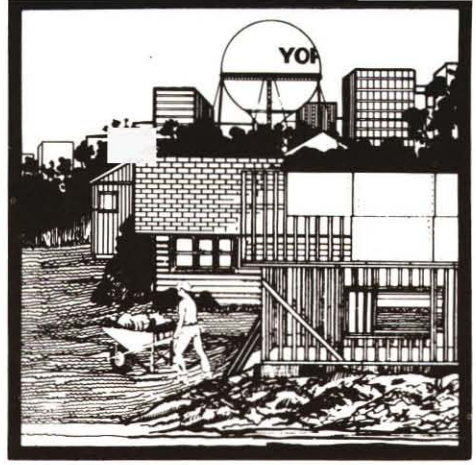

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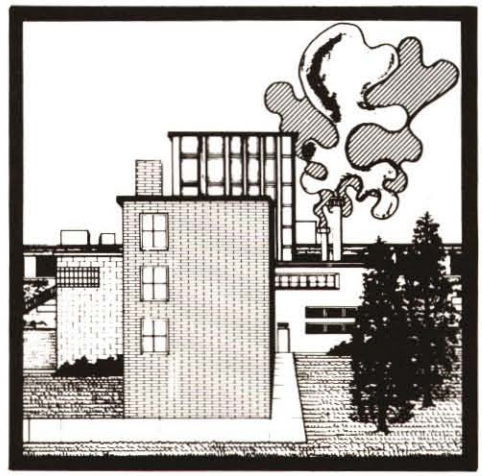

GROUNDWATER RESERVOIR MANAGEMENT

State Water Planning and Review Process
Nebraska Natural Resources Commission

MARCH 1982

POLICY ISSUE STUDY
ON
GROUNDWATER RESERVOIR MANAGEMENT

STATE WATER PLANNING AND REVIEW PROCESS

AN APPENDIX TO THE GROUNDWATER RESERVOIR MANAGEMENT POLICY ISSUE STUDY

POTENTIAL GROUNDWATER RESERVOIR MANAGEMENT TECHNIQUES AND ASSOCIATED IMPACTS

REPORT
OF THE
NATURAL RESOURCES COMMISSION
TO
GOVERNOR CHARLES THONE
AND
THE MEMBERS OF THE NEBRASKA LEGISLATURE

MARCH 1982

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Introduction

This volume serves as the Appendix to the Policy Issue Study on **Groundwater Reservoir Management.** The material presented here is summarized in Chapter 4 of that report.

This volume is divided into three sections and a set of appendices. Section 1 identifies and discusses significant environmental, technological, economic, social, and legal/institutional/administrative factors which influence or are influenced by groundwater development in Nebraska. These factors also serve as "checklists" for the impact analysis of management techniques presented later in this volume.

Section 2 examines "baseline" conditions, projecting anticipated economic trends related to agricultural development in Nebraska absent any additional significant public actions which might influence the rate and/or amount of groundwater withdrawal and use. The impacts of these projections also are analyzed, based upon the impact criteria (factors) previously identified.

Presented in Section 3 is a series of potential management techniques intended to meet objectives calling for stabilization or reduction of groundwater use. Also included is a discussion of impacts which may occur should these techniques be implemented.

This volume concludes with a series of appendices which serve as supporting information for materials found in the main text.

It should be noted here that the proposed management actions and alternatives presented in this report are oriented toward areas of the state where groundwater depletion problems are occuring or are likely to occur. Impacts associated with various actions and alternatives may not be appropriate indicators of events likely to occur in areas of Nebraska where recharge may be adequate to replace present or projected rates of withdrawal.

Administrative-legislative action alternatives needed to implement the management techniques identified in Section 3 are presented in the second volume of this report. In addition, alternatives which promote continued groundwater development at the historic rate or higher are considered.

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Section 1

Impact Parameters Associated With Groundwater Management

INTRODUCTION

The basic intent of a groundwater management "strategy" is to affect the rate and/or amount of groundwater development and utilization to accommodate various and often competing needs. To evaluate the benefits, costs and conflicts associated with groundwater use, the Groundwater Reservoir Management Task Force identified five basic parameter "groups" to establish the bounds for impact examination: environmental, technological, economic, social, and legal/institutional/administrative. To immediately follow is a discussion of various "factors" identified within each parameter group as possibly affecting or being affected by varying degrees of groundwater utilization. Significant issues raised in this ensuing discussion are referred to in later sections of this report as "checklist" criteria for evaluating the impacts of management actions and policy alternatives.

ENVIRONMENTAL CONSIDERATIONS

Introduction and Conceptual Framework

The focus of this analysis of environmental considerations is on changes and impacts in various natural systems which can be associated with changes in groundwater level and in the rate, amount, and location of groundwater withdrawal and use. This analysis considers current issues and trends and the possible effects of a range of management actions. Its scope and depth are limited and selective due to the large number of intervening factors and influences which affect the relationships between groundwater levels, groundwater management and various environmental impacts. Some environmental or natural systems affect the level and rate of use of groundwater. These factors include climate, soil texture, soil moisture conditions, quality of groundwater, vegetation and groundwater supply.[01]

The conceptual framework for this discussion is the relationship between changes in groundwater level and a changing set of environmental factors. A primary emphasis is on changes in groundwater levels in areas of high water table. Other factors reflect changes in land use and management which may be associated with the type of agricultural development related to groundwater withdrawals. These relationships are illustrated in Figure 1-1 and are discussed below.

In discussing these relationships there are several important limitations: (1) Causal relationships are not well defined. There are definite associations between changes in the level of groundwater and other factors, but these may be limited by site-specific conditions such as soil type or depth, water level or other factors. These relationships may be non-linear.[2] Generalization about these relationships to large areas of the state should be done with extreme caution. (2) These relationships are also subject to many site-specific management decisions. Some impacts of water use can be mitigated by choice of technology, such as irrigation scheduling, fertilizer management, crop rotation and other aspects of water management. Soil and vegetation impacts can be significantly influenced by soil conservation practices such as those promoted by the Soil Conservation Service and other education and technical assistance programs. Habitat changes can be affected by practices such as those available through the Natural Resources Districts and the Game and Parks Commission on a cost-share basis. Basic cropping and farm management decisions will also have a significant effect on environmental impacts.

This analysis is based on two workshops held by the Nebraska Water Resources Center, interviews and published information, primarily secondary sources. The following discussion reviews the major relationships between changes in groundwater level and various environmental factors, with examples and illustrations provided where possible.

In Section 2 of this report the effects of management actions are considered beginning with the existing conditions as projected which would represent the "no additional public action" (Baseline) alternative. In Section 3, the analysis considers possible impacts of a range of actions and options, along with an examination of illustrative examples of management ("For Instance" Cases).

Environmental Factors Related to Groundwater Management

These factors are seen as the important considerations in the set of relationships between groundwater management and various natural systems as they are illustrated in Figure 1-1. These factors overlap and mutually influence each other in some cases as they are affected by changes in groundwater level, rate and amount of withdrawal and location of withdrawal (as well as by other factors).

WATER

Groundwater Quantity. Areas of high water table are the most responsive to groundwater withdrawals as related to the following impacts:

A. Effects on wetlands, wet or fresh meadows. This is primarily a concern in the Sandhills where there is some evidence of seasonal reductions in wet meadows as related to groundwater withdrawals.[3] In addition, numerous areas have been drained for cropland. Declines have been noted in the Beaver Creek area, although Lower Loup NRD staff indicated that there is currently more concern about temporary declines in stock wells in that area.[4] Effects on vegetation are related to changes in wetlands. Hay crops, aquatic vegetation and related habitat could be affected.

B. Evapotranspiration (ET) potentials are significantly affected by groundwater level changes in areas of high water table. Drying of wetland areas can lead to a shift in the type of consumption of groundwater and provide "ET salvage" for other uses such as crops. Bureau of Reclamation research in Merrick County indicates that small declines in the water table can provide a shift from marshy area vegetation having ET rates near those of a lake (40 inches per year) to crop uses (with lower ET rates of 20 to 30 inches per year) with little effect on stream flow and stable water level because of the salvage of ET. In other words, about a foot of groundwater table is saved by drying up the wet area according to BuRec staff. [5] This sort of trade-off points to additional effects of management of areas of high water tables.

Other effects of changes in groundwater level as related to the quantity of groundwater will include changes in the hydrologic properties of aquifers and related impacts.[6] These can occur in areas not necessarily characterized by high water table.

Groundwater Quality. Leaching of agricultural chemicals caused by application of groundwater through irrigation is the primary relationship between changes in groundwater level, groundwater management and groundwater quality. Impact is again focused on areas of high water table. Leaching of nitrates is a concern because of documented impacts on human health and that of livestock. Cattle have been shown to be vulnerable to total nitrate from forages as well as water.[7] Soil depth and soil type are factors in the percolation of chemicals into groundwater supplies.[8]

There is, in terms of level of concentrations, significant evidence of nitrate problems in the central Platte area and in Holt County.[9] Studies of Holt County[10] and Merrick County[11] associate nitrate concentration with infiltration from nonpoint sources derived from irrigation of corn with groundwater (although there are other sources of nitrogen in groundwater, both natural and human-induced, e.g., septic tanks, livestock concentrations). The rate of increase of nitrate concentrations appears to be growing in those areas where it is reported to be significant. Positive correlations between irrigated coarse-textured soils and higher nitrate-nitrogen levels were demonstrated in a Merrick County study.[12] Well-drained soils and shallow water tables are associated with increasing nitrate concentrations. Approximately 75 percent of Merrick County has groundwater within 10 feet of the soil surface, while in the remainder of the county groundwater occurs 11 to 20 feet below the surface.[13]

A Holt County study stresses as well that the "effects of agricultural development on the chemical degradation of groundwater are especially pronounced and rapid in areas of coarse textured soils".[14] Hergert observed the factor of soil depth and asserts that fine-textured soils are leaching nitrates into groundwater supplies as well.[15]

Leaching of herbicides and pesticides may also be related to groundwater usage, soil type,

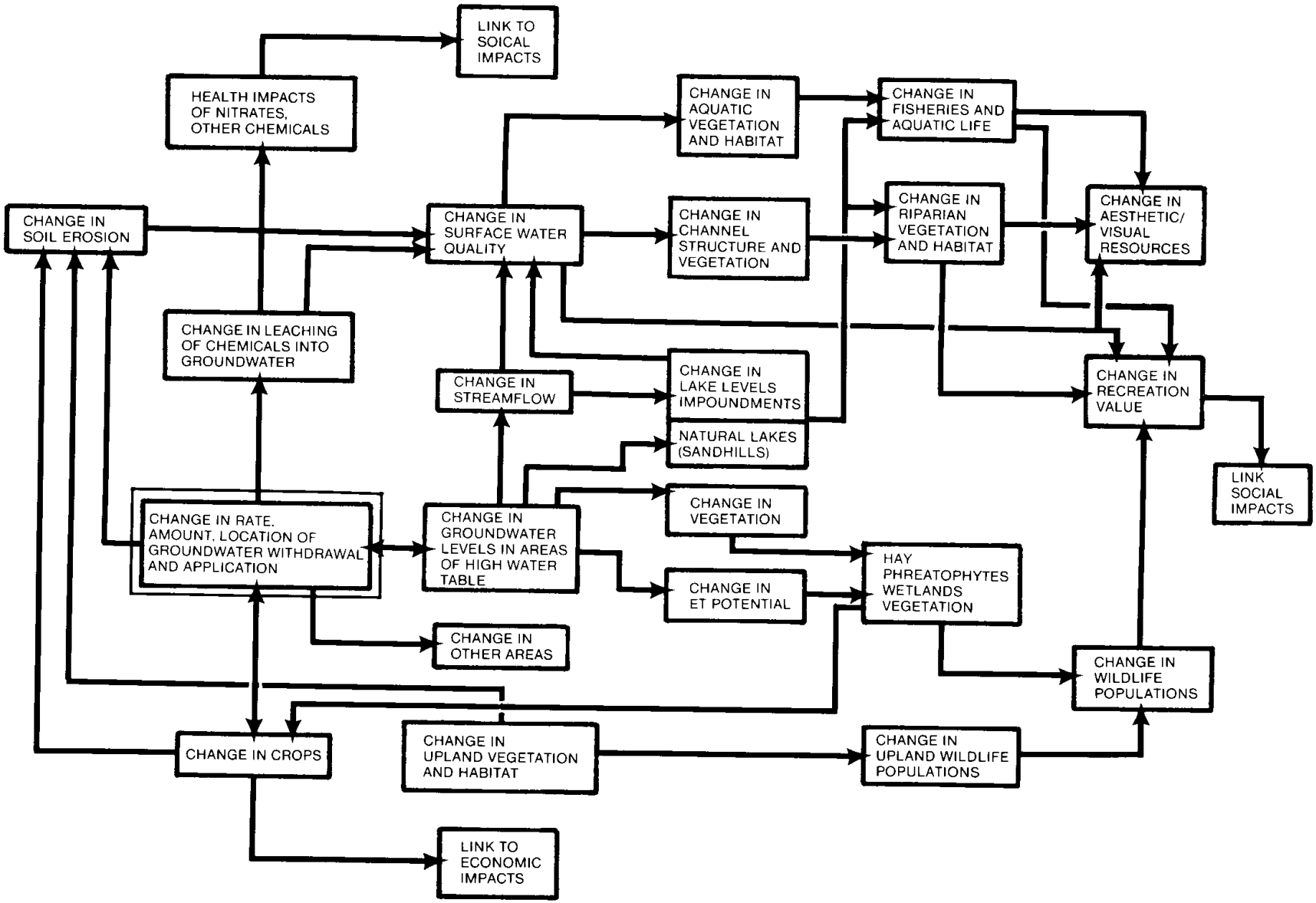

Figure 1-1
Conceptual Framework For Environmental Impacts Of Groundwater Reservoir Management

and areas of high water table. Reuse of groundwater may lead to change in quality in the form of progressive increases in dissolved solids concentrations.[16]

Chemical changes in groundwater quality associated with dewatering of aquifers is an additional potential impact of changes in groundwater levels, as are changes in water quality due to influxes of water of lower quality from another source due to reduction in head.[17]

Surface Water Quantity

A. Change in streamflow as a result of change in groundwater level is most significant in areas of high water table, but is of course subject to several hydrologic variables with respect to ground-surface water relationships. The range of effects could include the drying up of streams, the reduction of flows or the reverse. The Frenchman River above Enders Reservoir has frequently been cited as an example of a reach of stream whose flow has been diminished by declines in water levels resulting from extensive irrigation well development. An SCS report describes reductions in flows as "about 19 percent".[18] Average discharges for 1978 and 1979 are well below the historic average for 39 years of records, according to USGS data.[19] The Cedar River at Fullerton went dry for the first time during the summer of 1980, an apparent effect of pumping immediately adjacent to the river rather than long term declines, and surface water diversions on long-held water rights.[20] The Loup River system, which derives almost all of its flow from groundwater discharge, could ultimately be affected by extensive groundwater changes.

Return flows from irrigation can also affect streamflow as was noted in the maintained flows of the Big Blue Basin during the dry summer of 1980. This occurred primarily in Lincoln Creek. It should be noted that the Big Blue River was dry at and below Seward during the summer of 1980.

Changes in streamflow will be subject to climate variations, water management affecting runoff vs. infiltration, soil type, surface water development and other factors as well as changes in water level.

B. Lake levels. Natural lakes such as those in the Sandhills which are associated with high water tables can be affected by changes in groundwater level. Reductions in size and depth of lakes could result with consequent impacts of vegetation, water quality and wildlife habitat.[21]

Impoundments that are dependent on streamflow, which in turn is affected by changes in groundwater level, are thus subject to the effects of irrigation development. Enders Reservoir, fed by the Frenchman River, is often cited as the prime example of this relationship.[22] Others may include Box Butte Reservoir and Swanson Lake.[23]

Surface Water Quality. Impacts on surface water quality which are the result of changes in groundwater level or the location, rate, or amount of groundwater development, may be associated with change in streamflow as well as the amount of water withdrawn and applied to the soil, use of chemicals and water, and land management practices. These impacts may include biological factors reflected in aquatic habitat, chemical concentrations and changes in water quality related to changes in the amount of sediment transported to receiving waters as a result of change in groundwater withdrawal, development or retirement of irrigation on particular lands, or other management actions. Clearly defined relationships are not easy to establish in direct terms between groundwater withdrawal and specific parameters of surface water quality.

Nitrate concentrations in surface waters are primarily associated with the percent of watershed planted in corn -- among other factors, according to Engberg's study of 11 streams in Nebraska: "The positive correlation of mean nitrate concentration to percentage of drainage area planted in corn probably reflects, to some degree, the amount of fertilizer used on that crop. It probably also reflects the extent of irrigation in that drainage area, as return flow from irrigated fields provides a medium for transport of nitrate from the fields to drainage courses".[24] However, a relationship between groundwater irrigation and these effects is not strictly established as distinctions were not made between groundwater irrigation and surface water irrigation. Another study showed nitrate concentrations in streams most significantly correlated with human and animal density.[25]

Bender's research on surface water quality parameters as statistically associated with streamflow does not establish clear patterns of impacts.[26] Only in the North Platte Basin do nitrate concentrations correlate with reduced streamflow in terms of less dilution of higher nitrate water and increased concentration, therefore, of nitrates. Turbidity and other factors do not correlate with reduced streamflow although some water quality indicators such as seasonal dichotomies between reduced streamflow and dissolved oxygen (direct relationships in the fall and winter, inverse in spring and summer) exist in some areas. Improvements in some non-point source water quality parameters are associated with low flows because of reduced runoff and related reductions in pollutants which would be associated with overland flow.

Bender notes that "water quality problems correlating with decreased streamflows were commonly found among all sampling stations for conductivity, pH, and dissolved solids. Notable instances of low flow problems for ammonia and phosphorous were observed downstream from major point sources of pollution in the Lower Platte and Middle Platte River Basins. Low flow problems for nitrate were observed on the tributaries of the North Platte River. These water quality problems can be explained by the dilution or flushing capabilities of a stream. These water quality parameters tend to become more dilute as greater quantities of water flows down a stream. When lower quantities of water flow down a stream, these parameters become more concentrated which can lead to water quality problems".[27]

Sedimentation and turbidity can result from runoff related to irrigation, depending on soil type, topography and management practices.

SOILS

Impacts on soils, with the exception of changes in soil moisture and other properties, are not a direct effect of changes in groundwater level or rate of use, but are secondary effects which are influenced by the development of agricultural or other land, change in crop or other vegetation that may be related to the availability of groundwater and the extent of its use. Land and water management practices will have significant effects on soils. Wind erosion has traditionally been a concern in the Sandhills and is now associated with irrigation development as grassland is converted to cropland. The potential for greater wind erosion is more predominant as land is laid bare. Whereas sandy soils, such as the Valentine type in the Sandhills, are most susceptible to wind and water erosion, fine textured soils may also be adversely affected by irrigation development.

Water erosion, while less significant in the Sandhills due to rapid infiltration and thus limited runoff, can be a significant impact of irrigation in other areas, dependent on soil type, slope, land management and cultural practices. The amount of water applied through irrigation is obviously an important factor in the amount of runoff and erosion. Erosion has effects on the water quality of receiving streams and lakes, such as transport of chemical pollutants, sedimentation and eutrophication. Instances of erosion resulting directly from groundwater irrigation are dependent on a number of factors and can be estimated with some degree of reliability by the Universal Soil Loss Equation.

VEGETATION AND WILDLIFE HABITAT

Changes in vegetation and wildlife habitat are in some cases a direct result of groundwater level changes in areas of high water table. Wetlands, wet meadows and streamflow are examples of this relationship where they are directly related to the level of groundwater.

Aquatic habitats are significantly and directly affected by major changes in streamflow and water quality factors, especially turbidity and dissolved oxygen. Field research by Lee Rupp during the mid-1970s in northeast Nebraska presented evidence of impacts on fisheries caused by dry streams or greatly reduced flows. The range of effects he observed extended from complete destruction of aquatic organisms in dry stream beds and greatly reduced habitats due to reduced flows.[28] Rupp investigated streams in the Loup, Elkhorn and Missouri drainage areas. The changes he observed were not necessarily the result of changes in groundwater levels, but were affected by drought and surface water diversions. Yet they provide an illustration of the extreme impacts of reduced streamflows. Reduced fish spawning and nesting sites due to flow reductions, as in the Frenchman River, is an additional effect.[29]

Less dramatic impacts include possible effects on cold water fisheries in Nebraska, such as Long Pine Creek[30] and other trout fisheries including the streams which drain into Lake McConaughy.[31] Other aquatic habitats are considered degraded due to turbidity and reduced flows.[32] Platte River braided channels and sandbars which are used by cranes could become stabilized, vegetated and thus altered due to reduced flows.[33]

Succession of vegetation and thereby habitat for various species will be related to changes in groundwater level particularly in areas of high water table such as Sandhills wetlands or lakes. Sandhills lakes that are directly connected to water tables could experience changes in water level and other aquatic habitat and, more significantly, in shoreline vegetation which serves as cover and nesting sites for waterfowl and shorebirds. Furbearers, particularly muskrats, could be affected by significant changes. Fisheries could be affected as well.[34] Changes in phreatophytes, such as cottonwoods, could result from declines in water levels below the root zones or from management actions. Changes in wetland vegetation from semiaquatic to terrestrial habitat or shifts in type of aquatic habitat could be associated with changes in wildlife. Hay yield could be reduced in the event of reduction of wet meadows leading to replacement by crops. The reverse processes are also possible should

water levels rise as they have in some areas due to groundwater recharge or possibly to changing agricultural practices as an SCS report on the Republican River Basin notes with reference to water level rises in Perkins County in 1977.[35]

Terrestrial vegetation, habitat and wildlife populations are less directly affected by changes in groundwater level (with the exception of riparian habitat and channel vegetation), but they are very much affected by the pattern of agricultural development associated with groundwater irrigation. Changes in the composition of crops, reduction of cover, windbreaks, fence rows and grasslands have significant effects on upland species of wildlife.

Prairie chicken populations show dramatic reduction from their historic range due to growth of intensive agricultural technology. Generally, when conversion from grass to cropland exceeds 60 percent of an area, habitat for this species is no longer available.[36] At present, small flocks persist. Cropland provides winter food, but has reduced native grassland habitat. The nine counties comprising prairie chicken range have experienced an increase in irrigated acres from 176,000 in 1965 to 450,000 in 1978.[37] Sharptail grouse have declined less, but their Sandhill range requires unbroken expanses of grassland with small pockets of brushy cover.[38] These have been reduced by irrigation in the Sandhills. Total Sandhills irrigation has expanded, primarily in the eastern portion, from 64,500 acres in 1965 to 535,000 acres in 1978.[39] These species also remain dependent on Sandhills wetlands.

Pheasant populations are also affected by agricultural practices in terms of necessary cover and food supplies. Diversity of crops (optimally 20 to 45 percent small grains and wild hay and less than 40 percent corn and alfalfa) is suitable habitat and pheasants have succeeded in many farmed areas.[40] Intensified farming and change in the diversity of crops will have an impact on pheasant populations as will land management practices. Quail populations have expanded out of river valleys, but remain limited by intensive agricultural operations.[41]

Deer populations appear to be related to the spread of intensified agriculture and will also be affected by any drying up of sources of water, such as small lakes and wetlands. Crop shifts over the last 15 to 20 years are indications of how the composition of upland vegetation and habitat is changing with respect to agricultural production with likely effects on certain wildlife populations in upland areas. As shown in Table 1-1, figures for Holt County indicate this trend in an area which has seen extensive change. It is not intended to represent any regional or state trend; rather, just the changes in one significant county.

These figures indicate shifts from more diversified crops to a more intensive irrigated agriculture focused on corn. It is likely that this pattern has had impacts on wildlife habitat with respect to the mix of types of croplands. Potentials exist for habitat improvements in combination with irrigated agriculture in terms of management of center pivot "corners" and other border areas.[42]

Loss of windbreaks as a result of intensive irrigated agriculture has often been noted as a by-product of groundwater development. An SCS study of the period 1970 to 1975 is not very conclusive on this subject. It appears that wider windbreaks are being replaced by narrower ones. Windbreaks are being removed for irrigation, but losses are offset by replacements. Sampled changes in Nebraska revealed losses in miles and acres of windbreaks of 2.7 percent and 5.6 percent, respectively, with a gain in the number of windbreaks of 0.9 percent in the sampled areas.[43] The extent to which the present degree of windbreak development reduces erosion is uncertain. Bagley argues that a far greater degree of windbreak development is necessary to accomplish soil conservation objectives.[44] Changes in windbreaks and their composition as well as in grasslands and mix of crops and their scale of development are significant by-products of groundwater development which have impacts on a wide range of upland wildlife species. Shifts from irrigated agriculture to dryland farming or possibly range land are possible effects of aquifer exhaustion or various public policies. These shifts will have a range of effects on erosion, habitat, and possibly on groundwater quality.

RECREATION AND AESTHETICS

Recreation and aesthetic impacts are closely related to a number of factors which have already been discussed. Recreation effects are related to surface water quality and streamflow and lake levels as well as vegetation and wildlife habitat factors. Water-related recreation activity ranks high in Nebraska as a desired activity and other recreation activities, such as camping or hiking, are often related to water.[45] Hence the quality of recreational experience will depend on the availability of water-related environments and their maintenance and range of opportunities. Aesthetic factors will be related to the quality of these same factors as well as changes in visual resources such as the agricultural landscape, surface waters and other areas which may be affected by changes in groundwater levels and the extent of groundwater development. Examination of summer visitation data and water in

Table 1-1. Crop Production in Holt County

Crop	Acres Harvested 1967	1969	1978	1979
Corn for All Purposes	86,530	93,200	189,300	192,500
Corn for Grain				
Irrigated	43,150	48,000	174,000	177,400
Non-Irrigated	35,590	33,590	6,000	7,700
Total	78,740	81,590	180,000	185,100
Sorghum for All Purposes	6,020		1,600	
Rye	4,480		3,000	3,100
Oats	11,240		5,900	4,700
All Hay	423,620	377,360	304,000	294,900
Wild Hay	363,280		245,500	220,800

Irrigated Wells	
1969	501
1980	1,952

Irrigated Acres	
1965	20,500
1966	27,400
1975	164,000
1978	222,000
1979	231,000

Source: Nebraska Department of Agriculture, Nebraska Crop and Livestock Reporting Service, *Nebraska Agricultural Statistics, Annual Reports 1968-69, 1978-79.*

storage data from 1975 through 1979 in Enders and Box Butte Reservoirs did not reveal clear patterns of association. This may result because of how water levels are managed seasonally, access costs, and lags in the quality of recreation, for example, good fishing following a year of high water levels (according to Nebraska Game and Parks Commission staff).

Actions designed to affect the rate, amount, location, or other aspects of groundwater withdrawal will have impacts on these factors which were discussed above. The "Baseline" (or no new public action) condition will be discussed in Section 2. This represents an estimate of existing conditions and trends projected into the future without any additional public intervention. In terms of effects, this direction of impacts will represent continued expansion of groundwater development, continued rates of use and, therefore, continued expansion of those indicators which represent impacts of the present trend of development. It should be clear that this does not necessarily represent stability.

The second basic direction or pattern of impacts will be those which result from some degree of reduction of the rate, amount, or location of groundwater withdrawal. These are examined in Section 3. These impacts may represent a moderation or change in some aspect of present trends, or a more distinct effect. These relationships are not linear, nor are they fully established or documented. Hence, in most cases, description of impact is only a rough estimate of what may happen.

In Section 3, six management actions and associated implementation methods and options are reviewed as to their estimated impacts. The performance of the actions is assumed. Variation in effects over time are not specified. Some of the actions are discussed by categories of impact, while some are discussed in summary form to avoid excessive repetition.

These management actions can be further subdivided into implementation methods and options which represent variation in how an action is carried out. It is assumed that this variation will not lead to significant differences in environmental impacts.

TECHNOLOGICAL CONSIDERATIONS

Introduction

Technological impacts are considered to be primarily on-farm technical changes which will occur to increase the productivity of water or other inputs either as a result of general scientific progress or in response to public water management activities.

Several technological factors have been identified as being significant for this study. The significant factors are basically those which either directly influence the need for and use of water, and/or which are important determinants of the effect which management actions have on impacts of interest to decision makers. Thus, it is important to keep in mind that the technological impacts are not an end result of interest to decision makers, as are such things as farm income, sociological change, etc.; rather, they are intermediate impacts of interest because of the effect they have on other considerations.

The analysis of technological factors and impacts is considered in three areas of this report. To immediately follow is an examination of the technological factors which will be considered in impact assessment. Section 2 includes an examination of the impacts expected to occur under the "baseline", i.e., in the absence of any further groundwater management actions (status quo). Portions of Section 3 are devoted to the impact assessment of the three groundwater reservoir management objectives and associated actions, methods and options formulated by the work group, and how they might affect or be affected by the technological factors listed earlier.

TECHNOLOGICAL FACTORS

EVAPOTRANSPIRATION (ET) PER UNIT OF GRAIN YIELD

Evapotranspiration is a "combined measure of water evaporated from the soil and plant surfaces (E) plus that water transpired (T) by growing plants".[46] The reduction of ET losses without a loss of per unit grain yield would have significant effects on groundwater reservoir management whereby less water would be used per unit of output.

CULTURAL PRACTICES

Cultural practices that can affect water use and water conservation methods include crop/variety determinations, tillage practices, weed suppression and runoff control.

CONVEYANCE SYSTEM EFFICIENCY

The efficiency of the irrigation conveyance system is determined by the ratio of the amount of water delivered to the field to that dispatched from the source, be it a well, reservoir, or gate. Most losses between these two areas will be due to spills, leaks, evaporation, weeds, or phreatophytes.

APPLICATION EFFICIENCY

Application efficiency is "the ratio of the amount of water retained in the effective root zone of the crop being irrigated **immediately** after watering to the total amount of water applied to the field".[47]

ECONOMIC CONSIDERATIONS

Introduction

The economic impacts associated with groundwater management could be defined to include a near infinite range of components. Everything from farm income change to the effect on municipal water supply costs and industrial development could be considered a relevant economic impact. Fortunately, however, it is unnecessary to consider such an extensive range of impacts due to the dominating effect of irrigation as the major consumptive use of groundwater.

Nearly all of the significant economic impacts from groundwater management stem from what happens at the farm level. Thus it is believed appropriate for public decision makers to focus their consensus on irrigated agriculture when considering the economic trade-offs associated with management choices. The empirical components of this analysis accordingly emphasize the farm level economic impacts.

The principal farm level economic impacts of interest include: changes in agricultural production, irrigated acres and farm income. Also of interest are the hydrologic changes which drive or determine the economic impacts, especially changes in static water levels and total water use.

Another set of economic impacts which are treated empirically, but in less detail, include the effects of changes in agricultural production on the output of other sectors in the Nebraska economy.

Procedures for Analyzing Farm Level Economic Impacts

Analysts in the UNL Department of Agricultural Economics and the Nebraska Natural Resources Commission have been busily engaged in analyzing groundwater management alternatives for the Ogallala Region of Nebraska since mid-1978. Their work, conducted under the auspices of the HighPlains/Ogallala Aquifer Study, formed the basis for the economic impact assessment discussed herein. Thus, the geographic delineation of the state and many of the assumptions and parameters of the study are different than they might have been if the work had been conducted solely for use by the Groundwater Reservoir Management Task Force. Moreover, these definitions and assumptions are occasionally at variance with those used in other work by the task force. For the most part such differences are insufficient to materially change the results.

Delineation of Study Area

As the first step in the analysis, the state was divided into five regions (Figure 1-2). The counties comprising each region were determined on the basis of similarity in hydrological, climatic, physical, and agronomic characteristics. Regions One through Four represent the study areas overlying the Ogallala aquifer. Region Five represents the Non-Ogallala Study region. Two counties, which comprise Region Six in Figure 1-2, were not included in the study area because they were outside the Ogallala aquifer region and were not analyzed as a separate region because of limited financial resources.

General Description of Economic Model

A multidimensional model framework was required to satisfy the objectives of this analysis because many physical and economic forces impact simultaneously on the agricultural production process. The recursive linear programming (RLP) framework chosen for this study enables a wide variety of forces, that are related to production changes, to be analyzed together. A schematic conceptualization of the key physical and economic forces includes commodity prices, energy and other factor input costs, commodity yields and irrigation development potential (Figure 1-3). Input-output quantities and associated prices feed into a budget generator for a given policy scenario. The RLP Model optimizes returns over variable cost subject to land, water and/or agronomic constraints. Flowing from the model are the outputs which include returns to land and management, water use, static water levels and agricultural production by crop and region.

The five region RLP Model contains 1,570 column activities and 1,001 rows. As illustrated in Figure 1-4, there are five regions in the model, five crops, four irrigation levels including dryland, two irrigations system types and four energy type sources for irrigation.

Five time periods were chosen for reporting results over a 43-year study period. Time periods chosen include 1977, 1985, 1990, 2000 and 2020. The 1977 year served as a base period and was chosen because it was the most recent year that all needed data were available. Time periods for reporting results of the analysis were chosen at closer intervals for the early years of the study and at wider time intervals near the end of the study period. More confidence can be placed in the results of the early time periods such as 1985 and 1990 than in the latter time periods. The matrix coefficients and right hand sides (RHSs) in Figure 1-4 identify the respective activities and how they interact in the RLP Model. Attention is now turned to a description of the individual components, illustrated in Figure 1-4, that comprise the basis of the RLP Model.

CROP YIELDS

This phase of the analysis had the objective of establishing yield projections for the principal crops in Nebraska including corn, soybeans, grain sorghum, wheat and alfalfa for both irrigated and non-irrigated conditions. These projections were made for each of the five regions into which the state was divided for purposes of the study (see Figure 1-2). The projections were made for the following four time periods: 1980-85, 1985-90, 1990-2000 and 2000-2020. The 1977 base year crop yields were determined from an average of 1976, 1977 and 1978 yields for the respective crops in each region.

The first step in developing yield forecasts was the establishment of yield trends by crop in each of the study regions for the period 1950-1978. In most cases, data permitted analysis to cover the 29-year period but in a few cases only a 23-year period (1956-1978) was permitted by available data. A multiple linear time series regression analysis was conducted for each irrigated and

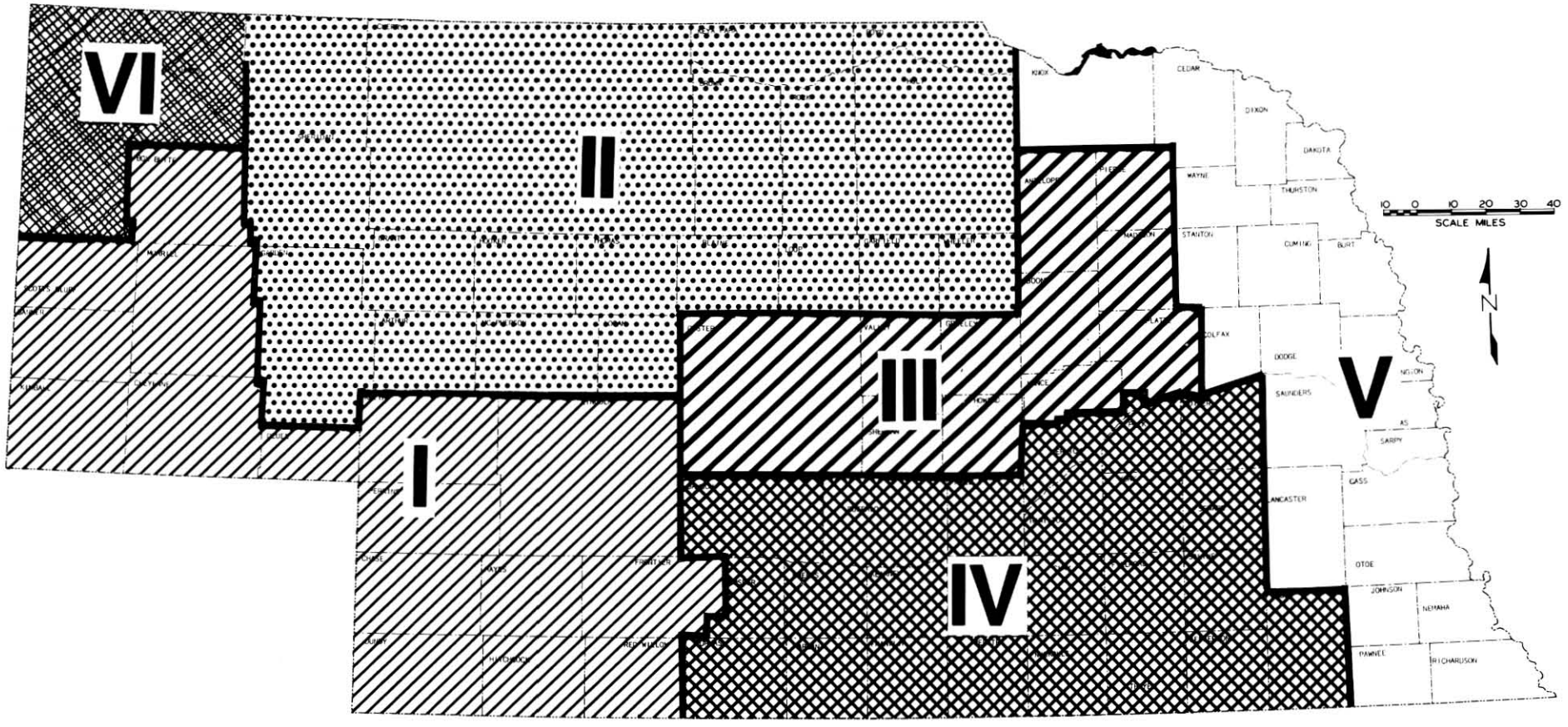

Figure 1-2. High Plains Study Regions

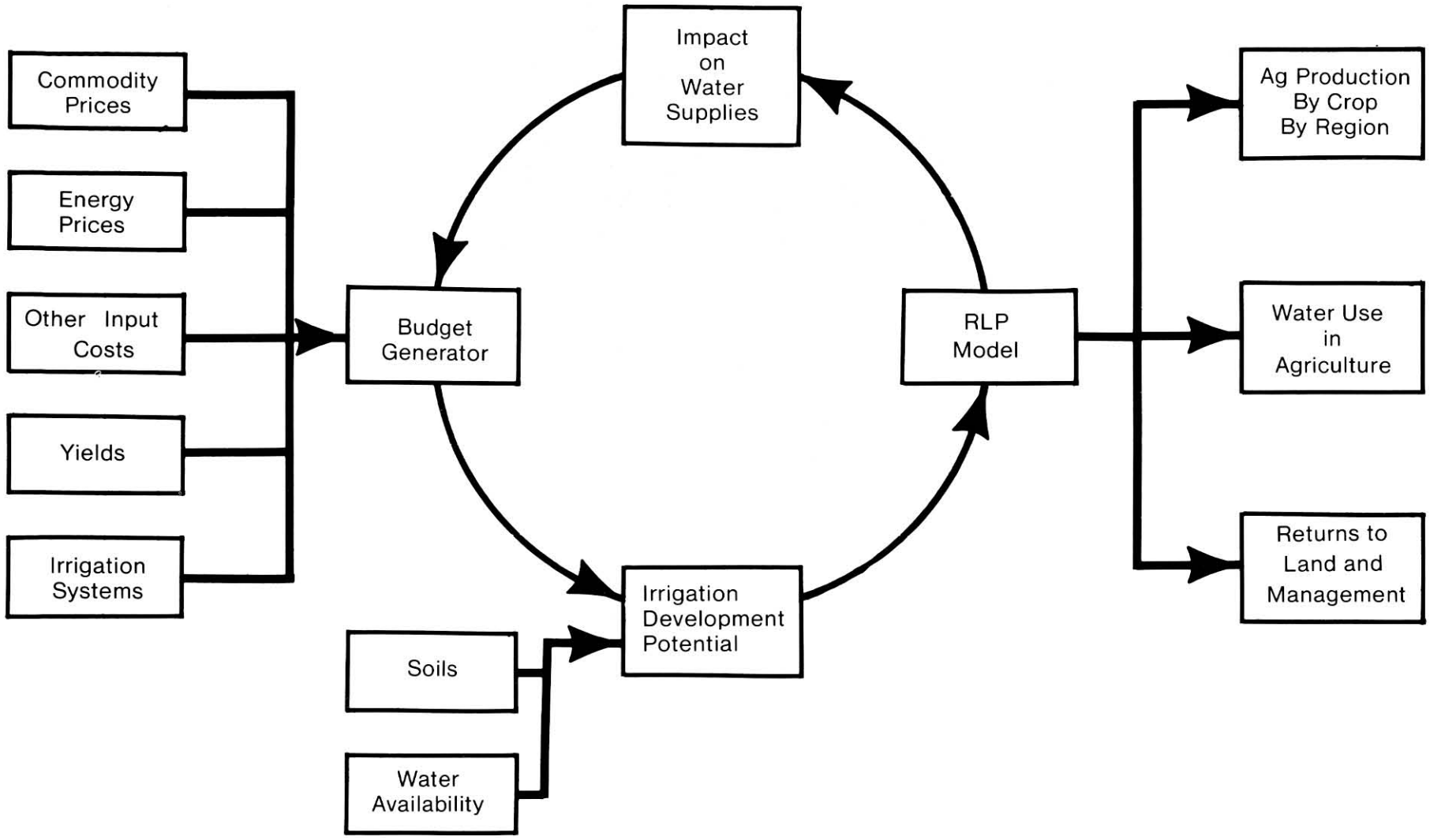

Figure 1-3. Schematic Conceptualization of the Agriculture Sector RLP Model.

+ - Crops 5
* - Irrigation Levels 4
⊥ - Irrigation Systems 2
Δ - Energy Types 4
- Regions 5

			25-Dryland Crop Production Activities	600-Irrigated Crop Production Activities	5-Range Livestock Production Activities (fx)	5-Surface Irrigation Production Activities (fx)	25-Fertilizer Purchase Activities ($/lb.)	5-Field Energy Purchase Activities ($/gal.)	25-Crop Handling Activities ($/bu.)	25-Crop Selling Activities	200-Fixed Irrigation Cost Activities	600-Variable Irrigation Cost Activities	25-Control Activities for Dryland Cropping Patterns (lo) (up)	25-Control Activities for Irr. Cropping Patterns (lo) (up)	5-Irr. land to Dryl. Transfer Activities	
			+++ ++ ## ###	+++ ++ *** ΔΔΔΔ ⊥⊥ ## ###	## ###	## ###	+++ ++ ## ###	## ###	+++ ++ ## ###	+++ ++ ## ###	+++ ++ ΔΔΔΔ ⊥⊥ ## ###	+++ ++ *** ΔΔΔΔ ⊥⊥ ## ###	+++ ++ ## ###	+++ ++ ## ###	## ###	RHS
Objective Function	N		-A	-B	+C	+D	-E	-F	-G	+H	-I	-J				
Fertilizer Application Rows (gal./acre)	L	+++++ #####	K	L			-I									
Field Energy Application Rows (gal./acre)	L	#####	M	N				-I								
Handling Cost Acct. Rows (bu./acre or tons/acre)	L	+++++ #####	O	P					-I							
Crop Production Transfer Rows		+++++ #####	-O	-P						I						
Dryland Constraint Rows	L	#####	I												-I	R
Irrigated Land Constraint Rows	L	#####		I											I	S
Pastureland Constraint Rows	L	#####			I											T
Surface Irrigated Land Constraint Rows	E	#####				I										U
Agronomic Constraint Rows (Dryland Crops)	E	+++++ #####	I													
Agronomic Constraint Rows (Irrigated Crops)	E	+++++ #####		I												
Water Accounting Rows	L	#####		Q												V
Irrigation Cost Accounting Rows (Fixed)	L	+++++ ΔΔΔΔ #####		I							-I					
Irrigation Cost Accounting Rows (Variable)	L	⊥⊥ +++++ ΔΔΔΔ #####		I								-I				
Control Rows for Energy Type And Irrigation System	G	⊥⊥ ΔΔΔΔ #####		I												W
Irrigated L. to Dryl. Transfer Acct. Row	L	#####													-I	

Rows - 1,001

-1,570.

Matrix Coefficients

A - Dryland crop production VC per acre (excluding irr. costs).
B - Irr. crop production VC per acre (excluding irr. costs).
C - RTLM per acre for range livestock production.
D - RTLM per acre for surface irrigation.
E - Fertilizer (anhydrous amonia) costs per pound.
F - Field energy costs per gallon.
G - Crop handling costs (per bu. or per ton).
H - Price per production unit per crop.
I - Fixed irrigation costs per acre by system and energy type.
J - Variable irrigation costs per acre by system, energy type, and water application level.
K - Pounds of fertilizer applied per acre (dryland).
L - Pounds of fertilizer applied per acre (irrigated).
M - Gallons per acre of field energy applied (dryland).
N - Gallons per acre of field energy applied (irrigated).
O - Units of crop produced per acre (dryland).
P - Units of crop produced per acre (irrigated).
Q - Acre inches of water applied.

RHS's

R - Dryland acres available.
S - Irrigated acres available (excluding surface irr. acres).
T - Pastureland acres available.
U - Surface irrigated acres available.
V - Acre inches of water available for irrigation.
W - Constraints on groundwater irrigation by irrigation system and energy type.

Figure 1-4. Nebraska High-Plains LP Model

dryland crop in each of the study regions. This procedure is similar to that followed by Thompson[48] and Swanson, *et. al.*.[49] In each case, the dependent variable was average harvested yield per acre in the respective regions and the independent variables included weekly periods of rainfall and weekly periods of temperatures above 95 degrees Fahrenheit. A time variable was used as a measure of yield gain per year for the period involved. These regressions were of the following form:

$$Y_{i=1} = A_0 + b_1X_{10} + b_2X_{11...30} + b_3X_{31...50};\ i = 1 \text{ to } 9$$

Where: Y = The respective irrigated and dryland crop
i = The respective crop
A_0 = intercept term
x_{10} = time
$x_{11...30}$ = twenty weekly precipitation variables
$x_{31...50}$ = twenty weekly temperature variables

The coefficient on the time variable was used by a team of agronomist (Hanway, Flowerday, and Waldrin) as one of the accepted bases for making projections. The 1980 yield forecast was based on extending the 29-year data trend, 1950-78, two years for the respective crops and regions and thereby establishing the current yield level from which projections were made.

The regressions identified weekly periods of rainfall or high temperatures that the analysis showed having significiant positive or negative effects on yield. since future weather predictions on a weekly basis are impossible, these could not be brought into play in making projections. Still, they consistently identified critical growth periods and contributed to scientific judgments involved in making the projections.

The scientists involved first considered the rates of yield gain that have been achieved. In many cases it was their judgment that the rate could be maintained through 1980-85 or perhaps 1985-90. Adjustments were made to place the rates in different regions in appropriate relationships. The agronomists made their projections based on the assumption that the real rate of investment in private and public research would be maintained.

A major judgment made by the agronomy team was the rate of increase that could be maintained through the four periods. A general consensus was that the rate that had been achieved through the 1950-1978 or 1956-1978 periods could not be maintained much longer in most crops. While separate judgments were made for each crop based on the specific factors that seemed important, a general pattern was developed for reducing the initial rate to three-fourths for 1990-2000 and to one-half for 2000-2020. The 29- or 23-year periods on which the regressions were based included the great expansion in use of fertilizer, in use of herbicides for weed control, in introduction of greatly improved varieties and improved cultural practices including some influencing water management. The major yield gains from some of these have already been made.

The final major judgment made by the agronomy team was in identifying the components or factors contributing to yield gains and their relative contributions through the four periods. The judgments show variety improvement as being the major contributing factor to yield gains after the year 2000.

The basis for making each of the crop yield forecasts in all the study regions is contained in a source document entitled, *"High Plains/Ogallala Aquifer Study Nebraska Crop Yield Projections"*, by Hanway, Flowerday and Waldrin.[50] The actual crop yields used in the study by region and time period are displayed in Table 1-2.

Responsibility for making full evapotranspiration (ET) and dryland yield forecasts was taken by the forementioned agronomy team. A team of agricultural engineers was responsible for development of the relationships between irrigation water applied and yields. Several water application rates and their accompanying crop yields per acre were estimated for each crop and study region. First, the water application rates were estimated that correspond to the fully irrigated yield forecasts made by the agronomy team. Secondly, two discrete crop yield reduction levels, 10 and 30 percent of the respective fully irrigated crop yields in each region, were made along with the water application rates that correspond to the 10 and 30 percent yield reductions. The following discussion describes the procedure used by the Agricultural Engineering Team in making these estimates. A complete discussion of their procedures is contained in a source document entitled, *"Development of Yield Reduction-Irrigation Crop Production Functions"*.[51]

Economic evaluation of groundwater resources and their use requires that crop yields be related to the amount of irrigation water applied. These relationships were developed through a calibrated computer simulation model corresponding to the study regions in Nebraska with three and four crops per region and five irrigation-soil systems per region-crop combination. Weather records of the past 15 to 27 years were used for each region to develop an average yield reduction-irrigation curve for the 65 region-crop-irrigation system-soil combinations simulated.

Table 1-2
Nebraska Projected Yields by Crop, Region and Time Period. (Bushels or Tons/Acre)

Crop / Region and Time Period	Dryland Corn	Irrigated Corn	Dryland Grain Sorghum	Irrigated Grain Sorghum	Dryland Soybeans	Irrigated Soybeans	Dryland Alfalfa	Irrigated Alfalfa	Dryland Wheat	Irrigated Wheat
Region I										
1977	30.79	113.10	39.11	71.46	0.00	35.75	2.28	4.18	33.23	47.00
1985	42.50	135.90	51.20	95.90	0.00	40.00	2.53	4.86	37.90	50.40
1990	45.00	145.40	56.20	106.90	0.00	42.80	2.68	5.23	40.40	55.40
2000	48.80	159.40	63.70	126.90	0.00	47.80	2.98	5.83	44.20	65.40
2020	53.80	179.40	71.30	156.90	0.00	55.80	3.46	7.03	49.20	81.40
Region II										
1977	43.90	119.06	49.63	72.85	0.00	35.75	1.48	3.97	35.70	47.00
1985	42.00	141.10	54.50	95.90	0.00	40.00	1.54	4.30	41.10	50.40
1990	44.00	150.60	59.50	106.90	0.00	42.80	1.62	4.57	44.30	55.50
2000	47.00	164.60	67.00	126.90	0.00	47.80	1.77	5.07	49.10	65.40
2020	51.00	184.60	74.60	156.90	0.00	55.80	2.07	6.15	55.50	81.40
Region III										
1977	61.52	117.19	62.70	90.21	27.37	36.77	2.66	4.15	32.44	47.00
1985	58.50	140.20	69.50	95.90	27.60	40.00	2.68	4.43	40.80	50.40
1990	62.00	151.20	75.50	106.90	29.10	42.80	2.83	4.64	44.20	55.50
2000	67.20	167.70	84.50	126.90	31.60	47.80	3.13	5.07	49.30	65.40
2020	74.20	189.70	93.50	156.90	35.60	55.80	3.61	6.11	56.10	81.40
Region IV										
1977	56.72	120.20	65.84	87.40	29.04	38.55	2.26	4.50	33.03	47.00
1985	53.00	149.80	84.50	103.00	28.40	48.60	3.46	4.85	42.60	50.40
1990	56.00	160.80	92.00	115.50	29.60	51.50	3.69	5.10	46.00	55.50
2000	60.50	179.80	102.00	135.50	32.10	56.50	4.15	5.62	51.20	65.40
2020	66.50	201.80	112.00	165.50	36.10	64.50	4.81	6.65	58.00	81.40
Region V										
1977	64.66	113.16	67.59	88.75	30.37	38.60	3.11	4.30	31.17	47.00
1985	68.20	134.40	83.90	101.20	30.20	40.40	3.32	5.36	43.20	50.40
1990	71.90	146.90	91.40	113.70	32.00	43.20	3.48	5.68	47.20	55.50
2000	77.50	166.90	101.40	133.70	35.00	48.20	3.81	6.32	53.20	65.40
2020	85.00	191.90	111.40	163.70	40.00	56.20	4.47	7.60	61.20	81.40

Two types of yield models were used in the project. Corn yields were predicted using a linear relative-transpiration function. Calibration data for the function was used from field research results of Watts, *et. al.*[52] Yields for sorghum, soybeans and winter wheat were approximated with a linear ET model described by Stewart, *et. al.*[53] The equation for sorghum was generated from the field data of Watts, *et. al.*[54]

The soybean curve was developed from field research results of Manam.[55] The yield formation model for winter wheat as described by Doorenbos and Kassam[56] was utilized to predict wheat yield reductions. Alfalfa yield reductions were based on the procedure described by Doorenbos *et. al.*[57]

The engineering team developed relative yield reduction-irrigation curves of the form:

$$YR(I) = \overline{Y}_R(d)\ [A(1-I/\overline{I}_f) + B(1-I/\overline{I}_f)^2]$$

Where: $\overline{Y}R(I)$ = the relative yield reduction water application amount;
$\overline{Y}_R(d)$ = the average dryland yield reduction;
$\overline{I}_f$ = the average full irrigation requirement, inches;
A = a linear coefficient;
B = a quadratic coefficient

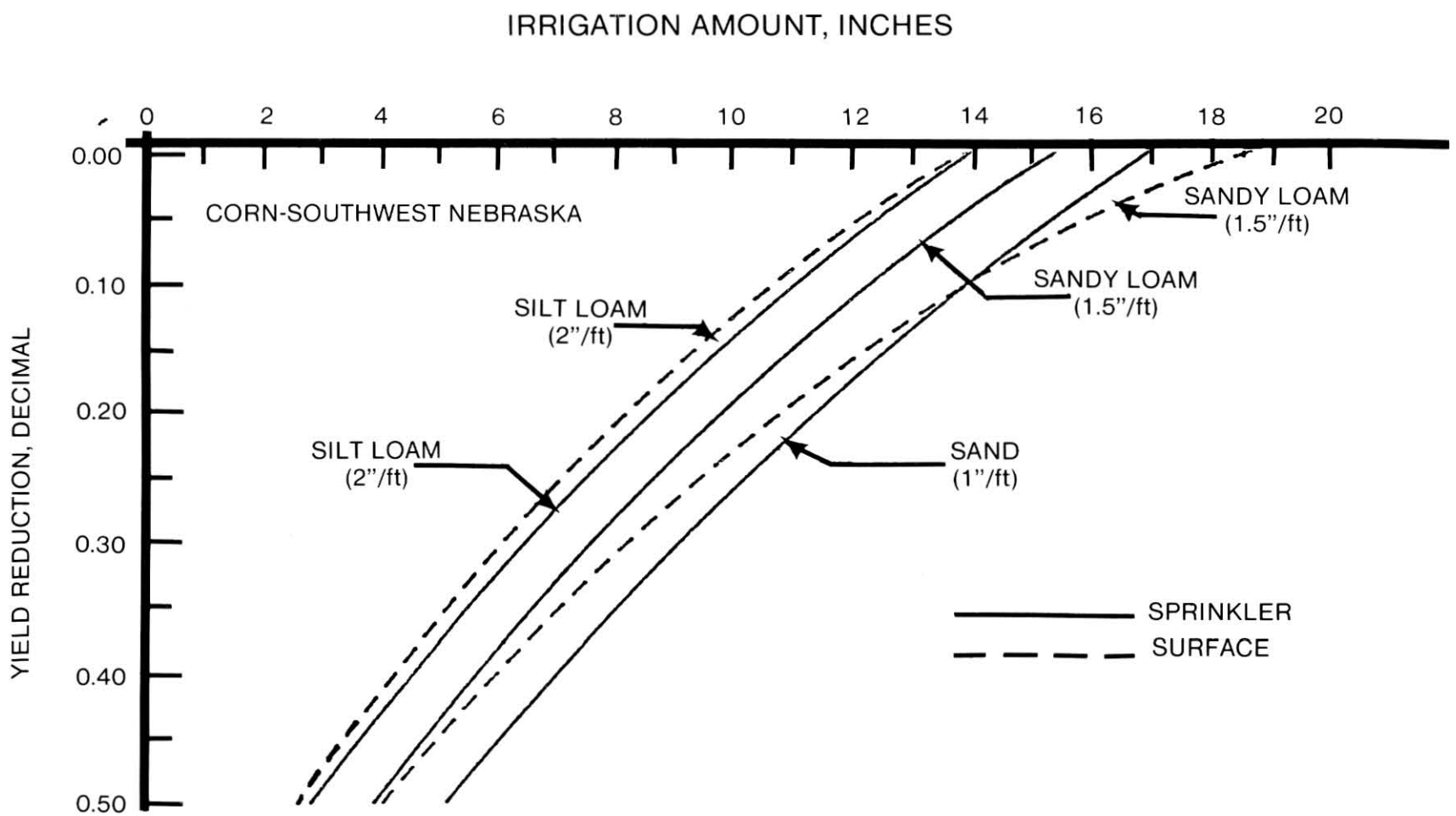

Figure 1-5. Yield reduction versus the amount of irrigation water applied for corn grown in Southwest Nebraska, three soil types and two methods of irrigation.

Table 1-3.

Yield Reduction - Irrigation Crop Production Empirical Constants. Average Full Irrigation Amounts and Average Relative Yield Reductions.

Region of State	Irrigation Method	Soil Type	Corn				Sorghum				Soybeans				Wheat			
			B	A	$\overline{I}_F$	$\overline{Y}_r(d)$	B	A	$\overline{I}_F$	$\overline{Y}_r(d)$	B	A	$\overline{I}_F$	$\overline{Y}_r(d)$	B	A	$\overline{I}_F$	$\overline{Y}_r(d)$
South West	Sprinkler	Sand	0.33	0.67	18.4	0.84	0.10	0.90	15.9	0.62	0.27	0.73	17.6	0.59	0.20	0.80	14.7	0.63
		Sandy Loam	0.36	0.64	16.7	0.78	0.03	0.97	15.1	0.56	0.20	0.80	16.5	0.54	0.28	0.72	12.9	0.56
		Silt Loam	0.40	0.60	15.8	0.74	-0.06	1.06	14.1	0.50	0.20	0.80	15.9	0.50	0.23	0.77	12.0	0.52
	Surface	Sandy Loam	0.74	0.26	22.5	0.78	0.27	0.73	19.1	0.56	0.44	0.56	21.2	0.54	0.46	0.54	14.8	0.56
		Silt Loam	0.67	0.33	17.0	0.74	0.13	0.87	14.3	0.50	0.45	0.55	16.8	0.50	0.35	0.65	11.5	0.52
North Central	Sprinkler	Sand	0.36	0.64	17.3	0.82	0.16	0.84	15.1	0.60	0.14	0.86	16.1	0.57				
		Sandy Loam	0.42	0.58	16.0	0.77	0.07	0.93	14.3	0.55	0.16	0.84	15.6	0.53				
		Silt Loam	0.45	0.55	15.0	0.71	0.06	0.94	13.3	0.49	0.19	0.81	15.5	0.49				
	Surface	Sandy Loam	0.90	0.10	21.7	0.77	0.47	0.53	19.2	0.55	0.52	0.48	22.2	0.53				
		Silt Loam	0.78	0.22	16.3	0.71	0.24	0.76	13.8	0.49	0.50	0.50	17.7	0.49				
North East	Sprinkler	Sand	0.17	0.83	14.2	0.75	-.01	1.01	13.4	0.52	0.14	0.86	14.0	0.48				
		Sandy Loam	0.47	0.53	13.8	0.67	-.01	1.01	12.4	0.45	0.19	0.81	13.5	0.42				
		Silt Loam	0.49	0.51	12.6	0.62	-0.10	1.10	11.2	0.39	0.28	0.72	12.6	0.38				
	Surface	Sandy Loam	0.91	.09	19.1	0.67	0.27	0.73	16.3	0.05	0.67	0.33	19.5	0.42				
		Silt Loam	0.94	.06	14.4	0.62	0.27	0.73	12.1	0.39	0.74	0.26	14.7	0.38				
East Central	Sprinkler	Sand	0.59	0.41	15.7	0.79	0.12	0.88	13.4	0.52	0.22	0.78	13.2	0.48				
		Sandy Loam	0.59	0.41	14.6	0.71	0.25	0.75	12.5	0.46	0.23	0.77	12.8	0.43				
		Silt Loam	0.66	0.34	13.5	0.65	0.40	0.60	11.9	0.40	0.23	0.77	12.1	0.38				
	Surface	Sandy Loam	0.89	0.11	20.4	0.71	0.27	0.73	18.8	0.46	0.55	0.45	16.7	0.43				
		Silt Loam	1.00	0.00	15.2	0.65	0.68	0.32	14.1	0.40	0.54	0.46	13.2	0.38				

Source: Martin, et/ al., Development of Yield Reduction - Irrigation Crop Production Functions. Nebraska Agricultural Engineering Department.

Equations were generated for all region-crop-irrigation system-soil combinations that were simulated. Characteristic curves for corn in the southwest region of Nebraska are shown in Figure 1-5. The average yield reduction-irrigation curves were cut off at a 50 percent yield reduction because it is probably infeasible to irrigate for yields below this level, and because the model was developed for stress in this range.

The crop production functions express relative yield reduction to the amount of irrigation water applied using a quadratic relationship. Values for the empirical constants (A) and (B), average irrigation requirements for full irrigation (full ET) and average relative dryland yield reductions for all situations simulated are listed in Table 1-3. These values are necessary to generate the yield reduction irrigation equation for each system listed in Table 1-3. It must be noted that these values are dependent upon the regions, crops, soils, irrigation systems and the irrigation management practices simulated. Other conditions would surely alter these values.

The Agricultural Engineering Team applied their simulation model assuming irrigators practice a high level of irrigation efficiency, i.e., people who wisely use their water and who have efficiently designed irrigation systems. Irrigation efficiency relates the gross irrigation amount to the required net irrigation. Since the average irrigator in the early study periods is unlikely to be as efficient as the simulated model results, inefficiency factors were applied to both the sprinkler and surface (gravity) systems in the respective time periods (Table 1-4). No data exists on the average irrigation efficiencies of various irrigation systems in Nebraska. The inefficiency factors in Table 1-4 were estimated by the Agricultural Engineering Team and other irrigation specialists in Nebraska. These inefficiency factors were applied to the full irrigation water applications developed by the yield

reduction simulation model. In the baseline or most likely agricultural scenario, it was estimated irrigators could reach that ideal efficiency with center pivot systems by the year 2000 based on currently available technology. Similarily, gravity irrigators using a reuse pit were expected to reach this maximum efficiency by the year 2020 (Table 1-4).

Table 1-4. Irrigation Efficiencies by Time Period and Irrigation System.

Time Period	Center Pivot Inefficiency Factor	Gravity with Reuse Pit Inefficiency Factor
1977	1.1541	1.2781
1980	1.134	1.25
1985	1.1005	1.2032
1990	1.067	1.1563
2000	1.0	1.0625
2020	1.0	1.0

Source: Based on the Experience of Nebraska Agricultural Engineers and Irrigation Industry Personnel.

CROP BUDGETS

Crop budgets were prepared for each crop in the respective study regions. A benchmark or typical farm unit was selected for each area where budgets were prepared. The Nebraska Extension Service's *Annual Crop and Livestock Production Cost* publication served as a guideline in the crop budget building process.[58] The standard cost-engineering budgeting approach was used in the study, *Agricultural Engineering Yearbook*.[59] The study required a very large number of crop budgets given the number of crops, regions and time periods analyzed. Because of the large number of budgets required, budgets were built for all dryland and irrigated crops for the 1977 base year and any physical quantity or real input price changes to these budgets over time were calculated with the aid of a budget generator.

Budgets for all time periods are in constant 1977 price levels.

Energy Prices -- Black and Veatch, Consulting Engineers, had the responsibility for making energy price forecasts used in the budgeting process. A source document entitled "Six-State High Plains/Ogallala Aquifer Energy Price Projections", contains the methodology employed in developing the energy price forecasts.[60] The actual prices used in this analysis are shown in Table 1-5.

Table 1-5. Energy Price Forecasts by Energy Source and Time Period in 1977 Constant Prices. [1/]

Year	Diesel/ Gallon	Electric/ KWH	Propane/ Gallon	Natural Gas/ 1,000 cu. ft.
1977	.41	.0313	.33	1.39
1985	.88	.0441	.49	3.45
1990	.89	.0471	.64	5.10
2000	.92	.0527	.66	5.28
2020	.97	.0602	.70	5.68

[1/]Energy prices include 7/10 of a year interest charges.

Source: Black and Veatch, Consulting Engineers, "Six-State High Plains - Ogallala Aquifer Area Study: Regional Study Element B-8 Energy Prices Projections," April 1, 1980.

Fertilizer Use and Prices. Fertilizer application rates were based on recommendations from agronomists Sander *et. al.*; [61], [62], [63], and Wiese, *et. al.*.[64] Nitrogen applications are based on the following functional relationships, where nitrogen in pounds/acre is a function of yield (Y):

(1)	Nitrogen Application for Corn	$N_C = .59904Y^{1.1213}$
(2)	Nitrogen Application for Grain Sorghum	$N_{GS} = .13806Y^{1.38025}$
(3)	Nitrogen Application for Wheat	$N_W = 1.5Y$

No nitrogen was applied to alfalfa or soybeans. Other soil nutrients and phosphorous fertilizer were applied to the soils in the respective regions based on general soil conditions in each region.

The prices of nitrogen and phosphorous fertilizer were forecasted to inflate at a rate faster than the general inflation rate.[65] Approximately two-thirds of the price of anhydrous ammonia is represented by energy costs, while 23 percent of the price of phosphorous is composed of energy costs. Natural gas is the major food stock for manufacturing anhydrous ammonia and was used as the basis for developing fertilizer price indices. The price indices and prices for nitrogen and phosphorous fertilizer for each study time period are shown in Table 1-6.

Table 1-6. Price Indices and Constant 1977 Prices for Nitrogen and Phospherous Fertilizer.

Year	Nitrogen Fertilizer Index	Nitrogen Prices/lb.	Phosphorous Fertilizer Index	Phosphorous Prices/lb.
1977	1.0	.13	1.0	.20
1985	1.98	.26	1.34	.27
1990	2.77	.36	1.62	.32
2000	2.85	.37	1.65	.33
2020	3.04	.40	1.71	.34

Source: Arthur D. Little, Inc. "Projected Fertilizer Prices," June 20, 1980.

Drying and Handling Costs. Drying costs were based on commercial rates commonly charged for corn and grain sorghum.[66] Corn and grain sorghum drying costs were based on two percent of the corn or grain sorghum price per point of average moisture dried per bushel. The average number of points of moisture dried increases from northwest to southeast Nebraska, largely as a function of rainfall and humidity.

Handling costs for each region and crop were calculated for both farm-to-market transportation expenses and from the field-to-farm site expenses. The number of miles traveled on the average from the farm to the grain elevators in the respective study regions were based on grain market surveys by Turner, *et. al.*[67] Farm density as well as grain elevator density is much greater in Study Regions Three, Four and Five than it is in Study Regions One or Two. Table 1-7 provides the total handling costs by region, crop and time period.

Table 1-7.
Nebraska Handling Costs by Crop, Region and Time Period. (Dollars/Bushel or Ton)

Region and Time Period	Corn	Gr. Sorg.	Soybeans	Alfalfa	Wheat
Region I					
1977	.13	.05	.05	2.31	.05
1985	.15	.05	.05	2.31	.05
1990	.15	.05	.05	2.31	.05
2000	.16	.06	.05	2.31	.05
2020	.18	.06	.05	2.31	.05
Region II					
1977	.25	.18	.19	2.40	.20
1985	.27	.18	.19	2.40	.20
1990	.28	.18	.19	2.40	.20
2000	.29	.18	.19	2.40	.20
2020	.30	.18	.19	2.40	.20
Region III					
1977	.16	.07	.06	2.58	.05
1985	.19	.07	.06	2.58	.05
1990	.20	.07	.06	2.58	.05
2000	.21	.08	.06	2.58	.05
2020	.23	.08	.06	2.58	.05
Region IV					
1977	.16	.07	.06	2.58	.05
1985	.19	.07	.06	2.58	.05
1990	.20	.07	.06	2.58	.05
2000	.21	.08	.06	2.58	.05
2020	.23	.08	.06	2.58	.05
Region V					
1977	.13	.07	.08	2.53	.06
1985	.16	.07	.08	2.53	.06
1990	.16	.07	.08	2.53	.06
2000	.17	.08	.08	2.53	.06
2020	.19	.08	.08	2.53	.06

Seed Prices. Seed prices over time were inflated at the same rate of real price increase as the respective commodity crop prices.

Insecticide and Herbicide Prices. Real prices of pesticides were forecasted to remain constant. However, real herbicide prices were forecasted to decline five percent by 1985 and a total of ten percent by 1990 from the 1977 base. Most of the herbicides were patented in the early to mid 1960s, and the patents are now expiring. This was the basis of projecting a real price decrease to 1990, with a leveling of prices after that.[68]

Interest Rates. Arthur D. Little, Inc., Economic Consulting Firm, had the responsibility for providing the Six-State High Plains Study with intermediate-term and short-term interest rates which reflect real (inflation adjusted) interest rates. Arthur D. Little used an historical interest rate data base from 1960 to 1977 from the Production Credit Association. They used simple regression analysis with interest rates as the dependent variable and the GNP deflater as the independent variable. This yielded a real interest rate of 0.061 percent for intermediate and short term loans. This 0.061 percent interest rate was used in the crop budgets for the portion of the year that cash was tied up.[69]

Labor Prices. Labor prices were estimated at $4.00/hour in 1977. This labor rate was not expected to inflate any faster than the general inflation rate, therefore, labor prices were held at the constant real rate of $4.00/hour through all time periods.

Fixed Machinery Costs. The fixed costs of crop production were developed for each crop and region based on standard cost engineering procedures. Fixed machinery costs were comprised of the following relationships:

(1) Annual Depreciation =

$$\frac{\text{Original 1977 Cost - Salvage Value}}{\text{Years of Useful Life}}$$

(2) Average Interest on Investment =

$$\frac{\text{Original Cost + Salvage Value}}{2} \times .061$$

(3) Average Taxes, Insurance and Housing =

$$\frac{\text{Original Cost + Salvage Value}}{2} \times .04$$

The original 1977 machinery costs were based on Nebraska Extension surveys of machinery costs at four locations in Nebraska. These machinery prices are contained in a source document entitled, "Prices of Machinery for Crop Budgeting Purposes, 'Summer 1977'".[70] Fixed machinery costs by region, crop and time period are contained in Table 1-8. These fixed machinery costs remain constant over time in 1977 prices.

Variable Irrigation Costs Per Acre. These costs were developed from the key relationships in the Nebraska "AGNET" program called "Pump", developed by Fischbach and Thompson, Nebraska Agricultural Engineers. The functional form of the respective variable irrigation costs are shown below, beginning on table 1-8, by irrigation system and energy type. Center pivot and a gravity with a reuse pit were the two irrigation systems used in the model; and diesel, electric, propane and natural gas were the four energy types modeled.

Fixed Irrigation Costs. Fixed irrigation costs were also developed from the key parameters in the AGNET "Pump" program. Fixed irrigation costs per acre for each irrigation system and

Table 1-8. Fixed Machinery Costs by Crop and Region.

	Region One	Region Two	Region Three	Region Four	Region Five
		----------dollars per acre----------			
Dryland Corn	12.87	16.31	18.31	18.31	22.47
Irrigated Corn	18.11	16.70	25.60	25.60	20.52
Dryland Grain Sorghum	13.35	13.80	16.93	16.93	18.71
Irrigated Gr. Sorghum	14.59	14.93	18.23	18.23	18.27
Dryland Soybeans	---	---	15.88	15.88	16.08
Irrigated Soybeans	12.95	13.24	17.48	17.48	16.33
Dryland Alfalfa 1/	13.82	12.11	6.32	6.32	4.34
Irrigated Alfalfa 1/	24.54	16.43	6.56	6.56	4.34
Dryland Wheat	11.56	14.63	14.62	14.62	13.75
Irrigated Wheat	12.77	---	---	---	---

1/The most common practice in Regions Three, Four and Five for alfalfa production is to custom or hire out the baling operation, hence their lower fixed costs.

energy type were developed based on the relationship of fixed irrigation costs as a function of feet of head. Fixed irrigation cost equations follow the variable irrigation cost equations, for the respective irrigation systems and energy types. These equations were developed by regression analysis in the following manner. The Pump Program was run for a range of lifts for each irrigation system and energy type. The resulting total fixed irrigation costs per acre were regressed against feet of head, which consisted of the respective range of lifts pumped plus the pounds per square inch (PSI) multiplied by the constant 2.31.

COMMODITY PRICES

The National Interregional Agricultural Projections Model (NIRAP) developed by Quance, *et. al.*[71] at Economics Statistics and Cooperatives Service (ESCS), USDA, was used to project agricultural commodity prices for the High Plains Study for the years 1985, 1990, 2000 and 2020. NIRAP is a computerized simulation of U.S. agriculture used to analyze alternative futures for U.S. agriculture based on differing scenarios and policy decisions.

The commodity price projections made by the NIRAP team reflect increasingly real commodity prices from 1985 to 2020. Commodity prices for Nebraska which were used in this study are shown in Table 1-9. Wheat prices in constant 1977 dollars were projected to increase 12 percent between 1985 and 2020. Increases of 15.5 percent, 14 percent, 14 percent and 10.3 percent were projected for soybeans, corn, grain sorghum and alfalfa, respectively.

Variable Irrigation Cost Equations

I. Sprinkler System - Combustion Engine -- Diesel

$$VIC_{SD_D} = \frac{.1143\,[L + (PSI)\,(2.31)]\,(W)\,(P_D)}{10.94} + .000332\,[L + (PSI)\,(2.31)]\,(W) + .0000152\,[L + (PSI)\,(2.31)]\,(GPM) + \frac{416.4\,(W)}{GPM} + \frac{27.2(W)\,(P_L)}{G.P.M.} + .5\,(P_L)$$

L = Lift — (Changes by region and over time — initially specified, but over time, altered according to the Δ SWL and gross pumpage relationship provided by NRC)

W = Gross Inches Pumped/Acre — (changes by Crop/Irr. Level/Region/Time Period)

P_f = Fuel Price Per Unit — (changes by type of fuel/time period), f = D, E, P, NG

GPM = Flow Rate or Gallons Per Minute pumping rate — changes per region

P_L = Price of Labor Per Hour (constant over time)

PSI = lbs/square inch (pressure) by Irr. System, by Region, by Time Period.

II. Sprinkler System - Electric

$$VIC_{SE} = \frac{.1143[L + (PSI)\,(2.31)]\,(W)\,(P_E)}{.885} + .0000117[L + (PSI)\,(2.31)]\,(GPM) + \frac{416.4(W)}{GPM} + \frac{27.2(W)\,(P_L)}{GPM} + .5(P_L)$$

III. Sprinkler System - Combustion Engine - Propane

$$VIC_{SC_P} = \frac{.1143[L + (PSI)\,(2.31)]\,(W)\,(P_P)}{6.89} + .000332[L + (PSI)\,(2.31)\,]\,(W) + .0000152[L + (PSI)\,(2.31)]\,(GPM) + \frac{416.4(W)}{GPM} + \frac{27.2(W)\,(P_L)}{GPM} + .5\,(P_L)$$

IV. Sprinkler System - Combustion Engine - Natural Gas

$$VIC_{SC_{NG}} = \frac{.1143[L + (PSI)\,(2.31)]\,(W)\,(P_{NG})}{66.7} + .000332[L + (PSI)\,(2.31)]\,(W)$$

$$+ .0000152[L + (PSI)(2.31)](GPM) + \frac{416.4(W)}{GPM}$$

$$+ \frac{27.2(W)(P_L)}{GPM} + .5(P_L)$$

V. Gravity System - Combustion Engine - Diesel

$$VIC_{GC_D} = \frac{.1143[L + (PSI)(2.31)](W)(P_D)}{10.94} + .000332[L + (PSI)(2.31)](W)$$

$$+ .0000152[L + (PSI)(2.31)](GPM) + 1$$

$$+ \frac{27.2(W)(P_L)}{GPM} + 1.1(P_L)$$

VI. Gravity System - Electric

$$VIC_{GE} = \frac{.1143[L + (PSI)(2.31)](W)(P_E)}{.885} + .0000117[L + (PSI)(2.31)](GPM)$$

$$+ 1 + \frac{27.2(W)(P_L)}{GPM} + 1.1(P_L)$$

VII. Gravity System - Combustion Engine - Propane (LP)

$$VIC_{GC_P} = \frac{.1143[L + (PSI)(2.31)](W)(P_P)}{6.89} + .000332[L + (PSI)(2.31)](W)$$

$$+ .0000152[L + (PSI)(2.31)](GPM) + 1$$

$$+ \frac{27.2(W)(P_L)}{GPM} + 1.1(P_L)$$

VIII. Gravity System - Combustion Engine - Natural Gas

$$VIC_{GC_{NG}} = \frac{.1143[L + (PSI)(2.31)](W)(P_{NG})}{66.7} + .000332[L + (PSI)(2.31)](W)$$

$$+ .0000152[L + (PSI)(2.31)](GPM) + 1$$

$$+ \frac{27.2(W)(P_L)}{GPM} + 1.1(P_L)$$

VIC = Variable Irrigation Costs/Acre

S = Sprinkler System; G = Gravity System; C = Combustion Engine; E = Electric
D = Diesel; E = Electric; P = Propane; NG = Natural Gas
H = Feet of Head (Lift + PSI (2.31) for Gravity; Lift + PSI (2.31) for Sprinkler
W = Inches Pumped/Acre
P_f = Fuel Price per Unit
F = Flow Rate in GPM
P_L = Price of Labor/Hr.

K_f = WHP hrs/unit fuel	Energy Price/unit
= .885 for Electric (KWH)	$/KWH
= 10.94 for Diesel (gal.)	$/gal.
= 66.7 for NG (1000 cu. ft.)	$/1000 cu. ft.
= 8.66 for Gas (gal.)	$/gal.
= 6.89 for LP (gal.)	$/gal.

Fixed Irrigation Cost Equations

I. **Sprinkler System - Combustion Engine - Diesel**
$FIC_{SC_D} = 22.49584 + .07947\ [L + (PSI)\ (2.31)]$ $R^2 = .97$

II. **Sprinkler System - Electric**
$FIC_{S_E} = 21.53603 + .05077\ [L + (PSI)\ (2.31)]$ $R^2 = .99$

III. **Sprinkler System - Combustion Engine - Propane (LP)**
$FIC_{SC_P} = 22.62701 + .05389\ [L + (PSI)\ (2.31)]$ $R^2 = .98$

IV. **Sprinkler System - Combustion Engine - Natural Gas**
$FIC_{S_{NG}} = 22.28278 + .0536\ [L + (PSI)\ (2.31)]$ $R^2 = .98$

V. **Gravity System - Combustion Engine - Diesel**
$FIC_{G_D} = 21.7845 + .07729\ [L + (PSI)\ (2.31)]$ $R^2 = .99$

VI. **Gravity System - Electric**
$FIC_{G_E} = 20.23474 + .05291\ [L + (PSI)\ (2.31)]$ $R^2 = .99$

VII. **Gravity System - Combustion Engine - Propane (LP)**
$FIC_{GC_P} = 21.56865 + .05211\ [L + (PSI)\ (2.31)]$ $R^2 = .99$

VIII. **Gravity System - Combustion Engine - Natural Gas**
$FIC_{G_{NG}} = 21.1921 + .05189\ [L + (PSI)\ (2.31)]$ $R^2 = .99$

Table 1-9. Nebraska Commodity Prices[2/]

Commodity	1977[3/]	1985	1990	2000	2020
	----------Dollars Per Bushel or Per Ton----------				
Wheat	2.54	2.88	2.90	2.96	3.23
Soybeans	6.32	5.98	6.02	6.24	6.91
Corn	2.05	2.49	2.53	2.70	2.83
Grain Sorghum	1.81	2.14	2.18	2.33	2.44
Alfalfa/Ton[1/]	36.87	42.56	43.08	45.28	46.96

1/ Alfalfa price/ton is based on Y = 10.34 + 12.94 (Price of Corn.)
2/ Based on USDA NIRAP Prices adjusted to Nebraska by historical Nebraska - to - U.S. Commodity price relationships since 1947. Where wheat, soybeans, corn and grain sorghum are .95, .98, .98 and .94, respectively of the average U.S. price.
3/ The average of prices received by U.S. farmers for the specified commodity in 1976, 1977 and 1978 adjusted to Nebraska by historical Nebraska - to - U.S. commodity price relationships since 1947.

WATER MODEL RELATIONSHIPS

Estimates of changes in static water levels due to irrigation over time were necessary for computing irrigation costs. These relationships were determined for each study region based on groundwater models developed by the Nebraska Natural Resources Commission (NRC). Agricultural Economics Economists provided NRC staff with a wide range of potential irrigation development and cumulative pumpage scenarios for each region which they used in running groundwater models. The Agricultural Economics Team, in turn, used the results of the various runs of the groundwater models in the respective regions to develop estimates of changes in static water level as a function of cumulative net withdrawals. The relationships between acres going out of production (aquifer exhaustion) and cumulative net withdrawals were developed in a similar fashion. These key relationships are illustrated in Table 1-10 for each region.

Table 1-10. Static Water Level Change and Physical Exhaustion Relationships by Study Region[1/]

Dependent Variable and Region	Intercept Term	Cumulative Net Withdrawals	Cumulative Net Withdrawals Squared	R^2
Static Water Level change				
Region One	10.444	8.2444 E-7(CNW)		0.989
Region Two	9.0462	7.0975 E-7(CNW)		0.934
Region Three	8.0425	7.8909 E-7(CNW)		0.957
Region Four	8.7968	4.8547 E-7(CNW)		0.907
Region Five	8.0182	3.0791 E-6(CNW)		0.932
Physical Exhaustion				
Region One	4771.5	+0.004577 (CNW)	+1.097 E-11(CNW^2)	0.993
Region Two	3080.6	+0.003 (CNW)	-1.653 E-11(CNW^2)	0.954
Region Three	5276.8	-0.0007193 (CNW)	+2.2206 E-11(CNW^2)	0.982
Region Four	19,003.0	+0.0003944 (CNW)	+4.2874 E-11(CNW^2)	0.969
Region Five	6,520.1	+0.0066112 (CNW)	+1.2648 E-10(CNW^2)	0.981

[1/] These relationships are based on the Nebraska Natural Resources Commission's groundwater models.

IRRIGATED ACREAGE PROJECTIONS

A combination of soil and groundwater criteria was used to determine the physical maximum irrigation potential from groundwater sources. As a first step, irrigability percentages were developed for each of the 145 soil associations in Nebraska (Table 1-11). These estimates were made by Dave Lewis, Soil Scientist, Department of Agronomy, UNL. Separate estimates of the irrigability of each soil association were made by the USDA Soil Conservation Service. The two separate estimates of irrigability were very close to each other. A soil association is comprised of similar slopes, parent material, depth, drainage, and texture [72, 73].

The next step in the procedure was to determine where there existed sufficient groundwater supplies for irrigation. The criteria selected were based on a combination of saturated thickness and well yield. Irrigation from groundwater was assumed to be feasible if the well yields in an area were over 700 GPM or 400-700 GPM with at least 50 feet of saturated thickness. No development was allowed on areas where well yields were below 400 GPM or if well yields were between 400-700 GPM but with a saturated thickness under 50 feet. The Agricultural Economics Department provided these criteria to the UNL Conservation and Survey Division, which in turn, provided saturated thickness and well yield maps of the entire state on the same scale (1:250,000) as the soil maps.

Acreages in each county that were in roads, railroads, farmsteads, parks, cities, rivers and lakes were subtracted out of each county to prevent overstating irrigation potential. The final procedure involved overlying the soil and water maps and digitizing the area in each county that met the combined soil and water criteria. The maximum groundwater acreage available in each county for the respective study areas is shown in Table 1-12. Acreages from surface water source irrigation were subtracted from the maximum groundwater acreage potential.

Once the physical potential for groundwater irrigation development was determined, some method or procedure was necessary to estimate how fast new annual groundwater irrigation development may occur in the future. Groundwater irrigation has historically been relatively profitable for Nebraska irrigators. It has helped to reduce the uncertainty of weather and has tended to stabilize yields and farm income. The estimated profitability of groundwater irrigated agriculture in the future was a key element in determining the rate of new irrigation development. Preliminary budgeting results from the baseline scenario's key input and output factors indicated that groundwater irrigation would likely continue to be relatively more profitable than dryland agriculture. Therefore, the criteria for the annual rate of new irrigation development was based on the annual rate that occurred between 1967 and 1977 (Table 1-12). The ten-year period represented some years where irrigation development occurred at a rapid as well as a slow rate. This annual rate of new groundwater irrigation development was assumed to take place over the entire study period in each county unless the physical irrigation acreage potential was reached (Table 1-12).

Table 1-11. Nebraska Soil Associations and Estimated Percent of Irrigability.

Soil Assoc. No.	Percent of Irrig.	Soil Assoc. No.	Percent of Irrig.	Soil Assoc. No.	Percent of Irrig.
1	40%	50	100%	98	100%
2	38	51	100	99	80
3	100	52	80	100	100
4	100	53	100	101	65
5	100	54	50	102	60
6	100	55	60	103	100
7	65	56	100	104	80
8	100	57	90	105	70
9	100	58	100	106	0
10	0	59	100	107	40
11	10	60	100	108	20
12	30	61	10	109	100
13	30	62	100	110	100
14	50	63	0	111	60
15	0	64	50	112	50
16	0	65	100	113	100
17	50	66	100	114	100
18	100	67	100	115	80
19	100	68	80	116	0
20	0	69	90	117	0
21	20	70	100	118	40
22	50	71	100	119	20
23	20	72	100	120	0
24	35	73	40	121	0
25	100	74	100	122	100
26	60	75	80	123	100
27	100	76	0	124	100
28	100	77	50	125	100
29	50	78	100	126	40
30	75	79	0	127	70
31	100	80	25	128	85
32	70	81	45	129	35
33	100	82	0	130	40
34	70	83	80	131	55
35	35	84	100	132	25
36	75	85	0	133	35
37	80	86	60	134	10
38	50	87	100	135	15
39	50	88	30	136	20
40	100	89	100	137	20
41	10	90	100	138	80
42	100	91	100	139	10
43	100	92	100	140	0
44	100	93	50	141	60
45	100	94	55	142	60
46	100	95	50	143	100
47	100	96	65	144	100
48	75	97	55	145	80
49	100				

Source: Dave Lewis, Soil Scientist, Department of Agronomy, UNL.

Table 1-12. Groundwater Irrigation Potential and Future Growth Rates in Nebraska, by County and High Plains Study Region. (Acres)

Region I

County	Ground-water 1977 Irrigation	Annual Rate From 1967 to 1977	Maximum Ground-water Acreage	Years to reach Maximum	Potential Growth 1985	1990	2000	2020
Banner	18,000	1,190	190,400	144.9	27,520	33,470	45,370	69,170
Box Butte	84,000	3,530	455,399	105.2	112,240	129,890	165,190	235,790
Chase	141,340	11,560	349,483	18.0	233,820	291,620	349,483	349,483
Cheyenne	37,000	2,130	518,180	225.9	54,040	64,690	85,990	128,590
Deuel	22,520	1,340	221,578	148.6	33,240	39,940	53,340	80,140
Dundy	82,063	6,980	351,344	38.6	137,903	172,803	242,603	351,344
Frontier	65,584	5,150	286,684	42.9	106,784	132,534	184,034	286,684
Hayes	25,560	2,240	253,330	101.7	43,480	54,680	77,080	121,880
Hitchcock	42,759	2,320	113,984	30.7	61,319	72,919	96,119	113,984
Keith	75,143	4,370	336,228	59.7	110,103	131,953	175,653	263,053
Kimball	29,000	1,440	369,782	236.7	40,520	47,720	62,120	90,920
Lincoln	118,847	6,870	608,774	71.3	173,807	208,157	276,857	414,257
Morrill	50,594	3,430	378,768	95.7	78,034	95,184	129,484	198,084
Perkins	82,935	7,200	497,874	57.6	140,535	176,535	248,535	392,535
Red Willow	54,619	3,470	151,604	27.9	82,379	99,729	134,429	151,604
Scottsbluff	36,800	1,610	83,269	28.9	49,680	57,730	73,830	83,269
Total	966,764	64,830	5,166,681	64.8	1,485,404	1,809,554	2,400,117	3,353,548

Table 1-12. (Continued) (Acres)

Region II

County	Ground-water 1977 Irrigation	Annual Rate From 1967 to 1977	Maximum Ground-water Acreage	Year To Reach Maximum	Potential Growth 1985	1990	2000	1020
Arthur	5,000	400	78,152	182.9	8,200	10,200	14,200	22,200
Blaine	11,000	950	128,042	123.2	18,600	23,350	32,850	51,850
Boyd	5,000	420	14,027	21.5	8,360	10,460	14,027	14,027
Brown	36,040	3,910	386,561	89.6	67,320	86,870	125,970	204,170
Cherry	37,000	3,130	796,079	242.5	62,040	77,690	108,990	171,590
Garden	30,000	1,340	363,756	249.1	40,720	47,420	60,820	87,620
Garfield	17,000	900	127,342	122.6	24,200	28,700	37,700	55,700
Grant	2,000	150	84,443	549.6	3,200	3,950	5,450	8,450
Holt	212,000	17,520	676,190	26.5	352,160	405,260	580,460	676,190
Hooker	3,000	310	91,381	420.9	4,680	5,730	7,830	12,030
Keya Paha	16,000	40	58,730	1,068.3	16,320	12,520	12,920	13,720
Logan	12,000	700	107,264	136.1	17,600	21,100	28,100	42,100
Loup	12,000	820	125,982	139.0	18,560	22,660	30,860	47,260
McPherson	6,000	520	137,587	253.1	10,160	12,760	17,960	28,360
Rock	54,000	4,970	279,926	45.5	93,760	118,610	168,310	267,710
Sheridan	35,400	2,200	713,460	308.2	53,000	64,000	86,000	130,000
Thomas	3,000	190	77,951	394.5	4,520	5,470	7,370	11,170
Wheeler	28,000	2,630	160,260	50.3	49,040	61,290	88,490	141,090
Total	525,440	43,020	4,407,133	90.3	852,440	1,018,940	1,428,307	1,985,237

Table 1-12. (Continued) (Acres)

Region III

County	Ground-water 1977 Irrigation	Annual Rate From 1967 to 1977	Maximum Ground-water Acreage	Years to reach Maximum	Potential Growth 1985	1990	2000	2020
Antelope	136,656	12,010	391,415	21.2	232,736	292,786	391,415	391,415
Boone	86,870	5,760	250,161	28.3	132,950	161,750	219,350	250,161
Custer	121,600	8,420	671,374	64.1	188,960	231,060	315,260	483,660
Greeley	47,600	3,380	176,383	39.0	74,640	90,040	123,840	176,383
Howard	72,080	3,470	208,455	43.3	99,840	110,190	144,890	207,290
Madison	54,950	4,710	279,389	47.7	92,630	116,180	163,280	257,480
Nance	42,011	3,020	174,471	47.2	66,171	76,271	106,471	166,871
Pierce	68,820	5,970	270,464	25.7	116,580	146,430	206,130	270,464
Platte	122,156	7,860	287,006	21.0	185,036	224,336	287,006	287,006
Sherman	40,300	1,930	158,035	61.0	55,740	65,390	84,690	123,290
Valley	43,400	2,780	131,350	40.6	65,640	67,040	94,840	131,350
Total	836,443	56,610	2,998,503	38.2	1,310,923	1,581,473	2,137,172	2,776,960

Table 1-12. (Continued) (Acres)

Region IV

County	Ground-water 1977 Irrigation	Annual Rate From 1967 to 1977	Maximum Ground-water Acreage	Years to reach Maximum	Potential Growth 1985	1990	2000	2020
Adams	142,000	5,930	310,688	28.4	189,440	219,090	278,390	310,688
Buffalo	200,371	8,270	356,085	18.8	266,531	307,881	356,085	356,085
Butler	86,000	4,570	232,305	32.0	122,560	145,410	191,110	232,305
Clay	173,000	6,180	299,098	20.4	222,440	253,340	299,098	299,098
Dawson	171,090	7,250	291,241	16.6	229,090	265,340	291,241	291,241
Fillmore	155,000	5,210	251,553	18.5	196,680	222,730	251,553	251,553
Franklin	61,540	3,260	221,635	49.1	87,620	103,920	136,520	201,720
Furnas	32,179	1,640	108,810	46.7	45,299	53,499	69,899	102,699
Gage	46,000	2,710	367,066	118.5	67,680	81,230	108,330	162,530
Gosper	49,048	3,150	158,728	34.8	74,248	89,998	121,498	158,728
Hall	183,644	4,440	224,240	8.0	224,164	224,240	224,240	224,240
Hamilton	235,000	7,460	319,047	11.3	294,680	319,047	319,047	319,047
Harlan	58,926	3,710	170,809	30.2	88,606	107,156	144,256	170,809
Jefferson	45,000	2,480	279,201	94.4	64,840	77,240	12,040	151,640
Kearney	141,015	5,860	278,429	23.4	187,895	217,195	275,795	278,429
Merrick	173,108	5,960	158,770	-2.4	173,108	173,108	173,108	173,108
Nuckolls	50,000	1,200	242,462	160.4	59,600	65,600	77,600	101,600
Phelps	128,708	5,970	222,085	15.6	176,468	206,318	222,085	222,085
Polk	128,000	4,710	175,539	10.1	165,680	175,539	175,539	175,539
Saline	74,000	3,240	98,981	7.7	98,981	98,981	98,981	98,981
Seward	96,000	4,560	244,384	32.5	132,480	155,280	200,880	244,384
Thayer	96,000	3,600	298,091	56.1	124,800	142,800	178,800	250,800
Webster	27,452	1,740	70,522	24.8	41,372	50,072	67,472	70,522
York	198,000	5,770	340,241	24.7	244,160	273,010	330,710	340,241
Total	2,756,081	108,870	5,720,010	27.2	3,578,422	4,028,024	4,694,277	5,188,072

Table 1-12 (Continued) (Acres)

Region V

County	Ground-water 1977 Irrigation	Annual Rate From 1967 to 1977	Maximum Ground-water Acreage	Years to reach Maximum	Potential Growth 1985	1990	2000	2020
Burt	37,890	2,840	168,029	45.8	60,610	74,810	103,210	160,010
Cass	4,000	170	80,248	448.5	5,360	6,210	7,910	11,310
Cedar	38,500	3,450	263,365	65.2	66,100	83,350	117,850	186,850
Colfax	40,700	2,140	175,491	63.0	57,820	68,520	89,920	132,720
Cuming	20,540	1,810	314,378	162.3	35,020	44,070	62,170	98,370
Dakota	10,000	840	77,299	80.1	16,720	20,920	29,320	46,120
Dixon	8,940	950	165,353	164.6	16,540	21,290	30,790	49,790
Dodge	82,525	5,200	265,208	35.1	124,125	150,125	202,125	265,208
Douglas	10,525	700	45,484	49.9	16,125	19,625	26,625	40,625
Johnson	10,000	770	139,967	168.9	16,160	20,010	27,710	43,110
Knox	27,726	2,420	254,930	93.9	47,086	59,186	83,386	131,786
Lancaster	20,000	1,160	275,310	220.1	29,280	35,080	46,680	69,880
Nemaha	4,000	320	19,784	49.3	6,560	8,160	11,360	17,760
Otoe	6,000	530	184,016	335.9	10,240	12,890	18,190	28,790
Pawnee	2,000	180	6,455	24.8	3,440	4,340	6,140	6,455
Richardson	2,000	170	-0-	-011.8	2,000	2,000	2,000	2,000
Sarpy	8,000	270	78,013	259.3	10,160	11,510	14,210	19,610
Saunders	52,000	3,560	423,231	104.3	80,480	98,280	133,880	205,080
Stanton	22,570	1,660	158,274	81.7	35,850	44,150	60,750	93,950
Thurston	5,120	350	138,059	379.8	7,920	9,670	13,170	20,170
Washington	9,900	790	128,368	150.0	16,220	20,170	28,070	43,870
Wayne	9,910	990	213,421	205.6	17,830	22,780	32,680	52,480
Total	432,846	31,270	3,574,683	100.5	681,646	837,146	1,148,146	1,725,944
Total for 5 Regions	5,516,574	304,600	21,867,010		7,908,835	9,275,137	11,808,019	15,029,761

POTENTIAL FOR LOW-PRESSURE CENTER PIVOTS

An emerging technology of key importance to Nebraska's groundwater irrigators is the development of reduced-pressure center pivot systems. The energy savings and therefore cost savings from adoption of reduced-pressure systems can be substantial. The energy savings from adoption of a low-pressure impact head center pivot system results from a pressure saving of approximately 35 pounds, based on an average 75 pounds for high pressure systems and 40 pounds for low pressure impact head systems. There are other types of reduced-pressure systems which reduce pressure even more, but their wide adoption is not as likely as the low-pressure impact heads, because their very rapid application rate causes runoff and erosion problems on many Nebraska soils. This study accordingly restricts its analysis of reduced-pressure systems to low-pressure impact heads.

Development of a methodology was necessary to determine on what soils low-pressure systems could be used without causing excessive runoff. The methodology employed was developed by Gilley.[74]

Using Gilley's methodology it was found that the percentage of the potential groundwater acreage in each region which could use low pressure impact head systems was 86 percent in Region One, 91 percent in Region Two, 63 percent in Region Three, 67 percent in Region Four and 57 percent in Region Five. A large proportion of the soils in Region Two are comprised of soils from a higher water intake family, while many soils in Region Five are either from a low water intake family or the slopes are too great for low-pressure systems to meet the established criteria.

CROP BOUNDING CONSTRAINTS

In a linear programming model with a finite number of alternatives, prediction of aggregative behavior could be grossly unstable if only the profit maximizing objective was considered. In some agricultural regions specialized cropping alternatives are relatively more profitable than others. Consequently, unless explicit upper and lower bounds are set to reflect uncertainty, a programming model will predict much greater specialization for a given year than what would likely be observed in reality. These bounds have the effect of limiting the concentration of the most profitable crop in a region.

Table 1-13 contains the actual bounding activities used in the study by region, crop and time period. Generally, alfalfa production was constrained to maintain a fairly constant production over time because its production is predominantly based on local livestock demand. Soybeans were the most profitable crop for some regions in most time periods. However, soybeans cannot be grown continuously, have more production uncertainty than some other crops in the study and are not commonly grown now in many areas of Nebraska. All these factors were considered for soybeans in the bounding procedure. Corn was allowed to enter the solution over a wide range of production levels.

Table 1-13. Nebraska Irrigated and Dryland Crops Agronomic and Bounding Constraints by Crop, Region and Time Period.

Region and Time Period \ Crop and Bound	Dryland Corn		Irr. Corn		Dryland G. Sorg.		Irr. G. Sorg.		Dryland Soybeans		Irr. Soybeans	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
Region I												
1977	.06	.15	.79	.90	.04	.10	.01	.10	.00	.01	.00	.01
1985	.03	.99	.20	.99	.09	.99	.03	.99	.00	.01	.03	.13
1990	.04	.99	.20	.99	.00	.99	.03	.99	.00	.01	.04	.14
2000	.04	.99	.20	.99	.00	.99	.05	.99	.00	.01	.05	.15
2020	.05	.99	.20	.99	.20	.99	.05	.99	.00	.01	.00	.10
Region II												
1977	.17	.25	.83	.95	.03	.10	.01	.10	.00	.01	.00	.01
1985	.14	.99	.20	.99	.10	.99	.01	.99	.00	.01	.01	.11
1990	.09	.99	.20	.99	.15	.99	.01	.99	.00	.01	.03	.13
2000	.05	.99	.20	.99	.00	.99	.01	.99	.00	.01	.05	.15
2020	.01	.99	.20	.99	.30	.99	.01	.99	.00	.01	.00	.10
Region III												
1977	.47	.67	.90	.98	.11	.21	.01	.08	.01	.10	.00	.02
1985	.32	.99	.20	.99	.20	.99	.01	.99	.00	.20	.05	.15
1990	.16	.99	.20	.83	.26	.99	.01	.99	.00	.35	.07	.17
2000	.11	.99	.20	.99	.30	.99	.01	.99	.00	.40	.10	.20
2020	.02	.99	.20	.99	.35	.99	.01	.99	.00	.45	.00	.15
Region IV												
1977	.07	.15	.88	.97	.44	.55	.06	.18	.00	.03	.00	.02
1985	.06	.99	.20	.99	.43	.99	.04	.99	.00	.13	.02	.15
1990	.05	.99	.20	.99	.43	.99	.04	.99	.00	.25	.00	.20
2000	.04	.99	.20	.99	.43	.99	.02	.99	.00	.39	.00	.29
2020	.02	.99	.20	.99	.43	.99	.02	.99	.00	.44	.00	.34
Region V												
1977												
1977	.39	.49	.84	.95	.17	.28	.03	.12	.08	.22	.01	.08
1985	.22	.99	.20	.99	.26	.99	.03	.99	.00	.34	.08	.18
1990	.14	.99	.20	.99	.31	.99	.03	.99	.00	.40	.08	.18
2000	.08	.99	.20	.99	.34	.99	.02	.99	.00	.45	.08	.18
2020	.03	.99	.20	.99	.36	.99	.02	.99	.00	.50	.08	.18

Table 1-13. Nebraska Irrigated and Dryland Crops Agronomic and Bounding Constraints by Crop, Region and Time Period. (Cont'd.)

Region and Time Period \ Crop and Bound	Dryland Alfalfa Lower	Dryland Alfalfa Upper	Irr. Alfalfa Lower	Irr. Alfalfa Upper	Dryland Wheat Lower	Dryland Wheat Upper	Irr. Wheat Lower	Irr. Wheat Upper
Region I								
1977	.01	.05	.13	.22	.42	.60	.05	.15
1985	.01	.07	.07	.20	.40	.60	.02	.90
1990	.08	.18	.04	.14	.39	.50	.02	.99
2000	.10	.22	.01	.11	.35	.50	.02	.99
2020	.02	.10	.01	.11	.32	.50	.02	.99
Region II								
1977	.49	.60	.14	.25	.15	.29	.00	.01
1985	.40	.50	.09	.20	.10	.99	.00	.01
1985	.40	.50	.09	.20	.10	.99	.00	.01
1990	.35	.45	.08	.18	.25	.99	.00	.01
2000	.30	.40	.05	.15	.40	.99	.00	.01
2020	.28	.38	.03	.22	.00	.99	.00	.01
Region III								
1977	.24	.34	.06	.15	.07	.18	.00	.01
1985	.22	.32	.07	.20	.05	.99	.00	.01
1990	.18	.28	.08	.18	.04	.99	.00	.01
2000	.15	.25	.07	.17	.03	.99	.00	.01
2020	.15	.25	.05	.15	.02	.99	.00	.01
Region IV								
1977	.11	.19	.03	.12	.34	.54	.00	.01
1985	.10	.20	.03	.20	.27	.99	.00	.01
1990	.08	.18	.04	.14	.18	.99	.00	.01
2000	.07	.17	.04	.14	.06	.99	.00	.01
2020	.06	.99	.03	.13	.04	.99	.00	.01
Region V								
1977	.12	.23	.04	.11	.09	.19	.00	.01
1985	.11	.99	.05	.20	.06	.99	.00	.01
1990	.10	.99	.07	.17	.04	.99	.00	.01
2000	.09	.99	.06	.16	.03	.99	.00	.01
2020	.08	.18	.05	.15	.02	.99	.00	.01

Application

The economic model described previously was used to analyze a selected set of alternative groundwater actions presented in this report. Analysis of the "Baseline" condition is conducted in Section 2, whereas the evaluation of potential management actions selected by the work group is found in Section 3. Further discussion clarifying and comparing economic impacts among the alternative actions is found in Chapter 5 of the full report.

SOCIAL CONSIDERATIONS

Introduction

Relationships between changes in groundwater levels associated with the rate, amount, and location of groundwater withdrawal, and various social factors occur in several ways as illustrated in Figure 1-6. Most "social" effects are transmitted through economic factors related to income or overall economic activity (employment) and return on investment. Water is an

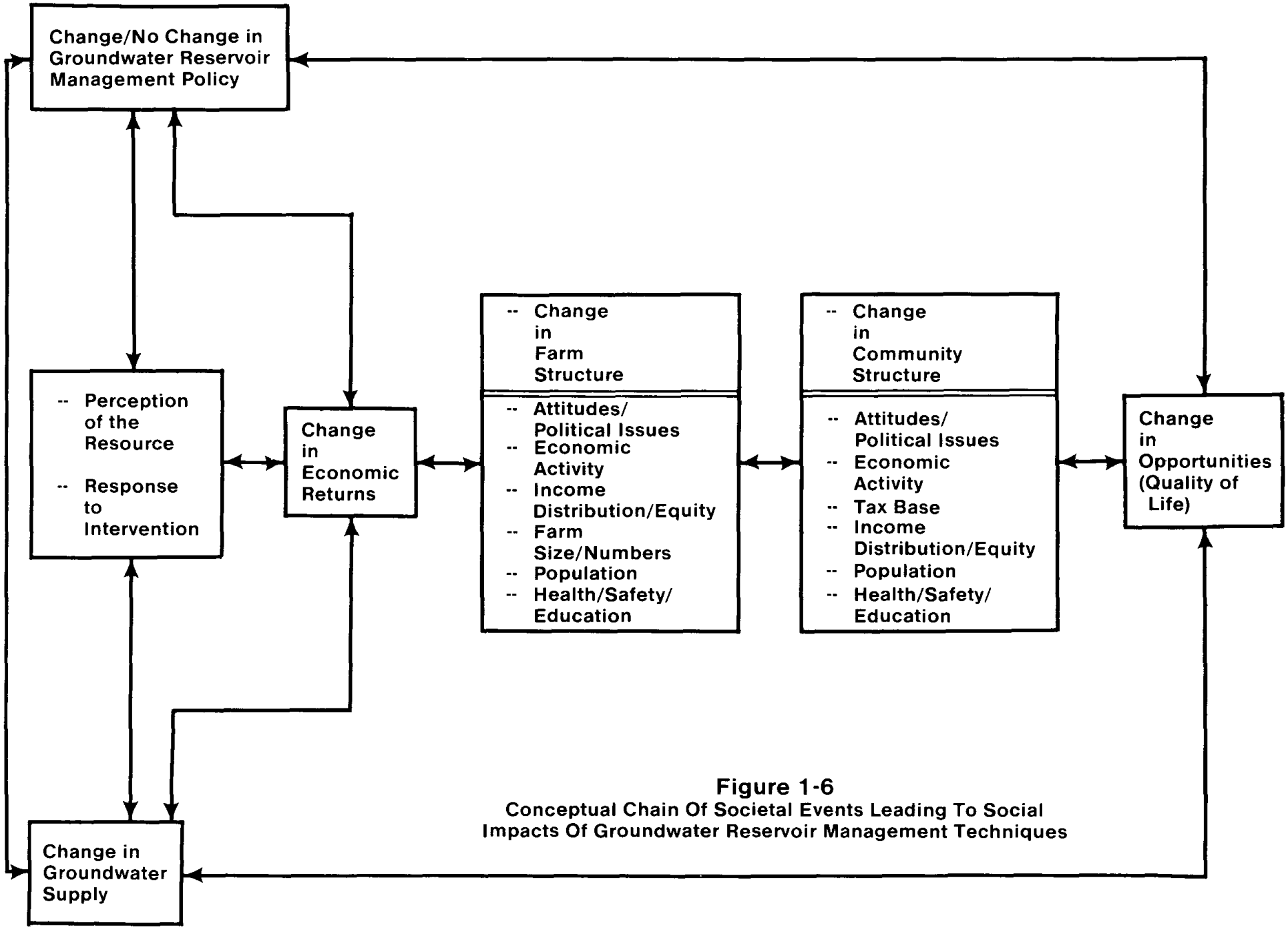

Figure 1-6
Conceptual Chain Of Societal Events Leading To Social Impacts Of Groundwater Reservoir Management Techniques

impact to agricultural production. The economic base of irrigated regions of the state is linked to water availability, costs of securing water (groundwater levels), and any changes in water availability and cost. Changes in economic returns affect the agricultural sector through various farm structure variables and will, at the same time, have impacts on community structure through employment multipliers of growth or decline. This will affect the extent and composition of economic activity, the size and structure of the resident population and the resource base, resource demand and resource level of the community. Over time the aggregated results of these changes will modify the overall quality of life in agricultural, rural and community sectors.

In addition, attitudes representing both community values and individual perceptions and responses will have a significant effect on use of water, rate of change or innovation and response to any sort of public intervention.

Social Factors

ATTITUDES

The rate of decline of an area's groundwater supply is greatly determined by attitudes toward the resource. People who perceive the supply as limited may desire to curtail the rate of utilization, while those who feel the groundwater supply is unlimited may call for no controls. In addition, those who feel that the resource is more valuable when used now as opposed to saving it for future generations may also desire minimal groundwater use regulations.

Attitudinal changes will result when groundwater quantities are viewed as being limited and declining. These attitude adjustments will occur through increased awareness of problems (from experience or education) or from alterations in economic returns due to limitations on water availability and/or increased pumping costs. Shifts in economic returns associated with groundwater decline may be sufficient to modify attitudes toward the resource such that groundwater management becomes a mandate. In other cases, reduced economic returns may result in induced changes in the structure of agriculture and local communities before significant attitudinal adjustments occur.

FARM STRUCTURE

Under conditions where groundwater declines result in modifications in agriculture with related changes in incomes and the profitability of agricultural production, the irrigator "response" to declining groundwater levels or increased groundwater management could have a profound effect on the farm structure of an area. For example, if groundwater levels decline significantly, or if irrigators are required to substantially reduce the amount of irrigation water available to their crops, production could be lowered and farm incomes would decline. Likewise, if irrigators "concentrate" irrigation water so that both irrigated and dryland crops must be grown, farm income may again decline and rural land use patterns will be altered. Declines in farm income may induce some farmers to "sell out". This, in turn, would lead to both increased farm sizes as other landowners add on to their holdings, and also to a shift in farm ownership patterns type of business organization of surviving farms. Farm populations would subsequently decline because of these changes.

COMMUNITY STRUCTURE

Restructuring of farming operations will lead to changes in community structure. Reduced farm incomes and/or fewer and larger farms imply reduced farm-related expenditures in nearby communities. Secondary economic consequeces include reduction of employment and, in the long run, changes in population number and composition. Reduced population levels could lead to lower tax revenues; and declining ability to fund public services, health, and safety. However, service demands may remain high due to the age distribution of the remaining population (typically a declining area has disproportionately high numbers of older persons who are heavy consumers of many services).

QUALITY OF LIFE

The effects of altered economic returns and modified agricultural and community structures will affect the quality of life of area residents. Quality of life, which consists of several intangible elements such as personal security, opportunities, well-being, happiness, contentment, etc., will be altered by changes in income, community services, health, and attitudes.

EQUITY

For the purposes of examining social factors and impacts in this report, "equality" and "fairness" were determined to be the primary consideration addressed by "equity". Aspects of equity include attitudes and beliefs regarding the type and distribution of opportunities for income, wealth, employment, etc., and also the nature of these opportunities as they actually exist and the

way in which these opportunities change as a result of management alternatives.

Equity will be a significant social factor with respect to intervention or change in groundwater withdrawals. It will be associated with attitudes but also with farm and community structure as related to income distribution.

LEGAL/INSTITUTIONAL/ ADMINISTRATIVE CONSIDERATIONS

Institutional Structure

State programs affecting groundwater development and use are administered by the Department of Water Resources (DWR), the Department of Health, and the Department of Environmental Control. Development of groundwater management policies to deal with groundwater mining are primarily the responsibility of natural resources districts (NRDs).

NATURAL RESOURCES DISTRICTS

Natural resources districts are local units of government established by the Legislature to deal with a variety of natural resources issues. Replacing over 150 single-purpose districts, the twenty-four NRDs are organized generally along river basin lines, are financed by a property tax of up to one mill, and are governed by a locally elected board of directors. The NRDs have broad natural resource responsibilities, including: (1) soil and water conservation; (2) flood and soil erosion control; (3) drainage; (4) water supply; (5) pollution control; (6) wildlife habitat management; (7) recreation; and (8) forestry and range management.

Some of the few regulatory authorities given to NRDs relate to groundwater management. Natural resources districts have the exclusive authority to initiate the process of designation (by the DWR director) of groundwater control areas. The NRDs are authorized to regulate, with DWR approval, groundwater development and use within control areas. The NRDs also are authorized to regulate groundwater irrigation runoff, and to stop the construction or use of illegal wells.

DEPARTMENT OF WATER RESOURCES

The Department of Water Resources is the state agency responsible for allocating and administering surface water rights. Those wishing to impound or use surface water must obtain a DWR permit to do so.

The DWR administers several programs regulating aspects of groundwater development and use, including: (1) well registration; (2) well abandonment; (3) groundwater withdrawals from pits near streams; (4) interstate groundwater transfers; (5) public water supplier groundwater permits; and (6) industrial use groundwater permits. The DWR is also responsible for state oversight in the designation and administration of groundwater control areas.

OTHER STATE AGENCIES

Several other state agencies have water-related responsibilities. The Department of Environmental Control is responsible for water quality. The Department of Health is responsible for protecting drinking water quality. The UNL Conservation and Survey Division collects groundwater quantity and quality information. The Natural Resources Commission is responsible for state water planning, administering state funds for natural resources development, and maintaining the natural resources data bank information system.

Nebraska Groundwater Law: An Overview

In Nebraska the right to use groundwater is, with the exceptions noted below, based on owning land overlying a groundwater supply. Groundwater may be used on the overlying land without waste, subject to statutory requirements regarding: (1) well registration; (2) well abandonment; (3) well spacing; (4) irrigation runoff control; (5) check valves; (6) road damage from irrigation; (7) artesian water control; (8) control area regulations; and (9) illegal well restrictions. The exceptions, where a DWR permit is required to develop and use groundwater, are: (1) groundwater withdrawals from pits within 50 feet of a stream; (2) the use of groundwater in another state; (3) the use of more than 3,000 acre-feet per year for industrial purposes; and (4) installation of new wells in groundwater control areas.

Well interference conflicts between irrigation, industrial, and public water supply wells (including municipal wells) are prevented to a significant degree by well spacing requirements. Well spacing requirements do not apply to domestic wells, but the Nebraska Supreme Court has ruled that irrigators must compensate domestic well owners when irrigation disrupts domestic supplies. The court suggested that conflicts between those using groundwater for the same purposes would be resolved by sharing the available supply, while conflicts between those using groundwater for different purposes would be resolved on the basis of preference (domestic

uses favored over all others and agricultural uses favored over industrial and manufacturing uses).

Groundwater transfer policies also are unclear. Surface water statutes suggest groundwater may be transferred by pumping it into a stream and withdrawing it downstream. The Nebraska Supreme Court has recently ruled that groundwater may not be transferred without legislative authorization. Transfers for public water supply purposes and industrial purposes are authorized if a DWR permit has been obtained. The NRDs and rural water districts are authorized to transport water, but the scope of this authority has not been determined. Interstate groundwater transfers are prohibited unless a DWR permit has been obtained.

Restrictions on groundwater development and use may be established in designated groundwater control areas to deal with groundwater mining or pollution. Control area procedures are initiated by an NRD, but the decision to designate a control area is made by the DWR. If a control area is designated, the NRD must, with DWR approval, establish groundwater controls. Authorized restrictions on groundwater use include restricting the timing or quantity of groundwater withdrawals. The NRDs have made six requests to establish control areas but only three control areas were designated by the DWR. Groundwater controls established include well spacing requirements and restrictions on groundwater withdrawals.

Groundwater quality is addressed in groundwater allocation law to a limited extent. Check valves are required on irrigation wells to prevent agricultural chemicals from siphoning into groundwater supplies when the well pump stops. Abandoned wells must be sealed to prevent pollution of groundwater supplies. Groundwater development and use can be restricted to prevent groundwater quality degradation.

Groundwater Rights of Use

COURT DECISIONS

The limits of private rights to use groundwater in Nebraska are unclear. Nebraska Supreme Court decisions have established that groundwater is public, that landowners have the right to develop groundwater, and that groundwater use must be without waste on the land of the well owner.[75] The court has ruled that an irrigator is liable for damages for interfering with domestic wells, and has suggested that well interference conflicts involving the same use would be resolved on the basis of proportional sharing of the available supply.[76]

General groundwater policy has not been legislatively established, suggesting a legislative acquiescence to judicial decisions. However, legislation has established several requirements relating to our restricting groundwater development and use.

REGISTRATION OF WELLS[77]

Although the Nebraska statutes do not have a general permit requirement for well installation, all wells, except domestic wells, must be registered with the DWR. Failure to comply with well registration requirements is a misdemeanor ($100-500 fine upon conviction). Wells in violation of registration requirements are illegal wells, the use of which may be stopped by an NRD.

WELL SPACING REQUIREMENTS

To reduce the likelihood of well interference conflicts, well spacing is required between high capacity wells, but not low capacity domestic wells. The effective date of well spacing requirements varies with the category of wells.

Irrigation wells[78]. Any irrigation well installed after September 20, 1957, must be located at least 600 feet from a registered irrigation well owned by another. Replacement wells for irrigation wells drilled prior to September 20, 1957, may be located within 600 feet of a registered irrigation well owned by another if the replacement well is located within 50 feet of the well it is replacing. Variance of the irrigation well spacing requirement may be obtained by applying to the DWR director for a special spacing permit. In evaluating the variance application, the director shall consider: (1) the size, shape, and irrigation needs of the land to be irrigated; (2) the groundwater supply; and (3) the effect on other groundwater users. Violations of irrigation well spacing requirements are a misdemeanor ($100-500 fine upon conviction). If an irrigation well violates these spacing requirements, it must be sealed. Wells violating irrigation well spacing requirements are illegal, the construction or use of which may be stopped by an NRD.

Irrigation, industrial, and public water supply wells[79]. The well spacing distance required among irrigation, industrial, and public water supply wells is 1,000 feet. Whether the well spacing requirement applies depends on when the particular well was installed. Any irrigation well installed after November 18, 1965, must be located at least 1,000 feet from a registered public water supply well. Irrigation wells installed after August 24, 1979, must be located at least 1,000 feet from a registered industrial well. Any

industrial well installed after November 18, 1965, must be located at least 1,000 feet from a registered public water supply well while industrial wells installed after August 24, 1979, must be located at least 1,000 feet from a registered irrigation well or industrial well owned by another. A public water supply well drilled after November 19, 1965, must be located at least 1,000 feet from a registered irrigation or industrial well, or the registered well of any other public supplier.

Variance of these well spacing requirements may be obtained by applying to the DWR for a special permit. Unregistered wells are granted well spacing protection for the 30 day registration period only. Public water suppliers may obtain temporary spacing protection for test holes and wells under construction by applying to the DWR and by notifying affected landowners. Violations of spacing requirements among irrigation, industrial, and public water supply wells may be enjoined. Such wells also are illegal wells, the construction or use of which may be stopped by an NRD.

WELL ABANDONMENT REQUIREMENTS [80]

All abandoned wells, except domestic wells, must be sealed in accordance with DWR regulations. The owner of an abandoned well must notify the DWR director of his intent to abandon the well by written notice within 60 days of abandonment. Violation of these requirements is a misdemeanor ($100-500 penalty upon conviction) and such wells are illegal wells.

CHECK VALVE REQUIREMENTS[81]

If a groundwater irrigator applies fertilizer, herbicides, or pesticides through his irrigation system, he is required to install a mechanical device, usually a check valve, on the well pump in order to prevent the chemicals from being siphoned down the well and contaminating groundwater supplies if the well pump stops. Violation of check valve requirements is a misdemeanor ($100 to 500 fine upon conviction). Wells operated in violation of check valve requirements are illegal wells, the use of which may be stopped by an NRD.

IRRIGATION RUNOFF CONTROLS[82]

Each person using groundwater for irrigation must control or prevent irrigation water runoff. All NRDs are required to adopt regulations to control groundwater irrigation runoff, and are authorized to enforce runoff control regulations. Wells used in violation of runoff controls are illegal wells, the use of which may be stopped by an NRD.

ROAD DAMAGE CAUSED BY IRRIGATION[83]

Road damage caused by irrigation runoff, spray from sprinkler irrigation systems, or other irrigation practices is a misdemeanor (zero to $100 fine upon conviction). In addition, sprinkler irrigation systems located on land bordering a public road must be equipped with an automatic device to shut off the endgun when the sprinkler approaches the road. Violation of the shutoff requirement is a misdemeanor ($100-500 fine upon conviction). However, an irrigator would not be guilty of a misdemeanor if the road damage resulted from equipment malfunction or the damage would not have occurred under normal weather conditions. Irrigation wells used in violation of these requirements may be illegal wells, the construction or use of which may be stopped by an NRD.

ARTESIAN WATER CONTROLS[84]

Flowing artesian wells must have a mechanism to control the flow unless the well discharge pipe is no larger than one half inch in diameter, or the water is used for irrigation or power production. Violation of artesian water control requirements are a misdemeanor (zero to $100 fine upon conviction). Wells operated in violation of artesian water control requirements are illegal wells, the use of which may be stopped by an NRD.

PUMPING FROM PITS NEAR STREAMS[85]

A DWR permit is required to withdraw groundwater from a pit located within 50 feet of a streambank, except that no permit is required to withdraw water from an irrigation water reuse pit located within a stream's headwaters. In evaluating a permit application, the DWR must consider the effect of the proposed groundwater withdrawals on surface water appropriations. Pits for which DWR permits have not been obtained may be illegal wells, the construction or use of which may be stopped by an NRD.

INTERSTATE GROUNDWATER TRANSFERS[86]

A DWR permit is required before groundwater withdrawn in Nebraska can be used in another state. The permit may be granted if the groundwater withdrawal is reasonable. A withdrawal is reasonable if: (1) it is not contrary to the conservation and use of groundwater; (2) is not

detrimental to the public welfare; and (3) the state into which the groundwater is to be transferred grants reciprocal rights to transport and use groundwater in Nebraska. Failure to obtain a permit is a misdemeanor ($100-500 fine upon conviction). Groundwater withdrawals can be enjoined until the DWR permit has been obtained. Wells in violation of this permit requirement are illegal wells, the construction or use of which maybe stopped by an NRD.

INDUSTRIAL WATER USE PERMIT[87]

A DWR permit is required to withdraw, transport, and use 3,000 or more acre-feet of groundwater per year for industrial purposes. The DWR director may grant the permit only if the director finds, after a public hearing, that the proposed groundwater use is in the public interest. In evaluating the public interest the director's consideration must include, but is not limited to: (1) possible adverse effects on existing water uses; (2) effects on reasonably anticipated local surface and groundwater needs; (3) alternative sources of industrial water supplies; (4) the economic benefits of the proposed industrial use; (5) the socioeconomic benefits of existing water uses; and (6) any waivers of liability the applicant has obtained regarding local water use interference conflicts. Violations of the industrial groundwater use permit requirement are misdemeanors (up to $1,000 fine and up to one year imprisonment upon conviction). Wells constructed without a permit are illegal wells, the construction or use of which may be stopped by an NRD. Water users adversely affected by such groundwater uses may sue for money damages or to stop or limit groundwater withdrawals.

Additional restrictions on groundwater development and use may be established in groundwater control areas as discussed below.

Groundwater Transfers

The status of groundwater transfers under Nebraska law is ambiguous. Interstate groundwater transfers and transfers for industrial or public water supply purposes are authorized if a DWR permit has been obtained. While a recent Nebraska Supreme Court decision rules that groundwater transfers are unlawful unless authorized by statutes, several statutes imply that they are lawful.[88]

Public water suppliers (including municipalities, NRDs, and rural water districts) may obtain a DWR permit to withdraw and transfer groundwater for public water supply purposes but are not required to do so. Permits may also be acquired for groundwater recharge operations. The permit may be granted, after a public hearing, if the DWR director concludes that the proposed use: (1) is reasonable; (2) is not contrary to the conservation and beneficial use of groundwater; and (3) is not otherwise detrimental to the public welfare. (Interstate and industrial groundwater transfer requirements are discussed above.)

Well Interference Conflicts

Nebraska well spacing statutes reduce the likelihood of most well interference conflicts except those involving individual domestic wells for which well spacing requirements have not been established. In *Prather v. Eisenmann*,[89] the Nebraska Supreme Court suggested that well interference conflicts will be resolved on the basis of proportional sharing if the parties use groundwater of the same purpose, and that preferences would be used as the basis to resolve conflicts between parties using groundwater for different purposes. (The preferences provide that domestic uses are preferred over all other uses, and agricultural uses are preferred over industrial and manufacturing purposes.[90] Domestic use is defined to include health, fire control, sanitation, and the watering of domestic livestock.) The preferred user would be required, however, to prove that the well interference was caused by the other party. The *Prather* rule does not address how conflicts involving nonpreferred users (those for purposes other than domestic, agricultural, industrial or manufacturing) would be resolved.

Persons adversely affected by groundwater uses pursuant to a public water supplier permit may sue for money damages.[91] Persons adversely affected by groundwater uses pursuant to an industrial use permit may sue for money damages or to stop or limit withdrawals.[92]

Groundwater Mining

Groundwater Management and Protection Act[93]

Control of groundwater development and use to deal with groundwater mining (i.e., long-term reductions in groundwater storage) and pollution are authorized in designated groundwater control areas. The NRDs have exclusive authority to initiate control area designation proceedings, but the DWR has sole authority to designate control areas. Authorized groundwater controls include restriction of well installation, well spacing, well pumping, and groundwater withdrawals.

Control area designation[94]. The first step in the designation process is for the NRD board of directors to request the DWR director to hold a public hearing to determine whether a control area should be designated. The NRD request for the hearing must be accompanied by an identification of the area the NRD thinks should be considered for control area designation. If the DWR director believes additional areas should be considered for control area designation, he may include the additional area in the public notice of the hearing after notifying the affected NRDs.

The hearing is held in or near the proposed control area within 120 days of the NRD request and is open to the public. Testimony must be presented by the NRD, the Natural Resources Commission (NRC), the UNL Conservation and Survey Division (CSD), and, where groundwater quality is at issue, the Nebraska Department of Environmental Control (DEC). The NRC testifies regarding relevant state water planning activities and the appropriateness of control area designation. The CSD testifies regarding relevant geological investigations, including any simulation models. The DWR is also authorized to conduct its own investigations.

After the hearing, a control area may be designated if the DWR director concludes that the uncontrolled development and use of groundwater has caused, or is likely to: (1) cause an inadequate groundwater supply to meet present or reasonably forseeable needs; or (2) cause groundwater quality pollution such that the water is unsuitable for current uses. In determining whether either of these two criteria have been fulfilled, the DWR director must consider: (1) whether conflicts between groundwater users are occurring or may be reasonably anticipated; or (2) whether groundwater users are experiencing, or will experience in the forseeable future, substantial economic hardship as a direct result of current or anticipated groundwater development or use. If the DWR director concludes that a control area should be designated, he must consult with the NRD, NRC, CSD, and, where water quality is concerned, DEC regarding control area boundaries. Area from a contiguous NRD may also be included in the control area if the NRD consents in writing to its inclusion. In addition, the control area may include area not identified by the NRD in requesting that control area designation hearing. The order designating the groundwater control area must define its geographic and stratiographic (geologic) boundaries. In addition, the director must consider in establishing control area boundaries: (1) the groundwater supply or quality problem which led to the control area designation; (2) the effect on political subdivisions; and (3) the socioeconomic and administrative factors directly affecting the ability of an NRD to implement a local groundwater management and control program. Control area boundary modification or dissolution may be accomplished by following control area designation procedures. Control area designation, boundary modification or dissolution hearings, however, cannot be initiated more than once a year.

Control area well construction permits[95]. Permits from DWR are required before most wells can be constructed within a control area. Exempted from the permit requirement are: (1) wells with a capacity of less than 100 gpm used solely for domestic purposes (hereinafter referred to as domestic wells); and (2) replacement wells if the column size is no larger than the column size of the original well.[96] A permit is required, however, if the capacity of a domestic well is increased to more than 100 gpm, or if the replacement well has a larger column size than the well it is replacing. Permits are not required for existing wells.

Information required in the permit application form includes: (1) the applicant's name and address; (2) whether the proposed use of the well is for domestic, municipal, irrigation, industrial, or other purposes; (3) the location of the proposed well; (4) for irrigation wells, the location and number of acres to be irrigated; (5) the proposed well's anticipated diameter, depth, and capacity; and (6) if known from test drilling, the proposed well's expected log. The completed application is returned to the NRD with a nonrefundable $25 filing fee payable to the DWR. The NRD must review the application and forward it to the DWR with any comments and recommendations within 30 days of filing.

The DWR director has 30 days to approve or disapprove an application. If the DWR director finds that the application is defective, the application is returned to the applicant for correction. If a corrected application is not filed with the DWR within 60 days, the application is cancelled. An application can be denied by the DWR, after consultation with the NRD, if the proposed well would violate NRD groundwater controls, or if the proposed use of water would not be a beneficial use for domestic, agricultural, or manufacturing purposes. The DWR could deny a permit if the proposed well would violate state well spacing requirements, although this is not explicitly identified as a basis for permit denial.

The well construction permit is valid for the period specified by the DWR in the permit. The period specified is usually less than one year, although a longer period may be requested in the permit application and granted by the DWR. If the

well is not completed within the period specified in the permit, the DWR director has the option of revoking the permit.

The rules regarding failure to complete well installation within the time specified in the control area permit are unclear. If well installation has begun, a new permit probably would not be required. If well installation has not begun, however, a new permit probably would be required.

Wells constructed in a control area must also be registered after completion with the DWR.

Well drillers constructing wells in a control area are required to inquire regarding whether a DWR permit has been obtained. Giving false information to a well driller regarding whether a DWR permit has been obtained, failure by the well owner to obtain a DWR permit, and construction of a well by a driller for which a permit has not been obtained all are misdemeanors ($100-500 fine upon conviction). A well constructed without a control area permit also is an illegal well, the construction or use of which could be stopped by an NRD. If the well otherwise meets all other state and NRD requirements, however, a late permit may be obtained as described below. If a late permit is obtained, the well no longer would be an illegal well. If a well is constructed without a control area permit and an application for a later permit is denied, the well would have to be abandoned and sealed. If a well is located in violation of NRD well spacing requirements, the well in most cases would have to be abandoned and sealed. In some control areas, however, NRD well spacing requirements may be waived by applying to the NRD board.

Late permits[97]. If a well requiring a DWR permit is constructed without a permit having been obtained, the well may be operated if and only if a later permit can be obtained. Otherwise, the well would be required to be abandoned and sealed. An additional nonrefundable $250 filing fee for a later permit is paid to the NRD in addition to the nonrefundable $25 filing fee paid to the DWR. The later permit application requires the same information as the control area well permit application. The NRD reviews the application and forwards it to the DWR within 30 days of filing. The NRD also comments regarding: (1) whether the well complied with all NRD rules in effect when the well was constructed; (2) whether the well complies with all NRD rules in effect when the late permit application was filed; and (3) whether the applicant has acted in good faith (i.e., failed to obtain a permit because the applicant did not know one was required).

The DWR reviews the later permit application upon receipt and returns defective applications to the applicant for corrections, following regular control area well permit procedures. An application for a later permit can be denied for the same reasons a control area well permit can be denied. In addition, a later permit application can be denied by the DWR, after consultation with the NRD, if the DWR director concludes that the applicant acted in bad faith in failing to obtain a control area well permit.

Groundwater controls[98]. An NRD has 18 months after control area designation within which to adopt groundwater controls. Authorized controls include: (1) allocation of the amount to be withdrawn; (2) rotation in pumping; (3) well spacing requirements more restricting than statutory well spacing requirements; and (4) other necessary, reasonable regulations. The NRDs may require well meters and may require irrigation scheduling to prevent groundwater pollution. The NRD may prohibit well drilling for one year within all or part of a control area if, after a public hearing, the NRD board concludes that groundwater depletion is so excessive that the public interest cannot be protected solely through implementation of other groundwater controls. The one year well drilling moratorium can be renewed for additional one year periods. Controls may be varied within a control area for differing climatic, hydrologic, geologic, or soil conditions if uniform controls would be inequitable or ineffective. Controls must be uniform within areas having substantially similar conditions, however.

Before the NRD board adopts controls, it must hold a public hearing to consider what controls should be adopted. In adopting controls the NRD must consider whether the proposed controls: (1) will mitigate or eliminate the condition which led to control area designation; (2) will encourage a high degree of water use efficiency; or (3) will improve control area administration. The NRD must also consider the groundwater preferences.[99] A public hearing is required after the NRD board has adopted or amended groundwater controls. After the public hearing the controls are forwarded to the DWR director for approval. The director may hold a public hearing regarding the proposed controls.

In evaluating the proposed controls, the director must consider the same factors the NRD must consider in adopting controls. The controls must be approved by the director before they take effect.

If a control area includes more than one NRD, groundwater control authorities must be exercised jointly and uniformly by the NRDs.

If the NRD has not adopted controls within 18 months of control area designation, the DWR director must adopt controls within 90 days. The DWR controls are enforced by the NRD.

A municipality using groundwater or five

percent of the well owners within a control area may, any time after a year of control area designation, petition the DWR to hold a hearing to determine whether controls are being enforced uniformly, fairly, or in good faith. If, after the hearing, the DWR director determines that controls are not being enforced fairly, the director assumes enforcement authorities for twelve months after which enforcement authorities revert to the NRD.

Control area administration. The NRDs are authorized to levy up to $0.018 per $100 actual value on all taxable property within a control area for purposes of control area administration.[100] If a control area is designated for both groundwater quantity and quality purposes, the NRD mill levy is $0.027 per $100 actual value. This may be supplemented by the NRD general mill levy authority of $0.035 per $100 actual value, which can be increased by popular vote.[101]

The NRDs are authorized to issue cease and desist orders for violation of groundwater controls, as well as the construction of or use of water from illegal wells.[102] The latter are defined as any well not in compliance with state law or NRD controls.[103] The NRD cease and desist orders may be enforced by the NRD through court order.

GROUNDWATER ADMINISTRATION

Six control area hearings have been requested and held. Three requests were granted and three were denied. Generally, control areas were designated only where the NRD could demonstrate that groundwater mining was occurring, based on the DWR interpretation of the inadequacy of supply criterion. Control areas were not designated where mining was not occurring even if user conflicts and individual economic hardships were occurring.

A. North Platte control area request. The first control area request dealt with conflicts between irrigation and domestic wells in Scottsbluff and Banner counties in western Nebraska. Domestic wells had been drilled into an artesian aquifer. Withdrawals from subsequently developed irrigation wells reduced the artesian pressure, causing water levels in domestic wells to fall below the well pumps. The domestic wells were replaced when the domestic wells stopped yielding water, causing the well pumps to overheat. The domestic well owners sued the irrigator for the cost of replacing their wells. In a 1974 decision the Scottsbluff County District Court ruled that because the irrigator's pumping disrupted the domestic water supplies, he was required to pay for replacing the domestic wells.

The domestic well owners subsequently asked the North Platte NRD to request a control area hearing. The NRD requested a hearing which was held October 5, 1976. The DWR director issued an order denying the request to designate a control area on January 7, 1977. The order stated that: (1) while irrigation development was causing seasonal artesian pressure reductions and water level declines, permanent water level declines (i.e., groundwater mining) were not occurring; (2) the private economic hardships of the irrigation-domestic well interference conflicts were not substantial and could be dealt with through private litigation; and (3) while the **avalability** of groundwater was somewhat diminished because of seasonal artesian pressure reduction, the **adequacy** of the groundwater supply was undiminished.

B. Upper Republican groundwater control area. The Upper Republican area of Chase, Perkins, and Dundy counties in southwestern Nebraska is one where groundwater is being mined. Center pivot irrigation development has contributed to: (1) groundwater level declines of more than 35 feet in some areas; (2) streamflow reductions in Frenchman Creek; and (3) reduction in surface water storage at Enders Reservoir. The Upper Republican NRD requested a control hearing which was held March 24, 1977. The DWR director issued an order designating a control area August 1, 1977, the first designated under the Groundwater Management Act. The order stated that: (1) groundwater mining was occuring; (2) conflicts between ground and surface water users were occurring; (3) unless supplemental water supplies could be developed, current groundwater supplies were inadequate to meet present or reasonable forseeable needs; and (4) substantial economic hardships affecting regional prosperity and water user conflicts could be anticipated as groundwater supplies were depleted. The control area covers 2,600 square miles, including an estimated 2,450 irrigation wells that irrigate nearly 310,000 acres.

The first controls approved under the Act were adopted by the NRD on January 7, 1978, and approved by the DWR director on March 27, 1978. The controls required: (1) meters on all wells (excluding domestic wells with a capacity up to 100 gallons per minute); and (2) certification of irrigated acres with the NRD. New high capacity wells are required to be located at least 1,320 feet from existing stock and domestic wells. In "critical townships", those where annual withdrawals exceed one percent of the remaining saturated thickness, new wells must be located at least 3,000 feet from existing wells. (Twenty-three critical townships have been

designated.) The regulations also limit groundwater transfers, which can be made, if at all, only with NRD board approval. The regulations indicated the NRD would adopt a groundwater allocation of 14 to 17 acre-inches per certified irrigated acre in 1980.

On March 7, 1980, the DWR director approved revised control area regulations. The major change was the establishment of groundwater withdrawal limitations for irrigators. Withdrawals are limited to 66 acre-inches per certified irrigation acre from January 1, 1980, to December 31, 1982, an annual average of 22 acre-inches per acre. Violation of this requirement can result in loss of up to half of the remaining or a subsequent groundwater allocation. The regulations also adopt a groundwater management objective of limiting groundwater supply reductions to a "manageable rate".

Earlier regulations submitted by the NRD to the DWR proposed to vary groundwater allocations based on different irrigation water distribution systems. Irrigators using gravity flow irrigation systems would have received a five year allocation of 110 acre-inches per certified irrigated acre, an annual average of 22 acre-inches per acre. Irrigators using sprinkler irrigation systems would have received a five year allocation of 80 acre-inches per certified irrigated acre, an annual average of 16 acre-inches per acre. The DWR director rejected this allocation as being unauthorized by statutes. Varying control area regulations are authorized if they are based on different climatic, hydrologic, geologic, or soil conditions. The director interpreted this as excluding variable regulations based on type of water distribution system. The proposed regulations submitted to the DWR director also included reduced allocations for four townships in Chase County at the request of local landowners. The gravity irrigation system allocations were 100 acre-inches per acre. The sprinkler irrigation system allocation was 70 acre-inches per certified irrigated acre, an annual average of 14 acre-inches per acre. This provision was alsc disapproved by the DWR director as being an unauthorized variable groundwater control.

C. Upper Big Blue control area. Another area where groundwater mining is occurring is the Blue River Basin in south-central Nebraska. The Upper Big Blue NRD requested a control area designation hearing which was held May 24, 1977. The DWR director issued an order designating a groundwater control area on December 22, 1977. The director's order noted that (1) groundwater mining was occurring; (2) conflicts among users were occurring and would increase as groundwater supplies diminished; (3) substantial economic hardships affecting regional prosperity were foreseeable as a direct result of groundwater supply reduction; and (4) the groundwater supply was inadequate to meet present or reasonable forseeable needs. The control area covers 2,700 square miles, including an estimated 10,000 irrigation wells that irrigate nearly 1.2 million acres.

Groundwater controls were adopted by the NRD, after a public hearing, on December 26, 1978. The controls were approved, by the director on January 9, 1979. The controls require: (1) that any flow meters installed meet NRD specifications; (2) any high capacity well must be located at least 1,000 feet from another's well; (3) require that any non-domestic abandoned well and replacement well be reported to the NRD; and (4) established groundwater use reporting requirements for municipal, industrial, and recreational wells. The controls do not immediately limit groundwater withdrawals. If the rate of groundwater increases, however, a three-year irrigation allocation of 48 acre-inches (16 inches per year) would automatically take effect. The controls encourage installation of flow meters and irrigation water reuse systems, the use of irrigation scheduling techniques to improve water use efficiency, and other voluntary measures to control groundwater depletion. In addition, irrigators must have water meters installed before they are entitled to receive a groundwater allocation.

D. Lower Platte South control area request. Conflicts between domestic and irrigation wells drilled in a semi-artesian aquifer in Butler, Lancaster, Seward, and Saunders counties in eastern Nebraska led to a request for a control area designation hearing by the Lower Platte South NRD. Irrigation groundwater withdrawals caused seasonal reductions in artesian pressure, interfering with withdrawals from domestic wells. On March 30, 1978, after a public hearing, the DWR director issued an order denying the control area designation request. The order stated that: (1) while irrigation groundwater withdrawals were causing seasonal artesian pressure reductions and water level declines, permanent water level declines were not significant; (2) the private economic hardships associated with irrigation-domestic well interference conflicts were not substantial and could be dealt with by means other than control area regulation (presumably private litigation); and (3) while the **availability** of groundwater was somewhat diminished because of seasonal artesian pressure reduction, the **adequacy** of the groundwater supply was essentially undiminished.

E. Little Blue control area. The Blue River Basin in south-central Nebraska is one of the major areas in Nebraska where groundwater mining is occurring. The Little Blue NRD requested a control area designation hearing which was held March 22, 1978. After the hearing the DWR director issued an order on January 2, 1979, designating a control area. The DWR director's order stated that: (1) groundwater mining was occurring and, unless supplemental water supplies were obtained, would continue; (2) conflicts between groundwater users would increase as groundwater supplies were reduced; (3) substantial economic hardships affecting regional prosperity were forseeable as a direct result of groundwater supply reduction; and (4) the groundwater supply was inadequate to meet presently forseeable needs. The control area covers 780 square miles, including an estimated 2,500 irrigation wells that irrigate nearly 300,000 acres.

Control area regulations establish that limitation of groundwater withdrawals will be the major groundwater control. High capacity (greater than 100 gallons per minute) wells must be metered by March 31, 1982. Irrigation groundwater allocations will be estimated annually after a public hearing and will be varied based on precipitation. Irrigation groundwater allocations can be subsequently varied no more than one inch annually. Unused allocations can be carried forward into future years. Future allocations can be drawn upon but whenever an irrigator has used up one year's allocation in advance, he cannot irrigate the following year. Groundwater allocations for all other high capacity wells (including municipal, industrial, fish and wildlife, and livestock wells) will be established after a public hearing by February 15, 1983.

F. Lower Loup control area request. In recent years ranches in north central Nebraska have been developed for center pivot irrigation, primarily for purchase by investors. Such intensive irrigation development could cause: (1) loss of wet hay meadows; (2) increasing nitrate levels in groundwater; (3) loss of or interference with domestic and stock wells; (4) streamflow reductions; and (5) soil erosion associated with cultivation of sandy soils. In response to these local concerns, the Lower Loup NRD requested a hearing to consider designating a control area in portions of Loup, Garfield, Wheeler, and Boone counties. The control area designation hearing was held February 25, 1980. The DWR director issued an order on May 1, 1980, denying the control area designation request. The order stated that: (1) while irrigation groundwater withdrawals were causing seasonal groundwater level reductions, groundwater supply reduction was not significant; (2) substantial local or regional economic hardships were neither existing nor reasonably forseeable; (3) groundwater quality degradation was occurring in isolated areas; but was not caused by groundwater mining and did not interfere with existing water uses; (4) existing conflicts between groundwater users could be dealt with by means other than control area regulation (presumably private litigation); and (5) regulation of agricultural practices to prevent soil erosion was beyond the scope or intent of the Groundwater Management Act (now the Groundwater Management and Protection Act).

IRRIGATION RUNOFF CONTROLS

The NRDs are responsible for administering runoff controls for groundwater irrigation regardless of whether a control area has been designated. The purpose of runoff controls is to reduce groundwater withdrawals for irrigation by preventing irrigation tailwater runoff and requiring reuse of irrigation tailwater. The runoff controls are administered on a complaint basis. A landowner may notify the NRD of irrigation runoff coming onto his land. The NRD will check to verify whether improper irrigation runoff has occurred. If so, the NRD will notify the irrigator that he has violated runoff regulations. Usually the NRD will assist the landowner in obtaining federal, state and/or local cost sharing assistance to install runoff control measures, such as construction of an irrigation reuse pit. If the irrigator refuses to cooperate, the NRD, after a hearing has been held to determine whether runoff regulations have been violated, can issue a cease and desist order. If the irrigator refuses to comply, the cease and desist order can be enforced by going to court.

COURT DECISIONS

Outside of groundwater control areas the legal rules for dealing with groundwater mining are unclear. The Nebraska Supreme Court, however, has suggested that under conditions of groundwater mining, groundwater users would share the available supply proportionally if they were using it for the same purpose. Domestic uses would be preferred over all others, while agricultural uses would be preferred over industrial and manufacturing uses. No decisions have been rendered dealing specifically with groundwater mining.

SUPPLY AUGMENTATION

The development of supplemental water

supplies has not yet been used to deal with groundwater mining in Nebraska. From 1936 to 1980 interbasin surface water transfers were not an option to deal with groundwater mining. In a 1980 decision, however, the Nebraska Supreme Court overruled an earlier decision prohibiting interbasin water transfers.[104] This decision means that interbasin surface water transfers are an option to consider in dealing with groundwater mining, although the cost of such transfers and environmental concerns will affect whether transfers can be implemented.

Another potential source of supplemental water is groundwater. Local or regional groundwater transfers could be an option for dealing with groundwater mining if their legal status were clarified.

Surface-Groundwater Conflicts

Nebraska law addresses the issue of conflicts between ground and surface water users in only two regards. A DWR permit is required before groundwater can be withdrawn from a pit located within 50 feet of a stream. The permit can be denied if the DWR director determines that the proposed withdrawal would interfere with surface water appropriations. This requirement has not been interpreted as applying to wells located within 50 feet of a stream.

The Blue River Compact between Kansas and Nebraska requires that irrigation wells installed after November 1, 1968, located on the lower reaches of the Big Blue River and Little Blue River, be subject to regulation during May to September by the DWR to maintain compact deliveries of surface water to Kansas.[105] Beyond these two provisions Nebraska law does not address the interrelationship of surface and groundwater.

Water Quality

Three features of Nebraska groundwater law address the interrelationship between groundwater development and use and groundwater quality. Check valves must be installed on irrigation wells if agricultural chemicals are applied through the irrigation system to prevent chemicals from siphoning into groundwater supplies. Abandoned wells (except domestic wells) must be sealed in accordance with DWR regulations to prevent groundwater contamination. Groundwater controls may be established to prevent groundwater quality pollution making it unsuitable for current uses. Groundwater controls have not been established for this purpose, however.

Related Legal Authorities

LAND USE CONTROLS

Counties and NRDs are authorized to adopt land use controls which could be used to restrict irrigation development. The NRDs are authorized to establish land use controls to conserve soil and water and to prevent and control soil erosion.[106] The proposed controls must be approved by 75 percent of the land-owners within the NRD voting in a public referendum. The land use controls may vary according to different land characteristics, but otherwise must be uniform throughout the NRD. The land use controls may vary according to different land characteristics, but otherwise must be uniform throughout the NRD. The land use controls cannot conflict with any municipal, county, or regional land use controls. Specific land use controls authorized include: (1) requiring the installation of terraces, dams, ponds, dikes, and other structures; (2) requiring particular types of cultivation and cropping practices; (3) prevention of cultivating highly erodable soils; and (4) other measures to conserve soil and water and prevent soils erosion.

Counties are also authorized to control agricultural land use.[107] If the county board has created a planning commission and adopted a county comprehensive development plan, the board may adopt a zoning resolution regulating, among other things, the use of land for agricultural purposes. The comprehensive development plan must address, among other things, land use, including agricultural land use. Zoning regulations, which can be adopted only after a comprehensive development plan has been developed, must be consistent with such plan and may address: (1) classifying land use to assure adequate provision for drainage, water supply, and soil fertility; (2) protecting property against blight and depreciation; (3) fostering agriculture; and (4) encouraging the most appropriate land use. In adopting the zoning resolution the board must consider, among other things, soil conservation, water supply conservation, and drainage. The county board may establish districts within which land use, among other things, is regulated. Any land use in violation of zoning requirements is a class III misdemeanor ($0-500 fine, no imprisonment to 3 months inprisonment, or both). Each day of continued violation after notice of violation has been given is a separate offense.

ENVIRONMENTAL REGULATIONS

The Nebraska Department of Environmental Control is authorized to prevent water pollution which could include preventing irrigation-related

groundwater development and use that would result in pollution of surface or groundwater supplies.[108]

FINANCIAL PROGRAMS

Two state cost sharing programs are available that relate to groundwater management: the Nebraska Water Conservation Fund (NWCF) and the Nebraska Resources Development Fund. The NWCF is available primarily to provide cost sharing to landowners to increase on-farm water storage and conservation.[109] The NWCF is administered by the NRC. Landowners may receive up to 75 percent state cost sharing on eligible water conservation practices including construction of water impoundment structures draining up to 2,000 acres, unless at least 90 percent of the land to be drained is grassland, in which case up to 5,000 acres can be drained by the proposed impoundment. Cost sharing is also available for construction of terraces, ponds, and other temporary water and sediment retention measures. As a condition of receiving Conservation Fund cost sharing, landowners must agree to maintain the water conservation practice for 10 years or refund the state funds received unless the NRC approves the practice modification.

The Resources Development Fund makes state financial assistance available for a broader range of groundwater management activities, including development of supplemental water supplies and pollution control.[110] Grants and loans (when the program or project is revenue generating) from the Development Fund are made to state agencies or political subdivisions. The NRC is authorized to acquire land for future state resource development projects and to acquire storage rights in water development projects.

Development Fund project or program proposals are evaluated by an advisory board to determine whether: (1) the proposed program or project would conflict with any state land or water plan; (2) the proposed program or project is economically and financially feasible; (3) the proposed program or project is technically feasible; (4) adverse environmental impacts are minimized; (5) the applicant is qualified to implement the proposed program or project; (6) any loan request can be repaid and that adequate operation and maintenance are provided during the loan's term; (7) the proposed program or project is coordinated with other state programs; and (8) money is available from the Fund. After considering the advisory board's recommendation, proposals may be approved by the NRC.

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Section 2

Baseline Condition And Projected Associated Impacts

OVERVIEW

For the purposes of this study, the "Baseline" condition is that which assumes no restrictions on water use or irrigation development. This essentially would be a continuation of present state policies. An examination of current state policies is found in the legal analysis portions of this section and Section 1. To follow is an evaluation of this scenario, according to the impact parameters previously identified: environmental, technological, economic, social, and legal/institutional/administrative. The time period selected for this analysis, particularly the economic impact assessment, extends to the year 2020.

PROJECTED IMPACTS ASSOCIATED WITH THE BASELINE CONDITION

Environmental Impacts

WATER

Groundwater Quantity. Areas of high water table are the focus of most impacts. These could include:

-- Continued seasonal and possibly permanent declines in Sandhills wetlands, wet meadows and shallow stock and domestic wells.

-- Loss of wetlands which are related to groundwater in other parts of the state.

-- ET salvage potential in areas where water level declines below the root zone of phreatopytes or emergent aquatic vegetation in marshy areas such as in Merrick County.

Groundwater Quality. Impacts will be most immediate in areas of high water table, but soil type and depth will be factors as well. Increased leaching of nitrates in areas of coarse soils and continued heavy water and nitrogen fertilizer use are likely as studies of existing conditions note. This will lead to increased concentrations of nitrate in groundwater supplies in areas such as the central Platte valley and Holt County where they are the highest, and a statewide trend of increase in concentrations.[1] Leaching in finer soils is also likely. Leaching of other chemicals such as herbicides and pesticides is more limited but, also, likely to continue.

Surface Water Quantity. Declines in groundwater levels in areas of high water tables will have effects on streamflows and lead to continued reductions in flow and eventually to dry streams in some areas. Examples include continued declines in Frenchman River above Enders Reservoir, estimated to be dry by 1990-95.[2] The Cedar River showed significant declines and the Platte River is projected to undergo continued reductions in flow.[3]

Lake levels, such as those in Enders Reservoir which are affected by diminished streamflows, will decline. Those Sandhills lakes, which are associated with groundwater levels, will decline in areas of intensive development as will base flow in the streams which drain the Sandhills.

Surface Water Quality. Where there are reduced flows there will be varied effects on water quality with respect to concentrations of chemicals. Some pollutants correlate with reduced flows under certain conditions. These should increase under existing trends. Increased runoff will also contribute to water quality problems of sedimentation and turbidity.

SOILS

Erosion from Runoff. Based on current trends, there will likely be an increase in soil loss in areas where soils are not excessively well-drained and where development in poorer classes of agricultural land is proceeding. In areas of Valentine or other very well-drained

soils, it is likely that increased development will not lead to commensurate increases in erosion from runoff.

Wind Erosion. In susceptible soils, such as sandy or fine grained soils, increased irrigation development will likely lead to increased soil loss from wind if cultural practices to reduce wind erosion are not used.

VEGETATION AND WILDLIFE HABITAT

Aquatic. Reductions in streamflow beyond a certain threshold will significantly alter vegetation and habitat to the extent of habitat destruction in dry streams. Current trends of habitat degradation, which are illustrated in the Stream Quality Inventories, published in the 1970s by the Game and Parks Commission, would likely continue. Changes in channel structure and vegetation due to reduced flow may have impacts on habitat in the Platte River, thus affecting whooping cranes, an endangered species. Sandhill cranes which utilize the valley as a Spring staging area also will be affected. Cold water fisheries could be affected by current rates of irrigation development.

Reductions in the area and depth of Sandhills wetlands will, as noted in the NRC Sandhills Decision Document, lead to succession of aquatic vegetation by plants more adaptable to dry areas. This would be accompanied by reductions in the presence of ducks and other migratory birds, shorebirds and other species. In wet meadows, hay crops may be reduced with additional impacts on wildlife.

Similar effects will accompany any substantial decline in the area and depth of Sandhills lakes which results from groundwater declines and expanded irrigation development.

Terrestrial. Expansion of irrigated acreage into areas which are presently grasslands will accentuate current rates of reductions in habitat diversity and will continue trends of decline in various wildlife population dependent on grassland, mixed agriculture or a smaller scale pattern of agricultural development. (This trend like most others depends a great deal on the extent of management practices, mitigating efforts, etc.) Upland game birds will be susceptible to these changes in areas where new agricultural land is being developed--such as the shift to irrigated corn in the Sandhills--or where agriculture is being intensified in terms of the layout of farm units which may lead to lack of cover and nesting areas. Shifts to dryland acreage will have effects on habitat depending on crop composition, reversion to grasslands, and management.

RECREATION AND AESTHETIC FACTORS

The quality of both of these factors, particularly recreation, will follow water quality, streamflow, lake level and both aquatic and terrestrial habitat parameters as they relate to the potential for recreation activity. Aesthetic factors will be similar and will also depend on judgments about the value of visual resources, particularly, as the NRC Sandhills Decision Document notes, the difference between a landscape of rangeland vs. that of irrigated agriculture, but also including such factors as presence of riparian vegetation, presence or absence of game and non-game wildlife vs. a more intensively managed landscape, perception of the degree of management of a landscape--geometry of cultivated fields, irrigation technology, modification of contours vs. the undeveloped landscape. These are issues which can be interpreted very differently on aesthetic grounds.

Technological Impacts

EVAPOTRANSPIRATION PER UNIT OF GRAIN YIELD

Techniques currently exist to reduce the amount of water lost to the crop from evaporation or transpiration without resultant reductions in grain yield:

Antitranspirants. Artificially induced reductions in ET rates by treating plant surfaces to modify normal evaporation or transpiration processes have been investigated but do not hold much promise to significantly reduce crop ET requirements in the near future.[4]

Genetic Improvements. Improvements in the adaptability of crops (especially corn) to limited water at selected stages in the life cycle (deficit or stress irrigation) with only minor reductions in yield show promise for water savings in the future.[5]

Modifications of plant size (dwarf varieties) which would significantly reduce ET demand are not expected to come about in the foreseeable future.

The development of shorter growing season crops appears to offer the greatest potential to reduce ET losses.[6] "Both state/federal and private seed company plant breeding experiments have shown good progress in the selection of crop varieties which take advantage of (decreasing the time required to reach maturity)".[7]

CULTURAL PRACTICES

Various tillage practices exist which reduce the amount of water lost through evaporation from the soil surface, runoff, and transpiration from weeds. Techniques such as reduced tillage, minimum tillage, mulch tillage, till-plant, no-tillage, trashy tillage, and basin tillage are all conservation tillage practices which save moisture for crops. Some techniques, such as trashy tillage, can save up to one to two inches of irrigation water per season.[8] "More than eight million of Nebraska's 19.4 million acres of planted cropland in 1980 were farmed with conservation tillage methods".[9] The potential exists, especially due to rising fuel costs, to expand the use of these water-saving practices throughout the state.

Although no new crop hybrids which produce current average yields per acre with reduced amounts of water are expected to be developed in the foreseeable future, hybrid improvements are expected which would increase yield per acre with current levels of water application. Such yield improvements would greatly increase the output (grain yield) per unit of water applied. According to a study by Dr. Donald Hanway, Dr. Albert Flowerday, and Dr. Richard Waldren in the Department of Agronomy at the University of Nebraska-Lincoln, the following crop yield projections are given:

Non-irrigated Corn. Continued gains in non-irrigated corn yields can be expected through the next 40 years. Present statewide average yields of 40-60 bushels per acre year are expected to reach 50-85 bushels per acre by the year 2020. Major expansion of corn as a non-irrigated crop in the western two-thirds of the state is not anticipated. When relative yields are compared, there appears to be a strong likelihood that sorghum will replace most of the non-irrigated corn acreage in Nebraska in the next two decades. As with other crops, the rate of yield gain in the periods ahead will be directly related to the public investment in research and extension.

Irrigated Corn. Approximately 70 percent of Nebraska's corn acreage is irrigated. Yields are very similar regardless of state location of the crop. Statewide yields of irrigated corn have been increasing about 2.5 bushels per acre per year. Present statewide yield averages of 120-140 bushels per acre per year are expected to increase to 180-200 bushels per acre per year by the year 2020.

Non-irrigated Grain Sorghum. Sorghum has demonstrated the ability to tolerate severe drought stress and then recover after more favorable growing conditions return.

Current statewide yield averages of 45-75 bushels per acre per year are expected to increase to 70-110 bushels per acre per year by 2020. The fact that the annual rate of yield gain shown by non-irrigated sorghum is essentually twice that of non-irrigated corn is very significant, especially since the principal sorghum acreage has a more stressful climate than the areas in which corn predominates. The indicated potential to produce under such conditions seems to justify substantial expansion of both research and extension efforts to take greater advantage of its unique characteristics.

Irrigated Grain Sorghum. In the past, farmers have found corn to respond much better than sorghum to high levels of fertilizer and water inputs. The yield advantage of corn over grain sorghum under irrigation probably reflects the much greater investment that has been made in corn research and extension and in farmer and supporting industry production experience for several decades. However, an expanded research program with sorghum in recent years is beginning to produce hybrids with greater response potential. Considering the greater stress tolerance of sorghum and its ability to use nitrogen fertilizer more efficiently than corn, a higher yield potential than in the past may lead to its replacing substantial acreages of irrigated corn across central and southern Nebraska. Current average yield of 90 bushels per acre per year are expected to increase to approximately 160 bushels per acre per year by 2020.

Non-irrigated Soybeans. The major portion of Nebraska's soybeans is grown in the eastern part of the state because of higher rainfall and less climatic stress. Even though soybeans are considered drought tolerant, plants are severely affected by lack of moisture during the flowering and pod filling stages of the growth cycle. Thus, extension of non-irrigated soybean acreages beyond the eastern third of the state seems unlikely. Yields are expected to increase from an average of 25-30 bushels per acre per year to only 35-40 bushels per acre per year by 2020.

Irrigated Soybeans. Only about nine percent of Nebraska's soybean acreage was irrigated in 1979. Increased research and extension activity will be needed to increase yield improvements which are currently only 10-25 bushels per acre more than dryland soybeans. Present average yields of 35-45 bushels per year are expected to increase to 55-65 bushels per acre per year by 2020.

Non-irrigated Wheat. Farmers employing good production practices with hard red winter wheat in Nebraska find it their most stable crop in terms of yield over a period of years. Present statewide average yields vary from 35 to 40

bushels per acre per year with yields by the year 2020 expected to reach 50 to 60 bushels per acre per year.

Irrigated Wheat. Although irrigated wheat is not utilized extensively in Nebraska, circumstances currently exist which could alter the present trend: (1) Wheat is a cool-season crop that grows during the cooler fall and spring months when evaportranspiration is relatively low; (2) Costs of production are relatively low; (3) Bread wheat is a major commodity in international trade; (4) Very little breeding or cultural practice research has been accomplished in the Great Plains under irrigated conditions because water and energy have been both abundant and cheap and other crops have been given priority; and (5) Limited research indicates that varieties need to be bred for irrigated production. Present average irrigated yields of 50 bushels per acre per year are expected to increase to 80 to 85 bushels per acre per year by 2020.

Non-irrigated Alfalfa. With the increased cost of fertilizer, more labor-efficient haying methods and favorable hay prices, the use of alfalfa could increase especially in the higher rainfall areas of the state. Yields are expected to increase from a one and one-half to three and one-fourth tons per acre average across the state to two to five tons per acre by the year 2020.

Irrigated Alfalfa. Approximately 20 percent of the alfalfa grown in the state is irrigated. If some major change in use would occur which increased the value and profitability of irrigated alfalfa production, increased research and extension efforts might be expected to produce higher yields. Yields are projected to increase from a current average of four to five tons per acre to six to seven and one-half tons per acre by 2020.

Irrigated Sugar Beets. Production of sugar beets in Nebraska is restricted to irrigated areas in the southwest and the Panhandle. Further yield gains from improved production practices by farmers will be relatively small because the general level of practices is now high. Present average yields of 20.5 tons per acre are expected to only increase to 23 to 24 tons per acre by 2020.

Irrigated Dry Edible Beans. Production of dry edible beans occurs only in western Nebraska. The future of this crop is dependent upon market demand and price. If export markets of considerable magnitude develop, then price and profitability would cause acreage to expand even further and would support increases in research and extension. In the absence of increased exports, acreages will change little and investments in improvement will probably not increase greatly.

Average yields are expected to increase from current average yields of approximately 1,800 pounds per acre up to 2,400 to 2,500 pounds per acre by the year 2020.

Non-irrigated Sunflowers. Through the last decade, especially the last five years, a number of farmers in various parts of the state have planted sunflowers. Growers will have to get food yields at relatively low unit costs, however, if production is to be profitable.

Nebraska has little research or production experience with sunflower. Present yield averages of 900 to 1,400 pounds per acre are speculated to approach 1,300 to 2,200 pounds per acre by 2020. However, substantial research and extension work would have to be undertaken to achieve these projected yields.

Irrigated Sunflower. The potential exists to grow irrigated sunflower in the state, but no satisfactory data base is available for making accurate yield projections. Extremely speculative observations place present average yields at 1,500 to 1,800 pounds per acre and at 2,300 to 3,100 pounds per acre by 2020.[10]

CONVEYANCE SYSTEM EFFICIENCY

Surface irrigation systems have the potential to improve conveyance system efficiency by reducing water loss from evaporation, transpiration, and deep percolation. Canal lining would reduce loss of water to deep percolation, but potential groundwater recharge from a "leaky canal" would be eliminated. The use of irrigation pipe rather than unlined canals in the delivery system would reduce water loss from deep percolation and evapotranspiration, but recharge would again be eliminated. Removal of weeds from open irrigation canals and ditches would reduce loss of water to ET. "Water losses or wastes due to spills, seepage, evaporation, and other casues from the conveyance or water delivery systems...can be substantially eliminated through (present) available technology, facilities and equipment".[11]

APPLICATION EFFICIENCY

As defined earlier, application efficiency is the ratio of the amount of water retained in the effective root zone of the crop being irrigated immediately after watering to the total amount of water applied to the field. Many techniques can be used to improve application efficiency: (1) Tillage practices, as discussed earlier, can be used to reduce loss of water through evaporation and transpiration, and also to reduce the amount of water lost to runoff; (2) Irrigation scheduling can be used to apply available water for optimum

crop production. "Water application reductions of 30 to 35 percent have been realized without any sacrifice in yields, using good scheduling techniques".[12] Approximately 25 percent of the irrigators in the state use irrigation scheduling[13]; and (2) Runoff water can be collected and reused to improve application efficiency. "When reuse systems are used, (surface) irrigation efficiencies can be increased to over 90 percent".[14] Normal application efficiencies for furrow irrigation with no reuse, the most common method of surface irrigation in the state, ranges "from 50 to 60 percent with tailwater accounting for the majority of water lost".[15] Overall, surface irrigation system efficiency in the state is considered to be at 65 to 70 percent presently, and is expected to improve to 85 percent by the year 2020.[16] Sprinkler systems are currently considered to be at 75 percent efficiency and are expected to also improve to 85 percent by 2020.[17] It must be remembered that application efficiency will vary significantly dependent upon soil type. Sandy or other fine textured soils allow water to infiltrate through the effective root zone of the crop more quickly than on other soils, thereby reducing irrigation water application efficiency.

Economic Impacts

CHANGES IN FEET OF LIFT

The effect of groundwater management alternatives on pumping lifts influences irrigation costs and thus the other impact parameters. When comparing the Baseline with the alternative management actions as presented in Section 3, it is found that lift changes are the largest for the Baseline, ranging from 104 feet of decline in Region V to 46 feet in Region II (see Table C-1, Appendix C; for geographic location of the regions, see Figure 1-2 on page 10).

CHANGES IN ACRES REVERTING TO DRYLAND

Under the baseline run, nearly two million irrigated acres are estimated to revert to dryland by 2020 (Table C-2, Appendix C). All areas of the state are projected to experience some aquifer exhaustion, but the most severe problems occur in Regions IV (787,654 acres) and I (551,907 acres).

CHANGES IN AGRICULTURAL PRODUCTION

The impacts which the various alternative management actions have on agricultural production are much more difficult to assess. Except for grain sorghum and to a lesser extent wheat, statewide baseline production totals are as high or higher than those from the alternative management actions presented in Section 3 (see Table C-3 through C-8, Appendix C).

RETURNS TO LAND AND MANAGEMENT

Perhaps the most useful of farm level economic indicators is the variation in returns to land and management (RTLM), defined as the amount of money remaining from crop agriculture after all production costs except land and management charges have been paid. It is not the same thing as net farm income, but differences in RTLM reflect differences in net farm income. Net farm income is essentially RTLM less land charges.

When comparing the Baseline condition with the alternative management actions presented in Section 3, the regulatory options reduce net returns in all regions and all time periods relative to the baseline, although the differences are less than one would expect, given the large production effects discussed earlier. When comparing the Baseline with those actions designed to improve efficiency, it was shown that the improved efficiency options reduce production costs without lowering production, thus improving net returns, in some instances higher than that expected in the Baseline (see Table C-9, Appendix C).

OFF-FARM ECONOMIC IMPACTS

The economic effects occurring at the farm level from groundwater management alternatives impact in other sectors of the economy. Changes in agricultural production, for example, effect the sales of fertilizer and farm machinery. These types of impacts are extremely difficult to analyze, however, because of the dynamic nature of the Nebraska economy. In other words, even if one knows the relationship between such things as agricultural production and fertilizer sales at some point in time, this relationship may change when agricultural production changes. Thus, the problem of dynamic structural changes.

The effects of the different alternative management actions and options on the outputs for each economic sector corresponds closely to the crop production impacts, i.e., the larger the impact on crop production, the larger the impact on other economic sectors (see Table C-10, Appendix C).

When comparing the Baseline to other alternative management actions and options examined in this report, it appears that the more restrictive options decrease outputs in other

sectors of the economy, whereas actions to promote irrigation efficiency increase outputs, although some might argue, not by a significant amount.

A more complete comparative analysis of the Baseline condition in conjunction with alternative management options is found in Appendix C.

SOCIAL IMPACTS

The following discussion of social impacts of baseline conditions occurs within two time frames: (1) **Short-term impacts**, or those impacts expected to occur in the near future under current levels of groundwater management and with current irrigation development trends; and (2) **Long-term impacts**, or those social impacts expected to occur when aquifer exhaustion takes place. The purpose of dividing the baseline into two parts is to contrast the social impacts of eventual aquifer depletion with those impacts expected to result in the immediate future from present levels of irrigation development. Both scenarios are presented to provide a balanced view of future impacts of current levels of irrigation in the state.

SHORT-TERM SOCIAL IMPACTS

Several social "elements" will be affected over the short-term by current levels of groundwater management and irrigation development:

Attitudes/Political Issues. Changes in the quality of life of a community often lead to demands for management techniques which alter water use practices. As groundwater pollution and reduced stream flows become more prevalent throughout the state, increased demands for management of the resource will occur. However, attempts to voluntarily conserve water may be difficult to accomplish if the resource is considered unlimited or if the individual cannot identify any overall effect from his/her efforts to reduce water use. Even if potential depletion of the aquifer is expected, many irrigators may not practice conservation because of an "if I don't use the water, someone else will" attitude. This could effectively negate the conservation practices of others.

Economic Activity. There is no question that irrigation has provided the basis for an economic "boom" in farm income and community growth in many areas of the state, such as in Aurora, Valley, Lindsay, and Imperial. The *Denver Post,* in 1979, stated that total agriculture production in the Upper Republican Natural Resources District (NRD), which encompasses Chase, Perkins, and Dundy counties and includes the city of Imperial, is valued at $95 million a year. However, if all irrigated land in the NRD (only 20 percent of the total land) reverted back to dryland wheat as it was two or three decades ago, total agriculture production in the three-county area would be valued at only $20 million a year -- a decrease of almost 80 percent.[18]

Recent economic expansion in Imperial, which local officials consider to be totally due to the irrigation economy of the area, includes expansion of commercial grain storage facilities, influx of several irrigation and farm implement dealers, increased fertilizer sales, improved rail service, and upgraded airport facilities.

Other areas of the state are also experiencing economic growth related to agriculture, but in some places the existence of manufacturing plants for production of irrigation pipe, center pivot systems, grain storage bins, and farm implements are providing the basis for the "boom". Although irrigation equipment manufacturing in the state began primarily at a local scale, national and overseas equipment sales will provide additional economic growth as these firms benefit from irrigation outside the state.

Tax Base. Installation of an irrigation system increases the value of the land to be irrigated, thereby potentially increasing tax revenues for local governmental bodies. Land values in Chase County, Nebraska, for example, have almost tripled during the past decade, from $37 million to $93 million, as a result of irrigation.[19] Therefore, an area which is experiencing irrigation expansion probably will have an increasing tax base and potentially greater tax revenues if local mill levies are not reduced. This implies that higher levels of community services, such as fire and police protection, road repair, and aid to schools could be provided if the cost of providing services increases more slowly than the rate of increase in tax revenues.

Income Distribution/Equity. While groundwater is readily available for irrigation, those with existing irrigation systems or with the credit or capital required to procure systems should continue to benefit. If financial incentives which contribute to consolidation of land holdings continue, income distribution will become more skewed. A study by Dr. Maurice Baker of UN-L states that "the small farmer who is unable to obtain the credit and capital required to develop irrigation (may be) bypassed by irrigation development".[20]

Consolidation of land also may make it more difficult for the young farmer to enter into the farming profession. "As farmers retire or otherwise leave farming, established farmers vigorously compete for newly available farmland either as potential renters or potential purchasers. The entry of new farmers in an environ-

ment in which land prices are high relative to near-term agricultural returns, equipment is increasingly expensive and production costs rising, and existing equity is crucial to even participate in farming, it becomes increasingly difficult if not impossible to maintain a steady stream of new farmer entry into agriculture".[21] This prevents a wider distribution of income and aids in the concentration of wealth.

Farm Size/Numbers. In 1974 aproximately 46 million acres of land were considered to be under farm production in Nebraska, which was a drop of one million acres from 1940. Average farm size in the state increased from 391 acres in 1940 to over 680 acres in 1974. Land under farm production in the state contained in farms greater than 500 acres in size increased from 56 percent in 1940 to 78 percent in 1974. During the same period, the amount of land in farms smaller then 260 acres decreased from 23 percent in 1940 to only seven percent in 1974. In short, farms have expanded and consolidated.[22] (See Table 2-1.)

Between 1940 and 1974, the number of farms in Nebraska has declined from approximately 121,000 to about 67,000. the number of farms over 500 acres in size increased from 14 percent of all farms in the state in 1940 to over 32 percent in 1974.[23] (See Table 2-2.)

Population. Local business expansion and introduction of new operations related to agriculture, feed yards, grain terminals, etc., should provide new job opportunities and, therefore, net population increase or retention of persons who otherwise would have out-migrated. Rural industrialization induced by stable local economies may also contribute to local population growth.

It is significant to note that the average age of farm operators in the state has been increasing steadily, from 46 years in 1940 to 50 years in 1974. More revealing is that in 1940, 28 percent of the farm operators were at least 55 years old, increasing to a share of 41 percent in 1974. Also, 23 percent of all farmers were 35 years old or younger in 1940, but decreased to 16 percent in 1974. (See Table 2-3.) Although the average age of the U. S. population is increasing in general, it is still important to note that the average age of farmers in Nebraska also is increasing.

These distributional changes within the age structure of farmers magnifies the impact that declining farm numbers has had on the overall size of the state's farm population. "With 121,060 farms in 1940, the farm population stood at approximately 495,500, around 4.1 persons per farm. In 1969, with 72,260 farms statewise, the farm population one year later was around 238,000, or about 3.3. persons per farm".[24]

Table 2-1

LAND IN FARMS IN NEBRASKA

BY FARM SIZE

(Post W.W. II Period)

FARM SIZE CLASS (Acres)	1940	1945	1950	1954	1959	1964	1969	1974
Under 50 ac.	182,065	167,872	162,122	134,106	127,865	109,484	91,579	98,566
50 to 99	720,773	543,859	586,766	440,584	381,050	336,478	307,213	319,960
100 to 179	5,538,621	4,282,315	3,946,799	3,383,977	2,563,319	1,900,935	1,548,115	1,400,300
180 to 259	4,273,573	4,354,328	4,279,611	4,068,265	3,378,363	2,518,195	1,905,299	1,558,743
260 to 499	9,916,810	9,952,984	9,571,792	9,570,133	9,539,805	8,897,650	7,654,401	6,717,344
500 to 999	7,290,571	7,473,650	7,300,303	7,418,053	7,821,573	8,455,950	8,495,588	8,724,023
1000 to 1999	19,421,568	20,977,933	21,533,175	22,471,462	6,586,112	7,207,150	7,514,640	7,785,730
2000 plus					17,376,736	18,366,500	18,317,118	19,567,346
All Land in Farms	47,343,981	47,752,941	47,330,568	47,486,580	47,774,823	47,792,500	45,833,953	46,172,012
% of Land in farms greater than								
250 acres	77.4%	80.4%	81.2%	83.1%	86.5%	89.8%	91.6%	92.7%
500	56.4%	59.6%	61.2%	62.9%	66.5%	71.2%	74.9%	78.1%
1000	41.0%	43.9%	45.8%	47.3%	50.2%	53.5%	56.4%	59.2%
2000					36.4%	38.4%	40.0%	42.4%

Source: Census of Agriculture

Table 2-2. Number of Farms in Nebraska, by Farm Size (Post W.W. II Period)

FARM SIZE CLASS (Acres)	1940	1945	1950	1954	1959	1964	1969	1974
Under 50 ac.	10,720	10,589	10,135	9,029	7,095	6,352	7,081	6,734
50 to 99	9,308	7,069	6,940	5,746	4,999	4,440	4,067	4,247
100 to 179	36,576	28,316	26,071	22,412	16,997	12,684	10,401	9,473
180 to 259	19,282	19,680	19,290	18,321	15,152	11,278	8,527	6,995
260 to 499	27,909	28,083	26,933	27,042	26,678	24,534	20,853	18,122
500 to 999	10,570	10,805	10,580	10,685	11,263	12,198	12,324	12,586
1000 to 1999	6,697	7,214	7,225	7,611	4,813	5,248	5,495	5,721
2000 plus					3,226	3,429	3,509	3,719
All Farms	121,062	111,756	107,174	100,846	90,223	80,163	72,257	67,597
% of Farms greater than:								
260 acres	37.3%	41.3%	41.7%	45.0%	50.8%	56.6%	58.4%	59.4%
500	14.3%	16.1%	16.6%	18.1%	21.3%	26.6%	29.5%	32.6%
1000	5.5%	6.5%	6.8%	7.5%	8.9%	10.8%	12.5%	14.0%
2000					3.6%	4.3%	4.9%	5.5%

Source: Census of Agriculture

Table 2-3. Farm Operators in Nebraska, by Age Group (Post W.W. II Period)

AGE GROUP	1940	1945	1950	1954	1959	1964	1969	1974	1940-1974 CHANGE: (Percent)
Under 25	4,615	3,335	4,511	2,410	2,441	1,864	2,143	2,656	-42.4%
25 to 34	22,178	19,199	19,660	18,243	14,140	10,578	8,806	7,751	-65.1%
35 to 44	28,033	27,261	24,643	24,563	20,470	18,162	15,357	11,604	-58.6%
45 to 54	30,031	28,461	23,742	23,961	22,496	20,765	13,814	17,086	-43.1%
55 to 64	21,037	21,396	19,162	19,317	18,561	17,876	17,909	16,578	-21.1%
65 plus	11,773	11,426	9,995	11,417	11,170	10,918	9,228	10,589	-10.1%
Ave. Age	46.2	46.9	45.9	47.1	48.1	49.2	49.3	50.3	
% of Operators older than:									
45 yrs. old	53.4%	55.2%	52.0%	54.7%	58.5%	61.8%	63.6%	66.8%	
55	27.9%	29.5%	28.7%	30.8%	33.3%	35.9%	37.6%	41.0%	
65	10.0%	10.3%	9.8%	11.4%	12.5%	13.6%	12.8%	16.0%	

Source: Census of Agriculture

This decrease in farm population would definitely be linked to the technological changes which occurred in agriculture, such as center pivot, which reduced the need for manual labor.

Health/Safety/Education. Prosperity resulting from irrigation may allow local communities to provide improved public services to area residents if the change in local tax revenues is greater than the change in costs of existing services. For example, increased tax revenues could be used for construction or expansion of hospital facilities, medical clinics, mental health centers, recreational facilities, police and fire protection, ambulance service, and water and sewer service.

However, increased irrigation development around communities has also contributed to degradation or depletion of municipal water supplies -- such as in David City, Sidney, and Seward. Rural domestic wells have also suffered negative effects from increased irrigation development.

Quality of Life. The current quality of life should be maintained while groundwater supplies are adequate. Irrigation expansion should provide economic stability to the state such that the majority of residents should benefit.

LONG-TERM SOCIAL IMPACTS

Several social "elements" will be affected:

Attitudes/Political Issues. When the resource is limited, efforts will be increased to

improve the efficiency of its use. For example, farmers in Texas have formed Underground Water Conservancy Districts (UWCD) which not only issue permits for new wells and enforce well spacing requirements, but also "patrol the area to locate farmers who are needlessly allowing irrigation water to run out the ends of fields and into nearby playa lakes. If a farmer refuses to stop 'wasting' water, the UWCD has the authority to seal the farmer's well".[25]

Economic Activity. The primary economic effect of a declining water supply will be a decrease in farm profits (and an associated revaluation of assets used in farming) over time caused by the simultaneous decline of irrigated acreages and increased pumping costs.[26] As farm profits decline, agricultural commercial activities in nearby communities will also decrease. Fertilizer and machinery sales will decline and less grain will be available for shipping to grain terminals or for cattle feeding operations. A Texas Water Resources Research Institute study states "with total agricultural output declining, significantly less inputs and labor will be required. Therefore, related agribusiness firms will be affected in a similar manner".[27]

Sectors that produce consumer services will be affected due to a reduction in available household expenditures. Investment opportunities for local financial institutions also may decline which, in turn, could contribute to the relocation of local firms. A study conducted by the Sociology Department at Texas A & M University noted that "financial institutions and local leadership will become more conservative as the risk of local investments increases".[28] Effects on communities will vary according to size, economic diversification, proximity to other communities, and potentials for other economic activity as a substitute. Beyond these factors, a "negative multiplier" is likely to operate in relation to groundwater declines and aquifer exhaustion.

Tax Base. As an area's groundwater supply is depleted, land values will decrease as irrigators revert to dryland farming practices. For example, in areas around Lubbock, Texas, land values have declined from about $600-650 per acre to around $400-$450 per acre in a decade due to declining groundwater levels.[29] The previously mentioned Texas A & M University study indicated: "A shrinking tax base will affect the institutions which depend on property taxes, especially local government and schools. A general decline in municipal service and the quality of education may occur".[30] Also, banks and other lending institutions may become less willing to make farm real estate loans. This will affect the farmer's cash flow which, in turn, will impact on the deposit growth of banks and rural infrastructure.[31]

Utility electricity generating capacity developed for irrigation may be underutilized and, thus, may become expensive for residents to support.

Income Distribution/Equity. When groundwater resources are not as plentiful, those with irrigation wells producing an acceptable economic return will continue to benefit from irrigation and may, perhaps, "receive a windfall in the form of higher land values while dryland farmers may sustain a loss in the value of their land".[32] This loss in land values will be even more profound if the land was originally purchased at irrigated prices. Other shifts in income distribution may result from a redistribution of the tax burden due to reductions in the property tax base, increase cost in acquiring compariable and, severance damages, and loss of asset values, income, and employment from making adjustments to changing economic conditions.[33]

Farm Size/Numbers. As groundwater supplies are depleted and irrigation becomes uneconomical, dryland farming would encourage add-ons from smaller farm units that could not succeed. This would vary area to area, but a return to the small dryland farms of the past half century would probably not occur. A study by a USDA agricultural economist states "The adjustment problems associated with a declining water supply are associated with attaining sufficient acreage to provide a minimum family disposable income under dryland conditions".[34]

Population. Net population decrease probably will occur from rural communities as farm incomes decline and dislocation of commercial establishments takes place. In addition, the Texas A & M study predicted significant net out-migration of rural on-farm residents. "With a shift from irrigated to dryland production the average size farm will, for economic survival, have to increase in size three to four times. This means that by (the year) 2015, three out of four farm families in the Southern High Plains will be displaced".[35] The level of net out-migration will depend upon the amount and rate at which irrigated land goes out of production and the number of businesses in a community which rely on local irrigated agriculture for their economic livelihood. "The population remaining in these areas will be increasingly older, limiting growth, and accentuating the social problems of the aged; expecially medical and welfare".[36]

Health/Safety/Education. Ultimately, as an area's groundwater supply is depleted, the local population and tax base will probably decline unless some substitute economic activity is introduced, e.g., manufacturing. This decline would

subsequently require local governments to reduce locally supported public services -- both those based on property taxation and those provided by non-profit institutions dependent to some degree on community prosperity and population density. Road repair, public safety, education and health would be among the major activities which may face reductions.

Quality of Life. Prosperity may continue in the short-term, but problems such as groundwater pollution, municipal water quality degradation and/or depletion, the necessity of redrilling domestic wells due to irrigation well interference, wetland depletion, reduced stream flows, reservoir depredation, loss of wildlife, and reduced recreational opportunities associated may become more prevalent. Conflicts will occur with greater frequency over water use efficiency, water rights, and resource management.

LEGAL/INSTITUTIONAL/ ADMINISTRATIVE IMPACTS

GROUNDWATER USE RESTRICTIONS

The only statutory statewide restriction on groundwater use is the irrigation runoff controls administered by NRDs. Enforcement of these controls would reduce over-irrigation.

Withdrawal restrictions have been established in the Upper Republican NRD groundwater control area. Irrigators in the Upper Republican are starting to grow crops requiring less water (pinto beans, grain sorghum, irrigated wheat) and are beginning to rotate corn with these other irrigated crops. Some flood irrigators are shifting to center pivots to improve irrigation efficiency. Irrigation scheduling and improved use of reuse pits have increased significantly. While these changes in irrigation practices are in part due to increased pumping costs (the average pumping depth is 150-175 feet) the groundwater allocation probably is also an important factor. The 22 inch allocation (gross withdrawals) is nearly the previous 22.68 inch irrigation water use average (net withdrawals) in the Upper Republican. Reduced allocations in the future could result in reduced average water withdrawals.

GROUNDWATER DEVELOPMENT RESTRICTIONS

Several groundwater development (i.e., well installation) requirements exist but probably have no significant effect regarding groundwater depletion. These include well spacing requirements and DWR permit requirements for pits near streams, industrial wells, and interstate water supply wells.

Critical township irrigation well spacing requirements in the Upper Republican control area are reducing the density of groundwater development in "critical townships". This may show the depletion rate in those areas.

CONTROL AREA ADMINISTRATIVE COSTS

The Upper Republican control area is the only one where active regulation is occurring. Current control area costs average between $22-23 per well and will increase to between $25-30 per well in 1982. (The Upper Republican control area contains approximately 2,750 wells.) The Upper Big Blue and Little Blue control areas are not yet enforcing groundwater controls. The current costs of the preliminary stage of control area administration are approximately $9 and $10 per well, respectively. The Little Blue expects to spend $34 per well in 1982, however, due to equipment purchases. The Upper Big Blue expects its 1982 costs to be between $10-11 in 1982. (The Upper Big Blue has approximately 10,000 wells as compared to approximately 2,500 for the Little Blue).

The DWR costs for administering its control area responsibilities average $13,000 per year.

FOOTNOTES

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[36]Schaffer, Albert, and Ruth C. Schaffer, "Sociological Impacts of Depletion...".

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Section 3

Potential Groundwater Management Techniques and Associated Impacts

INTRODUCTION

Groundwater mining (i.e., the permanent reduction of the amount of groundwater in storage) suggests that ultimately groundwater withdrawals will be reduced and perhaps cease: (1) because the groundwater aquifer supply is physically depleted; or (2) because groundwater withdrawals cost more than they are worth. The eventual reduction of irrigation associated with groundwater mining leads to local and perhaps statewide contraction in economic activity. One of the purposes of this study is to determine whether the economic losses associated with groundwater mining can be avoided or postponed by reducing current and future groundwater uses.

One of the major policy issues relative to groundwater mining is whether current uses should be restricted in order to have more groundwater available in the future. If groundwater uses are not curtailed through private or public action, they will ultimately be reduced or stopped in some areas because of physical depletion or because further withdrawals are uneconomical. In some parts of Nebraska the physical or economic exhaustion of local groundwater supplies may occur in a matter of decades; in other areas in a matter of centuries.

The first part of this section will center on the general components of "groundwater management strategies" which may be put into motion to affect the rate and/or amount of groundwater withdrawn in Nebraska. Following this discussion is a presentation and assessment of management techniques identified by the work group to meet an overall goal of managing groundwater resources to stabilize or reduce groundwater use. Specific examples ("For Instance" Cases) of some of these techniques are presented to facilitate analysis. Management alternatives which permit groundwater development at the historical rate or higher are examined in Chapter 5 of the report.

GENERAL COMPONENTS OF GROUNDWATER MANAGEMENT STRATEGIES

An effective groundwater management strategy may have as many as eight general components: (1) management objectives; (2) management actions; (3) implementation methods; (4) implementation options; (5) criteria; (6) geographical scope; (7) implementation agency; and (8) funding options. A general introduction to each will be presented in turn.

Groundwater Management Objectives

As articulated in the work plan, the purpose of this study is to determine the appropriate rate of utilization of the existing groundwater supplies. For the purpose of this report, however, the overall **goal** of managing groundwater **is to stabilize or reduce groundwater use.** In some instances, the intent might be to avoid or reduce the adverse environmental consequences associated with groundwater use for irrigation, such as water pollution from sediment and agricultural chemicals, soil erosion, streamflow reduction, and wetland loss. The management techniques work group identified three **objectives** to further clarify the purposes of the overall goal: (I) to reduce irrigation water need; (II) to reduce future groundwater development; and (III) to reduce the amount of groundwater withdrawn.

Another set of management objectives worthy of consideration, although not consistent with the overall goal, above, comprises those which are intended to either maintain the current rate of groundwater development and/or withdrawals which exceeds the historic pattern. Although not addressed specifically in the presentation and analysis of alternative management techniques

which follow, specific administrative-legislative action alternatives designed to meet those objectives are examined in Chapter 5 of the report.

Management Actions

Management Actions are those activities which are taken to accomplish the management objectives. They are designed to effectuate a water supply impact (i.e., a change in the amount and/or rate of groundwater withdrawal). They also may have other impacts which may either be beneficial or detrimental. Some actions might be implemented voluntarily, others might need to be mandated by legislation or administrative regulation before they are followed. The work group identified a number of management actions; some might work to achieve only one objective; others might work toward two or three. These management actions include: (1) improving irrigation efficiency; (2) improving crop water use efficiency; (3) improving water conservation practices; (4) reducing groundwater development based on water supply criteria; (5) reducing groundwater development based on geographic/environmental criteria; and (6) reduce groundwater withdrawal to prolong groundwater supplies and reduce environmental impacts.

Implementation Methods

Mechanisms designed to execute the management actions are denoted as **implementation methods.** The work group identified three types of implementation methods appropriate to carry out the management actions as presented in this report: (1) research and educational efforts; (2) financial incentives and/or disincentives; and (3) regulating groundwater development and use.

RESEARCH AND EDUCATION

Research in how to reduce water use or how to avoid adverse environmental consequences can be the basis for educational programs to persuade irrigators to change their practices. Educational efforts are most successful, however, when irrigators can personally benefit substantially by improving their water use. Reasons for wanting to improve water use include the possibility of reduced supplies in the future, increased irrigation costs, or the potential of water use regulations. The absence of these factors may reduce irrigator interest in educational programs, thus reducing a program's potential effectiveness. In particular, educational programs may be less effective in persuading landowners to voluntarily foresake private economic gains for the general welfare.

FINANCIAL CONSIDERATIONS

Another implementation method for reducing groundwater use is through financial programs which may involve: (1) establishing financial incentives to reduce or forego water development and use; and (2) by establishing financial penalties for increasing groundwater development and use. Financial incentives may be a method of associating what otherwise would be disassociated costs and benefits (e.g., taxing groundwater users to buy the development rights of those who do not develop groundwater). Groundwater development could be discouraged or prohibited by taxing groundwater development. This could be accomplished by taxing new wells, newly irrigated land and/or new irrigation equipment. The rate of tax would need to be fairly high to effectively reduce groundwater development.

Where owners of land overlying groundwater supplies have not yet developed high capacity wells, their groundwater development rights could be purchased and retired. This means that high capacity wells could not be developed on the land for which the development rights had been sold.

An advantage of this approach is that landowners who sell their groundwater development rights are compensated for not developing high capacity wells. This approach arguably is more equitable in that landowners who have not developed wells are not economically disadvantaged relative to groundwater users. Purchasing groundwater development rights could be expensive, however.

REGULATION OF GROUNDWATER DEVELOPMENT AND USE

A third implementation method for reducing groundwater use is by regulating irrigation. Regulations may take many forms, may affect many aspects of groundwater use, and may be imposed and administered by either state or local agencies.

Regulations could be in the form of a state law that allows no exceptions. A statewide moratorium on drilling irrigation wells would be one example. There also could be a statewide law with a degree of flexibility, by prohibiting drilling of wells without a permit from a state agency, for instance.

In specifying the degree of flexibility to be allowed, many aspects of groundwater use could be affected differently. As a condition of a permit, the law might require that irrigation scheduling be used to improve water use efficiency. On the other hand, if the intent was to reduce erosion and sedimentation in surface waters, a permit might be refused if the soils are too erodible, or it might be granted on the condition that special control measures be used on the irrigated land. Any of these regulations could be administered by a state agency, an NRD, or a county, if the Legislature gives them the necessary authority.

Management Options

Each of the three implementation methods described above may be carried out in a variety of ways. For example, an implementation method which prescribes financial incentives and disincentives may contain provisions calling for: (1) cost-sharing; (2) tax credits; (3) imposition of new, or higher taxes; (4) irrigation charges; and (5) payments to landowners for nondevelopment (e.g., fee-simple purchases, or purchases of easements or development rights; and others.

These variations associated with the implementation methods are referred to as **implementation options.** In some cases, they are the same for all implementation methods, particularly those associated with education and research. On the other hand, management options associated with regularory methods may vary considerably. One of the reasons that implementation methods are further subdivided into options is that variations in impacts may occur, depending upon which option is utilized.

The relationship between management options and the other components of management strategies is depicted in Figure 3-1.

Figure 3-1.

Interrelationship of Selected Management Strategy Components

- **MANAGEMENT GOAL:** **TO STABILIZE OR REDUCE GROUNDWATER USE**
  - **MANAGEMENT OBJECTIVE I:** **REDUCE IRRIGATION WATER NEED**
    - **MANAGEMENT ACTION 1:** Reduce irrigation water need by improving irrigation efficiency
      - **Implementation Method 1a:** Encourage adoption of improved irrigation practices through research and education
        - **"For Instance" Case 1a(i):** Achieve an average irrigation efficiency, through research and education, equal to today's maximum attainable efficiency by 1985 for sprinkler and by 1990 for gravity systems
      - **Implementation Method 1b:** Encourage adoption of improved irrigation practices through financial incentives
      - **Implementation Method 1c:** Require adoption of improved irrigation practices through regulation
    - **MANAGEMENT ACTION 2:** Reduce irrigation water need by improving crop water use efficiency
      - **Implementation Method 2a:** Encourage adoption of improved practices to increase crop water use efficiency through research and education
        - **"For Instance" Case 2a(i):** Reduce crop irrigation water needs, through research and education, by ten percent per year per unit yield through plant breeding and reduced tillage
        - **"For Instance" Case 1a/2a:** Improve both irrigation efficiency and crop water use efficiency through research and education
      - **Implementation Method 2b:** Encourage adoption of improved practices to increase crop water use efficiency through financial incentives
      - **Implementation Method 2c:** Require adoption of improved practices to increase crop water use efficiency through regulation
    - **MANAGEMENT ACTION 3:** Reduce irrigation water need through improved water conservation practices
      - **Implementation Method 3a:** Encourage adoption of water conservation practices through research and education
      - **Implementation Method 3b:** Encourage adoption of water conservation practices through financial incentives
      - **Implementation Method 3c:** Require adoption of water conservation practices through regulation

Continued

MANAGEMENT OBJECTIVE II: REDUCE FUTURE GROUNDWATER DEVELOPMENT

- **MANAGEMENT ACTION 4:** Reduce groundwater development based on water supply criteria
  - **Implementation Method 4a:** Encourage irrigators, through research and education, not to develop irrigation wells which would violate groundwater supply criteria
  - **Implementation Method 4b:** Encourage irrigators, through financial incentives, not to develop irrigation wells which would violate groundwater supply criteria
    - **Implementation Option 4b(i):** Purchase groundwater development rights which, if exercised, would violate groundwater supply criteria
    - **Implementation Option 4b(ii):** Discourage groundwater development violating groundwater supply constraints by increasing the cost of development through taxing authorities
  - **Implementation Method 4c:** Require irrigators, through regulation, not to develop irrigation wells which would violate groundwater supply criteria
    - **Implementation Option 4c(i):** Prohibit or limit groundwater development that would violate groundwater supply criteria
      - **"For Instance" Case 4c(i) (a):** Impose a statewide well drilling moratorium effective in 1985
    - **Implementation Option 4c(ii):** Prohibit or limit groundwater development that would violate groundwater supply criteria, but compensate landowners for the loss of development rights

- **MANAGEMENT ACTION 5:** Reduce groundwater development based on geographic/environmental criteria
  - **Implementation Method 5a:** Encourage irrigators, through research and education, not to develop irrigation wells that would violate geographic/environmental criteria
  - **Implementation Method 5b:** Encourage irrigators, through financial incentives or disincentives, not to develop irrigation wells that would violate geographic/environmental criteria
    - **Implementation Option 5b(i):** Purchase groundwater development (well drilling) rights which, if exercised, would violate geographic/environmental criteria
    - **Implementation Option 5b(ii):** Discourage groundwater development (well drilling) that would violate geographic/environmental criteria by increasing the cost of development through taxing authorities
  - **Implementation Method 5c:** Require irrigators, through regulation, not to develop irrigation wells that would violate geographic/environmental criteria
    - **Implementation Option 5c(i):** Prohibit or limit groundwater development that would violate geographic/environmental criteria
      - **"For Instance" Case 5c(i) (a):** Institute a program that would restrict new development to 50 percent of the unconstrained rate by precluding development on fragile lands, e.g., steep slopes, erodable soils
    - **Implementation Option 5c(ii):** Prohibit or limit groundwater development that would violate geographic/environmental criteria, but compensate landowners for the loss of development rights
    - **Implementation Option 5c(iii):** Condition groundwater development on meeting performance standards regarding geographic/environmental criteria

Continued

MANAGEMENT OBJECTIVE III: REDUCE GROUNDWATER WITHDRAWALS

- **MANAGEMENT ACTION 6:** Reduce groundwater withdrawals to prolong groundwater supplies and reduce environmental impacts
  - **Implementation Method 6a:** Encourage irrigators, through research and education, to reduce groundwater withdrawals to prolong groundwater supplies and to reduce adverse environmental impacts
  - **Implementation Method 6b:** Encourage irrigators, through financial incentives, i.e., purchase rights to withdraw groundwater, to reduce groundwater withdrawals to prolong groundwater supplies and to reduce adverse environmental impacts
  - **Implementation Method 6c:** Require irrigators, through regulation, to reduce groundwater withdrawals
    - **Implementation Option 6c(i):** Restrict groundwater withdrawals through an allocation program
      - **"For Instance" Case 6c(i) (a):** Phased in allocation program, allocating 90, 80, 70, and 60 percent of unconstrained pumpage per developed acre in 1985, 1990, 2000, and 2020, respectively; concentration would be permitted
      - **"For Instance" Case 6c(i) (b):** Allocation of 80 percent of unconstrained pumpage per developed acre beginning in 1985; concentration would be permitted
      - **"For Instance" Case 6c(i) (c):** Allocation of 60 percent of unconstrained pumpage per developed acre beginning in 1985; concentration would be permitted
      - **"For Instance" Case 6c(i) (d):** Development moratorium plus a 60 percent allocation program with concentration allowed
    - **Implementation Option 6(ii):** Require irrigators, through regulation, to either reduce irrigated acreage or grow crops using less water

Management Criteria

Criteria for implementation are required for many groundwater management options. If the objective is to reduce future development, for instance, and it is to be done by regulations, a decision must be made whether to preclude development based on aquifer life criteria, environmental or geographical criteria, or simply time criteria (first applications). Different criteria may have significantly different impacts. For instance, the criteria on which education and research methods were based could have different social and economic impacts. The criteria on which financial and regulatory methods were based would certainly have different impacts of all kinds.

MANAGEMENT CRITERIA FOR REDUCING IRRIGATION WATER NEED

It is assumed in this case that a reduction in need for irrigation water does not mean a reduction in economic return, so the first criterion is that all actions will produce the same amount of crops or an equivalent return if different crops must be substituted. This criterion, in addition to being an economic criterion, could also be a social (i.e., attitudinal) criterion. Other types of criteria that could be used include physical (particulary water supply), technological, and environmental.

Social criteria would be related primarily to the attitude of the irrigator toward the action. If it could be demonstrated to irrigators that they could increase returns by growing a different variety, or could save money by using conservation practices that reduced pumping costs, their attitude might be more favorable and implementation more likely. Economic gain might not be the only factor that could change attitudes, however. In some cases, helping to preserve the water supply for generations to come might influence some people's attitudes.

Technological criteria might also influence decisions on incentives or regulations to reduce water need. In some cases, technological factors may make it difficult or impossible to use different crops or conservation practices. For instance, the farm machinery needed to plant or harvest new types of crops may not work in some types of soils, or on the slopes prevalent in some areas.

Physical criteria would include not only the amounts of groundwater and its projected life, as mentioned previously. It also might include soils, climate, prevalence of weeds and other pests. The extent of the water supply, rate of depletion, and its longevity would probably be the most important physical criterion.

Environmental criteria also could be used. Incentives for using crops that required less nitrogen fertilizers, as well as less water, could have a beneficial effect on the concentrations of nitrates in the water. Also, incentives or regulations

encouraging the use of ecofallow or cover crops could have an effect on wildlife and erosion.

MANAGEMENT CRITERIA FOR REDUCING FUTURE DEVELOPMENT

Criteria for determining the location of land to be developed or restricted could be based on time (first to apply for a permit, first to construct, or other); on geographical limits (50 percent of a section, 10 percent of a township, etc.); on environmental criteria (steep slopes or erodible soils, water pollution potential, etc.); or on economic criteria (more productive lands, land with shallower water tables, etc.). This all might be based on aquifer life criteria, or some other water goal. Presumably the intended outcome of any action would be to reduce groundwater mining. Some criteria for the amount of reduction, or rate of depletion (aquifer life) could be the basis for the selection of other criteria.

The variation in impacts due to different criteria might be substantial. For instance, if time criteria are used, the first ones to apply for a permit would develop soonest, and the economic impact will accrue to them. The overall economic impact to the region might be same, but it could be significantly different. If the land that was developed was less productive than that of other applicants, the regional impact could be smaller. The social impacts associated with economics could also be different.

The environmental impacts also could vary significantly. If the first applicants owned sandy lands, the increases in concentrations of nitrates in the groundwater could be much greater. The impacts on soil erosion, wetlands, and other environmental factors could all vary. For this type of criteria, there is no way to predict which lands might be developed, so it is nearly impossible to estimate the potential impacts.

On the other hand, if environmental criteria are used, the impact could be estimated to some extent, depending on the criteria selected. For example, if it were decided to preclude development on all claying soils on slopes over ten percent, the potential impacts on soil erosion and economics could be estimated.

MANAGEMENT CRITERIA FOR REDUCING WITHDRAWALS

Criteria for determining how much water can be used on each irrigated acre could be based on water supply, area irrigated, crops grown, water requirements, economics, or time. These are all complicated by the period the allocation can cover (16 inches per year or 80 inches in five years) and possible concentration of acres.

Water supply criteria are those based on the amount of water in storage and the allowable rate of depletion (or aquifer life). Groundwater depletion rates are the best examples of a groundwater supply criteria. The depletion rate could range from no depletion to, e.g., ten percent annual depletion. Depletion rates may be expressed in terms of the life of the groundwater supply: A 100 year life would suggest a depletion rate of up to two percent per year, etc. Depletion rates could be local (e.g., within three miles of a proposed well site), regional (e.g., within all or part of an NRD) or statewide.

Area criteria include different bases for allocations. Water could be allocated on the basis of total acres owned, acres irrigable, or acres actually developed and capable of being irrigated. Different allocations could also be provided for different crops, such as alfalfa or corn, which have different evapotranspiration requirements.

If groundwater is allocated, another issue is whether the location of use of the allocation can be concentrated. Use could be: (1) restricted to the tract from which the groundwater was withdrawn: (2) unrestricted; (3) subject to a ceiling regarding the quantity used on any acre; (4) unrestricted subject to per well withdrawal limitations, etc.

An allocation based on overlying acres allowing concentration could be an indirect way of establishing a development restriction: A four inch allocation per overlying acre (with a 16 inch per acre ceiling) might result in irrigators developing 50 percent of their land and using an average eight inches per irrigated acre; developing 33 percent of their land and using an average 12 inches per irrigated acre, etc. The overlying acre basis could also permit allocating groundwater on a "sustained yield" (zero depletion) basis.

Use restrictions are significant when allocations are low enough to force cropping changes or acreage reductions. If irrigators cannot concentrate their allocations on fewer acres, they may be unable to maximize their profits within the limits of their allocation.

If groundwater is allocated, another issue is the allocation time period. Allocations can be single or multi-year; unused allocations may (or may not) be used subsequently; and future allocations may (or may not) be used earlier, etc. The extended period of allocation allows more flexibility, so irrigators can use a little more in dry years and cut back in wet years without losing any of their allocation. This can be used, with variations, in the allocations under most of the other types of criteria.

Concentration of allocations may not be so

flexible. Under some criteria, the allocation might be expressed as a certain number of acre-inches per acre, and the irrigator might not be able to use the total quantity of water on fewer acres, thereby giving more water per acre.

Geographical Scope of Policy Implementation

Groundwater management policies may be statewide, sub-state, regional (e.g., NRDs), or limited to problem areas. Some policies may be appropriate statewide, such as groundwater conservation or irrigation water use efficiency requirements. Others may be appropriate only in problem areas, e.g., where soil erosion or water pollution potential is high.

Implementation Agency

POLICY DETERMINATION

Groundwater policies may be determined: (1) at the state level by the Legislature or an administrative agency; (2) at the local level by, e.g., a natural resources district; or (3) privately by individual water users. For example, the Legislature can establish statewide requirements such as a maximum depletion rate, establish general guidelines for NRDs to implement, or give NRDs the option to act or not.

A disadvantage of statewide requirements is that conditions vary so widely across the state that inflexible requirements might be inappropriate in many areas. Leaving policy decisions completely to local entities, however, means that in some instances no action will be taken even where some action would benefit both local water users and the state. An intermediate approach is for the state to require local action or, in the event that local units fail to act, assumption of control by the state.

POLICY IMPLEMENTATION

Groundwater policies can be implemented at the state level, locally, or cooperatively. State administration is not greatly subject to local political pressures, but may not be flexible enough to adapt to varied conditions. Conversely, local administration may be overly responsive to local political concerns, but can be more adaptable to changing local conditions.

Funding Groundwater Management Alternatives

Four major sources of funding for groundwater management efforts are: (1) federal; (2) state general fund; (3) local property taxes; and (4) water use charges. Federal funds are generally available for research and educational efforts only, although they are available for soil conservation practices also.

An advantage of water use charges is that by in effect raising irrigation costs, they increase irrigator incentives to use water more effectively.

GROUNDWATER MANAGEMENT STRATEGY RANGE

Eight components of groundwater management strategies have been defined. The list of elements in each component given in the previous discussion is not complete, but it provides the background information to start to conceptualize the range of management techniques available for achieving the goals set by state policymakers. Looking at the number of elements under each component, it becomes obvious that there are a multitude of combinations yielding a wide variety of possible strategies. In fact, there are too many to even list them, much less evaluate their impacts.

To follow is a presentation of a range of management techniques identified by the work group as mechanisms to meet the three management objectives stated previously. In general, the techniques are presented to the extent that the first four components identified in the preceding discussion of management strategies -- management objectives, management actions, implementation methods, and implementation options -- are the main focus of discussion. An analysis of the remaining components -- management criteria, geographic scope, implementing agency, and funding considerations -- are also considered to an extent, but will be given greater attention in the discussion of administrative-legislative action alternatives, found in Chapter 5 of the report.

To facilitate the analysis of the management techniques in the ensuing pages, illustrative examples *("For Instance" Cases)* of various actions and options are presented as case studies to indicate how and to what extent the management techniques are carried out. Inclusion of these "For Instance" Cases also serves to facilitate the impact analysis (primarily economic) of the management techniques.

Following the presentation of each management action and its associated implementation

option(s), management option(s) and "For Instance" Case(s) is a discussion of various impacts which may result as each action is implemented. The impact assessment will center on considerations discussed in Section 1 of this report, according to the five impact parameters previously identified: environmental, technological, economic, social and legal/institutional/administrative. Where appropriate, the analyses of impacts associated with the "For Instance" Cases is considered in conjunction with data on water user response, water levels and other economic factors for several projected time periods. This review will be varied in its focus and level of detail. Some significant aspects of impact analysis have been covered to the extent they can be in the discussion of the actions and options. Others require the more specific focus of these "For Instance" Cases. In some cases additional aspects of a management action may be added to illustrate significant concerns. A summary table outlining management actions and options and their associated impacts is found in the Appendix.

MANAGEMENT OBJECTIVE 1: REDUCE IRRIGATION WATER NEED

Reducing irrigation water need means that less water is needed to maintain production. Many actions to meet this objective can be initiated privately with the benefits accruing directly to each individual irrigator. These actions are more likely to be implemented, however, when irrigators face reduced groundwater supplies (because of water use regulations, reduced well yields, or both) or because they incur higher pumping costs (because of higher energy costs, increased pumping depths, or both).

The management techniques work group identified three ways to reduce irrigation water need: (1) by improving irrigation efficiency (e.g., through irrigation scheduling); (2) by improving crop water use efficiency (e.g., through switching to crops or crop varieties using less water); and (3) by improving on-farm water conservation (e.g., by increasing groundwater recharge through conservation tillage or improved soil conservation practices).

To follow is a discussion of each management action and adjunct management option(s) formulated by the work group to meet this Objective, accompanied by an analysis of impacts according to previously-identified impact parameters.

MANAGEMENT ACTION 1: Reduce irrigation water used by improving irrigation efficiency *(e.g., irrigation scheduling, reuse pits)*

One way to reduce groundwater withdrawals for irrigation is to improve irrigation efficiency by, e.g., irrigation scheduling. This can be accomplished through research and education, through financial incentives, and by regulations.

Implementation Method 1a: Encourage irrigators to adopt improved irrigation practices *(e.g., irrigation scheduling)* **through research, demonstration projects, and persuasion**

Irrigators can be encouraged to adopt irrigation scheduling techniques through research, demonstration projects, and persuasion. Irrigators are not likely to respond to such efforts, however, unless they are persuaded that it will be profitable for them to do so. Agencies involved would include the UNL Agricultural Experiment Station and USDA Agricultural Research Service, and Cooperative Extension Service and Natural Resources Districts (NRDs).

To facilitate impact analyses for this option, an illustrative example [hereinafter denoted as *"For Instance" Case 1a (i)]* is a program of education and research to improve irrigation efficiency designed to achieve an average irrigation efficiency equal to today's maximum attainable efficiency by 1985 for sprinklers, and by 1990 for gravity systems.

Implementation Method 1b: Encourage irrigators to adopt improved irrigation practices *(e.g., irrigation scheduling)* **through cost sharing assistance or state income tax credits for the cost of such practices**

Irrigators can be encouraged to adopt irrigation scheduling techniques through cost sharing assistance or state income tax credits for the cost of such practices. (Conversely irrigators could be taxed for failing to do so.) Financial incentives might increase the rate at which irrigators adopted irrigation scheduling techniques if the irrigators believed they would financially benefit from doing so. Financial incentives might be an attractive option if only to focus irrigator attention on scheduling techniques as a private water management option. Cost sharing assistance programs could be administered by the Nebraska Natural Resources Commission (NRC) and NRDs, which administer current state cost sharing programs. Tax programs could be administered by the Nebraska Department of Revenue (NDR).

Implementation Method 1c: Require irrigators to adopt improved irrigation practices *(e.g., irrigation scheduling)* **through legislative requirement or administrative regulation**

Irrigators could be required to adopt irrigation scheduling techniques, although monitoring such a program would be difficult. A simpler way to accomplish the same objectives would be to restrict groundwater withdrawals directly, and expect irrigators to use scheduling as a method for coping with less water.

IMPACT ASSESSMENT OF MANAGEMENT ACTION 1 AND ASSOCIATED IMPLEMENTATION METHODS

ENVIRONMENTAL IMPACTS

Groundwater Quantity -- Possible reductions in the rate of decline in groundwater levels (where declines exist) with most important effects in areas of high water table in terms of impact on maintenance of wetlands, ET potentials, surface vegetation, and phreatophytes. In all cases the maintenance or prolonging of water supplies will be a major effect of a successful program.

Groundwater Quality -- These practices could have an important effect on the leaching of nitrates and possibly other chemicals into groundwater supplies, particularly in areas of high water table. Long term reductions in nitrate concentrations are unlikely, but widespread adoption of these practices could lead to stabilized levels.[1] These impacts will depend on management of nitrogen as well as efficient irrigation, otherwise leachate loadings could remain the same.[2] This factor could also have an effect on the reuse of irrigation water and its quality and consequent impact on existing supplies.

Surface Water Quantity -- Effects in terms of maintained streamflow could be possible in some areas of high water table where reductions in rate or amount of decline are possible. Maintenance of Sandhills lakes and some impounds may result. Reuse of irrigation water could reduce runoff and affect streamflow in those areas without excessively well drained soils.

Surface Water Quality -- Some changes possibly are associated with streamflow. Other modest effects could be related to concentrations of chemicals in groundwater supplies, but there are many intervening factors in both of these instances. Reduced runoff could lead to improvements in conditions of sedimentation and other non-point pollutants.

Soils -- Significant effects could include reduced water erosion in vulnerable areas due to reduced water application and reuse of irrigation water. No effect on wind erosion.

Vegetation and Wildlife Habitat -- Impacts in these areas will primarily follow changes in groundwater level in areas of high water table with the resulting maintenance of some Sandhills wetlands and lakes if rates or amount of water level declines are reduced. This could lead to maintained vegetation and habitat in these areas. Riparian and some aquatic vegetation could be affected as well as hay crops in wet meadow areas in the Sandhills. Maintained streamflows could have parallel effects. Wildlife populations affected could have parallel effects. Wildlife populations affected could be those dependent on wetlands and aquatic habitat, including ducks and other migratory birds, shorebirds, furbearers and fish species.

Terrestrial conditions do not appear to be directly related to this management action and are not really predictable since they depend on a range of management decisions not specifically related to increasing the efficiency of irrigation. Recreation and aesthetic effects will be related, as noted to any changes in surface water quantity and quality and in habitat and wildlife populations.

The environmental impacts of *"For Instance" Case 1a(i)* do not appear to be dramatically different than those associated with the baseline trends for average lift, acres reverting to dryland, or the composition of crop production (particularly corn) which would be sustained. Effects related to changes in the rate of groundwater decline would probably be modest, although significant effect could be felt in some areas of high water table. Effects on wetlands, wet meadows, streamflow and related vegetation and habitat would be moderate. Some effects could be seen in the areas of reduced leaching of nitrates due to reduced water use and reduced runoff in areas of soil types which are not excessively well-drained. Reversion to dryland from aquifer exhaustion is slightly less than the baseline trend and could have some effects on habitat if acreage reverts to grassland. Otherwise aggregate changes in vegetation are small. It is likely that losses of riparian and aquatic habitat would continue near present levels.

TECHNOLOGICAL IMPACTS

As stated in the technological impacts analysis of the baseline scenario, current irrigation scheduling technology can reduce water applications by 30 to 35 percent without any sacrifice in yields. Increased research and education may

induce more irrigators to use scheduling, but the degree of sophistication of on-farm scheduling techniques and, thus, water savings may continue to vary greatly.

Since current technology exists to substantially eliminate water loss from the conveyance and water delivery systems, additional incentives or regulations may be required to eliminate current water losses. It must be remembered, however, that these water losses often return to the groundwater reservoir through deep percolation and are not totally lost. However, chemical leaching will degrade water which has deep percolated.

It is estimated that the installation of reuse pits on surface irrigation systems would increase irrigation efficiency the greatest of any single practice.[3]

ECONOMIC IMPACTS

To analyze the economic effects of this Action, the RLP Model was applied to *"For Instance" Case 1a(i).*

Changes in Feet of Lift

When this case is compared to the Baseline, it appears that improving efficiency has relatively little impact on lifts because total pumpage does not change much (see Table C-1, Appendix C).

Changes in Acres Reverting to Dryland

Steps taken to improve irrigation efficiency appear to have relatively small impact in reducing the number of acres reverting to dryland, when compared to the Baseline condition (see Table C-2, Appendix C).

Changes in Agricultural Production

Even though, overall, agricultural production would increase with improved efficiency, such an increase is not appreciable when compared to the Baseline condition (see Tables C-3 through C-8, Appendix C).

Returns to Land and Management

When compared to the Baseline and other management actions analyzed in this report, it was found that the highest annual returns to land and management occur for options which are aimed toward improving efficiency. These options lower costs without lowering production, thus improving net returns (see Table C-9, Appendix C).

Off-Farm Economic Impacts

Except for the dryland crop sector, output in other sectors of the Nebraska economy would increase, though slightly, with improved irrigation efficiency, as compared to the Baseline condition. Output in the dryland crop sector indicated a slight decline. See Table C-10, Appendix C.)

Summary

Economic analysis indicates that steps taken to improve irrigation efficiency will do little to extend aquifer life, but would appreciably improve the profitability of agriculture.

A more complete comparative analysis of this Action in conjunction with the Baseline condition and other alternative management actions is found in Appendix C.

SOCIAL IMPACTS

Social Impacts of Management Actions

Social impacts associated with each of the three groundwater management Actions identified for this Objective (Reduce irrigation water need by improving irrigation efficiency; reduce irrigation water needs by improving crop water use efficiency; and reduce irrigation water need through improved water conservation practices) are all very similar; therefore, they will be discussed collectively.

Attitudes/Political Issues -- Reductions in water use would probably be viewed favorably as long as water need restrictions were not so tight that shifts in cropping patterns would result. However, others might view moderate restrictions as not being strict enought to do much good.

Innovative irrigators may be very receptive to adopt water saving techniques. However, there will always be those who will resist changes in their present on-farm practices.

Economic Activity -- Irrigators should benefit from reduced irrigation water need, regardless of the size of the operation, through reduced energy costs. Irrigation scheduling, use of improved crop varieties, and other similar practices would be low-cost to adopt and would improve irrigation water use efficiency. However, if improved water conservation practices require large initial capital expenditures, such as with terrace construction or reuse pit installation, adoption of such practices may occur slowly and the stream of net benefits will be less than the reductions in pumping costs. However, state and

federal cost-assistance programs would allow irrigators to financially accommodate such practices.

Tax Base -- No major impacts have been identified.

Income Distribution/Equity -- The reduction of irrigation water need would be equitable to both large and small irrigation operations as long as the regulatory methods used take into account existing on-farm irrigation efficiency so that those irrigators that already are near peak efficiency would not be penalized. For example, a required ten percent increase in irrigation efficiency across the board could be unfair since it would be much more difficult and costly for an efficient irrigator to increase efficiency by ten percent than it would be for an inefficient irrigator.

Also, a ten percent increase in irrigation water use efficiency will have different results if the original level of efficiency was 150 percent of crop water need as opposed to 100 percent. Increasing efficiency from 150 percent to 140 percent (or lower) should increase irrigation profitability. Increasing irrigation water use efficiency from 100 percent of total crop water need to 90 percent (or lower) probably will reduce profits.

Farms would probably continue to increase in size at the current rate, which would effectively reduce the number of farms in the state.

Population -- No major impacts have been identified.

Health/Safety/Education -- No major impacts have been identified.

Quality of Life -- The existing lifestyle would probably be maintained for a longer period since aquifer life would be prolonged.

Social Impacts of Implementation Methods for Management Action 1

Implementation Method 1a -- Some irrigators are operating near peak irrigation efficiency levels with present technology such that additional improvements would be difficult. Nevertheless, individuals that are unaware of more efficient irrigation techniques may benefit from increased educational efforts. Some irrigators, however, may not be readily receptive to any new ideas for efficiency improvements.

Increased research, persuasion, and education may bring about several benefits. First, new water conservation techniques may be discovered more quickly if additional emphasis is placed on research. Second, demonstration projects and other educational efforts may foster changes in attitudes toward the resource; that is, that groundwater supplies are limited and water conservation may be in the best interests of everyone. Finally, increased persuasion to adopt water-saving practices could result in additional peer pressure on irrigators and might improve irrigation efficiency.

Implementation Method 1b -- Inequalities could result from this approach due to the significant differences in scale of operations of irrigated farms in the state. For example, a corporate farm in the Sandhills with 24 irrigation wells could benefit more than the irrigator in eastern Nebraska with one well if incentives were based on number of wells or acres irrigated. Cost sharing assistance may not be as beneficial to small-scale irrigators if they had difficulty in securing matching funds for potential grants.

Implementation Method 1c -- Requirements or regulations to adopt improved irrigation practices could be inequitable if current efficiency levels of individual irrigators are not taken into consideration. For example, irrigators who are currently operating at 85 percent of optimum irrigation system efficiency levels would have greater difficulty in improving their efficiency by 10 percent than those who are presently only at 50 percent efficiency. Also, across the board requirements would not take into account unique topographical or climatic differences which could affect present irrigation practices.

Social Impacts of Administration Methods

Various administrative methods could be used to carry out the management actions for meeting this objective. Control could originate from the local level, such as from county governments, or from the state level. State level control can lack responsiveness to unique local problems, while local control does not always consider statewide or regional consequences of potential policy. Therefore, an equitable approach may involve policy formulation at the state level with implementation occurring at the local level.

In addition, various public sector agencies are perceived differently: NRDs are perceived as potential regulators while the Extension Service is often considered strictly as an educational body. Response to suggested new irrigation techniques from these two sectors may be quite different.

LEGAL/INSTITUTIONAL/ADMINISTRATIVE IMPACTS

Management Action 1

Legal analysis of this action depends on how it is implemented (see Implementation Methods 1a, 1b, and 1c). Research and educational

programs to improve irrigation efficiency are currently implemented by federal, state and local entities. Cost sharing assistance to irrigators for improving irrigation efficiency could be implemented by grants from the Resources Development Fund. State income tax credits to improve irrigation efficiency would require new legislation. Irrigation efficiency requirements could be established in control areas designated to address water depletion or quality concerns, or possibly could be established by the Nebraska Department of Environmental Control (DEC) to prevent surface or groundwater pollution. Other actions to improve irrigation efficiency would require new legislation.

Implementation Method 1a -- Research and educational programs are currently being implemented cooperatively by the UNL Agricultural Experiment Station and Cooperative Extension Service, the USDA Agricultural Research Service, and NRDs. These programs are likely to be continued and could be expanded or accelerated through additional funding.

Legal analysis of *"For Instance" Case 1a (i)* finds that research and educational programs are currently being implemented cooperatively by the UNL Agricultural Experiment Station and Cooperative Extension Service, the USDA Agricultural Research Service, and NRDs. These programs are likely to be continued and could be expanded or accelerated through additional funding.

Implementation Method 1b -- NRD cost-sharing assistance for improved irrigation practice could be implemented through grants from the Resources Development Fund (RDF), although RDF grants have been made primarily for surface water reservoir construction. Expanded RDF funding, other cost share programs, or state income tax credits would require new legislation. Administration of this option should pose no particular difficulties.

Implementation Method 1c -- This could be implemented: (1) by NRDs in groundwater control areas; or (2) by DEC to protect water quality. Implementation beyond this would require new legislation.

Administration of this option could be difficult, requiring field level surveillance. Withdrawal limitations could indirectly trigger adoption of improved irrigated practices and be much easier to administer.

MANAGEMENT ACTION 2: Reduce Irrigation Water Need By Improving Crop Water Use Efficiency

Groundwater use for irrigation could be reduced by improving crop water use efficiency. This could be accomplished by developing crop varieties using less water, or by switching to crops requiring less water, such as grain sorghum or soybeans. This action could be implemented by encouraging or requiring irrigators to improve crop water use efficiency, but they are more likely to do so if they are persuaded that such action will be profitable.

Implementation Method 2a: Encourage irrigators to adopt practices improving crop water use efficiency *(e.g., improved crop varieties)* **through research, demonstration projects, and persuasion**

Irrigators can be encouraged to adopt practices improving crop water use efficiency through research, demonstration projects, and persuasion. They are not likely to respond to such efforts, however, unless they are persuaded that it will be profitable for them to do so. Existing programs of this nature, implemented by the Agricultural Experiment Station, Cooperative Extension Service, the USDA Agricultural Research Service and NRDs, could be accelerated by additional funding.

To facilitate impact analyses for this option, an illustrative example [hereinafter denoted as *"For Instance" Case 2a (i)]* might be an education and research program to reduce irrigation water needs by ten percent per unit yield through plant breeding and reduced tillage.

Another example is a combination of the above "For Instance" Case and *"For Instance" Case 1a (i)*, described on page 108. The resultant illustration is a program which is designed to improve **both** irrigation efficiency and crop water use efficiency through research, education, and voluntary action [hereinafter denoted as *"For Instance" Case 1a/2a].*

Implementation Method 2b: Encourage irrigators to adopt practices improving crop water use efficiency *(e.g., improved crop varieties)* **through cost sharing assistance or state income tax credits for the cost of such practices**

Financial incentives might increase the rate at which irrigators adopted irrigation scheduling techniques if the irrigators believed they would financially benefit from doing so. Cost sharing assistance programs could be administered by the Nebraska Natural Resources Commission and NRDs. Tax programs could be administered by the Nebraska Department of Revenue.

Implementation Method 2c: Require use of practices improving crop water use efficiency *(e.g., improved crop varieties)* **through legislative requirement or administrative regulation**

Irrigators could be required to adopt practices which improve crop water use efficiency, although monitoring such a program would be difficult. It is possible that a program of this nature might be implemented by NRDs in control areas.

IMPACT ASSESSMENT OF MANAGEMENT ACTION 2 AND ASSOCIATED IMPLEMENTATION METHODS

ENVIRONMENTAL IMPACTS

Groundwater Quantity

Primary impacts could be maintenance of areas of high water table, or reductions in rate or amount of decline. Wetlands, wet meadows and ET potentials (loss of ET salvage) could be affected.

Groundwater Quality

Reduced leaching of nitrates and other chemicals could accompany reduced use of water, subject to management of chemicals.

Surface Water Quantity

Effects will be related to reductions in the rate or amount of decline in areas of high water table and their relationship to streamflow, lake levels in Sandhills and impoundments. Reductions in runoff could also have an impact.

Surface Water Quality

Effects will be related to streamflow and changes in groundwater quality due to reductions in leaching and runoff resulting from reduced water application.

Soils

Reduced water erosion could result from reduced runoff as it is related to reductions in water use. No effect on wind erosion.

Vegetation and Wildlife Habitat

Impacts will be related to effects on wetlands, wet meadows, phreatophytes and other vegetation related to reductions in the rate or amount of decline in areas of high water table. Maintenance of wetland vegetation, hay crops and related species could be an effect of reduced water use. Changes in terrestrial vegetation and habitat could be related to any substitution of types or composition of crops, but probably not to improvements in present predominant species populations.

Recreation and Aesthetic Effects

Effects will be associated with changes in surface water quantity and quality and habitat.

An examination of *"For Instance" Case 2a (i)* reveals that environmental impacts related to water levels would appear to be slightly more pronounced, but still quite close to the baseline trend, thus suggesting continued impacts on streamflow, many wetlands, and high water table areas. Reduced leaching of nitrates due to reductions in water use and reduced erosion due to tillage reduction could be the most significant effects. These would be related to possible increases in herbicide use and possibly insecticide use, and reductions in late summer streamflow related to reduced runoff in certain areas. Habitat improvements could be related to presence of crop residues. Large scale changes in habitat (from the baseline) are not likely--depending on the management of dryland acres.

Environmental impacts identified for *"For Instance"* Case 1a/2a indicate a continued trend of sustained use of resources illustrated in small improvements in average lift (except in Region V) and the largest corn acreage of any action (statewide, but reflecting particularly Regions IV, and V). Hence there would be slight moderation of baseline trends related to groundwater levels and maintenance of wetlands, wet meadows and streamflow. Reductions in erosion and leaching of nitrates could be continued impacts, at a level proportional to reductions in water use and other management variables. Streamflow could be affected by reductions in runoff.

TECHNOLOGICAL IMPACTS

Improved crop water use efficiency can be achieved through the discovery and use of improved crop varieties or by switching to crops using less water. As discussed earlier, crop yields are expected to continue to improve in the future. In fact, many feel that increased levels of research could result in substantial improvements in future crop yields.[4] Improved yields would be very significant if water allocation programs were implemented. For example, if water allocations were cut back to 90 percent of full crop requirements, yield reductions due to crop stressing could create less economic hardship if crop yield averages had improved over current averages due to improved crop varieties. However, people generally desire the most from new technology

(the potential production of that technology rather than the previous possibilities). Therefore, new hybrid yields become the accepted standard, and reduced yields due to smaller water allocations may be socially and economically unacceptable to the irrigator.

ECONOMIC IMPACTS

To analyze the economic effects of this Action, the RLP Model was applied for "For Instance" Cases 2a(i) and 1a/2a.

Changes in Feet of Lift

When these cases are compared to the Baseline, it appears that improving efficiency has relatively little impact on lifts because total pumpage does not change much. (See Table C-1, Appendix C).

Changes in Acres Reverting to Dryland

Steps taken to improve crop water use efficiency appear to have relatively small impact in reducing the number of acres reverting to dryland, when compared to the Baseline condition. However, in some instances, when both irrigation efficiency and crop water use efficiency are used in tandem, more appreciable retention of irrigated lands may result, even though significant reversion to dryland is still projected to occur. (See Table C-2, Appendix C.)

Changes in Agricultural Production

Even though, overall, agricultural production would increase with improved crop water use efficiency, such an increase is not appreciable when compared to the Baseline condition. However, when both crop water use efficiency and irrigation efficiency are applied, agricultural production may actually improve to an appreciable extent. As shown in Table C-3 through C-8, Appendix C, increases in production are noticeable for the years 2000 and 2020, when compared to the Baseline.

Returns to Land and Management

When compared to the Baseline and other management actions analyzed in this report, it was found that the highest annual returns to land and management occur for options which are aimed toward improving efficiency. In fact, a combination of both irrigation efficiency and crop water use efficiency yields the highest values overall. Efficiency options lower costs without lowering production, thus improving net returns. (See Table C-9, Appendix C.)

Off-Farm Economic Impacts

Except for the dryland crop sector, output in other sectors of the Nebraska economy would increase, though slightly, with improved crop water use efficiency as compared to the Baseline condition. Output in the dryland crop sector indicated a slight decline.

When improved irrigation efficiency and improved crop water use efficiency are used in tandem, increases in output for non-dryland crop sectors are more appreciable than if either of these options were used alone. However, output in the dryland crop sector would show a similar magnitude in decline. (See Table C-10, Appendix C.)

Summary

As concluded in the assessment of Action 1, economic analysis indicates that steps taken to improve crop water use efficiency (with or without an associated improvement in irrigation efficiency) will do little to extend aquifer life, but would appreciably improve the profitability of agriculture.

A more complete comparative analysis of this Action in conjunction with the Baseline condition and other alternative management actions is found in Appendix C.

SOCIAL IMPACTS

Same as those associated with Management Action 1 (Improved Irrigation Efficiency) and associated Implementation Methods 1a, 1b, and 1c, above.

LEGAL/INSTITUTIONAL/ADMINISTRATIVE IMPACTS

Management Action 2

Legal analysis of this action depends on how it is implemented (see Implementation Methods 2a, 2b, and 2c). Research and education programs to improve crop water use efficiency are currently implemented by federal, state, and local entities. Cost sharing assistance to irrigators for improving crop water use efficiency possibly may be available from the Resources Development Fund. State income tax credits to irrigators for improving crop water use efficiency would require new legislation. Crop water use efficiency requirements possibly could be required in control areas designated to address water depletion concerns. Other options to improve irrigation efficiency would require new legislation.

Implementation Method 2a -- Legal analysis of this Method and *"For Instance" Cases 1a(i)* and *1a/2a* indicates that research and educational programs are currently being implemented cooperatively by the UNL Agricultural Experiment Station and Cooperative Extension Service, the USDA Agricultural Research Service, and NRDs. These programs are likely to be continued and could be expanded or accelerated through additional funding.

Implementation Method 2b -- Implementation of this method would require new legislation. Administration of this method could be difficult, requiring field level surveillance.

Implementation Method 2c -- Implementation of this method probably would require new legislation, although there is a small chance that this could be implemented by NRDs in control areas.

Administration of this method would be difficult, requiring field level surveillance. Withdrawal limitations could directly trigger crop water use efficiency improvement and be much easier to administer.

MANAGEMENT ACTION 3: Reduce irrigation water need through improved water conservation practices *(conservation tillage, etc.)*

Groundwater use for irrigation could be reduced by improving the utilization of natural precipitation and irrigation water. Storage of water in the soil profile could be increased by a number of on-farm conservation practices. Residue management, minimum or conservation tillage, and basin tillage are all methods that have been shown to be effective in conserving soil moisture, thereby making it available to crops. In addition, some of these practices may also increase recharge to the aquifer.

Implementation Method 3a: Encourage irrigators to adopt water conservation practices *(e.g., conservation tillage)* **through research, demonstration projects, and persuasion**

Irrigators could be encouraged to improve on-farm water conservation practices through research, demonstration projects, and persuasion. Irrigators are unlikely to adopt such practices, however, unless they are persuaded that such actions would be profitable.

Implementation Method 3b: Encourage irrigators to adopt water conservation practices *(e.g., conservation tillage)* **through cost sharing assistance or state income tax credits for the cost of such practices**

Irrigators could be encouraged to adopt on-farm water conservation practices by providing cost sharing or by providing state income tax credits for such practices. This might provide the additional incentives needed to increase the adoption of on-farm water conservation practices.

Implementation Method 3c: Require irrigators to use water conservation practices *(e.g., conservation tillage)* **through legislative requirement or administrative regulation**

Irrigators could be required to adopt water conservation practices, although monitoring such a program (e.g., by NRDs or DEC) would be difficult. The DEC probably could establish water conservation requirements to protect water quality.

IMPACT ASSESSMENT OF MANAGEMENT ACTION 3 AND ASSOCIATED IMPLEMENTATION METHODS

ENVIRONMENTAL IMPACTS

Groundwater Quantity

Moderate effects in terms of reduction in the rate or amount of decline in groundwater levels could have effects on the maintenance of wetlands, wet meadows and other areas. ET potentials for crops would be affected in these areas.

Groundwater Quality

Significant impacts could result from the increased requirements for herbicides and possibly pesticides which are related to conservation tillage.[5] Reduced use of water could reduce the leaching of nitrates and possibly other chemicals.

Surface Water Quantity

This factor will be influenced by reductions in water use which may effect reduced rates or amounts of decline in areas of high water tables leading, in turn, to similar effects on streamflows in some areas. Additionally, increased infiltration due to remaining crop residues should reduce runoff and reduce streamflow and possibly lake levels which depend on overland flow of water. This would be more of a factor in areas outside the Sandhills.

Surface Water Quality

Reduced erosion, in those areas without excessively well drained (sandy) soils, should lead

to reductions in sedimentation and transport of other pollutants by runoff. Increased use of chemicals could still lead to increased concentrations in surface water supplies, depending on amount of runoff, amount of leaching into groundwater supplies and ground and surface water inter-relationships. Changes in streamflow have varying associations with water quality indicators. Where streamflows undergo a reduction in their rate or amount of decline, some water quality parameters may show improvement. Additionally reduced flows will lead to improvements, possibly, in those parameters which are related to runoff, given the above noted association between low flow and reduced runoff.

Soils

Impacts on soil erosion from conservation tillage and other water management practices can lead to reduced wind and water erosion in many situations, dependent on soil type and slope. Improvements in soil moisture will also result.

Vegetation and Wildlife Habitat

Increased cover and food due to presence of crop residues may improve habitat for upland species which can adapt to an agricultural environment such as pheasants or small mammals.

Other practices of rotation, etc., could have additional effects of improved habitat for various types of birds and small mammals. Impacts associated with reduced water use will be similar to other alternatives--possible maintenance of vegetation and habitat which are dependent on groundwater levels, particularly in areas of high water table.

Recreation and Aesthetics

These factors will depend on improvement in surface water quality and the maintenance of vegetation and wildlife habitat.

TECHNOLOGICAL IMPACTS

As mentioned in the technological impact analysis of the baseline scenario, over 40 percent of the state's cropland in 1980 was farmed with conservation tillage practices. Since up to one to two inches of irrigation water per season can be saved with these techniques, in addition to fuel savings and erosion control, it is expected that more irrigators will utilize these techniques. Continued research and education programs will aid in achieving even greater utilization of conservation tillage. Financial incentives would also increase the adoption of these techniques.

ECONOMIC IMPACTS

Even though no "For Instance" Cases were formulated in conjunction with this particular Action, it is estimated that the resultant economic impacts would be similar to those Actions promoting efficiency (Actions 1 and 2). Conservation practices may have a minor beneficial impact on extending the water supply, but the amount of lift required to utilize the groundwater will still increase over time. It is also anticipated that a significant amount of lands will be converted from irrigation to dryland.

Agricultural production, however, might increase, but not appreciably when compared to the Baseline. Returns to land and management might also increase, as conservation techniques may actually lower costs without reducing production, thus potentially improving net returns.

It is also anticipated that output in most other sectors of the Nebraska economy would increase slightly as compared to the Baseline condition. Output in the dryland crop sector may experience a slight decline.

In summary, steps taken to improve conservation practices may not appreciably extend the life of the aquifer, but might noticeably improve the profitability of agriculture.

SOCIAL IMPACTS

Same as those associated with Management Action 1 (Reduced Irrigation Water Need) and associated Implementation Methods 1a, 1b, and 1c, above.

LEGAL/INSTITUTIONAL/ADMINISTRATIVE IMPACTS

Management Action 3

Legal analysis of this Action depends on how it is implemented (see Implementation Methods 3a, 3b, and 3c). Research and educational programs to improve on-farm water conservation are currently implemented by federal, state and local entities. Cost sharing assistance to irrigators to improve on-farm water conservation is available from federal, state and local entities. State income tax credits to improve on-farm water conservation would require new legislation, as would regulations and other options to increase on-farm water conservation.

Implementation Method 3a -- Research and educational programs are currently being implemented cooperatively by the UNL Agricultural Experiment Station and Cooperative Extension Service, the USDA Agricultural Research Service, and NRDs. These programs are likely to be continued and could be expanded or accelerated through additional funding.

Implementation Method 3b -- Cost-sharing assistance provided by NRDs for irrigation water conservation practices could be implemented, e.g., through grants from the Resources Development Fund, although RDF has not been used for this purpose. Expanded RDF funding, other cost share programs, or state income tax credits would require new legislation. Administration of this option should pose no particular difficulties.

Implementation Method 3c -- Current law prohibits improper runoff from groundwater irrigation statewide. Runoff requirements are administered on a complaint (case by case) basis by NRDs. The typical irrigator response to irrigation runoff controls is installation of irrigation water reuse pits. The NRDs could step up enforcement runoff controls but this would require a greater allocation of NRD funds and staff to this program. The DEC probably could establish water conservation requirements to protect water quality. Beyond this, additional efforts would require new legislation, such as requiring all irrigators to install reuse pits, etc.

Administration of this option could be difficult unless substantial penalties for noncompliance were authorized.

MANAGEMENT OBJECTIVE II: REDUCE FUTURE GROUNDWATER DEVELOPMENT

Another objective identified by the work group for stabilizing or reducing future groundwater use while maintaining current production levels on irrigated land is to reduce the number of additional acres developed for irrigation in the future. In some cases, developers may be persuaded to reduce or delay development voluntarily, and in other cases, reductions may have to be mandatory.

The major issue is whether groundwater development (i.e., well drilling) should be limited in the future either: (1) to protect existing groundwater users; or (2) to prevent or reduce adverse environmental consequences associated with groundwater use, irrigation, or both. Groundwater development can be limited through education, through financial incentives, or by a variety of regulations. These approaches can be varied by management objectives and criteria.

Two reasons for reducing groundwater development are: (1) to avoid violating groundwater supply objectives [e.g., exceeding a local, regional (substate), or statewide depletion factor (including zero depletion)]; and (2) to avoid violating geographical or environmental objectives (e.g., causing water pollution, soil erosion, streamflow reduction, or wetland reductions).

Various types of actions could be taken to achieve Objective II, including those delaying development in certain areas to later years, and those that preclude development of an area, or type of areas, forever.

Aquifer life can be extended by reducing the rate of groundwater mining, and the growth of that rate can be slowed by reducing the number of acres developed each year. A ceiling could be placed on the number of acres that could be developed in a given area every year, and developers could be prohibited from irrigating more, or they could be paid for not irrigating in that year.

Not developing some areas for irrigation could serve two purposes; to reduce the rate of groundwater mining; and to meet geographical or environmental objectives, e.g., reducing water pollution, soil erosion, streamflow reduction, or wetland reduction. Permanently preventing the use of land for certain purposes can be accomplished by many means, including outright purchase, purchase of easements, zoning, permit requirements, and others.

Restricting groundwater development has substantial distributional or equity impacts. Those who have not drilled wells are precluded from doing so and thus are prevented from realizing the private economic benefits of irrigation. Those who have drilled wells and caused groundwater supply problems are protected.

To follow is a discussion of each management action and associated option formulated by the work group to meet this Objective, accompanied by an analysis of impacts according to impact parameters identified previously.

MANAGEMENT ACTION 4: Reduce groundwater development based on water supply criteria

Groundwater depletion rates are the best example of a groundwater supply constraint. The depletion rate could range from no depletion to, e.g., 10 percent annaul depletion. Depletion rates may be expressed in terms of the life of the groundwater supply -- a 100 year life would suggest a depletion rate of up to one percent per year, etc.

Depletion rates could be local (e.g., within three miles of a proposed well site), regional (e.g., within all or part of an NRD) or statewide.

Implementation Method 4a: Encourage irrigators through research, demonstration projects, and persuasion not to develop irrigation wells which would violate groundwater supply criteria *(e.g., depletion rates)*

Landowners might be persuaded by educational programs not to develop wells that would violate: (1) groundwater supply constraints; or (2) geographical/environmental constraints (both are discussed below). Educational programs will likely fail, however, if landowners believe that groundwater development would result in economic gain.

Implementation Method 4b: Encourage irrigators through financial incentives or disincentives not to develop irrigation wells which would violate groundwater supply criteria *(e.g., depletion rates)*

Irrigators can be encouraged not to develop wells which would violate groundwater supply criteria through financial incentives or disincentives, some of which are described in Implementation Options 4b (i) and 4b (ii), below. Financial incentives might increase the rate at which irrigators adopted these options if the irrigators believed they would financially benefit from doing so.

Implementation Option 4b(i): Purchase groundwater development rights which, if exercised, would violate groundwater supply criteria *(e.g., depletion rates)*

Where owners of land overlying groundwater supplies have not yet developed high capacity wells, their groundwater development rights could be purchased and retired. This means that high capacity wells could not be developed on the land for which the development rights had been sold.

An advantage of this approach is that landowners selling their groundwater development rights are compensated for not developing high capacity wells. This approach arguably is more equitable in that landowners who have not developed wells are not economically disadvantaged relative to groundwater users. Purchasing groundwater development rights could be expensive, however.

Implementation Option 4b(ii): Discourage groundwater development *(e.g., well drilling)* **violating groundwater supply constraints** *(e.g., depletion rates)* **by increasing the cost of development through taxing authorities**

Groundwater development could be discouraged or prohibited by taxing groundwater development. This could be accomplished by taxing new wells, newly irrigated land and/or new irrigation equipment. The rate of tax would need to be fairly high to effectively reduce groundwater development.

Implementation Method 4c: Require irrigators to reduce groundwater development based on water supply criteria through legislative requirements or administrative regulation

Irrigators could be restricted from developing through regulatory methods through controls implemented at the NRD level. Two such controls are outlined in Implementation Options 4c(i) and 4c(ii), below.

Implementation Option 4c(i): Prohibit or limit groundwater development *(well drilling)* **that would violate groundwater supply criteria** *(e.g., depletion rates)*

Groundwater development violating: (1) groundwater supply constraints; or (2) geographical/environmental constraints (discussed below) could be prohibited by well drilling restrictions. Groundwater development restrictions can be either well spacing regulations or well drilling prohibition.

A major impact of groundwater development limitations is that landowners who could otherwise drill wells and enjoy the economic benefits of groundwater use are prevented from doing so. Those who have created the groundwater mining situation are in effect rewarded for their efforts while those who have not contributed to the problem are penalized through development restrictions. To the extent this is perceived as being unfair, development restrictions can be coupled with purchase of development rights, in effect compensating landowners for the loss of their development rights.

An illustrative example of this Option is an imposition of a statewide well drilling moratorium, effective in 1985 thereinafter cited as *"For Instance" Case 4c(i) (a) 1.*

Implementation Option 4c(ii): Prohibit or limit groundwater development *(well drilling)* **that violated groundwater supply criteria** *(e.g., depletion rates)* **but compensate landowners for the loss of their groundwater development rights**

This is similar to Implementation Option 4c(i), except that owners would be compensated for the loss in the value of their groundwater rights due to regulations denying the use of those rights.

IMPACTS ASSESSMENT OF MANAGEMENT ACTION 4 AND ASSOCIATED IMPLEMENTATION METHODS AND OPTIONS

ENVIRONMENTAL IMPACTS

Groundwater Quantity

The most significant impacts would be in terms of the maintenance of supply as affected by reductions in the intensity of development. This would lead in general to reductions in the rate of decline of areas of high water tables leading to maintenance of wetlands, wet meadows and changes in other factors.

Groundwater Quality

As the development of groundwater is reduced in aggregate, leaching of chemicals could be reduced, but this will depend on soil type, water management by individuals and other factors.

Surface Water Quantity

Streamflow and lake level conditions should improve as a result of reduced groundwater development, particularly with respect to maintenance of areas of high water table.

Surface Water Quality

As related to improved flow, or at least reductions in the rate or amount of decline, surface water quality parameters should show some improvement.

Soils

As related to reduced development or less intense development, reduced soil erosion rates could be expected, depending on management and types of areas under development. Runoff should be reduced in rate of increase. Total wind erosion rates could be diminished as well, although there may not be any significant improvement at a given location.

Vegetation and Wildlife Habitat

Reductions in the extent of groundwater development could have impacts on aquatic vegetation and habitat related to areas of maintained high water tables, or at least reductions in rates of decline. Riparian and stream habitat, as well as wetland and aquatic habitat, could be affected. Terrestrial vegetation and habitat conditions could be improved due to reduced development in terms of the composition and diversity of crops, maintenance of grasslands, windbreaks and native vegetation and reduced intensity of agriculture.

Recreation and Aesthetics

These factors will depend on improvements in the conditions of surface water quantity and quality, vegetation and wildlife habitat.

An examination of environmental impacts associated with *"For Instance" Case 4c(i) (a)* indicates that hydrologic effects, reflected in average lift, would be significant with respect to the baseline and would suggest more significant prolonged life of resources related to areas of high water table such as wetlands, wet meadows, streamflow and related vegetation and habitat. Reduced rates of increase in corn production which are well below the baseline and all other management actions could affect reduced leaching of nitrates and subsequent improving trends in groundwater quality and to some extent in surface water quality -- also reflecting reduced rates of streamflow decline, but these could be offset by concentrated water use in vulnerable areas. Reduced rates of acreage reverting to dryland and reduced crop production suggest the maintenance of substantial acreages of grassland thus maintaining habitat for those species, such as upland game birds and small mammals able to coexist with agriculture. Reductions in wind and water erosion are likely due to the reduced rates of development of new land, some of which would be in the Sandhills, but other acreages in other areas would probably reflect the continued absence of development in less suitable areas (steep slopes, erodable or poorly drained soils). Predicted changes in Sandhills wetlands and lakes would be substantially modified by this case.

TECHNOLOGICAL IMPACTS

The technological impacts under this Action would probably be similar to those of the baseline condition. No new incentives would exist to improve irrigation water use efficiency. Irrigators

would probably continue to adopt new irrigation practices, which reduce erosion, cost, etc., at the current rate.

ECONOMIC IMPACTS

To analyze the effects of this Action, the RLP Model was applied to *"For Instance" Case 4c(i)(a).* This case would preclude any new irrigation development after 1984. Old wells could be replaced, but no new land could be brought into production. It is assumed for purposes of empirical evaluation that the case is implemented in a manner which does not lead to accelerated development prior to 1985.

Changes in Feet of Lift

Implementation of this particular case would noticeably extend aquifer life. For example, if new well drilling were prohibited in 1985, the projected increase in the average feet of lift from 1985 to 2021 in many areas of the state (e.g., Region II and V) would be about **one-half** of that projected under the Baseline condition for the same period (see Table C-1, Appendix C).

Changes in Areas Reverting to Dryland

If well drilling were prohibited in 1985, the amount of irrigated acreage reverting to dryland because of aquifer exhaustion is anticipated to be considerably less than under the Baseline condition in some areas of the state. For example, in Region III, projected reversion resulting from a drilling prohibition is only 33 percent of that expected under the Baseline Condition during the years 1977 to 2020. (See Table C-2, Appendix C). This is a consequence of the extended lift of the aquifer which is projected to occur under this case.

Changes in Agricultural Production

When compared to the Baseline, a well drilling prohibition is anticipated to result in a noticeable increase in output of grain sorghum and wheat. Slight decreases are projected to occur in the production of soybeans and alfalfa; however, corn production is expected to decrease by about 47 percent by 2020 if the well drilling prohibition were instituted in 1985. (See Tables C-3 through C-8, Appendix C.)

Returns to Land and Management

All regions of the state are projected to experience smaller returns to land and management under this case as compared to the Baseline. However, the differences are less than might be expected, since fewer irrigated acres would revert back to dryland production under this option than under the Baseline condition. Since irrigated acres have higher RTLM/Acre, total RTLM are affected less than expected. In fact, it is anticipated that within a decade or two beyond 2020, RTLM from this and other restrictive options would be higher than the Baseline condition, if the well drilling prohibition were implemented in 1985. (See Table C-9, Appendix C.)

Off-Farm Economic Impacts

As expected, output in the dryland crop sector is projected to show a significant increase by 2020 when compared to the Baseline, with a significant decrease anticipated to occur in the irrigated crops sector. Outputs in other sectors of the Nebraska economy are expected to experience declines, relative to the Baseline. (See Table C-10, Appendix C).

Summary

This regulatory option is expected to extend aquifer life substantially, but total crop production is projected to be reduced below the Baseline condition in the future. However, improvements in agricultural production, relative to the baseline case, would probably occur in problem areas within one or two decades after 2020.

A more complete comparative analysis of this Action in conjunction with the Baseline condition and other alternative management actions is found in Appendix C.

SOCIAL IMPACTS

Social Impacts of Management Actions

Since the social impacts of the two Actions identified for this Objective (Reduce groundwater development based on groundwater supply criteria; and Reduce groundwater development based on geographical/environmental criteria) are very similar, both are addressed in the context of the overall Objective.

Attitudes/Political Issues -- In areas of rapid drawdown or severe depletion, landowners seek to capture a share of the remaining groundwater and reap economic returns "before someone else uses up all the water". In doing so, they accelerate the rate of withdrawal and hasten the arrival of the time when irrigation becomes infeasible. The typical pattern is "boom and bust" as everyone tries to get a part of the economic returns (the boom), and in doing so ensures that "the bust" will soon arrive.

If development restrictions are imposed, residents may perceive that irrigation activity (and hence economic activity) in the area has "peaked" and that the viability of the region may slowly deteriorate. Intense political pressure may be exerted to remove the restrictions and to replace them with a more equitable solutions to solve the groundwater overdraft problem of the area.

Economic Activity -- Economic activity related to irrigation would be affected if development restrictions were used as management techniques. The degree of economic impacts would depend upon the number of acres of land prohibited from being developed for irrigation. If significant amounts of land were involved, economic impacts would occur in the form of lost "potential" revenues. Irrigation system dealers would experience declines in sales, and other commercial sectors thay may have expanded operations in preparation for future irrigation development might suffer losses, especially if the restrictions were imposed with little or no warning. In effect, the economic "boom" associated with irrigation would level off.

Tax Base -- To the extent that the value of irrigation potential is reflected in the price of land, land values will be affected by the imposition of development restrictions. Land with irrigation could be expected to increase in price. Land where development is barred could be expected to decrease in price. Tax revenues may decline in areas where land is potentially irrigable but is prevented from being developed if mill levies are not adjusted to compensate for decreased land values. The length of time which local governments have to prepare for reduced tax revenues would be a very important aspect of planning for future public expenditures.

In areas where groundwater is being depleted rapidly, development restrictions could be used as a means of preventing the loss of private and public capital investment. The extent of the community infrastructure such as raods, schools, and other public facilities may reflect a level of economic activity and a population size that cannot be sustained if groundwater supplies are depleted. If this happens, substantial losses of public investment will result.

Income Distribution/Equity -- As previously mentioned, land with existing irrigation systems probably would increase in value in the event of development restrictions. Non-irrigated land would decrease in value. Distribution of wealth could become more concentrated through the use of well drilling restrictions.

It has been argued by some that all landowners should have equal access to water resources below their land. Development restrictions could prevent those who have chosen to delay development from having access to the water resources beneath their land. To the extent that wells and irrigation systems are installed to "beat" the restrictions, the possibility of restrictions may speed development and the rate of depletion of water supplies. It is viewed as unfair to "force" a landowner to develop irrigation at a certain time if he is to develop at all.

Farm Size/Numbers -- Restrictions on irrigation development probably would slow the expansion of irrigated farming operations greatly. However, as dryland farmers attempt to specialize crop production to maximize profits, other nearby dryland operations might be willing to sell. This would lead to add-ons which would eventually increase the size of dryland farming operations in an area.

Population -- Dislocation of irrigation-related businesses could result in net population decline. Potential businesses might hesitate to relocate in an area with well drilling or other development restrictions, thereby curtailing potential population increases.

Health/Safety/Education -- Development restrictions based on geographical or environmental criteria could have beneficial affects on water quality.

Quality of Life -- The existing quality of life might be maintained for a longer period of time since aquifer life would be prolonged. However, the suppressed economic growth associated with development restrictions or a moritorium might lead to altered lifestyles that reflect the curtailment of an area's "boom" period.

Social Impacts of Implementation Methods and Options

Implementation Method 4a -- It may be difficult to discourage irrigators, both large and small-scale, from developing irrigation capabilities if profits could be realized from such development. If it can be shown that irrigation development would adversely affect economic returns from other aspects of the operation, such as increased erosion or loss of the irrigator's wet meadows, development may be forestalled. However, if the non-aggregate consequences of irrigation development are minimal such that the negative impacts associated with an individual well are indiscernible, development may not be prevented.

A. **Implementation Option 4b(i)** -- The purchase of groundwater development rights would be equitable to farmers who have not developed irrigation capabilities on their farms. Where a moratorium would prevent non-irri-

gators from drilling a well thereby preventing them from sharing in economic gains from irrigation development, the option to sell development rights would allow a non-irrigator to obtain economic benefits without drilling a well.

This technique, however, could be a serious barrier to young farmers trying to gain access into irrigated agriculture. Equipment and land costs alone are difficult obstacles to overcome, but water pricing would pose additional economic barriers.

B. **Implementation Option 4b(ii)** -- If taxation of irrigation development was utilized, land which would not produce favorable economic returns might not be developed. For example, if the potential crop value of an irrigable area of land did not exceed its tax liability, it is doubtful if an irrigator would install a well. However, if potential crop values and tax deferment benefits from an irrigable area exceed the taxes required, it is likely that a well or wells would be drilled. Taxation policies may be very unpopular with farmers as a method of restricting development.

C. **Implementation Option 4c(i)** -- Well drilling restrictions could be unfair since those who did not contribute to groundwater decline are prevented from capturing the benefits associated with irrigation. Those who did contribute to groundwater decline are allowed to continue to irrigate.

D. **Implementation Option 4c(ii)** -- Economic growth might be reduced with this technique, but non-irrigators would be allowed to obtain economic benefits without drilling a well. This technique, however, could be a serious barrier to young farmers trying to gain access into irrigated agriculture.

Social Impacts of Administration Methods

Policy decisions at the local level may neglect to consider statewide or regional consequences. Implementation at the state level may be unresponsive to unique geographical situations in various areas of the state. Also, out-state residents may be unreceptive to accepting regulations formulated in "Lincoln" rather than in their own local area. Irrigators may, in effect, feel that they have had "their" water taken away from them if regulation occurs at the state level.

LEGAL/INSTITUTIONAL/ADMINISTRATIVE IMPACTS

Management Action 4

Legal analysis of this action depends on how it is implemented (see appropriate implementation methods and options). Research and educational programs regarding whether to develop irrigation are currently provided by UNL. Purchase of development rights possibly could be implemented: (1) in groundwater control areas established to address water depletion; or (2) through Resources Development Fund grants. Groundwater development restrictions could be implemented in control areas established to address water depletion concerns, as could compensated development restrictions. Discourageing development through taxing authorities is subject to considerable legal uncertainty. Other options to restrict irrigation development would require new legislation.

Implementation Method 4a -- Research and educational programs are currently being implemented cooperatively by the UNL Agricultural Experiment Station and Cooperative Extension Service, the USDA Agricultural Research Service, and NRDs. These programs are likely to be continued and could be expanded or accelerated through additional funding.

The effectiveness of this option is uncertain. Persuading landowners to sacrifice the private economic benefit of irrigation development for the general welfare will be difficult.

A. **Implementation Option 4b(i)** -- Implementation of this option probably would require new legislation, although it possibly could be implemented by NRDs in control areas or through Resources Development Fund grants. Administration would pose no particular difficulty if adequate funding were available.

B. **Implementation Option 4b(ii)** -- Implementation of this option would require new legislation. Such legislation could violate state and federal constitutions if it invalidly discriminated between categories of landowners, e.g., current irrigators and future landowners.

If a constitutional statute were enacted, administration would pose no particular difficulty if adequate enforcement authorities were granted (i.e., substantial penalties for violation).

Implementation Method 4c --

A. **Implementation Option 4c(i)** -- This can be implemented by NRDs in groundwater control areas established to deal with water depletion. Broader implementation of this option would require new legislation. Administration would pose no particular difficulties (aside from local political concerns), if adequate enforcement authorities were granted (i.e., substantial penalties for violations).

Legal analysis of **"For Instance" Case 4c(i) (a)** concludes that new legislation would be required to implement it. Well drilling can be prohibited for one year periods in control areas under current law, however.

B. **Implementaiton Option 4c(ii)** -- This option probably could be implemented by NRDs in groundwater control areas established to deal with water depletion. Broader implementation of this option would require new legislation. Administration of this option would pose no particular difficulty if adequate funding were available.

MANAGEMENT ACTION 5: Reduce groundwater development based on geographic/environmental criteria

These are constraints calculated to reduce or prevent adverse environmental impacts, such as streamflow reduction, wetland loss, soil erosion, or groundwater pollution.

Implementation Method 5a: Encourage irrigators through research, demonstration projects, and persuasion not to develop irrigation wells that would violate geographic/environmental criteria *(e.g., nitrate pollution, soil erosion, reduced streamflows)*

Irrigators can be encouraged not to develop irrigation wells that would violate geographic/environmental criteria. This could be accomplished through the expansion of existing programs administered by the UNL Agricultural Experiment Station, Cooperative Extension Service, the USDA Agricultural Research Service or NRDs.

Implementation Method 5b: Encourage irrigators through financial incentives or disincentives not to develop irrigation wells that would violate geographic/environmental criteria

Groundwater development violating geographic/environmental criteria could be discouraged through outright purchase of well-drilling rights and through taxation mechanisma, as described in Implementation Options 5b(i) and 5b(ii), below.

> **Implementation Option 5b(i): Purchase groundwater development** *(well drilling)* **rights which, if exercised, would violate geographic/environmental criteria** *(e.g., nitrate pollution, woil erosion, reduced streamflows)*

Groundwater development rights could be purchased by state agencies (such as DEC and the Game and Parks Commission) and by NRDs to: (1) mitigate groundwater quality degradation caused by aquifer dewatering; (2) prevent soil erosion; and (3) protect wildlife habitat.

> **Implementation Option 5b(ii): Discourage groundwater development** *(well drilling)* **violating geographic/environmental constraints** *(e.g., nitrate pollution, soil erosion, reduced streamflows)* **by increasing the cost of development through taxing authorities**

Taxes could be levied (by NRDs, for example) on landowners as a disincentive for irrigation development in areas where considerable nitrate pollution, soil erosion and streamflow reduction are likely to occur.

Implementation Method 5c: Require irrigators through legislative requirements or administrative regulation not to develop irrigation wells that would violate geographic/environmental criteria

Development of irrigation wells could be restricted through prohibiting or limiting development with or without compensation, or by requiring irrigators to meet certain performance standards prior to development. These are described further in Implementation Options 5c(i), 5c(ii) and 5C(iii), below.

> **Implementation Option 5c(i): Prohibit or limit groundwater development** *(well drilling)* **that would violate geographic/environmental constraints** *(e.g., nitrate pollution, soil erosion, reduced streamflows)*

The DEC probably could restrict groundwater development to protect environmental values. Counties or NRDs could restrict groundwater development to prevent soil erosion through land use regulations.

An illustrative example of this Option is one which restricts new development to 50 percent of the unconstrained rate through programs which preclude development on fragile lands, e.g., steep slopes, erodable soils [hereinafter cited as *"For Instance" Case 5c(i) (a)].*

> **Implementation Option 5c(ii): Prohibit or limit groundwater development** *(well drilling)* **that would violate geographic/environmental constraints** *(e.g., nitrate pollution, soil erosion, reduced streamflow,* **but compensate landowners for the loss of development rights**

This is similar to Implementation Option 5c(i), except that landowners would be compensated for the loss in value of their groundwater rights due to regulations denying the use of those rights.

Implementation Option 5c(iii): Condition groundwater development *(well drilling)* **on meeting performance standards regarding geographic/environmental constraints** *(e.g., nitrate pollution, soil erosion, reduced streamflows)*

Groundwater development could be conditioned on meeting performance standards regarding, e.g., surface or groundwater depletion rates, soil erosion rates, or groundwater pollution rates. For example, an irrigator could be permitted to irrigate sandy soils with steep slopes only as long as erosion did not exceed 10 tons/acre annually. If the rate were exceeded, the irrigator could be required to stop irrigating, be given a certain time within which to meet the standards, or forfeit a performance bond.

IMPACT ASSESSMENT OF MANAGEMENT ACTION 5 AND ASSOCIATED IMPLEMENTATION METHODS AND OPTIONS

ENVIRONMENTAL IMPACTS

Groundwater Quantity

Where an environmental or geographic standard is applied, it is possible that rates of decline would be diminished. This could particularly be true if criteria were focused on restricting development in: areas with high water tables, such as the Sandhills, thus affecting wetlands; areas of coarse soils and high water tables such as Merrick County, or large areas of the state. Restrictions which are very selectively based on slope, soil type, or vegetation might not lead to aggregate changes in groundwater levels by major sub areas of that state or for the state as a whole. Restrictions related to streamflow as well as high water tables would likely lead to reduced rates of decline within certain areas.

Groundwater Quality

Criteria related to slope may not greatly reduce leaching of nitrates in sandy soils in that infiltration may not be significantly reduced when compared to more level land.[6] In areas of fine-grained soils, development restrictions based on slope could lead to reduced infiltration and leaching and reduced erosion. Erosion and downward migration of nitrates are greatest in areas of hilly loess and sandy ridges.

Criteria related to high water tables and soil type would appear to lead to reduction in nitrate leaching. In order to have the desired effect of environmental restrictions, it appears that soil type, slope and water levels need to be considered together. Management practices are a critical factor as well.

Surface Water Quantity

Criteria related to impact on streamflow and areas of high water table will, subject to the hydrology of specific areas, affect the rate of decline of streamflow, lake levels in impoundments dependent on affected streams, and in Sandhills lakes.

Surface Water Quality

Impacts on surface water quality will be associated with improvements in streamflow and with reductions in leaching into groundwater supplies as well as with any possible reductions in runoff from areas of finer textured soils which may result from restrictions based on slope.

Soils

Restrictions based on slope would result in reduced runoff and soil loss in areas of fine-grained soils. Restrictions based on soil type as well as slope could lead to reduced erosion from wind.

Vegetation and Wildlife Habitat

Restrictions based on soil type and/or slope could lead to reduced row crops with maintenance of grasslands, or development of dryland farming. Presence of grasslands would lead to some habitat advantages for some upland gamebirds such as prairie chickens or pheasants which could also benefit from diversity of crops resulting from dryland farming. Opportunities for habitat development related to irrigation, such as watered corners, would be reduced. Restrictions related to water level or streamflow would lead to maintained aquatic vegetation and habitat, continued hay crops, migratory birds, small mammals and other species.

Recreation and Aesthestics

These factors would be most affected by restrictions based on slope which maintained grasslands and reduced erosion and by restrictions based on streamflow and water level which lead to improvements in surface water quantity and quality.

Environmental analysis of *"For Instance" Case 5c(i) (a)* concludes that water level impacts are less significant than those associated with a

moratorium or several other management actions--about midway between baseline trends and the *"For Instance" Cases* such as *4c(i) (a) and 6c(i) (d)* which utilize a moratorium. Trends toward impacts of groundwater decline including loss of wetlands and wet meadows, streamflow and lake level decline and related effects on habitat would be moderated in relation to effects on the rate of groundwater decline, or a focus on areas of high water table. Crop production and acres reverting to dryland are in the middle range, thus suggesting moderate impacts in terms of changes in leaching of nitrates and concentrations in groundwater supplies, and changes in agriculturally-related wildlife habitat.

Specification of management approaches may illustrate other potential effects. Restrictions by slope will not have significant impacts on rates of infiltration and leaching of nitrates in sandy soils. Nor would runoff be a major factor in these areas. Reductions in leaching of nitrates would (aside from nitrogen management) be most affected by restrictions based on areas of high water table, slope and topography, and soil type.

Reductions in erosion from runoff will be related to restrictions in slope and soil type with an emphasis on fine textured soils. Reductions in erosion from wind will be related to soil type and topography as well as management factors including vegetation.

Reductions in rate of decline of wetlands, wet meadows or streamflow will be related to areas of high water table, particularly in the Sandhills areas.

In short, restrictions of the rate of development based on slope and soils, as in *"For Instance" Case 5c(i) (a),* will probably have its most significant effects on erosion, limited effects on groundwater quality--more if applied to soils existing in combination with areas of high water table, such as Valentine soils in the Sandhills and moderate effects on ground and surface water quantity--again varying in relation to areas of high water table with greater effects in areas such as the Sandhills. Vegetation and habitat and surface water quantity would follow groundwater quantity effects.

TECHNOLOGICAL IMPACTS

No significant technological impacts have been identified.

ECONOMIC IMPACTS

To analyze the effects of this Action, the RLP Model was applied to *"For Instance" Case 5c(i) (a),* which is a restriction of new irrigation development to 50 percent of the unconstrained rate. For purposes of analysis, it is assumed that this option is implemented through a well drilling permit process, where permits are granted only for those lands where it is expected that severe erosions and/or groundwater pollution will not occur.

Changes in Feet of Lift

As compared to the Baseline, implementation of this particular case is projected to extend aquifer life, although not as noticeable as the option which prohibits well drilling beginning in 1985 *["For Instance" Case 4c(i) (a)].* (See Table C-1, Appendix C).

Changes in Areas Reverting to Dryland

The restrictions of new irrigation development to 50 percent of the unconstrained rate is projected to result in somewhat less acreage reverting to dryland, resulting from aquifer exhaustion, as compared to the Baseline condition. However, this option is not believed as "successful" in curbing reversion as that which prohibits well drilling in 1985 *["For Instance" CAse 4c(i) (a)].* (See TAble C-2, Appendix C).

Changes in Agricultural Production

When compared to the Baseline, implementation of this option is anticipated to result in an appreciable increase in grain sorghum output with slight improvements in wheat production. Soybean and alfalfa output is projected to be slightly below production levels under the Baseline condition. Corn output is expected to be about 25 percent below production anticipated under the Baseline in 2020; however, this reduction is not as severe as compared to corn production levels if well drilling were prohibited in 1985. (See Tables C-3 through C-8, Appendix C).

Returns to Land and Management

All regions of the state are projected to experience smaller returns to land and management under this case as compared to the Baseline. However, the difference is less severe when compared to that option which prohibits well drilling as of 1985.

Since more irrigated acres (and hence higher returns per acre) would be retained under a restriction of new development to 50 percent of the unconstrained rate when compared to the Baseline, it is anticipated that within a decade or two beyond 2020, RTLM from this and other restrictive options would be higher than the

Baseline projections. (See Table C-9, Appendix C).

Off-Farm Economic Impacts

The magnitude of the off-farm economic impacts of this case is roughly **one-half** that associated with that which prohibits well drilling as of 1985 *["For Instance" Case 4c(i) (a)]*. As expected, output in the dryland crop sector is projected to show an increase, relative to the Baseline, by 2020, with a noticeable decrease anticipated to occur in the irrigated crops sector. Outputs in other sectors of the Nebraska economy are expected to experience declines relative to the Baseline. (See Table C-10, Appendix C.)

Summary

This and other regulatory options are expected to noticeably extend aquifer life, but total crop production is projected to be reduced below the Baseline condition in the future. However, improvements in agricultural production, relative to the Baseline, would probably occur in problem areas within one or two decades after 2020.

A more complete comparative analysis of this Action in conjunction with the Baseline condition and other alternative management actions is found in Appendix C.

SOCIAL IMPACTS

Same as those associated with Management Action 4 and associated implementation methods and options. In addition, the use of performance standards [Implementation Option 5c (iii)] could provide an equitable approach in restricting irrigation development. Water quality could be improved, thus protecting the health of area residents.

LEGAL/INSTITUTIONAL/ADMINISTRATIVE IMPACTS

Management Action 5

Legal analysis of this Action depends on how it is implemented (see description of associated implementation methods and options). Research and educational programs regarding whether to develop irrigation are currently provided by UNL. Purchase of development rights possibly could be implemented: (1) in control areas established to address groundwater pollution; (2) by DEC to address surface or groundwater quality concerns; (3) by NRDs to prevent soil erosion and protect wildlife; or (4) by the Nebraska Game and Parks Commission to protect wildlife habitat. Compensated and uncompensated groundwater development restrictions could be implemented: (1) in control areas established to address groundwater pollution caused by aquifer dewatering; (2) by DEC to address water quality concerns; and (3) by NRD or county land-use controls to prevent erosion. Discouraging irrigation development through taxing authorities is subject to considerable legal uncertainty. Other options to restrict irrigation development would require new legislation.

Implementation Method 5a -- Research and educational programs are currently conducted cooperatively by the UNL Agricultural Experiment Station and Cooperative Extension Service, the USDA Agricultural Research Service, and NRDs. These programs are likely to be continued and could be expanded or accelerated through additional funding. Voluntary measures are unlikely to prevent irrigation development violating geographic or environmental criteria, however, unless the landowner believes that such development would not be profitable.

Implementation Method 5b --

A. **Implementation Option 5b(i)** -- Groundwater development rights possibly could be purchased: (1) in control areas established to deal with groundwater quality degradation caused by aquifer dewatering; (2) by DEC to protect water quality; (3) by the Nebraska Game and Parks Commission to protect wildlife habitat; (4) by counties to prevent soil erosion; and (5) by NRDs to protect wildlife habitat and prevent soil erosion. Additional funding to implement this approach under existing law or new authorization to implement this approach both would require additional legislation.

This approach could be effectively administered with adequate funding, substantial penalties, and vigorous enforcement.

B. **Implementation Option 5b(ii)** -- This approach probably could not be implemented: (1) because taxing rates high enough to discourage development would probably be considered a development restriction instead of a tax and therefore beyond the authority of the taxing entity; and (2) if the tax created categories of taxpayers (e.g., irrigators versus potential irrigators) that could not be justified for tax reasons. In other words, attempts to use taxing authorities for purposes other than raising revenue are of doubtful legality. These approaches could be used to raise revenue for groundwater management purposes, however, which might prevent marginally profitable irrigation development.

Implementation Method 5c --

A. **Implementation Option 5c(i)** -- Restricting groundwater development could be implemented in control areas created to address groundwater quality problems. The DEC probably could restrict groundwater development to protect environmental values. Counties or NRDs could restrict groundwater development to prevent soil erosion through land-use regulations. Other means of implementing this approach would require new legislation.

This approach could be implemented with adequate funding, substantial penalties, and vigorous enforcement.

Analysis of *"For Instance" Case 5c(i) (a)* indicates that this approach possibly could be implemented by DEC to protect surface and/or groundwater quality. Otherwise statewide prohibition of irrigation development on fragile lands would require new legislation. This approach could possibly be implemented in groundwater control areas, however, or by NRD or county land-use controls, under current law.

B. **Implemented Option 5c(ii)** -- Compensated groundwater development restrictions could probably be established: (1) by NRDs in control areas established to address groundwater pollution; (2) by DEC to protect environmental quality; or (3) by NRDs or counties to prevent soil erosion. A possible source of funding is the Resources Development Fund.

This approach could be implemented with adequate funding, substantial penalties, and vigorous enforcement.

C. **Implementation Option 5c(iii)** -- Conditioning groundwater development on meeting environmental constraints probably could be implemented by DEC, or could be implemented in control areas established to address groundwater quality problems. Counties and NRDs could condition groundwater development to prevent soil erosion through land use regulations. Other means of implementing this approach would require new legislation.

This approach could be implemented with adequate funding, substantial penalties, and vigorous enforcement.

MANAGEMENT OBJECTIVE III: Reduce groundwater withdrawals

Probably the best way to deal with groundwater mining is to reduce current withdrawals to prolong the life of groundwater supplies. A difference between reducing withdrawals and restricting groundwater development is that withdrawal restrictions apply to all groundwater users and do not necessarily penalize those who have not developed.

Reducing irrigation water needs as discussed previously would have the effect of reducing withdrawals, but it may not reduce them enough to slow the rate of groundwater mining to desired levels. Under some circumstances, withdrawals could be reduced further and current production levels could still be maintained. In some cases, however, reductions would have to be severe enough to cause changes in production to slow the rate of mining sufficiently.

Withdrawal limitations can be achieved by education, financial incentives, or regulation. In addition, withdrawal restrictions can be varied considerably regarding the allocation basis, location of use restrictions, quantity of water allocated, and allocation period.

The management techniques work group identified two reasons for restricting groundwater withdrawals: (1) to avoid violating groundwater supply objectives [e.g., exceeding a local, regional (substate), or statewide depletion factor (including zero depletion)]; and (2) to avoid violating geographic or environmental objectives (e.g., causing water pollution, soil erosion, streamflow reduction, or wetland reduction).

Reducing groundwater withdrawals is probably the most effective groundwater management technique because: (1) it creates private incentives to use water more efficiently; (2) it is relatively straightforward to administer; and (3) it can reduce the adverse environment impacts of irrigation water use.

Management actions that would work toward achieving Management Objective III can be classified as: (1) those that improve irrigation efficiency while maintaining current production levels; and (2) those that restrict the amount of water pumped to an amount less than the full evapotranspiration requirements of crops currently grown by irrigators. Those in the first category could require little or no change or expense on the part of the irrigator. It is quite likely they would result in a net economic gain for the irrigator. Actions in the second category would probably require significant adjustments by the irrigators, and in extreme cases, might even reduce profits.

Irrigators could enhance their irrigation efficiency by improving their facilities and their management. Facilities can be improved by capturing and reusing tailwater, by means such as reuse pits. Equipment can also be improved to reduce water losses. For instance, in places where water is becoming more valuable, some irrigators are modifying their center pivots to reduce evaporation losses. Management of irrigation can be improved markedly by irrigation scheduling.

In some cases, additional restrictions on withdrawals might be implemented voluntarily. First, the decrease in production of some crops, like corn, is not directly proportional to the decrease in the amount of water transpired. If pumping water is sufficiently expensive, the reduction in the value of production might be less than the change in production, resulting in a net gain to the irrigator. Second, the decreased amount of water may not be adequate for the current crop, especially corn and alfalfa, but it may be sufficient for producing another crop, and perhaps more than corn at high pumping costs.

In some instances, however, it may not be possible to slow the rate of groundwater mining adequately without reducing the irrigator's returns. In those cases, implementation of any restrictions will be more difficult.

To follow is a discussion of the Management Action formulated by the work group to meet this Objective, accompanied by an analysis of impacts according to impact parameters identified previously.

MANAGEMENT ACTION 6: Reduce groundwater withdrawals to prolong groundwater supplies and reduce environmental impacts

Irrigators can be encouraged or required to reduce their withdrawals through educational programs, financial incentives or disincentives, and regulatory methods, as described in Implementation Methods 6a, 6b, and 6c, below.

Implementation Method 6a: Encourage irrigators through research, demonstration projects, and persuasion to reduce groundwater withdrawals to prolong groundwater supplies and to reduce adverse environmental impacts *(e.g., nitrate pollution)*

Irrigators could be encouraged to reduce withdrawals by improving irrigation efficiency or by improving crop water use efficiency through research, demonstration projects and persuasion. Educational efforts are likely to fail, however, unless irrigators are persuaded that reducing withdrawals is more profitable than not doing so.

Implementaiton Method 6b: Encourage irrigators through a financial incentive, i.e., the purchase of rights to withdraw groundwater, to reduce groundwater withdrawals to prolong groundwater supplies and reduce environmental impacts

Rights to withdraw groundwater could be purchased from landowners and retired. If this occurred, the land for which withdrawal rights had been purchased could not be irrigated with groundwater. Implementation of this option could be expensive if many irrigated acres were retired.

Implementation Method 6c: Restrict groundwater withdrawals based on legislative or administrative action

Groundwater withdrawals can be restricted by metering wells and establishing groundwater allocations (i.e., restrictions on quantities withdrawn), or by requiring irrigators to either reduce irrigated acreages or grow crops using less water. These are described below in Implementation Options 6c(i) and 6c(ii).

Implementation Option 6c(i): Restrict groundwater withdrawals through an allocation program

Once allocations are established, irrigators would cope with restrictions as best they can by improving irrigation efficiency, crop water use efficiency, increasing on-farm water conservation, crop substitution and rotation, and/or acreage reduction.

If groundwater is allocated, one issue is on what basis will the allocation be based: (1) per irrigated acres; (2) per irrigable acres; (3) per overlying acres (i.e., acres overlying a groundwater supply); and (4) per well (e.g., based on capacity, etc).

An allocation based on overlying acres could be an indirect way of establishing a development restriction: A four inch allocation per overlying acre (with a 16 inch per acre ceiling) might result in irrigators developing 50 percent of their land and using an average eight inches per irrigated acre; developing 33 percent of their land and using an average 12 inches per irrigated acre, etc. The overlying acre basis could also permit allocating groundwater on a "sustained yield" (zero depletion) basis.

If groundwater is allocated, another issue is whether the location of use of the allocation is restricted. Use could: (1) be restricted to the tract from which the groundwater was withdrawn; (2) be unrestricted; (3) be subject to a ceiling regarding the quantity used on any acre; and (4) be unrestricted subject to per well withdrawal limitations, etc.

Use restrictions are significant when allocations are low enough to force cropping changes or acreage reductions. If irrigators cannot concentrate their allocations on fewer acres, they may be unable to maximize their profits within the

limits of their allocation.

If groundwater is allocated, a major issue is what quantity is allocated. The lower the allocation the longer the aquifer life. Different allocation levels include: (1) allocations designed to achieve water supply objectives (e.g., one percent annual depletion, 70 year aquifer life); (2) quantities sufficient to maintain current cropping patterns and irrigated acres but eliminate waste; (3) allocations to achieve geographic/environmental objectives; and (4) allocation by price (e.g., a fixed or graduated charge on quantity pumped); etc.

Aquifer life may not be significantly increased if allocations merely eliminate waste but do not result in significantly reduced net withdrawals. Allocations resulting in crop changes or acreage reductions may be necessary to significantly extend aquifer life.

If groundwater is allocated, another issue is the allocation time period. Allocations can be: (1) single year; (2) multiyear; (3) unused allocations may (or may not) be used subsequently; or (4) future allocations may (or may not) be used earlier, etc.

Allowing borrowing and carryovers of allocations can give irrigators the flexibility to deal with precipitation variation and/or crop rotation. For example, less water may be used in wet years, making more water available for dry years.

An illustrative example of this Action is a phased-in allocation program, allocating 90, 80, 70 and 60 percent of unconstrained pumpage per developed acre in 1985, 1990, 2000 and 2020, respectively. Concentration would be permitted. [Hereinafter, this example is cited as *"For Instance" Case 6c(i) (a)]*.

Another example is a program directing an allocation of 80 percent of unconstrained pumpage per developed acre for all years, beginning in 1985. Concentration would be permitted. [Hereinafter, this example is cited as *"For Instance" Case 6c(i) (b)]*.

A third example is a program directing an allocation of 60 percent of unconstrained pumpage per developed acre for all years, beginning in 1985. Concentration would be permitted. [Hereinafter, this example is cited as *"For Instance" Case 6c(i) (c)]*.

A final example is a development moratorium, plus 60 percent allocation program with concentration allowed [hereinafter cited as *"For Instance" Case 6c(i) (d)]*. In essence, this is a combination of *"For Instance" Cases 6c(i) (a) and 6c(i) (c)*.

Implementation Option 6c(ii): Require irrigators to either reduce irrigated acreage or grow crops using less water, by legislative or administrative regulation

Groundwater withdrawals could be reduced: (1) by requiring crops requiring less irrigation water to be grown; or (2) by requiring irrigators to reduce irrigated acres. Both approaches would be difficult to administer, requiring field checks during the irrigation season for compliance. Both approaches could also be achieved indirectly by restricting groundwater withdrawals.

IMPACT ASSESSMENT OF MANAGEMENT ACTION 6 AND ASSOCIATED IMPLEMENTATION METHODS AND OPTIONS

ENVIRONMENTAL IMPACTS

Environmental Impacts of Implementation Method 6a and Implementation Option 6c(i)

Groundwater Quantity

Reduced allocations of groundwater would lead generally to reduced rates of decline in groundwater levels, maintenance of areas of high water table and reductions in the rate of loss of wetlands and wet meadows, with effects on reduced ET salvage potential as well.

Groundwater Quality

Reductions in leaching of nitrates and possibly other chemicals could result from these actions due to reduced withdrawals of groundwater. The degree of concentration of use of groundwater and particular conditions in areas of high use could, however, lead to sustained impacts of leaching in susceptible areas.

Surface Water Quantity

Reductions in rate of streamflow decline could result from these actions if they lead to the maintenance of areas of high water table. Lake levels in impoundments dependent on affected streams could be maintained. Sandhills lakes related to areas of high water table could be maintained as well. Reduced runoff could reduce streamflows in some areas outside the Sandhills.

Surface Water Quality

Improvements in surface water quality would primarily be associated with improvements in streamflow. Reduced erosion would also lead to water quality improvements.

Soils

Reduced water erosion could result from reduced withdrawals. Concentration of water use could cause erosion. Possibly water and wind erosion could be increased with shifts to crops which require less water.

Vegetation and Wildlife Habitat

Aquatic vegetation and habitat in wetland areas, lakes and streams which are maintained due to reductions in groundwater withdrawals would be sustained to a degree as a result of these actions. Migratory birds, fisheries and riparian vegetation and habitat would also be sustained. Terrestrial vegetation and habitat would be dependent on land management decisions related to water availability. If concentration of water takes place, non-irrigated areas may revert to grassland or dryland crops. Habitat diversity may result leading to improved conditions for upland game birds such as pheasants and prairie chickens and other species. Reduced opportunities for habitat related to irrigation would result.

Recreation and Aesthetics

These factors would be related to improvements in surface water quantity and quality and maintenance or improvement of habitat and wildlife populations.

The environmental impacts associated with *"For Instance" Case 6c(i) (a)* would include moderate maintenance of resources related to groundwater levels, due to reduced rates of decline of groundwater levels. Wetlands, lakes and streamflow rates of decline would be reduced accordingly with consequent effects on riparian and aquatic habitat.

Cropland habitat diversity would be increased by a level of corn production somewhat below the baseline trend and grain sorghum considerably above that trend. Acreage reverting to dryland is significantly below the baseline and most other alternatives [except *"For Instance" Cases 6c(i) (c) and 6c(i) (d)]*. Overall habitat effects do not appear to be greatly different than baseline trends.

Reductions in leaching of nitrates and erosion from runoff should be related to reduced groundwater withdrawal and use. These may be offset by concentration of water use in fragile areas. Reduced runoff may affect later season streamflows in some areas.

Environmental impacts associated with *"For Instance" Case 6c(i) (b)* will be the closest to the baseline of any of the allocation actions, although impacts will be more pronounced than impacts of *"For Instance" Cases 1a(i), 2a(i) and 1a/2a* in most instances.

Hence, effects on areas of high water table, wetlands, wet meadows and streamflow would be moderate in terms of sustaining the life of these resources.

Impacts on habitat and vegetation will be close to baseline conditions and to the effects of *"For Instance" Cases 1a(i), 2a(i) and 1a/2a.*

Reductions in water withdrawal could lead to proportional reductions in leaching of nitrates into groundwater supplies and reductions in erosion from runoff in susceptible areas. These could be offset to some extent by the effects of concentrated application of water in vulnerable areas.

Environmental impacts associated with *"For Instance" Case 6c(i) (c)* are quite pronounced with respect to *"For Instance" Cases 6c(i) (a) and 6c(i) (b)*, and other actions except for *"For Instance" Cases 4c(i) (a) and 6c(i) (d)*, each of which involves a moratorium. Effects would thus be more significant in terms of reductions in rate of groundwater levels [than other actions except *"For Instance" Case 6c(i) (d)]* in that average lifts are considerably less than those of these other actions. It could be expected that maintenance of wetlands, wet meadows, streamflow and lake levels would be sustained at a significantly greater rate than the baseline trend and all other actions, except *"For Instance" Case 6c(i) (d).*

Reduced water use could lead to reduced leaching of nitrates into groundwater and reduced erosion, both subject to being offset by effects of concentration of water use in vulnerable areas. Late season streamflow may be affected by reduced runoff in some areas.

Reversions to dryland farming are about one-third of the statewide baseline trend and are particularly notable in Region IV. Overall shifts in crop composition are notable in the increase in grain sorghums, in Region I, but otherwise in the middle range of the actions and thus not related to a dramatic shift in upland habitat and vegetation.

Environmental impacts associated with *"For Instance" Case 6c(i) (d)* are at one extreme in terms of average lift, and acres reverting to dryland and close to it in corn production. Yet in many ways impacts are not dramatically different in degree from *"For Instance" Case 6c(i) (c).* They suggest reductions in the rate of groundwater decline thus affecting areas of high water tables, wetlands, ET potentials and streamflow and lake levels in some instances.

Reductions in erosion and leaching of nitrates into groundwater could be expected subject to the effects of concentration in vulnerable areas.

There may be effects on late season streamflows due to reduced runoff.

Improvements in riparian and aquatic habitat can be associated with wetland and streamflow improvements.

Terrestrial habitat will be affected by the extent to which grasslands are not developed, the fate of dryland acreage and how it is managed and management of other cropland and its composition.

In summary, impacts which are possibly suggested by economic data suggest that the two "For Instance" Cases involving a moratorium will have the most significant effects. Close to them are the more stringent allocation programs. Environmental restrictions will be effective to the extent they are closely fitted to particular conditions.

Implementation Method 6b

Environmental impacts of this method would be similar to those of Management Action 4, Implementation Method 6a, and Implementation Option 6c(i), depending whether the Action restricts the amount of water which can be withdrawn, or whether it reduces the intensity of groundwater development as Management Action 4, above. The latter appears to be most likely, as land with rights to develop purchased would then revert to dryland farming, grassland, or other use. The primary effects would be those resulting from decreased declines in water levels and those resulting from shifts from irrigated crops to dryland or grassland.

Implementation Option 6c(ii)

Environmental impacts associated with this option would be similar to those of Implementation Method 6a and Implementation Option 6c(i), with an emphasis on the effects of reduced groundwater withdrawals and shifts in vegetation and related habitat in areas which are not irrigated or which undergo a major shift in crops. The question of concentration of irrigation on limited areas could result in problems of soil erosion and continued leaching of nitrates into groundwater supplies, depending in both cases on slope, soil type and in the latter, depth of water.

TECHNOLOGICAL IMPACTS

Technological impacts associated with each of the implementation methods identified to meet this Action are similar; therefore, they will be discussed collectively.

Reduced groundwater withdrawals will necessitate an increase in irrigation and crop water use efficiency. However, the techniques used to achieve increased efficiency will vary according to the amount of groundwater withdrawn. For example, if an allocation system is used and the allocation is high enough to only eliminate waste, the use of existing irrigation scheduling and conservation tillage practices may be enough to allow the irrigator to continue to grow fully irrigated corn. However, if allocations are tight such that cropping pattern shifts will be required, increased emphasis may be placed on growing crops which use less water. For this case, added research for yield improvement in, say sorghum, would be very beneficial.

Current technology exists such that irrigation conveyance and application efficiencies can be improved greatly. However, crop yield improvements, such that greater yields can be produced with current water application levels, may hold the greatest promise in helping the irrigator to economically cope with reduced water usage.[7]

Increased research and subsequent extension work in the area of crop stressing may also be very beneficial for irrigators operating under an allocation system.

Technological impacts associated with Implementation Method 6b would be similar to those of the baseline condition. No incentives would exist, from a supply standpoint, to improve irrigation water use efficiency. It is noted that when considering technological impacts associated with Implementation Option 6c(ii), additional research into the improvement of crop yields would be necessary to maintain the economic status of the irrigator. Dryland farming techniques would also need to be improved so that crop yields could be maintained at economically acceptable levels.

ECONOMIC IMPACTS

To analyze the economic effects for this particular Action, the RLP Model was applied to the "For Instance" Cases identified above, according to the following assumptions:

"For Instance" Case 6c(i) (a) -- Restrict groundwater withdrawals to 90, 80, 70 and 60 percent of the historical rate per irrigated acre in 1985, 1990, 2000, and 2020, respectively. This option is essentially a phased-in allocation program where irrigators receive a total allocation per ownership unit (not per well) to be used in the most profitable manner.

"For Instance" Case 6c(i) (b) -- Restrict groundwater withdrawals statewide to 80 percent of the historical rate per irrigated acre, beginning in 1985. This example is the same as *"For Instance" Case 6c(i) (a),* above, except for

the amount of the allocation.

"For Instance" Case 6c(i) (c) -- Restrict groundwater withdrawals statewide to 60 percent of the historical rate per irrigated acre, beginning in 1985. This example is the same as *"For Instance" Case 6c(i) (a)*, above, except for the amount of the allocation.

"For Instance" Case 6c(i) (d) -- Prohibit well drilling statewide beginning in 1985 and restrict groundwater withdrawals statewide to 60 percent of the historical rate per irrigated acre, beginning in 1985. This example is a combination of *"For Instance" Cases 4c(i) (a) and 6c(i) (c)*, above, and is intended to represent the most severe possible reductions on the use of irrigation water. Although more severe reductions are theoretically possible, it is unlikely that any decision maker would seriously entertain the possibility, because of the extremely negative "short-run" economic impacts.

Changes in Feet of Lift

When compared to the Baseline, each of the allocation schemes represented in the four "For Instance" Cases above appear to noticeably extend the life of the aquifer. For the Baseline, lift changes over the 43 year time period are projected to range from 104 feet of decline in Region V, to 46 feet in Region II. In comparison, *"For Instance" Case 6c(i) (d)* (drilling moratorium and 60 percent allocation) appears to be the most "successful" option in affecting lift changes. If implemented, this option is projected to result in lift changes ranging from 54 feet of decline in Region I, to 24 feet in Region II.

When comparing all the options analyzed by the RLM Model in this report, it is found that the greatest impacts on mitigating lift changes are caused by a drilling moratorium. (See Table C-1, Appendix C.)

Changes in Areas Reverting to Dryland

When one compares dryland reversion projected under the Baseline condition with the more severe regulatory options, the potential dramatic effects which may result through stringent groundwater management become apparent. Under the Baseline, nearly two million irrigated acres are estimated to revert to dryland by 2020. In comparison, under the most restrictive example *[For Instance" Case 6c(i) (d)]*, the number of acres reverting to dryland statewide by 2020 falls under 600,000. Even the relatively liberal 80 percent allocation program *["For Instance" Case 6c(i) (b)]* results in a 60 percent reduction in acres reverting to dryland. (See Table C-2, Appendix C.)

Changes in Agricultural Production

Corn -- Each of the Cases indicated corn production levels below that expected under the Baseline condition, with *"For Instance" Case 6c(i) (d)* (drilling moratorium and 60 percent allocation) showing the most significant decrease (about 46 percent) when compared to the Baseline in 2020.

Grain Sorghum -- Each of the cases, except for 6c(i) (b), (80 percent allocation) is projected to produce outputs appreciably higher than the Baseline in 2020. Production of grain sorghum under the 80 percent allocation scheme is anticipated to be about 11 percent below the Baseline in the same year.

Soybeans and Alfalfa -- Production for each allocation scheme is projected to be lower than the Baseline, although not significantly, by 2020.

Wheat -- All but the most restrictive case (drilling moratorium and 60 percent allocation) are projected to produce a lower output of wheat than the Baseline in 2020. Wheat output under the moratorium and 60 percent allocation is projected to run about 11 percent above production under the Baseline in 2020. (See Tables C-3 through C-8, Appendix C.)

Even though many of these regulatory schemes significantly reduce the number of acres reverting to dryland, they do so at the expense of substantial reductions in agricultural prodution. In other words, the production decrease caused by a drilling moratorium and/or allocation programs are greater than what is gained by preventing some land which is already irrigated from reverting to dryland production.

Returns to Land and Management

When comparing all of the "For Instance" Cases analyzed in this report, it was found that the lowest statewide returns occurred under the most restrictive case (moratorium and 60 percent allocation). Although this and other regulatory options reduce net returns in all regions and all time periods relative to the Baseline, the differences are less than one would expect, given the large production effects discussed earlier.

Consider, for example, the impact of a drilling moratorium combined with a 60 percent allocation program *["For Instance" Case 6c(i) (d)]*. As of 2020, annual statewide returns are $815 million less than the Baseline. Although this is a large sum, it amounts to less than $700 for every acre prevented from reverting to dryland as of that year.

If one looks at the same relationship on a regional basis, the results are perhaps more revealing. In Region V, for example, where the

greatest amount of aquifer exhaustion occurs, the net returns cost of preventing reversion to dryland is less than $0.25 per acre as of 2020. Moreover, it is clear that within a decade or two beyond 2020, RTLM from very restrictive management schemes in the problem regions would be higher than the unrestricted (Baseline) case, if such programs were implemented by 1985. (See TAble C-9, Appendix C).

Off-Farm Economic Impacts

Except for the most restrictive scheme (drilling moratorium and 60 percent allocation), all of the "For Instance" Cases associated with this Action are projected to produce outputs below the Baseline condition in all sectors of the Nebraska economy by 2020. Some of these differences are significant (see Table C-10, Appendix C). For the drilling moratorium and 60 percent allocation example *["For Instance" Case 6c(i) (d)]*, all sectors except dryland crops show a decline. Dryland production under this scheme is projected to be about 22 percent above the Baseline output in 2020.

Summary

Regulatory programs, either well drilling limitations, allocation programs or both, can substantially extend aquifer life as reflected in the amount of land reverting to dryland production, and static water levels. All of the regulatory schemes reduce total crop production in all regions in all study years after implementation. These reductions are small in the problem Regions (I and IV) by 2020, but nevertheless present. Annual improvements in agricultural production, relative to the Baseline, would probably occur in the problem regions within one or two decades after 2020.

A more complete comparative analysis of this Action in conjunction with the Baseline condition and other alternative management actions is found in Appendix C.

SOCIAL IMPACTS

Social impacts associated with each of the implementation methods identified to meet this Action are similar; therefore, they will be discussed collectively.

Attitudes/Political Issues

"In practice, the selection of an allocation level is likely to be a continually evolving activity. The lack of economic impact and hydrologic information, plus political constraints, will probably mean that initial allocation levels will be rather high (seek to eliminate waste only) followed by gradual reductions over many years. As allocations are gradually reduced, decision makers will learn more about the current economic cost of reduced withdrawals and the impact of groundwater levels. This will enable them to make better informed, long-term decisions regarding the tradeoffs between prolonged aquifer life and short-term economic returns".[8]

Economic Activity

Restrictions on groundwater withdrawals could have various economic effects largely dependent upon the level of restriction required. If the goal of restricting groundwater withdrawals is to eliminate waste only, economic activity probably would be similar to the conditions stated earlier under Objective I: Reduce Irrigation Water Need. Basically, irrigators would benefit from reduced energy use. However, tight restrictions which contribute to shifts in cropping patterns could reduce economic returns to the irrigator. For example, shifts from fully irrigated corn to irrigated sorghum or partially irrigated corn could reduce profits.

Tax Base

The local tax base may not be severely affected by restrictions on groundwater withdrawals. However, reduced economic activity due to reductions in profits from irrigated agriculture would have negative effects on local public expenditures.

Income Distribution/Equity

Inequities can exist when restrictions are placed on groundwater withdrawals. Allocations per well may be unfair because an "irrigator with two wells per quarter section would be much less affected than an irrigator with one well per quarter section".[9] Uniform allocations could be considered unfair since irrigation water needs are variable among irrigators. "Water needs depend on different circumstances such as precipitation, amount of subsoil moisture available, type of water distribution system, and soil type. The impacts of a uniform allocation on irrigators would therefore vary widely, and perhaps inequitably".[10]

For example, if irrigators reach maximum feasible efficiency, it would be very difficult for them to cope with a subsequent drought situation if no "carry-over" of allocations were allowed. However, if irrigators were somewhat inefficient, it would be possible for them, in the

case of a dry year, to become more efficient and, therefore, have additional water available for their crops. A dry year could have serious effects on irrigators at peak efficiency.

Farm Size/Numbers

Restrictions which attempt only to eliminate waste would probably not have significant impacts on farm size or numbers. Tighter restrictions which attempt to prevent further groundwater mining will contribute to a shift to dryland farming. This shift would lead to an increase in farm size as dryland farmers attempt to increase the scale of their operations.

Population

If restrictions were such as to result in a lower level of economic activity, population might decline. Some net population decline could occur; however, the rate would be highly dependent upon the strictness of the regulations.

Health/Safety/Education

Reduced withdrawals may lead to reductions in domestic and municipal water quality degradation.

Quality of Life

The existing quality of life might be maintained for a longer period of time since the life of the aquifer would be prolonged. However, if economic activity is suppressed, life-styles may change to reflect the end of the economic "boom" of the area.

For this particular Action (voluntary reduction of withdrawals), it may be difficult to encourage irrigators to reduce groundwater withdrawals if reduced crop yields would result. If the non-aggregate consequences of current irrigation practices are minimal such that the associated negative impacts are indiscernible, development may not be prevented.

For **Implementation Method 6b**, the social impacts would basically be the same as a selective moratorium with reimbursement given to the affected landowner. The number of acres taken out of irrigation production would significantly affect the degree of social impacts associated with this Action.

For **Implementation Method 6c**, economic returns could be reduced and some loss of population would result. However, these alterations would be highly dependent upon the degree of restrictions.

Requiring irrigators to reduce irrigated acreage or grow crop using less water **[Implementation Option 6c(ii)]** would have significant social impacts if resultant farm incomes declined. Reduced farm incomes could induce more farmers to "sell out", expenditures for farm-related products would decrease, population could decline, etc.

Social Impacts of Administration Methods

Policy decisions at the local level may neglect to consider statewide or regional consequences. Implementation at the state level may be unresponsive to unique geographic situations in various areas of the state.

LEGAL/INSTITUTIONAL/ADMINISTRATIVE IMPACTS

Implementation Method 6a

Research and educational programs are currently being implemented by the UNL Agricultural Experiment Station and Cooperative Extension Service, the USDA Agricultural Research Service, and NRDs. These efforts could be expanded or accelerated through additional funding.

Voluntary methods will not be successful in reducing groundwater withdrawals unless irrigators are persuaded it is profitable for them to do so.

Implementation Method 6b

Purchase of withdrawal rights: (1) probably could be implemented by NRDs in control areas established to address either groundwater depletion or groundwater pollution; (2) probably could be implemented by NRDs to prevent soil erosion and protect wildlife; (3) possibly could be implemented by DEC to protect environmental quality; (4) possibly could be implemented by the Nebraska Game and Parks Commission to protect wildlife habitat; and (5) possibly by counties to prevent soil erosion. The Resources Development Fund is a possible source of funding. Other withdrawal purchase authorization would require new legislation.

This option could be implemented with adequate funding, substantial penalties, and vigorous enforcement.

Implementation Method 6c

Implementation Option 6c(i) -- Under existing law, groundwater withdrawals can be limited by NRDs in groundwater control areas. Encouraging a high degree of water use efficiency is one

factor NRDs must consider in developing withdrawal limitations. Beyond this, NRDs are given considerable latitude in developing withdrawal limitations, subject to one probable limitation. Control areas can be designated where local groundwater supplies are inadequate or pollution is making water unfit for current uses. Withdrawal limitations probably can be implemented only to address the problems which are the basis for control area designation. In addition, DEC probably could regulate groundwater withdrawals to achieve water quality objectives. Other options to regulate groundwater withdrawals would require new legislation.

Withdrawal limitations could be implemented with adequate funding, substantial penalties, and vigorous enforcement.

Implementation of statewide withdrawal restrictions, as outlined in *"For Instance" Cases 6a(i) (a), 6a(i) (b), 6a(i) (c) and 5a(i) (d)*, would require new legislation. These approaches could be implemented in control areas under current law, however.

Implementation Option 6c(ii) -- Reduction of irrigated acreage probably could be implemented by NRDs in control areas established to address groundwater depletion. Crops grown possibly could be regulated in these control areas, and probably could be regulated through county or NRD land-use controls to prevent erosion. Other regulations limiting the number of acres or crops grown could be authorized by new legislation.

Implementation of this action would require legislation, although there is a small chance that these restrictions could be implemented in groundwater control areas. These restrictions would require extensive field level surveillance which would be difficult and expensive.

FOOTNOTES

1. Roger Gold, IANR, UNL, interview, June 3, 1981.
2. Gary Hergert at Nebraska Water Resources Center, Environmental Factors Workshop, April 24, 1981.
3. Interview with John Overing, Irrigation Specialist, State Soil Conservation Service, July 28, 1981.
4. Technological Impacts Seminar, May 18, 1981.
5. U. S. Council on Environmental Quality, *Environmental Quality, 1979*, 10th Annual Report, p. 394. The report notes that minimum tillage may require tradeoffs between reduced erosion, more water available in the soil for plant growth and other factors vs. possibly twice the conventional requirements for herbicides and possible greater insecticide requirements.
6. Gary Hergert at Nebraska Water Resources Center, Environmental Factors Workshop, April 24, 1981.
7. Technological Impacts Seminar, May 18, 1981.
8. Aiken, J. David, and Raymond J. Supalla, "Groundwater Management in Nebraska", Proceedings of the Specialty Conference on Legal, Institutional and Social Aspects of Irrigation and Drainage and Water Resources Planning and Management, ASCE, Blacksburg, Virginia, July 26-28, 1979.
9. Ibid.
10. Ibid.

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Appendix A.

Summary Matrix of Potential Groundwater Management Techniques and Associated Impacts.

Appendices

The appendices which follow contain supporting materials for the subject matter found in the main body of this volume. *Appendix A* presents a capsule summary of management techniques and their impacts as presented in Sections 2 and 3. *Appendix B* contains lists of those who attended workshops sponsored by the Nebraska Water Resources Center to identify the array of impact criteria associated with groundwater management. An expanded analysis of economic factors and impacts associated with the groundwater management techniques is presented in *Appendix C*.

BASELINE:
No new public action (present trends)

Environmental Impacts

Seasonal/permanent declines in wetlands, lakes, areas of high water table; ET salvage potential; increased leaching of nitrates and other agricultural chemicals; streamflow declines in many areas; surface water quality problems; erosion increase in dryland areas; reductions in aquatic and terrestrial habitat; fish and wildlife population declines; negative impact on recreation resources.

Technological Impacts

Increased use of shorter growing season crops, no-till or minimum tillage practices, improved crop hybrids which produce greater yields per unit of water applied, and scheduling.

Economic Impacts

Lift changes will range from 46-104 feet of decline across the state; nearly two million irrigated acres are estimated to revert to dryland by 2020.

Social Impacts

Increased land values for irrigable lands; unequal distribution of wealth; larger farm sizes; increased or maintained population opportunity for improved funding to education, health facilities, safety until groundwater is economically depleted.

Legal/Institutional Impacts

Only current statewide restrictions on groundwater use is irrigation runoff controls; withdrawal restrictions are used in one groundwater control area; some well installation requirements exist.

MANAGEMENT ACTION 1:
Reduce irrigation water need by improving irrigation efficiency

Environmental Impacts

Modest impact on wetlands and other areas of high water table; reduced leaching, runoff, and erosion; minimal effects on wildlife habitat.

Technological Impacts

Technologies currently exist to substantially improved irrigation efficiencies -- added incentives may be needed to increase adoption of such practices.

Economic Impacts

Relatively little impact on lift over baseline; small impact in reducing the number of acres reverting to dryland; improved net returns; no appreciable change in overall agricultural productions off-farm economic sectors would increase output slightly.

Social Impacts

Farm size would continue to increase; Action would be fair to large and smallscale irrigation operations; quality of life would be maintained; voluntary controls would not be acceptable if they were unprofitable.

Legal/Institutional Impacts

Research and education programs to improve irrigation efficiency are currently implemented; cost sharing assistance could

be implemented; state income tax credits would require new legislation; irrigation efficiency requirements could be established to address water depletion or quality concerns in control areas; other actions to improve irrigation efficiency would require new legislation.

Implementation Method 1a:
Adopt improved irrigation practices through research and education

Social Impacts
Increased awareness of improved practices; adopt such practices; attitudes toward groundwater use may be changed.

Legal/Institutional Impacts
Research and educational programs are likely to be continued and could be expanded or accelerated through additional funding.

Implementation Method 1b:
Adopt improved irrigation practices through financial incentives

Social Impacts
Financial incentives could be inequitable, such that, a large irrigation operation could benefit more from the incentives than would a small operation.

Legal/Institutional Impacts
Expanded Resources Development Fund funding; other cost share programs, or state income tax credits would require new legislation. Administration of this option should pose no particular difficulties.

Implementation Method 1c:
Require adoption of improved irrigation practices through regulation

Social Impacts
Regulations to improve irrigation efficiencies may be unfair.

Legal/Institutional Impacts
Implementation beyond NRDs in control areas or DEC to protect water quantity would require new legislation.

MANAGEMENT ACTION 2:
Reduce irrigation water need by improving crop water use efficiency

Environmental Impacts
Maintain, to some degree, areas of high water table, wetlands, etc.; reduce leaching; maintain streamflow; reduced runoff; minimal impact on wildlife habitat.

Technological Impacts
Crop water use efficiency could be improved somewhat with present technology. However, substantial improvements could be made with added research.

Economic Impacts
Relatively little impact on life over baseline; small input in reducing the number of acres reverting to dryland; improved net returns; no appreciable change in overall agricultural production; off-farm economic sectors would increase output slightly.

Legal/Institutional Impacts
Research and education programs to improve irrigation efficiency are currently implemented; cost sharing assistance could be implemented; state income tax credits would require new legislation; crop water use efficiency requirements could be established to address water depletion concerns in control areas, other actions to improve crop water use efficiency would require new legislation.

Implementation Method 2a:
Adopt practices improving crop water use efficiency through research and education

Social Impacts
Farm size would continue to increase; Action would be fair to large and small-scale irrigation operations; quality of life would be maintained; voluntary controls may not be acceptable if they were unprofitable.

Legal/Institutional Impacts
Existing programs are likely to be continued and could be expanded or accelerated through additional funding.

Implementation Method 2b:
Adopt practices improving crop water use efficiency through financial incentives

Social Impacts
Farm size would continue to increase; Action would be fair to large and small-scale irrigation operations; quality of life would be maintained; voluntary controls would not be acceptable if they were unprofitable.

Legal/Institutional Impacts
Implementation of this method would require new legislation.

Implementation Method 2c:
Require use of practices improving crop water use efficiency through regulation

Social Impacts
Regulations could be unfair.

Legal/Institutional Impacts
Implementation of this method would probably require new legislation.

MANAGEMENT ACTION 3: Reduce irrigation water need through improved water conservation practices

Environmental Impacts
Maintain areas of high water table; reduced erosion; possible effects on increased habitat, water quality, increased cover and food for wildlife.

Technological Impacts
Existing methods exist to reduce water need -- primarily through conservation tillage.

Economic Impacts
Relatively little impact on lift over baseline; small impact in reducing the number of acres reverting to dryland; improved net returns; no appreciable change in overall agricultural production; off-farm economic sectors would increase output slightly.

Social Impacts
Farm sizes would probably increase; quality of life would be maintained; Action would be fair to most irrigators.

Legal/Institutional Impacts
Research and education programs to improve on-farm water conservation are currently implemented; cost sharing assistance is available; state income tax credits would require new legislation.

Implementation Method 3a:
Adopt water conservation practices through research and education

Social Impacts
Farm size would continue to increase; Action would be fair to large and small-scale irrigation operations; quality of life would be maintained; voluntary controls may not be acceptable if they were unprofitable.

Legal/Institutional Impacts
Existing programs are likely to be continued and could be expanded or accelerated through additional funding.

Implementation Method 3b:
Adopt water conservation practices through financial incentives

Social Impacts
Farm size would continue to increase, Action would be fair to large and small-scale irrigation operations; quality of life would be maintained; voluntary controls may not be acceptable if they were unprofitable.

Legal/Institutional Impacts
Expanded Resources Development Fund funding, other cost share programs, or state income tax credits would require new legislation.

Implementation Method 3c:
Require adoption of water conservation practices through regulation

Social Impacts
Regulations could be unfair.

MANAGEMENT ACTION 4: Reduce groundwater development based on water supply criteria

Environmental Impacts
Maintain groundwater and surface water quantities; maintain habitat if development is limited.

Technological Impacts
Increased use of improved irrigation practices and crop varieties.

Economic Impacts
Aquifer life would be noticeably extended; less irrigated land would revert to dryland; increase in sorghum and wheat production; decrease in soybeans and alfalfa; reduced returns to land and management; off-farm economic sectors would experience declines.

Social Impacts
Increased land values for irrigated lands; land restricted from irrigation may decrease in value; landowners who created overdraft

problem would not be penalized; population growth may be limited.

Legal/Institutional Impacts
Research and education programs could be implemented; development restrictions; could be implemented; discouraging development through taxing authorities is subject to legal uncertainty.

Implementation Method 4a:
Encourage irrigators, through research and education, not to develop irrigation wells which would violate groundwater supply criteria

Social Impacts
It will be difficult to encourage irrigators not to develop potentially profitable irrigation capabilities.

Legal/Institutional Impacts
Research and educational programs are likely to be continued and could be expanded or accelerated through additional funding.

Implementation Option 4b(i):
Purchase groundwater development rights which would violate groundwater supply criteria

Social Impacts
Allowing farmers to sell development rights would provide a means of obtaining economic benefits without drilling a well. It could be equitable to those who have chosen not to develop irrigation capabilities.

Legal/Institutional Impacts
Implementation would require new legislation.

Implementation Option 4b(ii):
Discourage groundwater development which would violate groundwater supply criteria by increasing cost of development through taxing authorities

Social Impacts
Implementation would be politically unpopular.

Legal/Institutional Impacts
Implementation would require new legislation.

Implementation Option 4c(i).
Prohibit or limit groundwater development that would violate groundwater criteria.

Social Impacts
Well drilling restrictions are unfair because the ones who created the problems are allowed to continue pumping.

Legal/Institutional Impacts
Implementation can occur in groundwater control areas; implementation in other areas would require new legislation.

Implementation Option 4c(ii):
Prohibit or limit groundwater development that would violate groundwater criteria but compensate landowners

Social Impacts
Would be a more fair method of restricting well drilling.

Legal/Institutional Impacts
Implementation could occur in groundwater control areas; implementation in other areas would require new legislation.

MANAGEMENT ACTION 5: Reduce groundwater development based on geographic/environmental criteria

Environmental Impacts
Reduced leaching; reduced water and wind erosion; maintain habitat.

Technological Impacts
Increased use of improved irrigation practices and varieties.

Economic Impacts
Aquifer life would be extended somewhat; total agricultural production would be reduced; smaller returns to land and management; reduced off-farm economic returns.

Social Impacts
Increased land values for irrigated lands; land restricted from irrigation may decrease in value; landowners who created overdraft problem would not be penalized; population growth may be limited.

Legal/Institutional Impacts
Research and education programs are currently implemented; purchase of de-

velopment rights could be implemented; compensated and uncompensated groundwater development restrictions could be implemented; discouraging irrigation development through taxing authorities is legally questionable.

Implementation Method 5a:
Encourage irrigators through research and education not to develop irrigation wells that would violate geographic/environmental criteria

Social Impacts
It would be difficult to encourage irrigators not to develop potentially profitable irrigation capabilities.

Legal/Institutional Impacts
Research and educational programs are likely to be continued and could be expanded or accelerated through additional funding.

Implementation Option 5b(i):
Purchase groundwater development rights which would violate geographic/environmental criteria

Social Impacts
Allowing farmers to sell well development rights would provide a means of obtaining economic benefits without drilling a well. It could be equitable to those who have chosen not to develop irrigation capabilities.

Legal/Institutional Impacts
This technique could presently be implemented in selected cases; additional funding opportunities would require new legislation.

Implementation Option 5b(ii):
Discourage groundwater development which would violate geographic/environmental constraints by increasing cost of development through taxing authorities

Social Impacts
Implementation would be politically unpopular.

Legal/Institutional Impacts
Implementation would require new legislation.

Implementation Option 5c(i):
Prohibit or limit groundwater development that would violate geographic/environmental constraints

Social Impacts
Well drilling restrictions are unfair because the ones who created the problem are allowed to continue pumping.

Legal/Institutional Impacts
Implementation could occur in groundwater control areas; implementation in other areas would require new legislation.

Implementation Option 5c(ii):
Prohibit or limit groundwater development that would violate geographic/environmental constraints but compensate landowners

Social Impacts
Would be a more fair method of restricting groundwater development.

Legal/Institutional Impacts
Implementation could occur in groundwater control areas.

Implementation Option 5c(iii):
Condition groundwater development on meeting performance standards regarding geographic/environmental constraints

Social Impacts
Would be a more fair method of restricting groundwater development.

Legal/Institutional Impacts
Implementation could occur in several ways to meet specific criteria; other means of implementation would require new legislation.

MANAGEMENT ACTION 6: Reduce groundwater withdrawals to prolong groundwater supplies and reduce environmental impacts

Environmental Impacts
Maintain groundwater and surface water quantities; reduce leaching and erosion; dryland crops could reduce wind erosion.

Technological Impacts
Technologies currently exist to substantially improve irrigation efficiency -- added incentives may be necessary to increase adoption of such practices.

Economic Impacts
Aquifer life would be extended; less irri-

gated land would revert to dryland; reduction of agricultural production; reduced net returns; reduced off-farm economic returns.

Social Impacts

Present trends probably continue -- increased farm size; continued level of quality of life; continued trends in income distribution.

Legal/Institutional Impacts

Research and education programs are currently implemented; purchase of development rights could be implemented.

Implementation Method 6a:

Encourage irrigators through research and education and persuasion to reduce groundwater withdrawals to prolong groundwater supplies and to reduce adverse environmental impacts

Social Impacts

Current trends would probably continue.

Legal/Institutional Impacts

Research and education programs are currently implemented. These efforts could be expanded or accelerated through additional funding.

Implementation Method 6b:

Encourage irrigators through a financial incentive to reduce groundwater withdrawals to prolong groundwater supplies and to reduce adverse environmental impacts

Social Impacts

Allowing farmers to sell development rights would provide a means of obtaining economic benefits without drilling a well. It would be equitable to those who have chosen not to develop irrigation capabilities.

Legal/Institutional Impacts

This technique could presently be implemented in selected cases; additional funding opportunities would require new legislation.

Implementation Option 6c(i):

Restrict groundwater withdrawals through an allocation program

Social Impacts

The degree of restriction would determine the severity of social impacts

Implementation Option 6c(ii):

Encourage irrigators to either reduce irrigated acreage or grow crops using less water.

Social Impacts

The degree of regulation would determine the severity of social impacts.

Legal/Institutional Impacts

These techniques could presently be implemented in selected cases; additional regulations would require new legislation.

Legal/Institutional Impacts

Withdrawals can only be limited in groundwater control.

Appendix B.

Participants of Factor/Impact Parameter Workshops Hosted by Nebraska Water Resources Center

Several seminars and workshops were conducted by the Nebraska Water Resources Center to assist in the formulation of impact factors and subsequent impact assessment of groundwater reservoir management. The purpose of these workshops was to obtain a broad and varied perspective of potential impacts from appropriate faculty at the University and officials from state government. Much of the information obtained from this process is directly or indirectly included in the impact sections of the report. Below are listed the participants of the workshops and seminars.

ENVIRONMENTAL FACTORS ASSESSMENT WORKSHOP PARTICIPANTS SEPTEMBER 12, 1979

Dr. A. Tyrone Harrison, School of Life Sciences, UNL
Dr. Robert Kaul, School of Life Sciences, UNL
Dr. Anthony Joern, School of Life Sciences, UNL
Dr. Eugene Martin, School of Life Sciences, UNL
Dr. Paul Johnsgard, School of Life Sciences, UNL
Dr. Gary Hergenrader, School of Life Sciences, UNL
Dr. James Gormly, Conservation and Survey Division, UNL
Dr. Paul Seevers, Conservation and Survey Division, UNL
Dr. Marvin Carlson, Conservation and Survey division, UNL
Bob Kuzelka, Conservation and Survey Division, UNL
Dr. Del Wedd, Department of Environmental Health and Safety, UNL
Dr. Robert Leavitt, Department of Agronomy, UNL
Dr. William Wayne, Department of Geology, UNL
Dr. Ronald Case, Department of Forestry, Fisheries and Wildlife, UNL
Dr. Robert Irving, Grants Development, UNO
Dr. Gary Lewis, Nebraska Water Resources Center, UNL
Susan Miller, Nebraska Water Resources Center, UNL

ENVIRONMENTAL IMPACTS SEMINAR PARTICIPANTS APRIL 24, 1981

Dr. Edward Peters, Department of Forestry, Fisheries and Wildlife, UNL
Professor Walter Bagley, Department of Forestry, Fisheries and Wildlife, UNL
Professor Howard Wiegers, Department of Forestry, Fisheries and Wildlife, UNL
Dr. Del Weed, Department of Environmental Health and Safety, UNL
Dr. Raymond Supalla, Department of Agricultural Economics, UNL
J. David Aiken, Department of Agricultural Economics, UNL
Dr. Charles Deknatel, Department of Community and Regional Planning, UNL
Dr. Gary Hergert, Department of Agronomy, UNL
Bob Kuzelka, Conservation and Survey Division, UNL
Chuck Lindau, Conservation and Survey Division, UNL
Dr. Curt Twedt, Game and Parks Commission

Gerald Chaffin, Game and Parks Commission
Jon Atkinson, Nebraska Department of Environmental Control
Thomas F. Pesek, Nebraska Natural Resources Commission
Steve Gaul, Nebraska Natural Resources Commission
Dr. William Powers, Nebraska Water Resources Center, UNL
Dr. M.-L. Quinn, Nebraska Water Resources Center, UNL
Bob Burns, Nebraska Water Resources Center, UNL
Donn Rodekohr, Nebraska Water Resources Center, UNL
Denis P. Gilbert, Nebraska Water Resources Center, UNL
Tom Cech, Nebraska Water Resources Center, UNL

SOCIAL IMPACTS SEMINAR PARTICIPANTS MAY 13, 1981

Dr. Otto G. Hoiberg, Emeritus, Department of Agricultural Economics, UNL
Dr. Bruce Johnson, Department of Agricultural Economics, UNL
Dr. Paul Gessaman, Department of Agricultural Economics, UNL
Michael Lundeen, Department of Agricultural Economics, UNL
Dr. F. Gregory Hayden, Department of Economics, UNL
Dr. Charles Deknatel, Department of Community and Regional Planning, UNL
Dr. Richard E. Lonsdale, Department of Geography, UNL
Bob Kuzelka, Conservation and Survey Division, UNL
Debra Embery, Nebraska Natural Resources Commission
Steve Gaul, Nebraska Natural Resources Commission
Dr. William Powers, Nebraska Water Resources Center, UNL
Bob Burns, Nebraska Water Resources Center, UNL
Tom Cech, Nebraska Water Resources Center, UNL

TECHNOLOGICAL IMPACTS SEMINAR PARTICIPANTS MAY 18, 1981

Dr. Raymond Supalla, Department of Agricultural Economics, UNL
Michael Lundeen, Department of Agricultural Economics, UNL
Paul Fischbach, Department of Agricultural Engineering, UNL
Bob von Bernuth, Department of Agricultural Engineering, UNL
DeLynn Hay, Department of Agricultural Engineering, UNL
Dr. Charles Deknatel, Department of Community and Regional Planning, UNL
Dr. F. Gregory Hayden, Department of Economics, UNL
Jerry Wallin, Nebraska Natural Resources Commission
Steve Gaul, Nebraska Natural Resources Commission
Dr. Darryll Pederson, Conservation and Survey Division, UNL
Bob Kuzelka, Conservation and Survey Division, UNL
Dr. William Powers, Nebraska Water Resources Center, UNL
Bob Burns, Nebraska Water Resources Center, UNL
Tom Cech, Nebraska Water Resources Center, UNL
Zahid Khan, Nebraska Water Resources Center, UNL

Appendix C.

An Analysis of Economic Factors and Economic Impacts from Groundwater Management Techniques (Expanded Discussion)

The following discussion is presented to provide a more complete, comparative economic analysis of the "For Instance" Cases presented in Section 3. Instead of analyzing each case separately, however, cases are examined below on a comparative basis, according to economic impact parameters identified in Section 1. Tables cited in Section 3 and in the following discussion also appear in this Appendix.

FARM LEVEL ECONOMIC IMPACTS

MANAGEMENT OPTIONS

The recursive linear programming (RLP) economic model described in Section 1 was used to analyze a selected set of groundwater management alternatives, denoted in this study as "For Instance" Cases (except for the Baseline). They were.

1. **Baseline or status quo.** This alternative assumes no restrictions on water use or irrigation development.
2. **Improve irrigation efficiency through research, education and voluntary action** *["For Instance" Case 1a(i)].*

Research and educational programs are currently being implemented cooperatively by the UNL Agricultural Experiment Station and Cooperative Extension Service, the USDA Agricultural Research Service, and Natural Resources Districts (NRDs). These programs are likely to be continued and could be expanded or accelerated through additional funding.

3. **Reduce irrigation water needs by 10 percent per unit yield through educational and research programs involving plant breeding and reduced tillage techniques** *["For Instance" Case 2a(i)].*
4. **Improve both irrigation efficiency and crop water use efficiency through research, education, and voluntary action** [denoted as "For Instance" Case 1a/2a, a combination of Cases 1a(i) and 2a(i), above].
5. **Prohibit well drilling as of 1985** *["For Instance" Case 4c(i) (a)].*

This option would preclude any new irrigation development after 1984. Old wells could be replaced, but no new land could be brought into production. It is assumed for purposes of empirical evaluation that the option is implemented in a manner which does not lead to accelerated development prior to 1985.

6. **Restrict new irrigation development to 50 percent of the unconstrained rate** *["For Instance" Case 5c(i) (a)].*

Assume that this option is implemented through a well drilling permit process, where permits are granted only for those lands where it is expected that severe erosion and/or ground water pollution will not occur.

7. **Restrict groundwater withdrawals statewide to 90 percent, 80 percent, 70 percent and 70 percent of the historical rate per irrigated acre in 1985, 1990, 2000 and 2020, respectively** *["For Instance" Case 6c(i) (a)].*

This option is essentially a phased in allocation program where irrigators receive a total allocation per ownership unit (not per well) to be used in the most profitable manner.

8. **Restrict groundwater withdrawals statewide to 80 percent of the historical rate per irrigated acre, beginning in 1985** *["For Instance" Case 6c(i) (b)].*

Same as *"For Instance" Case 6c(i) (a),* above, except for the amount of the allocation.

9. **Restrict groundwater withdrawals statewide to 60 percent of the historical rate per irrigated acre, beginning in 1985** ["For Instance" Case 6c(i) (c)].

Same as *"For Instance" Case 6c(i) (a)*, above, except for the amount of the allocation.

10. **Prohibit well drilling statewide beginning in 1985 and restrict groundwater withdrawals statewide to 60 percent of**

the historical rate per irrigated acre, beginning 1985 *["For Instance" Case 6c(i) (d)].*

This option is a combination of *"For Instance" Cases 4c(i) (a) and 6c(i) (c)*, above, and is intended to represent the severest possible reductions on the use of irrigation water. Although more severe reductions are theoretically possible, it is unlikely that any decision maker would seriously entertain the possibility, because of the extremely negative "short run" economic impacts.

The above management alternatives are by no means an exhaustive list of policy options available, but they do span the full range of reasonable options. Thus it should be possible to draw reasonable inferences from these results for most any other alternative in which policy makers are interested.

CHANGES IN FEET OF LIFT

The effect of the various alternatives on pumping lifts influences irrigation costs and, thus, other impact parameters. The lift differences across alternatives are quite large (Table C-1). Lift changes over the 43 year time period are the largest for the Baseline, ranging from 104 feet of decline in Region V to 46 feet in Region II, and smallest for Alternative 10 (drilling moratorium and 60 percent allocation), ranging from 54 feet of decline in Region I, to 24 feet in Region II. Generally speaking, the improved efficiency options have relatively little impact on lifts because total pumpage does not change much. The greatest impacts, as one would expect, are caused by a drilling moratorium.

CHANGES IN ACRES REVERTING TO DRYLAND

Under the baseline run nearly two million irrigated acres are estimated to revert to dryland by 2020 (Table C-2). All areas of the state are projected to experience some aquifer exhaustion, but the most severe problems occur in Region IV (787,654 acres) and I (551,907 acres). When one compares this outcome with the more severe regulatory scenarios, the potential dramatic effects which groundwater management could have become apparent. Under the most restrictive alternative *["For Instance" Case 6c(i) (d)]*, the number of acres reverting to dryland statewide by 2020 falls to under 600,000. Even the relatively liberal 80 percent allocation program *["For Instance" Case 6c(i) (b)]* results in a 60 percent reduction in acres reverting to dryland relative to the baseline case. Again, the efficiency options have a relatively small impacts.

CHANGES IN AGRICULTURAL PRODUCTION

The impacts which the various management alternatives have on agricultural production are much more difficult to assess. Except for grain sorghum and to a lesser extent wheat, statewide baseline production totals are as high or higher than those from the other management alternatives (Table C-3). None of the management alternatives result in an appreciable increase in agricultural production, relative to the baseline, even by the year 2020. Indeed, the most severe alternatives significantly decrease agricultural production (especially corn) for all time periods. What this means is that even though many of the regulatory options significantly reduce the number of acres reverting to dryland, they do so at the expense of substantial reductions in agricultural production. In other words, the production decreases caused by a drilling moritorium and/or allocation programs are greater than what is gained by preventing some land which is already irrigated from reverting to dryland production.

The region by region results (Tables C-4 through C-8) show a similar pattern.

Returns To Land And Management

Perhaps the most useful farm level economic indicator are the variations in returns to land and management (RTLM). First, a definitional comment. RTLM are herein defined as the amount of money remaining from crop agriculture after all production costs except land and management charges have been paid. It is not the same thing as net farm income, but differences in RTLM reflect differences in net farm income. Net farm income is essentially RTLM less land charges.

If one could measure net farm income effects directly, such a measure would be preferred to the RTLM proxy for policy making purposes. However, one cannot measure net farm income effects directly, because as the profitability of agriculture changes so do land values and associated land charges.

The impact of the various management options on RTLM is quite pronounded and different than one might expect (Table C-9). The highest annual returns occur for the improved efficiency cases, while the lowest statewide returns are for the most restrictive case *["For Instance" Case 6c(i) (d)]*. The improved efficiency options lower costs without lowering production, thus improving net returns. Although the regulatory options reduce net returns in all regions and all time periods relative to the baseline, the differences are less than one would expect, given the large production effects discussed earlier.

Consider, for example, the impact of a drilling moratorium combined with a 60 percent allocation program. As of 2020, annual statewide returns are $815 million less than the baseline. Although this is a large sum, it amounts to less than $700 for every acre prevented from reverting to dryland as of that year.

If one looks at the same relationship on a regional basis the results are perhaps more revealing. In Region V, for example, where the greatest amount of aquifer exhaustion occurs, the net returns cost of preventing reversion to dryland is less than $0.25 per acre as of 2020. Moreover, it is clear that within a decade or two beyond 2020, RTLM from very restrictive management options in the problem regions would be higher than the unrestricted (baseline) case, if such programs were implemented by 1985.

SUMMARY

The principal conclusions which one can draw from the foregoing analysis include:

1. Improved efficiency alternatives will do little to extend aquifer life, but would appreciably improve the profitability of agriculture.
2. Regulatory options, either well drilling limitations, allocation programs or both, can substantially extend aquifer life as reflected in the amount of land reverting to dryland production, and static water levels.
3. All of the regulatory options reduce total crop production in all regions in all study years after implementation. These reductions are small in the problem regions (I and IV) by 2020, (I and IV), but nevertheless present. Annual improvements in agricultural production, relative to the Baseline case, would probably occur in the problem regions within one or two decades after 2020.
4. Adoption of management alternatives which extend aquifer life would make irrigators who face poor water situations better off at the expense of current or prospective irrigators who face better water availability conditions.

OFF-FARM ECONOMIC IMPACTS

The economic effects occurring at the farm level from groundwater management alternatives impact in other sectors of the economy. Changes in agricultural production, for example, affect the sales of fertilizer and farm machinery. These types of impacts are extremely difficult to analyze, however, because of the dynamic nature of the Nebraska economy. In other words, even if one knows the relationship between such things as agricultural production and fertilizer sales at some point in time, this relationship may change when agricultural production changes. Thus, the problem of dynamic structural changes.

A first approximation of the off-farm impacts on other economic sectors is possible, however, if one is willing to accept the limits of a comparative statics approach. This was done for purposes of this analysis by using an input-output model developed by Charles Lamphear, Department of Economics, UNL. His model, recently updated to 1977 prices and conditions, permits one to assess the effects of the changes in agricultural output on the outputs of other major sectors in the Nebraska economy.

The effects of the different management options on the outputs for each economic sector correspond closely to the crop production impacts, i.e., the larger the impact on crop production, the larger the impact on other economic sectors (Table C-10).

In considering the results of the analysis it is clear that the economic sectors most affected, other than irrigated and dryland crop sectors, are wholesale and retail trade; services; finance, insurance and real estate (FIRE) sectors; and household incomes. These sectors incurred reductions of $32,701,000., $128,485,000., $159,766,000., $314,867,000., and $841,811,000., respectively, from the most restrictive management option, relative to the Baseline.

Groundwater policy makers wishing to maintain economic output or minimize the temporary reductions associated with extended aquifer life should focus on those alternatives which have the most favorable impact on total agricultural production.

Table C-1. Impacts of Groundwater Management "For Instance" Cases on Estimated Average Feet of Lift, by Region and Time Period

Region		Feet of Lift per "For Instance" Case									
		1a(i)	2a(i)	1a/2a	4c(i)(a)	5c(i)(a)	6c(i)(a)	6c(i)(b)	6c(i)(c)	6c(i)(d)	Baseline
I	1977	129.69	129.69	129.69	129.69	129.69	129.69	129.69	129.69	129.69	129.69
	1985	147.16	147.16	147.16	147.16	147.16	147.16	147.16	147.16	147.16	147.61
	1990	154.04	154.91	154.04	154.40	154.58	153.19	152.35	150.66	150.46	154.76
	2000	170.81	171.51	168.83	167.16	169.74	166.01	165.16	159.50	158.91	172.23
	2020	215.58	211.93	208.84	189.32	203.26	195.56	199.80	183.96	182.17	217.20
	2021	218.53	214.58	211.51	190.22	205.16	197.53	202.09	185.60	183.14	220.09
II	1977	94.58	94.58	94.58	94.58	94.58	94.58	94.58	94.58	94.58	94.58
	1985	105.70	105.70	105.70	105.70	105.70	105.70	105.70	105.70	105.70	105.70
	1990	107.94	108.36	107.94	108.70	108.78	107.51	107.08	106.14	108.85	
	2000	114.69	114.83	113.68	113.53	114.67	112.24	111.81	108.93	108.62	115.81
	2020	135.80	133.21	132.07	122.33	128.57	124.97	127.33	118.86	117.82	136.81
	2021	137.34	134.57	133.43	122.74	130.54	125.94	128.49	119.65	118.24	138.34
III	1977	123.02	123.02	123.02	123.02	123.02	123.02	123.02	123.02	123.02	123.02
	1985	136.46	136.46	136.46	136.46	136.46	136.46	136.46	136.46	136.46	136.46
	1990	141.46	142.13	141.46	141.04	141.15	140.75	140.04	138.02	138.48	141.26
	2000	152.78	153.35	151.14	149.59	151.41	148.79	148.08	143.38	142.94	153.22
	2020	184.28	181.38	178.43	164.32	174.66	167.60	171.12	157.95	157.14	184.99
	2021	186.34	183.20	180.25	164.99	176.02	168.88	172.67	158.97	157.83	187.02
IV	1977	109.57	109.57	109.57	109.57	109.57	109.57	109.57	109.57	109.57	109.57
	1985	126.54	126.54	126.54	126.54	126.54	126.54	126.54	126.54	126.54	126.54
	1990	132.70	133.64	132.70	133.46	133.58	131.66	130.62	128.54	128.41	133.69
	2000	146.48	147.63	144.27	144.79	146.43	141.02	139.98	133.47	133.13	148.07
	2020	177.29	174.95	170.45	164.04	171.90	157.16	161.04	144.69	144.19	179.74
	2021	178.78	176.23	171.77	164.77	172.99	157.92	162.04	145.21	144.71	181.17
V	1977	71.18	71.18	71.18	71.18	71.18	71.18	71.18	71.18	71.18	71.18
	1985	88.13	88.13	88.13	88.13	88.13	88.13	88.13	88.13	88.13	88.13
	1990	96.30	96.30	96.30	96.15	96.42	94.94	93.58	90.85	90.54	96.68
	2000	115.88	112.76	112.76	109.47	113.45	108.28	106.92	97.92	96.95	117.43
	2020	169.21	158.89	158.89	127.66	149.61	137.89	144.47	119.55	117.04	171.47
	2021	173.12	162.43	162.43	128.27	151.85	140.23	147.33	121.37	117.78	175.31

Table C-2.
Accumulated Acres Reverting to Dryland from Aquifer Exhaustion, by Region and Time Period

Region		Acres per "For Instance" Case									
		1a(i)	2a(i)	1a/2a	4c(i)(a)	5c(i)(a)	6c(i)(a)	6c(i)(b)	6c(i)(c)	6c(i)(d)	Baseline
I	1977-84	44,570	44,570	44,570	44,570	44,570	44,570	44,570	44,570	44,570	44,570
	1977-89	85,079	90,336	85,079	87,269	88,344	80,038	75,014	65,017	65,017	89,421
	1977-99	190,277	194,897	177,417	166,592	183,299	159,241	153,861	118,381	114,711	200,243
	1977-2019	515,576	486,638	462,424	316,913	419,613	362,101	393,504	279,093	266,674	528,514
	1977-2020	539,223	507,603	483,333	323,342	434,095	376,596	410,726	290,564	273,417	551,909
II	1977-84	11,710	11,710	11,710	11,702	11,702	11,710	11,710	11,710	11,710	11,702
	1977-89	20,685	22,345	20,685	23,687	23,983	18,994	17,291	13,844	13,505	24,279
	1977-99	45,829	46,307	42,266	41,726	45,759	37,059	35,486	24,588	23,383	49,707
	1977-2019	105,102	99,417	96,756	70,673	90,657	78,340	84,838	59,859	56,448	107,214
	1977-2020	108,282	102,457	99,905	71,892	93,069	81,064	87,901	62,376	57,845	110,273
III	197-84	0	0	0	0	0	0	0	0	0	0
	1977-89	0	0	0	0	0	0	0	0	0	0
	1977-99	2,297	2,671	1,350	628	1,491	325	92	0	0	2,589
	1977-2019	57,752	49,712	42,107	14,407	33,327	19,571	25,990	6,550	5,757	59,840
	1977-2020	63,872	54,689	46,718	15,403	36,369	21,807	29,084	7,617	6,432	65,947
IV	1977-84	37,798	37,798	37,798	39,131	39,131	37,798	37,798	37,798	37,798	39,131
	1977-89	68,007	73,864	68,007	72,730	73,455	61,943	56,268	46,089	45,507	74,185
	1977-99	185,650	198,576	162,131	167,508	185,065	130,784	121,576	72,763	70,667	203,592
	1977-2019	698,575	647,464	554,731	435,558	583,883	324,235	384,891	166,385	161,246	754,187
	1977-2020	732,099	674,990	581,109	448,391	606,140	335,750	401,506	171,868	166,633	787,654
V	1977-84	26,758	26,758	26,758	26,758	26,758	26,758	26,758	26,758	26,758	26,758
	1977-89	47,154	50,482	47,152	46,755	47,448	43,637	40,164	33,348	32,583	48,142
	1977-99	103,218	106,401	93,615	83,734	95,720	80,251	76,286	51,394	48,832	108,124
	1977-2019	307,883	282,502	262,344	141,919	223,835	178,510	203,488	114,895	106,866	318,243
	1977-2020	325,859	297,918	277,626	144,023	232,935	187,260	214,719	120,785	109,217	336,098
State	1977-84	120,836	120,836	120,836	122,161	122,161	120,836	120,836	120,836	120,836	122,101
	1977-89	220,925	237,027	220,925	230,441	233,230	204,612	188,737	158,298	155,445	236,027
	1977-99	527,271	548,852	476,779	460,188	511,334	407,660	387,301	267,126	257,593	564,255
	1977-2019	1,684,888	1,565,733	1,418,362	979,470	1,351,315	962,757	1,092,711	626,782	596,991	1,767,990

Table C-3. Impact of Groundwater Management "For Instance" Cases on Nebraska Crop Production

		Bushels or Tons (000) per "For Instance" Case									
		1a(i)	2a(i)	1a/2a	4c(i)(a)	5c(i)(a)	6c(i)(a)	6c(i)(b)	6c(i)(c)	6c(i)(d)	Baseline
1977	Corn	737,234	737,234	737,234	737,234	737,234	737,234	737,234	737,234	737,234	737,234
	Gr. Sor.	155,952	155,952	155,952	155,952	155,952	155,952	155,952	155,952	155,952	155,952
	Soybean	35,019	35,019	35,019	35,019	35,019	35,019	35,019	35,019	35,019	35,019
	Alfalfa	4,969	4,969	4,969	4,969	4,969	4,969	4,969	4,969	4,969	4,969
	Wheat	90,547	90,547	90,547	90,547	90,547	90,547	90,547	90,547	90,547	90,547
1985	Corn	1,029,346	1,029,346	1,029,195	1,029,195	1,029,195	1,004,040	971,224	874,176	974,176	1,029,195
	Gr. Sor.	202,870	202,870	202,870	202,914	202,914	200,560	199,824	204,188	204,188	202,914
	Soybean	81,460	81,460	81,460	81,455	81,455	82,834	84,336	83,772	83,772	81,455
	Alfalfa	5,197	5,197	5,197	5,197	5,197	5,152	5,065	4,867	4,867	5,197
	Wheat	83,839	83,710	83,839	83,725	83,725	84,036	84,036	84,036	84,036	83,725
1990	Corn	1,200,075	1,198,177	1,200,075	1,035,653	1,116,960	1,078,590	1,079,384	951,937	905,298	1,198,265
	Gr. Sor.	224,167	225,489	224,167	245,153	234,803	221,441	221,441	221,119	242,539	224,452
	Soybean	116,613	116,616	116,613	116,362	116,477	127,563	127,573	123,640	122 859	116,592
	Alfalfa	5,376	5,377	5,376	5,278	5,328	5,336	5,335	5,172	5,205	5,377
	Wheat	74,000	74,162	74,000	79,523	76,858	74,087	73,929	73,623	78,964	74,182
2000	Corn	1,555,278	1,552,623	1,561,652	1,053,013	1,202,921	1,349,571	1,416,183	1,237,721	1,049,570	1,550,608
	Gr. Sor.	236,130	236,814	234,695	300,847	268,970	231,495	229,141	232,266	294,208	237,153
	Soybean	166,510	166,489	166,518	164,994	165,730	166,882	173,703	166,922	163,965	166,468
	Alfalfa	5,332	5,334	5,326	5,194	5,265	5,105	5,235	4,987	5,171	5,336
	Wheat	62,062	62,182	61,720	70,158	66,247	60,970	60,827	59,916	68,709	62,342
2020	Corn	1,975,278	1,991,849	2,011,424	1,039,256	1,504,878	1,649,446	1,868,953	1,352,044	1,056,296	1,964,330
	Gr. Sor.	270,288	266,393	260,893	375,438	323,589	352,658	243,344	472,685	359,483	273,441
	Soybean	231,659	231,706	232,046	220,622	225,967	213,976	219,829	219,375	222,031	231,315
	Alfalfa	5,435	5,419	5,402	5,345	5,393	5,165	5,361	5,028	5,300	5,445
	Wheat	64,059	63,363	62,712	73,189	68,769	60,785	61,556	58,731	71,467	64,434

Table C-4. Impact of Groundwater Management "For Instance" Cases on Crop Production, Region I

		Bushels or Tons (000) per "For Instance" Case									
		1a(i)	2a(i)	1a/2a	4c(i)(a)	5c(i)(a)	6c(i)(a)	6c(i)(b)	6c(i)(c)	6c(i)(d)	Baseline
1977	Corn	95,959	95,959	95,959	95,959	95,959	95,959	95,959	95,959	95,959	95,959
	Gr. Sor.	6,542	6,542	6,542	6,542	6,542	6,542	6,542	6,542	6,542	6,542
	Soybean	357	357	357	357	357	357	357	357	357	357
	Alfalfa	883	883	883	883	883	883	883	883	883	883
	Wheat	43,753	43,753	43,753	43,753	43,753	43,753	43,753	43,753	43,753	43,753
1985	Corn	173,840	173,840	173,840	173,840	173,840	170,709	158,536	132,110	132,110	173,840
	Gr. Sor.	18,850	18,850	18,850	18,850	18,850	18,482	17,745	18,401	18,401	18,850
	Soybean	1,768	1,768	1,768	1,768	1,768	1,614	2,979	4,891	4,891	1,768
	Alfalfa	1,007	1,007	1,007	1,007	1,007	1,007	1,007	876	876	1,007
	Wheat	44,747	44,618	44,747	44,618	44,618	44,618	44,618	44,618	44,618	44,618
1990	Corn	227,281	226,626	227,281	186,196	206,468	194,739	194,913	166,150	156,892	226,740
	Gr. Sor.	21,299	21,312	21,299	20,866	21,088	20,659	20,645	20,617	20,305	21,309
	Soybean	3,008	2,999	3,008	2,449	2,725	6,910	6,931	6,973	5,618	3,001
	Alfalfa	965	965	965	920	943	965	965	965	920	965
	Wheat	45,866	45,943	45,866	47,223	46,576	45,618	45,543	45,396	46,740	45,929
2000	Corn	316,240	315,608	317,998	193,217	254,063	254,312	273,186	233,240	200,311	314,877
	Gr. Sor.	41,721	41,739	41,672	38,903	40,331	38,968	38,940	38,759	38,703	41,760
	Soybean	5,359	5,348	5,390	3,230	4,283	10,901	10,928	11,106	3,354	5,335
	Alfalfa	935	936	931	965	951	891	926	880	953	937
	Wheat	44,664	44,729	44,482	47,801	46,301	43,952	43,875	43,368	47,067	44,805
2020	Corn	429,567	433,746	437,243	185,096	306,845	313,443	407,456	202,527	192,352	427,699
	Gr. Sor.	63,069	62,963	62,690	56,228	59,673	119,968	57,607	201,921	55,870	63,161
	Soybean	16,018	16,179	16,314	16,702	11,341	12,136	12,013	12,460	6,982	15,945
	Alfalfa	1,139	1,131	1,124	1,166	1,153	1,097	1,105	1,012	1,152	1,142
	Wheat	47,311	46,902	46,561	51,171	49,289	44,684	45,132	43,498	50,462	47,494

Table C-5. Impact of Groundwater Management "For Instance" Cases on Crop Production, Region II

		Bushels or Tons (000) per "For Instance" Case									
		1a(i)	2a(i)	1a/2a	4c(i)(a)	5c(i)(a)	6c(i)(a)	6c(i)(b)	6c(i)(c)	6c(i)(d)	Baseline
1977	Corn	55,928	55,928	55,928	55,928	55,928	55,928	55,928	55,928	55,928	55,928
	Gr. Sor.	1,443	1,443	1,443	1,443	1,443	1,443	1,443	1,443	1,443	1,443
	Soybean	188	188	188	188	188	188	188	188	188	188
	Alfalfa	612	612	612	612	612	612	612	612	612	612
	Wheat	4,568	4,568	4,568	4,568	4,568	4,568	4,568	4,568	4,568	4,568
1985	Corn	108,778	108,778	108,778	108,779	108,779	97,161	91,290	76,145	76,145	108,779
	Gr. Sor.	3,187	3,187	3,187	3,187	3,187	2,959	2,959	2,959	2,959	3,187
	Soybean	337	337	337	337	337	2,325	2,462	2,462	2,462	337
	Alfalfa	595	595	595	595	595	551	503	503	503	595
	Wheat	6,459	6,459	6,459	6,458	6,458	6,785	6,785	6,785	6,785	6,458
1990	Corn	144,479	144,265	144,479	122,060	133,039	120,518	120,574	101,495	97,202	144,017
	Gr. Sor.	5,053	5,066	5,053	4,973	5,027	4,734	4,720	4,092	4,639	5,081
	Soybean	1,383	1,381	1,383	1,165	1,272	3,871	3,878	3,981	3,244	1,378
	Alfalfa	642	642	642	586	614	602	602	575	551	642
	Wheat	7,940	7,970	7,940	8,146	8,076	8,331	8,301	8,240	8,312	8,005
2000	Corn	215,116	215,047	215,629	131,414	172,980	167,114	180,630	151,794	134,057	214,557
	Gr. Sor.	9,255	9,263	9,200	8,943	9,130	9,395	9,371	9,205	8,659	9,315
	Soybean	3,493	3,491	3,501	2,126	2,805	7,046	7,054	7,108	2,170	3,484
	Alfalfa	605	605	604	473	540	500	520	496	468	606
	Wheat	8,678	8,687	8,608	9,163	8,959	8,505	8,475	8,260	8,802	8,754
2020	Corn	311,246	312,145	312,566	136,882	223,628	216,847	284,059	145,099	139,133	310,911
	Gr. Sor.	13,665	13,547	13,492	12,439	13,100	55,882	12,372	104,639	12,143	13,709
	Soybean	10,931	10,963	10,978	4,802	7,851	7,968	7,943	8,040	4,882	10,919
	Alfalfa	636	633	632	446	542	625	628	583	440	037
	Wheat	10,769	10,640	10,579	11,274	11,085	11,192	11,336	10,782	10,951	10,817

Table C-6. Impact of Groundwater Management "For Instance" Cases on Crop Production, Region III

		Bushels or Tons (000) per "For Instance" Case									
		1a(i)	2a(i)	1a/2a	4c(i)(a)	5c(i)(a)	6c(i)(a)	6c(i)(b)	6c(i)(c)	6c(i)(d)	Baseline
1977	Corn	132,343	132,343	132,343	132,343	132,343	132,343	132,343	132,343	132,343	132,343
	Gr. Sor.	9,712	9,712	9,712	9,712	9,712	9,712	9,712	9,712	9,712	9,712
	Soybean	3,908	3,908	3,908	3,908	3,908	3,908	3,908	3,908	3,908	3,908
	Alfalfa	983	983	983	983	983	983	983	983	983	983
	Wheat	2,680	3,680	2,680	2,680	2,680	2,680	2,680	2,680	2,680	2,680
1985	Corn	186,974	186,974	186,694	186,974	186,974	184,774	181,742	161,012	161,012	186,974
	Gr. Sor.	14,411	14,411	14,411	14,411	14,411	14,288	14,288	15,178	15,178	14,411
	Soybean	7,735	7,735	7,735	7,735	7,735	7,479	7,479	7,479	7,479	7,735
	Alfalfa	961	961	961	961	961	961	921	921	921	961
	Wheat	1,827	1,827	1,827	1,827	1,827	1,827	1,827	1,827	1,827	1,827
1990	Corn	223,130	223,130	223,130	190,787	206,958	191,208	191,208	165,450	157,334	223,130
	Gr.Sor.	16,786	16,786	16,786	19,806	18,296	16,651	16,651	17,791	20,635	16,786
	Soybean	13,280	13,280	13,280	14,007	13,643	18,121	18,121	18,121	18,002	13,280
	Alfalfa	1,011	1,011	1,011	993	1,002	1,011	1,011	954	957	1,011
	Wheat	1,297	1,297	1,297	1,584	1,440	1,297	1,297	1,297	1,584	1,297
2000	Corn	315,320	315,272	315,444	205,581	260,447	276,365	294,213	254,267	205,663	315,282
	Gr. Sor.	13,420	13,429	13,396	25,316	19,368	14,882	13,097	14,974	25,300	13,427
	Soybean	15,942	15,945	15,934	18,245	17,094	14,922	14,920	14,920	18,110	15,944
	Alfalfa	995	995	995	934	965	920	995	920	934	995
	Wheat	595	595	594	1,326	960	592	592	592	1,325	595
2020	Corn	428,074	429,207	430,396	216,108	322,501	375,934	401,275	344,065	217,391	427,765
	Gr. Sor.	6,966	6,708	6,464	32,883	19,836	7,414	5,520	6,227	32,605	7,033
	Soybean	25,085	25,024	24,966	26,574	25,809	22,512	22,567	22,402	26,508	25,101
	Alfalfa	912	910	909	931	921	820	905	825	928	913
	Wheat	83	74	65	1,021	549	40	47	25	1,011	85

Table C-7. Impact of Groundwater Management "For Instance" Cases on Crop Production, Region IV

		Bushels or Tons (000) per "For Instance" Case									
		1a(i)	2a(i)	1a/2a	4c(i)(a)	5c(i)(a)	6c(i)(a)	6c(i)(b)	6c(i)(c)	6c(i)(d)	Baseline
1977	Corn	318,943	318,943	318,943	318,943	318,943	318,943	318,943	318,943	318,943	318,943
	Gr. Sor.	92,011	92,011	92,011	92,011	92,011	92,011	92,011	92,011	92,011	92,011
	Soybean	4,485	4,485	4,485	4,485	4,485	4,485	4,485	4,485	4,485	4,485
	Alfalfa	1,034	1,034	1,034	1,034	1,034	1,034	1,034	1,034	1,034	1,024
	Wheat	29,141	29,141	29,141	29,141	29,141	29,141	29,141	29,141	29,141	29,141
1985	Corn	434,792	434,792	434,792	434,641	434,641	427,090	417,024	391,462	391,462	434,641
	Gr. Sor.	85,485	85,485	85,485	85,529	85,529	84,086	84,086	86,376	86,376	85,529
	Soybean	33,379	33,379	33,379	33,734	33,734	33,739	33,739	31,263	31,263	33,734
	Alfalfa	1,189	1,189	1,189	1,189	1,189	1,189	1,189	1,139	1,139	1,189
	Wheat	21,769	21,769	21,769	21,784	21,784	21,769	21,769	21,769	21,769	21,784
1990	Corn	477,661	476,999	477,661	426,207	451,585	450,912	451,317	409,649	390,058	476,963
	Gr. Sor.	80,346	80,556	80,346	94,818	87,693	78,363	78,157	81,318	92,277	80,568
	Soybean	53,351	53,334	53,351	51,701	52,517	53,369	53,385	49,463	49,302	53,333
	Alfalfa	1,283	1,283	1,282	1,310	1,297	1,282	1,281	1,202	1,308	1,283
	Wheat	12,570	12,619	12,570	15,980	14,291	12,520	12,473	12,389	15,734	12,621
2000	Corn	544,507	543,027	547,198	418,604	480,585	506,075	513,626	462,048	400,048	542,453
	Gr.Sor.	59,071	59,616	58,080	100,354	80,070	55,560	55,169	57,664	95,359	59,828
	Soybean	88,959	88,909	89,050	83,319	86,106	81,932	88,768	82,061	82,672	88,890
	Alfalfa	1,343	1,344	1,342	1,383	1,364	1,240	1,339	1,236	1,377	1,345
	Wheat	318	3,223	3,111	6,212	4,724	3,015	2,986	2,836	5,915	3,238
2020	Corn	569,997	576,221	587,513	405,806	485,855	540,114	550,568	489,281	406,428	563,225
	Gr. Sor.	69,726	67,376	63,113	123,698	97,485	56,241	53,764	49,109	110,005	72,282
	Soybean	118,830	119,139	119,700	108,132	113,380	110,745	118,804	111,353	109,790	118,494
	Alfalfa	1,240	1,236	1,227	1,314	1,278	1,112	1,212	1,095	1,289	1,245
	Wheat	2,563	2,444	2,229	5,314	3,977	1,694	1,835	1,328	4,677	2,692

Table C-8. Impact of Groundwater Management "For Instance" Cases on Crop Production, Region V

		Bushels or Tons (000) per "For Instance" Case									
		1a(i)	2a(i)	1a/2a	4c(i)(a)	5c(i)(a)	6c(i)(a)	6c(i)(b)	6c(i)(c)	6c(i)(d)	Baseline
1977	Corn	134,061	134,061	134,061	134,061	134,061	134,061	134,061	134,061	134,061	134,061
	Gr. Sor.	46,243	46,243	46,243	46,243	46,243	46,243	46,243	46,243	46,243	46,243
	Soybean	26,081	26,081	26,081	26,081	26,081	26,081	26,081	26,081	26,081	26,081
	Alfalfa	1,457	1,457	1,457	1,457	1,457	1,457	1,457	1,457	1,457	1,457
	Wheat	10,404	10,404	10,404	10,404	10,404	10,404	10,404	10,404	10,404	10,404
1985	Corn	124,961	124,961	124,961	125,961	124,961	124,306	122,363	113,448	113,448	124,961
	Gr. Sor.	80,937	80,937	80,937	80,937	80,937	80,745	80,745	81,275	81,275	80,937
	Soybean	37,881	37,881	37,881	37,881	37,881	37,376	37,376	37,376	37,376	37,881
	Alfalfa	1,446	1,446	1,446	1,446	1,446	1,446	1,446	1,429	1,429	1,446
	Wheat	9,037	9,037	9,037	9,037	9,037	9,037	9,037	9,037	9,037	9,037
1990	Corn	127,525	127,157	127,525	110,403	118,909	121,214	121,372	109,193	103,812	127,416
	Gr. Sor.	100,682	100,768	100,682	104,689	102,698	101,033	100,945	100,773	104,682	100,708
	Soybean	45,591	45,622	45,591	47,040	46,320	45,292	45,258	45,192	46,691	45,600
	Alfalfa	1,476	1,476	1,476	1,468	1,472	1,476	1,476	1,477	1,469	1,476
	Wheat	6,328	6,334	6,328	6,621	6,475	6,321	6,315	6,302	6,594	6,330
2000	Corn	164,096	163,669	165,383	104,197	133,846	145,704	154,528	135,922	108,874	163,439
	Gr. Sor.	112,663	112,767	112,348	587,332	120,071	112,689	112,562	111,764	126,187	112,824
	Soybean	52,757	52,795	52,643	58,074	55,442	52,081	52,032	51,727	57,659	52,815
	Alfalfa	1,454	1,454	1,454	1,437	1,445	1,455	1,455	1,456	1,439	1,454
	Wheat	4,942	4,947	4,927	5,656	5,303	4,906	4,899	4,859	5,600	4,950
2020	Corn	236,393	240,469	243,705	95,363	166,050	203,108	224,497	171,073	100,992	234,730
	Gr. Sor.	116,862	115,899	115,134	150,190	133,485	113,152	114,081	110,789	148,859	117,255
	Soybean	60,794	60,400	60,088	74,412	67,586	60,514	58,501	65,120	73,868	60,955
	Alfalfa	1,508	1,509	1,509	1,489	1,499	1,511	1,511	1,513	1,490	1,508
	Wheat	3,334	3,302	3,278	4,409	4,870	3,175	3,206	3,097	4,366	3,346

Table C-9. Impact of Groundwater Management Options on Total Returns to Land and Management by Region

		Dollars per year (000) per "For Instance" Case									
Region		1a(i)	2a(i)	1a/2a	4c(i)(a)	5c(i)(a)	6c(i)(a)	6c(i)(b)	6c(i)(c)	6c(i)(d)	Baseline
I	1977	105,599	105,599	105,599	105,599	105,599	105,599	105,599	105,599	105,599	105,599
	1985	235,434	230,353	235,434	230,353	230,353	230,624	220,147	185,809	185,809	231,323
	1990	272,783	273,122	179,184	238,050	252,147	248,942	249,013	205,443	217,578	267,292
	2000	445,534	453,000	456,984	329,213	386,234	374,326	406,104	336,827	337,286	444,802
	2020	710,096	730,804	735,835	426,278	569,877	599,763	646,635	550,269	434,715	710,946
II	1977	27,720	27,720	27,720	27,720	27,720	27,720	27,720	27,720	27,720	27,720
	1985	88,767	85,347	88,767	85,347	35,347	82,628	73,975	52,042	52,042	84,907
	1990	115,464	116,607	119,733	98,014	104,966	97,568	97,585	70,533	78,549	111,717
	2000	215,751	221,965	223,001	143,382	179,289	164,012	184,828	139,943	146,090	215,133
	2020	385,051	397,442	398,692	196,426	291,654	306,163	335,190	275,971	198,986	385,190
III	1977	123,713	123,714	123,714	123,714	123,714	123,714	123,714	123,714	123,714	123,714
	1985	224,098	219,961	224,098	219,961	219,961	221,390	216,484	187,507	187,507	220,913
	1990	267,413	268,087	272,975	246,740	254,436	251,827	252,043	215,119	229,610	263,105
	2000	417,770	424,784	426,854	342,361	379,450	59,390	386,664	325,751	344,500	417,948
	2020	628,885	643,936	645,958	460,621	546,385	542,131	582,349	490,599	462,984	630,967
IV	1977	342,084	342,084	342,084	342,084	342,084	342,084	342,084	342,084	342,084	342,084
	1985	700,796	692,227	700,796	692,097	692,097	690,751	677,210	637,465	637,465	697,805
	1990	773,964	773,123	894,894	737,570	749,312	739,289	737,798	670,816	691,987	766,908
	2000	1,089,901	1,098,975	1,106,948	1,002,405	1,043,373	1,002,640	1,041,072	934,822	970,085	1,091,978
	2020	1,425,072	1,449,328	1,460,562	1,292,318	1,357,968	1,315,843	1,371,596	1,214,246	1,273,437	1,427,798
V	1977	286,723	286,723	286,723	286,723	286,723	286,723	286,723	286,723	286,723	286,723
	1985	415,867	413,818	415,867	413,818	413,818	414,632	412,554	399,564	399,564	414,420
	1990	471,626	471,851	474,384	467,348	468,139	464,032	463,945	444,945	460,059	469,579
	2000	625,314	628,660	630,244	609,129	616,854	595,040	609,183	575,403	611,863	625,242
	2020	846,827	855,944	857,963	810,320	829,783	785,900	814,638	750,873	813,004	847,304
State	1977	885,841	385,841	885,841	885,841	885,841	885,841	885,841	885,841	885,841	885,841
	1085	1,664,963	1,641,705	1,664,963	1,641,576	1,641,576	1,640,026	1,600,370	1,462,387	1,462,387	1,649,369
	1990	1,901,250	1,902,790	1,931,170	1,787,722	1,829,000	1,801,659	1,802,383	1,606,856	1,677,784	1,875,601
	2000	2,794,270	2,827,384	2,844,032	2,426,490	2,605,199	2,495,415	2,627,850	2,312,746	2,409,824	2,795,104
	2020	3,995,931	4,077,505	4,099,009	3,185,062	3,595,667	3,549,800	3,750,137	3,281,958	3,183,126	4,002,287

Table C-10. **Impact of Groundwater Management Options on the Outputs from the Nebraska Economy, by Sector, as of year 2000**

Sectors	Baseline Outputs	Differences From Baseline (000) per "For Instance" Case								
		1a(i)	2a(i)	1a/2a	4c(i)(a)	5c(i)(a)	6c(i)(a)	6c(i)(b)	6c(i)(c)	6c(i)(d)
Livestock and Livestock Products	$4,344,852	+117	+51	+274	+14,047	-7,021	-6,347	-3,838	-9,799	-14,396
Irrigated Crops	7,816,827	+15,700	+6,502	+37,135	-1,603,724	-801,479	-552,707	-322,725	-849,395	-1,605,352
Dryland Crops	1,724,191	-6,214	-2,294	-14,940	+411,052	+205,352	-18,074	-24,586	-32,579	+375,921
Mining and Manufacturing	19,897,341	+772	+338	+1,811	-93,316	-46,640	-42,454	-25,693	-65,552	-95,701
Retail	3,386,881	+1,074	+465	+2,523	-125,799	-62,875	-54,850	-33,036	-84,638	-128,485
Wholesale	1,969,327	+270	+117	+634	-31,970	-15,979	-14,156	-8,542	-21,850	-32,701
Services	6,431,013	+1,360	+586	+3,198	-156,775	-78,356	-66,756	-40,097	-102,973	-159,766
Fin., Ins. and Real Est. (FIRE)	8,793,905	+2,583	+1,124	+6,063	-307,606	-153,744	-137,238	-82,876	-211,845	-314,867
Utilities and Transportation	3,271,911	+941	+398	+2,220	-102,696	-51,326	-40,060	-23,801	-61,704	-103,838
Constr., Sp. Trades, Maint. and Repairs	4,066,365	+269	+117	+632	-32,142	-16,065	-14,386	-8,690	-22,207	-32,911
Households	24,068,226	+7,118	+1,032	+16,730	-825,359	-412,516	-354,618	-213,225	-547,083	-841,811
TOTALS OF ALL SECTORS=		+23,991	+8,436	+56,281	-2,882,383	-1,440,649	-1,301,643	-787,109	-2,009,624	-2,953,908