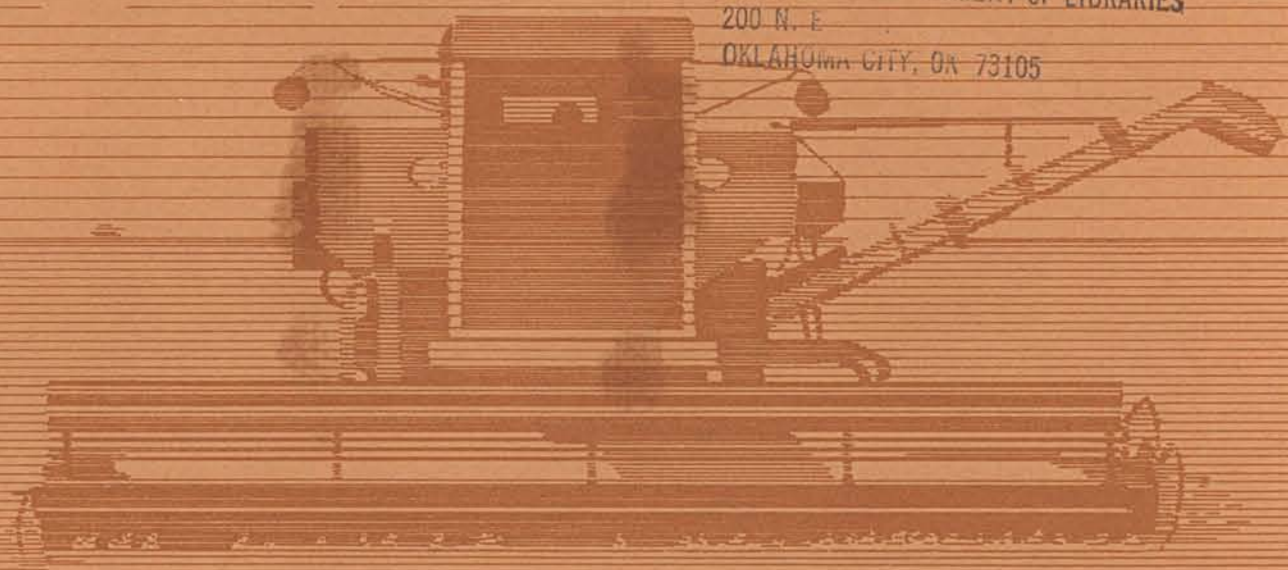
SIX-STATE HIGH PLAINS OGALLALA AQUIFER REGIONAL RESOURCES STUDY

SUMMARY

High Plains Associates:
Camp Dresser & McKee Inc.
Black & Veatch
Arthur D. Little, Inc.

A report to the U.S. Department of Commerce and the High Plains Study Council

July, 1982



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OGALLALA AQUIFER
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A Report to the U.S. Department of Commerce
and the
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March 1982

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Third Printing
December 1982

NOTICE

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Subsequent to the printing and distribution of the Final Report of the Six-State High Plains-Ogallala Aquifer Regional Resources Study, March 1982, the U.S. Army Corps of Engineers and the State of Colorado submitted corrections to the previously submitted results of their studies which were used in preparation of the Final Report. This third edition contains corrected data provided to holders of the first and second printing as an Errata Notification dated August 13, 1982. Corrected data are underlined or marked with an asterisk to note differences from earlier printings.

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The final report on the Six-State High Plains-Ogallala Aquifer Regional Resources Study is in fulfillment of Contract No. CO-A01-78-00-2500, under a grant from the U.S. Department of Commerce, Economic Development Administration. The statements, findings, conclusions, recommendations, and other data contained herein are solely those of the Grantee(s) and do not necessarily reflect the views of the Economic Development Administration or the U.S. Government.

HIGH PLAINS ASSOCIATES

Camp Dresser & McKee Inc.
Black & Veatch
Arthur D. Little Inc.

March 31, 1982

The Honorable Malcolm Baldrige
Secretary of Commerce
Department of Commerce
14th Street between Constitution
and E Street, N.W.
Washington, DC 20230

The Honorable William P. Clements
Governor of Texas
Chairman, High Plains Study Council
State Capitol
Austin, TX 78711

Gentlemen:

High Plains Associates, as General Contractor, are pleased to submit this final report on the Six-State High Plains-Ogallala Aquifer Regional Resources Study in fulfillment of our Contract No. CO-A01-78-00-2550 with the U.S. Department of Commerce. The Study has been conducted pursuant to the provisions and objectives of Public Law 94-587 (90 Stat. 2943), Sec. 193 which authorized the Study, under direction of the High Plains Study Council. We have been assisted in the Study by each of the states, Colorado, Kansas, Nebraska, New Mexico, Oklahoma and Texas.

The report and associated study reports present the results of our analyses of the economic, environmental and social impacts at the local, subregional, state, regional and federal levels of alternative water resource management strategies which would extend the duration of availability of water for irrigation from the Ogallala Aquifer or augment the Aquifer supply. Our projections of the future of the energy sector of the High Plains regional economy and the potential for future nonagricultural economic developments are also presented. We believe that this information, combined with that in the U.S. Army Corps of Engineers' report on potential interstate interbasin water transfers, will be useful to the High Plains Study Council and the Secretary in formulating recommendations to the states and the Congress for actions ". . . to assure an adequate supply of food to the Nation and to promote the economic vitality of the High Plains Region. . ." (P.L. 94-587, Sec. 193).

We appreciate the opportunity to conduct this comprehensive resources and impacts study so important not only to the High Plains Region and the states but also to the Nation. It is, we believe, the first effort of this complexity to analyze the multiple problems engendered by depleting natural resources on a multi-state regional basis.

Respectfully submitted,

Harvey O. Banks, Study Director
President, Water Resources Division
Camp Dresser & McKee Inc.

C.W. Keller, Executive Partner
Black & Veatch

Frank G. Feeley
Arthur D. Little Inc.
Project Manager

HOB:ll

Enclosure

ACKNOWLEDGEMENTS

The High Plains Study has been conducted with the participation of governmental agencies at the federal, state, and local levels; universities; and firms in the private sector. The number of individuals within these entities, and the number of entities, make it impossible to acknowledge the contribution of each. We do want to express, however, appreciation by the General Contractor team (High Plains Associates) for the cooperation and many courtesies that have been extended us by participants in the Study.

The duration and complexity of the Study effort resulted in problems of continuity as the work progressed. The professional and cooperative approach of all involved eased those problems, and facilitated the timely completion of the Study and this report.

The state contributions to overall Study completion were significant, and deeply appreciated. The High Plains Study Council provided continuing policy guidance, and its Liaison Committee diligently translated the Council's work into constructive assistance and direction to the General Contractor to achieve Study objectives.

The state agencies and several universities in the Study states were responsible for and performed complex research, and worked together to coordinate their efforts with those of the General Contractor.

Federal agencies--both at the Washington and field levels--were cooperative and helpful. A diverse array of experience and skills within the federal establishment were made available to the Department of Commerce through the Technical Advisory Group.

Of special note are direct cooperative contributions of counsel and Study input from:

- U.S. Department of Commerce, through the Economic Development Administration, was assigned responsibility for Study oversight.

The courtesy and assistance of all personnel in that Department has been appreciated.

- U.S. Army Corps of Engineers which conducted separate and concurrent studies of interstate water transfers under provisions of the legislation authorizing this Study.

- U.S. Geological Survey (USGS) which is carrying out a concurrent study of the Ogallala Aquifer. The USGS has generously made the results of its work available to the General Contractor. Maps prepared through the USGS project are included as a part of this report.

- U.S. Fish and Wildlife Service has prepared and made available to the General Contractor team an environmental impacts assessment report. This report has been used extensively and has been very helpful in Study activities.

- U.S. Department of Agriculture made available use of its National-Inter-regional Agricultural Projections (NIRAP) model to project various indications used in the Study. Advice and support by the Department's personnel was appreciated.

The General Contractor has had the opportunity to consult with the members of its Consulting Panel throughout the Study. The interest and special contributions of these talented people has been of great benefit to the Study and to the development of this report.

Finally, with gratitude, we want to recognize individually two very key participants in the Study who tragically did not live to see its completion:

- Dr. Jean McFarland, Chief, Economics Research Division, Department of Commerce. Dr. McFarland participated as the EDA member in the High Plains Study Council. She added wisdom, knowledge and good judgment to the Study effort.

° Jack O. Horton, Member, Consulting Panel. Mr. Horton was President of Horton and Company, Inc., in the energy and natural resources field. He was formerly Assistant Secretary for Land and Water Resources, and, then, Deputy Under Secretary in the Department of Interior. His knowledge and special insight are deeply appreciated by all of us.

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PREFACE

The Six-State High Plains-Ogallala Aquifer Regional Resources Study (the High Plains Study) evolved as a regional response to compelling pressures from resource depletion and resultant potential economic, social, and environmental changes. Objectives and scope of the Study are consistent with the geographic similarities among the states. An understanding of the origin and development of these problems is essential to an appreciation of their gravity in terms of the Region, the states and the Nation, and to their possible solutions.

Settlement of the High Plains has become a part of the folklore highlighting this Nation's expansion. As frontiers were pushed westward, the Plains became an avenue to the undeveloped West. The use of barbed wire and the windmill made habitation of the Plains an acceptable alternative to further westward migration. Barbed wire provided a way to establish property lines on the vast prairies and the windmill facilitated the pumping of shallow ground water from hand dug wells. With horses, plows, and handguns, a ranching and farming culture was established on the Plains reaching a peak of early development in the late 19th century.

Unusually wet years in the 1880's invited large-scale settlement by eastern farmers on the broad, fertile lands. A return to the low-rainfall conditions more characteristic of the Plains led to disaster in the next decades. A.M. Simons wrote in "The American Farmer" (late 19th century):

> "From the 98th meridian west to the Rocky Mountains there is a stretch of country whose history is filled with more tragedy and whose future is pregnant with greater promise than perhaps any other equal expanse of territory within the confines of the Western Hemisphere."

This cycle of boom and bust continued in the Plains in the wake of cycles of rain and drought up to and through the disastrous coincidence of drought and the Great Depression of the 1930's. In the late 30's, the combination of drilled wells, which tapped the ground water resources of the Ogallala Aquifer, improved pumping technology and cheap energy opened this vast fertile land to large-scale irrigation. The Ogallala water resource was described at the time, as "an inexhaustible supply", and a "vast underground river."

World War II interrupted development of large-scale irrigation, but in the years following irrigated agricultural production exploded on the Plains. Abundant water and cheap energy fed the growth of one of the most productive and stable agricultural enterprises in the world.

We know now that the water resources of the Ogallala Aquifer are not inexhaustible. Cheap energy is no longer available to pump the remaining stores of water. Land and climate well suited to large agricultural enterprises remain, but the Region is faced with a simultaneous decline in water and the energy resources to support such enterprises. The Nation is faced with a potential reduction in the agricultural production capacity that has contributed substantially to both feeding and clothing its own population and to providing commodities for foreign export.

This potential depletion of natural resources became the background for formulating the High Plains Study. Six states, through their state governments and their Congressional representatives, determined to undertake a comprehensive study to identify and evaluate alternatives for the future of the Region. Recognizing the geographic unity of the Plains, the six states committed themselves to participation in the Study, at both a research and policy level.

With the support of the states, the Study was authorized by Congress in 1976 as Sec. 193, P.L. 94-587. It was begun in October 1978. Its completion represents the product of a unique effort of the federal government, the states, and private enterprise to examine problems on a regional basis and to develop alternatives for their solution.

EXECUTIVE SUMMARY

SIX-STATE HIGH PLAINS-OGALLALA AQUIFER REGIONAL RESOURCES STUDY

INTRODUCTION

The problem of depleting Ogallala Aquifer water supplies to support 15 million acres of irrigation crop farming in the High Plains was addressed by the U.S. Congress in Section 193, Public Law 94-587. The Congressional intent was clear and concise in directing the Secretary of Commerce ". . . to examine the feasibility of various alternatives to provide adequate water supplies" for the High Plains Region, and ". . . to assure the continued economic growth and vitality of the region." The High Plains Study Council, made up of the governors of the six states and three representatives of each state appointed by the Governor and a representative of the Department of Commerce, was also clear and concise in stating overall study objectives: "(i) to determine potential development alternatives for the High Plains, (ii) to identify and describe the policies and actions required to carry out promising development strategies, and (iii) to evaluate the local, state, and national implications of these alternative strategies or the absence of these strategies."

GEOGRAPHIC AREA

The High Plains area extends over parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma and Texas in the Great Plains land resource region of mid-continental America. Much of the High Plains is underlain by the Ogallala Formation, a major aquifer supplying most of the water needs of the area's large agricultural economy.*

The Ogallala Formation, of Tertiary age, is an unconsolidated remnant of vast deposits of gravel, sand, and silt eroded from the ancestral Rockies. Erosion has reduced the area of the extensive deposits that once covered all of the Great Plains region, leaving the Ogallala as the principal geologic unit associated with the High Plains today.

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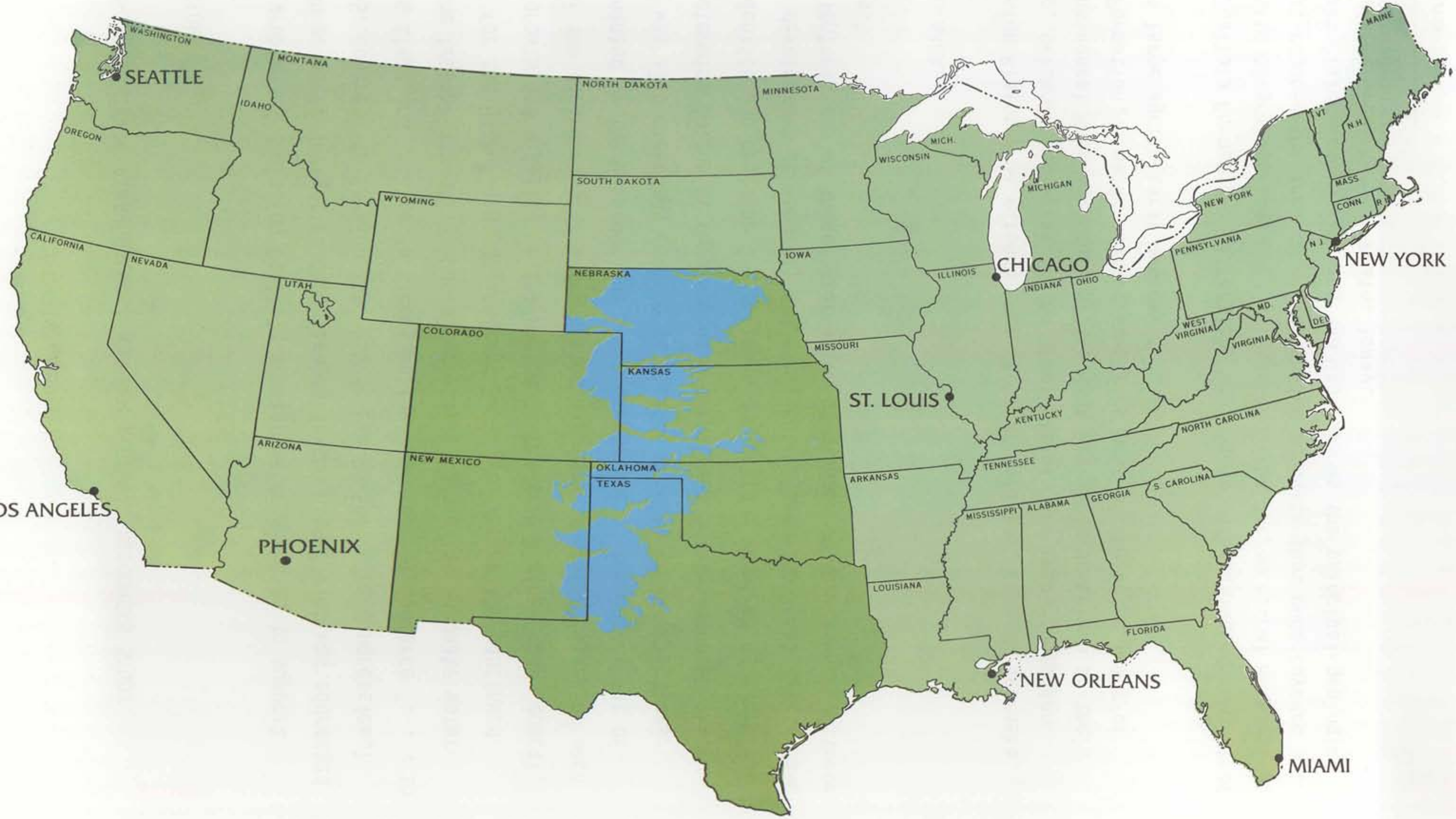
* See Figure 1

FIGURE 1: THE HIGH PLAINS REGION—OGALLALA AQUIFER



The area encompassed by this Study includes 180 counties in the Region underlain in whole or in part by the Ogallala Formation or Aquifer, an area of about 220 thousand square miles.

STATEMENT OF PROBLEM

The High Plains Study Region offered large quantities of good quality water, abundant low cost energy, deep soils, level terrain, and a climate favorable to agricultural enterprises. Development of irrigated agriculture, largely supplied by water from the Ogallala Aquifer, expanded rapidly following World War II. Total irrigated acreage in the Study area expanded from about 3.5 million acres, mostly in Texas and Nebraska in 1950, to more than 15 million acres in 1980.

As irrigated acreage expanded, water requirements grew. Less than 7 million acre-feet of water were withdrawn from the Ogallala in 1950. By 1980, more then 21 million acre-feet were pumped annually even though over the same period improved irrigation efficiencies had reduced per acre application of water by about 30 percent from 2 acre-feet per acre to about 1.4 acre-feet per acre.

Feed grain crop production grew from 150 million bushels in 1950 to 1.25 billion bushels in 1980. The Region marketed about 38 percent of the fed beef cattle production in the Nation by 1980.

A complex infrastructure of agricultural business supply developed--fertilizers, farm equipment, and capital investments.

Energy production from the oil and gas reserves became an important sector in the regional and subregional economies. Over the long term, these reserves will be seriously depleted.

With this progressively expanding agricultural economy came larger demands for water from the Ogallala, coupled with simultaneous and complex changes in the availability of low cost natural gas. As a result, this Study was undertaken to project the probable consequences of various water resource management alternatives for the High Plains Region and depletion of the energy resources. These consequences will have local, state, regional, and national impacts. The measure of the extent and timing of those impacts were the key problems resulting in authorization of the Study.

STUDY AND REPORT ORGANIZATION

Responsibility for administrative direction of the Study, and for final recommendations to the Congress, was assigned by the authorizing legislation to the Secretary of Commerce acting through the Economic Development Administration (EDA). The states and EDA formed the High Plains Study Council to assure policy guidance for the Study, and to submit its conclusions and recommendations to the Secretary and the Congress. Key federal agencies were represented on a Technical Advisory Group formed by EDA to provide technical review support.

Technical direction of the Study was provided by the High Plains Associates (General Contractor) made up of the consulting firm of Camp Dresser & McKee Inc., as prime contractor, in association with Black & Veatch as joint venturer, and Arthur D. Little, Inc., as subcontractor. Vital research was carried out by the states. Concurrent studies by federal agencies contributed directly to Study results.

The full $6 million authorized for the Study was appropriated by Congress. Two million was allocated to the states for state level research basic to the Study under subcontracts with the General Contractor, and $775,000 to the U.S. Army Corps of Engineers for studies of interbasin transfers under a contract with EDA.

The High Plains Associates entered into a contract with the Department of Commerce in September 1978, and negotiated subcontracts in the spring and summer of 1979 with each of the six states for performance of state and farm-level work elements. These state subcontracts involved work tasks by state agencies, universities, and private consultants.

The Plan of Study outlined three research elements which were conducted by the states:

° State and farm-level research
° Energy production impacts
° State water resources evaluations and economic and other impacts

Regional assessments were performed by the High Plains Associates of important Study elements (division of responsibilities among the three members of the team shown in parentheses):

° Interbasin transfer assessment (CDM)
° National and regional impact assessment (ADL)
° Agriculture and water technology assessment (CDM)
° Preliminary environmental assessment (CDM)
° Unconventional water supply assessment (CDM)
° Institutional assessment (CDM)
° Crop prices assessment (ADL)
° Energy price and technology assessment (B&V)
° Dryland farming assessment (ADL)
° Nonagricultural development potential assessment (ADL)
° Alternative development strategy assessments (ADL)
(via a regional input/output model)

This Report, together with separate documents presenting the special Regional Assessments, the state reports on research conducted by each of the six states, and the U.S. Army Corps of Engineers report on interbasin transfers describe how broad Study objectives have been met. Chapter One provides background information which led to the Study, and Chapter Two provides information on the Region under study and its diminishing water and energy resources. Chapter Three defines the alternative water management strategies selected for analysis. Chapter Four defines the Study's methods of analysis, starting with 1977 as the base year with monetary results expressed in terms of 1977 dollars. Chapter Five describes impacts of projected "Baseline" conditions reflecting a continuation of present trends to 2020 without a new purposeful public policy and action program to alter the trends, and Chapter Six describes impacts of strategies designed to alter trends in water availability and use in the future to 2020. In Appendix A, the brief discussion of methodology included in Chapter Four is expanded, and the models used in the Study's analytical framework are described in detail. Appendix B presents detailed tables showing Study results. Appendix C provides task detail on the Study organization and identifies source agencies and entities which can be contacted with respect to the Study.

In this Executive Summary, the results of the several analyses are synthesized and presented. This is accomplished by inter-strategy comparisons highlighting significant quantitative differences in impacts among water management strategies, and by summarizing those results of the separate regional assessments that significantly relate to the quantitative strategy analyses. The methods of analysis chosen were those appropriate to the objectives of the Study as defined in the authorizing legislation. Analyses of benefit and cost comparisons would only be made for specific projects or actions undertaken as a part of implementing Study results.

In arraying results, the intent is to provide information about projected outcomes as an aid in making major policy choices, and for choosing among mechanisms for translating policy into program administration. Thus, the results of the High Plains-Ogallala Aquifer Regional Resources Study are portrayed to facilitate an effective response by the Council and the Secretary of Commerce to the Congressional intent.

ALTERNATIVE STRATEGIES AND INTER-STRATEGY COMPARISONS

To carry out the Congressional directives and to fulfill the High Plains Study Council objectives, two incremental management strategies to reduce water demands in the Region and three strategies to increase regional or subregional water supplies were formulated. These water demand and supply management strategies were evaluated in comparison to projected "Baseline" conditions, i.e., the continuation of present trends in use of Ogallala Aquifer water with no new public policies or programs to effect greater water conservation or to increase supplies. The probable future of the energy sector and the effect on the High Plains regional and subregional economies was analyzed including projections of future energy prices. The potential for future nonagricultural development in sustaining the regional economy was assessed.

The Framework for Impact Assessment

The water management strategies analyzed in the Study are:

° A "Baseline" trend projection of currently available water conservation and use technology and practices already in use to some extent, with no new purposeful public policy to intervene with action programs for altering the course of irrigation water consumption. (the Baseline)

° A strategy which would stimulate voluntary action to reduce water demands through research, education, demonstration programs and incentives, using technology and practices either not considered in the Baseline analysis or reflected at rates which would be purposefully accelerated. (Management Strategy One)

° A strategy which assumes Strategy One policies and programs, and in addition projects further water demand reduction by mandatory programs of a regulatory nature to control water use. (Management Strategy Two)

° A strategy to add local water supply augmentation actions to demand reduction efforts. These actions could include local practices such as cloud-seeding, local storage, ground water recharge, desalination, and snowpack and vegetation management. (Management Strategy Three)

° A strategy of intra-state surface water interbasin transfers, importing water into the High Plains Region in accordance with State Water Plans of the six High Plains states. (Management Strategy Four)

° A strategy of interstate surface water transfers, importing water from sources in areas adjacent to the Ogallala Region by means of large-scale federal-state or federal projects to restore and maintain irrigation of the acreage that would have reverted to dryland farming by 2020 under Strategy One or Two. (Management Strategy Five)

For each water management strategy, state-level linear programming (LP) models were used to project crop production, irrigated and dryland crop acreages, value of agricultural production, returns to land and management (plus returns to imported water for Strategy Five), and ground water use, each for 1985, 1990, 2000 and 2020. State and regional input/output (I/O) models were then used to project industry sector activities, sector employment, total value added, total household income, and state and local tax revenues, each related to the LP projections for the future years.

A special feature of the regional I/O model was its division of outputs by northern (Nebraska, Kansas and Colorado) and southern (Oklahoma, New Mexico and Texas) subregions so as to highlight the probable difference in conditions in the future for these parts of the Study region. Projections of energy production, economic effects and prices were incorporated into the LP and the I/O models.

Projected trends in energy production and availability are important factors in the regional economy. These projections, however, do not indicate significant differences among the effects of the several water management strategies although a major interstate water diversion project under Strategy Five would impose unique energy production and use requirements. Over the Study period to 2020, the decline in crude oil and marketed natural gas production is projected to continue. By 2020, these production levels are projected to be approximately 1/10 the levels at the beginning of the Study period. Electricity production, however, is projected to increase, both in installed generating capacity and electric energy production, by approximately threefold over the Study period. Some increase is projected in water consumption associated with energy production.

Comparison of Economic Indicators Among Strategies

Table 1 shows some key economic indicators of projected strategy effects, by northern and southern subregions and the Region for the Baseline,

Table 1: INTER-STRATEGY COMPARISONS OF KEY REGIONAL ECONOMIC INDICATORS

Base Year 1977*

	Irr. Acres (1000's)	Dry. Acres (1000's)	Total Value of Agr. Prod.** (Million 1977 $)	Returns to Land & Management (Million 1977 $)	Water Remaining in Storage (Million Ac-Ft)	Total Value Added All Sectors*** (Million 1977 $)	Employ-ment (1000's)
NORTH							
Baseline	7,480	11,595	2,610	850	2,673.0	7,047	444.2
SOUTH							
Baseline	6,805	6,675	1,960	200	367.4	14,406	563.6
REGION							
Baseline	14,285	18,270	4,570	1,050	3,040.4	21,453	1,007.8

* Water Management Strategies MS-1 and MS-2 do not become operative until 1985, MS-5A and MS-5B in 2000.
** Includes product value from dryland as well as irrigated crop production.
*** Includes energy and other sectors as well as agricultural sector.

Table 1: INTER-STRATEGY COMPARISONS OF KEY REGIONAL ECONOMIC INDICATORS (Cont'd)

1990

	Irrigated Acres		Dryland Acres		Total Value of Agr. Prod.**		Returns to Land & Management		Water Remaining in Storage		Total Value Added All Sectors***		Employment***	
	1000's	%Δ*	1,000's	%Δ*	Million 1977 $	%Δ*	Million 1977 $	%Δ*	Million Ac-Ft	%Δ*	Million 1977 $	%Δ*	1,000's	%Δ*
NORTH														
Baseline	9,480	%	11,605	-	4,640	%	1,775	%	2,521.6	%	11,957	%	533	%
MS-1	9,710	2.4	11,575	-0.3	4,710	1.5	1,805	1.7	2,528.8	0.3	12,028	0.6	537	0.7
MS-2	9,420	-0.6	11,820	1.9	4,425	-4.6	1,730	-2.5	2,536.5	0.6	11,699	-2.2	521	-2.4
SOUTH														
Baseline	6,355		7,105	-	2,770		530		266.8		26,643		703	
MS-1	6,400	0.7	7,070	-0.5	2,785	0.5	531	-	272.0	2.0	26,662	0.1	704	0.2
MS-2	5,635	-11.4	7,765	9.3	2,565	-7.4	495	-6.6	273.6	2.5	26,514	-0.5	696	-1.1
REGION														
Baseline	15,835		18,710	-	7,410		2,305		2,788.4		38,600		1,237	
MS-1	16,110	1.7	18,645	-0.3	7,495	1.1	2,335	1.3	2,800.8	0.5	38,690	0.2	1,241	0.4
MS-2	15,055	-4.9	19,585	4.7	6,990	-5.7	2,225	-3.5	2,810.1	0.8	38,212	-1.0	1,216	-1.6

* Change from Baseline.
** Includes product value from dryland as well as irrigated crop production.
*** Includes energy and other sectors as well as agricultural sectors.

Table 1: INTER-STRATEGY COMPARISONS OF KEY REGIONAL ECONOMIC INDICATORS (Cont'd)

2020

	Irrigated Acres		Dryland Acres		Total Value of Agr. Prod.**		Returns to Land & Management		Water Remaining in Storage****		Total Value Added All Sectors***		Employment***	
	1000's	%Δ*	1,000's	%Δ*	Million 1977 $	%Δ*	Million 1977 $	%Δ*	Million Ac-Ft	%Δ*	Million 1977 $	%Δ*	1,000's	%Δ*
NORTH														
Baseline	12,410	%	11,825	-	8,110	%	3,990	%	2,209.1	%	19,636	%	555	%
MS-1	13,305	7.2	11,710	-1.0	8,475	4.5	4,035	1.1	2,193.0	-0.7	20,048	2.1	568	2.4
MS-2	13,280	7.0	11,410	-3.5	7,550	-7.0	3,670	-8.0	2,300.0	4.1	18,855	-4.0	531	-4.3
MS-5A	16,280	31.2	9,845	-16.7	9,385	15.7	4,540**	13.8	2,193.0	-0.7	21,162	7.8	604	8.9
MS-5B	15,475	24.7	10,265	-13.2	8,375	3.3	4,070***	2.0	2,300.0	4.1	19,787	0.8	563	1.5
SOUTH														
Baseline	5,635	-	7,725	-	3,385	-	920	-	125.7	-	29,540	-	778	-
MS-1	5,685	0.9	7,685	-0.5	3,400	0.4	955	3.8	139.4	10.9	29,577	0.1	780	0.2
MS-2	4,755	-15.6	8,520	10.3	3,035	-10.3	880	-4.3	163.0	29.7	29,270	-0.9	770	-1.1
MS-5A	7,320	29.9	6,160	-20.3	3,815	12.7	1,100***	19.6	139.4	10.9	30,011	1.6	793	1.8
MS-5B	6,020	6.8	7,350	-4.9	3,335	-1.5	1,020***	10.9	163.0	29.7	29,609	0.2	780	0.2
REGION														
Baseline	18,045	-	19,550	-	11,495	-	4,910	-	2,334.8	-	49,176	-	1,333	-
MS-1	18,990	5.2	19,395	-0.8	11,875	3.3	4,985	1.5	2,332.4	-0.1	49,625	0.9	1,347	1.1
MS-2	18,035	-0.1	19,930	1.9	10,585	-7.9	4,550	-7.3	2,463.0	5.5	48,125	-2.1	1,301	-2.4
MS-5A	23,600	30.7	16,005	-18.1	13,200	14.8	5,640***	14.9	2,332.4	-0.1	51,173	4.1	1,397	4.8
MS-5B	21,495	19.1	17,615	-9.9	11,710	1.9	5,090***	3.7	2,463.0	5.5	49,396	0.5	1,343	0.7

* Percent change from Baseline.
** Includes product value from dryland as well as irrigated crop production.
*** Includes returns to imported water - no cost charged in farm budgets for imported water.
**** Water remaining in storage is the same for MS-1 and MS-5A, and for MS-2 and MS-5B.

and Strategies One, Two, and Five. Strategy Three, local water supply augmentation, could not be quantified meaningfully, because data were fragmentary and did not support a finding of significant regional potential. Strategy Four was quantified for Nebraska and Oklahoma, reflecting interest by those states in intra-state imports. Strategy Five was analyzed in two ways: an interstate import constrained to water needed to restore irrigation to acreage reverting to dryland farming by 2020 due to aquifer depletion under projections of Strategy One and under Strategy Two; these analyses are described as Strategies Five-A and Five-B, respectively.

It is important to note that in making its studies of interbasin diversion, the Corps of Engineers did not make a determination that there would be surplus water available for such imports from the sources.

Regional Comparisons - North and South

Because Aquifer thickness generally increases from south to north, the volumes of ground water in the Ogallala Aquifer of New Mexico, Oklahoma and Texas have historically been less than that available to the northern Ogallala states. By the base year 1977, the three southern states had only a 12 percent share of Ogallala water remaining in storage for the entire Region. Much of the southern High Plains has been in irrigated production over a longer period of time than the Northern Ogallala and the South's available ground water supply is therefore depleted more extensively.

The effects of the more limited water supply in the southern Ogallala are reflected in the key indicators summarized in Table 1. Most indicators show a very different pattern of projected impacts between north and south, both across the Study period for 1990 and 2020, and among the water management strategies, in comparison to the Baseline.

Under Baseline conditions in 1977, the southern Ogallala has a relative parity with the North in irrigated acres, with about 48 percent of the Regional total, but has only about 36 percent of the dryland acreage. The disparity in total cropland acreage in the South is reflected by lower value of agricultural production and in returns to land and management from agricultural sales. In contrast, the South enjoys a relative advantage over the

North in the key regional economic indicators displayed in Table 1, due primarily to a more vigorous and diversified nonagricultural economy in 1977, particularly in the energy sector. Total value added by all sectors in the South is more than double that of the northern Ogallala. Employment in the South constitutes about 56 percent of total regional employment.

By 1990, the differences beteen the southern Ogallala states and the northern subregion are even more pronounced for the agricultural sector indicators. These differences are accentuated by the impacts of the alternative water demand (reduction) strategies MS-1 and MS-2. The projected effects of these water demand strategies reflect the impact of further depletion of water remaining in Ogallala storage in the South.

Under the most favorable water use reduction strategy (MS-2) for extending the Ogallala water supply in the South, the southern subregion still declines from a 12 percent share of regional water in storage in 1977 to less than 10 percent in 1990. Irrigated acreage for the southern three states falls to only 40 percent of total regional irrigation (down from 48 percent in 1977) for Baseline. Irrigated acreage under MS-1 and MS-2 are even less as a percent of total regional irrigation, with a projected 11 percent decline in acreage for MS-2 in comparison with Baseline projections for 1990.

The related economic effects of MS-2 in 1990 are consistent by negative for the South, with a 7.4 percent loss in total value of agricultural production and a 6.6 percent loss in returns to land and management in relation to 1990 Baseline projections. Subregional economic indicators--total value added, all sectors, and employment projections show insignificant interstrategy differences from Baseline for 1990.

The water supply (importation) strategies MS-5A and 5B are projected to be in place by the year 2000 and Table 1 indicates the comparative impacts for 2020 of these strategies, both to Baseline and the water demand reduction strategies MS-1 and MS-2. The 2020 projections indicate a significant further decline in ground water remaining in storage from 1990 for the southern Ogallala states, for all strategies, as well as for the Baseline.

By 2020 the southern Subregion is projected to have only 5.0 percent of remaining Ogallala water in storage under Baseline, and a scant 7.0 percent under the more favorable water supply strategies MS-2 or MS-5B.

Total irrigated acreage for the Southern Ogallala is most favorable for MS-5A, at 7.32 million acres or about 30 percent above Baseline projections for 2020, while the least favorable is MS-2 with only 4.75 million acres remaining in irrigation, down almost 16 percent from Baseline projections. This impact on irrigated acreage is reflected in similar patterns of favorable increases in total value of agricultural production (up about 13 percent) and returns to land and management (up by almost 20 percent for MS-5A, and corresponding negative impacts from MS-2.

Many other interregional and interstrategy comparisons can be derived from the key indicators summarized in Table 1. Additional indicators and more detailed analyses of these projected impacts can be found in Chapter Five (Baseline) and Six (Alternative Water Management Strategies) of the main Report.

Comparisons of Other Regional Impacts Among Strategies

In addition to the quantitative projections and comparisons of strategy economic impacts discussed above, other impacts shed light on strategy differences within the Region. Six other impacts are described here and in the accompanying matrix. These effects are discussed generally in a region-wide context, although subregional variations are shown between the northern and southern tiers of states within the Region.

Crop Production - Table 2

Four major crops are well-suited to irrigation in the High Plains--corn, wheat, grain sorghums, and cotton, in that order, of 1977 value of production. These four crops, irrigated and dryland together, in 1977 accounted for nearly 94 percent of all principal crop production value in the Region. By 2020, the Baseline projections change this order sightly to move cotton ahead of grain sorghum production. Virtually a one-crop cotton economy in Texas would replace sorghums, while Nebraska corn dominates all crop production in

Table 2: INTER-STRATEGY COMPARISONS - REGIONAL CROP PRODUCTION AND RESOURCE DEPLETION PROJECTIONS

STRATEGY	REGIONAL CROP PRODUCTION: REGIONAL FEED GRAINS	REGIONAL CROP PRODUCTION: REGIONAL FIBERS AND OILS	REGIONAL CROP PRODUCTION: NATIONAL FOOD GRAINS	SOIL AND WATER RESOURCE DEPLETIONS
BASELINE	1977 corn + sorghum crop 1,162 million bushels for regional beef feedlot/processing industry, 15.8% of U.S. production. 1990 - 1,513 million bushels 2020 - 2,219 million bushels	1977 cotton crop, 2.96 million bales, processed for yarns, cloth, oil, meal, 24.9% of U.S. production. 1990 - 4.94 million bales 2020 - 5.94 million bales	1977 wheat crop 327.5 million bushels for national flour/cereal markets, 16.4% of U.S. production. 1990 - 350 million bushels 2020 - 472 million bushels	Remaining storage of 3,040 mil. acre-feet 1977 drops 23% to 2,335 mil. acre-feet 2020; concentrated in the northern area, critically short in South. Soil depletion serious for cotton production.
MS-1	Production up slightly, to 1,540 million bushels in 1990, 2,325 million bushels in 2020. Percent of U.S. crop up 0.6%. Still excellent base for beef industry.	Little crop production change any year to 2020 as most water demand reduction efforts already projected in Baseline. Still good base for fiber/oil industries.	Production lower by only 0.3% and 0.2% in 1990 and 2020. No adverse national effects; percent of U.S. crop virtually unchanged.	Little change from Baseline storage drawdown. Beneficial effect on cropping but adverse from soil mining in one-crop cotton farming areas.
MS-2	Production drops for corn 12%, 1990, 15%, 2020, less for sorghum from Baseline. Percent of U.S. crop down 1.8% for corn up 1.5% for sorghum in 2020.	Production down 8.0% in 1990, 10.7% in 2020; 1990 crop - 4,548,000 bales. 2020 crop, 5,307,000 bales or 28.7% share of U.S. crop in 2020. Still good base.	Production rises by 2.4% in 1990, 0.3% 2020. Percent of U.S. crop share is still virtually unchanged.	Some increase in water remaining in storage. Most water savings in voluntary conservation policies. Soil saving effects probably beneficial.
MS-5A	By 2020, a 22.4% rise in corn crop, but sorghum drops 6.0%. Share of U.S. corn crop up, sorghum down. Large feedlot growth supportable.	With import, crop rises by 19% to 7,103,000 bales, 37.2% of U.S. share, by 2020, relative to Baseline.	Wheat production down 7.5% with water import by 2020; National effects limited. Percent of U.S. crop 0.8% below Baseline.	Little change from Baseline water remaining in storage. Imported water all goes to formerly irrigated lands. More intensive cropping could further deplete soil.
MS-5B	By 2020, a 4.5% drop in corn, 5.0% rise in sorghum. Feed grain base for beef industry expansion assured under any strategy.	Crop rises 4.9% to 6,232,000 bales; dryland production above MS-5A.	Production down 5.7% with water import by 2020. Percent of U.S. down 0.6%.	Slight increase from Baseline water remaining in storage. Rate of drawdown slows, extending Aquifer life. Intensive cropping further depletes soils.

the northern subregional three states under Baseline projections. Wheat, the Region's "natural" crop, remains important in all states except New Mexico. The feed grains, primarily corn and sorghums or milo, account for over 55 percent of regional production value over the Study period.

Generally, projections for the several strategies do not indicate a marked change in the current mix of crops and the relative sizes of their volume of production to 2020. Corn (almost all in Nebraska) and cotton (almost all in Texas) do indeed expand in the years ahead, but only slightly at the expense of other crops. Also, the strategies would not cause major shifts in the share of each crop in national production. The water demand reduction strategies (Strategy One and Strategy Two) occasion the least departures from the Baseline projections, while the import strategies cause the most, raising the regional share of high-water-using crops such as corn.

Soil and Water Resource Depletions - Table 2

The continued sufficiency of basic ingredients for High Plains crop production--its soils and ground water--must be considered. Of most concern is the diminishing ground water supply, with higher pumping lifts and energy costs. Table 1 shows estimates of water remaining in storage by years for Baseline and each strategy. Some of this water in storage cannot be recovered with existing technologies. A second concern in some areas in the High Plains is the possible effect on soil productivity of intensive one-crop farming without crop rotation to restore soil nutrients.

Compared to Baseline, all strategies could by definition be viewed as beneficial to the water depletion problem. The water demand reduction strategies could be considered beneficial with respect to maintenance of soil productivity, because their effect would be to promote wise farming practices to maximize returns by soil-saving methods as efforts at water-saving methods are applied.

Environmental Quality - Table 3

The High Plains is generally flat to gently rolling with vegetation typical of the Plains' moderate to low-rainfall environment. Shallow river

Table 3: INTER-STRATEGY COMPARISONS - ENVIRONMENTAL AND ECONOMIC CONSIDERATIONS

STRATEGY	ENVIRONMENTAL CONSIDERATIONS*	ECONOMIC ASPECTS		
			NATIONAL	
		REGIONAL	CONSUMER PRICES	EXPORTS
BASELINE	See Chapter Five for Baseline description. Little direct effect from evaporation reduction or improved efficiency in irrigation systems and management. Reduced runoff into upland wetlands and streams expected, lowering aquatic habitat values.	Value of agricultural production more than doubles, as does the Region's total value added, resulting in a strong economy.	43-year average annual farm price increase projected at 0.6%, translates to 3.2% increase in food costs.	Agricultural crop exports rise by 150% - $21 to $51 billion, 1985-2020, nationally. This demand will keep Region's prices high.
MS-1	MS-1 and MS-2 show comparatively little change in overall effects on fish and wildlife resources from Baseline conditions projected. Combination of lower corn acreage and reduced tailwater runoff to playas may lower winter carrying capacities for migratory waterfowl. Reduced soil erosion rates and amounts of chemical fertilizers and pesticides residues in runoff waters will benefit wetland and aquatic habitats.	Improvement over Baseline growth is not significant by any economic measure.	Crop production changes so little that crop and food prices remain unaffected.	Volume of exports not expected to change from that projected in the Baseline.
MS-2	Extensive weed suppression would eliminate habitat for upland game and nongame species, partially offset by mulching and fallowing. Modified playa lakes would reduce habitat value to both migratory and resident species. MS-2 effects on somewhat magnified scale over MS-1.	Farm production is lower under this water demand reduction strategy and carries economy lower.	Crop production is lower, prices rise. Effect on consumer about $2.60 per year per person at retail level (marked up).	Volume of exports falls due to higher farm prices; grain and oilseed down 1.4%, cotton 1.7%
MS-5A	Effects weighted toward negative; reduction of import source stream discharges and those below reservoirs coupled with loss of riparian habitat major concern. Holding reservoirs in Region would inundate areas of riparian and stream habitat valuable for fish and wildlife species. Conveyance facilities could block migration and movement patterns. Animals could be trapped in open canals. Use of some streams to convey water could give local benefits. Terminal reservoir effects same as for holding reservoirs. Also, fluctuating water levels would render management for fish and wildlife largely ineffective. Impacts of diversions from source streams might be felt as far downstream as Louisiana.	Crop production up greatly with water import, but regional growth is only 4.1% over Baseline, employment only 4.8% higher.	Production rises, lowering farm commodity and retail food price - by about $2/person.	Exports expand with lower farm prices; in 2020, grain exports up 100 million bushels, cotton one-half million bales, but total value lower.
MS-5B		Less favorable to regional economy than MS-5A or MS-1; creates 10,000 more jobs than Baseline.	Production rises over Baseline but much less than in MS-5A; impact on consumers not significant.	Exports expand less than in MS-5A, as price drop is less, but value offsets decline.

* Adapted from U.S. Fish and Wildlife Service Report.

and tributary stream valleys crossing the Plains afford residual habitat for wildlife from intensively cropped fields and grasslands. River valleys and sand hills in the northern states and the playa lakes provide vital habitat for waterfowl migrating along the Central Flyway to and from Canadian breeding grounds.

Environmental effects of the various strategies have been examined by the U.S. Fish and Wildlife Service and by the General Contractor. Many of the environmental impacts which are influenced by farming practices and aquifer depletion will occur under the Baseline, but the rate of change would be altered to differing degrees by the different water management strategies. Major factors evaluated were physical, biological and cultural. Under physical factors, soil loss due to wind erosion is probably the most significant consideration. Generally, dryland farming and farm abandonments result in greater soil losses than in irrigated agriculture. Negative effects on water resources result from streamflow reduction and ground water drawdown. Already beginning to occur in some areas, greater reductions in streamflow are expected in parts of the Loup, Niobrara, Elkhorn, Blue, Platte and Republican Rivers in Nebraska; the Republican, Soloman, and Cimarron Rivers in Kansas, and others. Where streamflow is reduced, aquatic habitat, potable supplies, diversions for agriculture and low-flow contributions to reservoirs are negatively affected. Streamflows will be reduced to some extent regardless of the strategy considered.

Two main types of biological impacts occur: the first results from streamflow reduction or direct increased use of surface waters, the second from land use changes caused by water availability variations. In the first, effects on aquatic habitat and associated species include direct loss or reduction of aquatic species and biological productivity and the degradation of habitat for related species such as waterfowl, wading birds and shorebirds. Riparian habitat has already been affected by reductions in surface flows. Species such as birds and small animals will be affected by losses or alterations in riparian habitat, including the invasion of exotics such as saltcedar. Aquatic habitat and fisheries in lakes and reservoirs may be affected by depletion of feeder streams. Modification of playa lakes and drainage of other wetlands may result in scarcity of water with adverse effects on wildlife resources.

Land use changes will affect both aquatic and terrestrial species. In terms of aquatic habitat, the effect is largely negative, in part because of loss of tailwater from improvement in irrigation. Water quality would improve, but turbid water is preferable to no water in this semi-arid Region. Terrestrial species would be more positively affected. Dryland farming and rangeland are less intensively used, and, in general, provide better wildlife habitat. Rangeland or native grasses provide excellent natural habitat. Achieving this benefit, however, would require that a conservation program be initiated to reseed abandoned acreages. Where irrigated agricultural acreage increases, effects may be negative because of siltation and draining of valuable wetlands and loss of cover and terrestrial habitat. Both habitat and wildlife are generally improved by conversion to dryland farming and rangeland. If reseeding is done, effects can be beneficial. Major adverse effect would be development of marginal lands in areas with surface or near surface water such as the sandhills.

The U.S. Fish and Wildlife Service made an environmental assessment of each of the alternative interstate, interbasin transfer routes evaluated by the U.S. Army Corps of Engineers. Adverse impacts on fish, wildlife and other natural resources at and near the points of diversion, at and around the conservation storage provided near the point of diversion, along the conveyance routes and at and around the terminal storage reservoirs were identified and to some extent quantified. A major negative environmental impact would be the large amount of land required for these facilities, much of which would be important habitat. The loss could be mitigated to some extent by acquiring replacement habitat.

No assessments have been made of the impacts downstream of the points of diversion considered by the Corps for interbasin transfers. Some possible impacts can be identified, however. Reductions in downstream discharges could result in changes in stream channel morphology, and could have an adverse impact on aquatic species and productivity, on riparian wildlife habitat, on water quality, on sediment transport, on minimum flows needed for salinity repulsion in the Mississippi River delta, and on freshwater inflows needed for the coastal fisheries in Louisiana.

With proper planning, impacts on cultural resources could be minimized.

Economic and Demographic Aspects

The inter-strategy comparisons considered here include:

- ° an overall or composite appraisal of the general health of the regional economy as expressed in part by such variables as enumerated in Table 1 and evaluated in other Study assessments;
- ° the effect of strategies or policies on national consumer prices; and
- ° their effect on exports to foreign markets.

Economic Effects - Table 3

The composite picture of the Region's general state of economic health under the various water management strategies is implicit in such factors as farm-level production, the value of that production, its profitability, regional value added by economic activities in all sectors off the farm (textiles, meat processing, energy, milling, fabricating, and other pursuits), regional population employment and income, and the state and local government tax revenues generated by these activities.

Between 1985 and 2020 under the Baseline situation, the percentage of per capita disposable income spent on food is projected to decline from 17.5 percent to 17.1 percent. During the same period, the value of major agricultural exports would more than double from under $21 billion to slightly over $51 billion (1977 dollars). Farm prices are projected to increase at an average annual real rate of about 0.6 percent. This would increase consumer expenditures on food, assuming current consumption patterns, by $40 to $50 per person. The following tabulation presents the projected direct impact on consumers of farm level price increases:

CONSUMER PRICE INCREASES DUE TO FARM COMMODITY PRICE INCREASES
UNDER BASELINE - 1977 to 2020

Item	Food Expenditure Increases Per Person	Per Family of Four
Wheat and Wheat-Based Products	$ 2.22	$ 8.88
Beef and Veal	17.48	69.92
Pork	9.80	39.20
Boilers	5.12	20.48
Eggs	3.03	12.12

When compared to total national production, the Region is projected to produce a declining proportion of national output for several crops under Baseline conditions. Table 5 shows the High Plains as a portion of total national output for four major crops. For example, wheat produced in the High Plains falls from 16.4 percent of the national total in 1977 to 10.4 percent in 2020.

Under Strategy One, projected crop production changes so little that crop price changes were not projected. With the cutback in water use under Strategy Two, regional production is reduced and national crop prices rise. A rough estimate suggests that consumer payments for food will increase about $1 per person per year at the farm level; perhaps as much as $2.60 when markups are added. The net increase thus ranges from $290 million at farm level to $750 million by 2020. The volume of exports will fall due to higher prices and reduced production with grain and oilseed exports down 1.4 percent and cotton down 1.7 percent in 2020. Total value of exports falls about 0.7 percent for a foreign exchange loss of some $365 million on those crops which are staples in the High Plains.

Rising production which would accompany Strategy Five-A water imports is projected to have a limited but positive value for the consumers. At the farm level, consumer expenditures for food and fiber should fall about $2 per person by 2020 due to price decreases associated with increased national production. Increased production and lowered prices expand the volume of exports. In 2020, grain exports rise nearly 100 million bushels (1.0

Table 5: NATIONAL DEPENDENCE HIGH PLAINS PRODUCTION

Crop	Year	Percent of National Production		
		Total	Irrigated	Dryland
Wheat	1977	16.4	3.1	13.3
	1985	13.4	1.6	11.8
	1990	12.8	1.0	11.8
	2000	11.9	0.7	11.2
	2020	10.4	0.4	10.0
Corn	1977	13.1	12.3	0.8
	1985	13.1	12.7	0.4
	1990	12.6	12.4	0.2
	2000	13.2	13.1	0.1
	2020	12.6	12.5	0.1
Sorghum	1977	39.7	22.8	16.9
	1985	36.8	20.0	16.8
	1990	34.5	18.4	16.1
	2000	33.4	18.5	14.9
	2020	29.8	15.0	14.8
Cotton	1977	24.9	16.5	2.4
	1985	31.2	22.6	8.6
	1990	33.8	25.1	8.7
	2000	35.5	26.8	8.7
	2020	31.9	23.0	8.9

percent) over Baseline and cotton exports rise 0.5 million bales (4.3 percent). However, the decreased price for all exports actually lowers the net value of agricultural exports in 2020 under Strategy Five-A by $100 million.

Legal/Institutional Aspects - Table 4

The institutional question in considering alternative water management strategies is whether the necessary statutes and institutions are in place and, if not, what is needed to make implementation possible. Institutional structures are summarized in Table 4 together with an appraisal of possible changes that might be required for implementing management strategies.

With respect to Strategy Five, each of the streams considered as a possible source for water transfer to the High Plains is interstate in character. Federal projects on each serve specific purposes--irrigation, municipal and industrial uses, flood control, hydropower, navigation, recreation, and other instream uses. Diversion to the Region could impair existing and future instream and offstream uses downstream from the diversion point. Depletions by future uses upstream of the point of diversion could decrease the amount available for transfer. If existing or authorized uses were impaired, or future upstream depletions limited, the tradeoffs involved would have to be evaluated and negotiated.

Before a specific transfer project could be proposed for authorization, detailed planning would be required to determine needs, projects and programs for development and management of water supplies for the Region, both imported and local, and future water needs within the basins of origin, both upstream and downstream of the point(s) of diversion.

Once a definite plan is formulated, an apportionment of waters of the interstate streams involved among basins of origin and the states of the High Plains would be required, either through congressional action or through an interstate or federal-interstate compact.

Table 4: INTER-STRATEGY COMPARISONS - LEGAL/INSTITUTIONAL CONSIDERATIONS

STRATEGY	LEGAL/INSTITUTIONAL ASPECTS		
	LOCAL	STATE	FEDERAL
BASELINE	There is sufficient authority at the local government level in all of the states to carry out many of the voluntary and regulatory water demand reduction and supply augmentation measures now in place or projected for the Baseline.	Each of the six states have water and natural resource agencies to administer programs at state and local levels and provide local assistance to districts and farmers.	Many state resource agencies are now supported to some extent by federal agencies and programs, such as those of the Department of Agriculture and Interior in present ongoing Baseline efforts.
MS-1	Implementation of MS-1 would require little change or realignment of the institutions in the area at local level. Additional funding and staff required.	Implementation of MS-1 would require little change or realignment of the institutions at state government level. Authorization and funding for selected financial incentives required. Additional funding and staff necessary.	Federal agency authorities to support state and local efforts in water demand reduction would need some extension to carry out certain MS-1 programs. Additional funding and some additional staff needed, particularly for research.
MS-2	Some local political subdivisions would need added powers to promulgate rules and regulations, and to enforce restrictions on uses of water. Additional funding and staff might be needed.	Nebraska, New Mexico and Oklahoma appear to have adequate statutory authorities to control ground water use although there may be constitutional questions as to power to reduce use under existing permits. Colorado and Kansas statutes may require broadening. State level agencies in Texas have no statutory authority to control ground water use. Additional funding and staff required.	Enforcement of mandatory restrictions on ground water use would not be a federal responsibility.
MS-5A	Local management agencies would be needed with adequate powers to contract for, receive and distribute imported water, to finance, construct, operate and maintain local facilities, and to levy and collect water charges and taxes to pay local costs and to repay allocated reimbursable costs of import project.	State legislation would be needed to provide necessary authorization for local management agencies, to contract with exporting states for water, to participate with the federal government or with the other states and the federal government in a federal-interstate compact management commission to plan, finance, construct, manage, operate and maintain the import project, and to provide necessary funding for cost-sharing and other costs.	Congressional actions needed to authorize and fund planning and feasibility studies, to provide for participation with the states in a federal-interstate compact management commission, and to authorize and fund federal participation in the import project.
MS-5B	Same as MS-5A	Same as MS-5A	Same as MS-5A

SENSITIVITY OF RESULTS TO VARIABLES

Long-term projections of events and conditions, such as have been made in this High Plains Study, require the qualification of uncertainty. The longer the term, the wider the margin of probable error in projections. This is particularly true of variables influencing and influenced by agricultural production, where the vagaries of weather, plant disease, insects, and the farm managers' skills add to uncertainties of production costs, demands, prices and research outcomes.

Sensitivity analyses can indicate how projections may vary under different assumptions about future trends. A few key assumptions most vulnerable to long-term variability were selected and the sensitivity of projected values to a different assumption for each was tested.

Water Use

Where the saturated thickness of the Aquifer is thin, as in Texas, projections of irrigated acreage towards the end of the Study period are extremely sensitive to the rate at which water use efficiency improves.

Crop Yields

Yields of the major High Plains crops are expected to increase but at a slower rate than historically since 1946 when dramatic productivity improvements began. If yield increases were to fall below projections, a compensating rise in national crop prices could be expected because of the lower production.

To test the sensitivity of Study results to yield assumptions, a national rate of crop productivity increase at 75 percent of the projected High Plains Study annual rate of increase was assumed. The result was an alternative crop price projection (analyzed by use of the NIRAP model) that was 6 to 12 percent higher by 2020 than with higher yield assumptions. Applying these lower yields and higher prices to major crops in Nebraska (a High Plains state with much of the production) in 2020, total value of production per acre falls by only $10 (1.8 percent) for corn, $7 (3.7 percent) for dryland wheat, $10 (3.8 percent) for irrigated wheat, and $20 (5.0 percent) for sorghum. The health of the regional farm economy is not highly sensitive to changes in crop yield rates of increase, provided changes in regional and national productivity trends are parallel over the Study period.

Energy Prices

Prices are projected to increase (crude oil at 0.4 percent per year in real dollars) after a period of rapid adjustment during which decontrolled domestic prices rise to world price levels.

A set of high band world oil prices based on oil escalating at 3.0 percent real prices after U.S. prices reach world market levels, rather than 0.4 percent, were used to test the sensitivity of farm production estimates to higher energy prices. These high band prices were incorporated into crop budgets in some states to test sensitivity of LP model results. In general, while higher energy prices caused some crop switching and lower returns, they did not cause farmers to abandon irrigated production while water remained available. Over the long run, lower returns resulting from higher pumping costs would reduce land prices. However, crop prices, total production, and value of farm production remains generally unaffected by higher energy prices within the range analyzed.

This apparent insensitivity conflicts with experience in the 1970's where some farmers were forced into dryland farming before ground water was exhausted by increased energy costs. These short-term effects, however, may not be consistent with the capacity for adaptation by farmers to long-term effects.

Because of dependence of the southern subregion economy on the energy sector, an increase in energy prices that would sustain this economy beyond the expected downturn by 2020 was examined. This analysis accounts for increased oil, gas and electric revenues and the resulting increase in value added in energy conserving sectors. No increase in production is assumed, and the higher energy price produces a net positive effect on the regional economy.

Farm Commodity Export Demand and Crop Prices

Domestic demand for crops is projected to grow at a moderate rate, due to slower population, economic and real per capita income growth than in the past (before 1977). Export demand for crops is projected to show strong growth responding to an expanding world economy, agricultural shortages abroad and U.S. policy encouraging agricultural exports. Export projections used for crop pricing by the NIRAP model in this Study show steady growth through 2020.

To test price sensitivity, export growth was reduced to the 30-year (1950-1979) trend for High Plains crops. The sensitivity analyses showed that by 2020, real crop prices for those crops would fall 19 percent for wheat and cotton, 22 percent for corn and sorghums, and 20 percent for soybeans. The effect on the farmer would vary from subregion to subregion depending upon many other factors, but on balance, decreases in value of production would lower returns to land and management sharply, likely reducing the total irrigated acreage in the Region but increasing ground water remaining in storage.

Drought

The strategy analyses and projections assume average rainfall and the same general climatic conditions that have been experienced in the recent past. To test the sensitivity of projections to drought conditions, a year in which yields fell due to insufficient rainfall was examined. Yield reductions for the worst year in the last ten indicate a loss of 25 percent for dryland wheat, sorghums and cotton compared to Baseline, and decreases in irrigated corn yields of 7 percent, irrigated sorghums of 16 percent and irrigated cotton by 25 percent. As a result, value added by farm production in the northern subregion would fall by 10 percent below Baseline in any year, in the southern subregion by 16 percent to 18 percent and for the Region by 12 percent. These changes do not reflect compensating adjustments in crop prices which might occur if production losses were not offset elsewhere.

While production is cut by drought even when imported irrigation water is available (Strategy Five-A), imports keep farm returns well above Baseline levels. In the northern subregion, in 2020, the improvement from a drought year without water imports totals 27 percent above Baseline value added in the farm sector. In the southern subregion, farm value added in 2020 in a drought is 3 percent less than Baseline, but 18 percent above the levels which would occur in a drought without water imports. For the Region, in 2020, water imports change a drought year loss of 12 percent from Baseline into a gain of more than 10 percent above Baseline.

These drought year gains from water imports work through the economy in a significant way. For example, by 2020, water imports shift a drought year economic loss of 2.8 percent from Baseline into a gain of 2.7 percent, a net saving of 5.5 percent or almost $2.7 billion. The swing in household income is comparable. The stabilizing effect on employment is even more notable, particularly in the northern area, which is more dependent on agricultural production. For the whole Region, a drought year employment loss of 2.7 percent converts to a 3.8 percent gain with the import strategy.

Increased Imports

In this analysis, the amounts of water to be imported to each state beginning in year 2000 were projected at double the amounts provided under Strategy Five-A, all water to be used for crop irrigation. Cropping patterns would not differ from those assumed in Strategy Five-A. This variation on Strategy Five measures the economic expansion that might occur if irrigation were greatly expanded by increased importation of water. No attempt was made to define the need for such expansion in the states or the relative value of added water. Prices were not recalculated, but would fall further in line with the reduced national crop prices projected under Strategy Five-A.

Results of the analysis show favorable effects carrying throughout the regional economy. The effects shown here, using the regional I/O model, somewhat overstate the net favorable effects because no downward revision in crop prices was made to reflect the continuing increase in national production which would follow from expanded irrigation in the Region. In the northern subregion, farm production rises $2.1 million above Strategy Five-A to 43.3 percent of total value added in the economy in 2020. For the Region, farm value added rises $2.4 billion in 2020 above Strategy Five-A, without compensating adjustments in crop prices, while total value added increases $3.3 billion above Strategy Five-A and $3.5 billion above Baseline.

TRANSITION TO DRYLAND FARMING

Surveys in nine Texas South Plains counties and in 14 Southwest Kansas counties were conducted to assess conditions that might be encountered in a transition from a presently mixed irrigation-dryland agriucltural economy to a dryland economy. Conditions before the beginning of substantial irrigation development in 1945, trends from 1946 through 1981, and projected conditions in these two areas as water becomes scarcer and more costly were analyzed.

Three probable sets of consequences could be projected as the transition to dryland farming occurs:

1. If the farmer, agri-business, and related economic interests are forced to operate in a nearly dryland farming economy in the near term, say the next three to five years, with stable land prices, high mortgages, rising energy and other production costs, and today's crop prices, resulting economic and social readjustments could be devastating for some.

2. If crop prices and yield relationships of 1975 to 1980 were to hold for the next 40 years, while projected rates of ground water depletion continue, adjustments would be difficult. Declines of 25 percent to 50 percent in gross incomes, depending on area, would occur over an extended time-span, but as an offsetting factor dryland farming involves lower production costs than irrigated farming.

3. If crop prices and yields increase more than farm costs, as projected in the analyses used for this Study, while rates of water depletion continue, the transition would occur within a long-term agricultural setting that could provide opportunities to cushion severe local economic and social disruptions.

NONAGRICULTURAL DEVELOPMENT

In the past 20 years, the High Plains Region's population grew by about five percent, a significantly slower rate than the 26 percent rate for the United States. Regional employment grew by 32 percent, compared to a U.S. increase of 50 percent. In contrast, the areas within the six states not overlying the Ogallala Aquifer experienced a 44 percent growth in population and a 75 percent growth in employment. Agricultural employment declined throughout this period with most of the Region's employment growth the result of a growth in smaller manufacturing and service sectors.

During the 1970s, the Region grew at about the same rate as the rest of the country. The major factors supporting this stronger growth were: oil and gas booms in western Texas and southwestern Kansas due to price increases and decontrol, and oil field equipment, financial and technical services needs of this industry; increasing concentration of feedlots and meat processing plants as more irrigation spurred the cultivation of corn and other feed grains; and, growth in other agricultural processing industries, including food processing, cotton ginning and textiles, and growth of agricultural production-input suppliers.

Manufacturers moved to the area to take advantage of the productive labor force, which has swelled due to increased participation by women, decline in farm employment, and baby-boom children entering the labor force. Most growth in manufacturing occurred in three metropolitan areas--Midland-Odessa, Lubbock and Amarillo--and in the High Plains of central Nebraska. Large increases in agricultural production have been projected for the Region for the next 40 years, and the value of oil and gas production is projected to rise in the near term. This presents opportunities for further increases in industries and services related to agriculture and energy:

° Agricultural Processing -- As synthetic fibers lose some of their competitive advantages, natural cotton fibers are likely to enjoy a comeback, and the Region's cotton production could support an expanded textile industry. Concentration of feedlots and meat packing plants have probably not yet run full course, and supporting industries could continue to grow. Other agricultural processing, such as oil seed mills and grain milling may expand with the expanded farm production.

- Agricultural Suppliers and Services -- Although farm production increases will not necessarily mean acreage increases, there will still be needs for additional inputs, such as fertilizers, new equipment and services to support production.

- Oil and Gas Suppliers and Services -- A fast growing industry now while new wells and enhanced recovery projects are being developed, but likely to decline as reserves are depleted.

A number of barriers exist to these developments and other development opportunities unrelated to agriculture or energy:

- Given the unlikelihood of a major population shift to the Region, the resident labor force cannot support large additional growth. Internal sources of labor force expansion in the 1970s are depleted. Employment rates are high due to high labor force participation.

- The effect of rapid growth in oil and gas development on local wage rates, the housing market, and demand for community services and facilities may threaten the ability of other industries to compete or expand and may discourage potential new employers from locating in the High Plains, particularly in the southern portion where manufacturing employment increased sharply in the 1970s.

- Distance from major markets and from sources of raw materials, dispersed population patterns, and lack of support industries and services limit the attractiveness of the Region for industries not related to the locally-based agriculture and oil and gas economies. The only areas today with diversified economies are Lubbock and eastern Nebraska.

Given these constraints, an aggressive economic development strategy would be required to sustain the growth rates of the last decade. Despite substantial increases which are projected for regional economic output, Baseline employment increases for the Study period to 2020 are forecast at about one-fourth the rate that occurred during the last decade, and at about 40 percent of the rate that has occurred since 1960. Three principal thrusts could be pursued regardless of the water management strategy or strategies adopted for the Region.

- Build an expanded labor force by keeping existing population, particularly youth, by attracting immigrants, particularly those who will find the environment suitable and will work for competitive wages, and by assuring an adequate supply of housing and recreational/cultural facilities to support an expanded population;

- Assist existing and new industry in expanding markets, in applying new technology, and in obtaining labor and raw materials; and

- Maintain and improve the infrastructure necessary to support processing industries by continued upgrading of road and rail systems to assure access to markets, by upgrading community facilities needed to support industry in growth centers, and by expanding the industrial and service infrastructure to provide a range of linkages for expanded activities.

ENERGY FUTURE

The Study Region is one of the major crude oil and natural gas producing areas of the United States. Although the Region has only about 1 percent of total U.S. population and 6 percent of the land area, the Region contributed 20 to 25 percent of domestic U.S. crude oil and natural gas production over the last decade.

The decontrol of crude oil and natural gas prices has resulted in a rapid increase in the value of these energy resources and in exploration and reservoir development activities. The direct impact of this increased activity on employment and income for the Region will be significant.

Crude Oil and Marketed Natural Gas Production

Over the Study period, the historical trend of decline in crude oil and marketed natural gas production in the Region is expected to continue. However, crude oil production is expected to increase from 1990 to 2000 due, primarily, to implementation of gas flooding techniques in the Permian Basin area of West Texas and eastern New Mexico. By 2020, both crude oil and natural gas production levels in the Study area are projected to be approximately one-tenth of current levels of production.

Electric Generating Capacity and Electric Energy Production

Electricity production is projected to increase regionally. Over the Study period, both installed electric generation capacity and electric energy production are projected to increase approximately threefold.

Water Consumption Associated with Energy Production and Processing

Water consumption associated with energy production in the Region is projected to increase since most of the projected water consumption will be directly associated with electricity generation. These increases will have some effect on the Ogallala Aquifer; however, much of this water could come from other formations or sources such as treated sewage effluent.

COST COMPARISONS

Effective water demand and supply management programs cannot be achieved without substantial investment in improved water management capabilities. This "no free lunch" truism is applicable to all the alternative water management strategies, including the Baseline scenario.

The alternative water resource management strategies represent a continuum of potential reductions in water demand or increases in water supply for High Plains Region agricultural uses over time, with an accompanying increase in cost of implementation.

Baseline - variety of effective agricultural water management practices have already been implemented extensively, although at varying rates and levels among the states, and these are projected to expand under Baseline assumptions.

Several agricultural water management improvements are presently eligible for cost sharing assistance and/or extension, demonstration, and technical assistance from existing public sector programs. Current (1978) expenditures by U.S.D.A. programs amount to about $120 million per year. This represents a federal investment of about $3.50 per irrigated acre. A matching investment by the private sector of about four to one, or $14 per acre annually, a typical rate from prior years, projects a total annual investment of about $17.50 per acre in agricultural water management improvements.

An average annual total cost per acre (both public and private investment) of $17.50 per acre for improved agricultural water management under Baseline assumptions would indicate a total regional cost of about $280 million in 1985 increasing to about $315 million by 2020 with the increase largelyresulting from projected increases in total irrigated acres.

Management Strategy One (MS-1) - the principal difference between Baseline and MS-1 projections is the assumption of expanded and accelerated voluntary adoption of improved agricultural water management practices and technologies due to new incentives (mainly public sector changes).

The cost of new incentive programs is projected to increase costs per acre by about ten percent over the Baseline, or to an average of $3.85 per acre for public investment and to an average of $15.40 per acre for private investments. In total regional cost, this represents a 1985 incremental cost increase of about $35 million and a 2020 cost of $41 million over projected Baseline costs.

Management Strategy Two (MS-2) - the added costs are primarily institutional costs required to administer a local/state regulatory program capable of implementing the projected mandatory reductions in annual water use rates by individual irrigators.

On the basis of projected average annual cost per well of about $50 for administration of MS-2 requirements, additional regional costs are estimated at about $6 million in 1985, increasing to $7 million by 2020. Initial capital costs (equipment) for well gauging and monitoring of pumping rates could be in the range of $100 to $150 per well, or a total cost of about $20 million.

Management Strategy Three - Current levels of agricultural research in High Plains Study states (all sources) of about $20-$25 million annually should increase by $1-$1.5 million each year until 1990, for an initial cost of $9 to $12 million. Determination of priority for funding for the various technologies should be at the discretion of the respective states.

Management Strategies Four and Five (MS-4, MS-5A and MS-5B) - relevant cost estimates and projections for the periods 2000 and 2020 are provided in detail for the water transfer strategies and alternaives in the state and regional (Corps) reports on the various water transfer options. Another cost for MS-4 and MS-5 options is related to increased irrigated acreage of 4.6 million acres by 2020 under MS-5A. The additional 4.6 million acres maintained in irrigation by MS-5A would represent an additional $90 million investment.

An additional cost associated with the water transfer alternatives relates to water dstribution costs from terminal reservoirs to the farm headgates. Distribution system capital costs from the terminal reservoirs to farm headgates are estimated at about $2,150 per irrigated acre. For the 4.6 million acres that are projected to go out of irrigated production by 2020 under MS-1 assumptions, the total capital cost for the necessary distribution systems could amount to $9.9 billion.

POLICY ISSUES

During the course of the High Plains-Ogallala Aquifer Regional Resources Study, analyses were made of the resource use alternatives available to the six states and to the Nation in the face of depletion of the Ogallala Aquifer and the decline of oil and gas production and reserves.

The alternatives were considered with the recognition that some constraints might hinder their implementation. For example:

- The Ogallala Aquifer has been intensively mined for irrigation since the years following World War II. Some areas such as in the South High Plains of Texas are already either out of water or water levels have dropped below economically feasible pumping lifts.

- The waters of the Missouri River System and the other streams being considered by the Corps of Engineers for interstate interbasin transfers to the High Plains are already largely developed, mostly by federal projects, and committed. For these interstate streams available storage has been committed for flood control, hydropower generation, navigation and local consumptive uses even where the water has not yet been fully developed and allocated.

- Upstream and downstream states are developing state water plans to meet their potential water needs that will have major long-term impacts on the potential availability of water for diversion to the High Plains Region.

Under these circumstances, certain public policy questions arise that will determine the mix of alternatives, including the option of no-action, to be implemented. These are not new questions -- they have been raised for many years in various contexts with respect to water and related resource management. Through the results of this Study, however, their resolution within the context of the High Plains Region may be possible. Experience in the Region indicates that the questions to be answered cannot be related singularly to an alternative strategy. Rather these questions relate to the choices to be made that will tailor alternatives and mixes of alternatives to the physical, social, economic, environmental and institutional conditions to local areas in the High Plains. This will shape the future of the High Plains Region.

1. Major changes would occur in production of agricultural commodities (feed grains, food grains, cotton, etc.) as the result of transition in the High Plains from irrigated to dryland farming. Climatic variations make dryland less assured, year to year, than irrigated production. These changes and uncertainties would impact federal policies on agricultural commodity market stability, international trade and balance of payments, inflationary controls, support for agricultural prices and income, and related programs. These impacts would be the basis for considering implementation of all alternative strategies for the Region. Would these impacts justify federal intervention to assure continued levels of agricultural production? How could these impacts be considered quantitatively in analysis of the federal subsidy that probably would be required for interbasin transfers of water? There also would be adverse economic and social impacts on the states. Would state intervention be justified, and if so, in what manner?

2. Should promotion of or a requirement for conservation of water and energy in irrigation enterprises be a major federal objective and program? If so, could and should this be built into programs of the Department of the Interior, Environmental Protection Agency, Department of Agriculture, and Corps of Engineers? Should such promotion include research and development aid to states and local districts, education, incentives such as low interest loans, or a mix of these and others built into existing agency programs? What could be the mechanism for getting it underway? If a federal requirement, in what manner should it be implemented? Should it be a major state objective and program? What actions should the states and state agencies take? Should primary responsibility for enforcement of conservation measures be at the local water resources management agency level? If so, what statutory changes would be necessary including source of funds? This would vary among the states as Strategies One, Two, and Three are considered.

3. The economic study results indicate that mandatory water demand management (Management Strategy Two) through laws and regulations controlling the use of Ogallala water, would significantly extend the duration of availability of such water but would result in decreased annual agricultural production and returns to land and management over the period to 2020. Would it be in the public interest to legally restrict current usage of the ground water with near-term economic detriment in order to prolong the availability of water for far future economic benefit?

4. Should investigation and planning of possible interstate interbasin transfers be continued? Should investigations and planning encompass the basins and states of origin? What institutional mechanism should be established for accomplishment? Should planning for an interstate transfer be integrated with planning for potential intrastate interbasin transfers?

5. Should further study be given to local water supply augmentation measures examined under Strategy Three such as desalting, direct use of brackish and saline waters, water harvesting, water banking, and other innovative approaches to augmentation of local water supplies for the Region? By whom? What actions, if any, should the federal agencies and the states take to encourage augmentation of water supplies from local sources?

6. Although the High Plains Study preliminary results indicate that the overall regional irrigation economy could be maintained into the next century, projections of oil and gas reserves indicate that adverse declines would have occurred by that time unless significant new reserves are found. Depletion of the Ogallala by the end of the Study period to 2020 would already have occurred in several intrastate subregions, with many other subregions going out of irrigation in the following decade or two. Experience with large-scale water diversions demonstrates that a long time period is needed for the necessary engineering, economic, financial, social and environmental planning and feasibility studies, and to achieve the political consensus required to move such projects to fruition. Is there a federal interest in making a participatory commitment now for that time frame in order to maintain the food and fiber production of the Region? Assuming that federal interest, what federal-state mechanism could and should be established to provide continuity of leadership over such an extended time frame?

7. The present Administration has emphasized reliance on the states as the responsible cornerstone for water resources planning and management. It has effectively moved to abolish the Economic Development Act of 1965 Title V Regional Commissions, and the River Basin Commissions. In the case of the six-state High Plains Region, action by an individual state could have little significant effect in implementing actions with regional consequences under any mix of alternative strategies. What would be the federal and state interests in:

    ° Continuation of a multi-state regional entity such as the High Plains Study Council as a planning and policy body?

    ° A new federal-state-local institutional mechanism, a compact or commission for example, for multi-state resource planning, development and management for the High Plains Region by itself, or in combination with upstream and downstream states in basins of origin for possible interstate transfers? Would such a mechanism, including states of origin, be of value in gaining support for both intrastate and interstate developments?

° A federal approach to planning and development for the High Plains Region on a regionalized systems basis? Including basins of origin?

8. In view of the increasing in-basin demands for consumptive and instream uses, and possible out-of-basin needs, for example the High Plains region, and the competition among states and with federal reserved and Indian water rights, for the waters of interstate stream systems, should the Congress establish an institution for continued investigations and planning to advise the Congress, states and others as to the proper allocation and reallocation of interstate waters among states, areas and uses?

9. The gains resulting from any regional alternative approach, and in some cases even a subregional approach, to solution of water problems of the High Plains, would not be distributed evenly among all those who might achieve some gain. What legal/institutional/financial mechanism(s) might be developed and implemented to achieve equitable distribution of costs and resultant obligation for repayment? Creation of zones of benefit and variable pumping assessments have been used in similar instances elsewhere.

10. Nonagricultural economic development might alleviate to some extent the adverse impacts on the regional economy of a decline in irrigated agriculture but would some positive actions for implementation. Should the states or local governments develop and carry out programs to stimulate nonagricultural development? Concentration of the labor force in a few centers might make the High Plains more attractive to industry. However, this would provide no relief for small farmtowns where irrigated farming is declining. What tradeoffs are possible and acceptable?

11. Base flows in interstate and intrastate streams have been significantly reduced in the High Plains Study area as pumping from the Ogallala has lowered ground water levels. Significant examples of this occur in the northern High Plains area in Nebraska and Kansas. This has had and will have increasing adverse impacts on availability of surface water for diverson for irrigation resulting in greater demands on the ground water and increased costs, and on the aquatic and riparian habitats. In the case of interstate streams, is there need for a mechanism for federal or state intervention or both, to prevent further reduction in base flows? Should the states take action and, if so, what?

12. As water levels in the Ogallala Aquifer continue to decline, and as surface application of pumped water is reduced because of economics, riparian wetland habitat will be increasingly

impacted. The High Plains Study area is a major flyway for migratory birds. Substantial federal law and policy have been established to protect water critical habitat. Is there a federal interest and appropriate role in intervening to minimize adverse impacts? Is there a state interest and appropriate role?

CHAPTER ONE

INTRODUCTION AND BACKGROUND

GEOGRAPHIC AREA

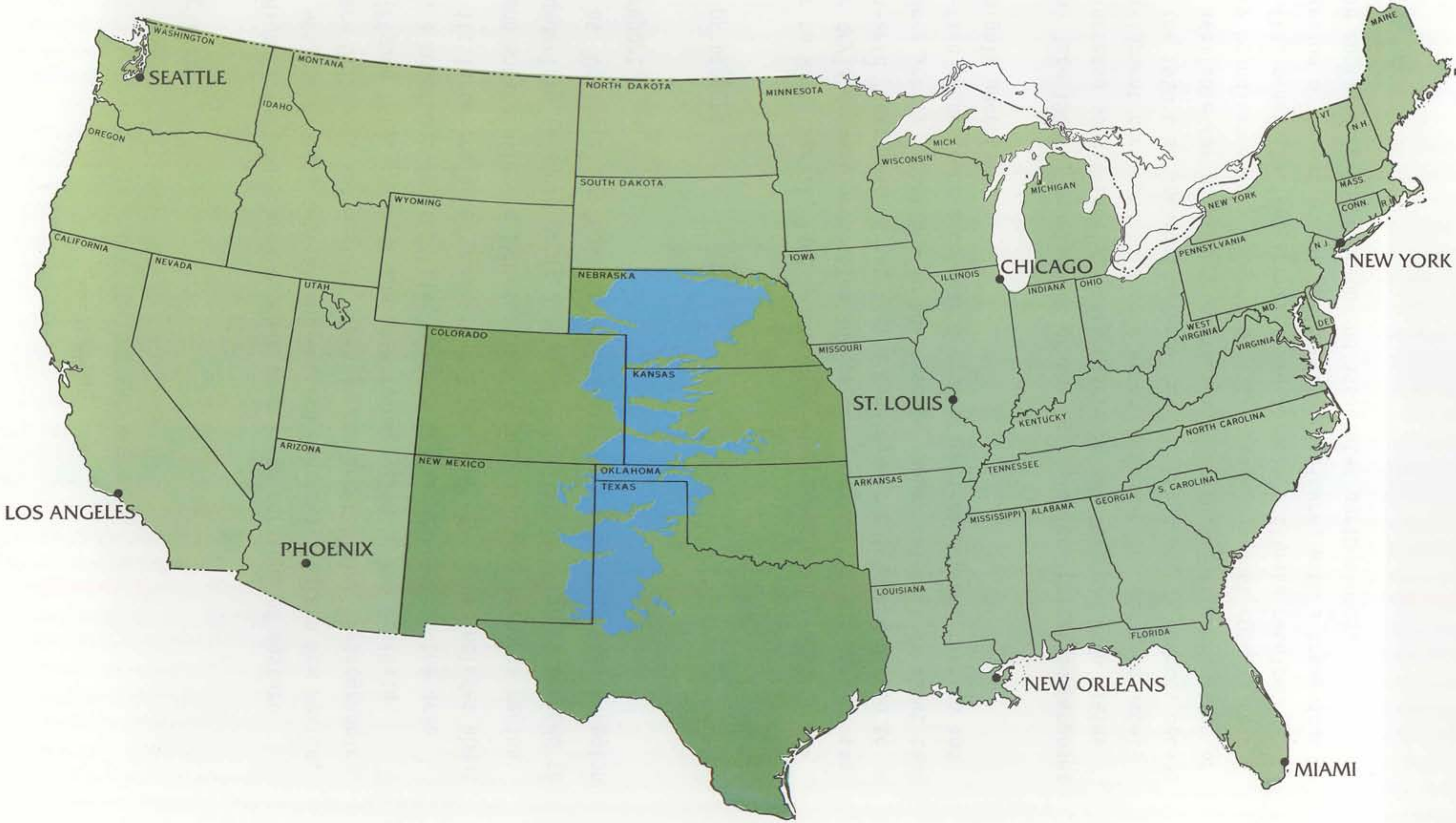
The High Plains Study area extends over large portions of eastern Colorado, western Kansas, central and western Nebraska, eastern New Mexico, northwestern Oklahoma, and western Texas in the Great Plains physiographic province (Figure I-1). Much of the area is underlain by the Ogallala Formation, a major aquifer supplying most of the water needs of the area including its large irrigated agricultural economy. The area includes about 220 thousand square miles in 180 counties in the six-state resource region which is underlain in whole or in part by the Ogallala Aquifer referenced to hereafter as "Ogallala" or "Aquifer". This is termed the High Plains Region for this report.

STATEMENT OF PROBLEM

Prior to World War II, land in the High Plains was used almost exclusively for dryland wheat production and cattle grazing. It was part of the vast, semi-arid "next year" Great Plains country extending from Mexico to Canada, where yearly variations in the average annual rainfall of about ten to twenty-five inches made each year's production from dryland farming and ranching highly uncertain.

In the late 1930's, development of the Ogallala for irrigation purposes began to increase significantly, particularly in the Southern High Plains area. Development continued to expand after World War II, and then accelerated in the 1950's as low-cost natural gas and other energy sources became generally available for pumping throughout the Region. This combination of a seemingly boundless supply of good quality water, low-cost energy, deep fertile soils, generally flat terrain, and favorable climate resulted in rapid expansion of investment in irrigated agriculture, with a tremendous increase in agricultural production and associated agribusiness.

FIGURE I-1: THE HIGH PLAINS REGION—OGALLALA AQUIFER



Irrigated acreage in the High Plains Study area expanded from less than 3.5 million acres in 1950, 70 percent concentrated in Texas and Nebraska, to more than fifteen million acres in 1980, an average annual increase of about 400 thousand acres over the thirty year period.

During the 1950 to 1980 period, agricultural production in the Region expanded enormously. With favorable production and demand conditions, the production of feed grain crops, primarily corn and grain sorghums, increased from less than 150 million bushels in 1950 to more than 1.25 billion bushels by 1980, an increase of more than 730 percent.

This expansion in feed grain production in the Region triggered a related development in the regional economy - the massive feedlot industry now centered in the High Plains. By 1977, the Region was marketing more than 9.0 million head of fed cattle annually, or about 38 percent of the national total production of grain-fed beef.

Accompanying the expansion in irrigated acreage and commodity production and the associated growth in the agriculturally dependent economy, annual water use for irrigation has increased dramatically in the Study area. In 1950, less than seven million acre-feet of water were withdrawn annually from the Ogallala for agricultural purposes. By 1980, water pumped annually from the Aquifer for irrigation had increased to more than 21 million acre-feet. Significant improvements in irrigation management and agricultural water use efficiency also took place during that period. In 1950, average water use per acre of irrigated crop production was about two acre-feet per acre. By 1980, average water use per acre for the six-state Ogallala Aquifer area had declined to about 1.4 acre-feet per acre, a thirty percent improvement.

With the expansion of land under irrigation and resulting increases in agricultural production came a marked and rapid expansion of associated agribusiness. The supporting economic sectors supplying financing, pumps, tubular goods, sprinklers, fertilizers, pesticides, processing plants, and farm equipment are in place, and represent a very large capital investment in addition to the investments in land itself.

Water and low-cost, readily available energy have been the driving forces in building and sustaining this successful economy. Water is almost wholly supplied from the Ogallala which is being progressively, and in some areas rapidly, depleted. Primary regional energy resources of crude oil and natural gas are being depleted even faster than Ogallala water in storage.

Because physical characteristics of the Ogallala vary widely over the Region, projections of the time remaining before the water resources of the Ogallala will be exhausted or depleted to the point where water levels fall below economically recoverable limits, are highly variable among subregions. Thickness of the Ogallala ranges from almost a feather edge to over 1,000 feet. Amounts of recharge vary geographically but are relatively small compared to current withdrawals. The Aquifer varies in the physical characteristics that determine how much water is stored or can be recovered in a given area. Development of irrigation has proceeded at differing rates in different areas. Because of these variances, the rate of depletion, and projected timing of loss of irrigation potential in local areas range widely over the study area. In some areas where the Aquifer is thin, land has already gone out of irrigation.

This simultaneous decline of the ground water and energy resource base of the High Plains Region threatens long-term impacts on the area's socioeconomic structure. Impacts will be felt in reduced levels of income by the labor force directly involved with irrigation enterprises and associated agribusinesses, and in reduced revenues to local, state and federal governments from property, income, and other taxes. Integrity of long-term investments may be jeopardized. Experience elsewhere indicates that the viability of small towns and communities dependent almost exclusively on the irrigated economy of the Region may be adversely affected. Public costs will increase to provide increased support for job training, income support, and certain health costs for the unemployed or underemployed. There may be significant environmental impacts. The impacts will be felt at the state and national levels as well as locally and regionally.

The problem is complicated by the diverse legal/institutional structures prevailing among the states for water resource management and their widely varying effectiveness. Present laws concerning ground water differ all the way from no state-wide regulatory controls in Texas to full authority of the State Engineer to control ground water extractions in New Mexico. Local agencies in Colorado, Kansas, Nebraska, Oklahoma and Texas have varying degrees of management authority. The authorities, the capabilities, particularly financial, and the local support of these agencies and their programs differ greatly from state to state.

There are choices, however, remaining for the Region. The water and energy resources are not gone, although they have been significantly diminished. The world energy crisis has caused here--as elsewhere--major cost/price adjustments. The regional economy is still healthy--but is faced with a declining resource base.

This Study was authorized and designed to examine this problem and to develop and evaluate potential alternatives for maintenance of the regional economy and production of food and fiber for the Nation. This report presents results of the analyses of several alternatives that may be considered by decision makers to sustain or perhaps expand the agricultural economy of the High Plains and to maintain the economic vitality of the Region. Of critical importance in studying these results are determinations of the level and nature of the state and national interests in maintaining the Region's agricultural production and its economy.

AUTHORITY FOR THE STUDY

The High Plains Study was authorized by the United States Congress October 22, 1976, in Public Law 94-587 (90 STAT. 2943). The language of the Act is quoted here in its entirety because of its unique regional concept, presenting explicit identification of the coordinated involvement contemplated from involved governmental entities at all levels, in concert with the private sector, and its call for alternative <u>regional</u> solutions to a <u>regional</u> problem <u>in advance</u> of adjustments to less abundant resources.

PUBLIC LAW 94-587--October 22, 1976, 90 STAT. 2943

Sec. 193. In order to assure an adequate supply of food to the Nation and to promote the economic vitality of the High Plains Region, the Secretary of Commerce (hereinafter referred to in this section as the "Secretary"), acting through the Economic Development Administration in cooperation with the Secretary of the Army, acting through the Chief of Engineers, and appropriate Federal, State, and local agencies, and the private sector, is authorized and directed to study the depletion of the natural resources of those regions of the States of Colorado, Kansas, New Mexico, Oklahoma, Texas, and Nebraska presently utilizing the declining water resources of the Ogallala aquifer, and to develop plans to increase water supplies in the area and report thereon to Congress, together with any recommendations for further congressional action. In formulating these plans, the Secretary is directed to consider all past and ongoing studies, plans, and work on depleted water resources in the region, and to examine the feasibility of various alternatives to provide adequate water supplies in the area including, but not limited to, the transfer of water from adjacent areas, such portion to be conducted by the Chief of Engineers to assure the continued economic growth and vitality of the region. If water transfer is found to be a part of a reasonable solution, the Secretary, as part of his study, shall include a recommended plan for allocating and distributing water in an equitable fashion, taking into account existing water rights and the needs for future growth of all affected areas. . . . . A sum of $6,000,000 is authorized to be appropriated for the purposes of carrying out this section.

ORGANIZATION FOR THE STUDY

Responsibility for administrative direction of the Study, and for final recommendations to the Congress, was assigned the Secretary of Commerce acting through the Economic Development Administration (EDA). The states and EDA formed the High Plains Study Council (Council) to assure proper state participation and policy guidance for the Study, to provide overall direction to the Study and to submit its conclusions and recommendations to the Secretary. Key federal agencies were involved in the early stages of planning, and were represented on a Technical Advisory Group formed by EDA to provide technical review support to that agency as the Study progressed. Members of Congress and their staffs were kept informed on progress during formulation of the Study program, and provided insight as to long-range national interests to be considered. Periodic briefings were conducted for the Congress during the Study.

Prior to final enactment of P.L. 94-587, Resources for the Future, Inc. (RFF) was awarded a grant, Project Number OER-511-G-76-3(99-7-13319), by EDA to work with the agency in developing a design for the Study. The RFF report was completed in July 1976.

In October 1976, the Congress authorized the Study at a funding level of $6 million.

The study design by RFF was reviewed and modified by the High Plains Study Council. The resultant Statement of Work was the basis for requesting proposals from contractors interested in conducting the Study on behalf of EDA and the Council. Proposals were submitted and interviews with selected contractor groups were held by EDA and the Council. Contract Number CO-A01-78-00-2550 was awarded on 28 September 1978 to the consulting firm of Camp Dresser & McKee Inc., as prime contractor, in association with Black & Veatch as joint venturer, and Arthur D. Little, Inc., as subcontractor (collectively, the General Contractor).

The full $6 million authorized for the Study was appropriated. The EDA allocated $2 million to the states for state level research basic to the Study under subcontracts with the General Contractor. The U.S. Corps of Engineers received $775,000 for studies of interbasin transfers under a contract with EDA.

<u>Economic Development Administration (EDA)</u>

EDA participated in Study formulation and selection of the General Contractor. A representative of EDA served as a member of the High Plains Study Council. The Agency administered the contract with the General Contractor and coordinated federal agency participation in the Study. Agency representatives reviewed Study results on behalf of the Secretary of Commerce.

High Plains Study Council (Council)

The Council was formed by the states and EDA to provide Study policy direction. The Council membership included the Governors of the six states, three members from each state named by the Governor, and a representative of EDA. The Council Chair rotated among the states, with each Chairman serving for one year.

The Council created a Liaison Committee made up of a technical representative from each state and chaired by a member of the Council. The Liaison Committee provided the technical interface between the General Contractor and the Council, and the point of contact for the General Contractor with state level researchers.

The plan of study formulated by the Council was the basis for overall study design.

The Council is responsible for preparing the Conclusions and Recommendations resulting from the Study for submission to the Secretary of Commerce.

General Contractor (High Plains Associates)

The General Contractor consortium, High Plains Associates, included Camp Dresser & McKee Inc., (CDM) of Boston, MA; Black & Veatch (B&V), Kansas City, MO; and Arthur D. Little, Inc., (ADL) of Cambridge, MA.

CDM, headquartered in Boston, Massachusetts, also has offices in several High Plains states, other parts of the United States and abroad. For the High Plains Study, Austin, Texas was designated as Project Headquarters. Harvey O. Banks, President, Water Resources Division, was designated as Project Director for the Study and was the responsible corporate officer for CDM. Ms. Jean O. Williams, Vice President, was Project Manager. In addition to overall responsibility for direction and management of the Study, CDM conducted the regional research in water resources availability, interbasin transfers (in cooperation with the Corps of Engineers), conservation, potential for water resources augmentation, legal/institutional matters, and environmental assessment.

B&V is headquartered in Kansas City, Missouri, with branch offices in several of the High Plains states and elsewhere in the United States. All major technical disciplines of engineering and management consulting are represented in the firm, which had primary responsibility for energy related aspects of the Study. Charles W. Keller was Partner-in-Charge of the Study for B&V and F.C. Wallace served as Project Manager until his retirement in 1981, when C.A. Vansant assumed that role. C.L. Banning served as Technical Director of B&V's activities.

ADL has its principal office in Cambridge, Massachusetts. It provides diversified consulting services, and brought to the Study a strong team of specialists for the regional research in agricultural economics and socio-economics under the direction of John M. Wilkinson until his retirement in 1980, when Frank G. Feeley was named to head the ADL effort. Mr. Wilkinson continued as consultant to the Study.

The General Contractor established a Technical Consulting Panel made up of nationally and internationally known experts in the disciplines involved in the Study. This Panel provided objective advice at periodic meetings as the Study proceeded. The Panel was chaired by Dr. William Fisher, Director of the Bureau of Economic Geology of the University of Texas at Austin. Its membership included:

Camilla Auger - Sociology
Lorne G. Everett - Resource Management
William L. Fisher - Energy/Mineral Resources
Robert M. Hagan - Agriculture/Irrigation
Jack Horton* - Public Administration
Victor A. Koelzer - Engineering
Joe M. Kilgore - Law/Institutions
Allen V. Kneese - Resource Economics
Frank Orazem - Agricultural Economics
Wilfred H. Pine - Agricultural Economics
George E. Radosevich - Law/Institutions
J. Herbert Snyder - Water Resource Management

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*Deceased

The role of General Contractor was to develop alternative strategies that might meet the basic study objectives expressed in the authorizing legislation, to evaluate the costs and the economic, environmental and social impacts of each alternative and combinations, at the local, state, regional and national levels, and to report this analysis to the Council and EDA.

Corps of Engineers (COE)

The Secretary of the Army, acting through the Chief of Engineers, was directed in P.L. 94-587 to consider alternatives for the transfer of water from adjacent areas as a means of supplementing available supplies. The work program of the Corps was an integral part of the overall Study and was carefully coordinated with work by the states and the General Contractor. The Corps assigned management responsibility for its involvement to the Southwestern Division in Dallas, Texas. The Southwestern Division was assisted by the Missouri River Division in Omaha, Nebraska, on those transfer options involving the Missouri River and tributaries. The Southwestern Division represented the Corps in coordinating with the High Plains Study Council and its Liaison Committee, and the EDA Technical Advisory Group.

A portion of the funding allocated to the Corps under provisions of P.L. 94-587 was used by the Corps to contract with the U.S. Fish and Wildlife Service for an environmental assessment of each diversion route and its facilities studied by the Corps.

The Corps' role was to identify potential sources and points of diversion for interbasin transfers, estimate potential export yields subject to appropriate constraints, lay out routings for conveyance, identify terminal storage possibilities, assess potential environmental impacts, prepare reconnaissance level designs and cost estimates, and report thereon to the Council and the Secretary of Commerce.

STUDY OBJECTIVES

This Study was undertaken to provide data and information necessary for decisions regarding the public policy questions arising as the result of potential threats to the long-term economic and social stability of a major region of the United States. The Study as authorized provided a mechanism through which the federal government, the several involved states, local governments, and the private sector could work together in a coordinated and comprehensive approach to a common problem.

P.L. 94-587 identified the Congressional objectives in authorizing the High Plains Study as (excerpted):

° Assure adequate water supplies to the area

° Assure an adequate supply of food to the nation

° Promote economic vitality of the High Plains Region

° Develop plans to increase water supplies in the area

° Assure continued growth and vitality of the region

The High Plains Study Council, in its Statement of Work, set forth its objectives for the Study as:

"1. Determine potential development alternatives for the High Plains.

2. Identify and describe the policies and actions required to carry out promising development strategies.

3. Evaluate the local, state and national implications of these alternative development strategies or the absence of these strategies."

Resource occurrence and availability problems and issues have been the subject of many governmental and private studies and programs in the High Plains. These studies and programs have been largely undertaken separately, with no connecting link to common objectives, or opportunities for an orderly interchange of findings. The High Plains Study was designed and conducted to use past work and to coordinate with concurrent studies.

ORGANIZATION OF THE STUDY

The General Contractor prepared an Interim Report submitted in January 1979. Using the Council's Statement of Work as a guide, this Interim Report laid out a detailed Plan of Study for regional and state level work elements to be performed during the Study. The Council approved the Interim Report and directed the General Contractor to proceed. The General Contractor entered into subcontracts in the spring and summer of 1979 with each of the six states for performance of state and farm-level work elements in conformance with the Plan of Study of the Interim Report. These state subcontracts involved work tasks by state agencies, universities, and private consultants. Work progress and budgets were monitored by the General Contractor, and by the responsible state agencies within each state.

The Plan of Study specified by the General Contractor in the Interim Report outlined three research elements to be accomplished by the individual states*:

- A-1 State and farm-level research
- A-2 Energy production impacts
- A-3 State impacts

The following regional study elements were defined to be performed by the General Contractor*; the division of responsibilities among the three members of the General Contractor team is shown in parentheses:

- B-1 Interbasin transfer assessment (CDM)
- B-2 National and regional impact assessment (ADL)
- B-3 Agriculture and water technology assessment (CDM)
- B-4 Environmental impact assessment (CDM)
- B-5 Unconventional water supply assessment (CDM)

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* State and regional study elements (the A and B series of research reports), and their principal components (separate work tasks) are outlined in more detail in Appendix "C". Information on the individual study elements can be obtained most directly through these sources.

B-6 Institutional assessment (CDM)
B-7 Crop prices assessment (ADL)
B-8 Energy price and technology assessment (B&V)
B-9 Dryland farming assessment (ADL)
B-10 Nonagricultural development and potential assessment (ADL)
B-11 Alternative development strategy assessments (via a regional input/output model) (ADL)

The Study period extended to 2020, starting with the basic data available as of 1977. All monetary values developed by the General Contractor have been expressed in terms of constant 1977 dollars.

COROLLARY STUDIES AND PROGRAMS

At the federal, state, and local levels of government and within the academic research community, many studies have been conducted that related directly to this High Plains Study. Every effort was made to:

° Identify these several efforts and appraise their relevance to the Study;

° Make appropriate arrangements to assure that full advantage was taken in the Study of data and results of these other studies; and

° Coordinate the High Plains Study with other on-going studies.

Of direct relevance to the Study, of course, was the work conducted on interbasin transfer of water by the Corps of Engineers. The General Contractor, in conducting its work under Study Element B-1, Interbasin Transfer Assessment, maintained continuing liaison with the Corps through the direct participation by the Project Director and other staff in all aspects of this work.

The Corps' Plan of Study and schedule for its work, and the Plan of Study of the General Contractor were designed to provide necessary exchange of inputs and outputs. The Corps, with the General Contractor, identified all reasonable potential sources that might provide supplemental water for subregions within the six-state Study area through interbasin transfers, either intra- or interstate or both. The Lower Mississippi River and Columbia River systems were excluded from consideration in accordance with Congressional intent as indicated in the Committee reports.

Another major federal study important to the High Plains Study is underway. This study by the U.S. Geological Survey (Survey or USGS) of the Department of the Interior involves a study of the Ogallala Formation and associated aquifers underlying parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming. The purpose is ". . . to develop the geohydrologic data base and computer models of the groundwater flow system needed to evaluate the responses for the aquifer system to groundwater management alternatives."

The High Plains Study and the Survey project were conducted over different study periods and for somewhat different areas. However, a common need for understanding of the physical characteristics of the Ogallala Formation linked the two studies. This is to be a product of the Survey work, and is essential in examining alternative development strategies for the High Plains Study area. Although the Survey project is not yet completed, several reports and hydrologic atlases from the Survey's work have been available to High Plains Study researchers.

The U.S. Bureau of Reclamation is conducting a study in five of the six states included in the High Plains Study--Texas, New Mexico, Oklahoma, Colorado, and Kansas. This Bureau study, titled the "Llano Estacado Playa Lake Water Resource Study," is the responsibility of the Amarillo, Texas, regional Bureau office. Its primary purpose is evaluation of the playa lakes as a resource for water collection and storage, a matter of importance to the High Plains Study. This study is also ongoing and extends beyond the termination date of the High Plains Study. Preliminary Bureau results of the "Llano Estacado Playa Lake" study have been available to High Plains Study researchers.

Other major federal activities and programs that contributed to the High Plains Study include:

- ° U.S. Department of the Interior Habitat Study for the Platte River system.
- ° Ongoing agency programs such as those of the U.S. Soil Conservation Service.
- ° Weather modification research and demonstrations.
- ° Research program of the Office of Water Research and Technology.
- ° Projections of demands for agricultural products, production, yields, input costs and output prices by the U.S. Department of Agriculture, particularly the National-Inter-regional Agricultural Projections (NIRAP) model.

In addition to the federal studies and programs, each of the six states has ongoing work and completed studies that were identified, evaluated, and, as appropriate, integrated into or with the Study. This work has been conducted by state agencies, university researchers, and local or regional governmental entities. State level investigations and information on the characteristics and the hydrologic and hydraulic response of the Ogallala Aquifer to local ground water withdrawals, to supplement information from previous and ongoing USGS studies, have been particularly important to the High Plains Study. These sources have enabled the state researchers to model the Aquifer's performance under conditions projected by the High Plains Study with a high degree of confidence and reliability.

CHAPTER TWO

THE HIGH PLAINS REGIONAL SETTING

INTRODUCTION

The physical setting of the Study area is a key to the development of its economy, patterns of population movement and land uses, and--to some degree--its institutional structures. More detail is presented on the resources of the Region, its economy, environment, and laws and institutions in separate regional study elements prepared as a part of the Study (see Appendix C). In addition, studies by the U.S. Geological Survey and Bureau of Reclamation of the Ogallala Aquifer area, as discussed in the previous chapter were conducted in part concurrently with this Study. Reports and results from both of those ongoing federal study activities provide additional detail on many of the physical aspects of the Aquifer and the Region*.

The Ogallala Aquifer underlies much of the High Plains Region, extending approximately 800 miles from Texas to South Dakota and having a maximum width of about 400 miles from Wyoming across Nebraska (See Figure II-1). Stored within the Ogallala Aquifer are approximately three billion acre-feet of ground water that today support one of the most intensive irrigated agricultural economies in the world. More than 14 million acres of farmland are now irrigated annually, approximately 20 percent of the total acreage irrigated in the nation. Over most of the Ogallala, however, water is being withdrawn far faster than it is being replenished.

The following illustrates some of the characteristics of the Study area:

High Plains Region

	1960	1970	1980
Population - Six States	18,202,872	20,219,173	25,375,665
Population - Ogallala Area	2,110,884	2,055,082	2,223,564

* See Map Packet inside back cover for four regional maps prepared by the U.S. Geological Survey as part of the Survey's High Plains Regional Aquifer System Analysis project.

Land - High Plains Study Region

Total - 220,070 Square Miles (140,845,000 Acres)

Irrigated Cropland (1977) - 22,320 Square Miles (14,285,000 Acres)

Dry Cropland (1977) - 28,547 Square Miles (18,270,000 Acres)

Other (1977) - 169,210 Square Miles (108,290,000 Acres)

Agricultural Production 1977 - Region - Six Major Crops

Wheat	Corn	Sorghum	Soybeans	Alfalfa	Cotton
327 Million Bushels	863 Million Bushels	300 Million Bushels	15 Million Bushels	5.5 Million Tons	3 Million Bales

Agricultural Production 1977 - Region - % of National Production

Wheat	Corn	Sorghum	Soybeans	Alfalfa	Cotton
16.4%	13.1%	39.7%	0.9%	N.A.	24.9%

Oil and Gas Production - Region

Crude Oil - 1977	Marketed Natural Gas - 1977
618 Million Barrels	4,638 Billion Cubic Feet

PHYSICAL SETTING

Geology

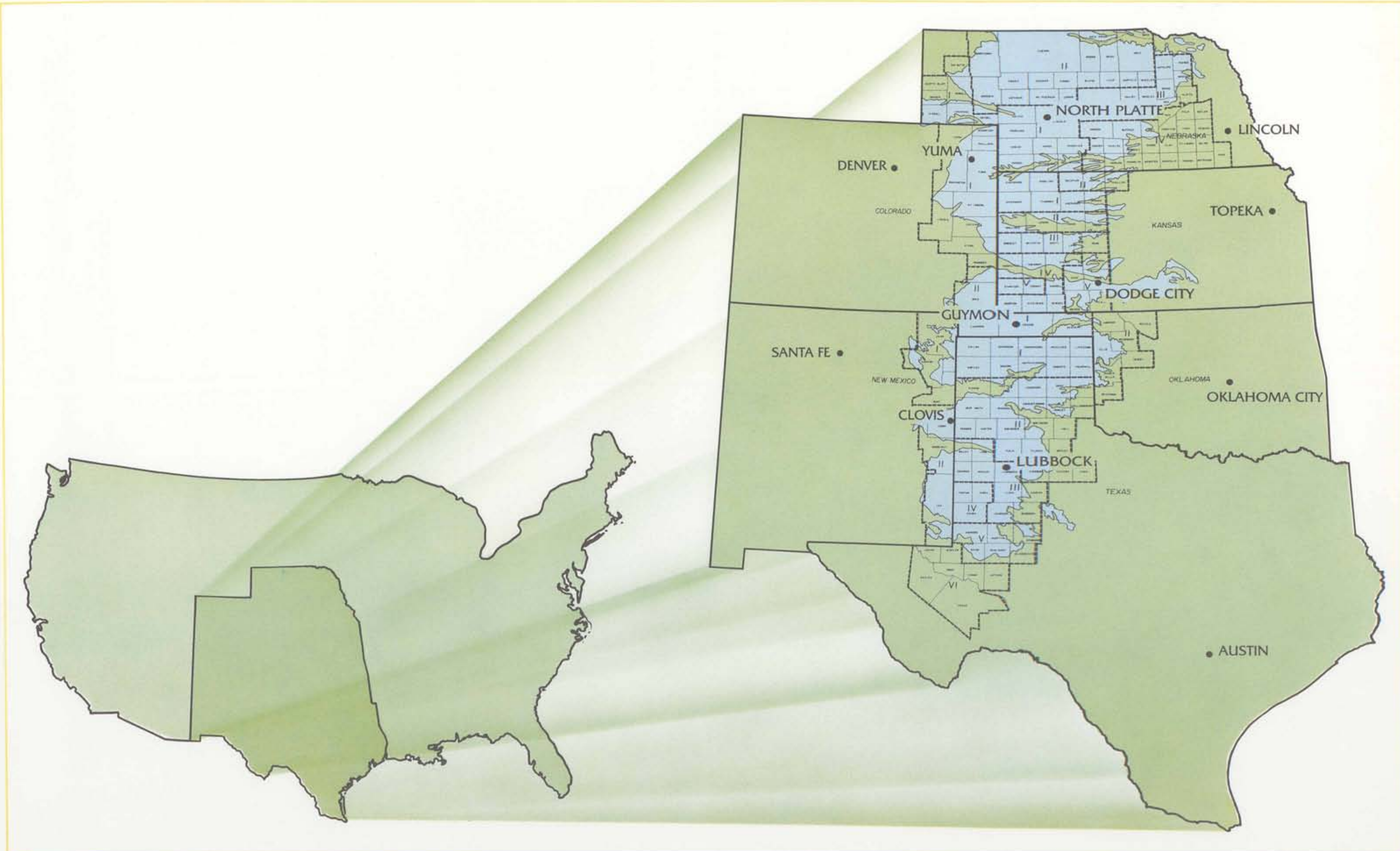
The geology of the Ogallala Aquifer is directly related to the history of the Rocky Mountains to the west. Mountain-building in the western United States began in the Mesozoic Era (about 150 million years ago), and has continued episodically to the present. The Ogallala deposition and its associated formations began in the Miocene era, and continued through the Pliocene; in most of the High Plains Study area the Ogallala is considered to be of Pliocene age. Newly exposed igneous and metamorphic rocks from the most recent uplift of the Rockies (about 10 to 12 million years ago), were subjected to intense weathering and erosion, and large volumes of sediment were shed into eastward flowing mountain streams. Where the streams emerged

OGALLALA AQUIFER

STUDY AREA

I-VI SUB-STATE REGION

FIGURE II-1: THE SIX-STATE HIGH PLAINS STUDY REGION



from the mountain ranges, gradients flattened and deposition occurred, particularly of the coarse sand and gravel-sized material. Alluvial fans originated at the canyon mouths and began to fill the stream valleys. As deposition continued, the alluvial fans coalesced into a broad alluvial plain that covered the fairly rugged pre-Ogallala topography, thus causing the wide range in thickness of the Ogallala. This broad alluvial plain now stretches eastward more than 400 miles from the Rockies across Nebraska and extends some 800 miles north and south from Texas to South Dakota. During deposition of the upper part of the Ogallala and continuing until today, wind deposition and erosion have extensively modified the upper part of the Ogallala Formation.

As the Rockies wore down, and perhaps as the climate became drier, deposition of new sediments diminished. Erosion became the dominant process and eventually separated the Ogallala from the Rocky Mountain source area. Several streams became entrenched across the alluvial plain; the Canadian, Arkansas, and Republican Rivers, for example. In Texas and New Mexico, the Pecos River extended its course headwardly, eroding a broad valley through the Ogallala, and even older strata, severing the Ogallala alluvial plain and many eastward flowing streams (Brazos, Colorado in Texas) from the Rocky Mountains. Erosion and redistribution of material from the eastward side of the Ogallala, perhaps associated with glacial melting, have reduced the present day extent of the Aquifer in the south and perhaps extended it in the north.

Depositional processes at work over geologic time imparted a degree of homogeneity to the Ogallala, yet resulted in considerable local variation. These depositional processes were marked by rapidly shifting multiple channels, extensive reworking of alluvial materials, and rapid changes in the appearance and content of the Formation both laterally and vertically. Distinct channel fills are obvious in the Ogallala Formation, and, at least in some places, channel complexes are persistent.

Thickness variations in the Ogallala Aquifer are related primarily to relief of the surface on which the Ogallala was deposited. In Texas and New Mexico, pre-Ogallala erosional relief was approximately the same as occurs today in the red bed plains. Solution of Permian salt beds in the southern High Plains during deposition of the Ogallala locally has magnified relief on the pre-Ogallala surface, and, thus the thickness of the Ogallala*.

Topography

Topography of the High Plains Region is commonly flat to gently rolling. Locally where wind action has been particularly effective the topography is hummocky. In general the top of the Ogallala Formation, and the wind blown soil cover, slopes gently downward from west to east. Surface elevations over the Ogallala range from a maximum of about 6,000 feet to the northwest to a minimum of about 2,600 feet in the southeast. Local relief has resulted from erosion. Several streams, for example the Red and Canadian Rivers in Texas, the Arkansas and Smoky Hill Rivers in Kansas and Colorado, the Republican River in Nebraska, and the South Platte River in Colorado have eroded partially or completely through the Ogallala. Continued solution of underlying salt beds in Texas and Oklahoma has left the upper surface of the Ogallala north of the Canadian River 250 feet lower in elevation than the upper surface of the Ogallala south of the Canadian, with a slightly steeper slope. Playas, shallow natural surface depressions, are common in much of the southern High Plains. The origin of the playas is subject to some dispute, but it is likely that solution of the underlying caliche and salt beds has caused local collapse; wind action has subsequently modified many of the playas. Wind action, acting on the loose surficial cover soil overlying the Ogallala Aquifer also has created widespread sand hills in parts of New Mexico and Texas, southwestern Kansas and central Nebraska (see Map #4, Map Packet). Recharge to the Ogallala Aquifer appears to be significantly greater in the sand hills than in other parts of the Ogallala area. Sand dunes, or more properly clay-sand dunes, are common on east and southeast sides of playas. Areas of lighter textured (sandy) soils also present additional management problems when put into cultivation.

Surface Water Drainage

The development of the existing surface drainage pattern in the Ogallala Study area reflects the erosive actions of present day climate on

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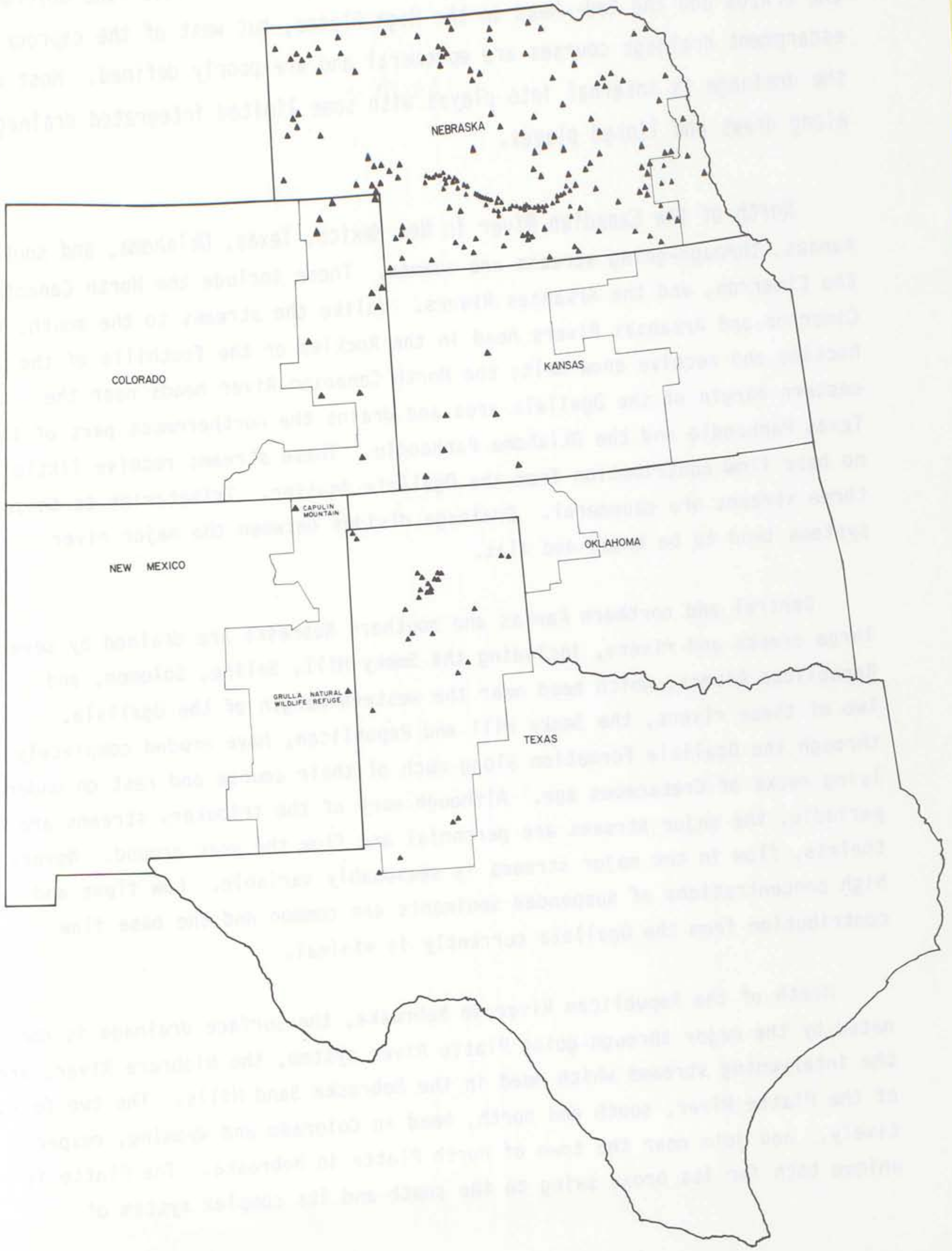
* See Map Packet inside back cover - Map #1.

FIGURE II-2: THE HIGH PLAINS REGION—PARKS, RECREATIONAL AREAS AND MAJOR RESOURCE AREAS



the original Ogallala deposition. South of the Canadian River in Texas and New Mexico, present surface drainage is poorly developed and there are no through-going streams. Several major river systems in Texas--the Colorado, the Brazos and the Red--head on the High Plains, but west of the caprock escarpment drainage courses are ephemeral and are poorly defined. Most of the drainage is internal into playas with some limited integrated drainage along draws and linked playas.

North of the Canadian River in New Mexico, Texas, Oklahoma, and southern Kansas, through-going streams are common. These include the North Canadian, the Cimarron, and the Arkansas Rivers. Unlike the streams to the south, the Cimarron and Arkansas Rivers head in the Rockies or the foothills of the Rockies and receive snow melt; the North Canadian River heads near the western margin of the Ogallala area and drains the northernmost part of the Texas Panhandle and the Oklahoma Panhandle. These streams receive little or no base flow contribution from the Ogallala Aquifer. Tributaries to these three streams are ephemeral. Drainage divides between the major river systems tend to be broad and flat.

Central and northern Kansas and southern Nebraska are drained by several large creeks and rivers, including the Smoky Hill, Saline, Solomon, and Republican Rivers, which head near the western margin of the Ogallala. Two of these rivers, the Smoky Hill and Republican, have eroded completely through the Ogallala Formation along much of their course and rest on underlying rocks of Cretaceous age. Although many of the tributary streams are periodic, the major streams are perennial and flow the year around. Nevertheless, flow in the major streams is seasonably variable. Low flows and high concentrations of suspended sediments are common and the base flow contribution from the Ogallala currently is minimal.

North of the Republican River in Nebraska, the surface drainage is dominated by the major through-going Platte River system, the Niobrara River, and the intervening streams which head in the Nebraska Sand Hills. The two forks of the Platte River, south and north, head in Colorado and Wyoming, respectively, and join near the town of North Platte in Nebraska. The Platte is unique both for its broad swing to the south and its complex system of channels. The Niobrara also heads in Wyoming and is the only stream that cuts completely across the Nebraska Sand Hills. Numerous other streams--the South, Middle and North Loup Rivers, the Cedar River, and the Elkhorn River--drain the central and eastern portions of the Nebraska Sand Hills. Drainage in the western part of the Sand Hills and locally in the central part is largely internal into the thousands of small ponds and lakes that occur among the sand hills. Streams in the northern part of the Ogallala High Plains tend to be perennial with year-round flows. Greater precipitation and, even more importantly, contribution of base flow from the Aquifer, allow the streams to flow continuously. These streams were the source of irrigation water long before ground water was used. Natural flow in streams to the south has been too small to be used extensively for irrigation.

Ground Water Hydrology

Ground water in the Ogallala Aquifer is contained within the voids (pore spaces) between the sedimentary particles that compose the Aquifer. The hydrology of the Ogallala is extremely complex. Basic geologic factors influencing the hydrology are:

- Sedimentary variability and the geologic evolution of the Ogallala alluvial plain.
- Eolian deposition and erosion.
- Climatic changes and the recent erosional history of the Ogallala.
- The formation of caprock and playas.
- Dissolution of underlying evaporites.
- Hydraulic interconnection with adjacent, subjacent, and even overlying alluvial aquifers.

In general, the water table of the Ogallala Aquifer parallels the present day topographic surface of the High Plains*. Natural ground water flow is from west to east, although there are local variations and flow reversals,

* See Map Packet inside back cover - Map #4.

particularly where pumpage has been large. On the average, there is little north-south flow gradient, in part because major through-going streams like the Canadian and Republican Rivers effectively segment the Ogallala Aquifer into discrete entities. Ground water in the Ogallala Aquifer is under unconfined to semi-confined conditions.

Hydrologic gains and losses in the Ogallala result from:

GAINS	LOSSES
Natural recharge from precipitation	Contribution to springs and baseflow in streams
Recharge from irrigation return flows	Downward and lateral leakage to adjacent and subjacent aquifers
Percolation from surface water bodies, particularly the northern High Plains	Ground water pumpage
Contributions from adjacent and subjacent aquifers	

Irrigation demands account for more than 90 percent of fresh water used in the High Plains area. More than 94 percent of the irrigation water is withdrawn from the Ogallala Aquifer. Many municipalities also depend on ground water for municipal and industrial purposes. Surface water diversions are used by some municipalities. In the southern High Plains, surface water quality is generally inferior to the quality of water from the Ogallala. Because of variation in annual rainfall, surface water sources may be less dependable from the standpoint of quantity. Extensive pumpage of ground water for municipal uses and for irrigation has affected municipal well yields. Many municipalities are finding it necessary to deepen wells and to obtain additional land or water rights to maintain or increase ground water supplies.

Present-day natural recharge is estimated by the U.S. Geological Survey to be from less than one-half to one inch per year over much of the Ogallala area. Locally in Nebraska the average annual recharge ranges upwards to six inches in sandy surface areas. Almost everywhere, natural recharge is insufficient to make up for withdrawals from the system. During the Pleistocene, when the Ogallala extended updip to the Rocky Mountains and perhaps the caliche caprock was absent or thinner, natural recharge was considerably greater and the water table was probably relatively high throughout the Ogallala. Both erosion and the onset of semiarid conditions over much of the Ogallala have reduced the amount of natural recharge to an insignificant level with respect to the quantity of water being used for irrigation.

In the southern High Plains, with the exception of the Canadian, Cimarron and Arkansas Rivers which are largely entrenched through the Ogallala, no significant surface streams cross the Ogallala Aquifer. From time to time, playas in the southern High Plains fill with surface runoff providing a potential source of recharge to the Aquifer; however it is estimated that as much as 98 percent of the water that accumulates in playas is lost to evaporation. In the northern High Plains, through-going streams like the Platte and greater amounts of rainfall provide more recharge to the Aquifer. The water table is still sufficiently high in Nebraska to maintain numerous small lakes and ponds in the depressions between the sand hills.

Climate

The climate of the High Plains area ranges from semiarid to subhumid. Temperature extremes are the norm. Winter daytime temperatures can range from below 0°F to the 70's and 80's. Summertime temperatures average in the 80's and commonly range over 100°F. Maximum daytime temperatures are higher in the south than the north. The mean annual number of days during which the daily temperature reaches 90°F or higher range from about 40 in the north to about 100 in the south.

Mean annual precipitation over the area ranges from 12 inches along the Texas-New Mexico border to about 26 inches in eastern Nebraska. Maximum rainfall tends to occur during the late spring and summer*. In the southern part of the Region, May and September are generally the wettest months; in the northern part of the area, June is the wettest month. Average rainfall amounts during the wet months range from three to four inches. Mean annual

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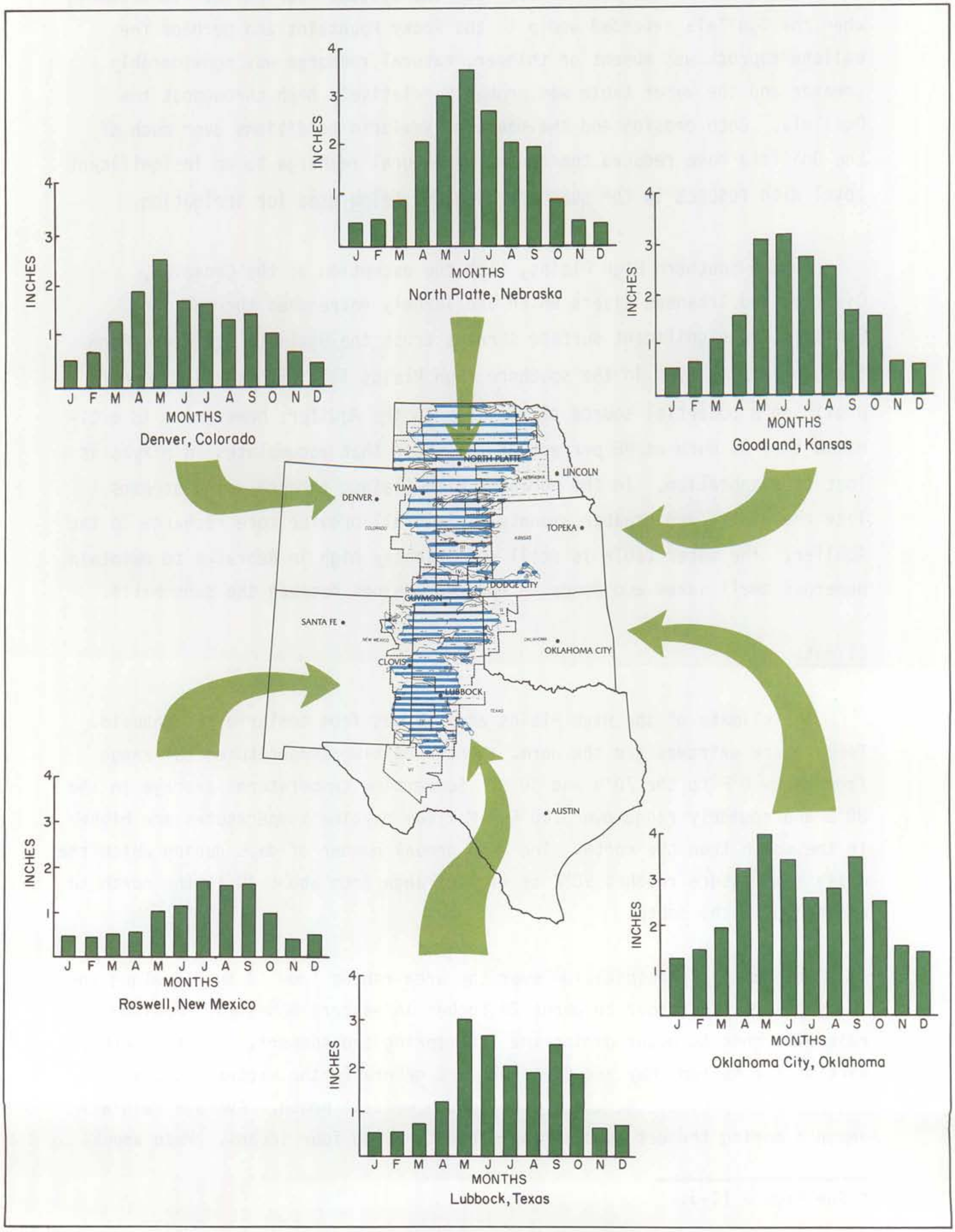
* See Figure II-3.

FIGURE II-3: THE HIGH PLAINS REGION—GENERALIZED PATTERNS OF PRECIPITATION



snowfall, a critically important source of soil moisture, ranges from four inches in Texas and New Mexico to 36 inches in Nebraska.

Average annual evaporation exceeds average annual precipitation over the entire High Plains. Mean annual lake evaporation ranges from 76 inches in the south to 40 inches in the north; 60 percent to 80 percent of the evaporation occurs from May to October, during the main growing season. Relative humidity can drop below 20 percent. The tendency toward high moisture loss from the ground and plants imposes a severe stress on crops. Added to this stress is the drying effect of the wind which blows nearly constantly the year-round.

Averages, however, do not tell the whole story. The High Plains is also a land of extremes. Rainfall in July has ranged from a low of less than one-half inch to a high of over seven inches. This is not to say that all the low rainfall months and all the high rainfall months will occur in the same year, but it does indicate the variability in monthly rainfall that may occur. Further, intense rainfall during a single storm event may be the only rainfall received for a month or more, particularly during the summer.

NATURAL RESOURCES

Soil Types of the High Plains

Soils of the High Plains are fine textured sandy, silty, clayey or loamy soils. Mean annual soil temperatures are greater than 47°F (8°C), and range up to 72°F (22°C) in the southern part of the Region. Calcium carbonate is a common constituent in most of the High Plains soils, particularly in the southern High Plains where a thick caliche horizon has developed. Soils in the northern part of the Region commonly have a buildup of clay at some depth in the soil profile. Locally, in the Sand Hills and other places, soils are very sandy and significant fractions of silt and clay are absent (see Map Packet - Map #4).

For nearly all the High Plains Region soil moisture is inadequate to support plant growth for long periods of time. Only in parts of Kansas and Nebraska is soil moisture considered average, that is, neither overly wet nor overly dry. Thus for much of the High Plains, supplemental water is needed to obtain dependable yields from most crops in successive years.

Over 30 percent of the High Plains would be classifed as prime soils, that is Class I and II of the USDA land classification system, if adequate moisture were available on the average 8 out of 10 years. In some states, such as Colorado and Kansas, Class I and II soils occupy more than 50 percent of the land included in the Study area. The ranking of so much of the High Plains area as Class I and II soils reflects the generally high fertility of the soils and the even topography.

Land Use

Cropland and improved pastureland are a major use of land on the High Plains, accounting for 23 percent of the 141 million acres included in the Study area.

Rangeland is the most common land use in the High Plains area, encompassing approximately 100 million acres. Some of this land is potentially productive if irrigated. Forest lands, except in isolated parks and wildlife areas and along major streams, are almost nonexistent. Urban lands also are relatively insignificant on the High Plains. Only Lubbock and Amarillo, in Texas, have populations in excess of 100,000 people. The next most populous cities, Midland and Odessa each with more than 50,000 people, are also located in Texas. All other cities in the High Plains Study area have less than 50,000 people.

Energy Resources

The Region has long been one of the major crude oil and natural gas producing areas in the United States. No other energy resources such as coal, lignite, or uranium, are produced in the Region in quantity. Crude oil and natural gas production is primarily located in two provinces, the Anadarko Basin and the Permian Basin.

The Anadarko Basin is noted primarily for natural gas production. It extends from eastern Colorado and western Kansas across the Texas Panhandle area and western Oklahoma. Geologically, the producing strata slope downward west to east and north to south. Thus, typical well depths in 1977 in southwestern Kansas were about 6,000 feet, while in the Texas Panhandle successful wells were about 10,000 feet, and in western Oklahoma wells were completed at depths of 17,000 to 20,000 feet.

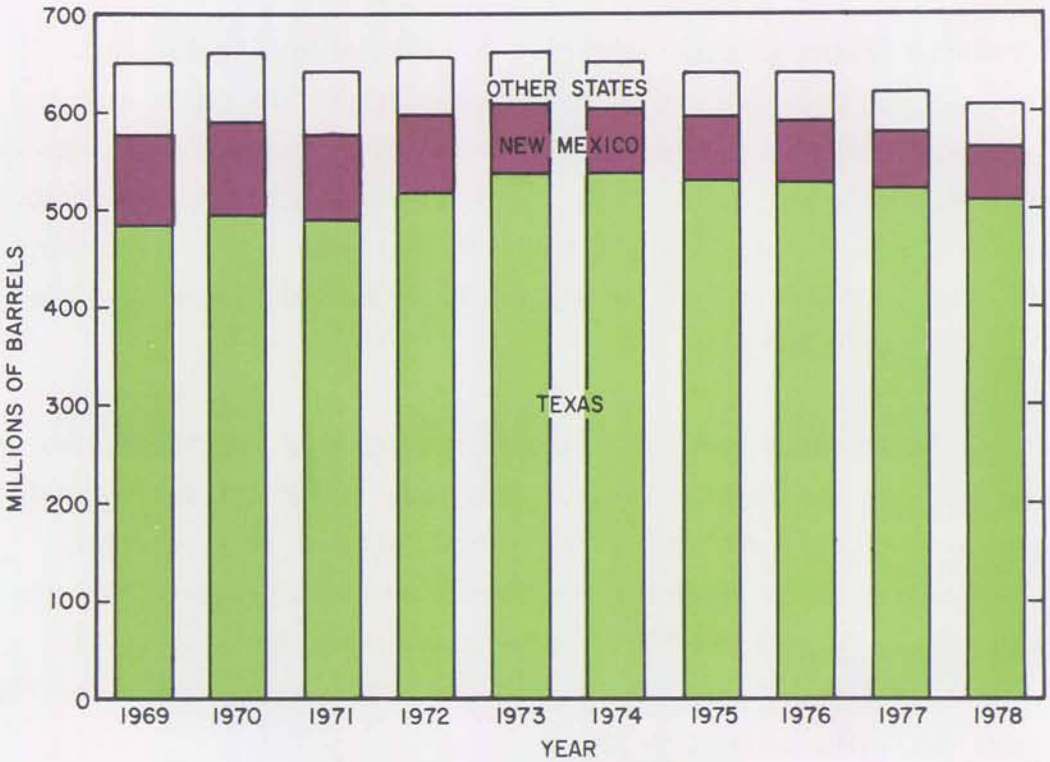
South of the Anadarko Basin and encompassing much of the New Mexico and Texas Study areas is the Permian Basin. This major crude oil and natural gas producing area is significant for having a wide interval of producing strata. The Permian Basin carbonate reservoirs are considered to be particularly favorable for enhanced oil recovery using gas flooding (CO_2) technology and, therefore, this area may in the future experience a reversal of the recent declining production trend.

Figure II-4 shows production trends of crude oil and natural gas for the Region. The graphs show that most of the regional production has come from the Texas Study area. Historically, the overall regional production has accounted for 20 to 25 percent of U.S. domestic crude oil and natural gas production.

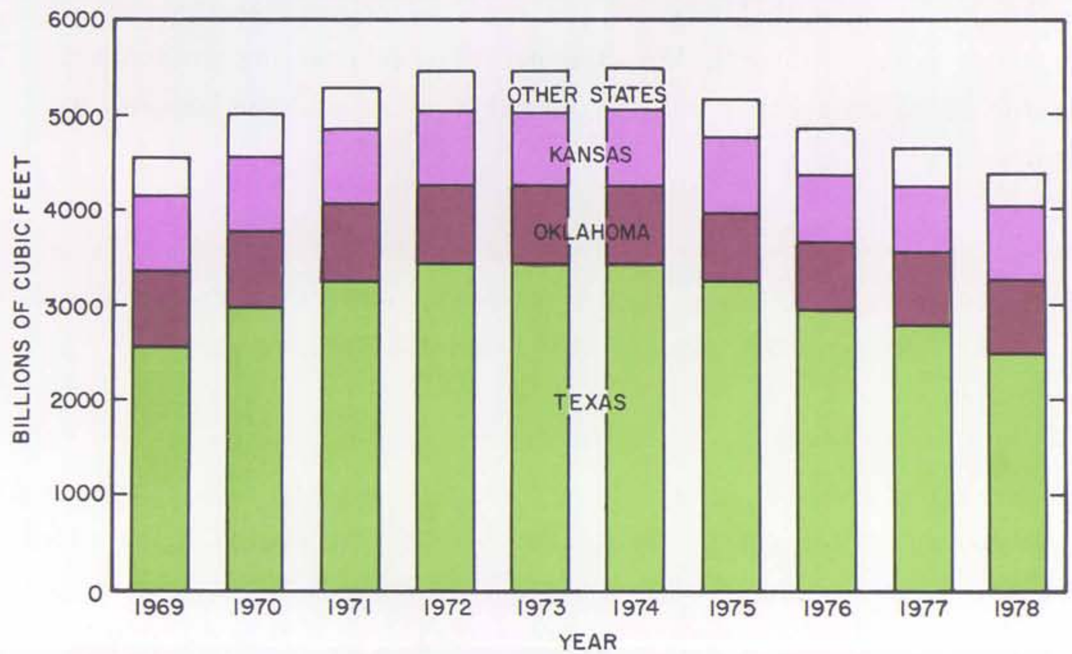
Regional consumption is a small fraction of the oil and gas produced. Compared to the 20 to 25 percent of U.S. domestic production, regional consumption in 1977 was only 0.5 percent (oil) and 3.6 percent (gas) of total U.S. consumption.

The increasing price of crude oil and natural gas has resulted in significant development of the energy-related economy of the Region. The share of total personal income in the Region derived from crude oil and natural gas production (including royalty payments) increased from 6 percent in 1973 to nearly 13 percent in 1978.

FIGURE II-4: THE HIGH PLAINS REGION—HISTORICAL CRUDE OIL AND MARKETED NATURAL GAS



CRUDE OIL PRODUCTION



MARKETED NATURAL GAS

ENVIRONMENT

Water Bodies

Four types of natural surface water bodies occur in the High Plains exclusive of streams. Three of these occur only in Nebraska.

- ° Fresh water lakes and wetlands in the central part of the Sand Hills of Nebraska. These lakes, ponds, marshes, and seasonally flooded meadows are hydraulically linked to the ground water system beneath the Sand Hills. Water levels in the lakes are controlled by the position of the ground water table.

- ° Alkali lakes in the western part of the Sand Hills of Nebraska. These lakes receive surface water runoff from the table lands to the west. Fine clay particles carried by the runoff have effectively lined the bottoms of these lakes with an impervious seal, such that there is no hydraulic connection between the lakes and the underlying ground water system. Because of evaporation, alkaline salts have been concentrated in and around the lakes.

- ° Rain basin wetlands in the south central part of Nebraska. Like the alkali lakes to the west, these wetlands are periodically flooded by rainfall runoff and, because fine clays line the bottoms of the depressions, are not hydraulically connected to the ground water system beneath the Sand Hills. Unlike the alkali lakes, however, there has been little or no salt buildup and the wetlands remain fresh.

- ° Playas and playa lakes in the southern High Plains. These are natural depressions which are widespread in Texas, New Mexico, and Oklahoma. Few of these depressions are permanently inundated; most are flooded seasonally after particularly large rainfall events. Many playas have been modified either for drainage, or to better capture and store rainfall runoff, or some combination. Playas range in size from a few acres to very extensive areas of hundreds of acres. It is estimated that more than 37 thousand playas are scattered unevenly throughout most of the High Plains Region south of the Platte River.

In addition to these natural water bodies, numerous reservoirs have been constructed in the High Plains area. These reservoirs have been constructed both for municipal water supplies and for irrigation water supplies. In general, reservoirs in the southern part of the area have more problems with water quality, sediment influx and yield than those in the northern part of the area. Some of the reservoirs in the northern part of the area have sufficiently high yields to allow hydropower generation.

Vegetative Cover

The vegetative cover types occurring in the Region are key factors in evaluating impacts of change on fish and wildlife resources. These vegetative cover types are identified* as:

1) "Riparian/Lowland Wetlands - This type is considered to occur within floodplain boundaries along major rivers and tributaries. Principal canopy species would include cottonwood, willow and saltcedar. Typical wetland vegetation would include cattail, rushes, sedges and a variety of rooted and floating vascular species. All cropland and other man-induced plant communities occurring within the riparian zone are excluded from this type."

2) "Upland Wetlands - Those upland sites located above the floodplains of streams and considered natural, isolated, closed drainage basins (including playas, Sandhill wetlands, and rainwater basins) are defined for the purposes of this report as upland wetlands. Water regimes vary considerably throughout their distribution within the study area. Some contain water throughout the year, some are wetted only seasonally, and others may contain water only for brief durations following heavy precipitation runoff."

* U.S. Fish & Wildlife Service Report, November 1981.

3) "<u>Upland Woodlands</u> - Those upland sites, above floodplains and drainages, with a canopy of trees such as spruce, fir, ponderosa pine, pinyon, juniper, and post oak and blackjack oak are included in this type."

4) "<u>Shrub-Grassland</u> - Primarily upland sites with a shrub canopy dominant or co-dominant to an understory of native grasses are included in this type. Shrub species include sandsage, shinnery oak, and mesquite."

5) "<u>Native Prairie</u> - Sites dominated by native grass species with little or no recognizable canopy of shrubs or trees are defined as native prairie."

6) "<u>Urban</u> - Sites reflecting a dominance of human inhabitance and structural development are termed urban sites."

7) "<u>Irrigated Cropland</u> - All agricultural croplands maintained by irrigation are thus defined."

8) "<u>Dryland Croplands</u> - All agricultural croplands not maintained by irrigation are defined as dryland cropland."

9) "<u>Introduced Grassland</u> - All pastures maintained as relative monocultures of exotic grasses such as bermuda grass, wheatgrass, weeping lovegrass, and exotic bluestems are defined as introduced grassland."

10) "<u>Barren</u> - This includes all areas void of vegetation or structure with exposed soils."

11) "Other -

   a) <u>River channel</u> - This includes recognizable open river channels with or without water.

   b) <u>Open water</u> - All recognizable bodies of artificially or naturally impounded water are included here."

Fish and Wildlife

The High Plains supports a rich and diverse assemblage of wildlife including numerous insects, birds, reptiles, amphibian, fish, and small mammals. Some of the wildlife has adapted to the cultivated lands and the restricted habitats of the windrows and turnrows. Some even thrive in cultivated fields, feeding on the crops and crop residues. Other wildlife can exist only in natural areas or the protected areas of the several wildlife sanctuaries and refuges that occur on the High Plains. Some of the perennial streams, particularly in Nebraska, support important fishery resources. Several species such as the whooping crane, bald eagle, American and Arctic peregrine falcons, black-footed ferret, swift fox, and various species of fish are either threatened or endangered.

One of the more important biological aspects of the High Plains is that it is located on the Central Flyway. Numerous ducks, geese and other birds depend on the area to provide stopover, staging and nesting grounds. The wetlands in the Sand Hills and the playa lakes are particularly important in this respect. The North and South Platte Rivers are also important. The fall game season attracts a large number of hunters to the area contributing to the economy of the High Plains.

INSTITUTIONAL SETTING

The six states of the Study area have diverse statutes, regulations and institutions regarding the management of the quantity and quality aspects of ground and surface water.

This difference includes highly developed local districts with relatively little water management authority, to poorly funded local districts with a great deal of water management authority; and from highly centralized state regulatory authority over ground water management to no ground water management authority at all at the state level. Detailed discussions can be found in report B-6, published separately.

Table II-1: IMPORTANT RESOURCE PRIORITIES* (IRP's) FOR THE STUDY AREA

IRP Title	Location of IRP	National Importance Rank (Total of 78)	Summary Statement/Goal
Migratory birds/ endangered species - Nebraska	Nebraska Subregion IV	12	Critical habitat for whooping crane Goal: Maintain habitat
Endangered birds - bald eagle	Entire study area	19	Many populations of bald eagles still threatened by habitat loss, pollution and human disturbance. Goal: Restore population
Migratory waterfowl - Sandhills area ground water recharge	Nebraska Subregion II	52	Endangered species & migratory waterfowl Goal: Preservation
Migratory waterfowl habitat losses - Rio Grande/Pecos Basins, New Mexico	New Mexico	57	Habitat destruction by Federal, State, and private developments. Goal: Restoration is needed to increase population
Migratory waterfowl - playa lakes	Nearly entire study area	59	High Plains migratory waterfowl Habitat is being destroyed & waterfowl use is greatly reduced. Goal: Preservation
Golden eagle - West Texas	Texas subregions	67	Livestock losses to eagles Goal: Reduce loss and protect eagles

* U.S. Fish and Wildlife Service Report, November 1981.

Each state has entered several interstate impacts on multistate rivers, which affects to some degree the manner in which it can manage certain water resources within the state.

Several federal agencies have active roles in the states as it relates to the Ogallala Aquifer. Several U.S. Department of Agriculture agencies including the Soil Conservation Service and Agricultural Stabilization and Conservation Service ASCS assist farming operations directly. The U.S. Army Corps of Engineers and the U.S. Bureau of Reclamation have assisted the states in the water resource planning efforts and in the development of water supply. The Bureau of Reclamation is the federal agency primarily responsible for the development of water for irrigation. The U.S. Geological Survey has assisted state and local agencies collect and interpret data on the Aquifer and surface water supplies. The Environmental Protection Agency and the U.S. Fish and Wildlife Service also have active regulatory and natural resources conservation and enhancement programs.

The states have varying organizational structures:

Colorado

Water resource planning and some water rights administration and control are accomplished within the Department of Natural Resources (DNR), but in different divisions.

The Colorado Water Conservation Board is responsible for state-wide water resource planning. The State Engineer serves as the executive director of the Division of Water Resources within the CDNR. The State Engineer shares the responsibility of administering water rights with district water judges in seven water districts throughout the state. Generally the State Engineer has broad authority to administer, distribute and regulate the waters of the state. Colorado law makes no distinction between ground and surface water with respect to appropriation. Ground water which contributes little or no flow to surface water streams is regulated by the Ground Water Commission. All other ground water is regulated by the State Engineer.

generally not adequately funded and in spite of their broad authority have not developed effective aggressive management programs. The Colorado policy on acceptable aquifer depletion is 40 percent in 25 years.

The Office of Health Protection, an agency of the Department of Health is primarily responsible for water pollution control in Colorado. Most of the water quality work is handled by the Water Quality Control Division.

Kansas

Extensive authority to regulate water in Kansas is vested in the Water Resources Division of the Department of Agriculture. That authority extends to special districts, water rights, irrigation, flood control, water storage, conservation, development and utilization. The Division's administrative head is the State Engineer, who also serves on the four interstate stream compact commissions.

State-wide water planning is now the responsibility of the recently created (1981) Kansas Water Office. The agency is responsible for planning to meet the state's water needs. The agency staff also administers the state's surface waters which are stored in federal reservoirs.

Several ground water management districts overlying the Ogallala Aquifer were formed in 1972. The districts have authority to manage ground water, but must rely on the Division of Water Resources for enforcement of their regulations. Inadequate funding prevents these agencies from carrying out their authority to the fullest extent.

The State Department of Health and Environment through its Water Quality Management and Water Pollution Control Sections are responsible for the protection of the quality of both ground and surface waters except for oil and gas production and hazardous waste disposal. Those aspects are handled by the Oil Field and Environmental Geology Section.

Nebraska

Water rights are administered by the Department of Natural Resources. The agency has some responsibilities in data collection, dam safety and construction, special districts, ground water regulation and interstate river basin compacts. Ground water regulation is shared with local districts and is implemented only after conflicts are occuring or may reasonably may be expected.

The principal water resources planning effort for the state is by the Nebraska Natural Resources Commission. The agency also is responsible for, among other things, providing assistance to the 24 natural resources districts which cover the entire state.

In Nebraska, these districts have been granted extensive planning and in certain instances, regulatory authority. A natural resources district can institute a control area over an aquifer and then set spacing requirements for wells, limit annual withdrawal of water, rotate the right to withdraw among users and declare a moratorium on the installation of new wells.

The Department of Environmental Control is responsible for the protection of air, water and land within the state including ground water. The agency also regulates livestock control and waste programs, particularly feedlots.

New Mexico

The Water Resources Division of the Department of Natural Resources consists of the Interstate Stream Commission and the State Engineer's office. The State Engineer is a member of the Interstate Stream Commission and has extensive authority in the administration of water rights, both ground and surface, water development and protection of the state's waters from over-use or contamination.

No local ground water districts exist to support the State Engineer or to share the authority. The State Engineer's authority includes the authority to deny an application for surface water if approval would be contrary to the public interest (N.M.S. §75-5-5 and 75-5-6).

Ground water is the property of the public in New Mexico and is subject to apportionment by the State Engineer after the engineer has designated a defined ground water basin subject to management control. He may deny an application for a permit with or without a hearing if he is of the opinion the permit should not be issued, (N.M.S. § 75-11-3 (7)).

The Health and Environment Department, like other states is a large agency with significant authority. The Environmental Improvement Division has regulatory authority for water quality and supply and liquid waste and solid waste sanitation and refuse disposal as well as many other authorities.

Oklahoma

The Oklahoma Water Resources Board is charged with the primary responsibilty for both the statewide water resources planning and the allocation of surface and ground water. The agency was charged with the responsibility of developing a state water plan, which has now been adopted by the Oklahoma Legislature.

The agency is moving forward with the adjudication of ground water and its appropriation on a "safe yield" basis, allocated by the surface acres overlying the ground water basin.

The Oklahoma Legislature has authorized the formulation of local districts but to date none have been organized.

The OWRB also has some responsibilities in water quality as does the state's Board of Health. A Pollution Control Board which consists of the administrative heads of seven state agencies and two other appointed members are responsible for coordinating the efforts of all state agencies in the field of environmental pollution.

Texas

The State of Texas has an extensive data collection, planning and surface water allocation authorities and capability in its Texas Department of Water Resources. Other agencies including the Texas Railroad Commission regulate certain aspects of ground water quality as it relates to oil and gas production and the Texas Department of Health insofar as drinking water is concerned. The state has little management control of ground water at the state agency level.

Three local ground water districts cover large portions of the Ogallala Aquifer. These districts have extensive and effective public education and demonstration programs. Unlike the other study area states with local districts with specific authority for ground water, these three agencies are well funded, through an ad valorem tax. With the exception of waste prevention and well spacing requirements, these districts have no regulatory authority to manage ground water.