ESTIMATING 1980 GROUND-WATER PUMPAGE FOR IRRIGATION ON THE HIGH PLAINS IN PARTS OF COLORADO, KANSAS, NEBRASKA, NEW MEXICO, OKLAHOMA, SOUTH DAKOTA, TEXAS, AND WYOMING

By Frederick J. Heimes and Richard R. Luckey

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Multiply inch-pound units	By	To obtain metric units
inch	25.40	millimeter
foot	0.3048	meter
mile	1.609	kilometer
acre	0.4047	square hectometer
acre-foot	1,233	cubic meter
square mile	2.590	square kilometer
gallons per minute	0.0631	liter per second

To convert from degrees Fahrenheit to degrees Celsius, subtract 32 and then divide the result by 1.8.

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ABSTRACT

Information on current trends in ground-water use for irrigation is required for the High Plains Regional Aquifer-System Analysis. Because available water-use information is inadequate, an approach based on physical sampling was used to estimate ground water pumped for irrigation on the High Plains during the 1980 growing season.

The amount of ground water pumped for irrigation was computed by combining water application estimates developed from sample data with mapped irrigated-acreage information. Irrigation application (inches of irrigation water applied) was measured at 480 sites in 15 counties in the High Plains during the 1980 growing season. The relationship between irrigation demand, calculated using the Blaney-Criddle consumptive-use formula, and measured application was used to estimate application for unsampled areas of the High Plains. The estimated application was calculated for each 1-degree latitude by 1-degree longitude area in the High Plains.

Application estimates multiplied by irrigated-acreage estimates, derived from analysis of Landsat-satellite imagery, yielded the volume of ground water pumped for irrigation. Estimates of ground water pumped for irrigation during 1980 were aggregated by State and as a total estimate for the entire High Plains. The estimate of ground water pumped for irrigation in the High Plains during 1980 was 17,817,000 acre-feet applied to 13,385,000 irrigated acres. Texas had the most dense irrigation development in the High Plains, while South Dakota virtually was undeveloped.

The sampled application data were evaluated for significant trends. The data showed a greater application for crops requiring more water such as corn and hay and less for crops such as sorghum, grain and cotton. The data also showed greater pumpage for flood-irrigation systems than for sprinkler-irrigation systems. Areas of the High Plains with thin saturated thickness tended to have a smaller average discharge per well, fewer irrigated acres per well, and a predominance of crops requiring less water.

INTRODUCTION

The U.S. Geological Survey began a 5-year study of the High Plains regional aquifer in 1978. The primary objective of the High Plains Regional Aquifer-System Analysis is to provide the hydrologic information needed for the development of computer models to evaluate the aquifer's response to ground-water management alternatives (Weeks, 1978). This report describes the results of 1980 sampling of ground-water pumpage for irrigation on the High Plains, one phase of the High Plains Regional Aquifer-System Analysis project. These data were collected to estimate the volume of irrigation water pumped during 1980 and to determine current trends in irrigation pumpage on the High Plains.

Collection and analyses of data for this report required the cooperation of the U.S. Geological Survey, the National Aeronautics and Space Administration, State and local agencies, and individual irrigators. Without their support this study could not have been conducted. The National Aeronautics and Space Administration provided funding for Landsat mapping of irrigated cropland used in computing total water use.

Physiography and Climate

The High Plains aquifer underlies an area of approximately 174,000 square miles, including parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming (fig. 1). This aquifer, which is composed of saturated gravel, sand, silt, and clay, is the only source of water for much of the area. The region is cultivated extensively and depends almost entirely on water from the aquifer to support the large areas of irrigated cropland. Flat to gently rolling terrain characterizes the High Plains region, which is a remnant of a vast plain that was formed by sediments deposited by streams flowing eastward from the Rocky Mountains. Erosion later isolated the plains from the mountains and formed escarpments that typically mark the boundary of the High Plains. Wind-blown sand and silt, derived from the beds of rivers that eroded the plains, were deposited over large areas of the High Plains. The largest expanse of wind-blown sand deposits and dune topography in the Western Hemisphere (about 20,000 square miles) is in the High Plains of north-central Nebraska (Madson, 1978). This dune area contains numerous small lakes and marshes. Smaller areas of sand dunes occur in many other parts of the High Plains.

Many lakes also occur in the southern part of the High Plains. These lakes are shallow depressions or playas that collect and store water during periods of runoff; some of the deeper playas store water throughout the year. Because playas in the High Plains generally are above the regional water table, the water surfaces in the playas do not reflect the altitude of the water table in the underlying aquifer, as many of the lakes in the sand hills of Nebraska do.

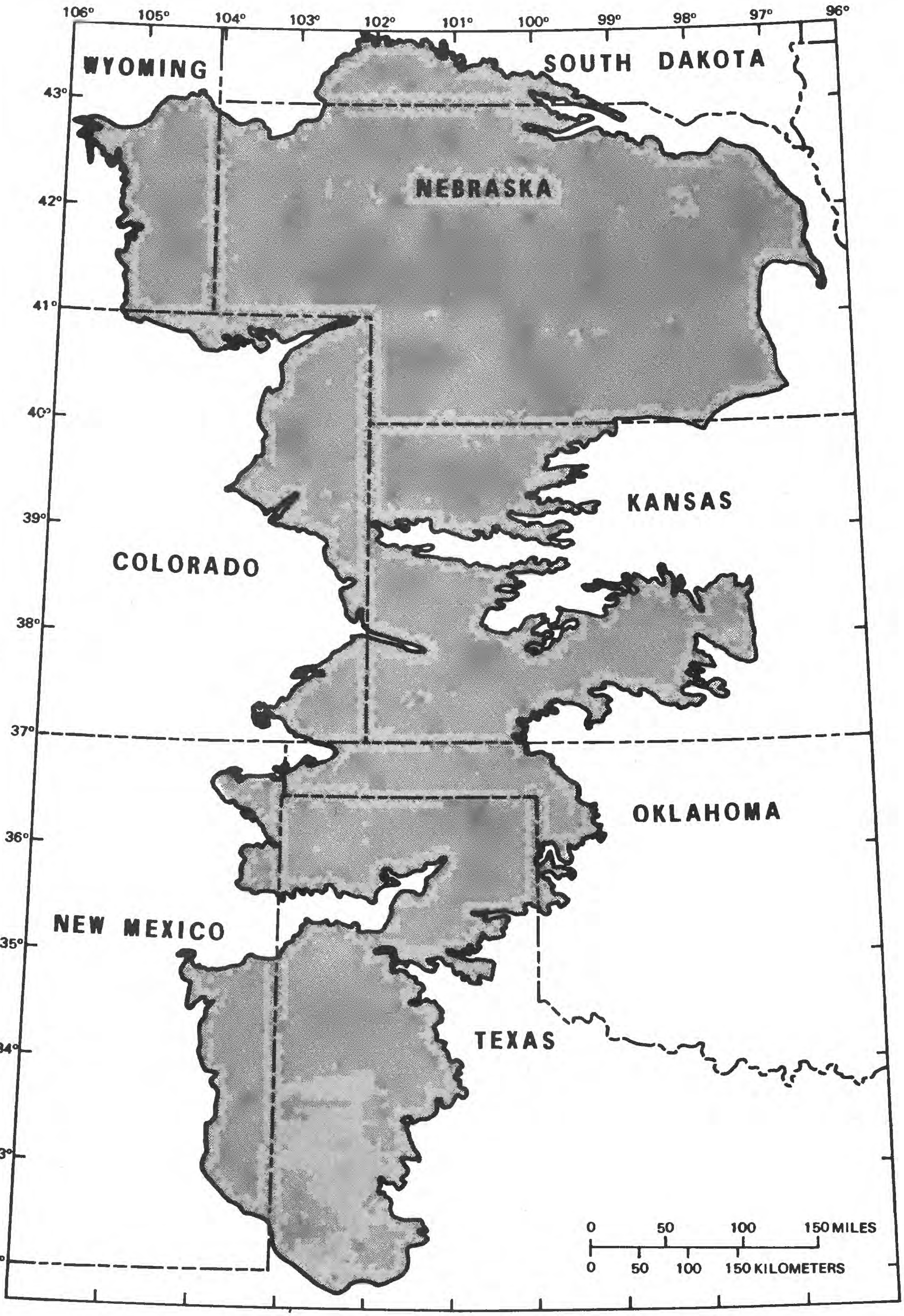

Figure 1.--Location of High Plains aquifer.

Generally, the High Plains has a typical middle-latitude, dry-continental climate that characterizes regions in the interiors of continents. The climate is one of abundant sunshine, moderate precipitation, persistent winds, little humidity, and a rapid rate of evaporation. Mean annual precipitation in the High Plains ranges from less than 16 inches along the western edge of the High Plains aquifer to about 28 inches in eastern Nebraska and central Kansas (fig. 2). Mean annual precipitation increases across the High Plains by about 1 inch for every 25 miles. Typically, about 75 percent of the precipitation falls during the growing season, April through September, a condition favorable to agriculture. However, much of the rain results from local thunderstorms, so large variations in precipitation can occur from place to place and year to year.

The climate of the High Plains region is characterized by large daily and seasonal extremes of temperature. The daily variation of temperature may range from 30° to 60° Fahrenheit, with seasonal extremes that change more than 130° Fahrenheit between winter lows and summer highs. The wind is changeable throughout the year as a result of cyclonic storms, and persistent winds and high summer temperatures cause rapid rates of evaporation in the High Plains. Mean annual class A pan evaporation varies from more than 55 inches in south-central South Dakota and northern Nebraska to more than 105 inches in west-central Texas and southeastern New Mexico (fig. 2). Because of the large evaporative demand, most of the water that enters the soil from precipitation is returned to the atmosphere by evapotranspiration. Recharge to the ground-water system may be several inches per year in sand-dune areas but, throughout much of the High Plains, recharge averages a small fraction of an inch per year (Theis, 1937).

Climate is the key factor in soil formation. The limy soils in the High Plains region formed under short grass with an absence of leaching because of the lack of precipitation. Because evaporation greatly exceeds precipitation, there is an upward movement of nutrient minerals in the soil profile. This condition makes the soils of the High Plains region ideally suited to agriculture, but lack of precipitation and the rapid rate of evaporation limit agricultural production.

Agricultural Development

Dryland farming and cattle grazing began in the High Plains region during the late 1800's and flourished until the drought of the 1930's. The "dust bowl" years of the 1930's coupled with technological advancements in well drilling and pumping plants and the availability of inexpensive energy spurred the development and increase of irrigated agriculture in the region. The development of irrigation resulted in large increases in crop yield and effectively removed the risks associated with dryland farming.

Development of irrigation during the 1940's and 1950's was greatest in the southern High Plains region, principally in the southern High Plains of Texas. Development began in this area because of the availability of inexpensive

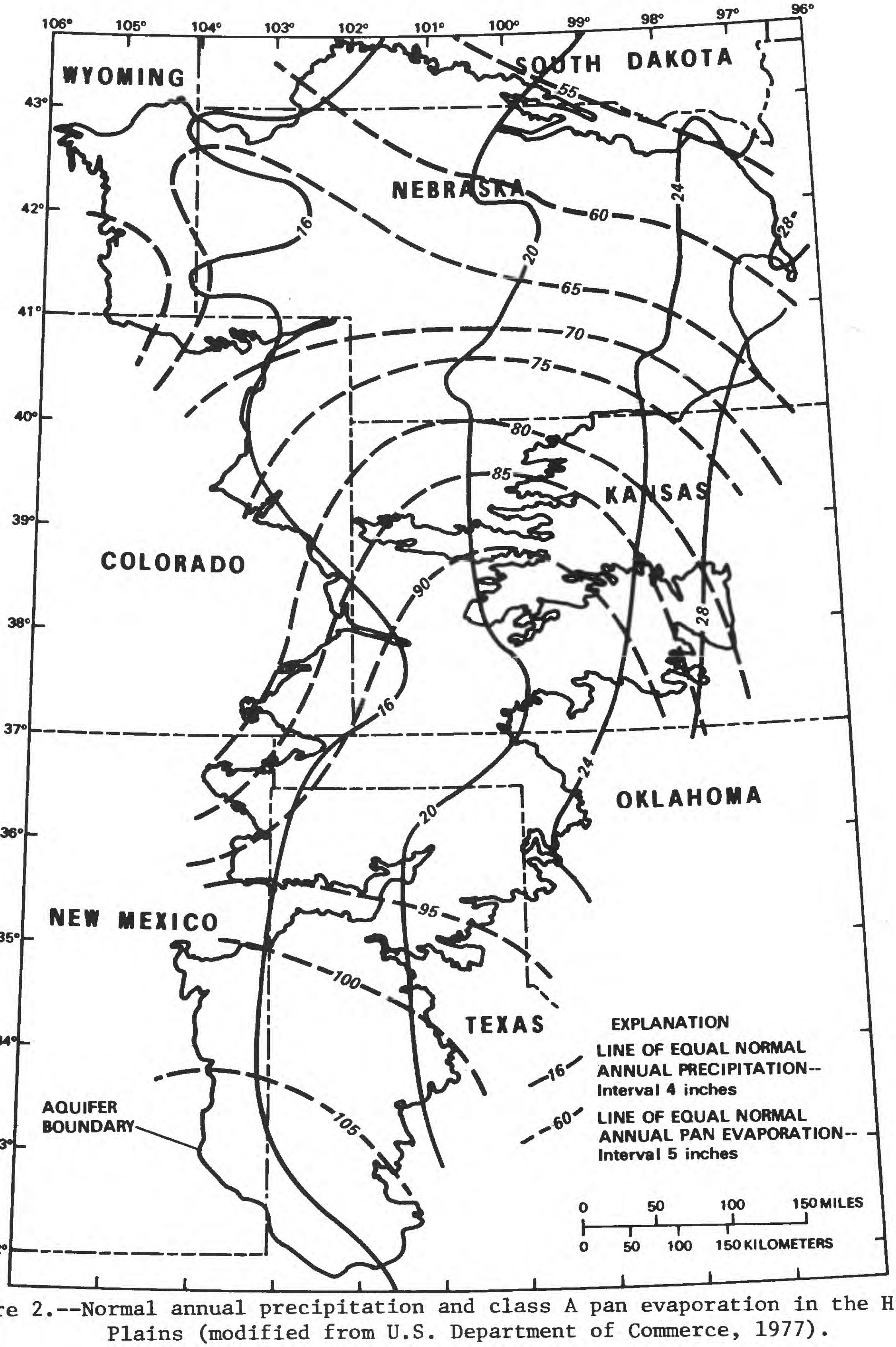

Figure 2.--Normal annual precipitation and class A pan evaporation in the High Plains (modified from U.S. Department of Commerce, 1977).

natural gas, a shallow water table, and financial resources. Since the 1950's, irrigation has developed throughout most of the High Plains. The development of the center-pivot irrigation system enabled vast areas of land to be irrigated that previously were not suitable for irrigation. The rapid increase of irrigation in the High Plains is illustrated in figure 3.

Irrigation has transformed the High Plains into one of the major agricultural areas in the United States. During 1977, about 35 percent of the area overlying the High Plains aquifer was cropland and about one-half of that area was irrigated. Irrigated cropland on the High Plains currently (1980) represents more than 20 percent of the total irrigated land in the United States. About 30 percent of the ground water used in the United States for irrigation is pumped from the High Plains aquifer. Grubb (1978) reported that, for the High Plains, total cash receipts for irrigated crops were more than $2 billion (nearly one-half of the High Plains total) and livestock production was valued at more than $10 billion.

Ground-water withdrawal for irrigation has caused areally extensive water-level declines in the aquifer (fig. 4). These declines result in decreased well yields and increased pumping costs. The declines, combined with large increases in all costs associated with irrigation, especially energy, have caused great concern about the future viability of irrigation on the High Plains. Reliable and timely information on the volume and areal distribution of water withdrawn for irrigation is essential to the effective management of the water in the High Plains aquifer.

Objective

The objective of this phase of the High Plains Regional Aquifer-System Analysis project was to provide an estimate of the quantity of ground water withdrawn for irrigation in the High Plains during 1980. Available estimates of ground-water withdrawals generally are based on occasional localized reported information or crop consumptive use estimated from climatic factors. The quality of the available reported information is quite variable, and accurate data are not available for the majority of the High Plains region. Calculations of consumptive water use by crops give reasonable estimates of historical withdrawals, but changes in irrigation techniques caused by increased energy costs and decreasing water availability are likely to decrease the accuracy of ground-water withdrawal estimates based on this approach.

Because available data and empirically based estimation techniques were not suitable for providing current data on ground-water withdrawals for irrigation, a sampling program was designed to provide an estimate of ground-water withdrawal for irrigation during 1980 that was based on measured data. A pilot program was conducted in 1979 to test methods and instrumentation for application to the 1980 pumpage-sampling program. The results of the 1979 pilot program are reported by Heimes and Luckey (1980). The results of the 1980 program are the subject of this report.

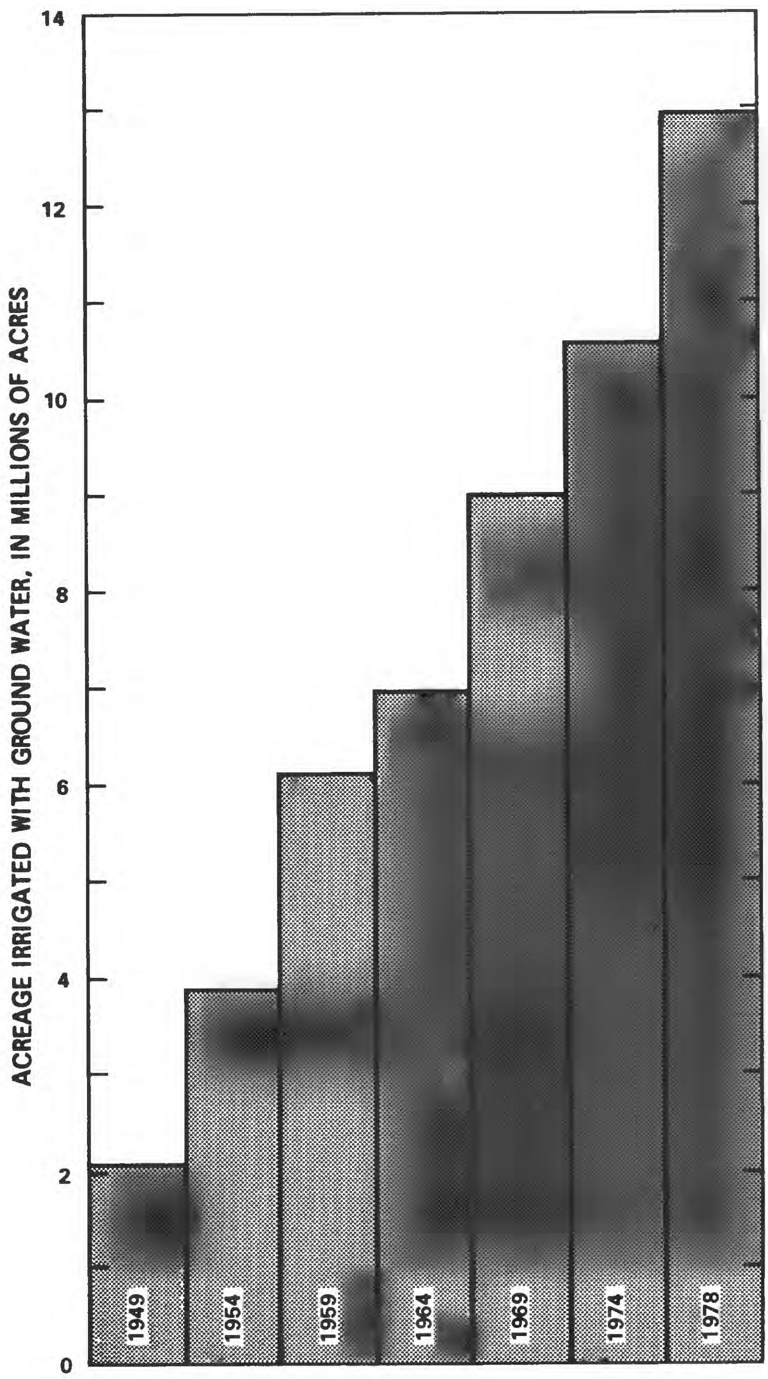

Figure 3.--Increase of irrigation on the High Plains from 1949 to 1978 (data from U.S. Department of Commerce, 1949-78).

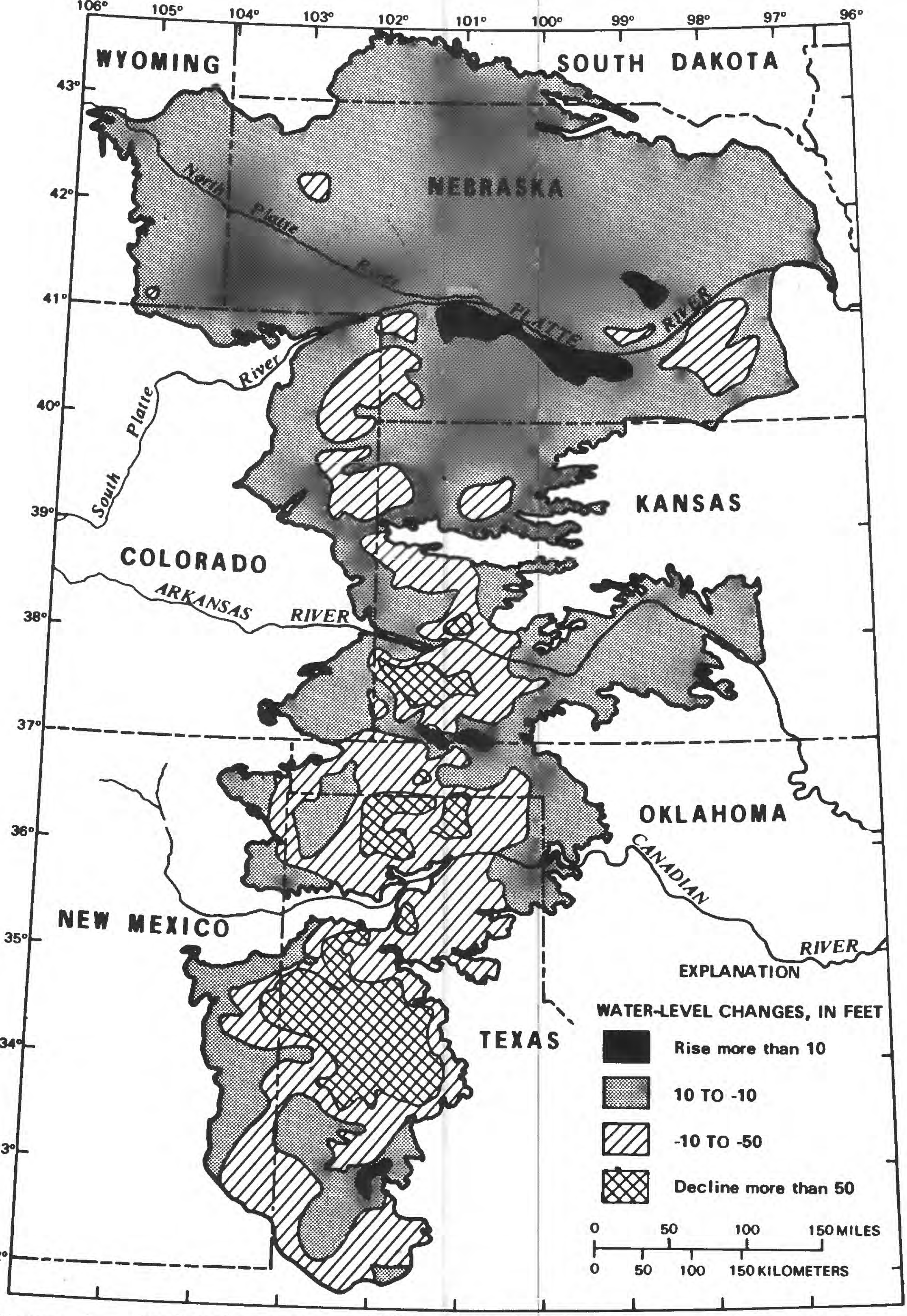

Figure 4.--Predevelopment to 1980 water-level changes in the High Plains aquifer (modified from Luckey, Gutentag, and Weeks, 1981).

Approach

The 1979 pilot program was designed to: (1) Develop a statistical approach to sample ground-water pumpage for irrigation, (2) test instrumentation and develop procedures for measuring the annual volume of ground water pumped from selected irrigation wells, (3) determine the relationship between the annual volume of ground water pumped and the acreage irrigated, and (4) develop a suitable approach to map irrigated cropland for the entire High Plains region in order to extend the sample.

For the pilot program, a stratified random sample was used to select 250 sites in two areas. Sites were stratified by crop and by area. The annual volume of ground water pumped at each site was computed by multiplying the pumping rate by the total time of pumping. Irrigated cropland maps are required to estimate the volume of water pumped for the High Plains. During the 1979 pilot program, various approaches were evaluated for mapping irrigated cropland. The results of the 1979 pilot program are presented in detail in Heimes and Luckey (1980). The 1979 tests provided the following information that contributed to the design of the 1980 pumpage-sampling program.

The stratified random sample used in 1979 was very cumbersome and was not incorporated in the 1980 pumpage-sampling design. For the 1980 program, a simple random sample was selected. Instrumentation that was found suitable during the 1979 pilot program was used in the 1980 sampling program. Landsat mapping of irrigated cropland, evaluated during the pilot program, proved to be the most efficient and least costly approach for mapping irrigated cropland throughout an area as large as the High Plains and was used in 1980.

The 1980 program was designed to provide the High Plains Regional Aquifer-System Analysis project with the best possible data on ground-water pumpage for irrigation for the entire High Plains. For 1980, 15 counties, strategically located throughout the High Plains, were selected for data collection, and sampling sites were selected randomly within the counties. Discharge, time-of-operation, crop-type, and crop-acreage data were collected at each of the sampling sites during the 1980 growing season. These data were used to compute the average depth of water applied (application), in inches, for each site. The data were analyzed to estimate the 1980 ground-water withdrawal for irrigation and also were analyzed to evaluate the effects of climate, water availability, crop types, and irrigation-system types on the application. The relationships between irrigation demands calculated using the Blaney-Criddle (U.S. Department of Agriculture, 1967) consumptive-use formula and sampled applications were used to estimate the applications in unsampled areas of the High Plains. Estimates of application were combined with 1980 irrigated-acreage data obtained from Landsat mapping to calculate the volume of water pumped during the 1980 growing season in the High Plains.

DATA COLLECTION

All or parts of 15 counties located in various parts of the High Plains region were selected for sampling during the 1980 irrigation season (fig. 5). A total of 480 individual sampling sites were selected in these 15 counties. The number of sampling sites that were selected in each area is shown in table 1. The county sampling areas were chosen to provide a representative cross section of irrigation systems, crop types, and physical factors such as geology, hydrology, soils, and climate occurring within the High Plains region. Individual sampling sites were selected randomly within each of the county sampling areas.

Discharge, time-of-operation, crop-type, and crop-acreage data were collected at each of the sampling sites. Data for most of the crops were collected from spring through fall in 1980. However, data were collected for winter grains from fall of 1980 through summmer of 1981 so application could be monitoried for an entire growing season.

Discharge

Discharge measurements were made using the transient-time (Clampitron*) flowmeter. The accuracy of the Clampitron flowmeter was tested throughly under laboratory conditions prior to the 1980 sampling program (Luckey, Heimes, and Gaggiani, 1980). Clampitron-flowmeter measurements were compared, whenever possible, with discharge measurements made using other methods to evaluate the reliability of the Clampitron flowmeter under field conditions. Most of the comparisons were made with calibrated inline flowmeters. The results of these comparative measurements are shown in figure 6. Values located on the solid line represent an identical measurement using both methods. Most of the differences between the comparative measurements are less than 5 percent. This indicates that the Clampitron flowmeter provided reliable measurements of discharge under field conditions. Only a small fraction of the sites could not be measured using this flowmeter or some other method to obtain a discharge.

Discharge for about one-third of the 480 sampling sites was measured two or more times during the growing season to determine if a significant decrease in discharge occurred. Discharge might decrease during the growing season as a result of increased pumping lifts. The relationships between the first and last discharge measurements at individual sampling sites are shown in figure 7. Data points located below the solid line indicate a decrease in the discharge measured later in the growing season; points located above the line indicate an increase in the discharge. Data presented in figure 7 show a fairly even distribution of points on either side of the solid line, indicating no significant trend in discharge during the growing season. The data also were analyzed for individual counties where sufficient data were available to determine if a trend in discharge was present for localized areas. No

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* Any use of trade names is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

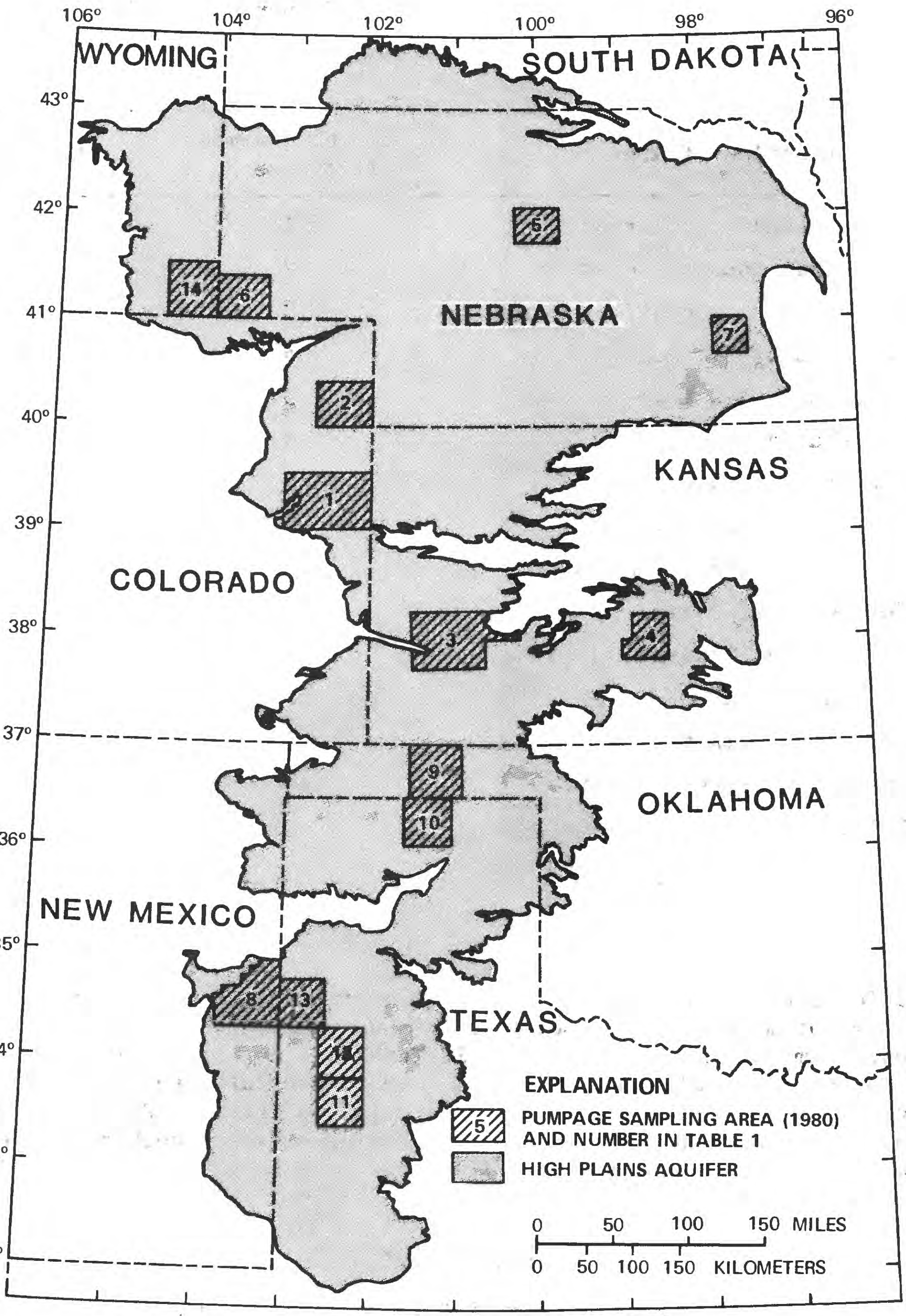

Figure 5.--Location of 1980 pumpage-sampling areas.

Table 1.--*Distribution of 1980 pumpage-sampling sites in the High Plains*

Location of area	Location number in figure 5	Number of sites
Kit Carson County, Colorado	1	25
Northern Yuma County, Colorado	2	40
Finney and Kearny Counties, Kansas	3	50
Stafford County, Kansas	4	50
Blaine County, Nebraska	5	50
Kimball County, Nebraska	6	20
York County, Nebraska	7	50
Curry County, New Mexico	8	16
Eastern Texas County, Oklahoma	9	15
Hansford County, Texas	10	35
Hockley County, Texas	11	20
Lamb County, Texas	12	20
Parmer County, Texas	13	59
Eastern Laramie County, Wyoming	14	30
TOTAL		480

significant trend in discharge could be identified for any of the counties where two or more discharge measurements were obtained during the growing season. Lamb and Hockley Counties in Texas did not have sufficient discharge data to determine if a trend existed. Thus, the data presented in figure 7 indicate that, for the majority of the wells in the High Plains, a single discharge measurement made during the growing season probably is a reasonable estimate of the average seasonal discharge.

Time of Operation

The Vibration Time Totalizer (VTT) is designed to measure time of pumping (Heimes and Luckey, 1980). Two VTT units were installed at each site for comparative measurements and as insurance against loss of data if one of the units failed. In addition to the time-of-operation data collected using the

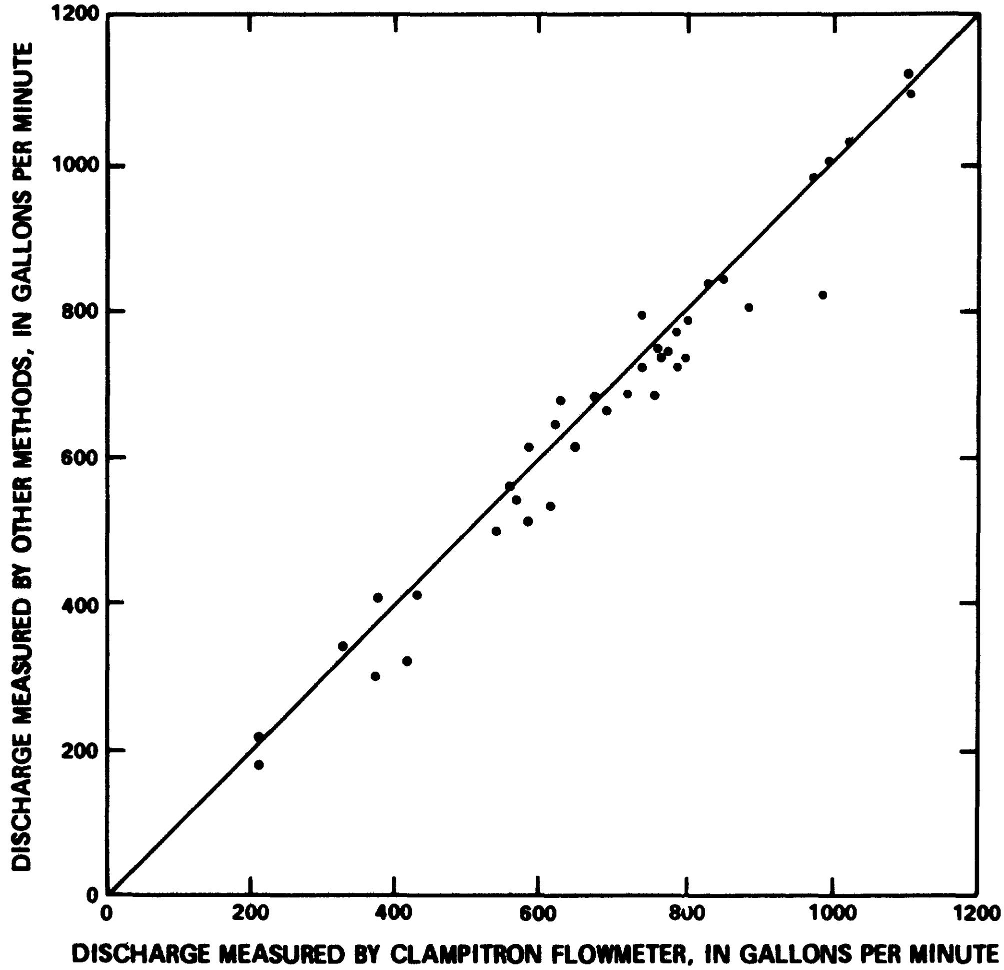

Figure 6.--Comparison of discharge by the Clampitron flowmeter with discharge measured by other methods.

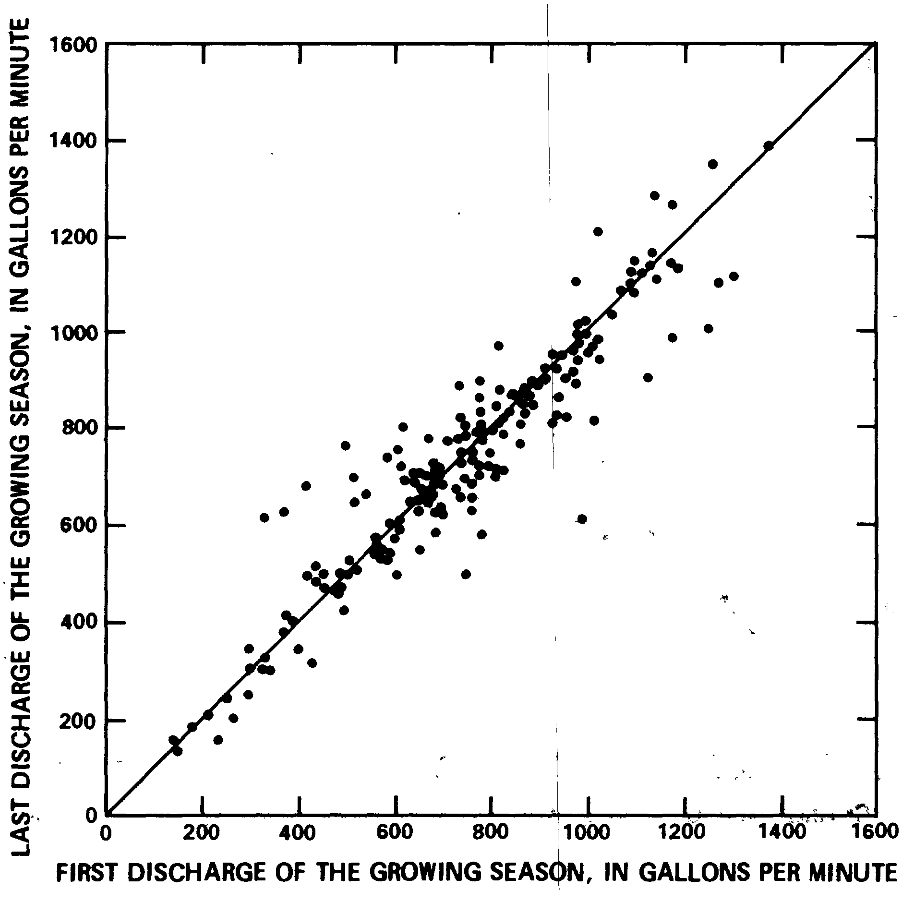

Figure 7.--Comparison of discharge measurements made early in the growing season with discharge measurements made later in the growing season.

two VTT units installed at each site, all other time-of-operation data that were available for the site were recorded. These other sources for data included electric and gas meters, engine-hour and pivot-hour meters, inline flowmeters, and logs kept by irrigators. About 50 percent of the VTT units used during the 1980 growing season were new production models, and the remaining 50 percent were prototype units that had been used in the 1979 pilot test. VTT pairs installed at each site consisted of various combinations of prototype and production models.

The new production models of the VTT units had an extremely large failure rate (approximately 70 percent) during the growing season. Time of operation from prototype VTT units or from other data sources helped to limit the quantity of data that was lost as a result of production VTT unit failures. However, VTT failures still resulted in loss of data from about 15 percent of the sites sampled during 1980.

The prototype VTT units and those production units that did function throughout the entire growing season had accuracies similar to the 95-percent accuracy obtained during the 1979 pilot program (Heimes and Luckey, 1980). The failure rate of the prototype units used during 1980 was about 15 percent, which was somewhat greater than the failure rate during the 1979 pilot program. However, the prototype units, which were designed for a limited service time, had been used for one or two growing seasons prior to their use in 1980, so a greater failure rate was expected.

The VTT unit is a reasonably accurate instrument for measuring time of operation of irrigation systems as indicated by the results obtained from the prototype units. The problems associated with production VTT units could be remedied by minor design changes and the exercise of adequate quality control during manufacturing.

Acreage and Crop Type

Detailed acreage and crop-type information were collected at each of the sampled sites. Several crops with different acreages often were irrigated at individual sample sites. Obtaining acreages for center-pivot irrigation systems was a relatively simple procedure. The acreage irrigated by most center-pivot systems could be obtained by measuring the radius of the circle and computing the area. Acreages irrigated by flood systems were more difficult to estimate because the fields often are irregular in shape, and sometimes it was difficult to determine which fields were irrigated by a given system. Accurate delineation of crop types and acreages sometimes required contacting the irrigator to determine what fields and crops were being irrigated at various times during the growing season. Incorrect acreage and crop data were collected for some sites when irrigators were contacted by phone to determine what acreages were irrigated by a given well or system. This generally occurred because of misunderstandings about which well or irrigation system was being measured. Onsite discussions with the irrigator were essential to avoid this confusion and to collect accurate data. Additional information on crop types and acreage generally could be obtained through local Agricultural Stabilization and Conservation Service offices. These offices required irrigators to report the acreages and crop types irrigated in order to be eligible for certain types of insurance or price supports.

DATA INTERPRETATION

A summary of the application data by area, crop, and system type for 1980 is contained in table 2. The table lists the acreage sampled and the average depth of irrigation water applied during the 1980 growing season. The average depth of application computed from sample data is acreage weighted. This assures that the depth of application for a large field is given a proportionally greater weighting than the depth of application for a small field. This is important because areal estimates of the volume of irrigation water pumped were made by using irrigated acreage.

Of the 480 sites selected for sampling in 1980, 374 sites provided usable data on seasonal irrigation withdrawals, representing a 78-percent data-recovery rate. Several factors combined to result in this greater than expected data-loss rate; the two principal factors were: (1) The previously discussed failure rate of production model VTT units used to monitor time of operation; and (2) a drought that occurred throughout large areas of the High Plains during the 1980 growing season.

As a result of very high temperatures and less than normal precipitation during critical periods of the growing season, irrigation-water requirements of some crops exceeded the design capacity of the irrigation systems in some areas of the High Plains during the 1980 growing season. This was most prevalent in the eastern High Plains of Kansas. Consequently, all or part of some crops were abandoned during the season or stressed to the extent that yields were significantly decreased, and these sites could not be used. Other factors that resulted in the loss of data at some sites included: (1) The inability to obtain a valid discharge measurement; (2) system complexities that prevented accurate identification of irrigated acreage; and (3) complex crop rotations that resulted in incomplete data for some crops.

Sample data were evaluated to see if the random sample adequately represented the distribution of the crops present in each county. Proportions of crop types obtained from the random sample in each of the counties agreed with available reported data on crop distributions for the counties. The data in table 2 for Texas County, Oklahoma, and for Hansford County, Texas, show no statistics for the small grains that comprise a significant proportion of the irrigated crops grown in those two counties. The site selected contained the proper distribution of small grains; however, problems with VTT units and scheduling of personnel for the long growing season (fall to summer) of the grains resulted in loss of data for the grain crop in these two counties.

Crops requiring larger quantities of water, such as corn and hay, tend to have greater depths of application than the crops requiring less water, such as

Table 2.--*Crop acreage and ground-water application for sites sampled in the High Plains during the 1980 growing season*

[Appl = average depth, in inches, of ground water pumped for irrigation]

Area	Crop	Irrigation-system type					
		Sprinkler		Flood		Both	
		Acres	Appl	Acres	Appl	Acres	Appl
Kit Carson County, Colorado	Corn	479	15.4	1,100	17.3	1,579	16.7
	Hay	419	8.9	90	24.7	509	11.7
	Dry beans	0	---	100	9.3	100	9.3
	Grain	100	8.3	0	---	100	8.3
	All crops	998	11.9	1,290	17.2	2,288	14.9
Yuma County, Colorado	Corn	4,232	16.5	120	21.7	4,352	16.6
	Hay	1,198	20.1	0	---	1,198	20.1
	Sorghum	0	---	50	10.6	50	10.6
	All crops	5,430	17.3	170	18.4	5,600	17.3

Table 2.--*Crop acreage and ground-water application for sites sampled in the High Plains during the 1980 growing season*--Continued

Area	Crop	Irrigation-system type					
		Sprinkler		Flood		Both	
		Acres	Appl	Acres	Appl	Acres	Appl
Finney and	Corn	1,812	22.1	378	26.9	2,190	23.0
Kearny Counties,	Hay	272	19.8	15	12.2	287	19.4
Kansas	Grain	390	7.7	228	15.7	618	10.6
	Sorghum	149	13.1	204	26.8	353	21.0
	Mixed	0	---	459	28.3	459	28.3
	All crops	2,623	19.2	1,284	25.2	3,907	21.2
Stafford County,	Corn	1,290	16.2	97	31.6	1,387	17.3
Kansas	Hay	590	15.1	155	19.7	745	16.1
	Sorghum	1,080	14.1	86	15.4	1,166	14.2
	Grain	0	---	155	12.3	155	12.3
	Soybeans	389	17.0	72	34.7	461	19.7
	Mixed	130	8.7	110	13.9	240	11.1
	All crops	3,479	15.2	675	19.8	4,154	15.9

Table 2.--*Crop acreage and ground-water application for sites sampled in the High Plains during the 1980 growing season*--Continued

Area	Crop	Irrigation-system type					
		Sprinkler		Flood		Both	
		Acres	Appl	Acres	Appl	Acres	Appl
Blaine County,	Corn	2,642	15.2	90	18.3	2,732	15.4
Nebraska	Hay	1,053	13.7	0	---	1,053	13.7
	Mixed	1,355	16.4	90	8.5	1,445	15.9
	All crops	5,050	15.2	180	13.4	5,230	15.1
Kimball County,	Corn	276	14.1	81	17.9	357	15.0
Nebraska	Hay	417	15.6	87	29.6	504	18.1
	Dry beans	686	8.7	59	15.2	745	9.2
	Grain	191	7.3	15	28.7	206	8.8
	All crops	1,570	11.3	242	22.1	1,812	12.8
York County,	Corn	1,368	9.7	2,474	16.6	3,842	14.1
Nebraska	Hay	30	5.6	0	---	30	5.6
	Sorghum	272	4.5	102	9.8	374	6.0
	Grain	30	.9	0	---	30	.9
	Soybeans	171	3.0	221	9.6	392	7.6
	Mixed	0	---	82	6.3	82	6.3
	All crops	1,871	8.4	2,879	15.5	4,750	12.7

Table 2.--*Crop acreage and ground-water application for sites sampled in the High Plains during the 1980 growing season*--Continued

Area	Crop	Irrigation-system type					
		Sprinkler		Flood		Both	
		Acres	Appl	Acres	Appl	Acres	Appl
Curry County,	Corn	486	25.3	340	29.7	826	27.1
New Mexico	Grain	1,231	10.2	248	14.5	1,479	10.9
	Sorghum	256	10.5	320	10.4	576	10.4
	Cotton	0	---	65	18.8	65	18.8
	Sugar beets	126	28.1	40	31.2	166	28.8
	Mixed	500	13.3	0	---	500	13.3
	All crops	2,599	14.5	1,013	19.2	3,612	15.8
Texas County,	Corn	0	---	296	37.1	290	37.1
Oklahoma	Hay	240	37.3	0	---	240	37.3
	Sorghum	210	8.6	0	---	210	8.6
	Mixed	0	---	35	47.1	35	47.1
	All crops	450	23.9	331	38.1	781	30.0
Hansford County,	Corn	0	---	300	58.9	300	58.9
Texas	Sorghum	0	---	899	20.3	899	20.3
	Mixed	0	---	100	40.8	100	40.8
	All crops	0	---	1,299	30.8	1,299	30.8

Table 2.--*Crop acreage and ground-water application for sites sampled in the High Plains during the 1980 growing season*--Continued

Area	Crop	Irrigation-system type					
		Sprinkler		Flood		Both	
		Acres	Appl	Acres	Appl	Acres	Appl
Hockley County,	Cotton	931	8.7	807	8.8	1,738	8.7
Texas	Hay	20	13.7	0	---	20	13.7
	All crops	951	8.8	807	8.8	1,758	8.8
Lamb County,	Corn	95	32.4	60	18.9	155	27.2
Texas	Cotton	296	8.3	1,009	16.8	1,305	14.9
	Mixed	0	---	547	23.5	547	23.5
	All crops	391	14.1	1,616	19.2	2,007	18.2
Parmer County,	Corn	554	27.9	2,536	31.7	3,090	31.0
Texas	Hay	306	33.3	0	---	306	33.3
	Sorghum	126	15.0	598	14.9	724	14.9
	Grain	270	16.1	250	35.2	520	25.2
	Cotton	268	11.1	474	11.8	742	11.6
	Dry beans	0	---	40	10.0	40	10.0
	Mixed	329	13.9	2,363	22.4	2,692	21.4
	All crops	1,853	21.3	6,261	25.1	8,114	24.2

Table 2.--*Crop acreage and ground-water application for sites sampled in the High Plains during the 1980 growing season*--Continued

Area	Crop	Irrigation-system type					
		Sprinkler		Flood		Both	
		Acres	Appl	Acres	Appl	Acres	Appl
Laramie County,	Corn	640	15.8	35	11.5	675	15.5
Wyoming	Hay	589	13.9	70	32.1	659	15.9
	Grain	862	8.6	0	---	862	8.6
	Mixed	690	14.0	5	34.5	695	14.2
	All crops	2,781	12.7	110	25.7	2,891	13.2
All areas	All crops	30,046	15.2	18,157	21.7	48,203	17.6

sorghum, grain, and cotton, as shown in table 2. Depths of application for flood-type irrigation systems are greater overall than the depths of application for sprinkler-type irrigation systems. Depths of application for many of the crops were less than expected considering the drought conditions throughout much of the High Plains during 1980. In some instances, the depth of application did not meet the irrigation requirement computed using crop consumptive-use formulas. This occurred in some areas where yields from irrigated crops were normal, indicating that the crops were not stressed adversely during the growing season. Further discussion of this trend and some possible causes are presented in the next section of this report.

The data indicate some distinct differences in the average discharge per well and the irrigated acreage per well for the various counties that were sampled (table 3). The average discharge per well for the counties that were sampled in the southern High Plains of New Mexico and Texas was significantly less than the average discharge per well for other counties in the High Plains. The corresponding acreages per well also had a similar but less pronounced trend. The predominance of crops requiring less water in the southern High Plains probably accounts for the less pronounced changes in acres per well between the northern and southern High Plains. The counties with smaller average discharges per well tend to be in areas where the saturated thickness of the aquifer is thin.

DATA EXTENSION

The primary goal of the 1980 sampling was to estimate the volume of ground water pumped for irrigation throughout the entire High Plains. Because of logistical constraints associated with sampling an area as large as the High Plains, the samples had to be clustered in relatively few areas. Climate, soils, crop distribution, and irrigation practices change significantly from one area to the next in the High Plains. Consequentely, a procedure had to be developed for extending data from sampling areas to other areas of the High Plains that would take these factors into account.

The method chosen to extend the sampled irrigation application to unsampled areas was based on the ratio between sampled application and calculated irrigation demand. Irrigation demand (estimated depth of irrigation water required by a crop during the growing season) was calculated for the major irrigated crops growing on the High Plains using the Blaney-Criddle formula (U.S. Department of Agriculture, 1967). Ratios developed for each crop in the sampled counties then were used to estimate application for unsampled areas. A weighted-average application then was calculated for each area. Proportions of various crops growing in the area were used as the weighting factors for individual crop application-demand ratios. Irrigation demand accounts for changes in climate and soils from one area to the next. Changes in crop distributions between areas were accounted for by estimating the proportions of crops grown in each county (Martinko and others, 1981). Differences in irrigation and cropping practices resulted in variations of application-demand ratios for individual crops growing in the various sampling areas.

Table 3.--*Average discharge and irrigated acreage for wells sampled in the High Plains during the 1980 growing season*

[Discharge in gallons per minute]

Location	Acres per well	Average discharge per well
Kit Carson County, Colorado	135	662
Yuma County, Colorado	158	1,002
Finney and Kearny Counties, Kansas	140	834
Stafford County, Kansas	119	802
Blaine County, Nebraska	125	806
Kimball County, Nebraska	120	600
York County, Nebraska	96	706
Curry County, New Mexico	109	400
Texas County, Oklahoma	130	751
Hansford County, Texas	108	811
Hockley County, Texas	61	188
Lamb County, Texas	108	396
Parmer County, Texas	78	456
Laramie County, Wyoming	126	685
All locations	108	625

Procedure

Extension of the application measured in sample areas to estimate the application in unsampled areas of the High Plains required the computation of the irrigation demand and determination of the distribution (proportions) of irrigated crops by area. Irrigation demand was calculated for areas with dimensions of 1-degree latitude by 1-degree longitude (1-degree cells) for the entire High Plains. The average distribution of irrigated crops, growing in each 1-degree cell was used to determine the proportion of each of the irrigated crops in the cell.

The Blaney-Criddle formula (U.S. Department of Agriculture, 1967) was used to compute the consumptive-use requirements for each irrigated crop for each 1-degree cell in the High Plains.

The formula is:

$$U = \sum_{i=1}^{n} (K_i F_i) , \qquad (1)$$

where

$K_i = (0.0173t - 0.314) \cdot (kc)$

$F_i = \frac{tp}{100}$,

and

U = seasonal consumptive use of the crop, in inches;

n = number of months in growing season of a particular crop;

i = index for month;

K_i = empirical consumptive-use crop coefficient for a given crop and month;

F_i = monthly consumptive-use factor;

t = monthly mean air temperature, in degrees Fahrenheit;

kc = a coefficient reflecting the growth stage of the crop; and

p = monthly percentage of daylight hours.

Irrigation demand is calculated from consumptive use using:

$$I = \sum_{i=1}^{n} (U_i - ep_i) , \qquad (2)$$

where

I = seasonal irrigation demand, in inches, for a particular crop;

n = number of months in growing season of a particular crop;

i = index for month;

U_i = monthly consumptive use of the crop, in inches; and

ep_i = monthly effective precipitation, in inches (total monthly precipitation that is available for use by the crop).

Values for the crop coefficient (kc) and the percentage of daylight hours (p) were interpreted from graphs and tables contained in a report by the U.S. Department of Agriculture (1967). Monthly mean air temperature (t) and precipitation for the 1980 growing season were compiled for 106 National Weather Service stations in the High Plains. Monthly effective precipitation (ep_i) was calculated using a formula contained in the same report (U.S. Department of Agriculture, 1967). Effective precipitation during the growing season is a function of total precipitation and the consumptive-use requirement of the crop. For this study, effective precipitation also included that part of non-growing-season precipitation that could be stored as soil moisture and then subsequently used by a crop during the growing season. The non-growing-season effective precipitation is a function of total precipitation, soil type, and the rooting depth of the crop. A more detailed discussion of the formulas and procedures used in the calculations is contained in Heimes and Luckey (1982).

Crop proportions for each 1-degree cell were determined primarily from 1980 agricultural statistics compiled by the Kansas Applied Remote Sensing Program as part of a contractual agreement with the U.S. Geological Survey (Mantinko and others, 1981). Irrigation demand and crop proportions for all areas of the High Plains for the 1980 growing season are shown in table 4.

Calculated irrigation demands were compared with the average applications for each of the irrigated crops for each sample area to establish a relationship between demand and application. For example, if in a particular sample area the average application for irrigated corn was 19.0 inches and the calculated irrigation demand for corn in the sample area was 16.0 inches, then the ratio of application to demand would be:

$$\text{Ratio} = \text{application/demand} = 19.0/16.0 = 1.19.$$

Ratios were calculated for each of the 14 sampling areas where adequate crop data were available. The ratios were examined for significant differences from area to area for individual crops. The ratios for corn, hay, and grain had significant differences from area to area. The other five crops did not have any significant difference in ratios among sampling areas. The ratios for corn, hay, and grain could be grouped into three zones by latitude: 31° to 35°; 35° to 39°; and 39° to 43° (table 5). The ratios for corn, hay, and grain were computed by averaging the data from the sample areas located in each of the latitude zones. The ratios for each of the other crops were computed as a single value for all latitude zones by averaging the ratios from all of the sample areas.

Many of the ratios shown in table 5 are less than 1, indicating that the quantity of water applied was less than the irrigation demand. Two factors may account for these small ratios. First, the irrigation demand represents the

Table 4.--*Calculated irrigation demands and crop proportions during 1980 for 1-degree cells located in the High Plains*

[Lat long = location of 1-degree cells, expressed as the southeast corner of the cell; P = proportions of irrigated crops growing in a 1-degree cell, expressed as a percentage; D = the irrigation demand, expressed in inches]

Location		Crops															
		Corn		Cotton		Dry beans		Grain		Hay		Sorghum		Soybeans		Sugar beets	
Lat	Long	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D
31	101	0	18.9	95	11.2	0	19.8	0	14.3	0	38.5	5	15.0	0	10.2	0	25.1
31	102	0	21.0	85	12.5	0	20.5	0	15.8	5	41.0	10	15.4	0	11.9	0	28.2
32	101	0	18.8	95	11.3	0	19.4	0	13.3	0	36.8	5	15.0	0	10.3	0	24.9
32	102	0	22.6	85	14.0	0	20.8	0	13.9	5	40.4	10	16.4	0	12.8	0	24.8
32	103	5	22.5	30	14.1	0	21.0	25	11.8	30	37.5	10	16.8	0	13.2	0	29.2
33	100	0	23.4	85	14.4	0	20.9	0	9.5	0	38.9	15	18.3	0	14.6	0	30.6
33	101	0	23.2	85	15.3	0	20.8	0	11.4	0	39.4	15	18.1	0	14.6	0	30.3
33	102	0	21.3	75	13.2	0	18.8	3	10.7	0	35.6	22	15.7	0	12.6	0	27.7
33	103	5	23.3	15	15.2	0	19.8	25	13.0	20	38.2	35	17.6	0	13.7	0	30.2
34	100	0	22.8	40	14.5	0	20.2	15	8.4	15	36.7	30	18.1	0	14.4	0	29.1
34	101	5	21.0	35	12.9	0	18.9	15	8.7	0	33.9	40	16.3	5	12.8	0	27.1
34	102	35	22.3	20	14.4	0	18.8	15	9.6	5	35.3	25	16.9	0	13.3	0	28.6
34	103	20	21.1	5	13.3	0	18.3	35	10.8	10	34.4	30	15.9	0	12.0	0	27.6
34	104	20	19.9	5	12.1	0	17.3	35	11.1	10	32.8	30	14.7	0	11.0	0	26.2
35	99	0	27.7	0	19.1	0	23.8	20	9.1	50	40.8	30	23.2	0	18.9	0	34.2
35	100	0	26.7	0	18.2	0	22.9	45	10.2	15	40.9	40	22.0	0	17.9	0	33.7
35	101	10	21.9	0	14.4	0	18.7	45	9.7	0	34.6	45	17.6	0	14.2	0	28.4
35	102	18	20.1	0	12.5	0	17.6	40	8.4	2	31.2	40	15.7	0	12.5	0	25.7
35	103	30	21.8	0	13.9	0	18.9	30	11.0	25	34.5	15	17.1	0	13.8	0	28.3
36	99	5	24.5	0	16.3	0	21.0	10	6.3	65	33.1	20	20.1	0	15.8	0	30.1
36	100	5	24.9	0	16.6	0	20.6	35	9.3	15	35.5	45	19.0	0	15.7	0	30.7
36	101	20	22.3	0	15.1	0	19.0	40	9.1	0	33.3	40	18.1	0	14.3	0	28.1
36	102	25	21.7	0	14.4	0	18.2	20	9.7	5	31.0	50	17.3	0	13.9	0	27.3
36	103	30	19.0	0	17.8	0	16.2	30	7.8	25	27.5	15	15.4	0	12.5	0	24.8
37	97	50	25.4	0	15.4	0	21.4	10	9.2	20	35.1	16	20.1	4	14.5	0	31.6

Table 4.--*Calculated irrigation demands and crop proportions during 1980 for 1-degree cells located in the High Plains*--Continued

Location		Corn		Cotton		Dry beans		Grain		Hay		Sorghum		Soybeans		Sugar beets	
Lat	Long	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D
37	98	50	23.2	0	14.3	0	19.2	10	9.1	20	32.3	16	18.3	4	13.5	0	29.2
37	99	45	22.1	0	14.7	0	18.8	20	8.0	15	31.1	20	17.8	0	13.6	0	27.8
37	100	55	23.0	0	15.6	0	19.7	25	8.5	0	31.4	20	18.9	0	14.5	0	28.3
37	101	35	21.3	0	14.4	0	18.4	30	8.5	0	29.6	35	17.4	0	13.3	0	26.4
37	102	30	19.4	0	12.7	2	16.4	28	8.6	10	26.9	30	15.5	0	12.3	0	24.5
37	103	30	19.3	0	12.8	2	16.6	28	8.4	10	27.1	30	15.6	0	12.4	0	25.0
38	97	45	24.2	0	14.4	0	20.3	8	11.0	5	34.0	35	19.0	7	13.7	0	30.4
38	98	55	22.6	0	13.8	0	18.9	5	11.7	10	33.1	27	17.6	3	12.7	0	28.9
38	99	50	21.2	0	13.9	0	18.3	15	8.4	10	28.9	20	17.3	5	12.6	0	26.5
38	100	55	21.2	0	13.7	0	18.6	20	8.5	5	28.4	20	17.3	0	12.5	0	26.5
38	101	60	17.4	0	11.0	0	15.3	20	6.2	5	22.4	15	14.2	0	9.9	0	22.1
38	102	65	17.2	0	11.4	5	15.4	15	6.9	10	23.7	5	14.1	0	10.4	0	21.9
39	99	80	19.2	0	11.5	0	18.0	2	8.3	8	28.1	10	15.6	0	11.0	0	24.7
39	100	75	19.4	0	11.9	0	17.7	3	9.8	7	27.4	15	15.7	0	11.3	0	29.1
39	101	75	12.8	0	6.8	0	11.4	9	8.3	7	18.5	9	9.6	0	6.8	0	17.4
39	102	70	17.3	0	10.7	7	15.3	13	8.7	8	24.2	2	13.9	0	10.3	0	22.2
39	103	65	13.6	0	8.0	0	12.7	5	6.6	30	19.1	0	10.9	0	8.2	0	17.9
40	96	82	15.3	0	7.7	0	14.1	0	9.2	1	24.0	12	11.6	5	8.2	0	20.6
40	97	82	17.2	0	9.3	0	15.0	0	10.9	1	25.0	12	13.1	5	9.7	0	22.7
40	98	90	16.4	0	8.9	0	14.9	0	9.5	3	23.9	5	12.8	2	9.5	0	21.7
40	99	92	16.6	0	9.3	0	15.3	0	10.3	6	24.4	2	13.0	0	9.7	0	21.9
40	100	93	14.9	0	8.4	0	13.7	0	10.2	5	23.0	2	11.9	0	8.8	0	20.3
40	101	88	15.0	0	8.5	0	13.1	3	10.4	8	21.4	1	11.5	0	8.7	0	20.1
40	102	75	16.6	0	10.1	8	14.7	4	10.2	8	22.5	5	13.3	0	10.4	0	21.4
40	103	65	12.8	0	6.9	0	11.9	5	9.4	30	19.3	0	9.9	0	7.7	0	17.4

Table 4.--*Calculated irrigation demands and crop proportions during 1980 for 1-degree cells located in the High Plains*--Continued

Location		Corn		Cotton		Dry beans		Grain		Hay		Sorghum		Soybeans		Sugar beets	
Lat	Long	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D
40	104	50	15.3	0	9.5	10	14.1	10	10.4	30	20.5	0	12.6	0	10.3	0	19.7
41	96	80	15.1	0	8.3	0	13.8	0	8.8	8	23.6	12	11.6	0	8.0	0	20.3
41	97	85	13.0	0	6.0	0	11.8	0	9.7	4	21.4	3	9.4	8	7.2	0	18.2
41	98	85	16.6	0	9.1	0	14.9	2	10.6	10	24.0	2	12.6	1	10.2	0	21.9
41	99	80	18.1	0	10.7	0	16.4	0	11.5	19	25.0	1	14.6	0	11.6	0	23.6
41	100	75	15.3	0	8.5	0	14.4	0	10.5	23	21.9	2	12.2	0	9.6	0	20.6
41	101	60	15.3	0	8.8	0	14.4	0	10.1	40	21.6	0	12.3	0	9.7	0	20.3
41	102	55	14.1	0	8.3	0	13.4	10	8.6	35	20.0	0	11.6	0	9.3	0	18.4
41	103	45	15.8	0	9.7	0	14.8	10	9.9	45	20.7	0	13.0	0	10.6	0	20.6
41	104	20	13.1	0	7.8	0	12.8	15	9.7	65	17.2	0	11.0	0	9.2	0	17.4
41	105	20	13.7	0	8.5	0	13.2	15	9.7	65	15.4	0	11.6	0	9.9	0	18.0
42	96	83	15.4	0	8.1	0	14.4	0	11.8	7	24.5	10	11.8	0	9.5	0	20.7
42	97	85	11.8	0	4.8	0	12.5	0	10.4	8	20.5	7	8.5	0	6.5	0	16.8
42	98	92	12.3	0	5.7	0	12.8	0	10.8	8	20.7	0	9.1	0	7.2	0	17.5
42	99	85	12.5	0	6.2	0	12.9	0	9.9	15	19.9	0	9.7	0	7.8	0	17.2
42	100	55	12.2	0	6.0	0	12.6	3	9.7	42	19.1	0	9.6	0	7.7	0	16.9
42	101	55	11.9	0	5.9	0	12.2	3	9.0	42	18.9	0	9.1	0	7.3	0	16.9
42	102	50	14.6	0	8.8	0	13.3	5	10.6	45	21.8	0	11.8	0	9.8	0	20.3
42	103	35	14.6	0	8.8	0	13.7	10	10.9	55	20.6	0	12.2	0	10.3	0	19.3
42	104	15	14.4	0	8.8	0	14.2	15	11.1	70	19.5	0	12.4	0	10.6	0	19.1
42	105	15	15.6	0	10.1	0	14.5	15	10.7	70	18.6	0	13.5	0	11.3	0	21.0
43	99	45	12.9	0	6.3	0	13.2	15	11.7	40	21.7	0	9.5	0	7.8	0	18.6
43	100	45	14.0	0	7.5	0	13.7	15	10.7	40	22.1	0	10.7	0	8.9	0	19.6
43	101	60	14.7	0	8.5	0	13.2	0	10.5	40	22.3	0	10.8	0	9.1	0	20.4
43	102	50	17.7	0	10.9	0	15.5	0	13.1	50	25.5	0	13.9	0	11.4	0	23.8
43	104	15	14.6	0	9.4	0	14.0	15	11.5	70	21.5	0	12.6	0	10.7	0	20.0

Table 5.--*Ratios of sampled pumpage to computed irrigation demand for irrigated crops grown on the High Plains during 1980*

Crop	Location by latitude range		
	31° to 35°	35° to 39°	39° to 43°
Corn	1.36	1.14	0.97
Cotton	.84	1/	1/
Dry Beans	.62	.62	.62
Grain	1.47	1.31	.87
Hay	.90	.65	.77
Sorghum	.85	.85	.85
Soybeans	1.15	1.15	1.15
Sugar beets	1.04	1.04	1.04

1/ Crop not grown in this latitude range.

amount of water required to maximize crop yield. However, as applied water increases and approaches irrigation demand, the crop yield increases only slightly (Hexem and Heady, 1978, p. 10). Hence to maximize profits rather than yield, an irrigator may apply less water than the irrigation demand if the marginal cost of the water exceeds the marginal worth of the crop. Additionally, some crops, especially cotton and sorghum, are drought tolerant and can be stressed at certain periods without greatly affecting the yield. Second, crop varieties have changed significantly in recent years and the crop growth factors (kc) used in the Blaney-Criddle calculations now may need to be re-examined.

The ratios developed between the application in the sample areas and calculated irrigation demand provided a means for estimating application in unsampled areas of the High Plains. Estimates of application for each 1-degree cell were calculated for each of the crops growing in the cell by multiplying the crop-irrigation demand by the appropriate ratio. The proportions of crops growing in the 1-degree cell were used to compute a weighted-average application for the cell. For example, if the following conditions existed in a given 1-degree cell:

Irrigated crop	Proportion	Ratio	Irrigation demand (inches)
Corn	0.80	1.14	17.4
Sorghum	.10	.85	14.2
Hay	.10	.65	22.4

the weighted-average application estimate, in inches, for the 1-degree cell would be:

$$(0.80 \times 1.14 \times 17.4) + (0.10 \times 0.85 \times 14.2) + (0.10 \times 0.65 \times 22.4) = 18.5.$$

Estimates of weighted-average applications for the 1980 growing season were made for all 1-degree cells in the High Plains region (table 6).

Regional Pumpage Estimates

Weighted-average application estimates for the 1980 growing season are based on climatic conditions and the distribution of irrigated crops in the area delimited by the 1-degree cell. Estimates for 1-degree cells include only the area of the cell within the High Plains. Considerable variation in crop distribution and application can be expected to occur in any given 1-degree cell because of the large area of the cell. However, estimating application for areas smaller than 1-degree cells is not justified with only 15 sample areas. Additionally, information on the distribution of irrigated crops is readily available only at the county or regional level.

To estimate the volume of ground water pumped for irrigation, the weighted-average applications for the 1-degree cells were combined with estimates of irrigated acreage. Irrigated acreage for the 1980 growing season was compiled using Landsat-satellite imagery. Analysis of Landsat imagery to map irrigated acreage was conducted by personnel of the U.S. Geological Survey at Moffett Field, California. Fifty-six Landsat scenes encompassing all areas of the High Plains were analyzed to map irrigated cropland. The central and southern High Plains required several Landsat scenes at different times during the growing season to provide complete maps of irrigated acreage because of the long growing season and the variability in growing season for individual crops. Computer analysis of the Landsat data was performed to separate irrigated cropland from other land-cover categories. For areas where irrigated-cropland data were compiled for several dates, these data were merged to provide a complete map of irrigated acreage for the growing season. Estimates of irrigated acreage, derived from the computer classification of Landsat data, subsequently were aggregated into cells of 1-minute of latitude by 1-minute of longitude (1-minute cells). This aggregation made the irrigated-acreage data compatible with other hydrologic and geologic data compiled for the High Plains study. Data for the 1-minute cells were aggregated to estimate irrigated acreage for the 1-degree cells.

Table 6.--*Estimated application of ground water for irrigation on the High Plains during the 1980 growing season*

[Location coordinates define the southeast corner cell of 1-degree latitude by 1-degree longitude; application is average inches of applied irrigation water for each 1-degree cell]

Location	Application	Location	Application	Location	Application
31 101	9.6	37 99	19.5	41 97	12.6
31 102	12.1	37 100	20.4	41 98	16.4
32 101	9.6	37 101	17.0	41 99	17.8
32 102	13.2	37 102	15.7	41 100	15.2
32 103	21.0	37 103	15.6	41 101	15.6
33 100	12.6	38 97	21.4	41 102	13.7
33 101	13.2	38 98	21.3	41 103	14.9
33 102	11.7	38 99	19.3	41 104	12.4
33 103	20.4	38 100	19.4	41 105	11.6
34 100	16.3	38 101	16.1	42 96	14.7
34 101	13.2	38 102	16.7	42 97	11.5
34 102	20.3	39 99	16.8	42 98	12.2
34 103	19.0	39 100	17.8	42 99	12.6
34 104	18.3	39 101	11.7	42 100	12.9
35 99	21.6	39 102	15.1	42 101	12.7
35 100	17.5	39 103	13.1	42 102	15.1
35 101	14.9	40 96	14.0	42 103	14.6
35 102	14.3	40 97	15.8	42 104	15.1
35 103	19.7	40 98	15.6	42 105	13.7
36 99	19.6	40 99	16.2	43 99	13.8
36 100	16.4	40 100	14.5	43 100	14.3
36 101	16.0	40 101	14.5	43 101	15.4
36 102	17.1	40 102	15.5	43 102	18.4
36 103	16.0	40 103	12.9	43 104	15.2
37 97	23.6	40 104	13.9		
37 98	21.7	41 96	14.4		

Mapping 1980 irrigated acreage in some areas of the southern High Plains was difficult. The analysis of Landsat data separated irrigated cropland from other land-cover categories principally by the characteristic reflectance of the lush growing vegetation associated with irrigated crops. However, in some areas of the southern High Plains, especially in parts of Texas, where ground-water availability is limited, stress-resistent crops such as cotton and sorghum may only be supplementally irrigated to protect against loss of yield during droughts. Therefore, during periods of adequate precipitation, these crops would not be receiving irrigation water and would have reflectances similar to their dryland counterparts. Because of the irrigation and cropping patterns in these areas, it was difficult to reliably separate irrigated crops from dryland crops. Consequently, the estimated irrigated acreage, compiled from Landsat imagery, for Texas and possibly New Mexico may be slightly less than the actual acreage irrigated. Underestimates of irrigated acreage would result in underestimates of water use for these States.

The volume of ground water pumped for irrigation is computed by multiplying the application by acreage irrigated. The volume of ground water pumped for irrigation was estimated for each 1-degree cell, and these estimates were aggregated to provide estimates by State. The estimated volume of ground water pumped for irrigation in the High Plains of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming is summarized in table 7. The estimated total volume pumped during 1980 in the High Plains was 17,817,000 acre-feet applied to 13,385,000 acres. Three States, Kansas, Nebraska, and Texas, accounted for about 88 percent of this pumpage. Texas, which accounts for 20 percent of the area in the High Plains and 29 percent of total pumpage, was the most densely developed area. South Dakota, which accounts for 2.7 percent of the area, but only 0.1 percent of the pumpage, virtually was undeveloped.

SUMMARY AND CONCLUSIONS

The objective of this study was to estimate the volume of ground water pumped for irrigation on the High Plains during the 1980 growing season. To accomplish this, ground-water application was sampled at selected locations on the High Plains. A total of 480 sites, located in 15 counties, were monitored for discharge, time of operation, crop type, and crop acreage during the 1980 growing season. Of these 480 sites, 374 provided usable data on ground water pumped for irrigation, representing 78 percent data recovery. An unusually large failure rate of VTT units used in monitoring time of operation of pumps and an extended drought throughout large areas of the High Plains were the primary reasons for the loss of data from 106 sites.

Applied irrigation water measured at sample sites was related to calculated irrigation demand (Blaney-Criddle), and the relationship was used to estimate the depth of applied irrigation water for unsampled areas of the High Plains. Estimates of the depth of applied irrigation water were combined with irrigated acreage, mapped using Landsat data, to calculate the total volume of irrigation water pumped for 1-degree cells located in the High Plains. The

Table 7.--*Estimated irrigated acreage and volume of ground-water pumped for irrigation in areas of the High Plains during the 1980 growing season*

State	Area of High Plains aquifer within State (square miles)	Irrigated acreage during 1980 (acres)1/	Volume of ground-water pumped (acre-feet)1/
Colorado	14,900	767,000	985,000
Kansas	30,500	2,795,000	4,215,000
Nebraska	63,650	5,101,000	6,240,000
New Mexico	9,450	325,000	519,000
Oklahoma	7,350	389,000	540,000
South Dakota	4,750	20,000	24,000
Texas	35,450	3,878,000	5,169,000
Wyoming	8,000	110,000	125,000
TOTAL	174,050	13,385,000	17,817,000

1/Values rounded to nearest thousand.

estimated total volume of water pumped in the High Plains during 1980 was 17,817,000 acre-feet applied to 13,385,000 acres. Three States, Kansas, Nebraska, and Texas, accounted for 88 percent of this pumpage. Texas was the most densely developed area for irrigation, while South Dakota virtually was undeveloped. Analysis of Landsat imagery generally provided accurate identification of irrigated acreage with the exception of some areas in the southern High Plains. In these areas of limited water availability, and hence limited irrigation, it was difficult to separate irrigated and dryland cropland using Landsat imagery. As a result, irrigated acreage may have been underestimated for these areas, which would produce a comparable underestimate in the volume of water pumped.

In addition to being used for estimating ground water pumped for irrigation, sampled applications were used to evaluate significant irrigation trends in the High Plains. The random sample indicated a distribution of crops similar to distributions reported for sample areas, indicating that the sample adequately represented the irrigated crops growing in the counties that were sampled. Irrigation application from the sample data had expected trends with relatively greater applications for corn and hay and lesser applications for sorghum, grain, and cotton. Flood-irrigation systems tended to apply larger quantities of water for any given crop than did sprinkler-irrigation systems. Discharge and acreage irrigated from sampled wells in areas where the aquifer has thin saturated thickness (primarily New Mexico and Texas) tended to be less than the discharge and acreage from sampled wells in areas of thicker saturated thickness.

The sampling approach used to estimate ground-water withdrawals for irrigation during 1980 provided current information on water use that was not available from other sources. Reported information on current water use was only available for small parts of the High Plains, and the methods used to estimate water use varied considerably from one area to the next. The sampling approach used in this study provided a consistent set of data on ground-water withdrawals for irrigation for all areas of the High Plains; it was based on actual measurements of water applied, instead of empirically derived estimates. Results obtained from the sampling program indicated that for many of the irrigated crops grown on the High Plains, estimates of applied water calculated using the Blaney-Criddle consumptive-use formula are significantly larger than the actual applied water.

Irrigation techniques, crop varieties, and cropping practices are changing rapidly in response to increased irrigation costs, and, in some areas, decreased availability of water. This means that some form of physical measurement of applied water is necessary to provide reliable estimates of water use. The sampling technique used in this study represents one approach to provide current data based on physical measurements.

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