Nebraska Natural Resources Commission
State Water Planning and Review Process

PROGRESS REPORT ON THE

SANDHILLS AREA STUDY

JANUARY 1984

NEBRASKA NATURAL RESOURCES COMMISSION

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January 26, 1984

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SUMMARY

Much has been done on the Sandhills Area Study since publication of the last comprehensive report in 1981, but much remains to be done. Many groups and individuals have contributed, and much information and understanding have been gained. In some instances, however, this information produced more questions than answers. This is a report on the progress made on the study in the past three years.

INTRODUCTION

In 1980, the NRC decided to study the Sandhills area north of the Platte River. Later funding limitations and a review of information compiled for the Decision Document made it evident that it would be impossible to study the entire area as a whole, so it was divided into sections. The NRC decided to focus on the eastern section first, relating the work to the entire area whenever possible. The eastern section is not precisely defined. Different boundaries are needed for hydrologic and economic analyses, but all work is centered on the Cedar River and Beaver Creek in Garfield and Wheeler counties.

This is a comprehensive study. All water and related resources, their current and potential uses, and the effects of their development, use, and management will be considered. The amount and degree of detail used in studying these subjects will vary. Some subjects, like the modeling of the groundwater, will be very detailed. Others, like the analysis of socio-economic impacts, will be much less detailed, because more detailed information is not available.

The study and this report are divided into six sections: land resources and erosion, water supply, water quality, ecology, economy, and social and legal-institutional framework. The report includes an introduction to each study topic and a description of the recent investigations and what was learned from them. Changes in the study resulting from this new information are noted. The additional questions brought up by this information and the needs for further study are also addressed.

LAND RESOURCES AND EROSION

Sand hills are the predominant feature of the landscape of the eastern section. Most of this section has Valentine soils; loess soils with more defined drainage ways are found in the southern and eastern parts. Most of the land is used as rangeland to raise cattle. Irrigation with center pivot systems has increased greatly in the last 10 years.

Wetlands are another outstanding feature of the area and are important to its hydrology, ecology, and economy. The terminology used by different groups in referring to these wetlands is a source of confusion. A number of wetland classification systems developed in the past have been used to inventory wetlands in the Sandhills. The Corps of Engineers also interviewed residents of the area to determine local names for wetland types. They compared these local terms to those employed in four widely used classification systems. This comparison points out that terms used to describe and classify wetlands mean different things to different people. This should be kept in mind and caution should be used when discussing wetlands.

The Valentine soils found in most of the eastern section are very susceptible to wind erosion. A wind erosion equation has been developed to estimate potential soil losses for a given set of conditions. The Soil Conservation Service used this equation to estimate the wind erosion hazard for the Sandhills. They also determined the residue requirements needed to control erosion within acceptable limits. Portions of the eastern section require up to 5,400 pounds of flat corn residue per acre for adequate protection against wind erosion.

There are indications that corn yields in Sandhills soils decrease after several years of continued production. More data on current yields and potential decreases are needed to evaluate their effects on erosion potential and the economics of irrigation.

Guidelines for determining the suitability of the land for different agricultural uses would be helpful for planning and for possible regulatory actions. A system should be developed to delineate areas that can and cannot sustain irrigation development and those areas where development would be questionable.

WATER SUPPLY

A data collection program was established to supplement the limited hydrogeologic data available for the eastern section. Test hole data and groundwater level data showed that the geology of the eastern section is not as simple as previously thought. A silty "confining layer" separates the upper aquifer of saturated dunesand from the underlying principal aquifer of sand and gravel and the Ogallala Formation. This confining layer is found beneath most of the eastern section. It may be one of the most important factors in the dynamics of the groundwater system and its contribution to streamflow.

The Department of Water Resources measured the base flow in the Cedar River and Beaver Creek. The base flow increased significantly beyond the points where test drilling data indicate that the confining layer has been incised by the streams.

Seasonal losses of stock and domestic wells, reductions in wet meadow hay production, and excess water problems caused by drainage of upstream fields have been reported by ranchers in the area. In addition, streamflow reductions in the Cedar River have been projected by the Bureau of Reclamation. These water supply problems are attributed to intensive irrigation. A proper assessment of these problems cannot be made without a detailed groundwater model of the area.

The Natural Resources Commission started to develop a groundwater model of a single aquifer system similar to previous models of the area. This effort was halted when the extent of the confining layer became known, because it brings up questions about recharge to the aquifers and the effects of pumping. More test hole drilling is needed to accurately delineate the extent of the confining layer. More water level measurements are needed to determine the relationship between the upper and lower aquifers. Additional precipitation data and better estimates of evapotranspiration in the eastern section are also needed to develop an adequate groundwater model.

WATER QUALITY

Data collected by a number of different agencies indicate that surface and ground water in the eastern section is of good quality. There is concern about the potential for high nitrate concentrations in the groundwater as experienced in the Central Platte area and in portions of Holt County. Groundwater nitrate concentrations have increased in these two areas to the point that they now generally exceed the 10 mg/l nitrate-nitrogen limit established for drinking water supplies. The conditions that contribute to contamination in these areas - intensive crop production with fertilizer and irrigation, coarse soils, and a relatively shallow water table - are also found in the eastern section. It is, therefore, likely that portions of this area will experience a similar increase in groundwater nitrate concentrations in the future.

High nitrate levels in the groundwater are a concern primarily because they can affect the health of infants. The 10 mg/l nitrate-nitrogen limit for drinking water supplies was established to protect infants from methemoglobinemia which can lead to brain damage or death. Higher concentrations can also affect livestock.

Nitrate leaching losses of over 90 pounds of nitrogen per acre per year from the root zone of irrigated and fertilized corn in Valentine soils have been documented. Losses of 35 to 45 pounds of nitrate-nitrogen have been recorded for unfertilized plots. Research to obtain data for predicting nitrate leaching losses under different management systems in the eastern section using a computer model is being conducted by the University of Nebraska for the NRC. A field site has been selected and some data has been collected.

A project is also underway to monitor the vertical and horizontal movement of nitrates in the groundwater. Clusters of wells were installed near three irrigation developments in the area, with each well in a cluster screened to a different depth. Data from the first year of sampling show the nitrate levels generally higher in the upper level of the aquifer, exceeding 10 mg/l in two of the 72 wells. Traces of atrazine were found at nearly all the sites.

Projections of nitrate concentrations in the groundwater of the eastern section were made by the Natural Resources Commission. The results show that the level of development has a significant impact on the projected nitrate concentrations. The significance of the confining layer is also shown by the results. Projected nitrate concentrations for the year 2020 exceeded 10 mg/l for all but the lowest leaching loss rate when it was assumed that the confining layer restricted the nitrates to the upper aquifer. None of the projections exceeded 10 mg/l when the nitrates were assumed to mix uniformly throughout the entire saturated zone. More reliable projections of nitrate concentrations can be made when additional hydrogeologic, leaching loss, and economic data becomes available.

ECOLOGY

The ecological resources of the eastern section include grasses and grasslike plants, and the fish and wildlife supported by this vegetation and the surface waters of the area. The plant species are distributed largely according to the availability of water. Distinct plant communities are found in valleys where the water table is near the surface, in uplands with well drained soils, and in blowout areas.

The Corps of Engineers conducted a study of the wetland vegetation of Garfield and Wheeler counties. They evaluated a procedure to delineate wetlands by the identification of wetland types using aerial photography. They concluded that with additional study, greater accuracy in delineating wetlands by this procedure could be achieved.

The conversion of rangeland to cropland can be expected to result in a loss of grassland habitat and some loss of wetlands. This change in habitat would result in a change in the numbers and diversity of wildlife.

ECONOMY

The economy of the eastern section is based on agriculture. Livestock cash receipts for Garfield and Wheeler counties totaled $26.8 million in 1981. Crop cash receipts for these counties increased seven-fold since 1970, to $9.8 million in 1981.

Projections of irrigated acres are needed to assess the impacts of irrigation in the future. The Farm and Ranch Economics Model was developed to evaluate the economics of irrigated agriculture and to project future levels of development. Several sets of projections were made by using different levels of crop yields and crop prices. These projections showed how sensitive the results were to these input data. More work should be done on the selection of crop yields and crop prices. Further study should also be given to the impacts on irrigation development of the Family Farm Amendment and federal tax laws and policies.

SOCIAL AND LEGAL-INSTITUTIONAL FRAMEWORK

An understanding of social conditions and attitudes of the residents is needed to evaluate the effects of water resources development on the people of the area. Indicators which can be used to assess social conditions were researched and the available data were reviewed. These indicators include population, employment, income, property ownership and values, housing, attitudes, health and safety services, education, and recreation and entertainment. The data are sufficient to provide a general description of existing conditions and trends but are not adequate for the determination of the impacts of irrigation development. More information is needed to assess the social impacts of irrigation. Additonal information is also needed to determine the acceptability of potential solutions to problems in the area.

Table of Contents

Table of Contents (Continued)

Table of Contents (Continued)

Table of Contents (Continued)

List of Tables

List of Figures

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CHAPTER 1. INTRODUCTION

This is a report on the progress made on the Sandhills Area Study in the past two years. It provides a summary of the work done and in progress, some insights gained from that work, and brief summaries of additional study needs. Basically, it updates the Sandhills Area Study Decision Document published in March 1981[25].

INTRODUCTION TO THE SANDHILLS

The Sandhills Region of Nebraska is by far the largest sand dune area in the Western Hemisphere. The sand dunes, which were created by the wind when the area was a desert sometime back in geologic history, are now stabilized by a fragile cover of grass. In fact, the Sandhills are the largest unbroken expanse of grassland in the United States. The Sandhills area is shown in Figure 1.

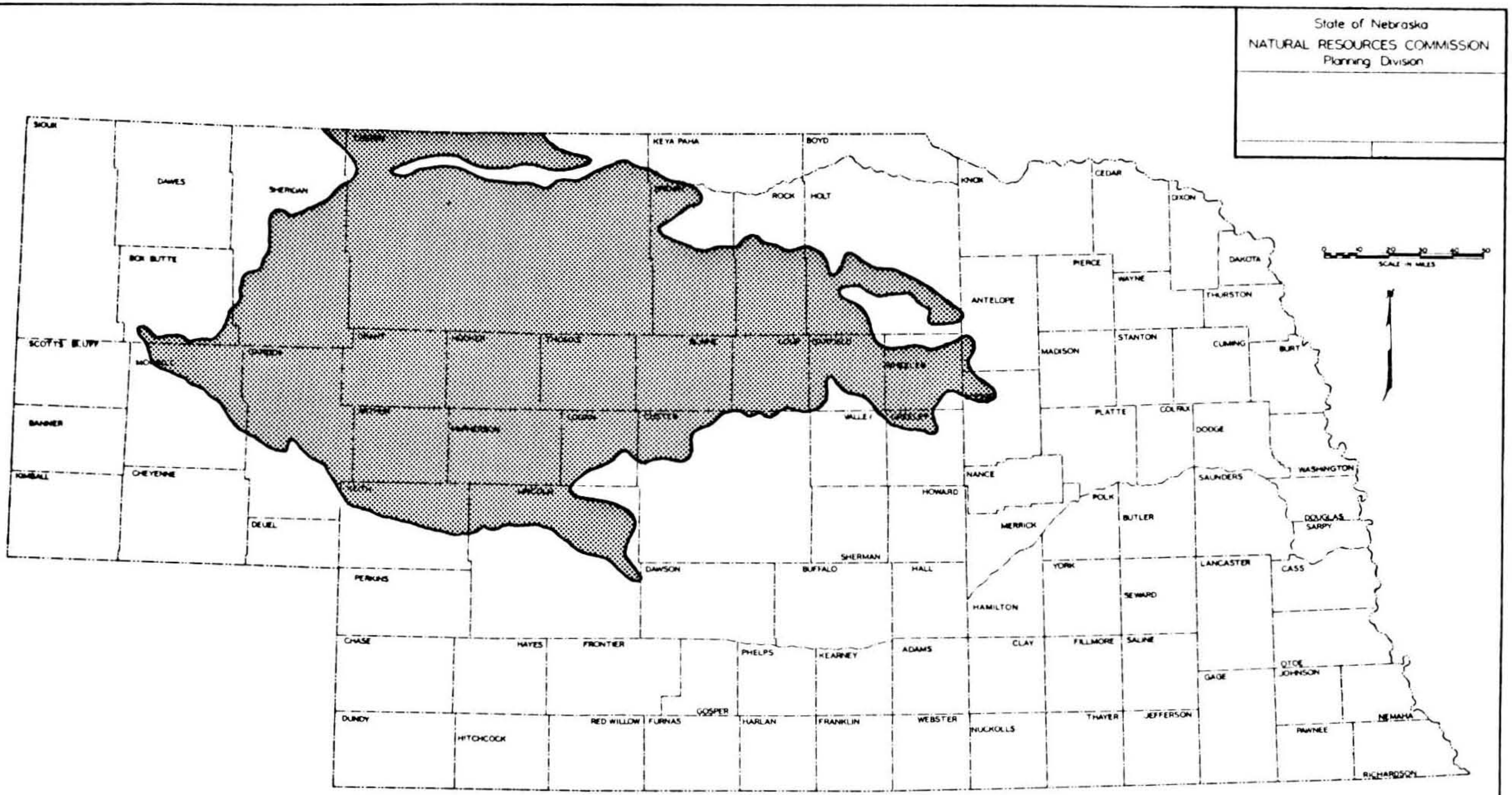
For many years, the primary use of this land has been as range for cattle. Early attempts to farm the land failed because of the droughty soils and wind erosion. Over the years, land holdings have been consolidated and ranches have grown in size and productivity. The economy and style of life in the area has become based on cattle ranching and associated activities.

The grass was not the only resource that made the area attractive to early cattlemen. Water was plentiful and easily accessible. Dependable streams, lakes, and wetlands abound in the region, all fed by the vast supply of groundwater in the sands, gravels, and permeable rocks under the dunes. The aquifers in the Sandhills are capable of producing all kinds of wells; shallow wells for domestic and stock water, and deep wells with enough capacity for stock water or irrigation.

The capability to pump up to 1,000 gallons per minute from the vast supply of water, coupled with the availability of low-priced range land that could be adapted to the use of center pivot sprinkler irrigation systems led to the development of more and more irrigated cropland in the past ten years. About five or six years ago, the pace of development and the size of the developments increased dramatically. This development has caused a wide range of impacts on the resources, economy, and quality of life in some parts of the region. These impacts caused local residents and officials to become concerned about the long-term effects of intensive development of the resources.

INTRODUCTION TO THE STUDY

The concerns of the local residents were relayed to local and state officials, who initiated several actions to establish controls that would minimize the adverse impacts. Some county officials began comprehensive land planning and zoning procedures, and the Natural Resources District requested that a groundwater control area be established. The residents' concerns were expressed at public meetings and hearings and these concerns eventually led the Natural Resources Commission to survey the area and authorize this study.



THE SANDHILLS AREA

Fig. 1

One of the primary concerns was current and potential soil erosion, because it caused a wide range of problems. When the land was first plowed, or the knobs were leveled, the wind blew large quantities of sand across the development and onto neighboring land. Fences were buried and rangeland was smothered. Many people became concerned that erosion of this type could never be stopped if the irrigated farms failed and the land was abandoned.

Other problems also caused concern. Shallow stock and domestic wells near large developments failed. Artesian wells stopped flowing during the irrigation season. Declining water tables in some areas reduced production from the wet meadows. Drainage from irrigated fields flooded meadows in other areas. Heavy truck traffic on roads built for light traffic caused deterioration of the roads and increased maintenance costs.

The potential for additional problems also caused concerns. Contamination of the groundwater with nitrates from fertilizers had occurred in areas with similar soils, and it appeared that it could occur in the Sandhills. In addition, previous studies had shown that irrigation could cause a substantial decline in the water table in the future, which would significantly reduce the flow in the Cedar River. This made the adequacy of the supply for the reservoir of a planned irrigation project questionable, and the project was dropped by the Bureau of Reclamation.

There is little doubt that irrigation produces economic benefits -- for the developer, the irrigator, and others. Suppliers, processors, and service personnel all benefit from the increased activity from crop production, even though the full economic multiplier effect is not felt locally when large operations trade outside the region. Irrigation can have beneficial impacts on both the economy and the quality of life in the region.

There must be some level of irrigation development that would enhance the economy of the region without extensively altering the cultural and physical resources. The rate and level of development that would balance the economic, social, and environmental impacts has yet to be determined.

The Natural Resources Commission reviewed the problems and issues and decided in February 1980 to conduct the Sandhills Area Study. The Commission consulted other agencies, districts and boards to secure their advice on study areas and needs. They also conducted several public opinion polls to determine the nature and extent of perceived issues and acceptable activities. A number of agencies, organizations, and individuals then cooperated in collecting available data and preparing a report on the current situation and trends, and potential strategies for management of the resources of the area. This "decision document", published in March 1981, provided the information needed to make a decision on the nature and course of the study.

SCOPE OF THE STUDY

This study is one of a series of Problem Analysis and Area Planning studies that are a part of the State Water Planning and Review Process. It is supposed to be a detailed study of the water and related resources of the entire Sandhills area north of the Platte River. Covering an area that large in that much detail made it necessary to break the area down into sections and schedule the sections over a period of years. The first section to be studied is the eastern section.

This will be a comprehensive water and related resources study, but it will focus primarily on irrigation development. Alternative strategies for management will be evaluated and the impacts on the area will be examined.

Eastern Section Study Area

The most easterly extension of the Sandhills has been one of the most intensively developed areas in the region in recent years. Groundwater irrigation development has extended northward from Greeley and Valley counties, westward from Antelope and Boone counties, and southward in Holt County. Many center pivots have been installed in large developments on the sandy soils of Wheeler and Garfield counties. Most of the sandy lands of these two counties are drained by the upper reaches of the Cedar River and Beaver Creek. Stream gaging stations on the Cedar at Spalding and Beaver Creek at Loretto make the upper parts of these two watersheds convenient boundaries for a study of this type.

These studies cannot be based entirely on hydrologic data. Information on population and economics is essential, and in most instances, this is available only for counties. In addition, county governments are likely to be a vital part of any management strategy, so it is important to consider them as a whole if possible. Garfield and Wheeler counties extend beyond the boundaries of the upper Cedar-Beaver area, but the study area has been extended to include all of them whenever possible. The eastern section is shown in Figure 2.

Level of Detail

The amount and level of detail in this study varies in different parts of the study. Most of the work has been reconnaissance study level. In a few cases, more detailed data has been used. In the inventory of land use, for instance, modern soil survey maps have been used for some, but not all, purposes. In most cases, soil association maps and similar data have been used in first stage work. In the final stage, more detailed data on soils and land use will be obtained and used wherever possible. The same is true of all other portions of the study.

Even the research projects conducted as part of the study differ in level of detail. Most of the research being done for the study is detailed. The geologic drilling by the Conservation and Survey Division and the NRC is gathering detailed information on the geology and groundwater of the area. The stream gaging by the Department of Water Resources and nitrate leaching investigation by the Department of Agricultural Engineering are similarly detailed. On the other hand, the research on the economy and social structure are restricted to available data, which is much less detailed in some respects.

PURPOSE OF THE STUDY

The purpose of the Sandhills Area Study is to produce a better understanding of the physical, ecological, economic, and social systems of the area; to identify perceived problems and issues; and to develop and evaluate potential technologies and policies that individuals, organizations, and governments at all levels could implement to address problems and enhance opportunities for development of the water resources.

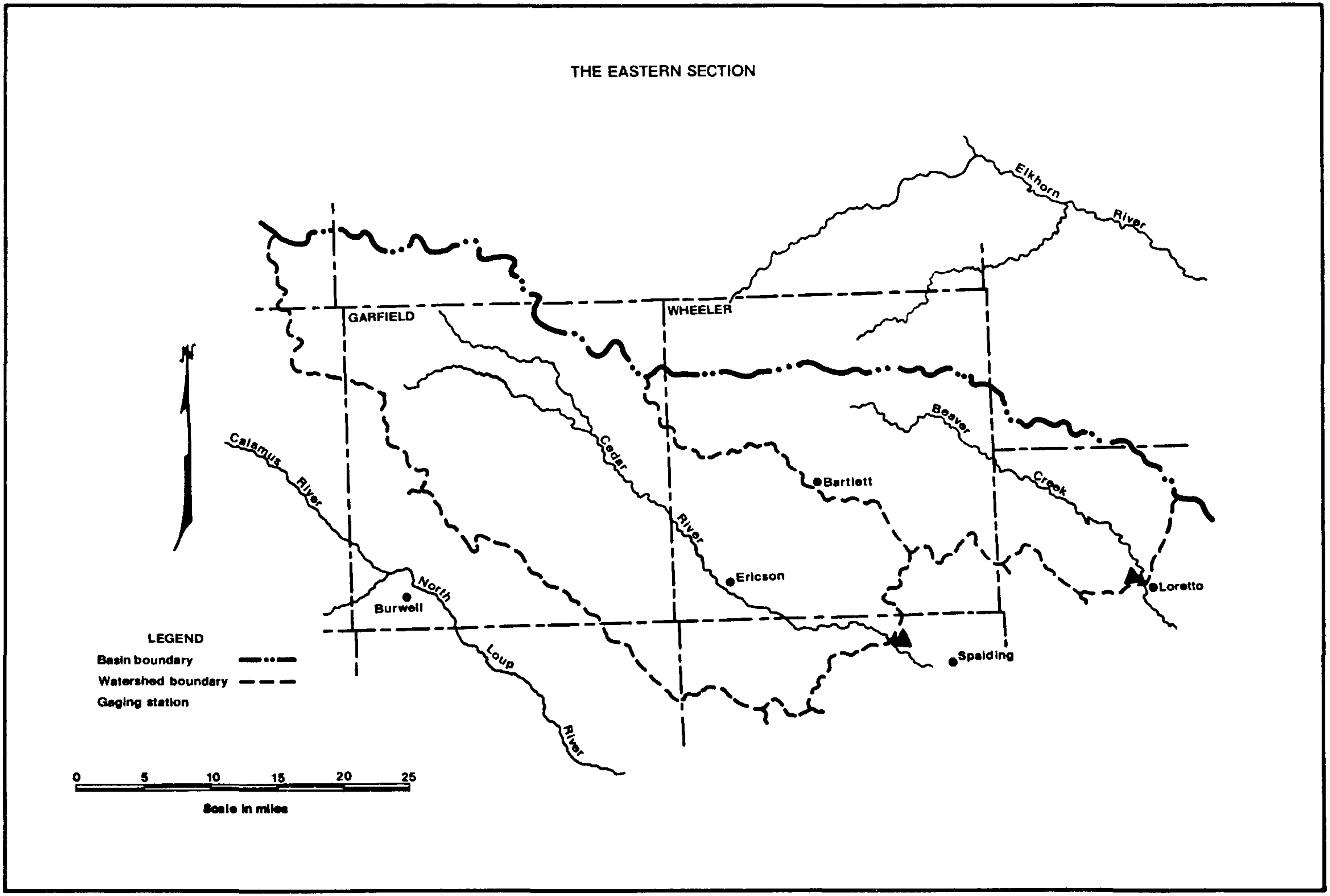

THE EASTERN SECTION
GARFIELD
WHEELER
Elkhorn
River
Beaver
Creek
Cedar
River
Calamus
River
North
Loup
River
Bartlett
Ericson
Burwell
Spalding
Loretto
N
LEGEND
Basin boundary
Watershed boundary
Gaging station
0
5
10
15
20
25
Scale in miles

Fig. 2

STATUS OF THE STUDY

The study of the eastern section was designed to be done in two stages. In the first stage, information on resources, problems, and issues was to be collected so an assessment could be made, and the issues to be analyzed in the second stage could be identified. This data collection included research projects to obtain new data on the geology, water quality, and streamflow in the area.

The information gained from the new data on geology and groundwater made it necessary to revise the study design. During the initial phase of the geologic drilling it was discovered that the geology of the eastern section, and perhaps much of the Sandhills, is more complex than previously believed. A relatively impermeable, clayey silt layer was found beneath the dune sands of most of the Eastern Section. This layer separates the aquifers, and makes it impossible to develop a simple groundwater model as originally planned. As a result, it is impossible to make preliminary projections of future water table declines and consequent problems.

This in turn affects the completeness of the information on economic and ecological impacts. Both are dependent to some extent on possible water table declines. Without the preliminary projections from the groundwater model, an assessment of the reduction in wetlands and wet meadow areas cannot be made. In fact, until the model is completed, there is some question whether the wetlands will increase or decrease.

Projections of future groundwater conditions will have to be postponed until the second stage of the study. The geologic drilling has just been completed, and more data on water levels will be collected this year. This will make it possible to develop a more detailed model of the area, as planned for the second stage.

STUDY PARTICIPANTS

This report was prepared by the Natural Resources Commission. The assistance provided by a number of individuals and agencies played an important role in the preparation of this material. The Commission provided funding for some of the work performed by these organizations. The Soil Conservation Service prepared material for the assessment and control of wind erosion. Conservation and Survey Division cooperated in the drilling of test holes, measurement of water levels, and the analysis of water quality. The Department of Water Resources conducted a series of base flow measurements and prepared a report on the surface water resources of the area. An economics model used in an earlier study was refined by the University of Nebraska-Lincoln Department of Agricultural Economics for use in the Sandhills Area Study. The section on social impacts was prepared with the assistance of the Water Resources Center. The Lower Loup Natural Resources District provided information and assisted in a number of ways. They were particularily helpful in making contacts with landowners when access to the land was required for data collection.

INTRODUCTION TO THE REPORT

This is a report on the progress made on the study by November 1983. Its purpose is to inform legislators, state agencies, natural resources districts, and other interested groups and individuals of the work that has been done, summarize what has been learned, and point out what must still be done. It should provide a better understanding of the cause of, and need for, the revision of the study design.

The material is presented in seven chapters. The first chapter presents introductory material. Chapters two through seven are each devoted to one of the six systems used to assess the study area: land resources and erosion, water supply, water quality, ecology, economy, and social and legal-institutional framework. Each chapter has a brief description of the system covered therein. The changes or problems caused by irrigation development are discussed in the level of detail allowed by the existing data. Technical measures that can be used to control these problems are briefly discussed.

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CHAPTER 2. LAND RESOURCES AND EROSION

Information on the land resources of the eastern section of the Sandhills gained since publication of the Decision Document is summarized in this chapter. The capabilities of the land and the existing uses of the land are briefly described. The problem of wind erosion and measures to control it are also discussed in this chapter.

DESCRIPTION OF LAND RESOURCES

The eastern section of the Sandhills actually lies in two different types of areas, the Sandhills and the edge of the dissected plains. For this study the boundaries of the eastern section are defined in two ways, as shown in Figure 2. Hydrologically the area includes the upper Cedar River and Beaver Creek watersheds. For economic and social analyses, the boundaries of Garfield and Wheeler counties define the limits of the study area.

GENERAL CHARACTERISTICS OF THE EASTERN SECTION

The surface features of this section are typical of the two topographic regions it lies in. These features are determined primarily by the soils and their parent materials. Most of the section is Sandhills, with sandy soils, but the southern and eastern parts lie in an area with soils derived from loess. The remnants of the plains formed by this material are dissected by streams and drainage ways. Surface features of the Sandhills portion are generally characterized by typical dune-sand relief. The dunes are largely the result of wind action on loose sand. The relief consists of irregularly distributed and sparsely grassed sand hills and ridges. The ridges and hills are separated by valleys, pockets, and swales of various sizes. Surface drainage in this sand region is generally poorly defined except in the areas near the rivers and creeks.

Areas with silty soils derived from loess are found along the southern and eastern boundaries of the study area. These areas are characterized by relief that ranges from nearly level plains to rough and broken land that has been severely eroded. The silts, sandy loams, and loamy sands that have developed in these areas allow much more surface runoff.

Most of the soils in the eastern section are similar to soils found throughout the Sandhills region. Their parent source is quartz sand deposited by either wind or running water. The major soil association found in the eastern section is the Valentine. This soil is an upland soil that developed on wind-deposited sand. The surface soil of the Valentine is thin and dark-colored and has either a fine sand or loamy sand texture. This soil absorbs precipitation rapidly and there is essentially no runoff. Slopes of Valentine soils range from one to 30 percent with some slopes to 50 and 60 percent. The areal extent of this soil association in the eastern section is greater than the combined area of all the other soils. An area along the southern border of Garfield County has soils that have developed on wind deposited loess. These are silty and loamy, well drained soils that have developed on uplands. In the southeastern corner of Wheeler County there is also an area of silty and loamy soils that developed in loess on uplands. This is a deep soil that is gently sloping to very steep and is well drained to excessively drained.

The eastern section extends into the northwestern corner of Boone County. Here the Valentine soil extends in a wedge narrowing to a point near Loretto on Beaver Creek. There is a transition from the sandy Valentine soils to the silty and loamy soils that have developed on uplands.

More detailed information will soon be available on the soils of Garfield and Wheeler counties. Soil surveys have recently been completed, and preliminary soils maps will soon be available.

WETLANDS

The numerous wetlands are one of the outstanding features of the eastern section. They have an important role in the hydrology, ecology, and economy of the area. There are many definitions of wetlands, and the same terms mean different things to different people. Wetlands are difficult to define because of their diversity and because they are transition areas between aquatic and terrestrial environments. These difficulties are increased by the fluctuations in water levels and the variation in the transition area from season to season and year to year.

Definition and Classification Systems of Wetlands

The Fish and Wildlife Service, in their report Classification of Wetlands and Deepwater Habitats of the United States, defines wetlands as lands that are transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water[5]. For this classification, wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season each year.

This Fish and Wildlife Service classification system, called the Cowardin system, is the most recent of a number of attempts to define wetlands. Those systems used some of the same terms used by farmers and ranchers who live in the Sandhills. Recently the Omaha District of the Corps of Engineers conducted a study that compared different attempts to classify and describe wetlands[36]. Table 1 summarized the results of the comparison of the different systems used to classify wetland areas and the terminology used in each.

A wetland classification system was developed as a framework for the national inventory conducted in 1954. This system is described in Circular 39 which was published by the Fish and Wildlife Service in 1956[32]. This classification system identified 20 wetland types for the national inventory. Types I through V are the most common in Nebraska so these classes were adopted and refined by the Soil Conservation Service (SCS) for their use throughout the state.

Other classifications of wetlands have been developed since Circular 39 but most have been regional systems that could not be used for a national inventory. The Corps of Engineers, which is responsible for a nationwide wetlands protection program, defines wetlands as "those areas that are inundated or saturated by

Table 1

COMPARISON OF WETLAND CLASSIFICATION SYSTEMS

Circular 39[a/] Terminology	Cowardin[b/]	Inventory of Omaha Wetlands District[c/]	USA COE	Sandhills Residents Local
Type V (Inland open fresh water)	PLR[d/]-Aquatic Bed, Uncon. Bottom Perm., Flood-Inter. Exp.	Open Water	Open Water	Pothole/Slough
Type III, IV (Inland shallow fresh marshes and inland deep fresh meadows)	PLR, Emergent Wetland, Aquatic Bed, Perm./Semi.-Perm. Flood-Inter. Exp.	Marsh	Marsh	Pothole/Slough
Type I (Seasonally flooded basins or flats)	Palustrine, Emergent Wetland - Temp. Flooded	Seasonally Flooded Basin	Subirrigated Meadow	Wet Meadow/Bog
Type II (Inland fresh meadows)	PLR, Emergent Wetland Saturated	Subirrigated Meadows	Subirrigated Meadow	Subirrigated Meadow

a/ Fish and Wildlife Service, 1953.

b/ Classification of Wetlands and Deepwater Habitats of the United States, by Lewis M. Cowardin, U.S. Fish and Wildlife Service, December 1979.

c/ Wetlands Inventory of the Omaha District, Remote Sensing Applications Laboratory, University of Nebraska at Omaha, sponsored by the Omaha District U.S. Army Corps of Engineers, June 1980.

d/ Palustrine, Lacustrine, Riverine

Source: U.S. Army Corps of Engineers [36] surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions." Their classification system in Nebraska identifies wetland areas as open water, marsh, and subirrigated meadows.

This Corps system was modified somewhat by Turner and Rundquist when they inventoried the wetlands in the Omaha District for the Corps in 1978[35]. This inventory utilized Landsat imagery and high-altitude color-infrared photography. The major modification made was classifying Type I wetlands (seasonally flooded basins) as open water, marsh, or riparian when they were detected. It was not possible to differentiate seasonally flooded basins because the inventory examined only one specific period in time (June 1978).

The Fish and Wildlife Service published the Cowardin system in 1979 as a new national classification system to replace Circular 39. This classification system was designed to describe ecological units, arrange them in a system useful to resource managers, furnish units for mapping, and provide uniformity of concepts and terms. However, this system is still not widely used by all State and federal agencies. This will undoubtedly change as there is greater exposure to the system on a national level.

What all these systems have in common is wetland classification categories that are not considered wetlands by local residents of the Sandhills. In local terminology these areas are often referred to as subirrigated meadows, wet meadows, or bogs. These are areas that can be used productively at intervals throughout the year - either to graze cattle or to cut hay or native grass. The areas that have permanent open water are locally referred to as sloughs or potholes and generally can be identified by emergent vegetation such as cattails, reeds, waterlilies, and bulrushes.

Subirrigated or Wet Meadows

Interspersed throughout the eastern section are inter-dunal areas or topographic lows that often intersect the water table or have a supply of groundwater close to the surface. Subirrigated or wet meadows are found in these areas. The soils in these areas support the growth of hay or native grasses that are an important economic resource to ranchers in this region.

Subirrigated Soil Characteristics. Soils found in areas identified as subirrigated or wet meadows in the eastern section share similar physical properties. The permeability of these soils is rapid, resulting in low runoff rates. The organic matter content is low to high, resulting in low to medium soil fertility. Since the water intake rates of these soils is high, they have a low available water holding capacity. The seasonal high water table, which is important in determining the yearly productivity of the wet meadows, ranges from above the surface to several feet below the surface in a dry year.

Some of these subirrigated soils can be cultivated, although problems can occur if proper precautions are not observed. If these soils are dryland farmed, wetness is a problem in early spring and the soils may be susceptible to wind erosion later in the summer. The soils are unsuited to gravity irrigation and are better suited for sprinkler irrigation with frequent, light applications of water. Soils that are irrigated are also susceptible to high water table problems, and some type of drainage system may be needed. Wind erosion may be a problem in some areas.

Economic Importance. The utilization of hay or native grasses from subirrigated or wet meadows is an important component of the cattle industry in the eastern section. The hay produced by these native grasses is an important supplemental feed source available to the cattle rancher, supplying the major winter feed source in some areas.

Native grasses can be harvested any time from early July to late August, although the earlier cuttings are preferred because of the higher feed value. The number of annual cuttings is usually limited to one, but during wet years sites that have been harvested early usually produce additional forage or regrowth which is used later.

Native hay has sold at or near the same market price as alfalfa. This price makes it a valuable crop that can be sold to other ranchers who lack adequate feed for the wintering of their livestock.

Location of Wetlands

Wetlands and wet meadows in the eastern section are associated primarily with the major streams that drain the region. The North Loup and Cedar Rivers and Beaver Creek have narrow bands of wetlands on both sides of the streams. Another prominent area of wetlands occurs among the inter-dunal valleys found throughout the irregularly distributed hills and ridges in the northern portions of both Garfield and Wheeler counties.

There have been several recent inventories by different groups that have produced maps of wetland areas in the Sandhills. The Bureau of Reclamation produced maps of wetland and subirrigated areas for the eastern section by using SCS county soil surveys from the 1930's. Wetlands and subirrigated meadows were identified and delineated on maps based on the soil types: wet soil or subirrigated soil. A map of the eastern section showing these subirrigated areas was prepared by the Natural Resources Commission (NRC) and distributed for review. The SCS provided preliminary material from soil surveys for Garfield and Wheeler counties now being prepared. A list of subirrigated soil types was provided for both counties. A comparison of this new information with the 1930's survey indicates the general distribution of subirrigated lands will not change substantially. Information from the new soil surveys and also from the ongoing national wetland inventory by the Fish and Wildlife Service will be used to refine the map of subirrigated areas.

In 1974, the Conservation and Survey Division conducted an inventory of wetlands over three areas of Nebraska, two of which are in the Sandhills[31]. This inventory utilized remote sensing techniques to gather information and identify three general classes of wetlands: (1) open water, (2) subirrigated meadows, and (3) marshes. Maps of the identified wetland areas were produced at a scale of 1:250,000. Unfortunately, the study only covers a small portion of the eastern section. The northern quarter of Garfield County and the northwest corner of Wheeler County are included on the North-Central Wetland Inventory map, one of three maps produced for this study.

The most recent wetland inventory that has provided some information on the location and areal extent of wetlands in the eastern section was the one conducted for the Omaha District of the Corps of Engineers. This inventory was conducted by Turner and Rundquist at the Remote Sensing Applications Laboratory, University of Nebraska-Omaha. This inventory utilized satellite and aerial imagery to inventory four classes of wetlands; (1) open water, (2) marshes, (3) riparian, and (4) subirrigated meadows. This wetland information was based on conditions during June 1978 and was mapped at the 7.5 minute quadrangle scale. Cronar overlays that fit the 7.5 minute quadrangles are available for the eastern section.

AGRICULTURAL CAPABILITY AND LIMITATIONS

In addition to the climate, the soils of an area are a major factor which determine the agricultural uses of land. Some soils are suited to a wide range of crops while others have some limitation that reduces the choice of plants or requires particular conservation practices to preserve the resource base. Some soils are better suited to permanent vegetation rather than cultivated crops.

The soils in the eastern Sandhills vary from fine sands with moderate to steep slopes to poorly drained wetland areas. The hazards to cultivation in this range of soils include wetness due to a high water table, alkalinity, wind erosion, water erosion, and steep slopes. One or more of these hazards make large portions of the area poorly suited for cultivation. Other portions are suited to irrigated corn, soybeans, alfalfa, and introduced grasses. Conservation practices such as sprinkler irrigation with frequent light applications of water, maintenance of a residue cover on the soil surface, or drainage of low areas may be required to sustain production.

The potential for irrigation development in the Loup River Basin was investigated for the Platte Level B Study[11]. Irrigable lands were identified and classified into groups A, B, C, and D. The limitations for sustained irrigation for groups A, B, and C are slight, moderate, and severe, respectively. The factors reviewed for this classification include slope, drainage, water table, depth of rooting zone, water holding capacity, intake rate, exchangeable sodium, and soluble salt content. Lands considered unsatisfactory for sustained irrigation were included in group D. Potential irrigated acreages for Garfield and Wheeler counties based on these classifications are shown in Table 2.

LAND USE AND LAND USE TRENDS

Cattle ranching is the dominant land use in the eastern Sandhills area. The region is ideal for cattle ranching because of the abundant rangeland grasses and water that are available for livestock. Recently, the acreage of cropland, primarily irrigated crops, has increased.

AGRICULTURAL LAND

Historically, the primary agricultural activity in the eastern section has been ranching, utilizing the native grassland as range. Farming, mostly irrigation with groundwater, increased significantly through the 1970's.

Table 2

EXISTING AND POTENTIAL IRRIGATION
IN
GARFIELD AND WHEELER COUNTIES

Land Category	Garfield County	Wheeler County
	(acres)	
Irrigable Lands with Slight to Moderate Limitations a/	63,880	17,870
Irrigable Lands with Severe Limitations b/	6,470	27,470
Total Irrigable Lands	70,350	45,340
Total County Area	365,800	369,332
1981 Total Irrigated Lands c/	23,000	48,000

a/ Land irrigability groups A and B, Platte Level B Study (Land Class I, II_C, II_E, II_W)

b/ Land irrigability group C, Platte Level B Study (Land Class III_C, III_W, IV_E, IV_W, VI_E)

c/ Nebraska Crop and Livestock Reporting Service[14]

Rangeland

The Rangeland Resources of Nebraska report indicated that approximately 87 percent of Garfield County and 89 percent of Wheeler County were classified as rangeland in 1969[3]. This is about 320,000 acres for each county. The area utilized as rangeland decreases as you approach the eastern and southern portions of the study area. In Boone County 25 percent of the land area was classified as rangeland in 1969.

Recently the total acreage of cropland has been growing. Most of this increase has resulted from a conversion of rangeland to cropland. The change in Garfield County has been from 24,000 acres of cropland in 1969 to 34,100 acres of cropland in 1981. The conversion of rangeland to cropland has been more pronounced in Wheeler County. Cropland increased from 23,000 acres in 1969 to 62,800 acres in 1981. This resulted in a decrease of the percentage of rangeland in Wheeler County from the 1969 figure of 89 percent to 78 percent in 1981. This trend of converting rangeland to cropland is predicted to continue. The use of center pivot systems has provided the farmer and rancher an opportunity to raise crops on rough and rolling land that could previously be used only for rangeland.

The utilization of rangeland in the eastern section depends on the forage that is produced. Much of the rangeland is used simply for grazing cattle. Native hay, sometimes called prairie hay or wild hay, is an important supplemental feed source produced on subirrigated meadows and upland sites on native rangelands. The amount of native hay production from wet meadow areas depend upon a variety of climatic variables. During wet years, excess water may impede the harvest. Less grass will be produced in dry years than in years of normal precipitation. The average yield of hay from wet meadows is approximately three-fourths of a ton per acre.

Wild hay production in Garfield and Wheeler counties averaged 0.65 and 0.83 tons per acre, respectively, over a ten year period (1972-1981), according to Nebraska Agricultural Statistics[14]. Wild hay production peaked in Garfield County in 1961 at 82,340 acres at a yield of 0.60 tons per acre; production peaked at 76,480 acres at yield of 0.50 tons per acre in Wheeler County in 1964. Subsequently, production in both counties has declined, and during 1981 both counties harvested approximately 50,000 acres of wild hay.

Irrigated Cropland

Irrigated cropland in both Garfield and Wheeler counties has increased substantially during the ten year period 1971 through 1980. Total acreage more than doubled in Garfield County and tripled in Wheeler County during this period. The acreage figures in Table 3 show the growth of irrigated agriculture in both counties.

Table 3

TRENDS IN IRRIGATED AGRICULTURE

	Garfield County		Wheeler County	
Year	Total Irrigated Area[a/] (Acres)	Center Pivots[b/]	Total Irrigated Area (Acres)	Center Pivots
1971	9,800	-	8,300	-
1972	10,900	4	11,500	50
1973	11,700	5	14,200	73
1974	12,100	13	16,700	98
1975	12,500	16	18,000	121
1976	14,000	30	23,000	158
1977	17,000	41	28,000	217
1978	20,000	70	30,000	226
1979	20,000	90	32,000	272
1980	22,000	108	44,000	376
1981	23,000	130	52,000	440
1982	23,000	-	53,000	-

a/ Source: Nebraska Crop and Livestock Reporting Service[14]
b/ Source: Remote Sensing Center, Conservation and Survey Division, UN-L

This rapid growth of irrigated agriculture can be attributed to the widespread use of self-propelled center pivot sprinkler systems. The use of center pivot systems has allowed development of sandy soils that could not be irrigated using traditional gravity methods. The growth of center pivot systems has been responsible for virtually all the growth in irrigated acres. Table 3 shows the growth of center pivots in relation to the growth of total irrigated acres in both counties.

Water Sources. The water source utilized by center pivot irrigation in the eastern study area is almost exclusively groundwater. However, there are areas irrigated with surface water. The areas that use surface water are concentrated along the Cedar River and Beaver Creek. There is also an extensive area irrigated from surface water sources along the North Loup River in the southwest corner of Garfield County around the town of Burwell.

Individuals along the Cedar River above the gage at Spalding have surface water rights to irrigate about 1,930 acres. Most of the acres with surface water rights are located in Wheeler and Greeley counties. Farmers along Beaver Creek above Loretto have water rights to irrigate about 2,330 acres, most of which are in Boone County.

Crops. Irrigated corn is the predominant crop grown in the eastern study area. Irrigated corn is responsible for approximately 90 percent of the total crop acreage harvested in both Garfield and Wheeler counties. The only other crop in the study area that has significant irrigated acres is alfalfa hay.

URBAN, BUILT-UP AND OTHER LANDS

The Nebraska Conservation Needs Report, published in 1969, identified 7,629 acres or two percent of the total land area in Garfield County as urban (Burwell), built-up, and other lands[13]. For Wheeler County, 11,513 acres or three percent of the county are in this category. Bartlett and Ericson are the only urban areas. The built-up and other lands category included railroad yards, cemeteries, airports, golf courses, parks, and recreation areas. Also included are miscellaneous land uses such as feedlots, farmsteads, farm roads, constructed dams, both public and private, and natural lakes, both public and private.

LAND RESOURCES PROBLEMS AND NEEDS

The major land resources problem in the eastern Sandhills area is wind erosion. The discussion on wind erosion in this section is directed toward the problems in cropland with little mention of rangeland problems.

WIND EROSION

Winds can erode the soils of the Sandhills when natural vegetation is reduced by overgrazing or removed mechanically. Wind erosion problems can include the loss of the soil, damage by blowing sand, and deposition. Problems of blowing sand have been reported by ranchers near irrigation developments. These problems were most evident when the sod was first broken and center pivots were installed; blowing sand was only a minor problem after the cropping system was well established. Seven ranchers reported a total of 75 acres of rangeland covered with sand. Two of these ranchers reported fences covered with sand. It has also been reported that blowing sand has damaged young corn plants to the extent that irrigators have had to replant three or four times in a single season.

Factors Affecting Wind Erosion

The process of wind erosion consists of the initiation of movement, transportation, and deposition of soil particles. Movement of soil particles begins when a strong, turbulent surface wind generates sufficient energy to overcome gravity. Most soil particles bounce over or roll along the surface when transported by the wind; only very small particles are moved by suspension. Deposition occurs when the wind subsides or when the particle becomes trapped or sheltered from the wind.

The major factors affecting wind erosion are climate, soil characteristics, surface roughness, vegetation, and length of erodible surface along the prevailing wind direction. The climatic factors - precipitation, temperature, humidity, and wind - affect soil moisture, which stabilizes the soil by the cohesive force of the water film surrounding the soil particles. Wind also provides the energy for particle movement. The texture, density, and structural stability of the soil determine erodibility. Large and extremely small particles are resistant to wind erosion as are soils which are held together by cohesion.

The velocity of the wind near the surface is affected by the surface roughness. A roughened soil surface can increase wind turbulence and expose smaller areas to greater wind forces but in general reduces wind erosion. Vegetation also reduces surface velocity and traps soil particles. The length of the erodible surface is also a factor in wind erosion as the rate of erosion increases with the length of the erodible surface along the direction of the wind to a maximum the wind can sustain. The maximum rate cannot be reached if the length of the unprotected eroding area is shortened sufficiently. Knowledge of the above factors can be used to estimate the wind erosion hazard and also to develop measures to control the problem.

Wind Erosion Equation

A wind erosion equation was developed for use by the Soil Conservation Service which relates soil loss to the factors which affect wind erosion[44]. The soil loss for a particular field can be determined by estimating numerical values for these factors based on the existing conditions in that field. The equation is often used in reverse to determine management requirements to keep erosion within acceptable limits. The wind erosion equation is:

$$E = f(I\text{-}K\text{-}C\text{-}L\text{-}V)$$

where:

- E = the potential average annual soil loss
- f = a symbol showing E to be a function of the other variables
- I = soil erodibility index
- K = ridge roughness factor
- C = climatic factor
- L = field length
- V = equivalent quantity of vegetative cover

Wind Erosion Hazard in Eastern Sandhills

An assessment of the wind erosion hazard for the Sandhills region was made by the SCS. A "hazard index" - the product of the soil erodibility index and the climatic factor - was computed for each general soils association area. A soil erodibility index for each association was calculated from the index of each major soil series within that association. Climatic factors were determined for the critical months of March, April, May, and June. They appear as bands across the Sandhills increasing from the east to the west and south. The wind erosion hazard for the eastern section of the Sandhills is shown in Figure 3.

In the eastern Sandhills area the wind erosion hazard is the lowest (index < 70) near the streams and in the wetland areas, particularly in northern Wheeler County, and along the transition zone to the hardlands in the south and east. The higher hazard areas are found across the central portion of the section where soils are predominantly of the Valentine series and the topography is more variable. These areas have a wind erosion hazard index of 90 to 100. The eastern Sandhills area has a much lower wind erosion hazard than the western Sandhills where, in places, the index exceeds 170. This variation is due to a drier climate and differences in soils.

The wind erosion hazard can also be expressed in terms of the vegetative cover or residue required to control the soil loss to an acceptable amount. Residue requirements are discussed in a following section of the report.

TECHNICAL MEANS OF REDUCING WIND EROSION PROBLEMS

Wind erosion should be recognized as a potential problem whenever there is inadequate cover on the soil surface. Wind erosion in rangeland can be controlled with proper range management, particularly proper grazing practices. Soil surveys indicate a variety of soils in the eastern Sandhills and a corresponding variability in the wind erosion potential. This information should be considered in the selection of sites for center pivot irrigation development.

Residue Requirements

Wind erosion in cultivated fields can be controlled if adequate vegetation or residue is kept on the soil surface. The amounts of residue required to control soil losses to acceptable amounts was calculated by the SCS utilizing the wind erosion equation described in a previous section. For these calculations it was assumed that the acceptable soil loss was four tons per acre per year, the field length was 3,000 feet, and the ridge roughness factor was 0.9. The residue requirement for flat small grain, standing grain sorghum, flat grain sorghum, standing corn, and flat corn for each wind erosion hazard index and these conditions are shown in Table 4. This table can serve as a general guide; the requirements for a particular field depend upon the characteristics of the site.

For the eastern Sandhills the maximum erosion hazard index is 90. Approximately 3,900 pounds of standing corn and 5,400 pounds of flat corn residue per acre are needed to control soil losses for these conditions. A yield of about 100 bushels per acre would be needed to produce 5,400 pounds of corn residue.

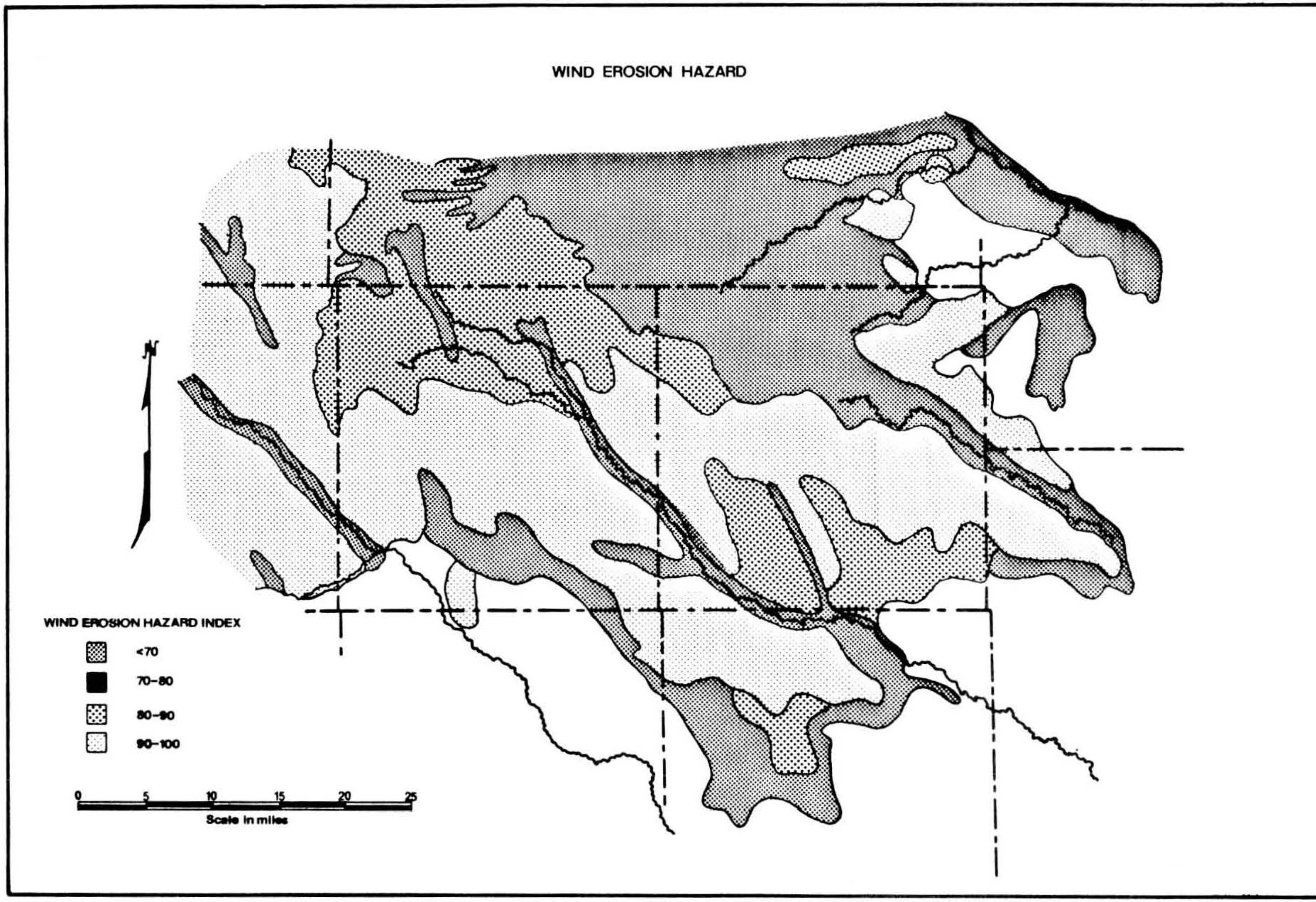
WIND EROSION HAZARD
WIND EROSION HAZARD INDEX
<70
70-80
80-90
90-100
0
5
10
15
20
25
Scale in miles

Fig. 3

Table 4

RESIDUE REQUIREMENTS FOR WIND EROSION HAZARDS

Wind Erosion Hazard Index[a]	Residue Requirements[b]: Flat Small Grain	Standing Grain Sorghum	Flat Grain Sorghum	Standing Corn	Flat Corn
			(pounds/acre)		
170+	2,500	3,750	7,500	5,500	7,500
160-170	2,250	3,500	6,950	5,250	6,950
140-160	2,200	3,300	6,550	4,800	6,550
130-140	2,100	3,000	6,400	4,600	6,400
120-130	2,050	2,900	6,300	4,500	6,300
110-120	2,000	2,800	6,250	4,400	6,250
100-110	1,850	2,650	5,750	4,200	5,750
90-100	1,750	2,500	5,400	3,900	5,400
80-90	1,650	2,300	5,000	3,500	5,000
70-80	1,550	2,200	4,800	3,300	4,800
<70	1,500	2,200	4,750	3,300	4,750

a/ The product of the climatic factor and the soil erodibility index in the wind erosion equation.

b/ Based on an acceptable soil loss of 4 tons/acre/year, a field length of 3,000 feet, and a ridge roughness factor of 0.9.

Source: Soil Conservation Service

Residue Management

The system of farming operations should be designed to disturb the crop residue as little as possible. The land should not be tilled in the fall; the stalks should be left standing following harvest. Cattle can be allowed to graze only if there is residue in excess of requirements. In the spring, planting should be done utilizing no-till methods in order to minimize disruption of the soil and residue cover. Herbicides are needed for weed control.

In fields where corn is cut for silage, the stalks are removed and little residue is left on the land. A cover crop such as rye should be sown following the cutting. In the spring a herbicide should be used to suppress the cover crop prior to no-till planting.

Other Management Practices

In addition to crop residue use and conservation tillage, other practices may be useful in controlling erosion on irrigated fields. The application of water with a center-pivot system can reduce wind erosion. This practice is limited by economics, the speed of the pivot, and by potential adverse effects to groundwater quality and quantity. Seriously eroding areas may require critical area planting of some cover crop. Emergency tillage to build up soil ridges may be beneficial under some circumstances. A system of perennial vegetation strips on the field borders can reduce erosion by reducing wind velocities near the surface. Field windbreaks can also reduce wind velocities.

ADDITIONAL STUDY NEEDS

Much is known about the land resources of the eastern section but additional information is needed to properly establish the best uses of this resource. The soil loss tolerance and capability and classification for agricultural uses should be addressed in the second stage of the study.

SOIL LOSS TOLERANCE

The soil loss tolerance, or permissible soil loss, is the maximum rate of soil erosion that will permit a high level of crop productivity to be sustained economically and indefinitely. This soil can be lost because soil formation about keeps pace with this rate of loss. The soil loss tolerance varies with the kind of soil. The SCS has determined the tolerance for each kind of soil. The primary factors in this determination are (1) the maintenance of an adequate rooting depth for crop production and (2) crop yield reduction. These values range from one to five tons per acre per year. The soil loss tolerance for the Valentine, Dunday, and Els series and most other soil series in the eastern section is five tons per acre per year[38].

The soil loss tolerance should be reviewed to verify that the rate established for these sandy soils is adequate for the sustained production of irrigated corn and not just for native grasses, the more conventional use of the land. In some places in the Sandhills, areas that were plowed and abandoned many years ago still have not been restored to full productivity. The rate of restoration in sandy soils in those areas may be much less than four or five tons per acre per year. There are many indications that corn yields decrease after several years of continued production on sandy soils in this area. While soil losses greater than five tons per acre per year may account for these reduced yields, the corn yield in sandy soils should also be re-examined for the effect on soil loss tolerance.

CAPABILITY AND CLASSIFICATION OF SOILS FOR AGRICULTURAL USES

The SCS identifies the capability class of each mapping unit in the county soil surveys. The description of the mapping unit includes a statement about the suitability of the area for growing crops. Both dryland and irrigated conditions are considered. It appears that no standardized criteria has been established to determine the suitability of soils for different agricultural uses. Guidelines for determining the suitability for different agricultural uses would be very useful for planning purposes and for possible regulatory actions. The criteria used by SCS should be documented for the second stage of the study. It would be very useful to have a delineation of areas where the land can be converted to irrigated cropland and where it should remain as rangeland. A gray area between these extremes where certain crops can be grown or where particular management practices are required may also need to be identified. An understanding of the site selection criteria from the developer's point of view would also be useful.

Table 2 shows that more acres were irrigated in Wheeler County in 1981 than are classified as irrigable, i.e. in groups A, B, and C. This indicates that some of the more marginal lands are being developed for irrigation. It is not known if irrigation on all of these lands can be sustained for a long period or if these operations are economical. It has been shown that wind erosion can be controlled with proper management; other problems as groundwater quality degradation are less well understood. The comparison of these figures for Wheeler County also indicates that the system or criteria used to classify irrigability of lands should be reviewed, particularly considering existing technology and management practices. This also should be done during the second stage of the study.

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CHAPTER 3. WATER SUPPLY

A description of the groundwater and surface water resources of the area is presented in this chapter. The efforts to gain a further understanding of the hydrology of the area and the needs for modeling the groundwater are described.

GROUNDWATER RESOURCES

The geology of the area must be understood in order to properly assess the groundwater resources. When this study began there was little detailed information on the geology of the area. It was therefore necessary to initiate data gathering programs.

DATA COLLECTION PROGRAMS

A program to drill geologic test holes was conducted by the Natural Resources Commission and the Conservation and Survey Division to gain a better understanding of the geology of the study area. Thirteen test holes were drilled by a contract driller in the fall of 1982. In the spring and early summer of 1983 the Conservation and Survey Division drilling rig was used to drill an additional 20 test holes. The drilling sites were located to supplement existing data and to fill in areas where no geologic information existed. Locations of the test holes are shown on Figure 4.

The depth to water table was measured in approximately 275 irrigation wells and several stock wells during the spring of 1983. Well owners were contacted in the fall of 1982 to obtain permission to measure their wells and to record pertinent information such as well depth, surface altitude, and exact location. The National Resources Commission, Conservation and Survey Division, and Lower Loup Natural Resources District participated in this effort.

PRELIMINARY RESULTS OF DATA COLLECTION PROGRAMS

The preliminary findings of the data collection effort revealed a significantly different interpretation of the geology of the study area than what had previously been envisioned. The prevailing concept of the geology of the study area prior to our drilling effort was that the sand deposits rested directly on the underlying sand and gravel layer to form a single aquifer. It was thought that isolated, or non-continuous, silt and clayey silt layers occurred within the sand, but these layers had little effect on recharge to the aquifer. The work done for the Level B Study and initial modeling efforts in this study were undertaken with this concept of the geology in mind.

The results of our test hole drilling program have changed this concept of the geologic conditions. An extensive confining layer of silt and clayey silt was found in 31 of the 33 test holes drilled throughout the study area. The sand, which was thought to connect to the sand and gravel, was found to be a relatively thin veneer on top of a clayey silt confining layer. This confining layer separates the upper aquifer of saturated dunesand, where it exists, from the underlying principal aquifer of sand and gravel and the Ogallala Formation.

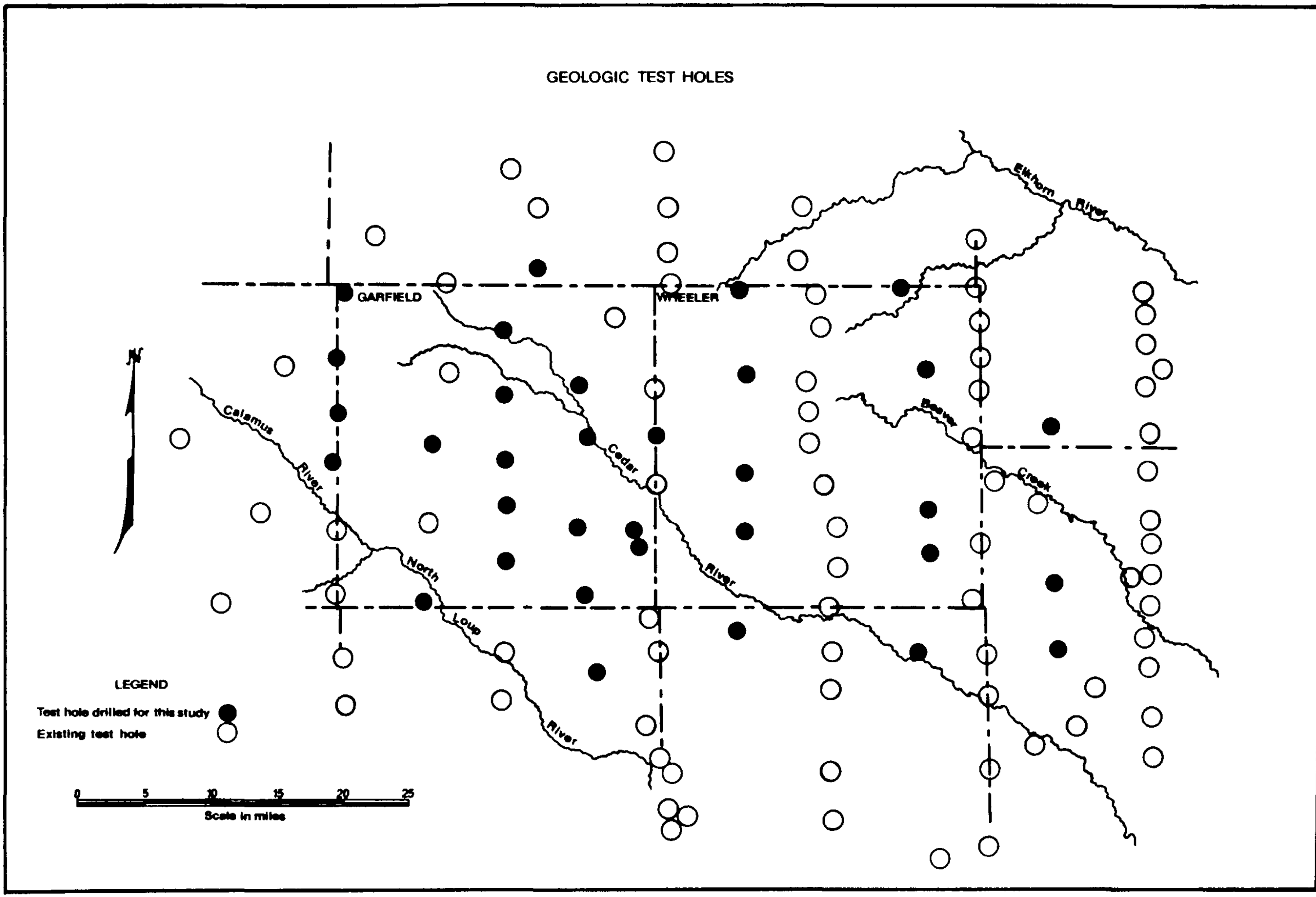

GEOLOGIC TEST HOLES
N
GARFIELD
WHEELER
Elkhorn River
Calamus River
Cedar River
North Loup River
Beaver Creek
LEGEND
Test hole drilled for this study
Existing test hole
0 5 10 15 20 25
Scale in miles

Fig. 4

The water levels of the upper sands and those of the principal aquifer do not coincide. Clusters of wells for water quality sampling installed recently for the Lower Loup Natural Resources District serve as piezometer nests which show that water levels in wells sealed above and below the confining layer are not the same. The difference in water levels is also evident where flowing wells occur along certain reaches of the Cedar River and Beaver Creek valleys. This phenomenon indicates that water levels in the aquifer beneath the confining layer are above the land surface while the water table in the sands above the confining layer is a few feet beneath the land surface. Evidence from other piezometer nests indicate that water levels of the principal aquifer are below the water levels of the dunesands in areas between drainageways.

Results from the drilling program and examination of irrigation well logs indicate that the confining layer has been completely incised below certain points on the Cedar River and Beaver Creek. Rapid increases in stream baseflow, measured in seepage runs on Beaver Creek and the Cedar River, appear to occur at the points of complete incision of the confining layer and continue for a considerable distance downstream from these points.

The most apparent differences in the prevailing concept of the geology and the newer or revised concept are illustrated in Figure 5. The old concept depicts a one-aquifer system with a water table condition. Silty clay layers are discontinuous. The new concept depicts two aquifers separated by a continuous confining layer. In this illustration the piezometric surface corresponds to the water level in wells finished in the lower sands and gravels, and the water table corresponds to the water level in wells finished in the sands overlying the confining layer. The piezometric level is higher than the water table in the river valley, and lower than the water table away from the river valleys.

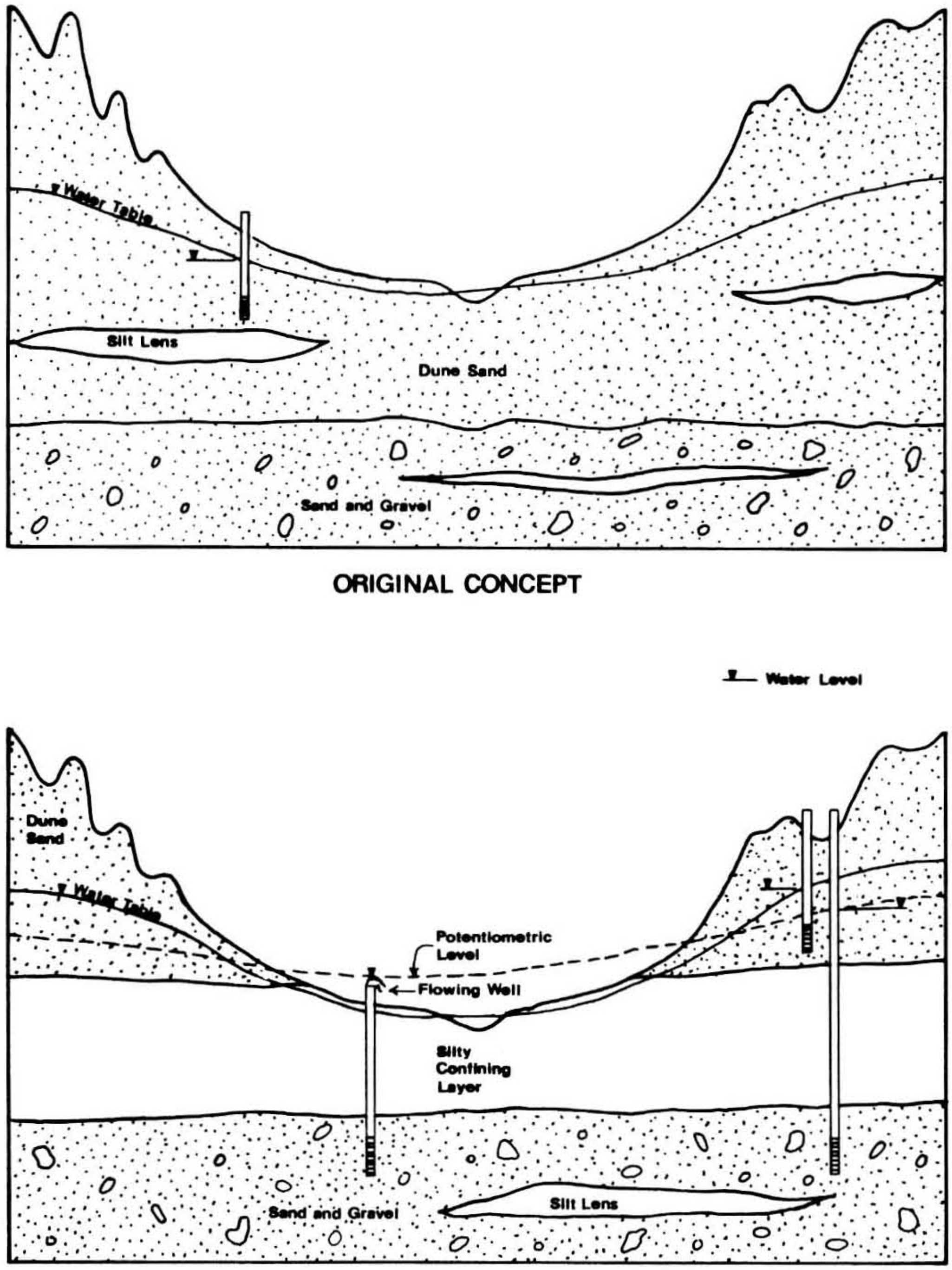
The new concept provides a basis for describing the groundwater flow system of the study area. Precipitation over the area results in either runoff, infiltration, or evapotranspiration. Dunesands have a higher proportion of infiltration than the loess hardlands. Water infiltrating the dunesand percolates downward until reaching the water table and then flows laterally. Eventually, this water either reaches wet meadows and lakes where it is lost back to the atmosphere through evapotranspiration, reaches a drainageway where it is lost as stream baseflow, or percolates slowly downward through the clayey silt layer and recharges the principal aquifer. Water entering the principal aquifer from above, along with groundwater inflow to the study area are either discharged vertically upward in the vicinity of the drainageways or leaves the study area as groundwater outflow to the east and south.

GENERAL DESCRIPTION OF GEOLOGY

The test hole information indicates a general repeating sequence of sediments occurring throughout the study area. These sediments can be described from youngest to oldest as follows:

(1) Surface dunesands - a relatively thin layer of fine to medium grained sand blown into dune morphology by wind action. The overall thickness is variable; it is usually thicker beneath the dunes and thinner in the meadows between the dunes.

ILLUSTRATION OF THE GENERALIZED CONCEPTS OF THE GEOLOGY AND GROUNDWATER OF THE EASTERN SECTION



REVISED CONCEPT

(2) Silty and clayey zone - a zone consisting of windblown silts, reworked silts and fluvial silts, clayey silts, and sands. Fine sands are occasionally interbedded with the fluvial and reworked silts.

(3) Sands and gravels - a layer of sand and gravel deposited throughout the study area. The thickness of this layer can vary from a few feet to over a hundred feet. The texture of the material varies both horizontally and vertically. Several clayey or silty lenses can occur in the sands and gravels. These layers range from less than one foot to greater than ten feet in thickness.

(4) The Ogallala Formation - a thick sequence of semi-consolidated sands, silts and clays. The predominant texture is sand and sandstone with interbedded silt, sandy silt, and clayey silt layers. Numerous fossilized rootlet casts and bone fragments are found throughout the formation. Marly zones, thought to be related to ancient soil development, also occur. The basal portion often contains siltstones, claystones, and coarse sand or very fine gravel containing numerous lithic clasts. This portion may be part of a pre-Ogallala geologic formation. This formation is frequently tapped by irrigation wells especially where the overlying gravel is relatively thin or is absent.

(5) Bedrock - shales or weathered shales of the Pierre Shale and marls and clays of the Niobrara Formation. These fine textured, sticky sediments form the base of the principal aquifer except where a portion of the overlying sediments are sufficiently impermeable to be considered as part of the bedrock.

The Principal Aquifer

The principal aquifer of the study area is comprised of two main geologic components, the younger sand and gravel layer and the older Ogallala Formation. All of the irrigation wells tap the sand and gravel and the majority extend deeper and partially penetrate the Ogallala sands and sandstone. Stock and domestic wells usually penetrate to the sand and gravel, but occasionally tap only the saturated dunesands resting on top of the silty zone.

No pumping tests have been conducted within the study area to determine the hydraulic characteristics of the principal aquifer. Hydraulic conductivities, storage coefficients, and transmissivities must, therefore, be estimated from texture descriptions.

The sand and gravel layer ranges in thickness from about 15 feet to about 140 feet with an average thickness of about 70 feet. Grain sizes range from fine sand to medium gravel with predominant grain size being coarse sand to very fine ic gravel. Hydraulic conductivity, an important aquifer characteristic, is a measure of the rate at which water can move through the aquifer material. Hydraulic conductivity for several test hole sites was estimated by using a chart developed by Reed and Piskin[30]. This analysis shows an average hydraul conductivity of 650 to 700 gallons per day per square foot (gpd/ft^2) for the sands and gravels. Transmissivity, an aquifer characteristic indicating its capability to transmit water, can be calculated by multiplying the saturated thickness by the hydraulic conductivity. Transmissivity for the sand and gravel layer is estimated to be in the range of 10,000 to 100,000 gallons per day per foot (gpd/ft). The porosity, or the volume of the space between the sand and gravel grains, is estimated at 25 to 40 percent of the total volume of the sediment. The specific yield, or "drainable porosity" is estimated at about 25 percent of the volume.

The Ogallala Formation is comprised of a sequence of sediments much finer than the sand and gravels. Texture ranges from clay size to very fine gravel. The thickness of the Ogallala sediments appears to be quite variable, ranging from around 200 feet to greater than 400 feet. Average thickness is about 360 feet. The texture of the sediments is equally variable, including very fine to very coarse sands, lightly cemented sands, silts, clayey silts, and siltstones. Hydraulic characteristics are difficult to determine because of this variability in texture. The coarser textured horizons yield significant amounts of water to wells and are an important source of water in the study area. Sufficient quantities of water are usually available for high capacity irrigation wells due to the great thickness of the Ogallala Formation.

The Confining Layer

The zone of silty material between the sands and gravels and the surface dunesand is referred to as the "confining" layer because it restricts vertical water movement and confines the underlying aquifer. The lateral extent of this layer is greater than was thought prior to the drilling of test holes for this study. The layer appears to be present throughout the study area except along lower reaches of the Cedar River and Beaver Creek where it has been incised. It is up to 180 feet thick and has an average thickness of about 65 feet. Generally, the thickest areas run parallel to main drainageways. It is composed of both windblown and fluvial silts, sandy silts, and clayey silts and sands. The upper portion is generally a massive yellowish brown silt or clayey silt, probably of eolian origin. Many test holes indicate a lower portion of cohesive, sticky, clayey silts or clayey sands, probably of fluvial origin. This lower portion frequently contains interbedded sand lenses.

The clayey horizons of the confining layer have very low hydraulic conductivities. Conductivities are estimated to be in the range of 20-50 gpd/ft^2 for the massive yellow silts and in the range of 10-20 gpd/ft^2 for the clayey sediments.

This confining layer has a significant impact on the water resources of the study area. It has a major influence on the rates of recharge to and discharge from the principal aquifer. The water table and artesian pressure are influenced by this layer. The leaching of nitrate to the aquifer, a problem discussed in the next chapter, is also affected by this layer.

SURFACE WATER RESOURCES

The surface water resources of the eastern Sandhills include streams, lakes, and marshes. The Cedar River and Beaver Creek drain this portion of the Sandhills and continue through the loess hills region to the south and east to the Loup River. These streams are shown in Figure 6. The lakes and marshes are located in the northern portions of Garfield and Wheeler counties and along the stream channels.

STREAMS IN THE EASTERN SECTION

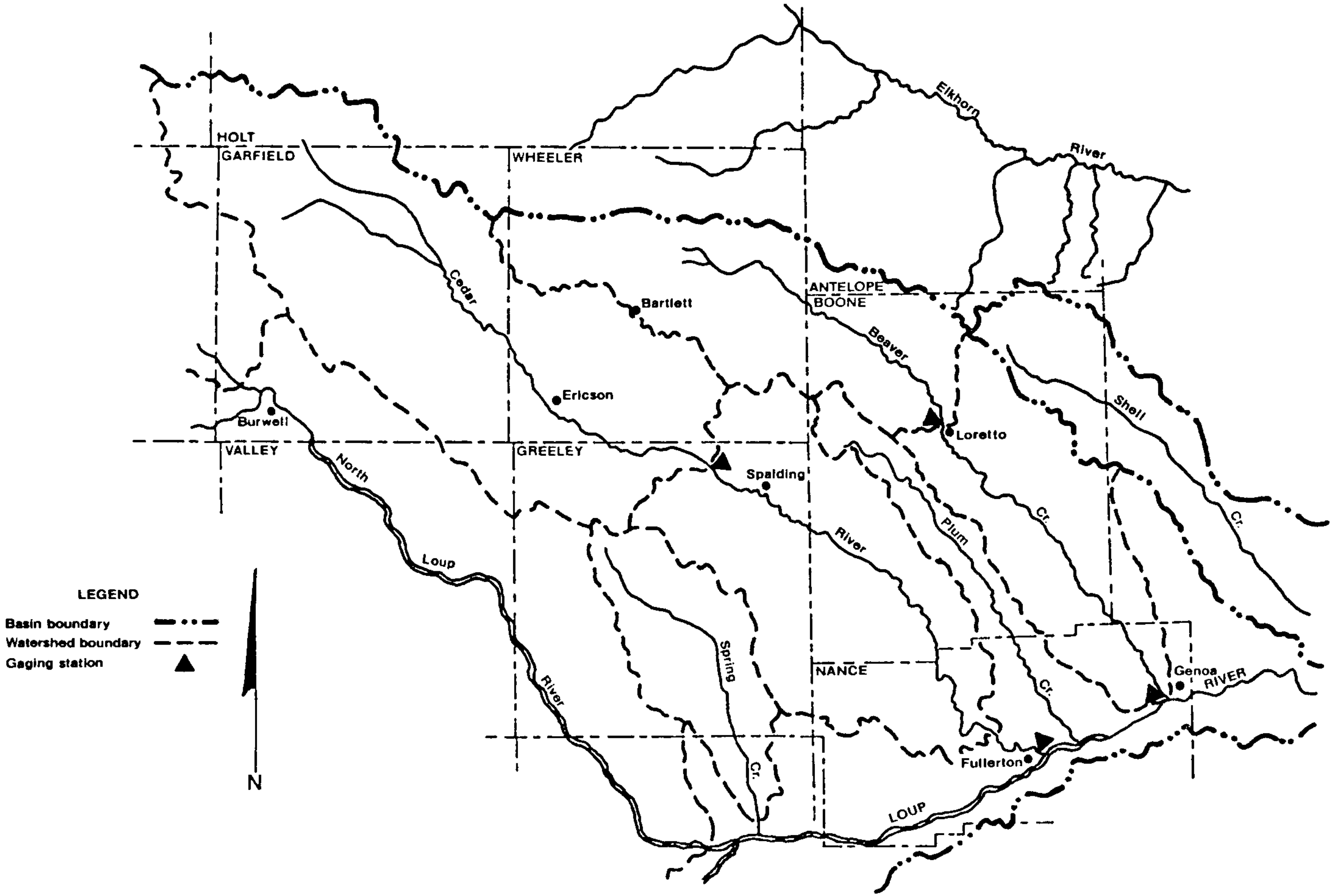


Fig. 6

CEDAR RIVER AND BEAVER CREEK

The surface water resources of the Cedar River and Beaver Creek were studied and reported on by the Department of Water Resources[28]. Both the Cedar River and Beaver Creek rise in the broad, marshy wet meadows of the eastern Sandhills. The sand formations surrounding the headwaters region tend to be low in relief and are set back a considerable distance from the channels. The waterways begin as shallow ditches which meander through cattails and marsh grass. These streams are fed by seeps and springs draining the vast groundwater reservoir underlying the Sandhills.

Water Supply Characteristics

Streamflow data for Cedar River and Beaver Creek consist of the records from continuously recording stream gaging and from various point measurements made throughout the basins since 1894. The collection of continuous streamflow records in the area began with the establishment of gages in 1940 near Fullerton on the Cedar River, and at Genoa on Beaver Creek (several months of continuous record were collected on the Cedar River near Fullerton in 1931 and 1932). Gages were added on the Cedar River near Spalding and on Beaver Creek at Loretto in 1944. Additional gages were operated on the Cedar River at Primrose and Belgrade from 1959 to 1965. Although four gages are in operation at present, the gages near Spalding and at Loretto were not operated for extended periods during the last three decades. Missing discharge records for those sites were estimated by the Department of Water Resources using hydrologic simulation techniques.

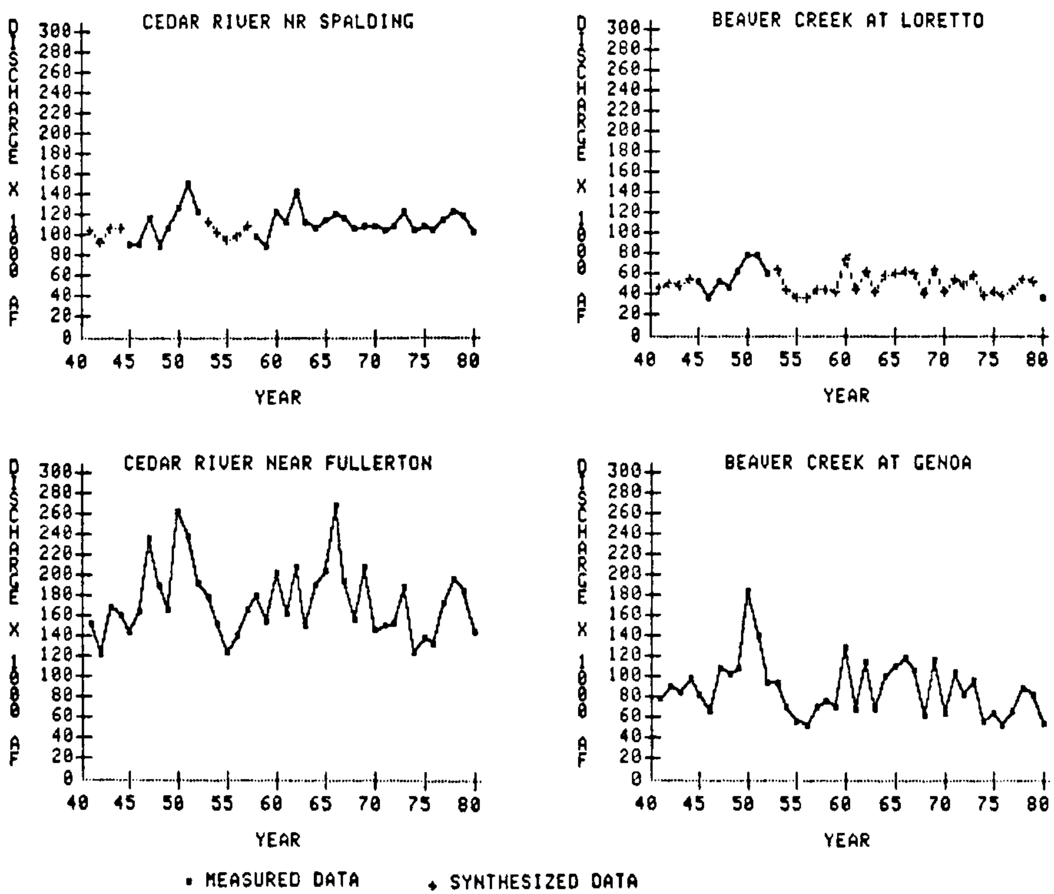
The other segment of the streamflow data base consists of point or miscellaneous measurements taken at many locations in the area. A portion of the miscellaneous measurements were obained under base flow conditions, i.e., during periods of no runoff, and when significant withdrawals and water use by nearby plant life are at a minimum. The remainder of the data base consists of miscellaneous measurements obtained under conditions varying from midsummer drought to severe flooding.

The gages at Spalding and Loretto are located several miles beyond the Sandhills in the loess hills region. The gage on the Cedar River near Spalding has a drainage area of 762 square miles, of which about 50 square miles are reported to contribute directly to surface runoff. The gage on Beaver Creek at Loretto has a drainage area of 311 square miles, of which about 100 square miles contribute directly to surface runoff. Although these gages, particularly the Loretto gage, are influenced by surface runoff from the loess hills, their records do exhibit the uniformity characteristic of Sandhills streams.

The average annual flow of the Cedar River at Spalding for 32 years of record is 111,600 acre-feet. The average annual flow of Beaver Creek at Loretto for 10 years of records is 57,090 acre-feet. Hydrographs showing the average annual water supply provided by these streams are shown in Figure 7. The Cedar River carries an average flow which is nearly double the discharge of Beaver Creek. The fluctuations in the hydrographs can be attributed to short term climatic variability, rather than significant changes in basin hydrology.

Table 5 lists the average flow expected during the wettest and driest months, and a statistical 30-day (monthly) average. Greater variability is evident when comparing average maximum and minimum values for the downstream stations in each basin. The impact of more rapid runoff is apparent.

AVERAGE FLOW AT GAGING STATIONS



Source: Nelson and France (28)

Fig. 7

Table 5

AVERAGE FLOW DURING MONTHS OF GREATEST AND LEAST FLOW
AND MEAN MONTHLY DISCHARGE (1941-1980)

Gaging Station	Maximum (Month)	Minimum (Month)	Mean
		(acre-feet)	
Cedar River near Spalding	10,844 (June)	7,843 (Sept.)	9,101
Cedar River near Fullerton	21,574 (June)	11,142 (Sept.)	14,478
Beaver Creek at Loretto	6,769 (March)	2,696 (Sept.)	4,311
Beaver Creek at Genoe	14,027 (June)	4,542 (Sept.)	7,362

Source: Nelson and France[28]

Table 6

MAXIMUM AND MINIMUM DISCHARGES IN
CEDAR RIVER AND BEAVER CREEK

Stream and Gage	Period of Record	Maximum	Minimum
		(cubic feet per second)	
Cedar River near Spalding	1944-1953, 1957-1981	4,000	30.00
Cedar River near Fullerton	1931-1932, 1941-1981	64,000	30.00
Beaver Creek at Loretto	1944-1953, 1979-1981	4,570	12.00
Beaver Creek at Genoe	1941-1981	21,200	0.41

Source: Nelson and France[28]

The lesser variability of flow throughout the year for the upstream gages becomes even more evident when the maximum and minimum monthly values are compared to the mean monthly values. For the Spalding gage, variability between the mean monthly flow value and average maximum monthly flow value amounts to 20 percent. For the Fullerton gage, the average maximum monthly discharge is nearly 50 percent larger than the mean monthly flow.

Despite the differences in period of record, it is evident that the range in discharge is far less for the Spalding and Loretto sites, which lie more immediately downstream from the Sandhills. Table 6 lists the maximum and minimum recorded discharges at the four continuous record stations.

The flood peaks on the Cedar River and Beaver Creek recorded at these gages are probably greater than at locations in the Sandhills a few miles upstream. From the observations of Department of Water Resources field personnel measuring larger discharges, it has been noted that sharp peaks at Spalding and Loretto were produced by the small tributaries draining loess hills which lie between the gages and the Sandhills. Storm hydrographs produced at other stations entirely within Sandhill watersheds are characterized by slow rises and recessions. Storm hydrographs of such streams exhibit rounded peaks which do not rise to the high discharge values common to streams draining less permeable land.

Base Flow

The base flow of a stream is defined as that portion of a stream's discharge which originates entirely from groundwater seepage. Much can be learned about the relationship between surface water and groundwater by analyzing the base flow measurements from a large number of sites in a watershed. This information can be used to define different physiographic regions and variations in near-surface geology.

Streamflow measurements were made at numerous points along the Cedar River and Beaver Creek and their tributaries during the fall of 1979, spring 1981, fall 1981, fall 1982, and spring 1983. Figures 8 and 9 show the base flow measured during these five periods for the upper portions of Cedar River and Beaver Creek, respectively. A variation in the groundwater inflow can be seen in these figures, reflecting the variation in precipitation in the months preceeding the measurements. The spring of 1979, fall of 1982, and spring of 1983 were considerably wetter than the other periods of study.

The Cedar River rises in the broad marshy wet meadows of northern Garfield County. It begins its flow toward the Loup River as two small streams, Big and Little Cedar Creeks. Big Cedar Creek above the confluence with Little Cedar Creek gains an average of 0.2 cubic feet per second per mile (cfs/mile). From the site below the confluence to the gaging station near Spalding, this stream gains about 3.4 cfs/mile. The low rate of groundwater inflow above the confluence with Little Cedar Creek is apparently due to the silt layer that underlies the surface in this area. This silt layer restricts the movement of groundwater from the aquifer to the stream. Big Cedar Creek and the Cedar River cut through this layer below Little Cedar Creek and therefore the aquifer can provide groundwater to the stream at a greater rate.

Beaver Creek gains less that 0.4 cfs/mile in its most upstream segment. The rate of inflow gradually increases to a maximum rate of 2.8 cfs/mile in the ssegment 23 to 29 miles below it headwaters. The rate of inflow gradually decreases beyond this point. A silt layer may exist in the upper reaches of Beaver Creek as it does in the Cedar Creek watershed.

LAKES AND MARSHES

Natural lakes and marshes are found in the study area in association with the wetland areas discussed in Chapter 2. These surface water bodies occur in the northern portions of Garfield and Wheeler Counties. Many of these areas are exposures of the water table. Seasonal and yearly fluctuatons in depth and areal extent can be expected. A report on Sandhills lakes by the Game and Parks Commission states that Wheeler County has 27 natural lakes with a combined area of 213 acres[10]. Most of these lakes have a depth of less than four feet. These lakes are slightly alkaline.

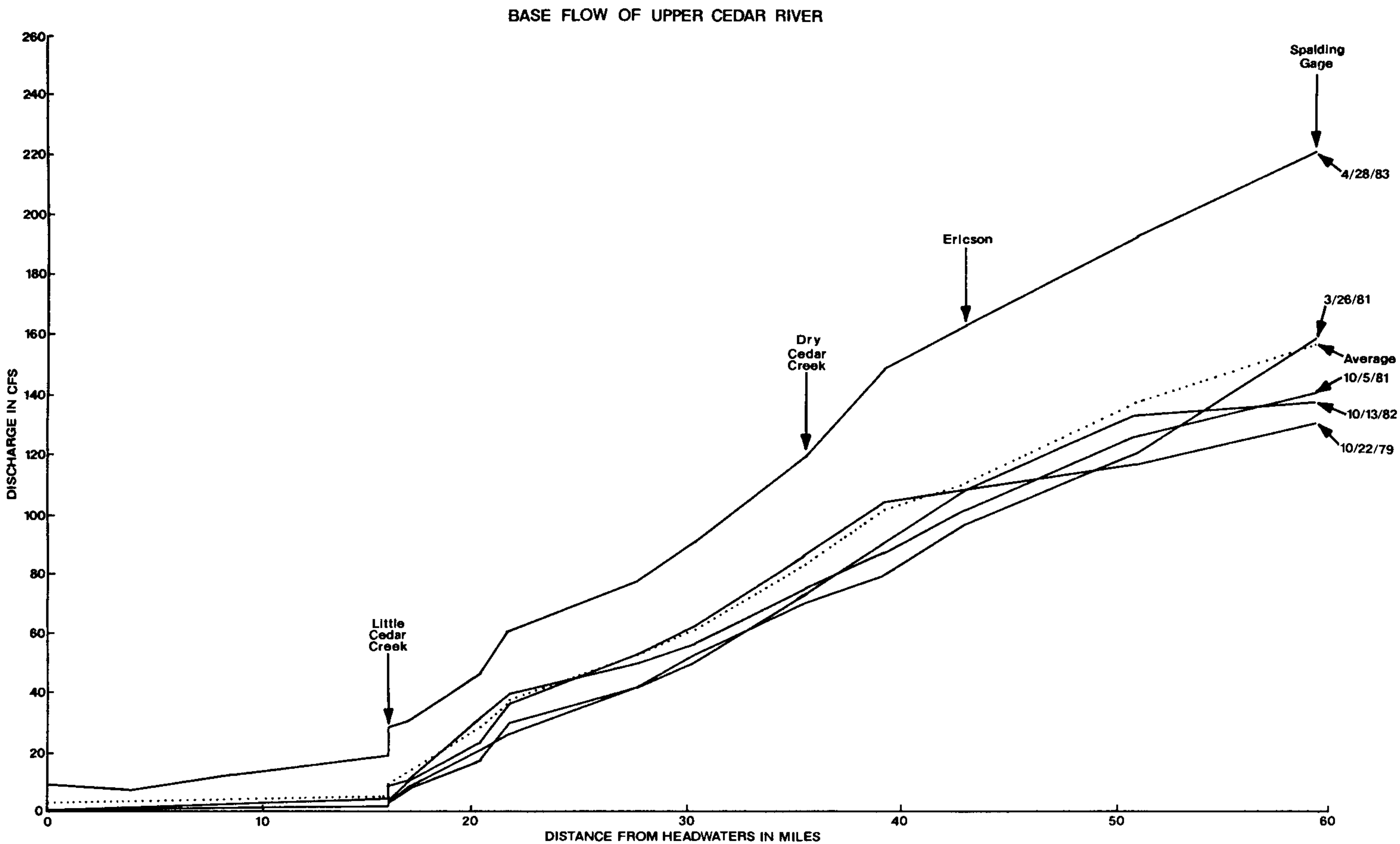

BASE FLOW OF UPPER CEDAR RIVER
DISCHARGE IN CFS
0
20
40
60
80
100
120
140
160
180
200
220
240
260
DISTANCE FROM HEADWATERS IN MILES
0
10
20
30
40
50
60
Little Cedar Creek
Dry Cedar Creek
Ericson
Spalding Gage
4/28/83
3/26/81
Average
10/5/81
10/13/82
10/22/79

Fig. 8

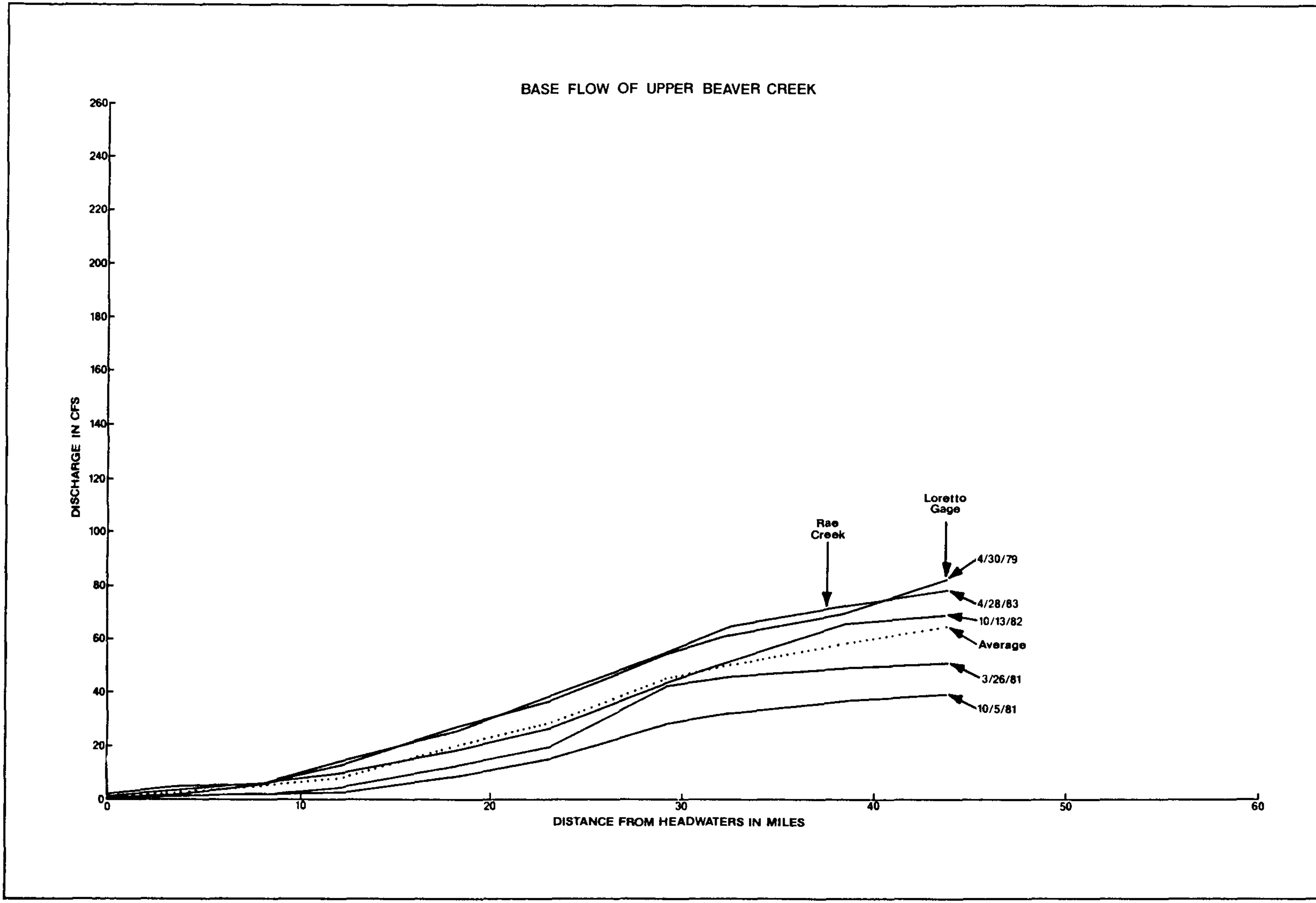

BASE FLOW OF UPPER BEAVER CREEK
DISCHARGE IN CFS
260
240
220
200
180
160
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
DISTANCE FROM HEADWATERS IN MILES
Rae Creek
Loretto Gage
4/30/79
4/28/83
10/13/82
Average
3/26/81
10/5/81

Fig. 9

There are several man-made lakes in the area. Ericson Lake, formed by a dam on the Cedar River in southern Wheeler County, is one of the largest bodies of water in the area.

WATER RESOURCES MODELING

A groundwater model of the eastern Sandhills area can be very useful in evaluating changes in water resources resulting from irrigation development. It can be used to simulate historic conditions and to predict effects of future water resources development. An effort to develop such a model was started but not completed because of the problems encountered.

THE GROUNDWATER MODEL

A groundwater model of the Loup River Basin originally developed for the Platte River Basin, Nebraska Level B Study, was adapted for the Sandhills Study[12]. It is a variation of the U. S. Geological Survey finite difference groundwater model developed by P. C. Trescott[34]. This program simulates groundwater flow in a single aquifer for a variety of situations, including well discharge, constant recharge, leakage and evapotranspiration. As irrigation development expands and stress on the aquifer increases, the model will simulate the resulting water levels.

The section of the Loup model adapted for this study includes most of Garfield and Wheeler counties and portions of Antelope, Boone, Greeley, Holt, Loup, Rock and Valley counties. The node size (13,050 feet on each side) and orientation from the Loup model were maintained for easier data conversion. Figure 10 shows the eastern section groundwater model area and orientation.

Input data taken directly from the Loup model include specific yield, transmissivity, stream locations, bedrock elevation, 1972 measured water levels and streamflow at inflow points. Some of the transmissivity values were modified based on more recent test hole data from the Conservation and Survey Division. A 1979 measured water level map for the model area was also developed from Conservation and Survey Division data.

HYDROLOGIC ACCOUNTING PROCESS

A series of computer programs were used to process several types of data for input to the finite difference groundwater model. These programs were originally developed by the U.S. Geological Survey but have been modified several times by the Natural Resources Commission. Input data required include climatic, crop, well, and soil data.

Programs

Potential evapotranspiration (PET) is calculated from climatic data in the first program of the series. Output from the PET program is combined with crop type and soil data to determine all the possibilities for crop consumptive water use in the modeled area. Finally, irrigated and dryland acreage data by crop

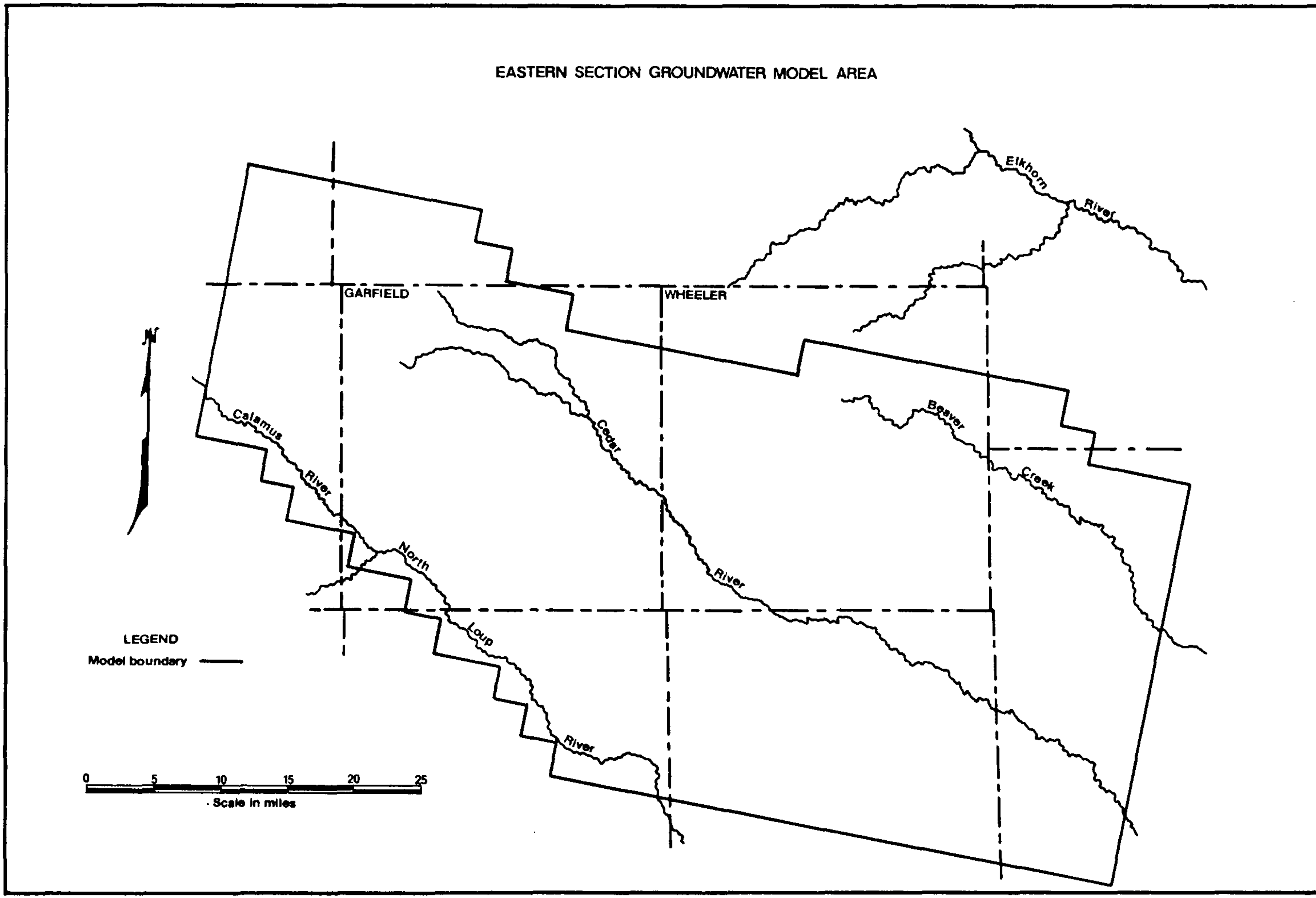

EASTERN SECTION GROUNDWATER MODEL AREA
GARFIELD
WHEELER
Elkhorn River
Calamus River
Cedar River
Beaver Creek
North Loup River
N
LEGEND
Model boundary
0
5
10
15
20
25
Scale in miles

Fig. 10

type and municipal and irrigation well data are added to the crop consumptive use output to produce a net recharge-discharge file which is the final input to the groundwater model.

Input Data

Precipitation, temperature, and percent possible sunshine are all climatic inputs to the PET program. Of the three, precipitation is the most crucial for accurate calculations. Monthly precipitation totals are required for each year modeled. There are eight National Weather Service stations reporting precipitaton data in or near the model area that have a minimum of thirty years of records. (Although the groundwater model was only run for the period 1972 to 1978, a thirty year average from 1952 to 1981 was used to substitute for missing records and to project climatic conditions for future predictive runs.) The eight stations are Albion, Bartlett, Elgin, Ericson, Greeley, North Loup, Ord, and Taylor. Only one of the eight stations, Taylor, is located in the upper third of the study area, leaving a large area without adequate climatic data. Because precipitation data is so critical in the hydrologic accounting process, the NRC gathered available records from local farmers and ranchers. Using their records, two "unofficial" precipitation stations, Ballagh and Mohr, were simulated for the upper portion of the modeled area to supplement the National Weather Service data. Figure 11 shows the locations of all the precipitation stations.

Two types of temperature data are required for calculating PET: average monthly temperature and the high and low temperatue for the hottest month of each year modeled. Since it doesn't vary greatly from one station to the next, the number of temperature stations isn't as critical as the number of precipitation station for PET calculations. There are only three Natonal Weather Service stations reporting a minimum of thirty years of temperature data in the study area: Albion, Greeley and North Loup. No temperature data was available for the upper half of the study area, so data was simulated for the Ballagh station using an average of two stations just north of the study area (Atkinson and O'Neill). Figure 12 shows the locations of the four temperature stations.

A soil map for the modeled area was adapted from the General Soil Map series published by the Soil Conservation Service and the Conservation and Survey Division. For each soil type, a water holding capacity and an infiltration rate are required to calculate consumptive water use. A range of values by soil types are included on the General Soil Map series.

Crop information is grouped into four types for consumptive water use calculations: row crop, small grain, alfalfa, and pasture. The number of acres by crop type for both irrigated and dryland production were taken from Nebraska Agricultural Statistics for 1972 to 1978 for each county in the modeled area. Irrigated acres were also grouped by surface water and groundwater use. For this study, it was assumed that the number of surface water irrigated acres remained constant from 1972 to 1978.

The number and location of all the active irrigation wells from 1972 to 1978 were obtained from the NRC Data Bank. Municipal well use was estimated using the assumption that 600 urban residents will use nearly the same volume of water as one irrigation well. To determine the number of irrigation well equivalents for each municipality in the modeled area, census populations were obtained for 1970 and 1980 and interpolated to get values for 1972 through 1978.

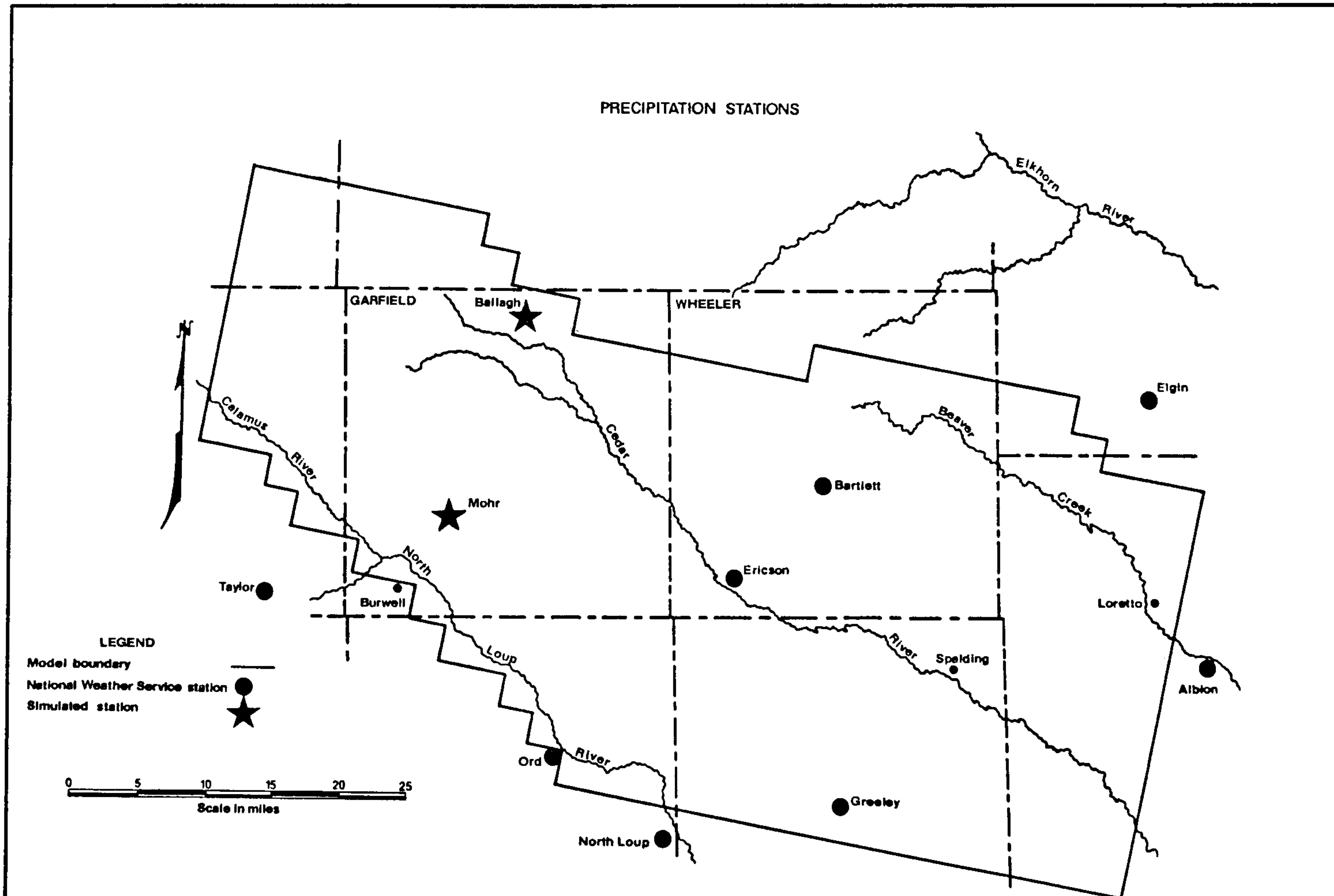

PRECIPITATION STATIONS
GARFIELD
WHEELER
Ballagh
Mohr
Elgin
Bartlett
Ericson
Taylor
Burwell
Loretto
Spalding
Albion
Ord
Greeley
North Loup
Elkhorn River
Cedar River
Beaver Creek
Calamus River
North Loup River
N
LEGEND
Model boundary
National Weather Service station
Simulated station
0 5 10 15 20 25
Scale in miles

Fig. 11

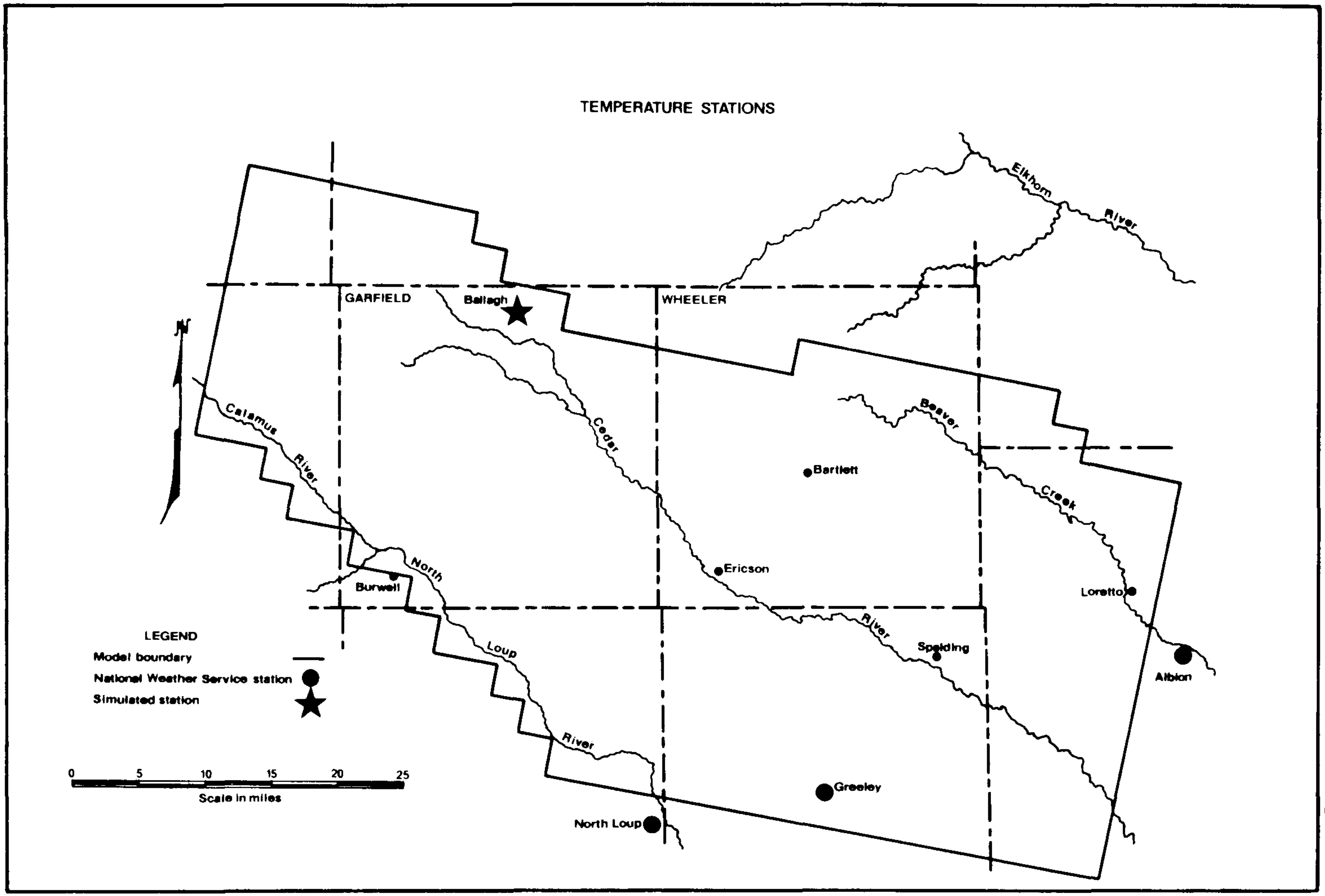

TEMPERATURE STATIONS
GARFIELD
WHEELER
Ballagh
Elkhorn River
Beaver Creek
Cedar River
Calamus River
North Loup River
Bartlett
Ericson
Burwell
Loretto
Spalding
Albion
Greeley
North Loup
LEGEND
Model boundary
National Weather Service station
Simulated station
0 5 10 15 20 25
Scale in miles

Fig. 12

MODEL USE AND RESULTS

A total of nine computer runs were made in an attempt to calibrate and verify the eastern Sandhills groundwater model. The first run was made with no change to the Platte Level B data other than reducing the areal extent to the upper Cedar River and Beaver Creek model area. This initial run pointed out several problems in the model. Adjustments in the transmissivity values were made to correct the flow into and out of the model area at the northwest and southeast boundary nodes. After three runs, it was discovered that the initial water tables were considerably off in several areas. Since significant water table declines or rises have not occurred in this area, a 1979 water table map developed by the Conservation and Survey Division was substituted, with some minor modificatons, for the 1972 data that was in the model. More runs were then made to correct the boundary flows and some other problem spots by changing transmissivity and recharge values. This led to very little improvement to the calibration or verification of the model.

At about this same time, hydrogeologic cross-sections were prepared based upon results of recent geologic test drilling. These cross-sections revealed a confining layer continuous over most of the area. It was previously thought that there were several confining lenses which limited recharge in localized areas and produced perched water tables. The new information indicates the only place the restricting layer does not occur is in the Cedar River and Beaver Creek valleys where it has been eroded.

The model developed for the Level B Study and modified for the eastern Sandhills area is designed to simulate a single aquifer with vertical uniformity. A model that can simulate two distinct layers is needed for an area with a confining layer as found in the study area. The original groundwater program had the capability to model two layers but it was never used in Nebraska. A two-layer model would require additional data on (1) the location, thickness, and transmissivity of the restricting layer and (2) water level information for the perched water and the confined aquifer. Since this data was not available, the groundwater modeling effort was suspended.

WATER SUPPLY PROBLEMS

A proper assessment of water supply problems cannot be made without a detailed groundwater model of the area. This section is therefore limited to a discussion of the types of problems that have occurred and been reported. No attempt is made to estimate the magnitude of these problems.

LOSS OF STOCK AND DOMESTIC WELLS

The loss of stock and domestic wells has often been reported by ranchers at hearings and public meetings in the area. Seventeen ranchers interviewed by the Commission staff reported seasonal problems with over one-third of approximately 300 wells[24]. Many of these wells were artesian wells that stopped flowing; other well went dry or lost prime. The ranchers attributed these problems to drawdowns due to pumping of nearby irrigation wells. To correct these problems the ranchers adjusted grazing patterns, lowered pumps, and drilled new wells.

REDUCTION IN HAY PRODUCTION

The hay production of wet meadows is important to the operation of many ranchers in the Sandhills. Production is closely related to the depth to water table. Paul Barnes, a graduate student at the University of Nebraska, studied wetlands near Beaver Creek in Wheeler County[2]. He found yields of four and two tons per acre where the water table was, respectively, two and four feet below the surface. A drop in the permanent water table of two feet could effectively cut the yields in half.

Ranchers have reported a range of changes in their wet meadows as a result of irrigation development in the area. The Commission interviewed 13 ranchers who reported changes in their wet meadows. Seven ranchers with over 8000 acres of wet meadows noted drier conditions and reduced yields of 20 to 50 percent. Wetter meadows occurred on three ranches downslope of irrigation developments. Two ranchers in this category said they were unable to harvest hay because of the high water table. Several ranchers reported a pattern of wetter meadows in the spring and drier meadows later in the summer.

REDUCED STREAMFLOW

The Bureau of Reclamation evaluated the water supply of the Cedar River Basin for the proposed Cedar Rapids Division. The 1978 report, Working Paper on Water Supply, stated that irrigated acreage in the Cedar River Basin above Spalding has increased from 4000 acres in 1970 to 25,000 acres in 1978[29]. It is estimated that 80,000 acres will be developed by the year 2000. The Bureau estimated that when the depletion for full development of 80,000 acres is reached, the average annual flow of the Cedar River near Spalding would be about 79 cfs or 57,000 acre-feet per year. This compares with a historic flow of 137 cfs or 99,400 acre-feet per year for the period 1931 to 1977.

DRAINAGE

One of the factors which can reduce crop yields is excess water in the root zone due to a low infiltration rate, flat topography, or high water table. As indicated in earlier sections of this report, wetlands and subirrigated lands make up a significant portion of the eastern Sandhills area. Preliminary data for soil surveys for Garfield and Wheeler counties indicates that over 23,000 acres in these counties have an excess water hazard.

A portion of the lands with an excess water hazard are now being irrigated with center pivot systems. To mitigate the wetness problems, some irrigators have constructed drainage ditches or tile drainage systems. Wetness is still a problem in some irrigated fields in the area as shown by the occurrence of spots where corn is not able to grow and mature.

A drainage system can reduce the excess water hazard in one area only to cause problems farther downstream. Five such cases were reported in Garfield and Wheeler counties by the Lower Loup Natural Resources District. Four of these cases were brought to the attention of the district as formal or informal complaints from about 15 landowners and the Garfield and Wheeler county boards. The problems caused by water drained from irrigated lands included inundation of county roads and meadows. In one case about 250 acres of hayland were flooded. Several dams have been constructed by irrigators to stop drainage water from flowing on to other people's land. These dams have not been very successful as they are made of sandy soil.

ADDITIONAL STUDY NEEDS

Without a detailed groundwater model, many questions relating to the water resources of the eastern Sandhills remain unanswered. It is therefore important to gather the information needed for the model in the second stage of the study.

HYDROGEOLOGIC DATA

The work done to date has provided important information but has also revealed a need for further investigation. The most significant finding of the drilling program is the importance of the silty layer of sediment in the near surface flow of groundwater. The test holes showed that the restricting zone is much more extensive in area than previously thought. Seepage measurements indicate rapid increases in streamflow in the areas where Cedar River and Beaver Creek incise the confining silts. Further modeling would require detailed information on the confining layer since its extent and hydraulic characteristics determine the amounts of recharge to the aquifer from the saturated dunesands and discharge from the aquifer to the Cedar River and Beaver Creek. A shallow test hole drilling program should be undertaken to accurately delineate the extent of the confining layer, particularly in the vacinity of the incising stream.

With the realization of a more extensive silty layer, it became apparent that some of the water level readings are reflecting water levels of the saturated dunesands while other reading are reflecting the water levels of the sands and gravels. Since the vast majority come from irrigation wells which penetrate to the sand and gravel, the map to be generated from the recent work effort will represent water levels of the gravel layer. It will be necessary to have readings of water levels of the "upper" and "lower" aquifers and a number of sites in order to obtain information on (1) water levels in the dunesands and (2) head differentials between the two aquifers. This differential is important because it creates the driving force for vertical movement of water through the silty layer and therefore affects recharge and recharge rates. Any effort to set up a two-layer model of the area will require water level measurements from both of these saturated materials.

PRECIPITATION

One of the biggest shortcomings in the current hydrologic accounting process is the lack of adequate precipitation data. The density of the National Weather Service stations in the study area is insufficient to record localized storm patterns, which are the major source of precipitation during the Midwest's growing season. For example, only 5.8 inches of rain were recorded officially at Ericson, 7.51 inches at Greeley and none at Fullerton during the August 12, 1966 flood on the Cedar River, the flood of record. However, a bucket survey conducted by the Bureau of Reclamation and the Corp of Engineers revealed that some residents in the area received rainfall in excess of 14 inches on that day. Obviously, with such large differences between recorded and actual precipitation, the resulting differences between calculated and actual pumping requirements will be very significant.

EVAPOTRANSPIRATION

Accounting for evapotranspiration (ET) from wetlands and wet meadows is another weakness in the groundwater model. While it is recognized that ET from certain plants such as cottonwood trees can be quite substantial, data on ET from native plants, including native grasses and emergent vegetation, is not available. Estimates based on irrigated grasses and cultivated plants must be used. The resulting error may be substantial because the area of wetlands and wet meadows is extensive and ET from these areas varies both seasonally and yearly. It may also be more important to the water balance and groundwater modeling than originally believed because the confining layer recently identified may reduce recharge and make more water available for ET. More research should be devoted to determining a reliable range of values for ET based on wetland size, plant species present in the wetland, and time of the year. When this information is available, the hydrologic accounting process should be modified to include the computation of ET from the many wetlands in the study area.

CHAPTER 4. WATER QUALITY

The usefulness of a water supply is determined by the quality of the water as well as the quantity. Materials dissolved or suspended in the water can make it unfit for some uses. Technology is available to remove these pollutants to within acceptable limits. Treatment is, however, costly and impractical in most cases.

WATER USES AND SOURCES OF POLLUTION

Water quality is affected by natural processes and conditions and by human activities, particularly domestic, industrial, and agricultural uses. Groundwater in the eastern Sandhills is used for livestock watering, irrigation of crops and pasture, and domestic uses including human consumption. Irrigation is by far the greatest use of groundwater. Extensive irrigation development has occurred in the area in the last few years. Surface water in the area is also used for livestock watering and irrigation. In addition, it supports fish and wildlife and provides for recreation.

These uses of water can degrade the existing quality of the surface and groundwater. Livestock and wildlife can introduce organic waste, salts, silt and other inert material, nutrients, and pathogens to water. Crop production utilizing irrigation and commercial fertilizer can increase the concentrations of nitrate and other salts in ground and surface water. Domestic wastewater can be a source of organic waste, inorganic materials, and pathogens. A variety of pollutants can be introduced to the water as a result of undesirable practices in association with recreational activities.

WATER QUALITY CRITERIA

Water quality criteria are numerical limits on parameters which quantify physical, chemical, and biological properties of water. Criteria have been adopted by the state as part of the water quality standards for surface water and groundwater. These standards have been established to protect the quality of the water for beneficial uses. Compliance with the standards is mandatory and they are enforceable by law. The criteria are based on (1) scientific guidelines which define the minimum quality of water which can be applied to various uses without problems, (2) existing water quality, and (3) existing or anticipated water uses. Water quality can be assessed by comparing the results of analyses of water supplies to these criteria.

In the eastern Sandhills area only the Cedar River and Beaver Creek are specifically addressed in the Nebraska Surface Water Quality Standards[19]. Designated uses for these streams include partial body contact, fish and wildlife, and agriculture; Beaver Creek is designated for partial body contact only above Rae Creek. Criteria for these streams are based on these designated uses.

Standards have been established to protect groundwater for human consumption, agriculture, industry, and other beneficial uses[17]. Criteria in the groundwater quality standards are based upon requirements for human consumption, so they should also provide adequate protection for the other uses.

WATER QUALITY DATA

A number of state, federal, and local agencies have authorities and responsibilities for water quality. Monitoring programs and special studies by these agencies generate data which can be used to assess the quality of streams and groundwater resources.

GROUNDWATER QUALITY DATA

The U.S. Geological Survey (USGS), Conservation and Survey Division (CSD), Department of Health, and Lower Loup Natural Resources District are involved in monitoring the quality of groundwater in the eastern Sandhills. The USGS and CSD cooperate in the collection of data for special studies and routine monitoring. Irrigation, livestock, and rural domestic wells are used to obtain samples which are analyzed for a variety of constituents that indicate suitability for different uses. Changes in groundwater quality normally occur at a relatively slow rate and therefore sampling in the area is infrequent. Also, the concentration of sampling points in the area is low. For the National Uranium Resources Evaluation Program, one of the special studies, samples were taken from approximately one well per ten square miles. Other data available for the eastern Sandhills area is much more sparse.

The Department of Health monitors the few municipal wells in the area for compliance with public water supply regulations. The sampling schedule varies for different parameters and the size of the population served. Communities with a population of less than 1,000 (Bartlett and Ericson) are required to submit one sample per month for microbiological testing. Communities the size of Burwell are required to submit two microbiological samples per month. Inorganic chemicals are normally analyzed only once every three years.

The Lower Loup Natural Resources District began monitoring groundwater quality several years ago. Irrigation, livestock, and rural domestic wells are sampled yearly. Although their analyses for chemical parameters are not done by standard laboratory procedures, the data should be useful in showing trends and identifying potential problems.

SURFACE WATER QUALITY DATA

Water quality data has been compiled for a number of sampling stations along the Cedar River and Beaver Creek over the last 30 years. Stations on the Cedar River that have been sampled, at least for a short period of time, include those at or near Ericson, Spalding, Cedar Rapids, Belgrade and Fullerton. Beaver Creek stations include Bartlett, Petersburg, Loretto, Albion, and Genoa. The monitoring program has been reduced in recent years and only the Cedar River near Fullerton and Beaver Creek at Genoa stations are currently monitored. These existing stations are part of a cooperative effort by the USGS and the Department of Environmental Control. A total of 17 physical, chemical, and biological parameters are determined on a monthly basis. Heavy metals and pesticides are analyzed quarterly. Although most of the data, and particularly the more recent data, are for stations beyond the Sandhills region, it can be used to assess the water quality in the upper reaches.

ASSESSMENT OF WATER QUALITY

The existing data base is not extensive but a general assessment of the water quality in the eastern section can be made with what is available. The Groundwater Quality Atlas of Nebraska, published by the Conservation and Survey Division in 1978, indicates the groundwater quality in the area is generally of good quality[6]. The Department of Environmental Control in their 1982 Water Quality Report concludes that the Cedar River and Beaver Creek appear to have good quality water with moderate yearly variation[18]. As groundwater is the source of surface water flowing out of the Sandhills, any changes in the quality of the former will also appear in the latter.

WATER QUALITY PROBLEMS

Within the last 30 years, concentrations of nitrate in the groundwater of two large areas in Nebraska have become a concern to health professionals and local residents. These areas include portions of Buffalo, Hall, Merrick, and Platte counties in the Middle Platte River Basin and a portion of Holt County in north-central Nebraska. The water table is near the surface, the topsoil is coarse, and the land is extensively irrigated in both these areas. Although irrigation development is a more recent phenomenon and is less extensive in the eastern Sandhills, the above conditions also apply to this area.

NITRATE CONCERNS

The limit for nitrate concentrations in drinking water supplies is 10 mg/l nitrate-nitrogen. This limit was established to protect infants against methemoglobinemia, oxygen starvation of the brain leading to brain damage and possible death. High levels of nitrate are also suspected to increase incidents of cancer in humans.

Livestock, particularly cattle and hogs, can be poisoned by high levels of nitrate. This chemical can cause abortions in livestock; nitrate can react with Vitamin A in hogs to cause a swaybacked condition. Several incidents of cattle deaths caused by nitrate poisoning have been reported in the eastern Sandhills area. Of the four cases reported in a Natural Resources Commission survey, three were caused by high levels of nitrate in water draining from irrigated fields.[24] The other deaths were caused by high levels of nitrate in corn stalks.

NITRATE RESEARCH IN NEBRASKA

Research in the Middle Platte River Basin has identified fertilizer as the primary source of nitrate entering the groundwater[7]. Research by Gary Hergert at the University of Nebraska Sandhills Agricultural Laboratory near Tyron has shown that nitrate moves down through the soil profile below the root zone at about seven feet per year[8]. Hergert also concluded that nitrate losses from irrigated corn on Valentine sand range from a low of 35 to 45 pounds of nitrogen per acre per year from unfertilized plots to over 90 pounds N per acre per year in plots which receive nitrogen in excess of crop requirements.

NITRATE DATA COLLECTION

The Lower Loup Natural Resources District, Conservation and Survey Division, and Natural Resources Commission are cooperating in an effort to monitor the vertical and horizontal movement of nitrate in the groundwater below irrigated lands. The three irrigation developments being monitored are located in northeast Garfield, central Wheeler, and northwest Boone counties. Six groups or clusters of wells were installed near each development as shown in Figure 13. These well clusters were located, to the extent possible, along the direction of groundwater flow to form a transect. Proper siting of the wells was complicated by the lack of hydrogeologic data and the difficulty in getting access to the land.

A test hole was drilled at each of the 18 cluster sites. One test hole at each transect was drilled to the base of the aquifer. The other test holes averaged approximately 130 feet in depth. At each cluster site two to five wells were installed -- a total of 72 wells were installed in all. Each well within a cluster was screened to a different depth to reflect the different geologic strata identified in the test holes.

These wells were sampled for the first time in the fall of 1982. This baseline data includes analyses for nitrate and a number of other chemical constituents. The concentrations of atrazine, a commonly used herbicide, were also determined. As a general rule, the nitrate levels were highest in the upper level of the aquifer. Nitrate concentrations exceeded the limit of 10 mg/l in two of the wells -- at one of the cluster sites in Wheeler County and one located in Garfield County. Traces of atrazine were found in the upper levels of nearly all the sites.

NITRATE MODELS

A computer model was developed by Darrell Watts from the University of Nebraska and Ronald Hanks of Utah State University to predict nitrate leaching losses from the root zone under different soils and management systems[42]. This model has been applied successfully to several sites in Nebraska with conditions similar to those in the Sandhills.

The Natural Resources Commission is providing funds to determine nitrate leaching losses in the eastern section with this model. Darrel Martin and Jim Schepers of the University of Nebraska have selected a site and are collecting data to calibrate the model. This project, which is also to identify management practices which minimize nitrate leaching, is to continue to April 1985.

A much simpler computer model for estimating nitrate leaching losses was developed at the University of California-Davis[33]. This steady state conceptual model is based on a series of equations defining the water balance and the nitrogen balance in the root zone. This model was used in the effort to project nitrate concentrations as described in the next section.

PROJECTIONS OF GROUNDWATER NITRATE CONCENTRATIONS

Estimates of future concentrations of nitrate that could occur in the groundwater of the eastern Sandhills area were made by the Natural Resources

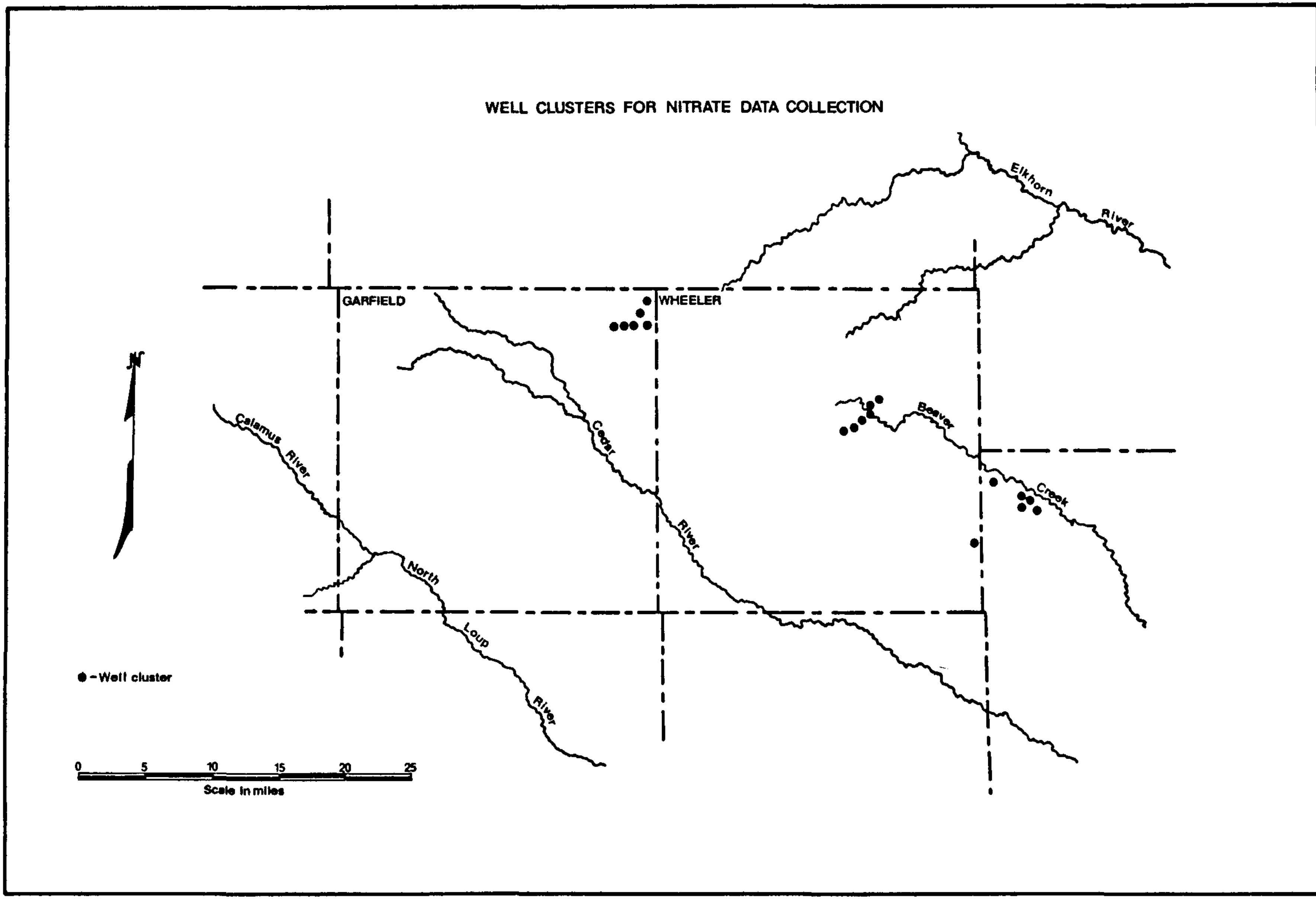

WELL CLUSTERS FOR NITRATE DATA COLLECTION
GARFIELD
WHEELER
Elkhorn River
Beaver Creek
Cedar River
Calamus River
North Loup River
N
● - Well cluster
0 5 10 15 20 25
Scale in miles

Fig. 13

Commission. A range of nitrate levels were projected for several leaching loss rates using a rather simplistic procedure assuming uniform mixing in the aquifer.

The California-Davis model was used to calculate an average annual nitrate leaching loss of 22.8 lb. N/acre for a fertilizer application rate of 160 lb/acre and a water application of 17.1 inches. Leaching loss rates reported by Hergert, 35 lb/acre and 90 lb/acre, were also used to project nitrate concentrations.

In addition to the three leaching loss rates, three sets of conditions were used in the projections. In the first case, the six-township area shown in Figure 14 was modeled. It was assumed that the aquifer is divided by a confining layer that restricts movement of nitrate from the upper layer to the lower layer. Thus, the nitrate leached from the root zone is concentrated in the upper aquifer. The nitrate in the upper aquifer is not available to crops as only water from the lower aquifer is used for irrigation. The irrigated area was assumed to remain constant for Case I at about 15.2 percent of the six-township area.

For the second and third cases, a larger portion of the two-county area is modeled as shown in Figure 14. The assumptions for Case II are similar to those for Case I, except that increases in irrigated acres as projected for the High Plains Study were used[26]. The confining layer was ignored in Case III. Therefore, the nitrate could be mixed throughout the entire aquifer. The nitrate in the irrigation water is available for crop use and therefore nitrogen fertilizer applications are reduced. Projected irrigated acres were taken into account in Case III as they were in Case II.

The concentration of nitrate calculated for the different leaching loss rates and different years for Cases I, II, and III, are shown in Tables 7, 8, and 9, respectively. The percent of land area irrigated is shown for Cases II and III, for which projected increases were taken into account.

The results show that a confining layer that restricts nitrate to the upper aquifer would have a very significant impact on water quality. The Garfield-Wheeler area with a confining layer is projected to have nitrate concentrations above the limit of 10 mg/l for all leaching loss rates by 2020. Without a confining layer, this area would not be expected to reach this limit. A comparison of Case I to Cases II and III shows that the level of irrigation development is also a significant factor.

Table 7

Projected Nitrate Concentrations in Groundwater
(Case I: Six-Township Area With Confining Layer)

	Nitrate Concentration		
	Leaching Loss (pounds nitrogen/acre)		
Year	22.8	35.7	89.2
	(mg/l nitrogen)		
1980	2.1	2.1	2.1
1990	5.3	6.9	13.7
2000	6.7	9.0	18.7
2020	7.5	10.3	21.9

MODEL AREAS FOR PROJECTIONS OF GROUNDWATER NITRATE CONCENTRATIONS

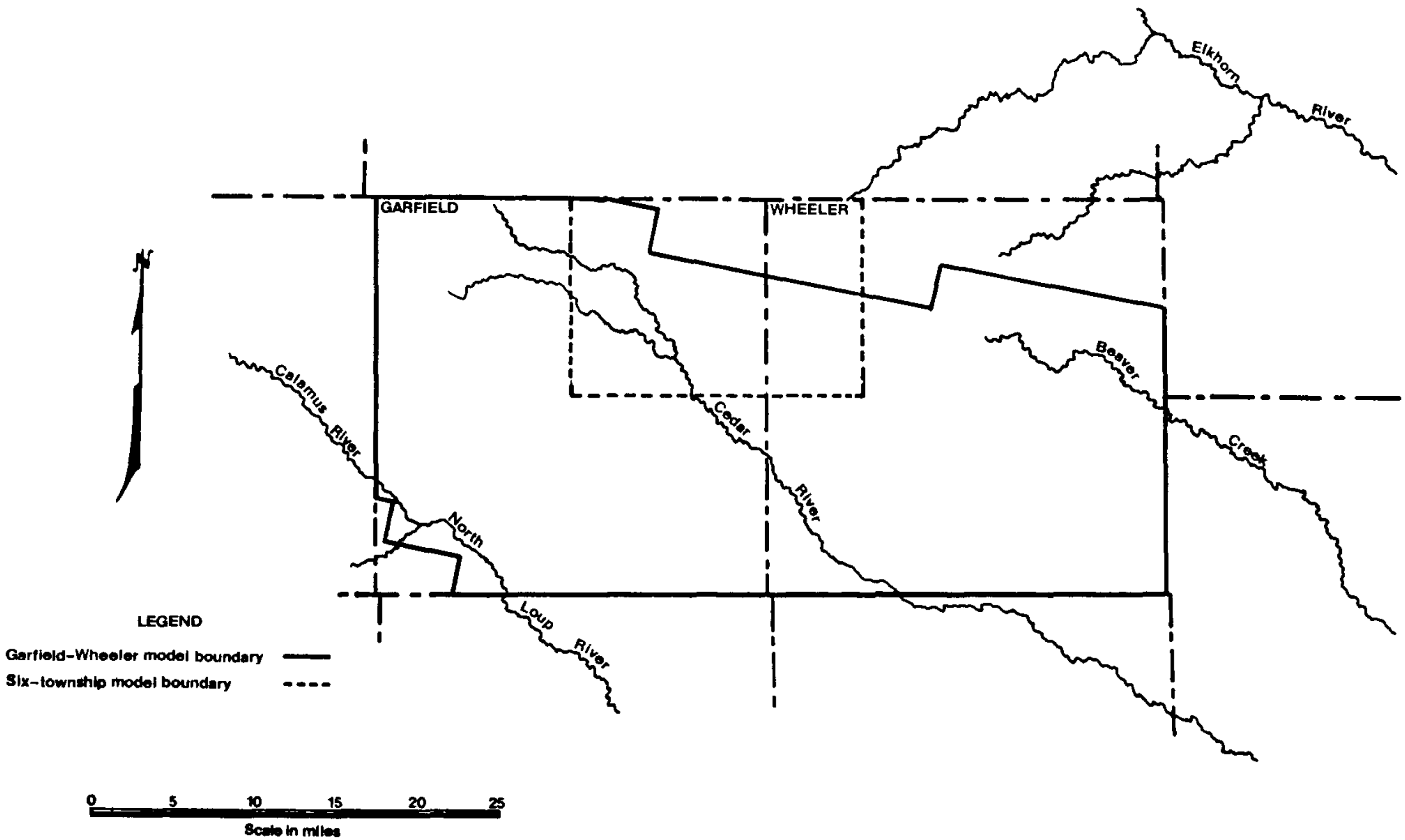


Fig. 14

Table 8

Projected Nitrate Concentrations in Groundwater
(Case II: Garfield-Wheeler Area With Confining Layer)

Year	Percent Development	Nitrate Concentration — Leaching Loss (pounds nitrogen/acre) 22.8	35.7	89.2
		(mg/l nitrogen)		
1980	7.6	2.1	2.1	2.1
1990	15.4	3.7	4.6	8.2
2000	21.4	5.6	7.4	15.0
2020	32.0	11.7	16.6	36.8

Table 9

Projected Nitrate Concentrations in Groundwater
(Case III: Garfield-Wheeler Area Without Confining Layer)

Year	Percent Development	Nitrate Concentration — Leaching Loss (pounds nitrogen/acre) 22.8	35.7	89.2
		(mg/l nitrogen)		
1980	7.6	0	0	0
1990	15.4	0.2	0.2	0.5
2000	21.4	0.4	0.5	1.1
2020	32.0	0.9	1.3	2.9

TECHNICAL MEANS OF REDUCING NITRATE PROBLEMS

Research has shown that some quantity of nitrate will inevitably be leached from the root zone when irrigated corn is produced on Valentine sands. Hergert has estimated that a minimum of 35 to 45 lb Nitrogen/acre/year will be leached with the most careful fertilizer management and irrigation water scheduling[8]. This fact indicates that site selection and spacing of center pivot systems in the eastern Sandhills area are important considerations affecting the water quality of the area.

Fertilizer should be applied in quantities that can be readily used by the crop at appropriate times during the growing season. Fertilizer should not be applied in the fall. The factors that should be considered in determining the amount of nitrogen to apply include: (1) a realistic yield goal, (2) nitrogen available in the soil profile, (3) nitrogen mineralizing capacity of the soil, and (4) the nitrogen available in the irrigation water. The growth stage of the crop must also be considered. Many of these practices were used in the Hall County Water Quality Special Project to demonstrate that amounts of fertilizer applied, and therefore leaching losses, could be reduced without yield reductions.

Wells should be sealed to prevent mixing of the water from the upper aquifer with the higher quality water of the lower aquifer. Water should be applied in quantities that minimize percolation and leaching of nitrate beyond the root zone. Electrical resistance blocks or tensiometers to monitor soil moisture and water meters can be used to determine the needed quantity of water.

When the groundwater nitrate concentration does reach the maximum allowable limit something must be done about the water supply. A deeper well, particularly one that reaches the lower aquifer, may be all that is needed to insure a safe water supply for years to come. Bottled water for drinking and cooking is a solution used by a number of individuals and communities. Water treatment systems to remove nitrate are available but may not be practical in most cases.

ADDITIONAL STUDY NEEDS

The projections were made to show potential high and low concentrations of nitrate in the groundwater of the area. Many assumptions and a simplification of geologic conditions were made for this effort. More reliable projections of nitrate concentrations will be possible when additional data is available. A better understanding of the geology of the area will be available with the further interpretation of geologic test hole data collected in 1982 and 1983. Accuracy of the nitrate leaching loss will be greatly improved with results of the modeling being conducted by Martin and Schepers of University of Nebraska. Data from the series of well clusters should provide valuable information on the movement of nitrate in the aquifer. The Farm and Ranch Economics Model discussed in the next chapter should provide improved information on projected irrigation development.

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CHAPTER 5. ECOLOGY

The Sandhills is the largest sand-dune area in the Western Hemisphere, and the largest unbroken expanse of grassland in this country. In addition, it contains most of the wetlands and lakes in this state. The ecological systems of the region are primarily based on these two resources.

ECOLOGICAL RESOURCES

The basic ecological resources of the region are grasses and grasslike plants, and water. These resources, and the fish and wildlife species they support, are discussed in the following sections.

PLANT COMMUNITIES AND SPECIES

The grasses and grasslike plants that form an almost continuous vegetative cover in the Sandhills are distributed largely according to the amount of available water. Interdunal, flat valley areas where groundwater is within reach of roots, upland areas with well drained soils, and blowout areas contain different distinct plant species. The areas in the valleys between the dunes where the water table is near the surface support stands of native grass used in ranching operations and are refered to as "wet meadows" or "subirrigated meadows". The upland regions support bunch grass plant communities that are utilized for grazing purposes. The blowout areas have grass communities that are the first to invade and stabilize these newly created bare sand areas.

The classification of plant communites by J. E. Weaver in Native Vegetation of Nebraska identified the most common species found in the three types of areas listed above[43]. Weaver also described the forbs which are distributed throughout the three regions.

Wet Meadow Plant Communities

The annually flooded zone at the edge of the wet meadow supports sedges, bluejoint and other hydric grasses. Other common grasses include big bluestem, switchgrass, Indian grass and slender wheatgrass. Little bluestem, tall dropseed, Junegrass, and western wheatgrass occur between the bluestem and lower hill slopes and this community as a whole is locally designated as hay meadows.

Blowout Plant Communities

Blowout grass is the first species to become established in the bottom or on the lower slopes of blowouts. It is a tall mesophytic grass adapted to strong winds and high temperatures. These grasses are characterized by sparse, small clumps of vegetation connected by course, tough rhizomes which are frequently 20 to 40 feet long. Associated grasses include sand lovegrass, Indian rice grass, needle-and-thread, and sand reed.

Bunch Grass Plant Communities

This plant community contains the most characteristic vegetation of the Sandhills. The most important species of this grass community include: little bluestem, sand bluestem, sand reed, and needle-and-thread. Junegrass sand dropseed, black grama, and several sedges make up the understory or ground layer.

Forbs

Forbs are non-grasslike herbaceous plants that are abundant and widespread but are of secondary importance in the Sandhills. The most important species of this community include: small soapweed, lance-leaved psoralea, spiderwort, sand milkweed, broctless mentzelin, sand sage, slenderbush eriogonum, and bush morning-glory.

Environmental Adaptation

The problem of securing an adequate water supply with unreliable precipitation and soils with little water holding capacity found in the Sandhills has been met by the vegetative communities found in the area. They have adapted to this environment by the development of deeply penetrating, usually widely branching, and thoroughly efficient root systems. The roots do not all draw upon the same soil level for their supplies of water and nutrients. The root system is so fixed that the various species may be grouped according to the layer or layers of soil occupied by them. This segregation of the root system into several more or less distinct levels is one of the chief adaptations of plants of the Sandhills to their environment.

The root system of the various plant communities found in the Sandhills are responsible for holding the soil and preventing wind erosion during periods of low moisture. There is a distinct variation in the root structure of plants peculiar to each vegetative zone.

In blowout communities the plants are characterized by grasses connected by coarse, tough rhizomes which are frequently 20 to 40 feet long. A large network of branched roots develop from the rhizomes which eventually hold the soil allowing other grasses to become established. The lance-leaved psoralea, common to blowout areas, has a taproot that reaches to depths of nine feet. It also has a network of rhizomes that connect the widely spaced plants.

The annually flooded zone at the edge of wet meadows supports numerous hydric grasses and other wetland forbs. The water table in this zone is high in the spring and early summer, dropping to three to five feet deep during the drier part of the year. Subsequently, the root systems of plants associated with this vegetative zone have relatively short branching root systems.

The bunch grasses have relatively short rhizomes and deep roots. Sand bluestem, sand reed, and little bluestem have root depths of eight feet. Buffalo grass has roots to eight feet and fine roots spread laterally about one foot on all sides from the base of the grass. Western wheatgrass reaches depth of eight to nine feet.

Forbs and other legumes found in the Sandhills often penetrate to depths of 15 to 20 feet. Sand milkweed has a taproot of 18 or more feet in depth. The lateral spread of roots in forbs is often great, extending 15 to 25 feet in all directions from the base of the plant.

CORPS OF ENGINEERS CLASSIFICATION OF WETLAND PLANT COMMUNITIES

The Omaha District of the Corps of Engineers conducted an investigation of the wetland vegetation of Garfield and Wheeler counties during the summer of 1983 to develop a data base[37]. A methodology for quantitatively distinguish wetlands from nonwetlands was applied to the wetland sites that were evaluated. As a result of this investigation three major types of wetlands were delineated and described; riparian, upland or choppy sandhill wetlands, and wet or subirrigated meadows.

The Corps selected six study sites for the evaluation, including two sites for each of the three general wetland categories. They assigned weighted numerical values - hydric values - to the wetland communities in selected sites. By correlating these values with the photo analysis and ground truthing conducteding over the same time period as the vegetative investigation, the Corps could analyze the procedure to delineate wetlands in Garfield and Wheeler counties. They conclude that through a broader analysis and evaluation of additional study sites, greater accuracy could be achieved in delineating wetlands by the identification of vegetative types.

FISH AND WILDLIFE SPECIES AND HABITAT

The Sandhills region supports a variety of big game animals, small fur-bearers, rodents, reptiles, upland birds, waterfowl, and fish. In the uplands, the most common larger carnivores are the coyote, long-tailed weasel, and the badger. Two species of jackrabbits are indigenous to the Sandhills. Numerous small rodents are also found in the region.

Sandhills bird life is well represented on the uplands, but as with plant and mammalian life, it is widely dispersed and composed of fewer species than might be found in a less homogeneous environment. The sharp-tail grouse, prairie chicken, pheasant, and various waterfowl, and a much larger number of non-game birds frequent the uplands. The wetlands provide the state's most significant waterfowl production area. For example, at the Valentine National Wildlife Refuge in the north-central part of the Sandhills, nearly 80 species of water-birds have been reported.

Approximately 50 species of fish can be found in the Sandhills lakes and streams. Northern pike, yellow perch, black crappie, large-mouth bass, and blue-gill are fairly common in several of the larger lakes. The smaller lakes and ponds often provide suitable habitat for bullheads.

IMPACTS OF CHANGING LAND USE

One ecological change that has been well documented is the loss of wetlands. At various times in the past, efforts have been made to drain wetlands in the Sandhills to improve agricultural production. A 1972 report by the Game and Parks Commission states that 28,010 acres of wetlands, amounting to 15.3 percent of the original wetlands, had been destroyed[23]. Most of these wetlands were lost from Cherry, Grant, Sheridan, and Arthur counties.

The Game and Parks Commission report identified 3,879 wetland acres in Garfield County, 86 percent of which were Type II inland fresh meadows. They did not report any wetland destruction, although 19 miles of drainage ditches were recorded during the survey.

In Wheeler County they recorded 4,026 acres of wetland of which 72 percent were classified as Type II, while six percent were classified as permanent water, Types IV and V. No wetland destruction was detailed, although 13 miles of drainage ditches were recorded.

Changes in land use can also impact wildlife dependent on a specific type of habitat. The conversion of Sandhills prairie to cropland would result in the loss of native climax vegetation which is best adapted to the climatic and edaphic characteristics of the Sandhills area. Native wildlife species, from insects to mammals, would be reduced in numbers and range. The greater vegetation and habitat diversity would be advantageous for some plant and animal species. Initially, there would be an increase in the numbers and diversity of plants and animals dependent on cropland. The ring-necked pheasant is an example of a species that would increase with increased development. The diversity and numbers of these species would increase with increased development until a threshold for each species is reached. Beyond that point the numbers would actually decrease especially if only one crop, corn, is grown.

CHAPTER 6 THE ECONOMY

The development of the water resources, especially for irrigation, and the analysis of its impacts is the primary focus of this study. Economics determine the feasibility and rate of development, and both development and continued irrigation have an economic impact on the region. It is necessary to understand the existing economy of the eastern section and trends in current changes to project potential development and its impacts. This chapter describes the economy and methods of projecting future activity.

DESCRIPTION OF THE ECONOMY

The economy of the study area is centered on agriculture. About 60 percent of the labor force is employed by agriculture and most other enterprises in the area supply, support, and service the agricultural sector.

AGRICULTURE

The nature of agriculture in the eastern section of the Sandhills is determined by the soil and climate of the area. Much of the area has sandy soil with little water-holding capacity, which is susceptible to wind erosion. Also, the area is relatively arid, averaging about 21 inches of moisture per year. These factors have produced to an economy based primarily on ranching. Livestock and livestock products constitute most of the value of agricultural products sold. Only in recent years, since irrigation came to the area, has crop production expanded enough to represent a significant part of the value of production. Net earnings from agricultural activities in Garfield and Wheeler Counties were about $3,000,000 in 1981[4]. This figure excludes the costs of production.

Ranching

The nature of the ranching operations varies considerably. Some of the ranchers with cow-calf operations sell all of their calves in October and November of each year. Others keep some or all of their calves over winter and sell them as long yearlings in late summer or early fall. A few ranchers keep no cows, but instead buy calves at weaning time, winter them, and sell them as feeders off grass in late summer or early fall approximately one year after buying them.

Some ranchers have installed irrigation systems on their lands. This has made it possible for them to increase production in a number of ways. Some have irrigated grass which increases the carrying capacity of the land considerably. Irrigated grass will carry two to three cows with calves per acre, whereas dryland pasture requires eight to 10 acres per animal unit. Others are using irrigation systems to grow corn and alfalfa for feed. This allows them to keep their calves, feed them the crops produced with irrigation, and sell them as fat cattle.

The number of cattle in Garfield and Wheeler Counties has increased slightly from 1970 to 1981 as shown in Table 10[14]. Cattle on feed make up a small

Table 10

NUMBERS OF CATTLE AND LIVESTOCK CASH RECEIPTS
FOR GARFIELD AND WHEELER COUNTIES

Year	All Cattle[a/]	Cattle on Feed[b/]	Livestock Cash Receipts
1970	83,400	8,600	$11,625,000
1975	97,600	11,200	16,044,000
1981	95,000	15,500	26,850,000
Two County Increase 1970-1981	14%	80%	131%
State Increase 1970-1981	8%	16%	128%

a/ All cattle in area on January 1st.
b/ Total number of cattle placed on grain feed during the year.

Sources: Cattle Numbers - NE Crop & Livestock Reporting Service[14]
Cash Receipts - UNL Bureau of Business Research

portion of the cattle in the area. Table 10 also shows the livestock cash receipts for the area and the increases in the number of cattle and cash receipts for the area and the State as a whole. The two-county area has experienced greater increases in these categories than has the entire state[4]. This is particularly true for cattle on feed.

Preliminary data for January 1, 1982 reports a 67 percent increase in the total number of cattle from 1981. The huge increase occurred in Wheeler County and is thought to result primarily from the development of an extensive irrigated farming and cattle feeding complex.

Irrigated Agriculture

Irrigation has increased considerably in the area in recent years. According to Nebraska Agriculture Statistics, the number of irrigated acres in Garfield and Wheeler counties increased from 14,600 acres in 1970 to 66,000 acres in 1980. This is an increase of 352 percent, as shown in Table 11. Irrigation in the state for that same time period increased by 80 percent. The rapid growth of irrigation in the area was due to the use of sprinkler irrigation, particularly the center-pivot self-propelled sprinkler systems, which made it possible to irrigate low-cost sandy soils on slopes not suited for gravity-type irrigation. The center-pivot systems opened thousands of acres of relatively low-cost land to irrigation development.

Table 11

IRRIGATED ACRES, CORN PRODUCTION, AND CROP CASH RECEIPTS
FOR GARFIELD AND WHEELER COUNTIES

Year	Irrigated Area (acres)	Corn for Grain (bushels)	Crop Cash Receipts (dollars)
1970	14,600	1,069,000	$1,364,000
1975	30,500	2,364,500	4,679,000
1981	66,000	5,215,000	9,820,000
Two County Increase 1970-1981	352%	388%	620%
State Increase 1970-1981	80%	67%	317%

Sources: Irrigated Acres and Production - Nebraska Crop and Livestock Reporting Service[14]
Cash Crop Receipts - UNL Bureau of Business Research

The increase in irrigation has increased agricultural production considerably in the area. In Garfield and Wheeler counties, corn production for grain was 388 percent higher in 1980 than in 1970. This gain was several times larger than the increase state-wide. The increase in cattle on farms was probably caused by the increased feed production with irrigation.

The results of irrigation on the economy are further reflected in figure farm cash receipts. The crop cash receipts in Garfield and Wheeler counties were 620 percent higher in 1980 than in 1970, which represented a gain that was about double the increase state-wide[4].

The growth of irrigation in the area produced growth in other sectors of the economy. Research conducted by the University of Nebraska shows that irrigation not only increases gross incomes for irrigators but expands the economic activity for farm suppliers and other businesses related to agriculture.

NON-AGRICULTURAL ACTIVITIES

The non-agricultural activities are for the most part closely related to agriculture. These businesses include wholesale and retail trade; service; finance, insurance, and real estate; and government. Most of this activity is centered in Burwell, which is the largest city in the two-county area and is the Garfield County seat. Net earnings from non-agricultural activities in Garfield and Wheeler counties were about $1,800,000 in 1981[4].

PROJECTIONS OF FUTURE AGRICULTURAL ECONOMIC ACTIVITY

In order to assess the impacts of irrigation in the future, projections of the irrigated area must be made. Irrigation development is dependent upon a number of factors including the availability of irrigable lands, and a water supply, the types of crops that can be grown, crop yields, crop prices, and the availability and price of energy. Laws and policies of government relating to water and land use and tax laws also affect irrigation development. A computer model which considers these factors was used to project future levels of development and the costs and benefits of crop production in the Sandhills.

THE FARM AND RANCH ECONOMICS MODEL

A linear programming model was developed for the Six-State High Plains Ogallala Aquifer Study[26]. The model was used to evaluate the economics of irrigated agriculture and to project irrigated acreages and acres reverting to dryland production due to aquifer exhaustion. The High Plains Model was improved for use in the Sandhills Area Study. The revised model was renamed the Farm and Ranch Economics (FARE) Model.

Improvements in the Model

In the High Plains Model the maximum rate of development of new irrigated acres was the historic rate for the period 1967 to 1977 and full development was forecast if returns were positive. This constraint was placed on the rate of development to ensure that future development would not be projected at a rate faster than wells could actually be drilled, capital acquired, and irrigation systems manufactured. The FARE Model was modified to calculate the rate of development based on the same maximum rate and the relative profitability of irrigated and dryland agriculture.

As the production of cattle on range is the major activity in the Sandhills, a routine has been addded to the model to calculate the returns from range livestock production. This activity is now one of the alternatives, in addition to the growing of different crops, that is considered in the model. The addition of a livestock feeding routine is planned to further improve the model.

The High Plain Model was developed in terms of 1977 dollars. For this study all dollar values in the FARE Model were multiplied by a factor of 1.5 to update costs and prices to 1981 dollars.

Description of the Model

The model is a combination of control programs and sub-routines that use specified input data to produce output files on which the results are recorded. The major parts of the modeling process are shown in the schematic diagram in Figure 15. A linear programming routine is the central part of the model. This routine calculates the profit maximizing choice of crops, given a set of cropping

SCHEMATIC CONCEPTUALIZATION OF THE FARE MODEL

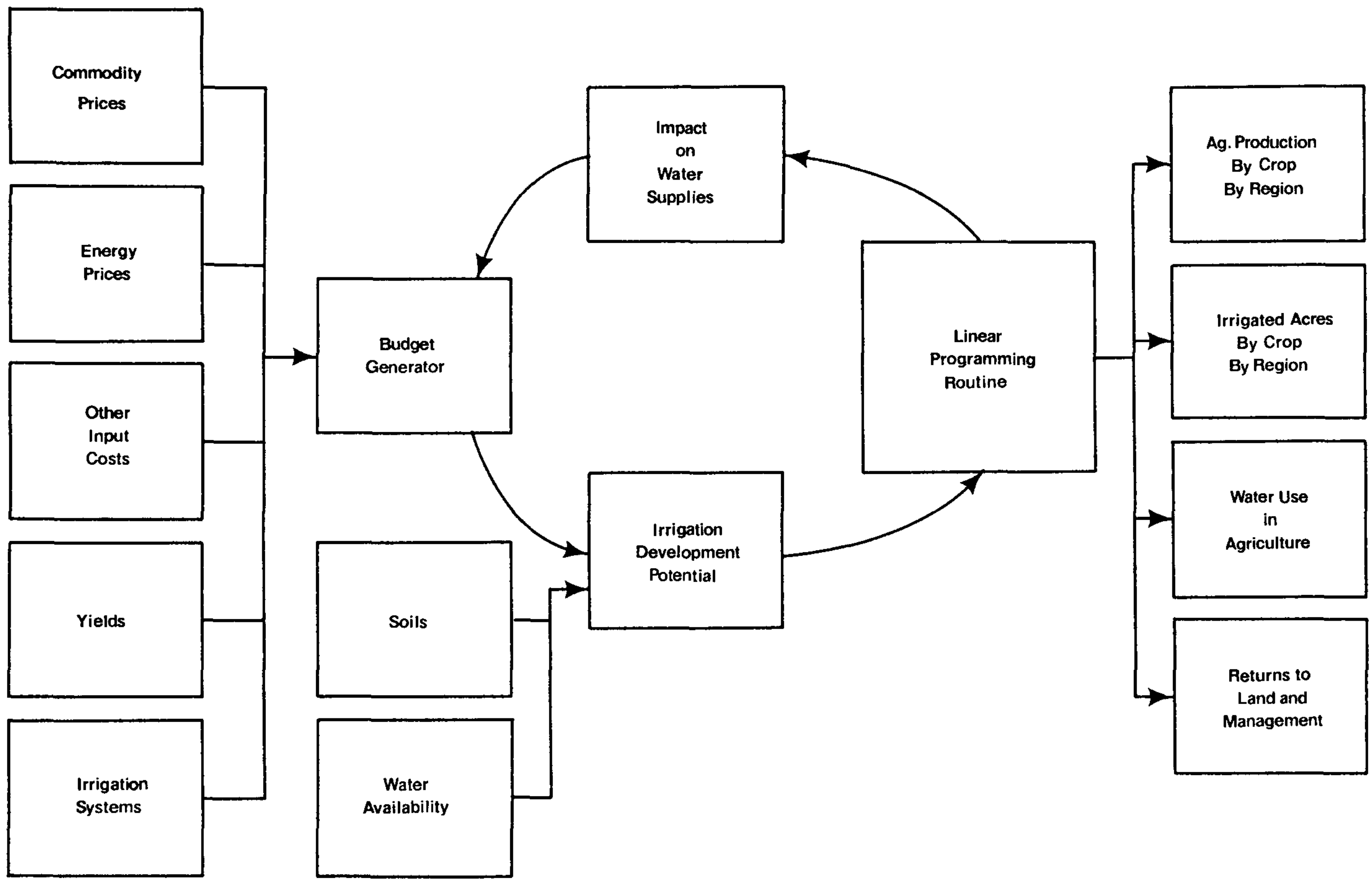


Fig. 15

alternatives and resource constraints. The cropping alternatives include corn, grain sorghum, soybeans, wheat, alfalfa, and rangeland for cattle. Four levels of irrigation are available: full irrigation, 90 percent and 70 percent of crop irrigation requirements, and dryland. Each of these cropping alternatives are budgeted for both sprinkler and gravity irrigation systems. Diesel, natural gas, propane, and electricity are included as energy sources.

Model Input. Physical and economic data are input to the model. The more important items include commodity prices, energy costs, other costs of production, crop yields, soils data, and water availability. The maximum allowable rate of development is also input. Most of this data was prepared for the High Plains Study.

Model Output. The most important results of the model are crop production, estimated returns to land and management, water use, energy costs and use estimates, acreages for dryland and irrigated crops, and the number of acres reverting to dryland production due to economic conditions or aquifer exhaustion. These results are generated for five regions in Nebraska. The Sandhills Area is approximated by Region II as shown in Figure 16. While the computations are made on a yearly basis, the results are printed out for the years 1977, 1985, 1990, 2000, and 2020. In the second stage of the study, all inputs will be updated to 1982, and the results will also start with that year.

MODEL RUNS

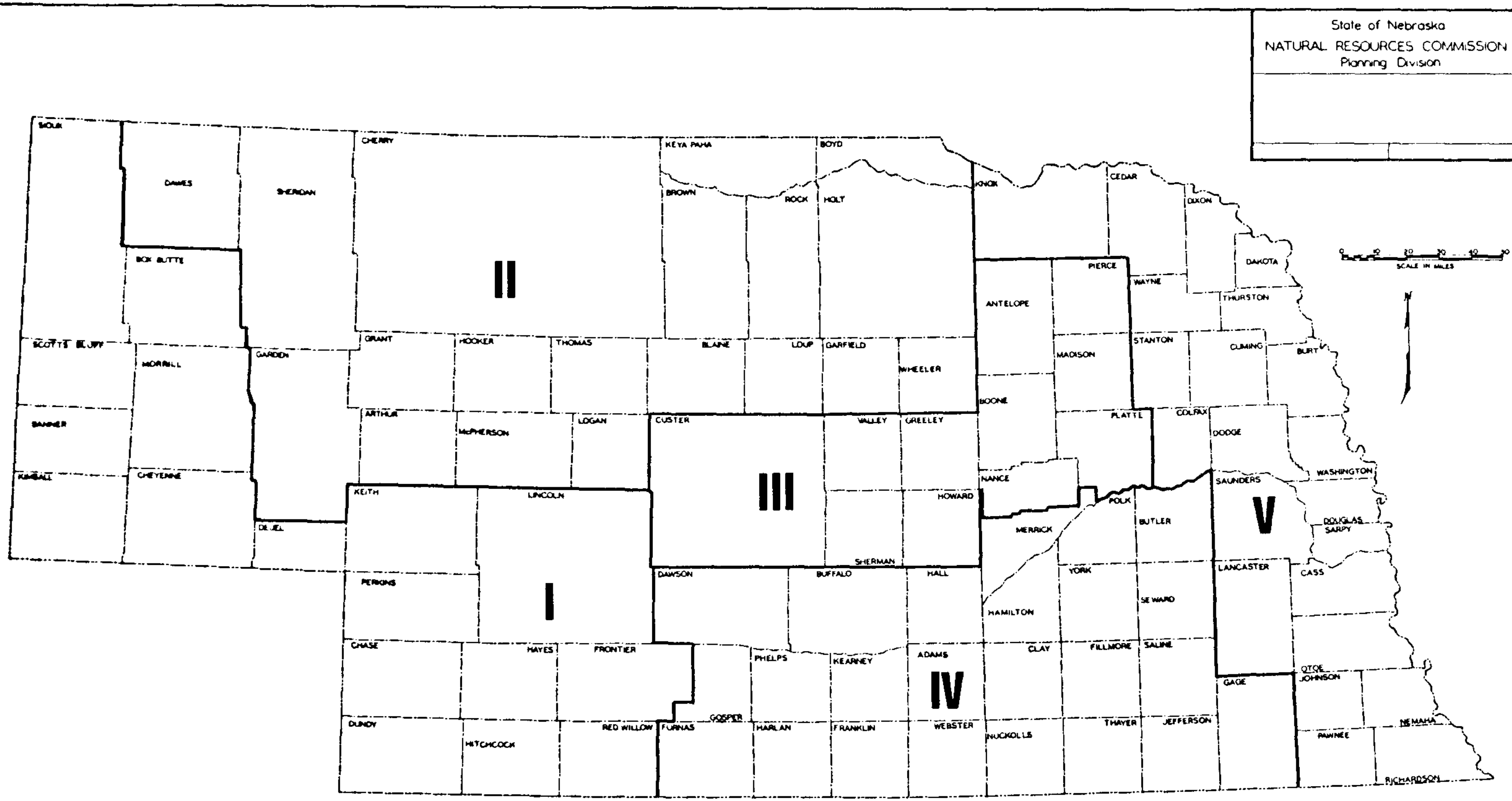
Crop yields and crop prices are two important factors in the model which are very difficult to estimate. For this reason several "model runs" were made to develop a range of results based on a range of crop yields and prices.

The first run was for "baseline" conditions developed for the High Plains Study, including crop yields and crop prices. However, crop prices were multiplied by a factor of 1.5 to update prices to 1981 dollars. For the first series of projections of alternative conditions, crop yields were varied while crop prices and other factors were held to baseline conditions. For the second series, crop prices were varied while yields and other factors were held to baseline levels. A comparison of the different variables used in the model runs is shown in Table 12.

Crop Yields

Projected crop yields for the baseline condition were taken from the High Plains Study. Baseline yields for corn, the primary cultivated crop in the Sandhills are shown in Table 13. Three alternative crop yields were used in the first series of alternative projections. These yields were all lower than the baseline yields. They were based on the limited knowledge of corn yields in the Sandhills; the other crop yields were reduced proportionally.

The first alternative crop yields were 80 percent of the 1977 baseline yields. For fully irrigated corn, this was 95 bushels per acre. These yields were held constant for the entire time period. This level was chosen because there is some indication that crop yields reported in Nebraska Agricultural Statistics, a source for the High Plains Study data, are too high. The limited information available indicates that corn yields in the Sandhills average around 100 bushels per acre; no increase in yields over the years has been documented.



FARE MODEL REGIONS

Fig. 16

Table 12

FARE MODEL RUNS FOR SANDHILLS AREA

Model Run	Crop Yields	Crop Prices
Baseline	Baseline Yields	Baseline Prices
2A	80% of 1977 Baseline Yields Held Constant to 2020	Baseline Prices
2B	1977 Baseline Yields Declining 1% per year to 2000, Held Constant to 2020	Baseline Prices
2C	1977 Baseline Yields Held Constant to 2020	Baseline Prices
3A	Baseline Yields	Average of 1977-81 Prices for 1977, Projected to 2020 in Straight Line at Same Rate as Baseline Prices
3B	Baseline Yields	1977 Baseline Prices Held Constant to 2020
3C	Baseline Yields	1977 Baseline Prices Decreasing 0.17% per year, Based on Decrease of Crop Prices to Relative Consumer Prices for 1950-1981
2C3B	1977 Baseline Yields held Constant to 2020	1977 Baseline Prices held Constant to 2020

Table 13

BASELINE CORN YIELDS FOR REGION II

Year	Dryland	Full Irrigated	90% Irrigated	70% Irrigated
		(Bushels Per Acre)		
1977	44	119	108	83
1985	42	141	127	99
1990	44	150	136	105
2000	47	164	148	115
2020	51	184	166	129

Source: Nebraska Natural Resources Commission[26]

The second alternative crop yields began at the 1977 baseline level, decreased one percent per year to the year 2000, and remained constant from the year 2000 to 2020. The yield for fully irrigated corn began at 119 bushels per acre in 1977 and decreased to 94 bushels per acre in the year 2000. This alternative was selected because limited research by the Soil Conservation Service and information from other sources indicate that crop yields in the Sandhills decline after several years of crop production on previously unbroken sod.

The third alternative crop yields were the 1977 baseline yields held constant for the entire time period. The yield for fully irrigated corn under this alternative is 119 bushels per acre. This yield level was selected as a compromise between the baseline yields which increased over time and the second alternative yields which declined over time.

Crop Prices

Projected crop prices for the baseline condition were based upon the High Plains Study, which were multiplied by a factor of 1.5 to update them from 1977 to 1981 dollars. The baseline crop prices are shown in Table 14. Three projections were also made with alternative crop prices. These crop prices were all lower than the baseline prices.

In the first alternative, the 1977 price was adjusted by substituting the average price for the years 1977 to 1981. Prices for 1978 through 2020 were increased at the same rate as the average increase for the baseline price. For corn, the adjusted 1977 price was $2.43 and the 2020 price was $3.61 per bushel. This adjustment was chosen because the factor of 1.5 used in the baseline to update costs and prices to 1981 dollars reflected the overall growth of the economy, but crop prices did not increase at this same rate.

The second alternative crop prices started at the 1977 baseline level and remained constant through the time period. For this alternative the price of corn was $3.07 per bushel for all the years of the study. This alternative was selected to determine what the results would be with no real growth of crop prices in the future.

Table 14

BASELINE CROP PRICES

Crop	1977	1985	1990	2000	2020
			(Dollars per unit)a/		
Corn (bushel)	3.07	3.73	3.79	4.05	4.25
Grain Sorghum (bushel)	2.72	3.21	3.27	3.50	3.66
Soybeans (bushel)	9.48	8.97	9.03	9.36	10.36
Wheat (bushel)	3.81	4.32	4.35	4.44	4.84
Alfalfa (ton)	55.30	63.84	64.62	67.92	70.44

a/ Prices are in terms of 1981 dollars

Source: Nebraska Natural Resources Commission[26]

The third alternative prices represented a decline equal to the historic rate. In the past, the prices for crops have not increased as fast as the prices for other things. A regression analysis was made for the index of prices received for total crops and the consumer price index for the period 1950-1981. This analysis indicated that the prices received for all crops have been declining at a rate of 0.17 percent per year relative to consumer prices. In this case the price for corn was $3.07 per bushel for 1977 and $2.85 per bushel in 2020.

MODEL RESULTS

The FARE Model projects returns to land and management and irrigated area. Returns to land and management are the income left after all budget costs except land and management charges are paid.

The returns to land and management for the fully irrigated and dryland baseline conditions and for the conditions defined for runs 2A, 2B, and 2C with full irrigation are shown in Figure 17. This figure shows that the projected yield values have a great effect on the returns. It shows that returns for dryland baseline yields actually become greater than the alternative yield levels with irrigation. The dryland projections may be influenced by lands in Region II that are not in the Sandhills, and may indicate that the dryland baseland yields should be reviewed.

Different yields also affect the projections for total acres irrigated in the sandhills. This appears reasonable because the development rate is based on the returns to land and management and the lower yields result in lower returns. Figure 18 shows total irrigated acres for the Sandhills baseline yields ranging from a little over one-half million acres in 1977 to about 2.2 million acres in 2020. Yield reductions of 20 percent are projected to result in the irrigation of 1.2 million acres by 2020. The one million acre difference in irrigated acres would mean a large difference in the economy of Nebraska. This is why the selection of yields is crucial when attempting to project future conditions.

The returns to land and management for fully irrigated and dryland baseline conditions and for the different crop prices defined for runs 3A, 3B, and 3C with full irrigation are shown in Figure 19. This figure shows that net income is affected significantly by the crop prices used in the model. With the crop prices adjusted downward as in run 3A, irrigators would lose money until about 1990. The returns for irrigation are very close to returns for dryland baseline conditions for constant prices as shown in line 3B. When crop prices are historically based, as shown by line 3C, returns fall below dryland baseline conditions at about 1985 and are the lowest of all conditions by 2020.

Total irrigated acres projected for Region II for the different price levels are shown in Figure 20. The range in projected irrigated acres for the different price levels is about the same as the range for different crop yields shown in Figure 18. This shows that crop prices and crop yields are equally important in the projection of irrigated acres.

A model run was also made with 1977 baseline prices and yields both held constant to 2020. Figure 21 shows that returns for irrigation under these conditions would be less than returns for dryland baseline conditions after about 1981. The returns to land and management become negative in about 2000. An irrigator would be

WEIGHTED AVERAGE RETURNS TO LAND AND MANAGEMENT GROUNDWATER IRRIGATION

SUB-REGION II

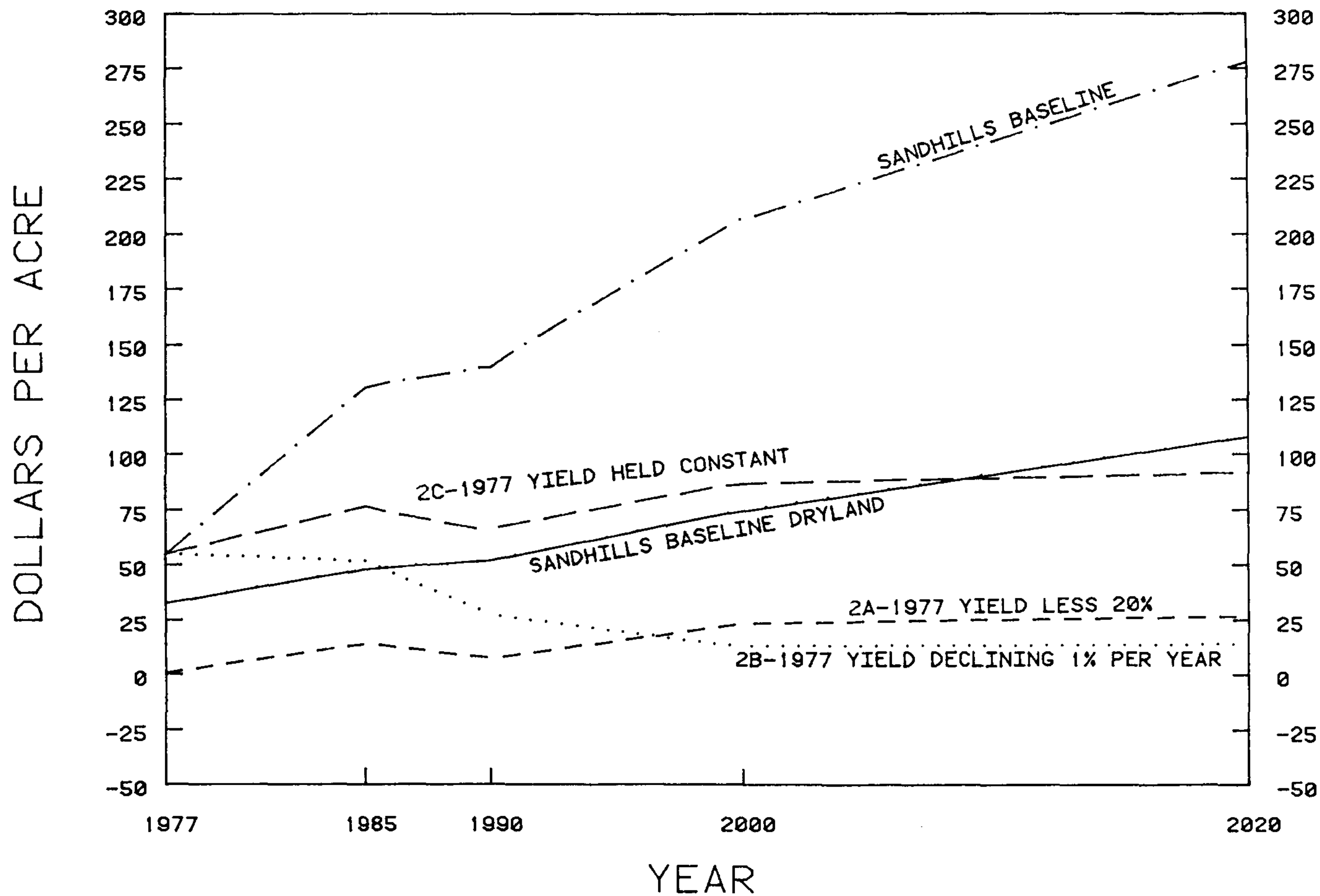


Fig. 17

TOTAL IRRIGATED ACRES
SANDHILLS BASELINE, RUNS 2A, 2B, AND 2C

SUB-REGION II

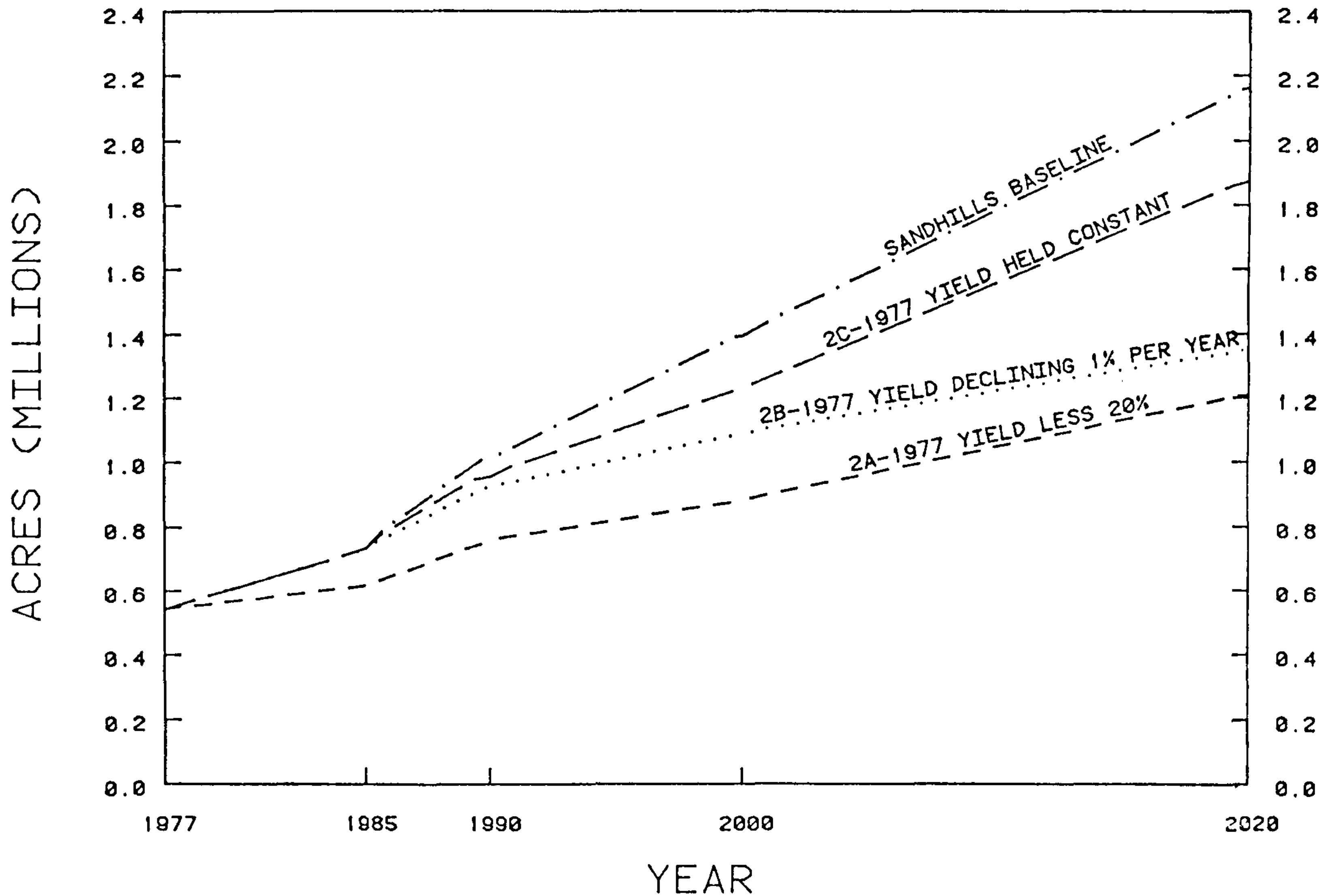


Fig. 18

WEIGHTED AVERAGE RETURNS TO LAND AND MANAGEMENT
GROUNDWATER IRRIGATION

SUB-REGION II

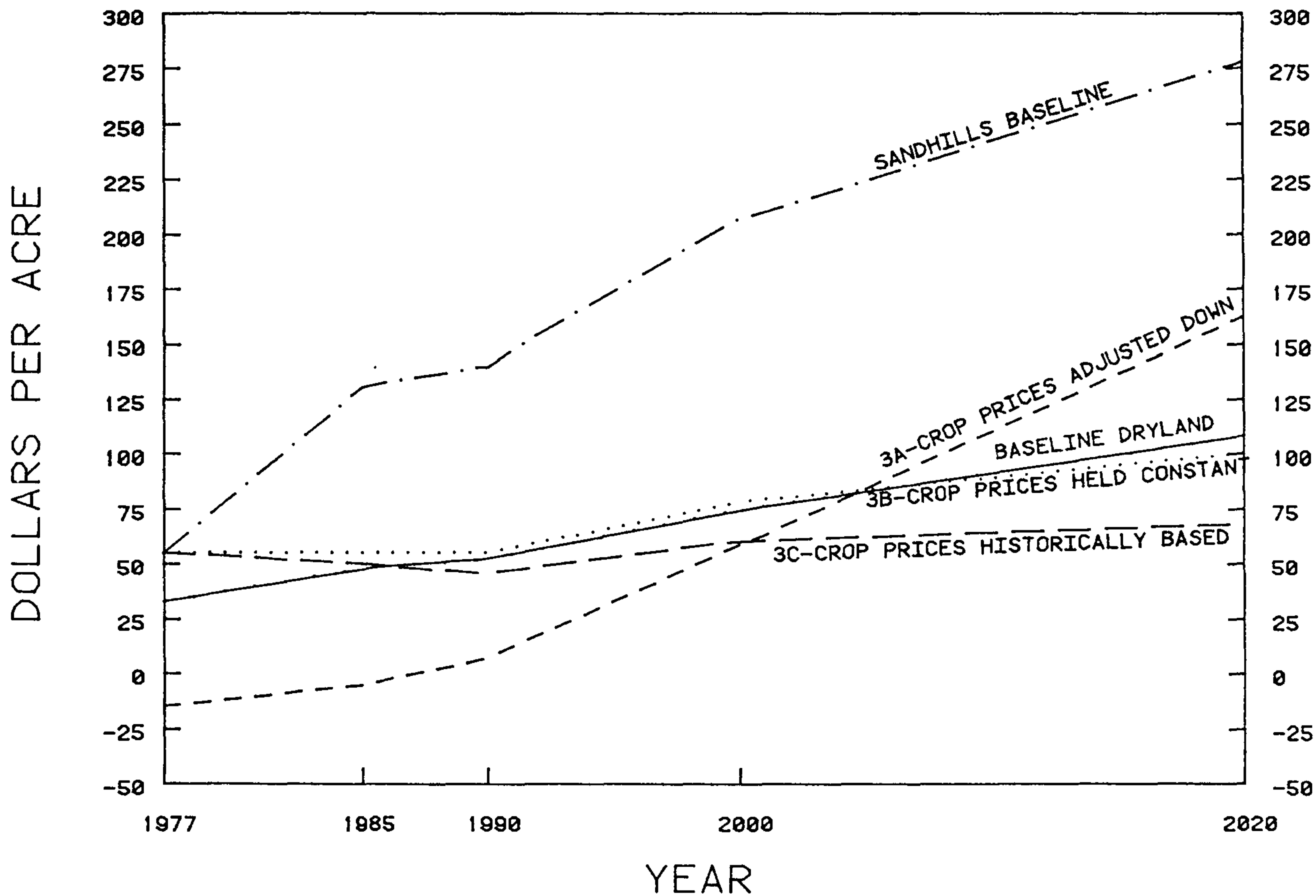


Fig. 19

TOTAL IRRIGATED ACRES
SANDHILLS BASELINE, RUNS 3A, 3B, AND 3C

SUB-REGION II

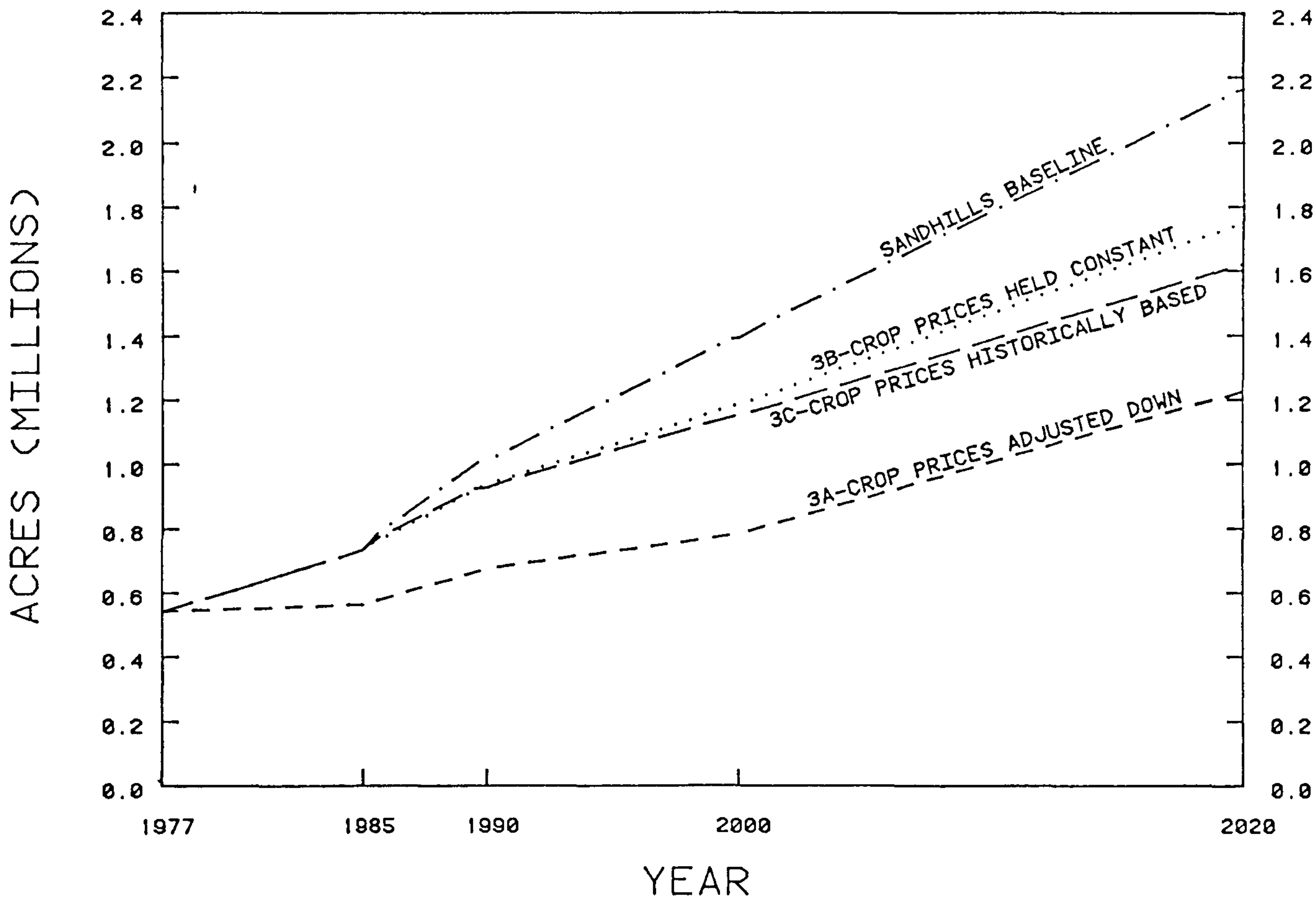


Fig. 20

WEIGHTED AVERAGE RETURNS TO LAND AND MANAGEMENT GROUNDWATER IRRIGATION

SUB-REGION II

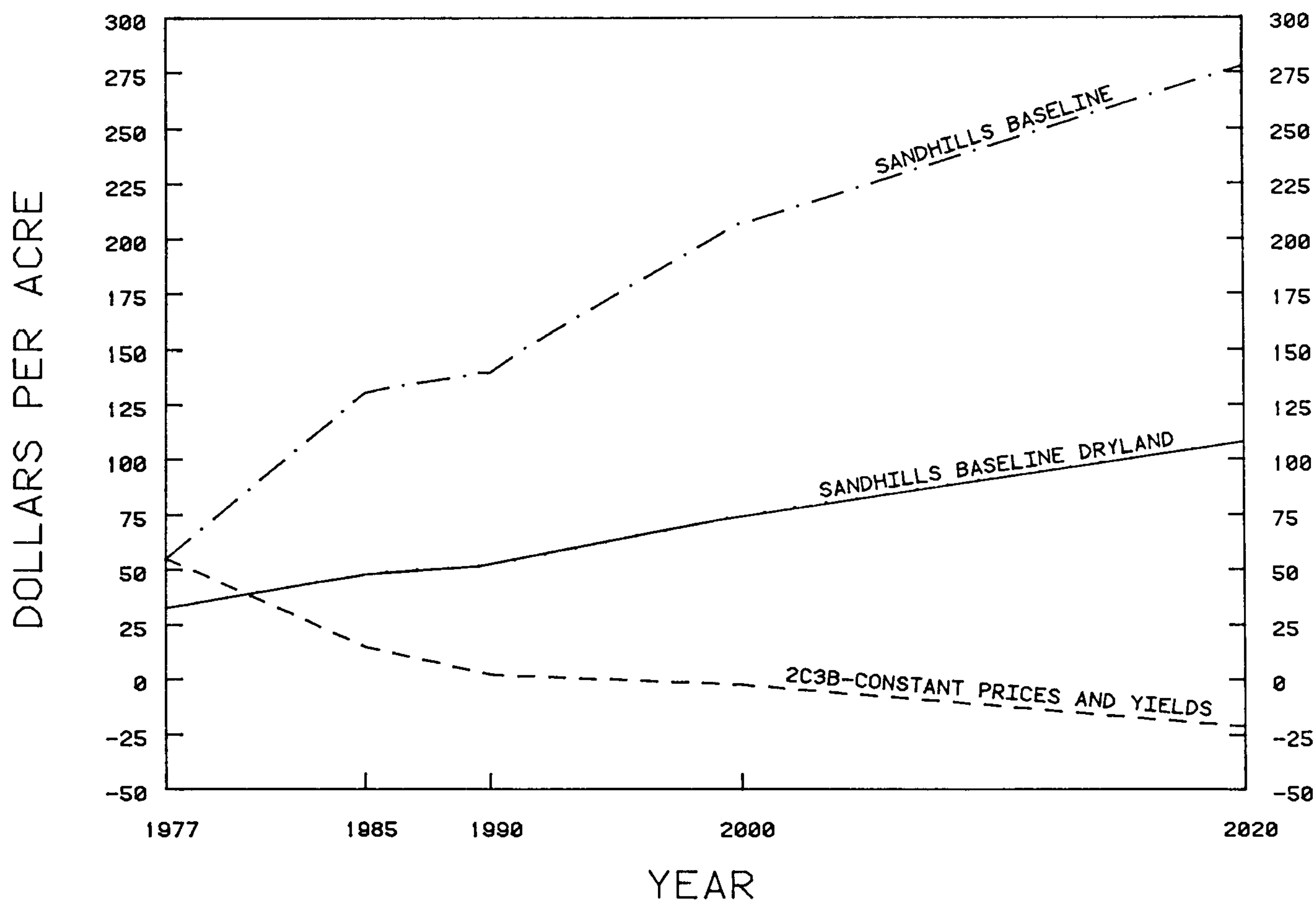


Fig. 21

losing almost $25 per acre by 2020. Figure 22 shows that the constant price and yield alternative would result in irrigated acres at a slightly lower level than any other of the price and yield combinations previously examined. The results also show the significance of the prices and yields used in the FARE Model.

ADDITIONAL STUDY NEEDS

There is an extensive economic data base and a number of useful tools such as the FARE Model for economic analyses. It is still very difficult to project economic activities for an area such as the Sandhills. The items discussed in this section would help to make such projections more reliable.

THE IMPACT OF THE FAMILY FARM AMENDMENT ON FUTURE IRRIGATION DEVELOPMENT

The Family Farm Amendment was approved by the voters in the November 1982 general election. The Family Farm Amendment will prohibit non-family farm corporations from farming and buying land for farming. While considering what maximum development rate should be used for the FARE model, it seemed probable that the Family Farm Amendment would have some impact on future irrigation development. An attempt was made to determine the extent of corporate farming in the Eastern Section.

To estimate the number of corporations that were involved in development of irrigation in the sandhills, a list of registered irrigation wells was obtained from the Data Bank. According to the list, there were 669 registered irrigation wells in Garfield and Wheeler counties in December 1982. The names of all the corporations that originally registered wells in the sandhills were found by searching through the records of the Department of Water Resources. It was found that about 30 percent of the wells were registered by partnerships or corporations.

An attempt was made to determine how many corporations might be considered "family corporations." According to the Family Farm Amendment, a family farm is not subject to any of the new restrictions. A family farm or ranch corporation is defined as one with at least 51 percent of the voting stock held by family members no more distantly related than first cousins. Also, at least one of the family members must live on the farm or be actively engaged in the day-to-day labor and management of the farm.

Records at the Secretary of State's office were searched for pertinent data. All farm corporations are required to file a report annually with the Secretary of State's office which lists the names and addresses of the officers and share holders. Some of the later report forms also list names and addresses of share holders living on the farm or actively engaged in farming. The names of thirty-eight corporations were found on the well registration list for Garfield and Wheeler counties. Of the thirty-eight names, only twenty had filed reports at the Secretary of State's office. Judging from the names and addresses of the stockholders listed in the reports, it appeared that about fifteen of the twenty may qualify as a family corporation. Due to the quality of the available data, this was a highly subjective judgment, but it seems to indicate that about

TOTAL IRRIGATED ACRES
SANDHILLS BASELINE AND RUN 2C3B

SUB-REGION II

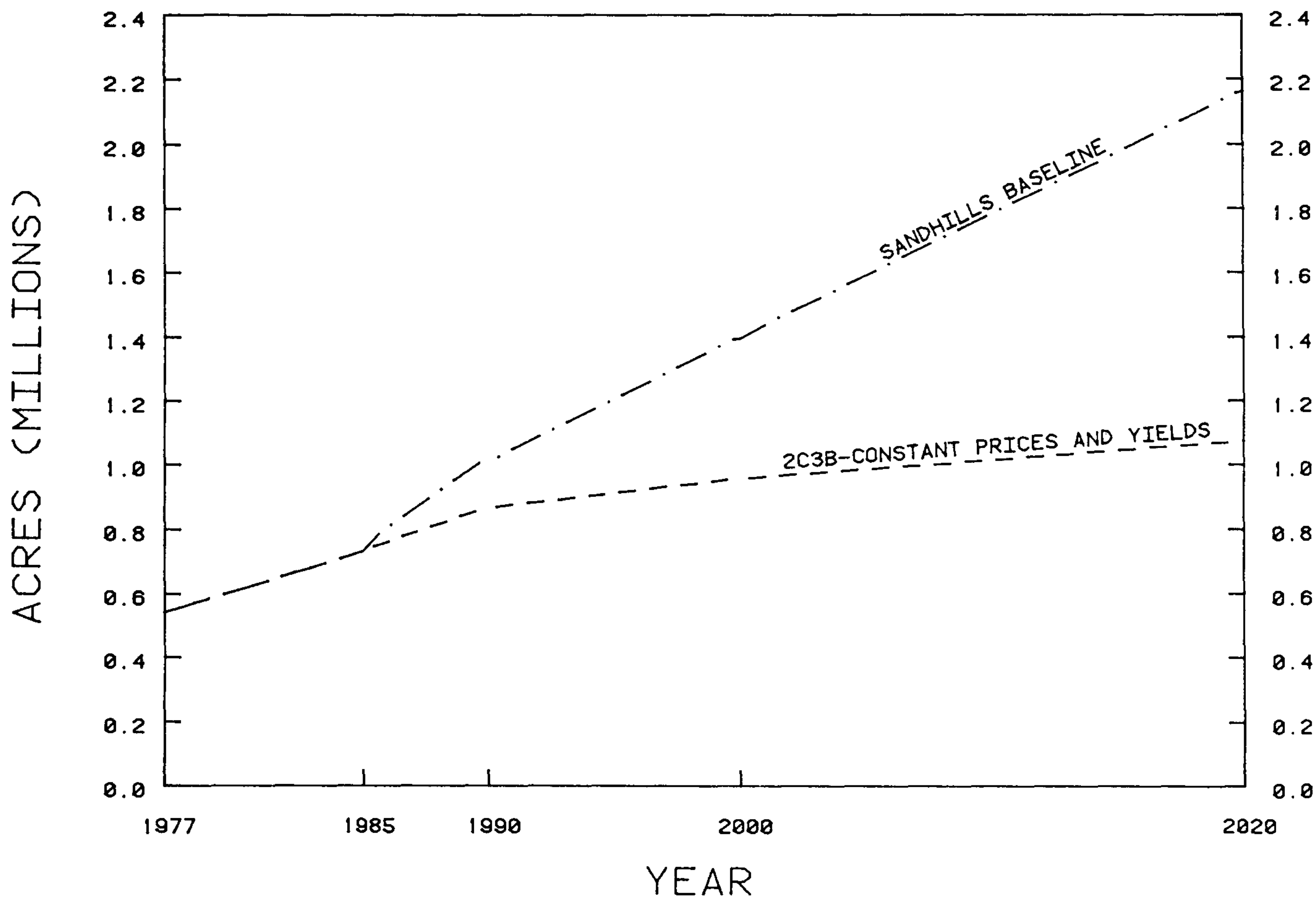


Fig. 22

one-quarter of the corporations would have been prohibited from developing irrigated land by the Family Farm Amendment.

The total number of wells registered by the twenty corporations that filed was about 157. The fifteen corporations that were judged to be family corporations accounted for 32 of the 157 wells or about 20 percent. The remaining 125 wells were owned by the 5 non-family corporations. One of the non-family corporations owned 100 of these 125 wells.

There are many uncertainties in this research. There is uncertainty as to the percentage of irrigation wells registered and the number of acres irrigated by each well, which makes it difficult to determine the total area irrigated. There is uncertainty as to the names used in registering wells compared to names used in reports filed with the Secretary of State's office. There also is uncertainty as to whether corporations will try to circumvent the new amendment. It appeared that at least one of the larger corporate farms had changed their method of reporting share holders on the 1983 report so the corporation was closer to the requirements for qualifying as a family farm. Because of all the uncertainties, no scientific conclusions could be drawn from the research.

In order to improve the FARE model and its ability to project irrigation development, more study should be made of the impact of the Family Farm Amendment. It may not be possible to determine these impacts for several years.

THE IMPACT OF TAX INCENTIVES ON FUTURE IRRIGATION DEVELOPMENT

Federal tax laws and regulations which provide for tax deductions and tax sheltering of income have been suspected to be the dominant economic incentive for irrigation development in the Sandhills. An analysis of the tax incentives for intensive development by Baker supports this hypothesis[1]. The impact of tax laws on future irrigation development should be studied in more detail. The FARE model may need to be revised to take into account the impact of federal tax laws on future irrigation development.

Baker simulated budgets for investments, costs, and returns for crop production and analyzed resulting income tax liabilities for irrigation developers classified as (1) ranchers, (2) farmers, (3) long-term investors, and (4) short-term investors. The returns on equity ran over 60 percent per year in some years for some investors. Returns of four to six percent per year were also common. The short-term investors maintain high returns on equity by liquidating after every fifth year. For most investors, before-tax cash flows were negative until the loan on the well and center pivot were retired. After-tax cash flows were positive for all simulated cases and they increased with increases in leverage and marginal tax rates.

The effects of regulations that control the density of development were also researched. The effects of taxes on returns if irrigation was limited to one or two quarters in each section were checked. It was found that regulating density of development reduces the attractiveness of irrigation development if cash flow is critical, but it increases net proceeds when the short-term investor liquidates, and they increase the amount of income that can be sheltered from taxation. This means that irrigation development might be increased and spread more widely, although water use per section might be reduced.

FUTURE USES OF THE MODEL

The FARE model will be continuously refined and improved for future use. Since the model runs discussed in this report were made, a surface water irrigation routine was added. The model can now be used to evaluate surface water development alternatives. Another refinement planned is to incorporate fed livestock production into the model. Presently it includes only range livestock production. These and other improvements will make the model a useful planning tool for the future.

The selection of crop prices and yields needs further study. As shown previously these factors are very important in the determination of returns to land and management and projected irrigated acres.

IMPACTS ON COUNTY ROADS AND TAX BASE

In addition to increasing agricultural production, irrigation development has also caused some problems for local governments. One of the problems is the added expense for the county government to provide an adequate road system for the increase in heavy truck traffic due to the irrigation activity. At this time it is not known if the increased costs will be offset by increases in revenue from the developed land. The counties will have more money to deal with some of these problems, because more tax revenues will be generated. Taxes on irrigated land are considerably higher than taxes on dryland.

It is difficult to determine the increase in revenue due to the development of irrigated land over time, because most counties have increased the value of both irrigated and dry land. Also, some counties have increased land values more than others. However, it is almost certain that irrigation will provide increased tax revenues.

To reinforce this, the land values of Sandhill counties that have had little irrigation development over time can be compared with Sandhill counties that have had more. Several counties could be compared, but Thomas and Wheeler have been chosen. They both have about the same number of agricultural acres but Wheeler has had much more irrigation development since 1968 as shown in Table 15[21]. The table shows the total actual value of agricultural land in Thomas County increasing 110 percent, as compared to 173 percent for Wheeler County.

A comparison of other counties where irrigation development has occurred shows similar results. A more detailed study is required to determine total increases in tax revenue due to irrigation. However, it is possible to determine a general estimate of a county's increase in agricultural land value due to irrigation. For this general estimate, Garfield County will be used.

According to the 1980 Nebraska Agricultural Land Valuation Manual, the value of average irrigated land in Garfield County, for tax purposes, is less than two times greater than average dryland but more than six times greater than average rangeland as shown in Table 16[22]. The table shows per acre value, for tax purposes, for average land as $685 for irrigated, $380 for dryland, and $100 for rangeland. This means that for average land being converted from rangeland to irrigated, there is a $585 per acre increase in value for tax purposes.

TABLE 15

VALUE OF AGRICULTURAL LAND

County	Year	Irrigated Land Number of Acres	Irrigated Land Actual Value	Total Agricultural Land Number of Acres	Total Agricultural Land Actual Value
Thomas	1968	528	$ 23,760	351,899	$ 8,556,595
Thomas	1980	2,772	720,720	353,189	17,994,405
Wheeler	1968	1,030	154,550	344,946	18,527,735
Wheeler	1980	36,191	12,990,600	344,184	50,604,150
Thomas Increase 1968-1980		425%			110%
Wheeler Increase 1968-1980		3,414%			173%

Source: Nebraska Department of Revenue[21]

TABLE 16

PER ACRE VALUE OF AGRICULTURAL LAND IN GARFIELD COUNTY

Average Irrigated	Average Dryland	Average Rangeland
$685	$380	$100

According to Nebraska Agricultural Statistics, Garfield County has experienced an increase of approximately 10,000 irrigated acres in the past 10 years. Assuming rangeland was converted, these added irrigated acres result in a $5,850,000 increase in actual land values for tax purposes. According to the Nebraska Department of Revenue, Garfield County's taxing rate on land was 0.003264 in 1980. Natural Resources Districts and Fire Districts levy additional land taxes but the county's general expense, including some road and bridge expense, is paid from the 0.003264 taxing rate. Multiplying 0.003264 times the $585 per acre increase equals about $1.91 per acre additional taxes due to irrigation. Assuming the 10,000 acre increase all came from rangeland, $19,100 in additional tax revenue would be produced by irrigation.

Wheeler County has experienced about 40,000 acres of irrigation development for the 10 year period from 1970 to 1980, according to Nebraska Agricultural Statistics. The additional tax revenue for Wheeler County would be approximately four times that of Garfield County, because Wheeler County's land values are similar to Garfield's. Further analysis and additional data are needed to determine the extent of the damage and the cost of maintenance to determine if increased revenues will cover them.

CHAPTER 7. SOCIAL AND LEGAL-INSTITUTIONAL FRAMEWORK

The changes in the eastern section due to the development of water resources have an effect on the people living in the area. An understanding of the social conditions of the area and the attitudes of the residents is needed to evaluate these effects. This information is also needed for any attempt to develop acceptable solutions to problems in the area. A framework or outline of the roles of government in the lives of the people and in their actions in relation to the natural resources is also needed for the development of solutions.

Indicators or factors which can be used to assess social conditions were selected as a first step to achieve these objectives. While these factors include a wide range of topics, only topics relevant to development of natural resources were considered. The changes in these factors that can be reasonably related to irrigation development can serve as an indication of the social impacts of development. The available data was limited; more effort will be required in the future to obtain the relevant data and to evaluate it.

CURRENT CONDITIONS AND TRENDS

The current social and institutional conditions reflected by the selected indicators are briefly discussed in this section. The trends that have occurred in recent years are also discussed.

POPULATION

The population in the eastern section peaked earlier in this century and have declined gradually. In 1980 the population of Garfield County was 2,202 down from the peak of 3,444 in 1940. The population in Wheeler County in 1980 was 1,054. The peak population was 2,531 in 1920. Recently the population declines have stabilized although, in Garfield County, a continued gradual decline is forecast, while Wheeler County's population is forecast to remain relatively stable. Table 17 summarizes recent population figures and population forecasts to 2000.

Table 17

POPULATION TRENDS 1960-2000

	1960	1970	1980	1990	2000
Garfield County	2,699	2,411	2,202	2,141	2,081
Wheeler County	1,297	1,051	1,054	1,057	1,072
State of Nebraska	1,411,300	1,488,493	1,569,825	1,705,077a/	1,787,789a/

a/ Nebraska Population Projections, UNL-Bureau of Business Research

Source: Nebraska Department of Economic Development[15]

The eastern section has an overwhelmingly rural character. However, this does not indicate there are large rural populations. The rural population in both Garfield and Wheeler counties are very small; in 1980 there were 980 and 784 rural residents, respectively, in these two counties. The urban areas that are found in the eastern section are also small, generally less than one thousand people.

Burwell is the only urban area in Garfield County. There have been some population changes in Burwell but the population has remained relatively stable since 1950, as shown in Table 18. In Wheeler County the population centers of Bartlett and Ericson have experienced declines, but the 1980 population figures indicate this has stabilized. The projections shown in Table 18 suggest that Burwell will show little change, Bartlett will increase, and Ericson will decrease in population in the future.

Both Garfield and Wheeler counties experienced substantial out-migration during the 1960's as shown in Table 19. Garfield County had an out-migration rate of 15.0 percent and Wheeler County had an out-migration rate of 29.3 percent. The State, during the same decade, had an out-migration of 5.2 percent. The rate of out-migration slowed considerably in the 1970's. During this decade Garfield County experienced an out-migration rate of 0.3 percent and the out-migration rate of Wheeler County was 6.9 percent. The out-migration rate of the State declined to 0.8 percent in the 1970's.

Younger age groups are more mobile than older age groups, which might help explain out-migration rates. Figure 23 provides a breakdown of the age-sex distribution of the populations for Garfield and Wheeler counties and for the State of Nebraska. From these graphs it can be seen that 67.2 percent of the population of Wheeler County consists of people under 45 years of age. This age group makes up 57.3 percent of the population in Garfield County. About 68.3 percent of the people in the State fall in this age group.

EMPLOYMENT

The labor force in the eastern section is concentrated in the agricultural sector as shown in Table 20. The agricultural sector includes farm owner-operators, tenant farmers, and share croppers; farm laborers and others involved in the production of crops and livestock; and people involved in such agricultural services as veterinarians.

Table 20 shows that employment in agriculture decreased significantly in Garfield and Wheeler counties from 1960 to 1980. Wheeler County, however, showed a nine percent increase in agricultural employment between 1970 and 1980. Table 21 shows that hired farm workers increased in both counties from 1969 to 1978[39]. The increase in this category of agricultural employment could be attributed to increased irrigation in the area.

In 1980 the service sector was the next largest employer in both counties. Services are defined as, "intangible output going to persons or business establishments as final consumption or in the creation of goods or other services." Examples of service activities are commercial lodging, amusement and recreation, automotive and related services, medical and health services, and legal services. The service sector employed 246 people or 24.7 percent of the labor force in Garfield County - just short of the 28 percent employed in agriculture. The next largest employer is the wholesale-retail trade sector employing 18 percent of the labor force.

Table 18

POPULATION TRENDS - URBAN AREAS

County	1950	1960	1970	1980	2000a/
Burwell	1,413	1,425	1,341	1,383	1,407-H 1,182-M 1,022-L
Bartlett	145	--	140	144	272-H 227-M 194-L
Ericson	186	--	122	132	105-H 87-M 75-L

a/ High, medium, and low projections from the Nebraska Population Projections, State, County, Region, and Town 1975-2020, UNL-Bureau of Business Research

Source: Nebraska Department of Economic Development[15]

Table 19

NET MIGRATION

Unit	1960 to 1970		1970 to 1980	
	Net Migrationa/	% of 1960 Population	Net Migration	% of 1970 Population
Garfield Co.	-406	-15.0	-7	-0.3
Wheeler Co.	-308	-29.3	-73	-6.9
Nebraska	-72,700	-5.2	-12,616	-0.8

a/ Net migration is the difference between the population for the end year and the beginning year plus the natural increase (births minus deaths) for the period. A plus sign (+) indicates immigration, a minus sign (-) denotes out-migration.

Source: Nebraska Department of Economic Development[15]

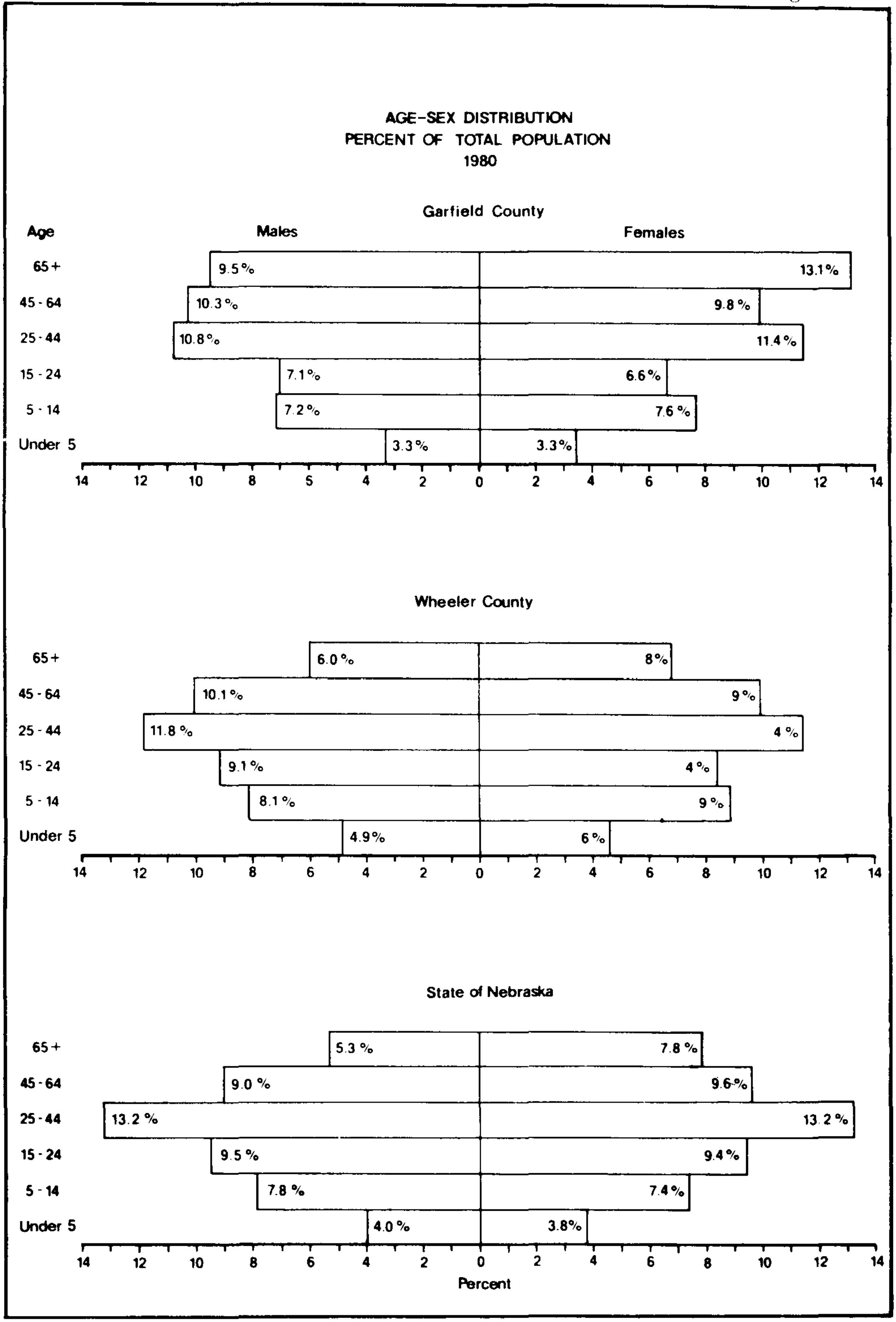

AGE-SEX DISTRIBUTION
PERCENT OF TOTAL POPULATION
1980
Garfield County
Age
Males
Females
65+
45-64
25-44
15-24
5-14
Under 5
9.5%
10.3%
10.8%
7.1%
7.2%
3.3%
13.1%
9.8%
11.4%
6.6%
7.6%
3.3%
Wheeler County
6.0%
10.1%
11.8%
9.1%
8.1%
4.9%
8%
9%
4%
4%
9%
6%
State of Nebraska
5.3%
9.0%
13.2%
9.5%
7.8%
4.0%
7.8%
9.6%
13.2%
9.4%
7.4%
3.8%
Percent

Table 20

CHARACTERISTICS OF THE EMPLOYED LABOR FORCE BY INDUSTRY - 1960-1980

Year	Garfield County						Wheeler County					
	1960		1970		1980		1960		1970		1980	
Industry	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Agriculture	557	48.5	322	29.0	283	28.4	341	69.3	230	58.2	252	54.0
Construction	60	5.2	34	3.1	94	9.4	8	1.6	16	4.1	30	6.4
Manufacturing	45	4.0	64	5.8	81	8.1	3	0.6	11	2.8	15	3.2
Transportation	7	0.6	30	2.7	33	3.3	4	0.8	6	1.5	5	1.1
Communications and Public Utilities	18	1.6	45	4.1	17	1.7	0	0.0	0	0.0	16	3.4
Wholesale Retail trade	164	14.3	226	20.5	180	18.1	48	9.8	63	15.9	49	10.5
Finance, Insurance and Real Estate	23	2.3	11	1.0	21	2.1	0	0.0	0	0.0	15	3.2
Services	182	15.8	253	22.8	246	24.7	20	4.1	43	10.9	75	16.1
Government[a/]	70	6.0	121	11.0	40	4.0	64	13.0	26	6.6	10	2.1
Not Reported	23	2.0	N	0.0	0	0.0	4	.8	0	0.0	0	0.0
Total Employed	1149	100	1106	100	995	100	492	100	395	100	467	100

a/ Government figures include public school personnel

Source: U.S. Department of Commerce, Bureau of the Census[41]

Table 21

HIRED FARM WORKERS
(Working 150 days or more)

County	1969	1974	1978
Garfield	37	35	77
Wheeler	35	49	113

Source: U.S. Department of Commerce, Bureau of the Census[39]

The service sector in Wheeler County is also the second largest employer with 75 people or 16.1 percent of the labor force. This percentage is significantly smaller than the figure for Garfield County and can be partially explained by the small urban population in Wheeler County (26 percent in Wheeler vs. 58 percent in Garfield). The wholesale-retail trade sector is the next largest employer at 49 or 10.5 percent.

In addition, between 1960 and 1980, both counties experienced increased employment in construction, manufacturing, and transportation as well as an increase in those employed in finance, insurance or real estate.

INCOME

The per capita income of Garfield and Wheeler counties was substantially lower than the State average as shown in Table 22[15]. The per capita personal income of these counties did, however, increase at a greater rate than the average rate of increase for the State of Nebraska from 1970 to 1980. Garfield and Wheeler counties increased 164 and 146 percent, respectively, while the State increased 142 percent over the same period.

Per capita income increases in contiguous counties show mixed changes. Two Sandhill counties west of Garfield have had quite different per capita increases. Loup County had only a 59 percent increase in per capita income, substantially below the State average, while Blaine County had a 140 percent increase, which is very near the State average of 142 percent. Both Loup and Blaine counties have significantly less irrigation development than Garfield and Wheeler counties.

Greeley and Valley counties, portions of which are in the eastern section, have much larger areas of irrigated land than the Garfield and Wheeler counties. However, their per capita income increases are lower than the increases experienced in Garfield and Wheeler counties, 125 and 135 percent respectively. These figures are not substantially lower than the increase average for the State. More data is needed to assess the significance of these differences.

Table 22

PER CAPITA PERSONAL INCOME

County	1970	1980	% Increase 1970-1980
	(Dollars)		
Garfield	3,116	7,495	164
Wheeler	3,010	7,313	146
Loup	2,835	6,361	59
Blaine	2,812	6,342	140
Greeley	2,649	5,184	125
Valley	2,107	4,780	135
Nebraska	3,748	9,086	142

Source: Nebraska Department of Economic Development[15]

Farm cash receipt increases for Garfield and Wheeler counties also increased at a rate greater than the State increased. Tables 10 and 11 show the cattle and livestock and crop cash receipt increases over the 1970-1981 time period. This was a period that also saw irrigation development in Garfield and Wheeler counties increase at a rate faster than the State increase. The larger percent increase in crop cash receipts compared with the livestock cash receipts increase may be a reflection of the irrigation development over the same time period.

PROPERTY OWNERSHIP AND VALUES

The 1978 Census of Agriculture reports a total of 263 farms in Garfield County and 182 farms in Wheeler County. The number of farms has decreased and their average size has increased in Garfield County from 1974 to 1978 as shown in Table 23. In Wheeler County, the opposite occurred; the number of farms has increased and their average size has decreased. The statistics on ownership are also contradictory when comparing the two counties. In Garfield County fewer full owners have more land and fewer tenants rent more land. The trends for Wheeler County are nearly the opposite of this. As there was much more irrigation development in Wheeler County during the period 1974-1978, that county should be studied for impacts of irrigation development.

The average value of the farm lands and buildings in 1978 was about $298,000 per farm in Garfield County and $519,000 in Wheeler County. From 1969 to 1979, the market value of Sandhills land increased more than three-fold. For example, Sandhills non-tillable rangeland valued at $45 to $50 per acre in 1969 sold for $160 to $170 per acre in 1979. Today's land prices have slipped back to about the 1979 level. Tillable rangeland is currently selling for about $235 per acre while center pivot irrigated cropland is selling for $700 to $900 per acre according to the Nebraska farm real estate market survey[9]. This difference in land value has been one of the factors causing the conversion of many acres of grass to irrigated cropland.

Table 23

FARM SIZE, VALUE, AND OWNERSHIP
FOR GARFIELD AND WHEELER COUNTIES

Category	Garfield County 1974	Garfield County 1978	Wheeler County 1974	Wheeler County 1978
Number of Farms	292	263	176	182
Total Acres	329,132	336,773	310,539	298,396
Average Size, Acres	1,127	1,281	1,764	1,640
Value of Lands and Buildings per Farm	$148,514	$297,746	$274,915	$519,072
Full Owners				
Number of Farms	147	135	84	92
Acres	104,890	127,732	105,190	74,185
Part Owners				
Number of Farms	98	85	71	69
Acres	186,901	166,592	188,766	211,695
Tenants				
Number of Farms	47	43	21	21
Acres	37,341	42,449	16,583	12,516

Source: U.S. Department of Commerce, Bureau of the Census[39]

Garfield and Wheeler counties have had more acres of grassland converted to irrigated cropland than some other areas of the State. This conversion has changed the land value in Garfield and Wheeler counties more than the rest of the State. According to the Census of Agriculture, the value of all farm lands in Garfield and Wheeler counties have increased 266 percent from 1969 to 1978, while the value for farm lands in the entire State increased 247 percent.

These changes in land value amount to an average annual rate increase of about 13 percent, when omitting the compounding factor. During this same time period, the rate of inflation, as measured by the General Price Level, averaged about 6.5 percent annually. In effect, the rate of appreciation in farmland values averaged twice the rate of inflation. An investor who held Sandhills farmland over this period of time experienced a real increase in wealth of about six percent per year. Based on these historical facts, it is obvious why many investors considered Sandhill farmland an effective hedge against inflation.

HOUSING

Housing is an important indicator of social conditions and is usually a reflection of income. The 1980 Census of Housing shows that there was a total of 1,488 year-round housing units in Garfield and Wheeler counties[40]. This is a four percent increase from 1970. About 70 percent of the occupied houses are occupied by their owners. There was a 60 percent increase in rental housing units rented in Wheeler County from 1970 to 1980. Thirty-eight houses lacked complete plumbing facilities in 1980, a decrease from 191 houses in 1970. Sufficient data has not been found to define other changes in the quality of the housing in these counties. The impact of irrigation development on housing in the area is difficult to assess.

ATTITUDES

The attitudes of the people in the area are an indication of social conditions and are particularly important for the consideration of acceptable solutions to the problems of the area. Research was conducted in 1980 to determine the attitudes of the Sandhills residents relating to irrigation development. The results of this study were reported in the Sandhills Area Study Decision Document [25].

The attitudes of the public are also expressed by socio-political responses to their problems. In 1979, the Lower Loup Natural Resources District requested a hearing to consider designation of a groundwater control area in parts of Loup, Garfield, Wheeler, and Boone counties. This request was filed under the authority of the Groundwater Management Act, now the Groundwater Management and Protection Act. The reasons for this request included loss of wet meadows and loss or interference of domestic and stock wells due to a lowering of the water table, streamflow reductions, increased nitrate levels in the groundwater, and increased soil erosion. After a hearing, the director of the Department of Water Resources denied the control area designation request.

Following the denial of the request for the control area, the Garfield County commissioners began efforts for the development of a comprehensive plan. With the adoption of a comprehensive plan, the county board could zone the county for different land uses. A draft comprehensive plan has been prepared.

In the November 1982 general election, Initiative 300, the Family Farm Amendment, received the support of 52 percent of those voting statewide. In Garfield and Wheeler counties, this initiative was supported by 57 and 56 percent, respectively, of the voters[27]. The initiative prohibits future purchases of land for agricultural use by non-family corporations and limited partnerships.

SOCIAL AND GOVERNMENT SERVICES

There are a number of social services available for the well being of the people of Garfield and Wheeler counties. Some services are provided by private entities, while others are functions of government. Some of the more important services are discussed in this section.

Governmental Framework

While federal and State governments certainly affect the people in the area, local government probably plays a more direct role. Both Garfield and Wheeler counties are precinct counties served by a board of commissioners. Burwell is the only city in the area; Bartlett and Ericson are villages. The Lower Loup Natural Resources District includes most of the two-county area. The northern portion of Wheeler County is part of the Upper Elkhorn Natural Resources District. The North Loup Public Power and Irrigation District includes a portion of southwestern Garfield County. School districts are also important in the area.

Governmental services provided to an area are related to the tax dollars available to provide these services. Property tax levies for Garfield and Wheeler counties totaled $2.2 million in 1980 as shown in Table 24[21]. These funds for local governments increased 82 percent since 1972. This increase compares to a 73 percent increase for the State for the same period. The effects of irrigation development on the property tax base are further discussed in Chapter 6.

State income tax is also shown in Table 24. The table shows that state income taxes collected from the residents of Garfield and Wheeler counties increased 379 percent from 1972 to 1980, while the statewide increase was 424 percent. This is the opposite of the comparison for property tax where these counties showed a greater increase than the entire State.

Table 24

TOTAL INDIVIDUAL INCOME TAX AND PROPERTY TAX COLLECTED

Area	State Income Taxes	Increase 1972-1980	Total Property Tax Levied	Increase 1972-1980
Garfield and Wheeler Counties				
1972	$ 70,767		$ 1,193,229	
1980	338,886	379%	2,173,275	82%
State of Nebraska				
1972	$ 49,055,998		$409,715,315	
1980	257,275,775	424%	708,671,291	73%

Source: Nebraska Department of Revenue[21]

Health and Safety Services

Health and safety services include such things as available hospitals, law enforcement, and fire protection. The only hospital in the area is located in Burwell. According to the State Health Department, heart disease is the number one cause of death in Garfield and Wheeler counties, followed by cancer and strokes. Accidents are the number four cause of deaths. The increase in exposure to operating farm machinergy associated with irrigation could change the accident rate in an area that was previously cattle ranching. However there is no data at the present time to support a change in accident rates.

The county sheriffs and the State Patrol are the primary law enforcement officials in the two counties. Fire protection is limited to volunteer fire district.

Education

There are seven elementary school districts and one junior-senior high school in Garfield County and one consolidated school district in Wheeler County. Enrollment in the schools is a reflection of the population of the area. There were 452 students enrolled in the Garfield County schools and 246 students enrolled in Wheeler County for 1982-83[16]. For the last ten year period, the enrollment in Garfield County has declined 8.9 percent and enrollment in Wheeler County is down 3.1 percent. The change since the 1981-82 term, however, shows a 2.5 percent increase for Garfield County and a 3.8 percent increase for Wheeler County. The gross pupil-teacher ratio is 12.9 for Garfield County and 11.8 for Wheeler County.

This information is not sufficient to determine the impact of irrigation development on the educational systems in these counties. Information presented in Chapter 6 would indicate that additional funding should be available for education due to the increased value of the land due to the conversion to irrigated agriculture.

Recreation and Entertainment

Recreation and entertainment opportunities in the Eastern Section are limited. Pibel Lake State Recreation Area in southern Wheeler County is the only State or federal recreation area. There are public campgrounds at Bartlett and Burwell. There are hunting and limited fishing opportunities in the area. Burwell has a movie theater and a municipal swimming pool. Other forms of entertainment include television, rodeos, and county fairs, and private eating and drinking establishments. Burwell sponsors one of the larger annual rodeos in the state. The rodeo is symbolic of the ranching tradition in the area. How or if recreation and entertainment has changed or will change due to irrigation development is not known at this time.

SOCIO-ECONOMIC PROJECTIONS

Projections of future economic and social conditions are required to assess the potential impacts of water resources development, including groundwater irrigation. Economic models such as the Farm and Ranch Economics model project the returns to the individual irrigator or dryland farmer, and the total returns to farmers and ranchers by county. They do not project the total economic effects, however. Irrigators purchase irrigation equipment and supplies, and greater quantities of supplies such as seed, fertilizer, and herbicides than dryland farmers. These increases provide more business for manufacturers, wholesalers, and retailers. Irrigators also sell their products to elevators, feeders, and processors, which provides business for transportation companies also. The businesses that deal directly with the farmer then increase their activity with their suppliers or purchasers, so the effects of investment and operation in irrigation spread throughout many sectors of the economy of the region and the state. If the increase is large enough, it can produce additional employment, increases in income, and improvements in the quality of life.

Projections of these regional economic and social effects are required to fully assess the benefits and costs to the state of planned and projected development. Since these are dynamic activities, a baseline projection is needed as a basis for comparison with the projections of conditions with planned development.

Regional socio-economic projections are difficult to obtain. The only projections of this type that have been made for state water resources planning were made in the Six State High Plains Ogallala Aquifer Study. In that study the Commission's sub-contractors developed an economic input/output model for the part of the state underlain by the Ogallala and associated aquifers. This model projected the changes in economic outputs in dollars in many sectors of the economy besides agriculture. It also projected changes in employment in those sectors, and the changes in population from the changes in employment. Other socio-economic factors could be calculated from these figures if needed.

Extensive preparation would be required to develop a model that would produce the needed projections for this study. Methods of developing this capability are being investigated as part of the Commission's Economic Base Activities, but it is unlikely that the methods and data base could be completed in time to contribute to this study.

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