ECONOMIC IMPLICATIONS OF DIMINISHING GROUNDWATER SUPPLIES IN THE HIGH PLAINS REGION

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Introduction

The Ogallala Aquifer, which underlies a vast area reaching from Nebraska to Texas, is an important source of water for homes, industries and irrigation (Figure 1). Irrigation wells first started tapping the Ogallala in the "Dust Bowl" days of the 1930s, eventually turning 16 million acres of dry cropland and range into highly productive irrigated lands. Irrigation has changed High Plains agriculture from an uncertain and meager existence to a more certain and more viable economic enterprise. Moreover, the growth of irrigated agriculture has been the major force in the growth and development of many rural towns and communities in the Region, and their future economic well being depends, in part, on the future of irrigated agriculture.

At the present time, the prosperity and level of economic activity created by irrigation development in the Ogallala Region is being threatened by declining groundwater supplies. The recently completed High Plains Ogallala Aquifier Study found that by the year 2000 over two million acres in the Region may revert to dryland agriculture from groundwater exhaustion, increasing to over five million acres by the year 2020, Supalla, Lansford, and Gollehon [5, p. 313]. These declines in irrigation imply a reduction in the volume of economic activity for all or portions of the region, with accompanying decreases in personal income, employment, tax revenues and the general quality of life. Declining groundwater supplies also mean increased competition for water across alternative uses, which has implications for municipal water supplies and non-agricultural economic activity.

Although the combined effect of groundwater declines and the importance of irrigated agriculture as the economic base for much of the Ogallala Region clearly means that one should expect economic adjustments in the years ahead, there is no a priori reason to believe that the adjustments will be painful or negative. What kinds of adjustments occur will depend on technology, the rate of change in water availability, the spatial characteristics of the aquifer, and prospects for the growth and development of non-water intensive economic activities in the Region. The primary purpose of this paper is to explore, from the standpoint of community planning, the economic implications of diminishing groundwater supplies in the Ogallala Region. This examination will be conducted in a dynamic context, giving consideration to each of the aforementioned factors.

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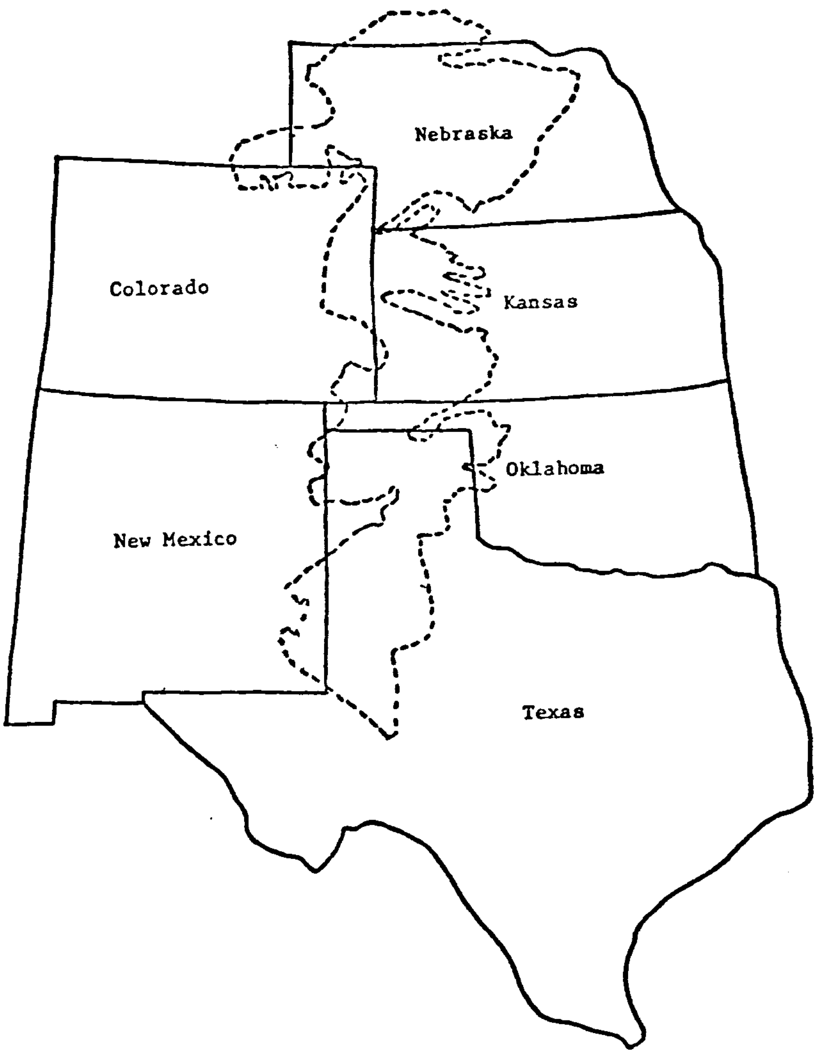
To achieve the paper's primary objective, the following six major subtopics were considered: (1) definition and description of the Ogallala Region; (2) implications of changing technology; (3) direct economic impacts, with emphasis on the agricultural sector; (4) regional indirect impacts; (5) community level impacts; and (6) opportunities for impact mitigation.

Figure 1. HIGH PLAINS OGALLALA FORMATION



Definition and Description of the Ogallala Region

The Ogallala Region receives its identity from geological rather than economic characteristics. With the possible exception of the general predominance of agriculture in the area, the Ogallala Region does not adequately meet most conventional definitions of an economic region. For instance, there is no central unifying socioeconomic node within its borders, nor are the various local retail trade centers economically linked in any significant way. The primary urban centers that do provide the better part of the Region's inputs for agricultural production, and also serve as major collection points for its agricultural outputs, are located in an east-west pattern outside the area. The major outside urban centers include Omaha, Denver, Kansas City and Oklahoma City. Any flow of trade in a north-south direction within the Ogallala Region is quite limited, despite the fact that the Region is elongated on a north-south axis.

TABLE 1

Structure of the Ogallala Regional Economy: Total Economic Output by Sector*

Economic Sector:	Northern States Value	Northern States % of Total	Southern States Value	Southern States % of Total	Total Ogallala Region Value	Total Ogallala Region % of Total
	(output in millions of 1977 dollars)					
Fare Production	3,733.5	25.0	2,719.8	9.0	6,532.3	14.3
Feedlot Livestock	1,479.5	9.9	1,271.3	4.2	2,750.8	6.1
Agricultural Processing	2,124.4	14.2	2,250.7	7.4	4,375.1	9.7
Ag. Support Services	425.3	2.8	437.4	1.4	862.7	1.9
Other Manuf. & Mining	1,478.3	9.9	3,968.5	13.1	5,446.8	12.0
Energy	950.6	6.4	11,309.8	37.3	12,260.4	27.1
Utilities	565.4	3.8	1,235.1	4.1	1,800.5	4.0
Transportation	286.8	1.9	993.8	3.3	1,280.6	2.8
Trade (Whsl. & Ret.)	1,779.6	11.9	2,642.2	8.7	4,421.8	9.8
Other Services	2,131.4	14.3	3,477.5	11.5	5,608.9	12.4
Total (All Sectors)	14,954.8		30,306.1		45,260.9	

*Source: Arthur D. Little, Inc. [1, pp. 98-108].

From an economic perspective, the Ogallala Area is actually a collection of subregions built around numerous small agricultural trade centers. However, subregional descriptive data is readily available for only a north-south differentiation, Arthur D. Little, Inc. [1]. The descriptive data indicates that the northern subregion, which includes the Ogallala counties in the states of Nebraska, Colorado and Kansas, differs markedly from the southern part, defined to include the Ogallala counties in Oklahoma, Texas and New Mexico.

Agriculturally related sectors account for nearly all of the basic economic activity in the northern subregion, with primary agriculture (farm production and fed livestock) accounting for over one-third of total economic output (Table 1). In contrast, the major economic base in the southern subregion is primary energy (oil and natural gas extraction), which accounts for over one-third of total output. Primary agriculture in the south is the second most important basic industry, accounting for less than 15 percent of total output.

These north-south differences in economic structure are extremely important when considering the implications of diminishing groundwater supplies. The fact that the northern subregion is much more dependent on primary agriculture implies that there is more potential for substantial adverse economic impacts from decreased irrigation. Also, the limited amount of non-agriculturally related economic activity in the northern subregion, suggests that there is very limited potential for economic growth from non-water intensive industries outside agriculture. The implications of the economic structure found within the southern subregion is less clear. On the one hand, primary agriculture accounts for a much smaller part of the total, which means that there is likely to be less total economic disruption from loss of irrigation. On the other hand, the dependence of the southern subregion on energy extraction industries is, at best, a mixed blessing. If one could expect the primary energy activity to be sustained over the long run, industries related to energy production could offer a potential substitute for any decline in irrigated agriculture. But unfortunately, primary energy is also projected to decline, thus, presenting the southern subregion with the need to cope with declines in both of its most important basic industries, Black & Veatch Consulting Engineers [2].

The analytical difficulties posed by subregional differences in economic structure, including the absence of strong economic linkages within the entire Region, are compounded by the fact that the hydrologic conditions found within the boundaries of the Ogallala Formation are also very different. Water availability ranges from over 1000 feet of remaining saturated thickness in the northern most part of the Region to current exhaustion in other areas, Weeks and Gutentag [8]. This means that some parts of the Region may experience growth in irrigated agriculture, while other parts incur significant declines. Indeed, it was recently estimated that there would be a net increase in total irrigated acreage within the Ogallala of about 26 percent over the next four decades, despite a 35 percent decrease in current irrigated acreage due to aquifer exhaustion, Supalla, Lansford and Gollehon [5, p. 313] and High Plains Associates [4, p. B-5].

Implications of Technological Change

In any economic assessment where the impacts are not expected to occur until some distant time, consideration of technological change is extremely important. Usually, the most important issue is that changing technology leads to different input/output relationships, and thus, to different impacts from a given change in direct economic activity. However, in the Ogallala case the technology issue is unusually important, because the potential beneficial effects from technological change in agriculture may partially or completely offset any negative economic impact due to groundwater exhaustion. In this analysis only agricultural technology is considered, however, while other presumably less important technological changes are ignored.

The components of agricultural technology which are most critical to an economic impact analysis include grain yield changes, both dryland and irrigated, and irrigation efficiency. Yield changes are especially important, because rising dryland yields will tend to mitigate the effects of reduced irrigation. The impact of improved irrigation efficiencies is less direct in that greater efficiency makes it possible to irrigate more acres with less water, thus lowering the rate of decline in total irrigated acres. Once total exhaustion occurs, however, irrigation efficiency is irrelevant because no irrigation is possible.

A review of historic changes in grain yields indicates relatively steady and reasonably rapid yield improvements in most crops over the past several decades, Hanway, et al. [3]. As an illustrative case, consider Southcentral Nebraska where corn is the major irrigated crop and grain sorghum is the major dryland crop. From 1950 to 1980 irrigated corn yields increased from about 75 to 137 bushels per acres, while dryland grain sorghum increased from 35 to 76 bushels per acre. Although the consensus view within the scientific community appears to be that yields will not improve in the future as rapidly as they have in the past, substantial improvements are still anticipated through the year 2020. A combined statistical and delphi technique used by University of Nebraska scientists resulted in forecasted yields for Southcentral Nebraska in the year 2020 of 203 and 112 bushels per acre for irrigated corn and dryland grain sorghum, respectively, Hanway, et al. [3, pp. 163-164]. These forecasts imply that the total level of economic activity generated by dryland agriculture in the year 2020 will be almost as great as the amount generated by irrigation at the present time.

The prospects for improved irrigation efficiency are somewhat more variable than the grain yield issue. The major gains in efficiency are expected to come more from adoption of currently known technology than from the development of new methods. The rate of adoption of existing technology, in turn, tends to be a function of the incentives to use it. This generally means that in those areas where groundwater availability problems are already present, efficiency levels tend to be higher than in those areas where water is still relatively abundant. Thus, some parts of the Region, most notably the northern subregion, have substantial potential for improved irrigation efficiency (15 to 30 percent), while other areas are already quite close to what is technically possible, Arthur D. Little [1].

Estimated Direct Impacts

Direct economic impacts from diminishing groundwater supplies could theoretically occur in any basic economic sector where there is a prospect for water shortages which would adversely affect economic activity levels. Shortages are extremely unlikely to develop for any sectors other than irrigated agriculture, however, because a great deal of groundwater, relative to non-agricultural needs, will remain after irrigated agriculture ceases. This will occur, because well yield requirements for irrigation are much higher than they are for most other purposes and because irrigation can afford to pay much less for water than any other sector. This means that when it becomes uneconomical for irrigation to continue, considerable water will still remain, albeit at well yields below about 300 gallons per minute. These factors make it possible to define direct economic impacts from groundwater declines as consisting only of changes in irrigated agriculture.

The direct economic impacts associated with groundwater induced changes in irrigated agriculture can be defined in several different ways, depending on the kinds of policy questions one wishes to address. For example, if one was interested in assessing the implications of groundwater declines for purposes of community planning, the relevant direct impacts consist of changes in the volume of economic activity over time. On the other hand, if one was interested in assessing the economic impact of water management alternatives, the relevant direct economic impacts consist of the differences in business volume with and without a given water management policy. Although focus of this analysis is on community planning issues rather than water policy, water policy aspects are still relevant as a mitigating measure to cope with potential impacts. Thus, direct economic impacts will be discussed from both perspectives.

The recently completed High Plains Ogallala Aquifer Study found that the regional value of agricultural production (measured in constant dollars) will likely increase substantially over time, despite the fact that over five million irrigated acres were projected to revert to dryland production by the year 2020 (Table 2). This finding may seem illogical in view of the fact that an irrigated acre produces from two to six times the gross sales value of a dryland acre, depending on location within the Region. The explanation involves three important considerations: agricultural technology; the prospects for new irrigation development in those parts of the Region where water supplies are relatively abundant; and excessive regional aggregation.

When unadjusted for technology and new irrigation development, agricultural sales from the Ogallala Region were projected to decrease from 4.7 billion in 1977 to 3.44 billion in 2020, due to aquifer exhaustion (Table 2). This decrease represents the annual direct economic loss associated with diminished groundwater supplies, but it is not indicative of what is likely to happen to direct economic activity in agriculture relative to current conditions.

When projected improvements in grain yields were incorporated in the analysis, year 2020 agricultural sales for the entire Ogallala were estimated to increase by 0.41 billion dollars, instead of decreasing by 1.26 billion (Table 2).

TABLE 2

Estimated Output Levels from Primary Agriculture, Given Expected Groundwater Declines in the Ogallala Region.

	YEAR								
	1977			2000			2020		
Situation:	**North**	**South**	**Total**	**North**	**South**	**Total**	**North**	**South**	**Total**
	(billions of 1977 dollars)								
Projected*	2.75	1.95	4.7	6.2	3.0	9.2	8.1	3.4	11.5
Projected (With No Change in Technology†	2.75	1.95	4.7	3.26	1.76	5.02	3.42	1.69	5.11
Projected (With No Change in Tech. or No New Irr'n. Dev't.)‡	2.75	1.95	4.7	2.38	1.70	4.08	1.91	1.53	3.44

*Estimates correspond to Baseline estimates developed as part of the High Plains Ogallala Aquifer Study, High Plains Associates [4, p. B-8].

†Compiled from High Plains Study results, proportionally adjusting baseline estimates using exhausted acres relative to the current acreage base.

‡Compiled from High Plains Study results by adjusting the no technology scenario for the amount of new development projected for the baseline scenario in the High Plains Study.

This means that for the two subregions combined, technology alone will more than compensate for a substantial amount of aquifer exhaustion. However, when the Ogallala was disaggregated into north and south subregions, the results were quite different. Technologically adjusted agricultural sales for the southern subregion were projected to decrease by 0.26 billion dollars between 1977 and 2020, while they were projected to increase by 0.67 billion dollars in the northern subregion. This interregional difference primarily reflects the fact that projected aquifer exhaustion in the southern subregion is greater than in the north when viewed relative to the total agricultural base. To a lesser extent, it also reflects smaller expected yield improvements for the crops which dominate the southern subregion.

When both new technology and new irrigation development were considered, agricultural sales were projected to increase substantially in both subregions, increasing from 2.75 to 8.1 billion dollars in the north and from 1.95 to 3.4 billion dollars in the south, as of the year 2020. Although the simultaneous occurrence of new irrigation and aquifer exhaustion may appear inconsistent, it reflects the large differences in localized water availability which characterizes the aquifer.

The fact that there does not appear to be any reason to expect significant declines in aggregate direct agricultural activity, within either the northern or the southern subregions, when changing technology and new irrigation development are considered, does not mean that there is no reason to be concerned about groundwater declines. Negative aggregate impacts may in fact occur, if economic exhaustion of the aquifer occurs more rapidly than estimated. This could occur either because of errors in estimating hydrologic relationships, or because of rapid changes in the economics of irrigation. If energy costs were to rise rapidly in real terms, for example, irrigation costs would increase, leading to a more rapid reversion to dryland agriculture. If the combined effects of hydrologic data errors and irrigation economics were large enough, the mitigating effects of changing technology would not occur fast enough to offset the differences in gross output between dryland and irrigated agriculture.

Another reason for remaining concerned about aquifer exhaustion is the heterogeneity of the Region and the washout effects of aggregation. Available data indicate that future groundwater exhaustion will be very site specific, perhaps limited to four or five areas within the entire Region. Much of the groundwater exhaustion is expected to occur in parts of Southwestern Nebraska, Western Kansas, Eastern Colorado and the Texas Panhandle. These areas will experience substantial decreases in direct agricultural activity even when new technology and new irrigation development are considered, with potentially extreme adverse impacts on the communities involved.

Regional Indirect Impacts

The regional indirect impacts from groundwater declines are essentially multiples of the direct impacts. A regional input/output analysis, conducted by Arthur D. Little, Inc. [1] for the High Plains Ogallala Aquifer Study, indicated that total economic output for the Ogallala Region changed by 1.61 dollars for every one dollar change in agricultural output. On a subregional basis the estimated multipliers were similar, with a southern area multiplier of 1.46 and a northern area multiplier of 1.73.

Individual sector output multipliers are perhaps of greater interest for community planning than aggregate output changes. On a sectoral basis, it has been estimated that the largest effects from groundwater declines would accrue, as expected, to the agricultural input and agricultural processing industries. Over 40 percent of the total indirect output impacts accrue to these sectors in both subregions (Table 3).

When the foregoing multipliers were applied to the estimated changes in direct agricultural activity, with appropriate modifications for new technology and new irrigation development, it was found that significant economic growth should be expected over the next few decades in both the northern and southern subregions, ceteres paribus (Table 4). The absence of declines in total economic activity does not mean, however, that there is little interest in preventing groundwater declines. If one could prevent aquifer exhaustion from occurring, total economic output for the Ogallala Region would increase by an additional 1.19 and 3.672 billion dollars in the years 2000 and 2020, respectively. The potential relevance of minimizing groundwater declines is most important within the parts of the subregions where most of the declines were projected to occur, but it is also significant for the southern subregion in the aggregate, because of expected declines in economic activity which are unrelated to water.

TABLE 3

Simple Output Multipliers for the Ogallala Region

Sector:	Output Multipliers North	South	Ogallala Region
		Dollars	
Farm Production	1.000	1.000	1.000
Feedlot Livestock	.061	.067	.063
Ag. Processing	.495	.177	.351
Ag. Support Services	.014	.014	.014
Other Manuf. & Mining	.086	.092	.089
Energy	.004	.008	.006
Utilities	.010	.015	.012
Transportation	.014	.023	.018
Trade (Whsl. & Ret.)	.011	.022	.016
Other Services	.035	.046	.040
Total (All Sectors)	1.729	1.464	1.610

Source: Compiled from data in Arthur D. Little, Inc. [1].

As noted earlier, the economic base of the southern subregion is dominated by energy extraction industries rather than primary agriculture. Recent analyses indicate that annual crude oil and natural gas production activity in the southern subregion should be expected to decrease by 320.0 million barrels (90.1 percent) and 2.518 trillion cubic feet (84.0 percent), respectively, by the year 2020, Black & Veatch Consulting Engineers [2, pp. D-7 to F-8]. When declines in primary energy were combined with groundwater induced changes in agriculture, the southern subregion's share of total regional economic activity declined from 67.2 percent to 60.1 percent by year 2020. This combined impact presents serious community planning implications for the subregion in total, as well as for those specific subareas where the groundwater declines are expected to be most severe.

Community Level Impacts

The limited economic linkages which characterize the Region and the localized character of groundwater declines means that the most important

TABLE 4

Total Economic Output Impacts Associated with Estimated Changes in Primary Agriculture, Ogallala Region*

	North	South	Ogallala Region
	(billions of dollars)		
Projected:			
1977-2000	5.965	1.537	7.245
2000-2020	3.285	.586	3.703
Projected (With No Change in Technology):			
1977-2000	.882	-.278	.515
2000-2020	.277	-.102	.145
Projected (With No Change In Technology, Or No New Irr. Develop.):			
1977-2000	-.640	-.366	-.998
2000-2020	-.813	-.249	-1.03

*Estimated by multiplying the direct economic impacts from Table 1 by the output multipliers in Table 2. Direct economic impacts were computed as the change in primary agriculture from 1977 to 2000, and from 2000 to 2020.

economic linkages involve community level impacts. The foregoing analysis implies that for regions defined to include more than 5 or 6 counties, it is unlikely that groundwater declines will be noticed in an aggregate economic sense, unless the declines occur more rapidly than anticipated. However, for those communities where the declines are concentrated, the economic impacts are likely to be severe. The total volume of economic activity may decline substantially over time, with consequent impacts on employment, out migration, personal income and public services.

Unfortunately, there is very little information available concerning potential community level impacts from groundwater declines within the Ogallala. However, it is reasonable to expect that the community level changes in direct and indirect economic activity will follow a pattern similar to the more aggregated subregions, but will be more extensive relative to the current economic base.

The significance of community level impacts, like in the more aggregate case, depends primarily upon the rate of change. The rate of change is of special importance, because change is usually costly and painful only if it occurs rapidly. For example, abrupt changes, such as those associated with the closing of a major industrial plant, result in unemployment, bankruptcies for service industries, under utilization of un-depreciated infrastructure facilities, high public service costs etc. In contrast, with gradual declines, out-migration can occur without the trauma of sudden unemployment, service industries can plan for full depreciation of facilities, and over investment in community infrastructure can be avoided.

Current evidence suggests that water availability induced reductions in basic economic activity will occur over two to three decades, even within the Ogallala communities which will be most severely affected. This rate of change would permit relatively painless and efficient adjustment, especially in view of the aged infrastructure which characterizes many rural communities and the prevailing skewed age distribution of the population, U.S. Census [7]. Within most of the communities where the most severe declines are expected to occur, it is unusual to find new schools, new hospitals or other items which might present adjustment problems over the next couple of decades. Also, the median age of the population in most of the critical communities is well above average, which means that the required population adjustments may occur naturally, rather than presenting a situation where large numbers of middle-aged workers will need to incur the trauma of seeking alternative employment.

The fact that the impacted communities may be able to adjust rather painlessly does not mean that there is no cause for concern. The possibilities for more rapid change than currently expected are greater at the community level than they are at a more aggregate level, because smaller communities are less diverse. Also, the fact that community level adjustments may not be catastrophic does not mean that decline is desirable. Most community officials do not welcome economic declines, irrespective of the rate of change. Thus, it is useful to consider opportunities for impact mitigation.

Opportunities for Impact Mitigation

There are several kinds of programs and policies which might be used to increase or maintain the economic vitality of those communities facing economic changes due to groundwater declines. The basic possibilities include development of substitute water supplies, groundwater management to slow the rate of aquifer exhaustion, research and education programs to accelerate the rate of change in agricultural technology, and programs to attract non-water intensive basic industries.

The opportunities for water supply augmentation as a mitigation measure appear to be rather limited. Although there certainly exists possibilities for local area augmentation with surface water supplies, as articulated in water development plans for the various states, High Plains Associates [4], it is also clear that such opportunities are small relative to the potential need. Meeting the agricultural needs for the region would require in excess of 10 million acre feet of water by the year 2020, High Plains Associates [4]. Quantities anywhere near this amount must be imported large distances from either the Missouri or Arkansas Rivers. Recently completed studies by the U.S. Army Corps of Engineers indicate that this would be prohibitively expensive, with costs exceeding benefits by about five to one, High Plains Associates [4].

Groundwater management appears to offer more potential than water supply augmentation, but again the potential is quite limited. Groundwater management cannot produce more water, and given that the Ogallala is essentially a stock resource, management can only slow the rate of exhaustion, not prevent it. Slowing the rate of aquifer exhaustion may be very useful in order to facilitate orderly community adjustment, but it is not a very useful direct means of maintaining economic vitality. Groundwater management might be used to maintain economic vitality indirectly, however, via policies which insure that there is adequate water available for economic diversification and other non-irrigation uses. In most cases, however, natural hydrologic and economic factors will provide for the necessary intersectoral allocation of available water supplies, for reasons discussed earlier.

The economic diversity option may offer substantial potential for some adversely affected communities, but it is difficult to generalize because of wide variations in the factors which influence the prospects for economic diversification. Transportation facilities, labor supplies, tax policies and other location factors are quite variable across the region. Unquestionably, some communities will find it possible to attract other basic industries, but in view of the rather dismal track record for rural development programs in other parts of the country, extensive success seems unlikely, Tweeten and Brinkman [6].

From an aggregate perspective, the greatest potential for impact mitigation appears to be investments in agricultural research and education programs. The impacts of agricultural technology which were discussed earlier are expected to occur without any change in real research and education investments. There is little doubt but that a rather modest increase in research and education funding would lead to additional mitigation as well as other payoffs, especially if the expanded efforts were focused on improving productivity of dryland agriculture. Even a modest water development project can easily cost over one-half billion dollars. The interest alone on this amount would be sufficient to fund the equivalent of at least two additional well funded agricultural experiment stations in the region. Also, much of the anticipated improvements in technology over the next two or three decades is expected to be due to increased adoption of existing technology, rather than the adoption of still to be developed technology. Thus, education efforts alone could serve to substantially accelerate the use of new technology. Although there is necessarily a great deal of uncertainty associated with this means of impact mitigation, and use of the method would require action at a relatively high political level, the potential would appear to merit an appreciable effort in this direction.

Summary and Conclusions

This analysis indicated that the economic implications of groundwater declines in the Ogallala Region are generally much less severe than is commonly believed. Although irrigated agriculture is a very important basic industry, especially in the northern part of the Ogallala Region, and substantial declines in irrigated acreage are expected to occur in some areas, such declines may not be accompanied by aggregate decreases in economic activity relative to current conditions. This was found to be the case primarily because of the offsetting effects of changing agricultural technology over the next two or three decades.

When the Ogallala Region was divided into two subregions, north and south, it was found that total economic activity would not decline relative to current levels, despite anticipated aquifer exhaustion in excess of five million acres, unless exhaustion occurs more rapidly than expected, or unless agricultural technology changed more slowly. However, when the issue was considered from the perspective of local communities, rather than multi-state subregions, it was found that substantial economic declines relative to current conditions were much more likely to occur, because of the localized concentration of aquifer exhaustion.

The estimated community level economic declines were projected to occur over several decades, which would in most cases allow communities time to adjust in a relatively painless and efficient manner. Thus, it was argued that community needs within the region consisted of a preference to avoid economic declines, rather than a more drastic need to cope with the kinds of community impacts which accompany rapid economic change.

With respect to the possibilities for mitigating aquifer exhaustion induced economic declines, four general approaches were considered: water supply augmentation, groundwater management, economic diversification, and expanded efforts to accelerate the rate of change in agricultural technology. In general, it was argued that water supply augmentation offered very little potential for impact mitigation; groundwater management could influence the rate of change, but not prevent it; economic diversification offered little potential except under special and unusual circumstances; and agricultural research and education offered substantial potential for impact mitigation, but the effects would be uncertain and required action at political levels well beyond multi-county communities.

These conclusions imply several important research needs. Perhaps the most important is the need for additional information regarding the magnitude and timing of impacts at very local levels. Currently available aggregate analyses effectively mask the most important impacts. Secondly, there is a need to consider the effects of varying rates of change on local communities. For example, what are the real economic implications of economic stability relative to managed economic change? Finally, there is the issue of the potential role of investments in agricultural research and education as a means of mitigating the economic consequences of declines in water availability. These issues should be explored further before drawing definitive conclusions regarding policies for adjusting to groundwater declines.

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