the long term. A 40-year time frame, as used in this study, does not measure the full impact of a zero depletion option, but it does show the trends in land and water use and net returns.

Even after 40 years, many wells in GMD4 would not be affected by a policy such as zero depletion. In groups 5A and 5B, the aquifer had declined only 25 percent from the 1991 estimated level. In all other groups, the saturated thickness had declined to a level that implemented the zero depletion policy. Groups 1A, 1B, 2A, and 2B had depleted their allowable reservoir by 2000; 3A and 3B depleted their reservoir by 2005; and 4A and 4B depleted their reservoir by 2021. Establishing a maximum depletable reservoir that perserves a specified percent of the aquifer means that wells on lesser saturated thickness likely will be affected first. Irrigators in 5A and 5B probably would not come under the maximum depletable reservoir limit until 2041 or later.

Net returns reported in Table 3 and shown in Figure 2 are combinations of net returns from crops and livestock. In the model, numbers of livestock were not allowed to exceed the 1991 numbers throughout the 1991-2030 period. Although livetstock numbers could have declined, they remained at the 1991 limit throughout the study period. With livestock numbers remaining stable, livestock net income remained relatively stable throughout. Thus, the decline in net returns shown in Figure 3 is mostly from a decline in net returns from irrigated crops. The increase in nonirrigated crops with its associated increase in net returns is helping to offset some of the decline in net income from irrigated crops because of decreased pumping.

Irrigated Acres

Irrigated acres for the baseline scenario holds steady until 2001 and then begins a steady decline. (Figure 3). Irrigated acreage in 2031 is 63 percent of the 1991 level for the baseline scenario (Table 4). This decline is the result of numerous factors, such as a declining water table causing irrigation costs to rise, GPM declines, and wells depreciated out and not being replaced.

Figure 3.

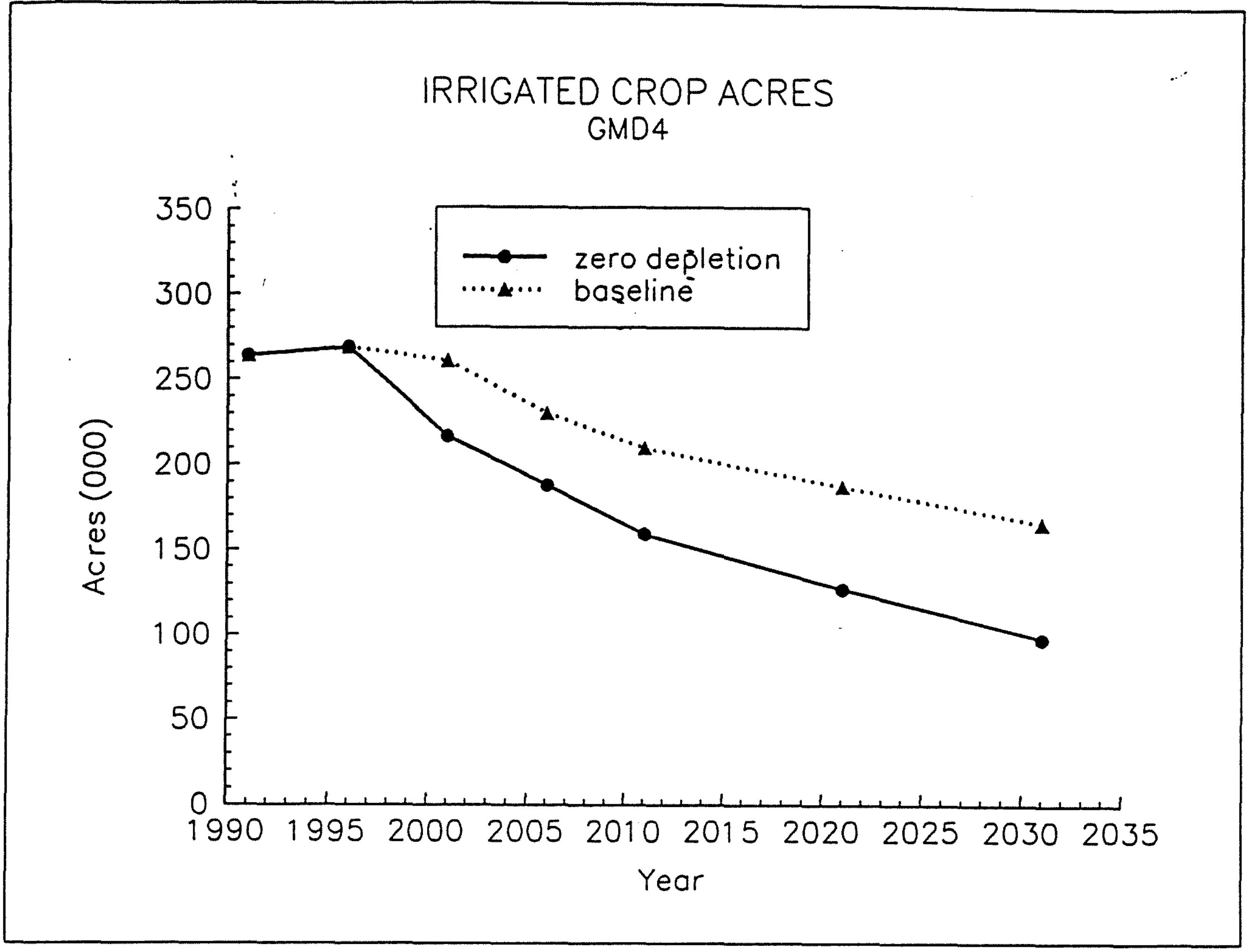


Table 4. Total Acres of Irrigated Crops in GMD4 by Option by Year in Thousands					
Year	Baseline	Zero Depletion	Year	Baseline	Zero Depletion
	(000)			(000)	
1991	264.067	264.067	2012	207.087	155.569
1992	264.958	264.958	2013	204.847	152.356
1993	265.849	265.849	2014	202.607	149.143
1994	266.739	266.739	2015	200.367	145.930
1995	267.630	267.630	2016	198.126	142.717
1996	268.521	268.521	2017	195.886	139.504
1997	266.998	258.054	2018	193.646	136.291
1998	265.475	247.586	2019	191.406	133.078
1999	263.952	237.119	2020	189.166	129.865
2000	262.429	226.651	2021	186.926	126.652
2001	260.906	216.184	2022	184.806	123.764
2002	254.722	210.444	2023	182.686	120.876
2003	248.538	204.704	2024	180.565	117.988
2004	242.354	198.963	2025	178.445	115.100
2005	236.170	193.223	2026	176.325	112.213
2006	229.986	187.483	2027	174.205	109.325
2007	225.854	181.743	2028	172.085	106.437
2008	221.722	176.003	2029	169.964	103.549
2009	217.591	170.262	2030	167.844	100.661
2010	213.459	164.522	2031	165.724	97.773
2011	209.327	158.782	Total	8939.961	7024.853

For the zero depletion scenario, irrigated acreage declines sharply as soon as the policy is implemented. Under provisions of the policy, irrigators would not be affected for 10 years after the starting date of 1991. By the end of the 10-year moratorium in 2001, groups 1A, 1B, and 2A had reached or exceeded the allowed aquifer decline. Unlike the baseline, irrigated acreage declines sharply after 2001. This pattern for zero depletion shows that the limit on water pumped is very effective on groups 1 through 3 by 2006. After 2006, groups 4A and 4B begin to be affected, but groups 5A and 5B are unaffected through 2031. Eventually, the irrigated acreage will converge for both scenarios. Economic factors plus the decline of the aquifer are causing the decline in irrigated acreage for the baseline, but regulatory policy is causing the decline for the zero depletion scenario.

Irrigated acreages in 2031 are 37 percent of that in 1991 for zero depletion and 59 percent of that in 1991 for baseline (Table 4). Over the 40-year period, irrigated acreage for zero depletion is estimated as 79 percent of that for baseline.

Irrigated acres for baseline decline because the supply of water has diminished and the pumping costs have increased. For the zero depletion option, the decline after 2011 is less than that prior to 2011. The more rapid decline prior to 2011 for zero depletion is caused by groups 1A through 3B having used their depletion limits; by 2020 groups 4A and 4B also have reached their limits.

As irrigated acreage declines, nonirrigated acreage increases. A 1-acre decrease in irrigated crop acreage does not necessarily lead to a 1 acre increase in nonirrigated crop, because some of the converted land shifts to fallow. Nevertheless, land that shifts from irrigated to nonirrigated crops does have a net reduction in income.

Water Pumped

Water pumped for the baseline scenario shows a small increase by 1996 but declines thereafter (Figure 4). After 2001, the rate of decline increases for baseline, as fewer acres are irrigated and the less water-efficient flood irrigation systems are not replaced as they depreciate. The amount of water pumped under baseline is 45 percent less in 2031 than in 1991. Increased pumping costs and lower well GPM that cause a change in crop mix and the less efficient systems not being replaced have all contributed to this reduction.

Under a zero depletion policy, groups 1A, 1B, 2A, and 2B almost immediately would reach their depletion limit, causing pumping to be restricted to a recharge amount. After 2001, the sharp decline moderates but continues throughout the remainder of the period, as groups 3A and 3B reach their limits in 2011 and groups 4A and 4B reach theirs by 2021. The decline continues thereafter, mostly because of the higher cost of pumping for groups 5A and 5B. The amount pumped for zero depletion is 71% less in 2031 than in 1991.

The amount pumped in 2031 is 36 percent less for zero depletion than for baseline. For the 40-year period, 24 percent less water is pumped under the zero depletion option than for the baseline. The effect of the zero depletion policy would be to reduce water pumping relatively more than the reduction in net returns. Total net returns were reduced less than 2 percent by the

Figure 4.

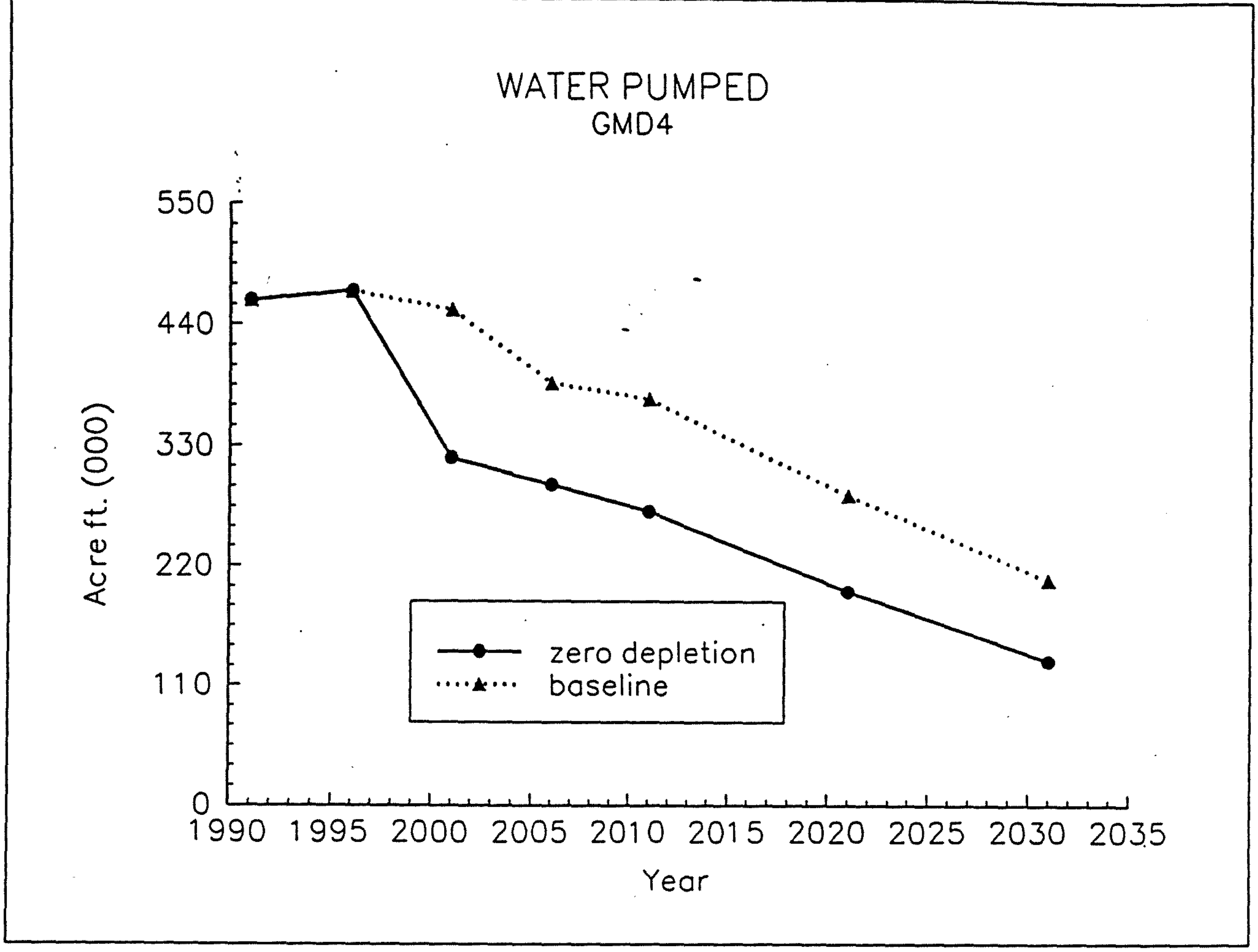


Table 5. Total Acre Feet of Water Pumped in GMD4 by Option by Year in Thousands					
Year	Baseline	Zero Depletion	Year	Baseline	Zero Depletion
	(000)			(000)	
1991	462.058	462.058	2012	364.027	262.690
1992	463.720	463.720	2013	355.239	255.308
1993	465.382	465.382	2014	346.451	247.925
1994	467.045	467.045	2015	337.663	240.542
1995	468.707	468.707	2016	328.875	233.160
1996	470.369	470.369	2017	320.087	225.777
1997	466.961	439.993	2018	311.299	218.394
1998	463.553	409.618	2019	302.511	211.011
1999	460.146	379.242	2020	293.723	203.629
2000	456.738	348.867	2021	284.935	196.246
2001	453.330	318.491	2022	277.183	189.872
2002	440.080	313.649	2023	269.430	183.499
2003	426.831	308.807	2024	261.678	177.125
2004	413.581	303.966	2025	253.925	170.752
2005	400.332	299.124	2026	246.173	164.378
2006	387.082	294.282	2027	238.420	158.004
2007	384.229	289.440	2028	230.668	151.631
2008	381.375	284.598	2029	222.915	145.257
2009	378.522	279.757	2030	215.163	138.884
2010	375.668	274.915	2031	207.410	132.510
2011	372.815	270.073	**Total**	14726.297	11249.512

zero depletion policy. The result that net returns are not reduced proportionately with reduced pumping shows the effect of shifting to nonirrigated crops and to less intensive use of water.

Summary

A zero depletion-type policy that limits the amount pumped when the aquifer drawdown reaches a specified target level changes irrigated agriculture in GMD4. Soon after the implementation of such a policy, the net returns, acres irrigated, and water pumping diverge between the zero depletion and baseline scenarios. But after 40 years, the net returns, crop acreage and mix, and water pumpage converge. The difference is that with the zero depletion-type policy, more water remains in the aquifer.

Net returns for the zero depletion option in 2031 were 83 percent of 1991.

Total returns over the study period for zero depletion were 99 percent of total baseline returns. Stable net returns from livestock and increased net returns from nonirrigated crops offset the impact of reduced irrigation.

Zero depletion policy begins limiting water pumped immediately after the initial 10-year moratorium for groups 1A, 1B, and 2A.

By 2005, groups except 3A and 3B reach their MDR limit and would be restricted to pumping no more than recharge thereafter.

After 40 years, irrigated acres are 37 percent of those in 1991, for zero depletion and 59 percent of those in 1991 for baseline. Total irrigated acreage for the 40-year period for zero depletion is 80 percent of that for baseline.

By 2021, groups 4A and 4B reached their MDR limits and would be restricted to pumping no more than recharge.

Groups 5A and 5B likely would not reach their MDR limits until 2041.

The zero depletion option would effectively reduce the amount of water pumped in GMD4. The impact of the zero depletion policy varies with saturated thickness and would not be the same for all irrigators. It almost immediately would reduce water pumped in areas of less than 50 feet of saturated thickness. Irrigators with 125 feet or more of saturated thickness could continue irrigation practices not affected by zero depletion for about 50 years..

Although zero depletion policy greatly reduces water pumped and acres irrigated, it has much less effect on net income. Income from livestock would not be affected greatly, and the net income from nonirrigated crops would increase because of the shift of land from irrigated to nonirrigated agriculture. For irrigators whose well yield is low, the per acre net income for irrigated crops is not much higher than that for nonirrigated wheat or grain sorghum.

Water use changes were similar to crop acreage changes. By the end of the study period, the zero depletion option had pumped 22 percent less water than baseline and pumped 71 percent less in 2031 than in 1991.

LIMIT ON WATER ALLOCATION OPTION

Another policy scenario, suggested by the Irrigation Policy Advisory Committee, was to evaluate the effect of water authorizations of 18, 15, and 12 acre-inches per acre in place of 24 acre-inches authorized by their water right. The authorized acreage remained unchanged. This section evaluates the impact of such options. The model for each option limited the total water available for pumping but did not specify an amount to be pumped. Thus, the essential difference between zero depletion and water authorization policies is that zero depletion limits the amount of water that can be pumped, whereas limiting the authorized amount limits the amount available but not necessarily pumped.

In the following text, the 24 acre-inch authorization also is referred to as baseline.

Net Returns

Net returns from crops and livestock for baseline declines slowly until 2001 and then decline at a higher rate until 2031 (Figure 5). Livestock enterprises interact with the crops for the use of water and land for forages and grain. Net returns from livestock are relatively stable throughout the study period. The 24 acre-inch authorization allows irrigators to maintain forage and grain production for the size of livestock enterprises allowed in the model. Net returns from crops decline throughout the study period as crops and livestock enterprises become more competitive for water. Net return analysis for baseline was discussed in the previous section.

For the 18 acre-inch scenarios, the total net returns from crops and livestock decline throughout the 40-year period (Figure 5). The reduced authorization results in more competition for water between the enterprises, this effect shows up sooner for the 18 acre-inch allocation than for baseline. Total net returns for the 40-year period for the 18 inch allocation are 97 percent of returns for baseline. Net returns in 2031 for the 18 acre-inch allocation are 82 percent of those in 1991 (Table 6). The 18 acre-inch allocation does affect acreage and water use but has relatively little impact on net returns because of the crop mix and irrigation regime selected.

The loss in net returns is from reduced net income from irrigated crops. Net returns from livestock are relatively stable throughout the period; net returns from nonirrigated crops increase a little as irrigated land shifts to nonirrigated crop use.

The 15 acre-inch and 12 acre-inch scenarios show the effect of limited authorization immediately, as net returns decline by 1996 compared to 1991 (Figure 5). This decline is the result of reduced net returns from irrigated crops.

Figure 5.

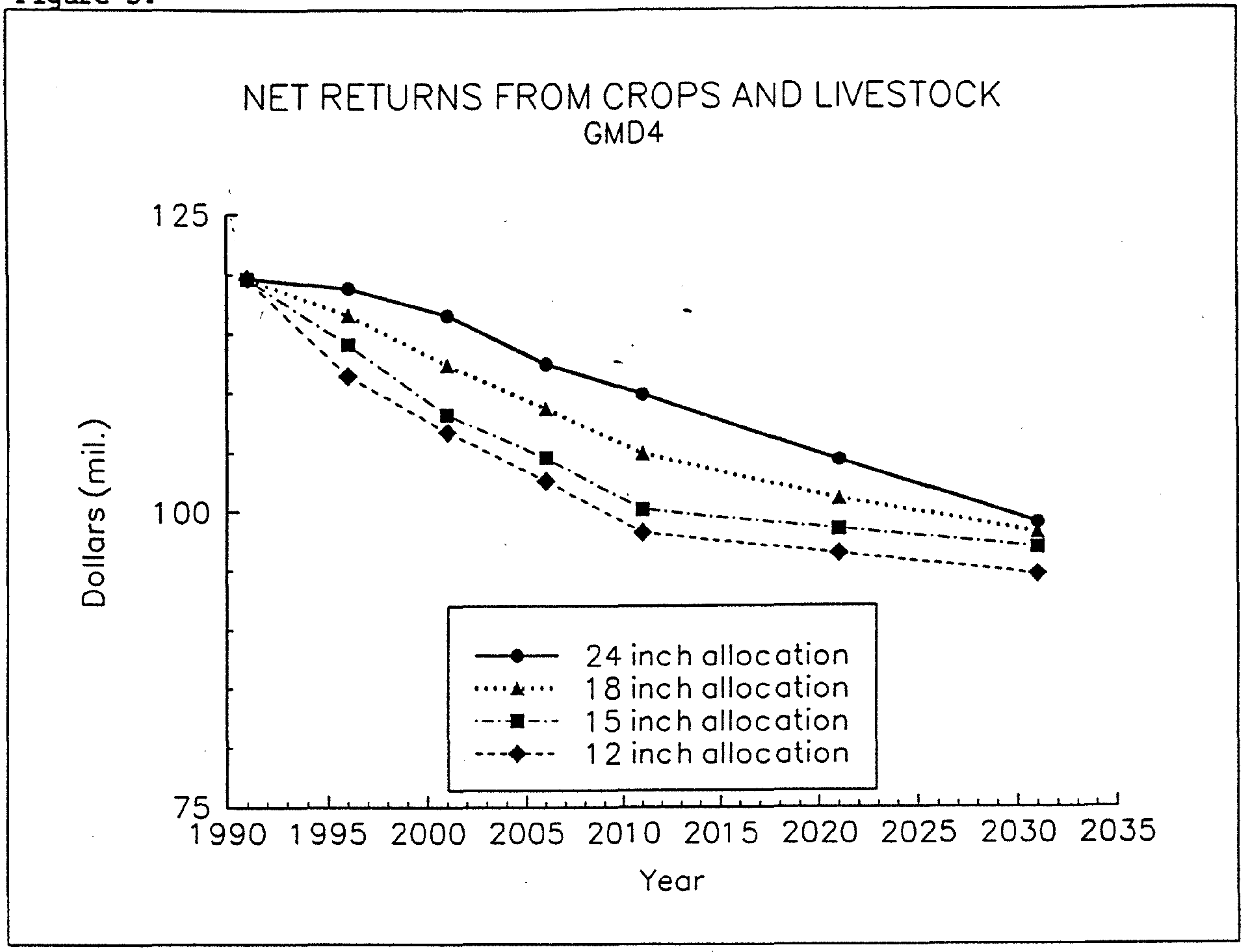


Table 6. Total Returns from Crops & Livestock in GMD4 by Option by Year

	Per Acre Water Allocation (Mil. $)					Per Acre Water Allocation (Mil. $)			
Year	24 in.	18 in.	15 in.	12 in.	Year	24 in.	18 in.	15 in.	12 in.
1991	119.614	119.614	119.614	119.614	2012	109.252	104.452	99.925	97.966
1992	119.444	118.991	118.491	119.262	2013	108.701	104.070	99.760	97.786
1993	119.274	118.368	117.368	118.910	2014	108.149	103.689	99.595	97.607
1994	119.103	117.746	116.246	118.557	2015	107.598	103.307	99.430	97.427
1995	118.933	117.123	115.123	111.347	2016	107.047	102.926	99.265	97.248
1996	118.763	116.500	114.000	117.853	2017	106.496	102.544	99.100	97.068
1997	118.303	115.611	112.824	115.614	2018	105.945	102.163	98.935	96.889
1998	117.843	114.723	111.647	113.376	2019	105.393	101.781	98.770	96.709
1999	117.383	113.834	110.471	111.137	2020	104.842	101.400	98.605	96.530
2000	116.923	112.946	109.294	108.899	2021	104.291	101.018	98.440	96.350
2001	116.463	112.057	108.118	106.660	2022	103.754	100.728	98.279	96.135
2002	115.642	111.375	107.392	105.836	2023	103.216	100.439	98.118	95.920
2003	114.820	110.693	106.667	105.013	2024	102.679	100.149	97.957	95.705
2004	113.999	110.011	105.941	104.189	2025	102.142	99.860	97.796	95.490
2005	113.177	109.329	105.216	103.366	2026	101.605	99.570	97.635	95.275
2006	112.356	108.647	104.490	102.542	2027	101.067	99.280	97.474	95.060
2007	111.845	107.884	103.610	101.663	2028	100.530	98.991	97.313	94.845
2008	111.335	107.121	102.730	100.783	2029	99.993	98.701	97.152	94.630
2009	110.824	106.359	101.850	99.904	2030	99.455	98.412	96.991	94.415
2010	110.314	105.596	100.970	99.024	2031	98.918	98.122	96.830	94.200
2011	109.803	104.833	100.090	98.145	Total	4507.234	4380.961	4259.522	4204.9463

Total net returns for the 15 acre-inch allocation for 1991 through 2031 are 94 percent of returns for baseline (Table 6). The 6-inch reduction from allocation of 24 to 18 acre-inches reduced net returns 3 percent, as did the 3-inch allocation reduction from 18 to 15 acre-inches. The model confirms the behavior of many irrigators who consider the use of 18 inches of water as the best practice. However, reducing water use another 3 inches has a greater impact on net returns because of the change in the crop mix and water use. Net returns in 2031 are 81 percent of those in 1991 for the 15 acre-inch allocation. After 1991, net returns for all scenarios began to diverge, but they were converging by 2031. Some time after 2031, net returns from baseline would be less than those from other scenarios because the water supply was depleted more in the earlier years.

The 12 acre-inch allocation has one-half of the water supplied by the 24 acre-inch allocation, but net returns are 93 percent of those for baseline for the 40-year period. The reason that the rate at which net returns decline slows as the allocation increases is that net returns from livestock remain relatively stable and income from crops being irrigated using 12 inches approaches that of nonirrigated crops. If the water allocations were to continue decreasing, net income would approach that received for nonirrigated crops.

Reducing the allocation below 24 acre-inches affects only those irrigators that had the well capacity to deliver the larger quantity. If an irrigator had authorization to apply 24 acre-inches on a 160-acre field, he would be affected by a policy to reduce the authorization to 18 inches only if his well had the capacity to deliver the 24 inches during critical growth stages. For example, it takes over 7.7 days to apply 1 acre-inch for crop use on 160 acres with a GPM well with 65 percent system efficiency. As well GPM diminishes, the number of days needed to apply water in a timely manner increases. Therefore, reducing an authorization does not necessarily result in a reduction in water pumped unless the well yield capacity has been large enough to take advantage of the higher authorization.

Reducing the water authorization from 24 to 18 acre-inches affects irrigators in groups 5A, 5B, 4A and 4B first because they have higher well yield capacities. Groups 1A, 1B, 2A and 2B are not affected until the allocation is decreased to 12 acre-inches. Thus, the impact of a reduced allocation is much different than that of zero depletion, in which those with the greatest amount of saturated thickness were affected the least. Also, the effect on net returns is greater with reduced authorization than with the zero depletion option, because the higher yielding wells are affected first. Irrigators with high well capacities tend to have greater acreage of fully irrigated corn. Thus, the option to reduce the water authorization affects the more profitable practices first.

Irrigated Acres

Irrigated acreage declines beginning in 1991 for all scenarios (Figure 6). Early in the period, it declines the least for the baseline scenario and most for the 12 acre-inch scenario. After 2001, the downtrend converges for all scenarios, but the 12 acre-inch allocation shows the smallest rate of decline. As expected, the long-term outlook for maintaining irrigated acreage is affected most adversely by the heaviest use of water early in the period. Heavier use of water for the baseline scenario in the early years lowers the water table relatively more, thereby reducing GPM and increasing pump costs more than for other scenarios.

Total irrigated acres for the 40-year period with the 18 acre-inch allocation is 99.6 percent of the acres for baseline (Table 7). It maintains irrigating acres by use of less water-intensive systems, using crops such as wheat and grain sorghum. Total irrigated acres are fewer for the 15 and 12 acre-inch allocations because of reduced acreage early in the 40-year period.
Total irrigated acreage for the 18 acre-inch allocation over the 40-year period is 99.6 percent of the acreage for baseline, the 15 acre-inch allocation has 98 percent of baseline acreage, and the 12 acre-inch allocation has 93 percent of baseline acreage. The full impact of reducing the allocation does not show until the allocation is cut 50 percent to 12 inches. This affects irrigators in every group, not only in those with high GPM wells.

Acreages in 2031 are 63 percent of that in 1991 for baseline, 62 percent for the 18 acre-inch allocation, 64 percent for the 15 acre-inch allocation, and 59 percent for the 12 acre-inch allocation. In 1991, the average GPM of wells in GMD4 was 571. Thus, reducing the allocation to 12 inches affects irrigators in all groups, even those with very low GPM as in groups 1A, 2A, and 3A.

The reduction in irrigated acres results in an increase in nonirrigated acres. Crop acres for nonirrigated land use increase, with some of the land being used for fallow.

Water Pumped

Water pumped for baseline shows a 2 percent increase between 1991 and 1996 (Figure 7). This increase is largely the effect of higher crop yields providing the incentive to increase water use. After 1996, higher pumping cost because of a decline in saturated thickness and reduced well GPM result in less water pumped. Water pumped decreases for the 18, 15, and 12 acre-inch allocations throughout the study period. Water pumped is affected most by the 12 acre-inch allocation, but pumping among all scenarios converges and is nearly the same after 2021. (Table 8).

A factor greatly influencing the water pumped and crop selection is the time available for pumping. As GPM decreases below the 700-800 GPM level for gravity flow and 500-600 GPM level for center pivot sprinklers, the well capacity is inadequate to fully irrigate corn on 160 acres for a gravity flow system or on 130 acres for a center pivot system. The model then makes the economic trade-off between fewer acres with more water per acre or maintaining acreage with less water per acre. With corn, the model chooses to maintain per acre water allocation but reduce acres irrigated. For grain sorghum and wheat, the choice is to maintain acres but reduce the per-acre application. As the GPM declines, the ability to maintain the irrigation application declines. Over time, as the aquifer water level declines, so does well GPM and its capacity to maintain adequate water application during critical plant physiological stages.

Water pumped for the study period for the 18 acre-inch allocation is 98.5 percent of that for baseline; 96 percent of baseline for the 15 acre-inch allocation; and 12 acre-inch allocation is 89 percent of baseline (Table 8). Thus, not until the allocation is less than 15 acre-inches does it

Figure 6.

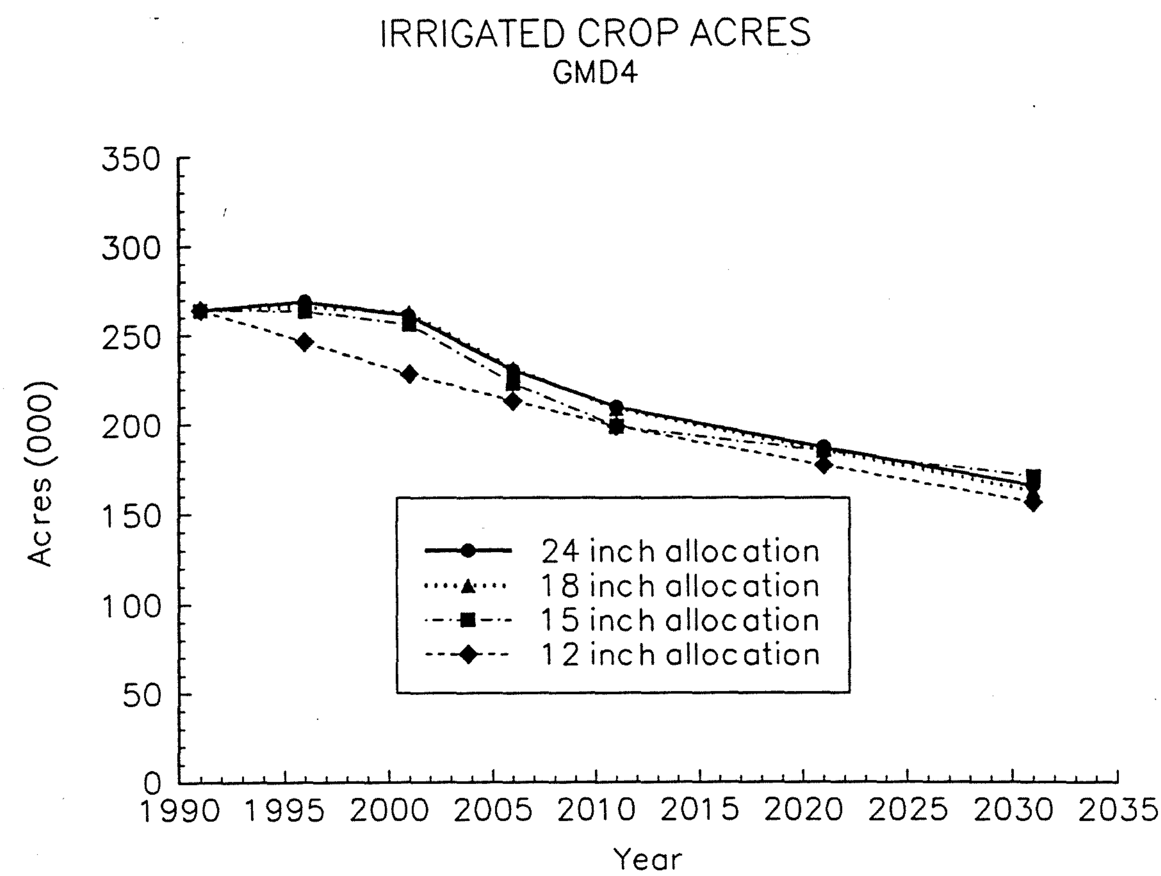


Table 7. Total Acres of Irrigated Crops In GMD4 by Option by Year in Thousands

	Per Acre Water Allocation (000)					Per Acre Water Allocation (000)			
Year	24 in.	18 in.	15 in.	12 in.	Year	24 in.	18 in.	15 in.	12 in.
1991	264.067	264.067	264.067	264.067	2012	207.087	206.215	197.264	196.496
1992	264.958	264.354	263.911	260.560	2013	204.847	203.962	195.880	194.321
1993	265.849	264.640	263.755	257.053	2014	202.607	201.710	194.496	192.147
1994	266.739	264.927	263.599	253.545	2015	200.367	199.457	193.112	189.972
1995	267.630	265.213	263.443	250.038	2016	198.127	197.204	191.729	187.798
1996	268.521	265.500	263.287	246.531	2017	195.886	194.951	190.345	185.624
1997	266.998	264.900	262.418	242.815	2018	193.646	192.698	188.961	183.449
1998	265.475	264.300	261.548	239.099	2019	191.406	190.446	187.577	181.275
1999	263.952	263.700	260.679	235.382	2020	189.166	188.193	186.193	179.100
2000	262.429	263.100	259.809	231.666	2021	186.926	185.940	184.809	176.926
2001	260.906	262.500	258.940	227.950	2022	184.806	183.683	183.425	174.871
2002	254.722	256.196	251.691	224.929	2023	182.686	181.426	182.041	172.815
2003	248.538	249.892	244.442	221.907	2024	180.565	179.170	180.657	170.760
2004	242.354	243.588	237.193	218.886	2025	178.445	176.913	179.273	168.704
2005	236.170	237.284	229.944	215.864	2026	176.325	174.656	177.890	166.649
2006	229.986	230.980	222.695	212.843	2027	174.205	172.399	176.506	164.594
2007	225.854	226.478	217.886	210.008	2028	172.085	170.142	175.122	162.538
2008	221.722	221.975	213.076	207.174	2029	169.964	167.886	173.738	160.483
2009	217.591	217.473	208.267	204.339	2030	167.844	165.629	172.354	158.427
2010	213.459	212.970	203.457	201.505	2031	165.724	163.372	170.970	156.372
2011	209.327	208.468	198.648	198.670	**Total**	8939.961	8908.557	8795.096	8348.152

have much effect on how much water is pumped. The average GPM in GMD4 was 571 in 1991; thus, most irrigators were not able to take advantage of a allocation higher than 15 acre-inches, or if they had an efficient system, they did not need a higher allocation. Reducing the allocation to 12 acre-inches impacts nearly all irrigators with regard to applying the needed water in a timely manner.

For baseline, the water pumped in 2031 is 45 percent of that in 1991; for the 18 acre-inch allocation, it is 44 percent of that in 1991; for the 15 acre-inch and the 12 acre-inch allocations, it is 48 percent of that in 1991 (Table 8). This shows that reducing the allocation reduces water use early, allowing more water pumped in later years.

For most groups (1A through 3B), the GPM declines by 2021 to levels that greatly impact water delivery. For these groups, its not the amount of water available in the aquifer that is the most important, but rather the time available for pumping water. As the GPM declines, pumping time becomes more important than the amount allocated. Groups 4A and 4B are marginal in this regard, but 5A and 5B are largely unaffected by the decline of GPM by 2031. Groups 4A, 4B, 5A, and 5B are affected by the limit imposed by a 12 acre-inch authorization, and not by well GPM.

Summary

Reducing the water allocation from 24 to 18 to 15 to 12 acre-inches affects net returns, irrigated acreage, and water pumped about as expected. However, a 50 percent reduction in allocation does not reduce net returns, acreage, or water pumped by 50 percent. A 50 percent reduction in allocation reduces net returns about 7 percent, acreage by about 7 percent, and water pumped by about 11 percent. These factors are affected proportionately by a reduction in water allocation because: 1) the model selected irrigation regimes that use water most efficiently, 2) less water-intensive crops were selected, and 3) time available to pump water was more important than the amount of water allocation, so some groups were not able to use 24 acre-inches very profitably.

An 18 acre-inch authorization was estimated to reduce total net return by 3 percent for the period. A 15 acre-inch authorization was estimated to reduce total net returns by 6 percent, and the 12 acre-inch authorization reduced total net returns by 7 percent.

Compared to the 24 acre-inch authorization, total irrigated acres for the period decreased less than 1 percent for the 18 acre-inch authorization, decreased 2 percent for the 15 acre-inch authorization, and decreased 7 percent for the 12 acre-inch authorization.

Compared to 1991 acreage, acres irrigated in 2031 were 63 percent for the 24 acre-inch authorization; 62 percent for the 18 acre-inch authorization; 64 percent for the 15 acre-inch authorization; and 59 percent for the 12 acre-inch authorization.

Total water pumped for the period was 1.5 percent less for the 18 acre-inch allocation than for baseline, 4 percent less for the 15 acre-inch allocation, and 11 percent less for the 12 acre-inch allocation.

Figure 7.

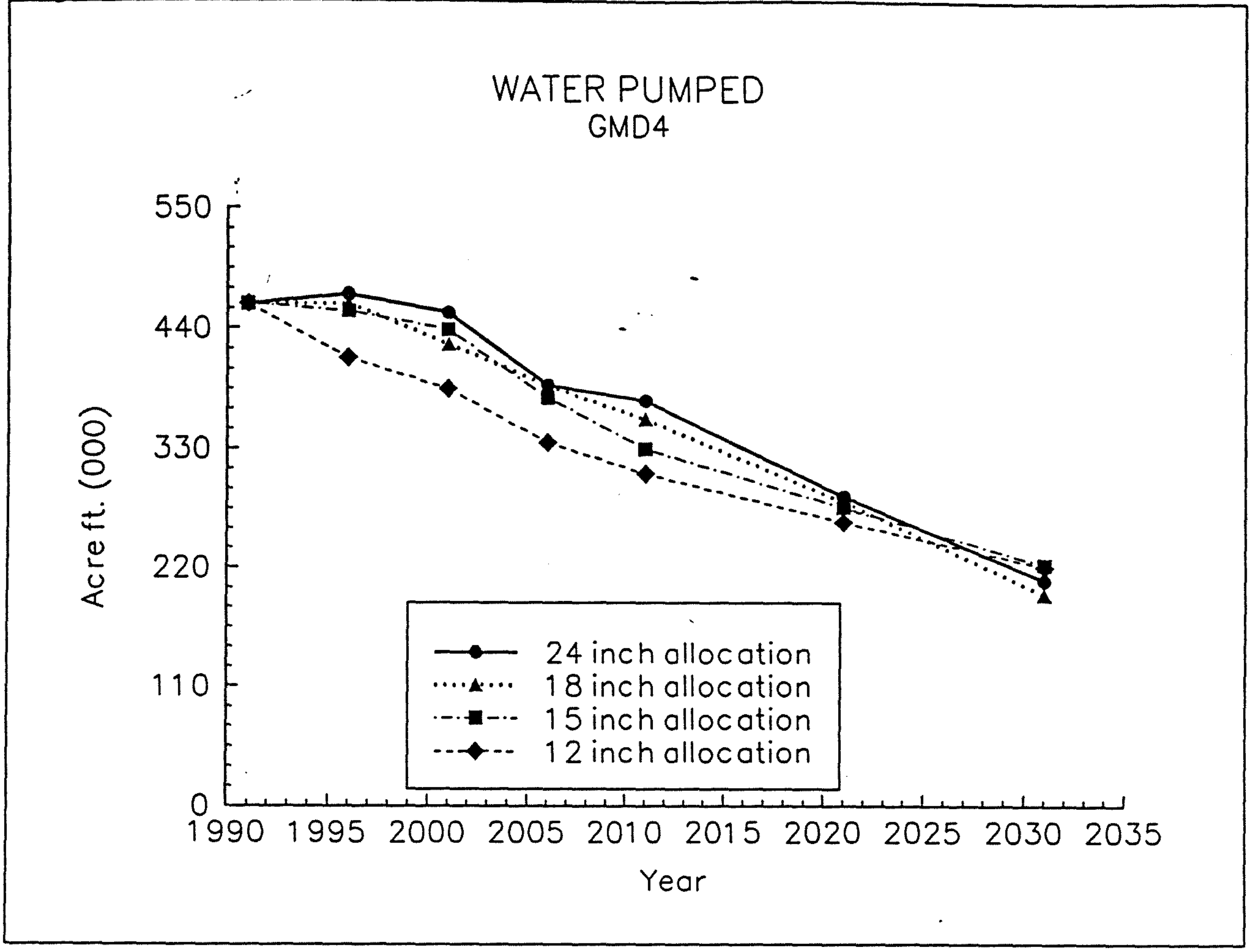


Table 8. Total Acre Feet of Water Pumped in GMD4 by Option by Year in Thousands

	Per Acre Water Allocation (000)					Per Acre Water Allocation (000)			
Year	24 in.	18 in.	15 in.	12 in.	Year	24 in.	18 in.	15 in.	12 in.
1991	462.058	462.058	462.058	462.058	2012	364.027	348.379	323.015	301.350
1992	463.720	461.980	460.644	452.064	2013	355.239	340.821	317.680	296.900
1993	465.382	461.902	459.231	442.069	2014	346.451	333.262	312.845	292.450
1994	467.045	461.823	457.817	432.075	2015	337.663	325.704	307.010	288.000
1995	468.707	461.745	456.404	422.080	2016	328.875	318.146	301.675	283.550
1996	470.369	461.667	454.990	412.086	2017	320.087	310.588	296.340	279.100
1997	466.961	460.726	451.612	406.489	2018	311.299	303.030	291.005	274.650
1998	463.553	459.784	448.234	400.892	2019	302.511	295.471	285.670	270.200
1999	460.146	458.843	444.856	395.294	2020	293.723	287.913	280.335	265.750
2000	456.738	457.901	441.478	389.697	2021	284.935	280.355	275.000	261.300
2001	453.330	456.960	438.100	384.100	2022	277.183	272.797	269.665	257.174
2002	440.080	442.912	425.624	374.080	2023	269.430	265.239	264.330	253.048
2003	426.831	428.864	413.148	364.060	2024	261.678	257.680	258.995	248.921
2004	413.581	414.815	400.672	354.040	2025	253.925	250.122	253.660	244.795
2005	400.332	400.767	388.196	344.020	2026	246.173	242.564	248.325	240.669
2006	387.082	386.719	375.720	334.000	2027	238.420	235.006	242.990	236.543
2007	384.229	380.563	366.246	328.360	2028	230.668	227.448	237.655	232.417
2008	381.375	374.406	356.772	322.720	2029	222.915	219.889	232.320	228.290
2009	378.522	368.250	347.298	317.080	2030	215.163	212.331	226.985	224.164
2010	375.668	362.093	337.824	311.440	2031	207.410	204.773	221.650	220.038
2011	372.815	355.937	328.350	305.800	Total	14726.297	14512.233	14161.924	13153.813

Water pumped in 2031 was 45, 44, and 48 percent of that in 1991 for the 24, 18, 15 and 12 acre-inch allocations respectively.

The zero depletion policy and a reduction in water authorization have significantly different impacts. The zero depletion policy reduces water pumped by limiting pumping after the saturated thickness has declined about 9 percent for groups 1A and 1B to 30 percent for groups 5A and 5B (Table D1). Those irrigators with the smaller saturated thickness are impacted first, whereas those with the saturated thickness greater than 125 feet may not be affected for 50 years.

Reducing the per-acre-inch allocation has a much different impact, because it restricts the amount available for pumping. For this policy to be effective, the irrigators must have wells with capacity to use their allocation advantageously. If an irrigator has an authorization for 24 acre-inches but a well capacity insufficient to use it profitably, reducing the authorization may not affect how much water is pumped. In this study, groups 5A and 5B were affected immediately by reducing the authorization, because they had the wells with capacity to use the 24 acre-inches if needed.

Thus, the two policies work in opposite ways. The zero depletion policy first affects groups 1A and 1B and gradually moves over time to include groups 4A, 4B, 5A, and 5B. However, the acre-inch allocation policy affects irrigators in group 5A and 5B first and as the allocation continues to be reduced, the impact gradually moves to include those in groups 4, 3, 2, and 1. The initial difference between these policies is that they impact different groups of irrigators.

The primary focus of this study was the impact of policies on water use and how much water use would be decreased. In this regard, the zero depletion policy reduces water pumped more than the most restrictive water allocation option. The zero depletion option pumps 22 percent less water than baseline over the 40-year study period, and 12 percent less than the 12 acre-inch allocation option. The zero depletion option in 2031 uses 29 percent of the amount used in 1991, whereas the 12 acre-inch allocation used in 2031 uses 48 percent of the amount used in 1991.

Under the zero depletion option, about 30 percent of the 1991 saturated thickness would be withdrawn, and thus, this policy would preserve about 70 percent of the acquifer. Restricting the water allocation would not protect the aquifer in the same way. Under the restricted water-allocation policy, pumping continues so long as it is profitable to do so.

Restricting water pumped to prolong the life of the aquifer cannot overlook the impact of such policies on net returns. Net return is one of the major factors influencing the irrigator's decisions, including that of how much water to use or save.

Net returns for the 40-year period were higher for zero depletion than for the most restrictive water-allocation option. Total net returns for zero depletion are 99 percent of returns for baseline; for the 12 acre-inch allocation, the total net return was 93 percent of the return for baseline. Net returns in 2031 are 83 percent of those in 1991 for zero depletion, and 79 percent of those in 1991 for the 12 acre-inch allocation.

Although zero depletion pumped 12 percent less water than the 12 acre-inch allocation, it had 6 percent greater net returns. In this 40-year period, the zero depletion policy would conserve more water with less reduction in net returns. This phenomenon happens because of how different groups of irrigators are affected first. In the early years, under zero depletion, groups 1A, 1B, 2A, and 2B are affected by the policy. These groups have the fewest irrigators and irrigated acres with relatively less irrigated corn. The impact of the 12 acre-inch allocation is to first limit water use in groups 5A, 5B, 4A, and 4B. These groups have the largest number of irrigators and irrigated acres with relatively more irrigated corn.

A zero depletion policy would conserve about 70 percent of the water available in the aquifer and the decline would stablize by about 2040-2050. Under the 12 acre-inch allocation, the saturated thickness of the aquifer would continue to decline well past 2050, until such a time when irrigating is no longer profitable in any of the groups.

LAND-USE AND CROP-YIELD TREND SCENARIOS

By using the model to test the effect of a policy, one is conducting a controlled experiment. The approach is to keep most factors fixed but vary a few important variables to more clearly see their impact.

The baseline model was constructed to describe the situation in 1991 with regard to the government program feed grains and wheat base acreage. The program allowed for little flexibility in shifting irrigated acreage among crops. The model allowed crop acreages to shift between irrigated and dryland, but they could not exceed a maximum base allotment. The impact of these constraints limits the flexibility in choosing what crops and irrigation regimes provide the highest net returns over time. Another assumption of the baseline model was that crop yield increase over time was one-half the increase experienced in the 40 years prior to 1991.

Two additional scenarios were tested to show the effect and test the sensitivity on results of the two assumptions. These scenarios were tested for baseline over time only and not for the zero depletion policy or for the 18, 15, or 12 acre-inch authorizations.

BASELINE PLUS CROP ACREAGE FLEXIBILITY SCENARIO (B+F)

All parameters and coefficients (prices, expenses, crop yield) are the same for this scenario as for baseline, except the limits on crop acreage. Total irrigated and nonirrigated crop acreage in the (B + F) option remained as in baseline, but the limits on corn, grain sorghum, wheat, alfalfa, soybeans, silage and other crop acreages were increased 1 percent per year. Thus, the acreage change allowed among crops was gradual over time.

BASELINE PLUS FLEXIBILITY PLUS CROP TREND SCENARIO (B+F+T)

Again, the basic model is unchanged from baseline, except that the crop acreage limits are relaxed 1 percent per year and crop yield trends increase at the same rate over the 40 years from 1991-2031 as they did in the 40 years prior to 1991. All other parameters, variables, and constraints are as in baseline.

RESULTS

Net Returns

The effects of providing more flexibility in crop acreage selection and increases in crop yield trend on total net returns are shown in Figure 8. Allowing the model greater flexibility to choose among crops significantly increases total net returns. Gradually increasing flexibility increases

Figure 8.

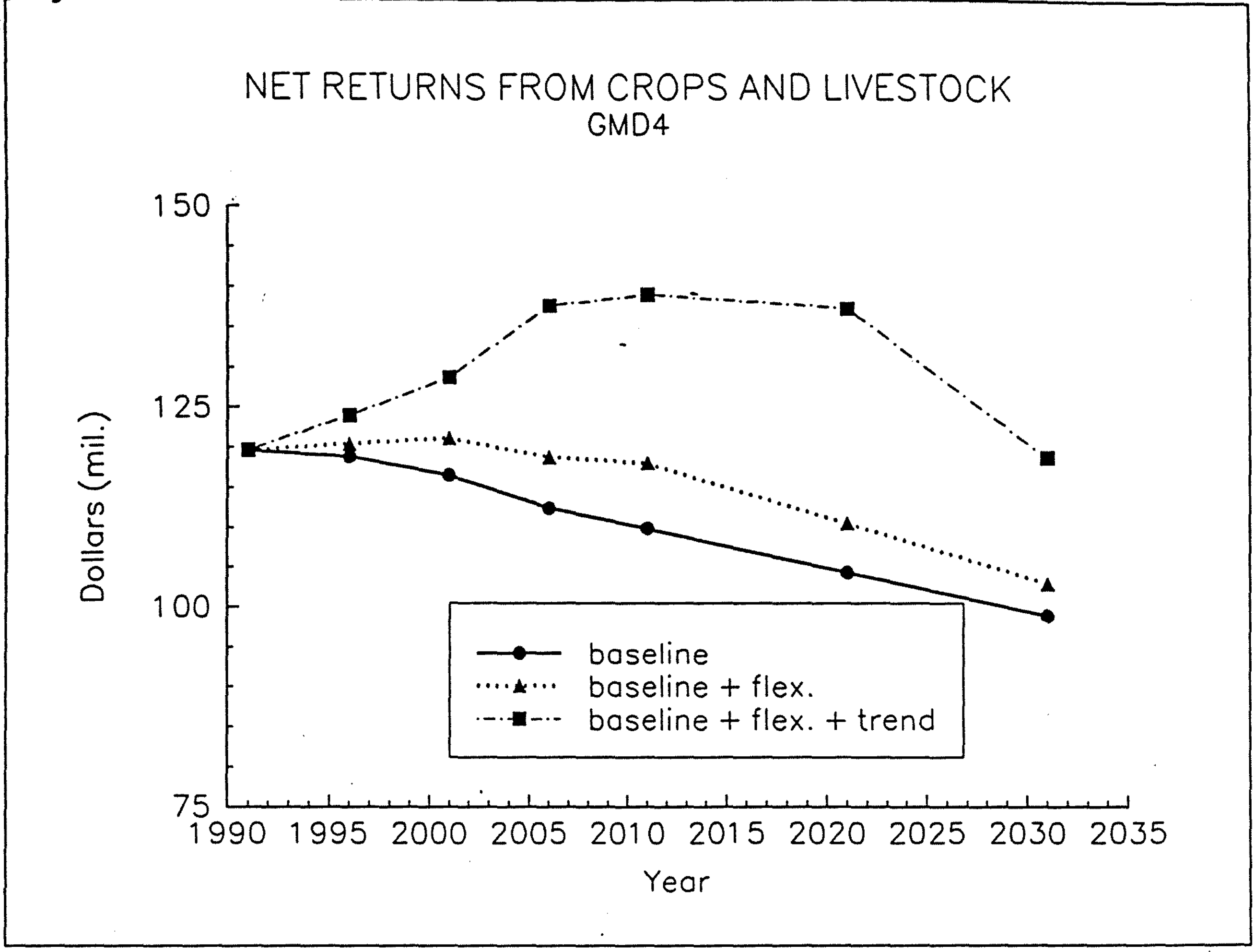


Table 9. Total Returns From Crops and Livestock in GMD4 by Option by Year							
Year	Baseline (Mil.$)	Baseline + Flex (Mil. $)	Baseline + Flex + Trend (Mil. $)	Year	Baseline (Mil. $)	Baseline + Flex (Mil. $)	Baseline + Flex + Trend (Mil. $)
1991	119.614	119.614	119.614	2012	109.252	117.222	138.809
1992	119.444	119.760	120.474	2013	108.701	116.472	138.642
1993	119.274	119.907	121.334	2014	108.149	115.721	138.475
1994	119.103	120.053	122.195	2015	107.598	114.971	138.308
1995	118.933	120.346	123.055	2016	107.047	114.220	138.142
1996	118.763	120.346	123.915	2017	106.496	113.469	137.975
1997	118.303	120.492	124.855	2018	105.945	112.719	137.808
1998	117.843	120.639	125.796	2019	105.393	111.968	137.641
1999	117.383	120.785	126.736	2020	104.842	111.218	137.474
2000	116.923	120.932	127.677	2021	104.291	110.467	137.307
2001	116.463	121.078	128.617	2022	103.754	109.716	135.441
2002	115.642	120.610	130.405	2023	103.216	108.966	133.575
2003	114.820	120.143	132.193	2024	102.679	108.215	131.709
2004	113.999	119.675	133.982	2025	102.142	107.465	129.843
2005	113.177	119.208	135.770	2026	101.605	106.714	127.977
2006	112.356	118.740	137.558	2027	101.067	105.963	126.112
2007	111.845	118.587	137.842	2028	100.530	105.213	124.246
2008	111.335	118.433	138.125	2029	99.993	104.462	122.380
2009	110.824	118.280	138.409	2030	99.455	103.712	120.514
2010	110.314	118.126	138.692	2031	98.918	102.961	118.648
2011	109.803	117.973	138.976	**Total**	4507.234	4715.561	5377.246

Figure 9.

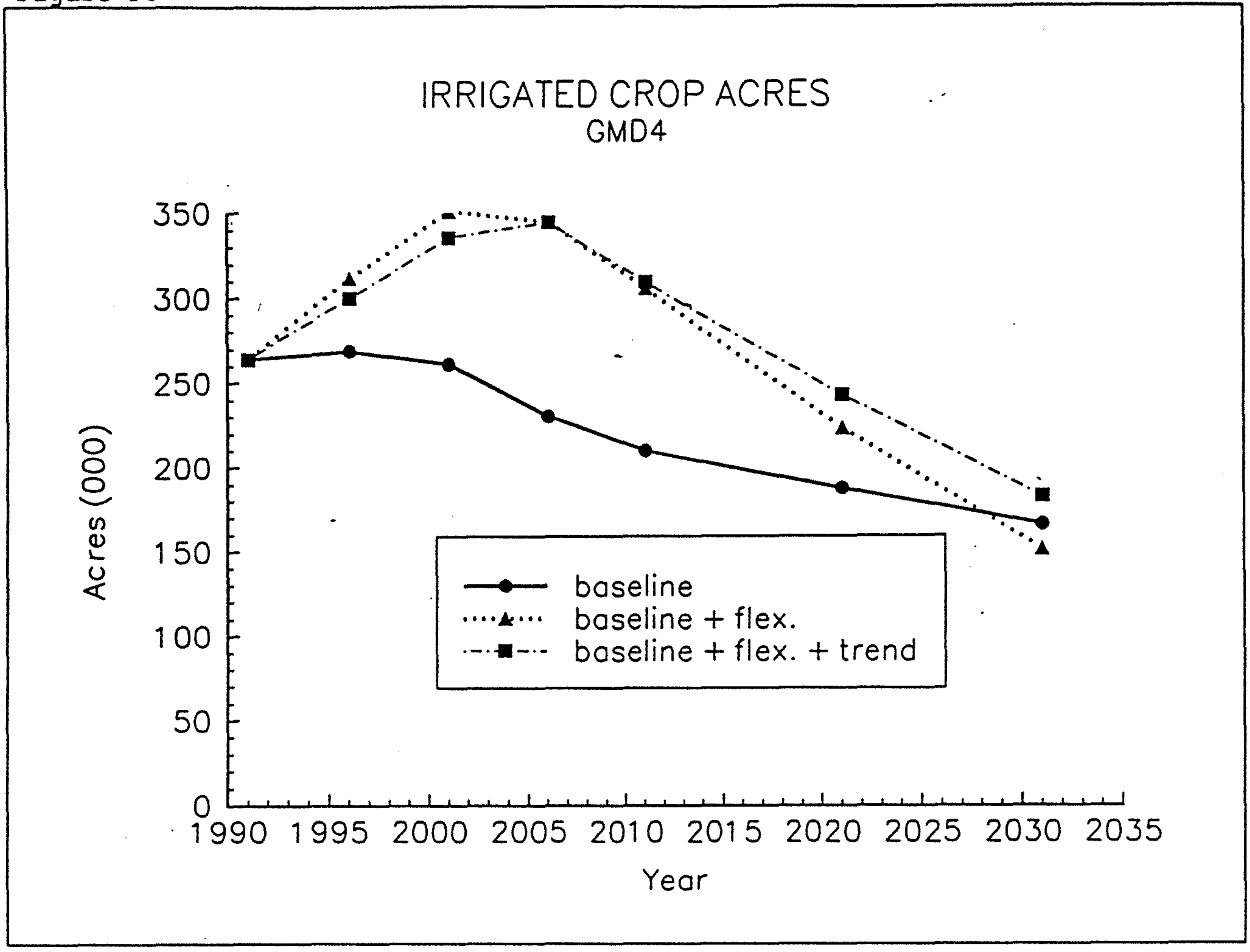


Table 10. Total Acres of Irrigated Crops in GMD4 by Option by Year

Year	Baseline (000)	Baseline + Flex (000)	Baseline + Flex + Trend (000)	Year	Baseline (000)	Baseline + Flex (000)	Baseline + Flex + Trend (000)
1991	264.067	264.066	264.067	2012	207.087	297.147	302.220
1992	264.958	273.528	271.202	2013	204.847	288.861	295.524
1993	265.849	282.989	278.338	2014	202.607	280.574	288.827
1994	266.739	292.450	285.473	2015	200.367	272.288	282.130
1995	267.630	301.911	292.609	2016	198.126	264.002	275.433
1996	268.521	311.372	299.744	2017	195.886	255.716	268.737
1997	266.998	320.833	306.879	2018	193.646	247.430	262.040
1998	265.475	330.294	314.015	2019	191.406	239.143	255.343
1999	263.952	339.754	321.150	2020	189.166	230.857	248.647
2000	262.429	349.215	328.286	2021	186.926	222.571	241.950
2001	260.906	358.676	335.421	2022	184.806	215.409	235.979
2002	254.722	355.818	337.179	2023	182.686	208.247	230.008
2003	248.538	352.959	338.937	2024	180.565	201.084	224.038
2004	242.354	350.101	340.696	2025	178.445	193.922	218.067
2005	236.170	347.242	342.454	2026	176.325	186.760	212.096
2006	229.986	344.384	344.212	2027	174.205	179.598	206.125
2007	225.854	336.594	337.153	2028	172.085	172.436	200.154
2008	221.722	328.804	330.094	2029	169.964	165.273	194.184
2009	217.591	321.013	323.035	2030	167.844	158.111	188.213
2010	213.459	313.223	315.976	2031	165.724	150.949	182.242
2011	209.327	305.433	308.917	Total	8939.916	11211.038	11427.794

the amount of net returns over baseline until 2001. Thereafter, as net returns decline, the difference between baseline and the B+F option narrows. The model allows for more flexibile crop choices after 2001, but other factors began to override this advantage. After 2001, water availability, the number of wells, and well GPM become more important in determining crop acreage and water use than flexibility considerations.

Appendix C shows the decline in well GPM over time by group. By 2011, GPM has declined for groups 1A, 1B, 2A, 3A, and 4A to levels that severely limit the acreage of corn that can be fully irrigated.

Allowing more flexibility for selecting irrigated crops increases net returns over the 40 years by 5 percent over baseline (Table 9). For the B+F option, net returns in 2031 are 86 percent of those in 1991. If the 2011 to 2031 trend in annual net returns continued after 2031, net returns for baseline and for B+F would be equal in about the year 2047, and thereafter, annual returns would be less for B+F than for baseline. The higher net returns are the results of more irrigated acres and water pumped for the B+F scenario. The long-term effects begin to appear after 2045 with lower net returns for the B+F option as compared to baseline.

Adding the increase in crop yield trend and relaxing crop acreage limits have a very dramatic impact on total net returns (Figure 8). Increases in crop yield trend improves the productivity of all resources used (land, water, labor, and capital). The rising yield trend provides the incentive for more water use and more corn and grain sorghum acreage. The sharp rise in net returns lasts until 2006, returns remain steady until 2021 and then begin an equally sharp decline. After 2006, the availability of water overrides the economic impact of improved crop yield and flexibility in crop acreage selection. The sharp decline after 2021 is the result of a sharp decline in irrigated acres. The early rise in net returns greatly increases irrigated acres but depletes the aquifer, the effects of which occur after 2021.

For the 1991-2031 period, allowing the model greater flexibility increased total returns 5 percent over baseline (Table 9). This increase is fairly evenly distributed over the period. By incorporating higher crop yield trends and more flexibility, the total returns were 19 percent higher than those for baseline. But for the B+F+T scenario, the income distribution was very uneven over time, with annual net returns at the end of the period very near those at the beginning. The reason net income does not continue to increase relative to baseline is that the water availability problem begins to limit corn acreage by about 2011. Thereafter, irrigated acres shift to lower valued crops.

Irrigated Crop Acreage

Irrigated crop acres are affected about equally by having added flexibility and by the combination of added flexibility plus increase in crop yield trend (Figure 9). This means that the higher increase in crop yields did not significantly alter the choices on how many acres to irrigate. Providing greater flexibility in the model greatly increased acres irrigated over that in the baseline. The increased acreage of irrigated cropland comes from a reduction in nonirrigated acres.

For baseline, the decline in irrigated crop acres begins after 2001, but the decline is at a slower rate after 2011. Likewise, the declines in the two other scenarios begin after 2006, but they are steeper. Water availability problems intensify after 2006 and more for the scenarios with greater allowance for switching crops, because the steep rise in irrigated acreage prior to 2006 has depleted the aquifer more.

Total acres irrigated for the 1991-2031 period were 25 percent higher than acres for baseline for the scenario including only increased flexibility and for the scenario having both more flexibility and higher crop yield trends (Table 10). The higher crop yield trend added about 3 percent to acres irrigated. The increase in acres irrigated was from a reduction in nonirrigated land use. This finding suggests that having higher crop yield trends would not affect crop acreage nearly as much as having more flexibility to select crops for specific water availability situations. To be able to take advantage of higher crop yield, the irrigator needs the flexibility to choose the most profitable crop.

By the end of the study period, irrigated acreages for each of the scenarios were nearly the same (Figure 9). The trend was for a much greater decline in irrigated acres for scenarios B+F and B+F+T than for baseline after 2006. The rapid rise in irrigated acres prior to 2006 had greatly depleted the aquifer in some areas so the long-term effect was a more rapid decline in irrigated acres.

Water Pumped

Water pumped shows the same pattern over time as acres irrigated (Figure 10). An increase in crop yield trend does not significantly change the pattern of water pumped over time, as compared with having more flexibility in selecting crops. However, having added flexibility over baseline greatly influences water pumped over time. Water pumped increases nearly one-third over baseline by 2011. Thereafter, pumping drops sharply and falls below baseline value by 2031. Early, heavy use of water more rapidly depletes the reservoir, thereby reducing the economic benefit from irrigation in later years.

Providing the model greater flexibility to choose crops to irrigate and higher yields resulted in more water being pumped. For the 1991-2031 period, 13 percent more water was pumped for both scenarios (Table 11). Water availability and well replacement problems have their impact beginning in 2011. Baseline acreage of irrigated corn can be maintained in only groups 4B, 5A, and 5B. In all other groups, the saturated thickness and associated well yield have diminished to levels that support a very limited number of irrigated acres.

IRRIGATED CROP ACREAGE COMPARED

This section compares irrigated corn, grain sorghum, and wheat acreages and dryland acres for three options; baseline, zero depletion, and baseline + trend + flexibility. Zero depletion options pump the least amount of water for the 1991-2031 period, and the baseline with increased

Figure 10.

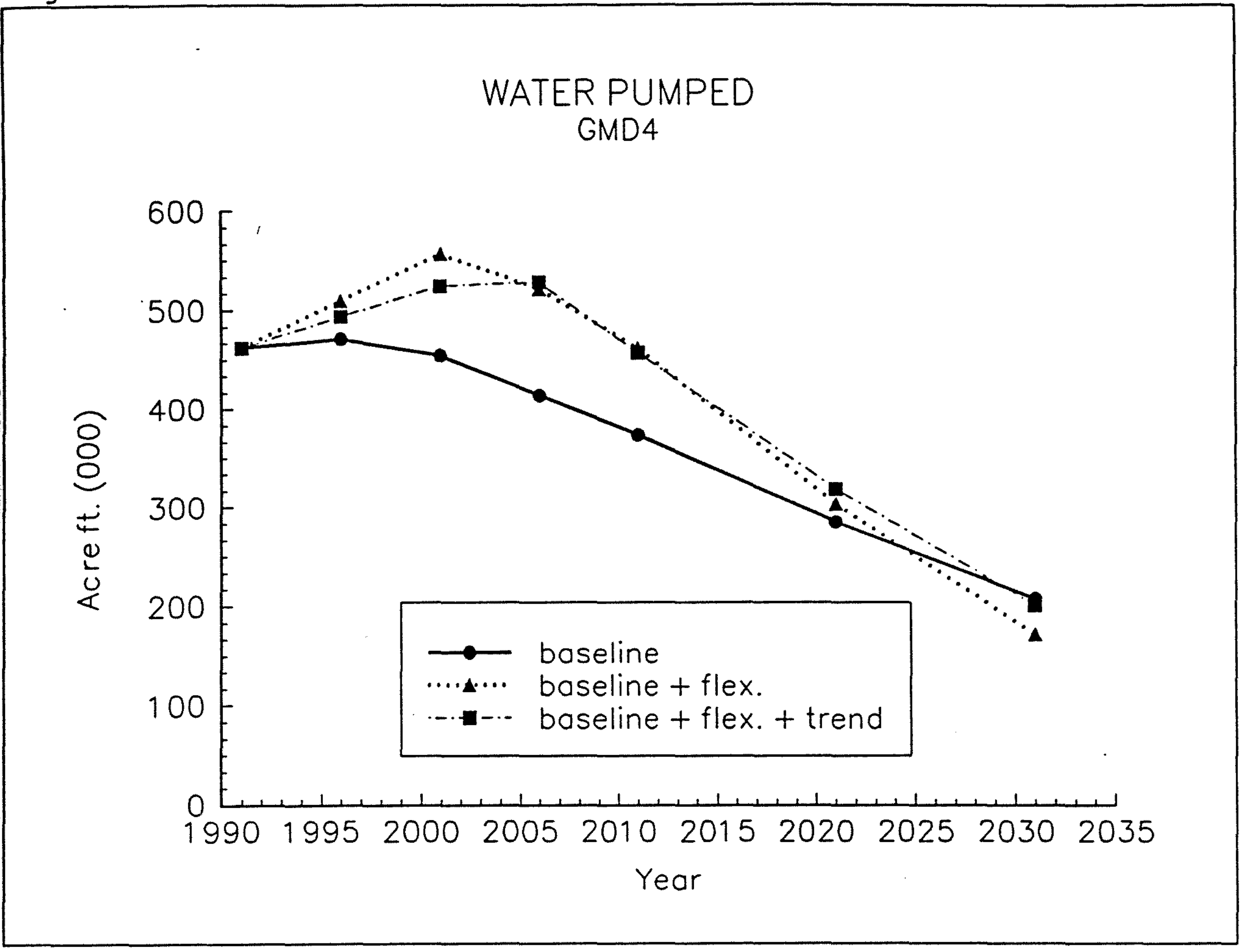


Table 11. Total Acre Feet Water Pumped in GMD4 by Year and Option

Year	Baseline (000)	Baseline + Flex (000)	Baseline + Flex + Trend (000)	Year	Baseline (000)	Baseline + Flex (000)	Baseline + Flex + Trend (000)
1991	462.058	462.058	462.058	2012	364.027	445.081	442.531
1992	463.720	471.440	468.249	2013	355.239	429.285	428.712
1993	465.382	480.822	474.440	2014	346.451	414.488	414.893
1994	467.045	490.204	480.632	2015	337.663	397.692	401.074
1995	468.707	499.586	486.823	2016	328.875	381.895	387.256
1996	470.369	508.968	493.014	2017	320.087	366.098	373.437
1997	466.961	518.350	499.205	2018	311.299	350.302	359.618
1998	463.553	527.732	505.396	2019	302.511	334.505	345.799
1999	460.146	537.114	511.587	2020	293.723	318.709	331.980
2000	456.738	546.496	517.778	2021	284.935	302.912	318.161
2001	453.330	555.878	523.969	2022	277.183	289.823	306.434
2002	445.279	548.925	524.725	2023	269.431	276.733	294.708
2003	437.227	541.971	525.481	2024	261.678	263.644	282.981
2004	429.176	535.018	526.238	2025	253.926	250.554	271.255
2005	421.124	528.064	526.994	2026	246.174	237.465	259.528
2006	413.073	521.111	527.750	2027	238.422	224.376	247.801
2007	405.021	509.064	513.470	2028	230.670	211.286	236.075
2008	396.970	497.018	499.190	2029	222.917	198.197	224.348
2009	388.918	484.971	484.910	2030	215.165	185.107	212.622
2010	380.867	472.925	470.630	2031	207.413	172.018	200.895
2011	372.815	460.878	456.350	**Total**	14856.268	16747.763	16818.997

flexibility and higher trend pumps the most water. Comparing these options with the baseline should provide a good overview of the impacts of various policies on water use.

Irrigated Corn

For the most part, irrigated corn acreage declines throughout the 1991-2031 period except for a small increase for B+T+F option from 1991 to 1996 (Figure 11). Irrigated corn in baseline declines the least after 2006. The decline for irrigated corn for zero depletion is largely the effect of water policy that limits the amount of water pumped to recharge after saturated thickness has declined a designated amount. However, the acreages for baseline and zero depletion converge in later years. The B+T+F option shows a small increase until 1996, and thereafter a rapid decline. By 2006, acreage for B+T+F is less than that for baseline, and by 2011, less than that for zero depletion. The decline in corn acreage for B+T+F is determined by the effect of a decline in saturated thickness on well GPM, availability of water, and pumping costs, thereby reducing net returns to corn. The long-term trend would be for irrigated corn acreage to continue to decline after 2031 for baseline and for B+T+F whereby a leveling off for zero depletion would be expected.

Acres of Irrigated Grain Sorghum

The acreage pattern over time is very different for irrigated grain sorghum than for corn (Figure 12). Acreage in baseline shows a sharp rise in initial years and a steady increase after 1996. This is caused by water use shifting from corn to grain sorghum because of lower well GPM and less water available. For zero depletion, acreage increases in the early years, decreases after 1996 until 2001, and then remains relatively stable thereafter. The zero depletion policy limits water pumped with the effect of use shifting from corn to grain sorghum. The B+T+F option shows very dramatic changes over time. First, a very steep rise in numbers of acres occurs until 2006, and later after 2011, an almost equally steep decline occurs. The early increase in acreage for B+T+F is caused by rising profit, and the decline after 2011 is caused by a decrease in water supply. The rise in acreage for B+T+F more rapidly depletes the aquifer, with the effect of eventually reducing irrigated acreage after 2011.

Irrigated Wheat Acreage

The acreage pattern for irrigated wheat is similar to that for grain sorghum (Figure 13)and is the consequence of not being able to maintain irrigated corn acreage over time in GMD4. For baseline, the increase in irrigated wheat is strong and steady throughout the period. Diminished water supply have yet to decrease irrigated wheat acreage. For zero depletion, irrigated wheat acreage increases until 2001 and then levels out until 2031. With the diminished water supply with the zero depletion policy, water use is maintaining irrigated wheat acreage. For the B+T+F option, the acreage until 2006 is a strong rise, but a decline thereafter. With added flexibility and higher crop yield trend, net returns provide a strong incentive to increase acreage and water use. The increased use of water cannot be maintained profitably after 2006, after which irrigated acreage decreases as net returns decrease. Inevitably, irrigated wheat acreage will decline under baseline sometime after 2031, as it does for B+T+F. The zero depletion option most likely will

Figure 11.

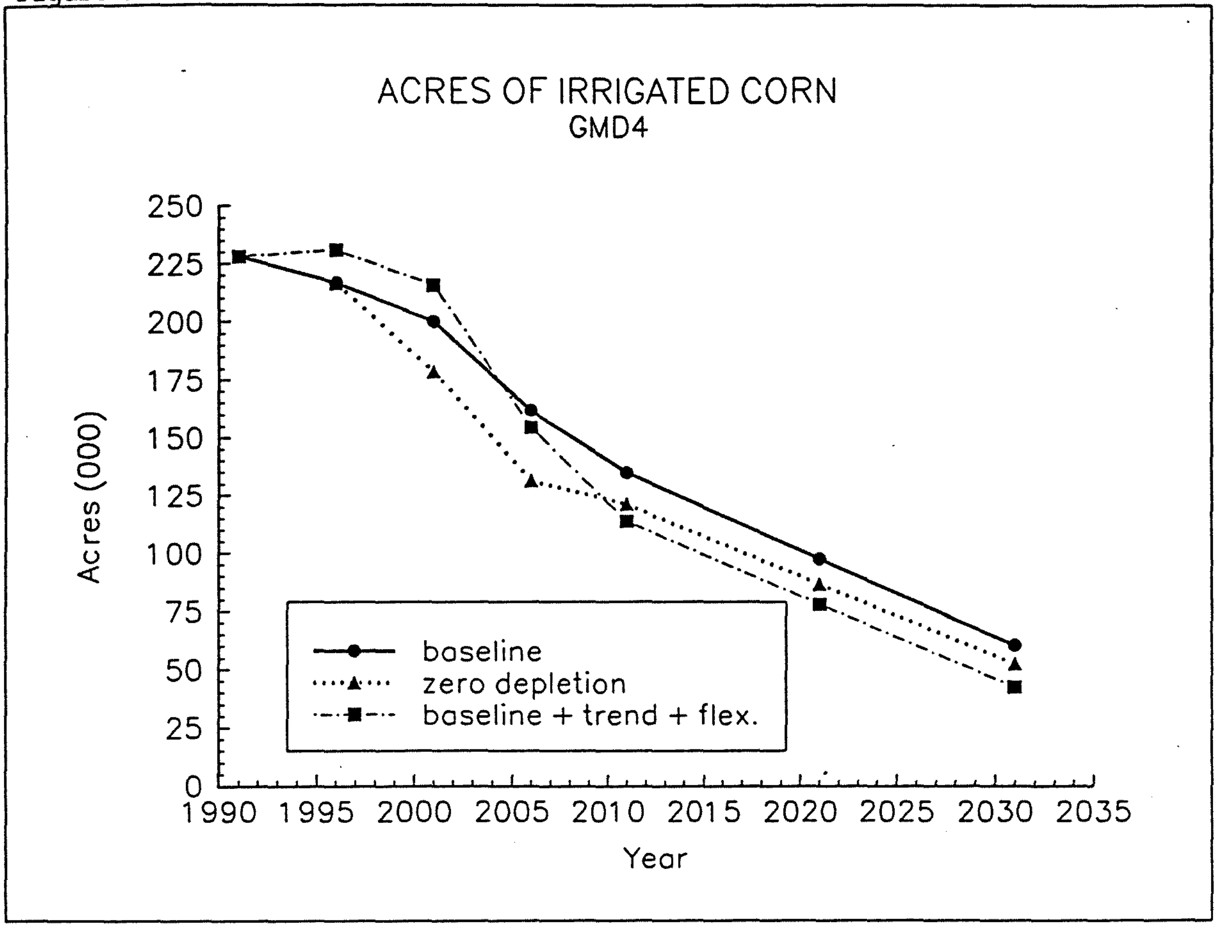
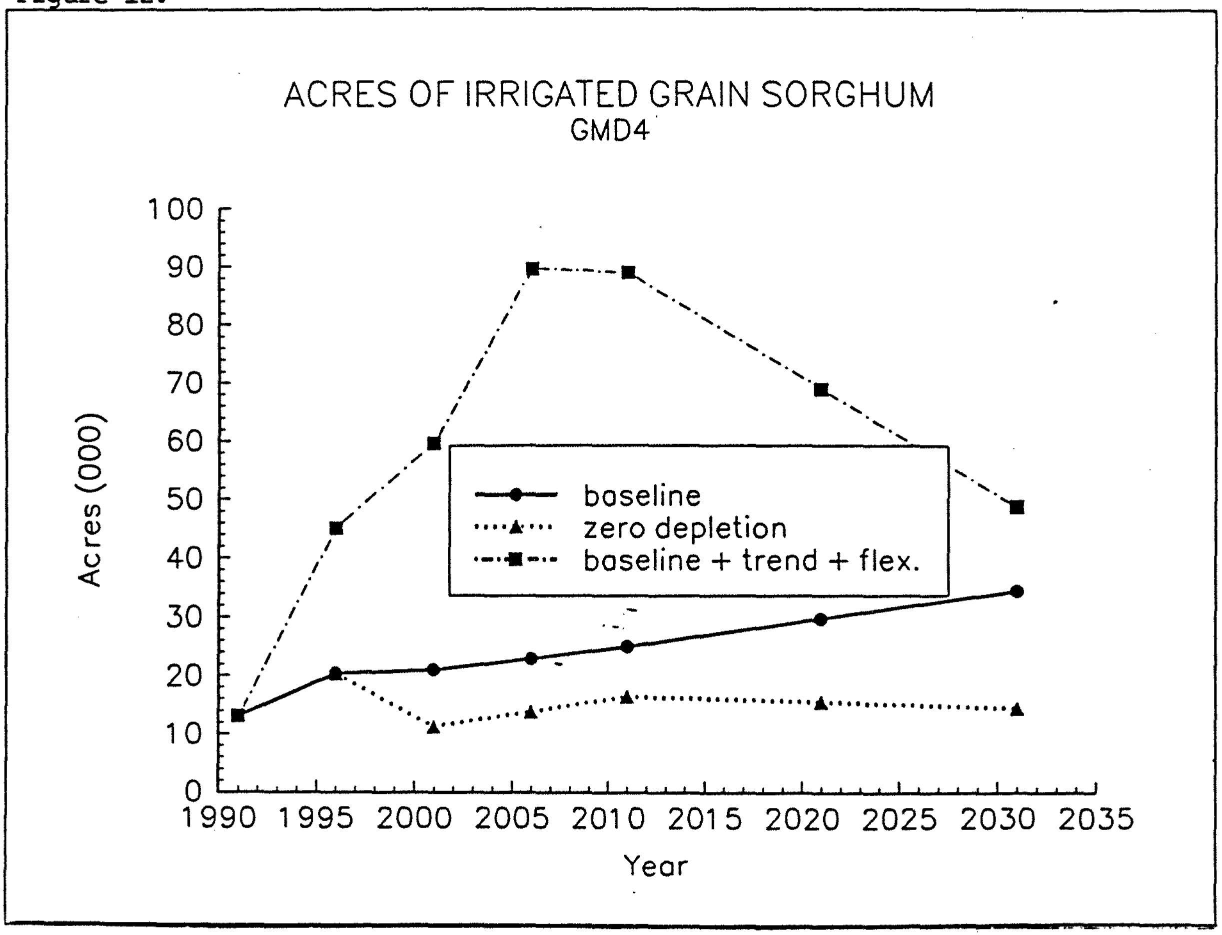


Figure 12.



continue with a lower but steady irrigated wheat acreage.

Acres of Dryland Crops

Policies on land and water use also affect dryland crop acreage (Figure 14). As total irrigated acres decrease, nonirrigated crop acreage increases. It is not a one-for-one acre shift, because some of the land shifting to nonirrigated crops is used for fallow. Nonirrigated cropland shows a steady increase for baseline throughout the 1991-2031 period. For zero depletion, nonirrigated crop acreage increases faster after 2001 than for baseline. The zero depletion policy would result in more of northwest Kansas being in nonirrigated crops. For the B+T+F option, nonirrigated crop acres decline until 2006 and rise thereafter. By 2031, nonirrigated crop acreage for B+T+F is nearly the same as for zero depletion and both are higher than baseline. Having rapidly depleted the aquifer under the B+T+F option, the region begins a more rapid transition to dryland agriculture after 2006.

Figure 13.

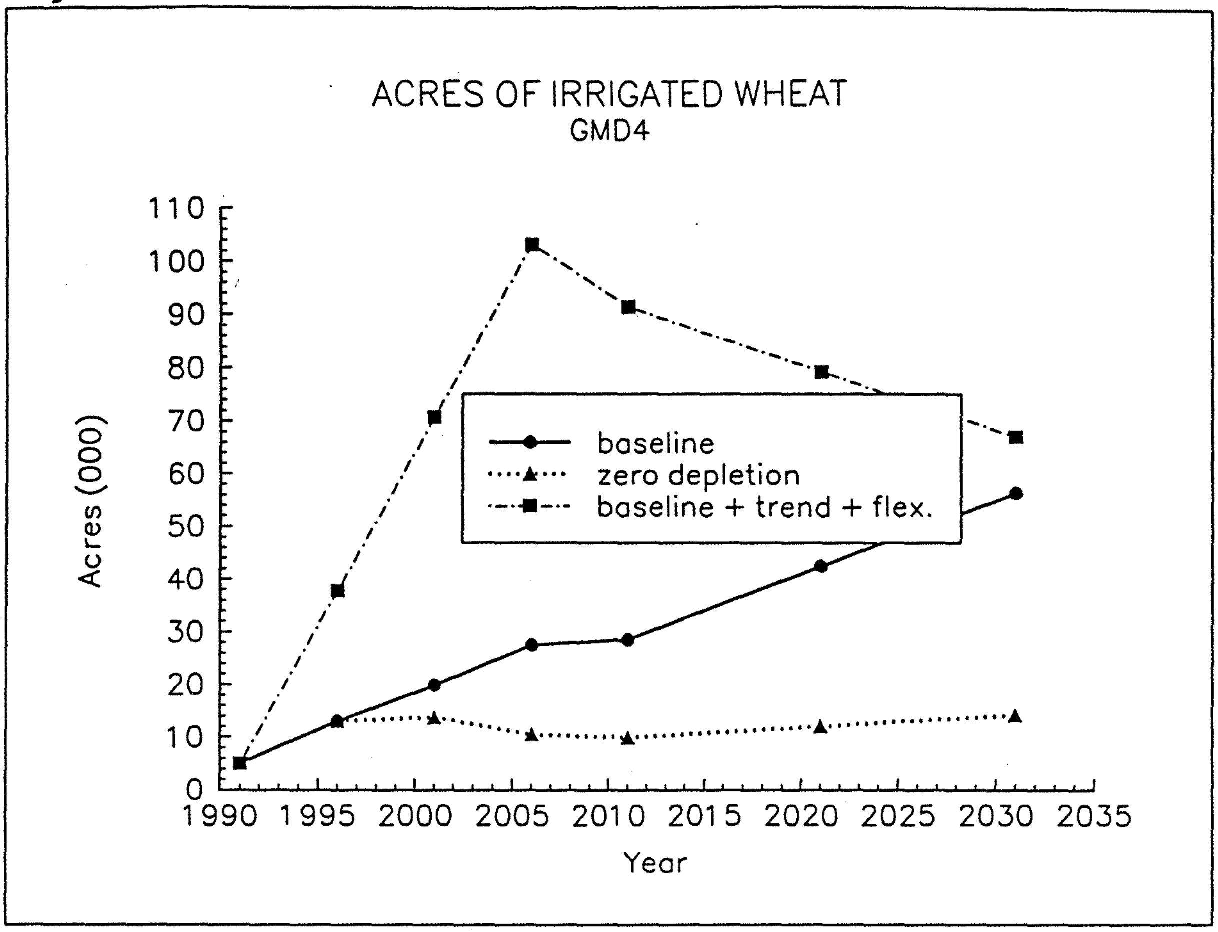
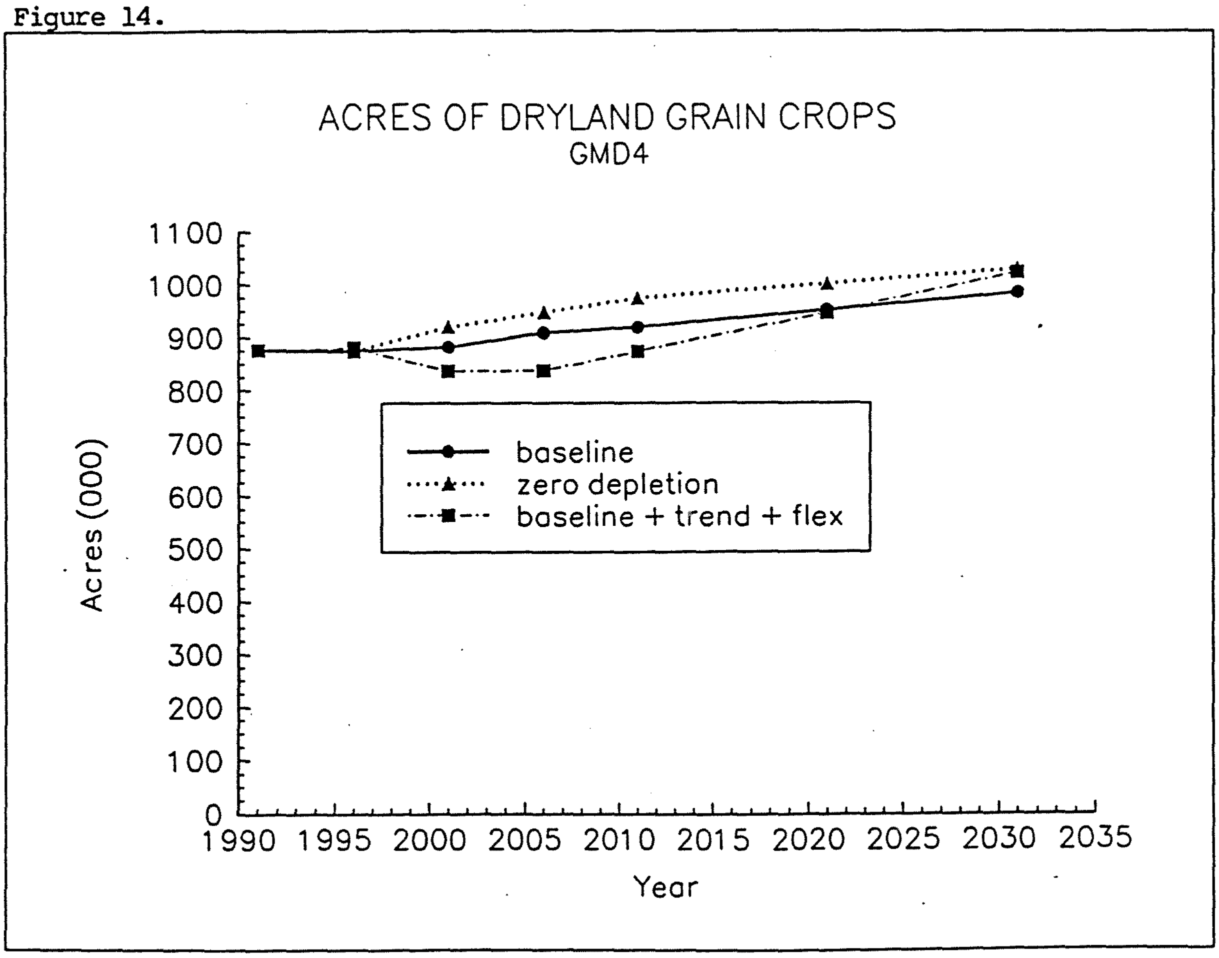


Figure 14.



SUMMARY

Water use by irrigators in GMD4 is influenced by many factors; some factors are related to hydrologic changes, some are controlled by irrigators, and some are associated with general water policies and by government farm programs. The composite of these factors influences irrigators differently, based on existing saturated thickness of the aquifer and well GPM. Great differences exist among irrigators in GMD4 in regard to the hydrology of the aquifer. In 1991, the saturated thickness ranged from less than 25 feet to over 150 feet. The range in well yield was from less than 150 to more than 1600 GPM. Irrigators response to policies that reduce water use will be different depending upon the saturated thickness of the aquifer and their well GPM.

Two general types of policies were studied. One policy, called zero depletion, reduced water pumped when the saturated thickness declined to a predetermined level. Once the saturated thickness reached that level and the irrigator had withdrawn the maximum depletion allowed, the annual withdrawal from the aquifer was limited to annual recharge. The other policy studied restricted the water authorization to 18, 15 and 12 acre-inches. Responses to these policies would be expected to be very different among irrigators. The differences were caused by differences in saturated thickness at the base period and well GPM. Well GPM becomes an important factor because it determines how many acres can be irrigated during the most critical crop stages, flowering and yield formation.

The major difference between the options is that zero depletion, by limiting the amount of water pumped, immediately impacts acreage and water use once the maximum depletable reservoir is reached. The option of limiting the water availability has little effect whenever time for delivery of water is important.

Under the zero depletion policy, the aquifer's saturated thickness is the key factor. If irrigators are allowed to withdraw 25 percent of the aquifer of the base year, then irrigators having a saturated thickness of 35 feet have 9.25 feet of saturated thickness available before pumping must be reduced, whereas those with 150 feet of saturated thickness have 37.5 feet available before pumping is reduced. In GMD4, some irrigators would not be affected by a policy that allows 25 percent of the aquifer to be withdrawn for 40 years under current usage, but others would be affected in 10-15 years.

Limiting the authorization to less than 24 acre-inches has a different effect. To fully irrigate corn requires about a 8.5 GPM per acre with a 65 percent efficient irrigation system. If the authorization is for 160 acres, than a well GPM of about 1350 is needed to meet water requirements for corn during the critical tasseling and silking stages. If the authorization is reduced to 18 inches, then the irrigator likely will reduce corn acreage so that fewer than authorized acreage can be fully irrigated. For example, for irrigators that have a 400 GPM well and 160 acres authorized for irrigation, time available for pumping becomes critical. Many irrigators with low GPM wells do not have the time to pump the allowed 24 acre-inches on 160 acres, so reducing the water authorization to 18 acre-inches or fewer may have little effect on their irrigation practices.

The two options impact groups of irrigators in different ways. The zero depletion option impacts groups with small saturated thickness first (groups 1 and 2). Under this option, group 5 was not affected by the end of the 40-year study. The option to limit water allocation had the greatest effect on the groups with the high yielding wells, because they could deliver the water as needed to a crop. By reducing the allocation, the amount of water pumped was reduced as well. But for the groups with low GPM (groups 1, 2 and 3), their greatest constraint was pumping time and not water availability. For these groups, reducing a water allocation had little or no effect until the allocation was reduced to 15 acre-inches or fewer, because well capacity was too low to use any allocation provided.

Two other scenarios were studied. One scenario relaxed the rigid constraints on the selection of crop acreage and allowed specific crop acreage to increase by 1 percent per year. The other scenario added to the crop flexible model an increase in crop yield trend so that the increase from 1991 to 2031 was the same as that from 1951 to 1991.

In the study, net returns were about four times greater per acre from irrigated crops than from dryland. Net returns from grain sorghum were higher than from corn for the 1991-2031 period, because over time, corn acreage was affected more by reduced water available. Net returns were less than 50 percent higher from irrigated wheat than from dryland crops. High water-efficient systems showed a high net return over the study period. A decline in the saturated thickness of 1 foot in the GMD4 region reduced net returns by nearly 1 million dollars per year. Groups 1B, 2B, 3B, 4B, and 5B, those with the high GPM, had about twice the net returns as their counterparts in groups 1A, 2A, 3A, 4A, and 5A. The scenario with the higher crop yield trend and flexibility in selecting crops increased average, annual, crop net returns by 22 million dollars above baseline, whereas providing crop-selection flexibility only increased average, annual, crop net returns by 5 million dollars per year over baseline (caution: the effect of higher crop yields and thus increased production on crop prices was not studied).

The number of irrigated acres was affected most by feet of saturated thickness. Within a saturated thickness group, those irrigators with the higher well GPM had nearly twice the irrigated acreage. Reducing the water authorization from 24 to 18 acre-inches increases irrigated acreage because of a shift from more to less water-intensive practices. Providing more flexibility to the model increases irrigated acreage by an average of 36,759 acres per year. The scenario with higher crop yield has an average of 41,524 more irrigated acres than baseline; thus, the higher trend adds only a small increase over that resulting from more flexibility. Irrigated crop acreage declines very early in the period, as acreage shifts to more water-intensive crops. However, irrigated acreage also declines late in the period, as reduced water availability limits irrigation of all crops. Two scenarios greatly reduced irrigated acreage. Reducing the water authorization to 12 acre-inches reduced acreage by an average of 14,795 acres per year, and the zero depletion option reduced acreage by 44,792 acres per year. The zero depletion option reduces acreage about as much as the model with increased flexibility.

Irrigated corn acreage is influenced significantly by both the feet of saturated thickness and well GPM. Most of the irrigated corn acreage is in the groups with 76 to 125 feet of saturated thickness. The cost of pumping large volumes of water per acre from the deeper wells with over 125 feet of saturated thickness has an adverse effect on the number of irrigated corn acres. Reducing the water authorization to 15 acre-inches reduces irrigated corn acreage by about 15,000 acres per year below baseline. Reducing the authorization to 12 acre-inches also reduced corn acreage, but not significantly more. The zero depletion option model has 35,073 fewer acres of irrigated corn than baseline for the 40-year period. Thus, the zero depletion option has the greater effect on irrigated corn acres, but acreage decreases throughout the period for all options. The availability of water in a timely manner becomes very significant in determining irrigated corn acreage. Adding flexibility to the model and increasing crop yields over time had little effect on the number of acres of irrigated corn acreage.

Irrigated grain sorghum acreage was influenced positively by saturated thickness, but only about half the amount compared to irrigated corn. The higher GPM group within each saturated thickness group had over twice the acres of grain sorghum as its counterpart with lower GPM, and acreage increased as feet of saturated thicknesss increased. Adding the crop selection flexibility to the model more than doubles grain sorghum acreage. This scenario had little effect on corn acreage, but its greatest influence on grain sorghum acreage. This illustrates the need for irrigators to adjust acreages of crops as water supply becomes more limited over time. However, the effect of higher crop yield trend is to reduce grain sorghum acreage. Higher trends result in irrigated acreage being used for crops other than grain sorghum.

The zero depletion option reduces total irrigated acres, and irrigated corn acreage but maintains irrigated wheat and grain sorghum acreages. The effect of the zero depletion policy was mainly on irrigated corn acreage.

Irrigated wheat acreage remains relatively stable over time for groups 1A, 2A, and 1B when the water authorization is decreased. The effect of reducing water authorization to 15 acre-inches was to increase irrigated wheat acres. Having less water available per acre favors the less water-intensive crops, such as wheat. Reducing the authorization to 12 acre-inches had an effect not significantly different than that of the 15 acre-inches authorization. A significant shift in acreage was from dryland wheat to irrigated wheat. The zero depletion option had 47,877 fewer acres per year on the average than baseline, with most of this reduction in corn.

Average water use per group in baseline over the study period was over 36,816 acre-feet per year, and because there were 10 groups, the average for GMD4 was 368,158 per year. Average water use per acre in baseline over the study period was 1.65 acre-feet. Reducing the saturated thickness 1 foot reduced water use by over 2,000 acre-feet. Water use by the groups with the highest GPM was nearly twice that by the groups with lowest GPM. Compared to baseline water use, reducing water authorization to 15 acre-inches decreased water use by an average of 14,109 acre-feet per year, and reducing it to 12 acre-inches decreased water use by 39,312 acre-feet per year. Adding flexibility to select acreage of irrigated crops increased annual water use by an average of 47,287 acre-feet over baseline. Increasing the crop yield trend in the model did not significantly increase water use over that in the model with added flexibility. Water use until 1996 increased for all options. After 1996, water pumped decreased for most options, but not B+T and B+T+F. The greatest effect on water use was a reduction of 86,920 acre-feet per year for the zero depletion option. The policy of limiting water pumped is a more effective way of reducing water use than reducing the water right authorization.

In the model results, flood irrigation systems were converted to more efficient sprinkler or drip line systems as rapidly as allowed. The conversion rate was restricted to no more than 5 percent per year of the remaining systems. Systems on areas of less than 80 acres could be converted to only the drip line system.

Model results showed fewer wells being replaced after 2011, except for the higher crop yield trend model. That model replaced many sprinkler wells and systems as they depreciated out. The higher yield trend model had much higher net returns that provided the incentive to replace wells, mostly in groups 4A, 4B, 5A, and 5B.

Increases in dryland acres occurred most consistently with the 12 acre-inch water authorization and zero depletion. The impact of the 15 acre-inch authorization was to reduce water use per acre instead of reducing acres irrigated. The 12 acre-inch authorization model had an increase of 25,600 acres per year over baseline, and the zero depletion model had an increase of 49,200 acres per year. Also, the shift to dryland was very significant by 2011 and continued to increase thereafter.

The higher crop yield trend model with flexibility showed a significant decrease in dryland grain sorghum. The acre shift was to irrigated grain sorghum. The model with only more flexibility showed more than twice the decrease in dryland grain sorghum acres from the higher trend model. By 2021, significant increase occurred in dryland grain sorghum acres over baseline. The zero depletion model had a small increase in dryland grain sorghum over baseline. The increase in dryland grain sorghum in the zero depletion model was much less than that for dryland wheat in the same model.

A policy such as zero depletion can reduce water pumped, thereby conserving the Ogallala Aquifer with a small reduction in net returns. However, the impact of such a policy is not distributed equally among all irrigators of GMD4. Those with little saturated thickness are affected first. The policy achieves most of its reduction in water by shifting from irrigated corn to irrigated wheat and grain sorghum.

A policy to limit the per acre water allocation is not as effective as zero depletion in reducing water pumped, but then only if the reduction is to 12 acre-inches. This policy affects those irrigators with highest GPM first, because they have wells with capacity to deliver large volumes of water to many acres in a timely manner.

Allowing irrigators more flexibility in selecting crops would increase net returns, acres irrigated, and water pumped. The effect would be to deplete the aquifer faster, thereby reducing income, acreage, and water use in the longer term.

A faster rising trend is crop yields has the greatest impact on net returns.

A policy that conserves water and prolongs the life of the Ogallala Aquifer and treats all irrigators equally will be difficult to achieve. Neither the proposed zero depletion policy nor restricting the acre-inch allocation achieves this goal. Each policy impacts a different group of irrigators in GMD4, thus making implementation very difficult. Given the great differences in saturated thickness and the availability of water in the aquifer, developing a policy in which every irrigator shares equally, on a per-acre basis, in conserving water may be impossible. The effect of a policy such as the zero depletion type after many years of pumping is to retain from 70 to 91 percent of the base saturated thickness. Reaching the point where all irrigators extract only the amount of recharge would take 50 years and possibly more. In the meantime, some irrigators would be affected immediately. However, this disparate effect also occurs under existing conditions.

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APPENDIX A

Description of the model in matrix format is given in Table A1. The columns indicate the choice variables from which the procedure selected the combination providing the highest net returns. The rows represent the restrictions and limits imposed and which cannot be exceeded in selecting the highest net return.

Choice Variables

The numbers in parentheses immediately below the column headings are the numbers of choices included in the model. For example, the column heading "produce irrigated crops, irrigation regime and system" has the number 202. The model includes 202 different combinations of the type of crop, the irrigation regime for producing the crop, and the irrigation system used. The model chose the combination of irrigated crops and acreage, irrigation system, irrigation regime, amount of water pumped, the period in which to pump, the dryland crops and acreage, the number of wells to use by system, land set aside, commodity sales, fertilizer purchases, amount of labor hired by quarter or month, livestock products produced and sold, and the decision to replace irrigation systems when depreciated. The model has a total of 370 variables, which are the choices from which the highest net return combination is selected. Below the column headings are the units of each variable.

Resource Limits

The left side of each row specifies the type. The OBJ equation is the so-called objective row and is used to determine the maximum total net returns. All the units in the OBJ equation row are in dollar units. A negative sign in the row means that the values represent costs or expenses, and a positive sign means the values represent income or sales.

To the right of each row name is a number in parentheses that is the number of constraints in that group. For instance, the model has one objective row, one total crop land constraint, one total irrigated land constraint, etc. The model has a total of 199 constraint and transfer equations. The model has upper limits on the acreage for each system, crop acreage base, and total acreage for the crop.

For the rows, other than the objective row, the + and - signs refer to the sign of the technical coefficients in that position in the matrix. The + sign means the resource is being used from that available for the region. The - sign means a resource or service is being provided.

The matrix is the same for all 10 regions except for the amount of resources available in each. The number of farm operators, irrigated and dryland, total acres, pastureland, number of wells by system, saturated thickness, GPM, and water authorization were different for each region.

Table A1. Model in Maxtrix Format

		Produce Irrigated Crops, Irrigation Regimes, and System (202)	Produce Dryland Crop (6)	Pump Water by Crop and Period and System (120)	No. Wells by Crop (4)	Land ARP (3)	Sell Commodities (4)	Purchase Fertilizer (5)	Hire Labor (12)	Produce and Sell Livestock (5)	Replace Irrigation System (5)
		(Acre)	(Acre)	(Hr)	(No)	(Acre)	(Bu)	(Unit)	(Hr)	(Unit)	(Unit)
OBJ equation $	(1)	(-)	(-)	(-)		(-)	+	(-)	(-)	(+)	(-)
Crop Land (Acre)	(1)	+	+			+					
Irrigated Land (Acre)	(1)	+									-
Acres by System (Acre)	(3)	+			-						
Acreage Base	(3)	+	+			+					
Acreage by Crop	(8)	+	+			+					
Pasture (Acre)	(1)									+	
Water Pumped (Acre)	(1)	+									
Labor Use (Hr)	(4)	+	+						-	+	
Field Time Available	(8)	+	+						-		
Crop Water Use (Ac in/Ac)	(63)	+		-							
Crop Production (Bu/Acre)	(6)	-	-				+				
Input Use (Lbs/Ac)	(3)	+	+					-			
Pumping Time	(27)	+		-							
Pump Time Limit (Hr)	(21)			+	-						
Well Limit (No)	(5)				+						-

APPENDIX B

The number of wells reported tested in GMD4 increased steadily until 1985 and thereafter declined sharply. This pattern existed for all reported systems. The implications of such a pattern are important, because replacement may follow a similar pattern. With an assumed well life of 45 years, the physical life of many wells will have come to an end by 2030. If the future economic outlook justifies well replacement, irrigated acres can be maintained, otherwise irrigated agriculture will be diminished greatly.

Table B1. Frequency of Number of Wells by Test Date in GMD4 by Group and by System

	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	Total
Flood											
1960	5	0	5	5	4	10	10	8	7	5	59
1965	4	2	4	1	6	12	6	13	6	7	61
1970	8	5	2	4	10	7	5	17	8	7	73
1975	20	13	12	10	11	24	19	48	16	13	186
1980	18	8	10	7	22	23	19	36	9	35	187
1985	28	25	28	21	33	50	51	66	49	68	419
1990	8	2	6	1	12	14	21	11	9	20	104
1995	1	0	0	0	0	1	0	0	0	1	3
Sprinkler											
1960	6	6	1	3	12	6	10	8	12	8	72
1965	6	2	13	1	7	4	5	5	10	12	65
1970	4	2	6	3	10	11	9	19	10	7	81
1975	12	19	23	27	15	27	32	24	1	17	197
1980	11	12	22	15	30	25	33	41	32	41	262
1985	48	33	61	55	111	89	110	116	93	74	790
1990	3	15	20	30	35	40	51	31	39	22	286
1995	1	0	1	0	1	1	1	4	2	1	12
High Efficiency Sprinkler											
1960	3	0	1	0	0	0	2	0	0	0	6
1965	1	1	0	0	1	0	1	0	2	0	6
1970	1	0	0	0	0	0	0	1	1	0	3
1975	1	0	0	1	1	0	4	2	2	0	11
1980	4	1	0	1	4	0	1	2	3	2	18
1985	8	1	2	2	7	1	2	1	4	1	29
1990	1	2	0	0	4	1	2	0	3	1	14
1995	0	0	0	0	0	0	0	0	0	0	0

APPENDIX C

Table C1. shows the decline in the average well GPM for each group beginning from the base year of 1991. By 2031, it is estimated that only 5B and marginally 4B in GMD4 have the well capacity to fully irrigate the authorized acres. By 2011, the GPM in wells in six of the groups has declined 50 percent or more from base year for GMD4. Many wells in GMD4 depreciated out by 2021 and 2031, but estimated well GPM discouraged reinvesting, except in groups such as 4B and 5B.

Table C1. Average GPM by Region and Period for Alternative Water Authorizations in N.W. Kansas

	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B
GMD4 - Baseline - 24 inch Authorization										
Baseline 1991	287	636	390	679	421	742	415	776	459	826
1996	224	503	337	580	362	637	381	731	436	788
2001	180	433	281	485	293	528	339	669	411	747
2006	133	234	232	396	241	426	295	608	387	710
2011	112	95	195	316	206	335	262	550	364	670
2021	98	28	147	195	168	196	203	444	323	590
2031	107	51	122	151	146	145	165	343	281	514
Not in GMD4 - Baseline - 24 inch Authorization										
1991	296	680	332	859	302	943	314	817	326	881
1996	254	484	309	661	286	702	301	691	313	789
2001	204	278	284	330	263	501	281	562	295	677
2006	165	128	261	186	243	371	264	439	278	574
2011	132	136	240	119	223	288	247	330	262	481
2021	121	160	203	58	187	188	214	310	229	319
2031	128	175	171	61	157	145	184	211	198	242

APPENDIX D

Calculating the Maximum Depletable Reservoir for the Zero Depletion Option.

The zero depletion option was based on the idea of a maximum depletable reservoir (MDR). An MDR is the amount by which the saturated thickness of a well or aquifer can be reduced by pumping. The formula used to determine the MDR, developed by staff of GMD4, allows the withdrawal of a percentage of the aquifer as measured from some reference year. The formula used was:

$MDR = St^{2*}.002$, where MDR is as defined and St is saturated at the reference year (1991 was used). The MDR for the 5 regions in GMD4 are:

Group	Average Saturated Thickness, 1991 (ft.)	MDR % (ft.)	% Saturated Thickness Withdrawn
1A	35	2.5	7
1B	39	3.0	8
2A	67	9.0	13
2B	66	9.0	13
3A	88	15.5	18
3B	88	15.5	18
4A	112	25.0	22
4B	113	25.5	23
5A	147	43.2	29
5B	150	45.0	30

The year-to-year decline in saturated thickness was estimated for each group. When the decline in saturated thickness reached the amount in feet specified by the MDR for that region, water pumped for irrigation thereafter was limited to the amount of recharge. Recharge was estimated as .5 inch per year for dryland and 1 inch per year for irrigated land.

APPENDIX E

Members of the Water Resource Study Advisory Committee

Ground Water Management District

Wayne Bossert - Manager
Sharon Steele - President
Eugene Schwarz - Vice President
Winfred Inlowes - Representative
Mike Foust - Treasurer
Jim Mosberger - Representative
Ray Luhman - GMD Staff
Keith Reavis - GMD Staff

Kansas State University

Barry Flinchbaugh - Extension State Leader, Agriculture Economics
Daniel Bernardo - Department Head, Agricultural Economics
Orlan Buller - Professor, Agricultural Economics
Rick White - Head, Northwest Research-Extension Center
Reba White - Northwest Area Extension Director
Mark Nelson - Northwest Area Extension Economist
Freddie Lamm - Irrigation Researcher, Northwest Research-Extension Center
Bob Standage - Thomas County Extension Agent, Agriculture
Dana Belshe - Sherman County Extension Agent, Agriculture

Local Concerned Producers Group

Lyle Saddler - Thomas County - Irrigator/Dryland
Max Embree - Thomas County - Irrigator/Dryland
Tom Sloan - Thomas County - Irrigator/Dryland
Ray Crumbaker - Thomas County - Dryland
Don Kistler - Thomas County - Dryland
Larry Ihrig - Sherman County - Irrigator/Dryland
Wilmer Bahe - Sherman County - Irrigator/Dryland
Alan Townsend - Sherman County - Irrigator/Dryland
Bill Gattshall - Sherman County - Irrigator/Dryland
Ted Ziekle - Cheyenne County - Irrigator/Dryland

Local Elected Officials

Ernest Kistler - Thomas County Commissioner - Producer
John Bremenkamp - Thomas County Commissioner - Manufacturing

APPENDIX F

Crop Yield per Acre per Irrigation Regime

Tables F1, F2, F3 and F4 provide estimates of crop yields per irrigation regime for corn, grain sorghum, wheat, and alfalfa, respectively. Total water available (rainfall plus irrigation) is given for each irrigation regime and for each crop growth stage with associated yield per acre. Computer models were used to estimate crop water use and soil water drainage and the crop yield associated with water use. Irrigation regimes were specified in the model. In the tables, the numbers below the heading 'irrigation regimes' are the dates on which irrigation began. The number of days needed to complete an irrigation was determined by the well yield as expressed in gallons per minute (GPM).

Rainfall during each crop stage is given for each crop. The rainfall given is a 30-year average.

Drainage is the amount of water that moves to below the root zone.

Table F1. Corn Yield per Acre by Irrigation Regime and Total Water Required by Crop Stage of Development.

CORN	CROP STAGES						
Regime	Pre-Vegetative Inches	Vegetative Inches	Flowering Inches	Yield Formation Inches	Mature Inches	Yield Bu	Drainage Inches
Rainfall	5.08	6.37	1.27	1.750	1.09		
Dryland						36.7	
Irrigation Regime #							
Pre-plant	4.99	11.65	3.52	3.43	.81	71.1	3.34
701	3.97	9.72	4.63	5.48	.97	118.4	.26
730	4.01	9.28	3.54	5.97	1.09	94.8	.50
825	4.23	10.38	3.44	4.45	1.14	83.6	1.47
401; 701	6.07	12.69	4.59	5.95	1.04	135.1	5.34
401; 715	6.52	12.14	4.25	6.51	1.07	129.5	5.32
401; 730	7.04	12.06	3.76	6.18	1.11	107.6	5.82
401; 825	8.23	12.07	3.53	4.60	1.14	88.7	7.16
701; 730	4.37	11.29	4.68	7.38	1.36	156.5	2.82
701; 825	4.62	11.60	4.57	6.32	1.36	141.1	3.63
401; 701; 730	8.68	13.37	4.73	7.07	1.24	158.8	8.76
401; 701; 825	9.28	12.84	4.60	4.38	1.37	148.6	9.58
401; 730; 825	9.41	12.11	3.75	6.39	1.50	114.6	9.49
701; 730; 825	4.81	11.74	4.69	7.76	2.78	162.5	7.09
401; 701; 730; 825	9.61	12.84	4.74	7.80	2.81	163.4	13.08

Table F2. Grain Sorghum Yield per Acre by Irrigation Regime and Total Water Required by Crop Stages of Development.

GRAIN SORGHUM	CROP STAGES						
Regime	Pre-Vegetative Inches	Vegetative Inches	Flowering Inches	Yield Formation Inches	Mature Inches	Yield Bu	Drainage Inches
Rainfall	5.08	6.38	1.27	1.75	1.09		
Dryland						51.8	
Irrigation Regime #							
Pre-plant	4.21	11.85	2.13	1.75	1.93	76.7	2.34
705	2.85	10.56	2.64	2.44	2.99	99.3	.19
715	3.04	10.69	2.09	2.33	3.37	90.4	.48
810	3.37	10.98	1.98	1.62	3.17	77.1	1.00
501; 705	6.29	13.17	2.86	2.68	3.16	108.9	4.82
705; 715	3.79	11.67	2.83	2.98	4.22	110.4	2.48
705; 810	4.12	11.74	2.81	2.59	4.24	111.4	3.43
501; 705; 715	8.41	12.57	2.93	3.10	4.37	118.1	8.17
501; 705; 810	8.84	12.57	2.90	2.64	4.41	113.6	9.15
501; 715; 810	8.79	12.08	2.29	2.45	4.19	99.1	8.56
705; 715; 810	4.24	21.77	2.85	2.79	6.20	117.1	6.17
501; 705; 715; 810	8.96	12.57	2.93	3.10	6.46	119.1	11.96
625	4.24	11.77	2.85	2.99	6.20	117.1	.17
501; 625	8.96	12.57	2.93	3.10	6.46	119.1	4.79
501; 625; 715	2.82	11.21	2.62	2.34	2.83	101.6	8.79

Table F3. Wheat Yield per Acre by Irrigation and Total Water Required by Crop Stage of Development.

WHEAT	CROP STAGES						
Regime	Pre-Vegetative Inches	Vegetative Inches	Flowering Inches	Yield Formation Inches	Mature Inches	Yield Bu	Drainage Inches
Rainfall	4.79	5.11	1.17	3.21	1.62		
Dryland						35	
Irrigation Regime #							
Pre-plant	3.69	8.96	2.11	5.65	1.85	40.4	1.46
401	3.25	7.82	2.38	6.54	2.28	46.0	.10
515	3.30	7.86	1.90	6.44	2.80	42.5	.17
610	3.82	8.47	2.07	5.51	2.40	41.0	1.14
625	3.34	7.96	1.95	5.02	1.68	36.6	.25
815; 401	4.85	10.38	3.13	7.31	2.61	50.6	4.73
815; 515	6.48	9.76	2.14	6.94	2.96	47.1	5.06
410; 515	4.14	9.26	3.01	8.39	3.40	54.1	3.57
401; 610	5.25	9.55	3.06	7.29	2.92	51.3	4.49
815; 401; 515	8.54	10.62	3.15	8.48	3.42	54.3	9.55
815; 401; 610	10.07	10.62	3.15	7.32	2.93	51.5	10.46
815; 515; 610	10.77	9.81	2.14	6.95	3.11	47.5	10.05
401; 515; 610	6.64	9.65	3.07	8.44	3.86	54.5	8.63
815; 401; 515; 610	11.51	10.62	3.15	8.48	3.85	54.8	14.62

Table F4. Alfalfa Yield per Acre by Irrigation Regime and Total Water Required by Cutting.

ALFALFA	CROP STAGES						
	Before First Cutting	Before Second Cutting	Before Third Cutting	Before Fourth Cutting	Fall	Yield	Drainage
	(Inches)	(Inches)	(Inches)	(Inches)	(Inches)	(Ton)	
Rainfall							
Dryland							
Irrigation Regime #							
401	9.58	5.86	4.35	1.91	1.57	5.2	.71
615	7.35	5.75	5.36	2.66	2.15	5.3	.04
805	5.15	4.96	3.68	3.14	3.17	4.9	.14
915	9.09	5.34	3.79	1.61	2.75	4.8	1.19
401; 615	10.35	6.87	6.15	3.15	2.73	6.3	1.77
401; 805	11.67	6.04	4.67	3.32	3.32	5.8	2.58
401; 915	9.89	5.46	4.14	3.33	3.94	5.5	4.62
615; 915	8.96	6.29	5.81	3.77	3.72	6.1	.91

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