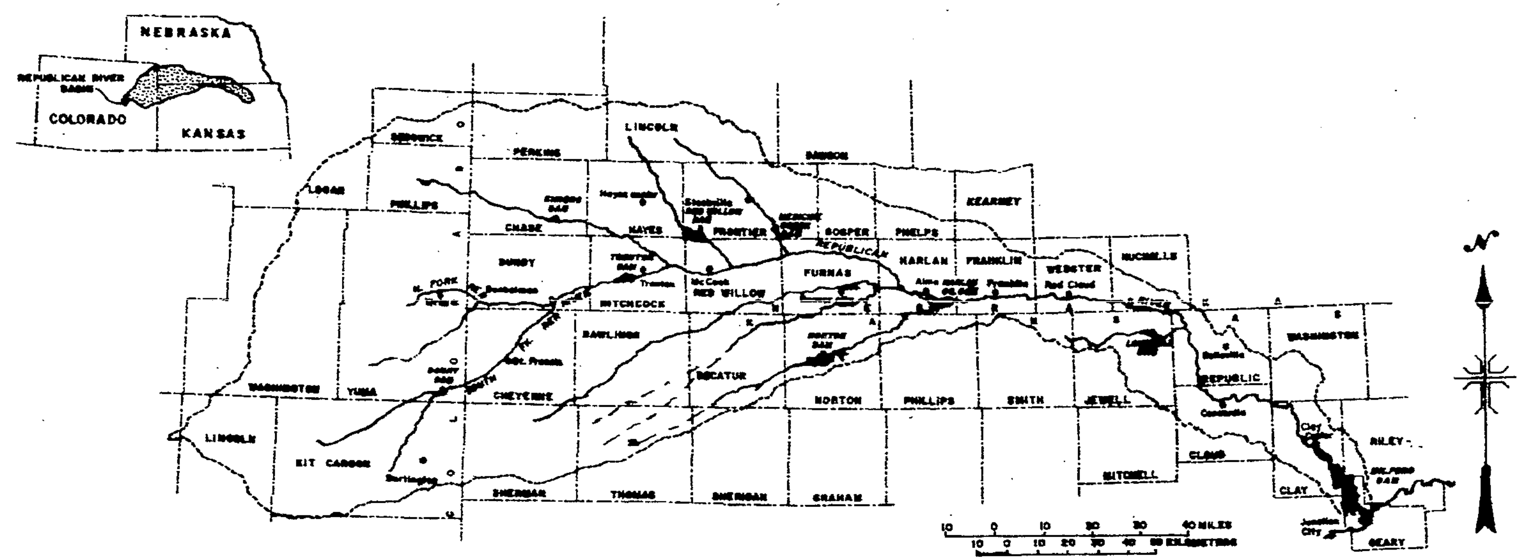
Special Report

Republican River Basin Water Management Study

Colorado, Nebraska, Kansas

February 1985

Department of the Interior
Bureau of Reclamation



REPUBLICAN RIVER BASIN

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- Assessment of Changes in Precipitation Regime of the Republican River Basin (Kansas State University, January 1983)

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- Reservoir Analysis Final Working Paper, Republican River (Fish and Wildlife Service, June 1982)
- Evaluation of Existing Use of Fish and Wildlife Resources, Final Working Paper, Republican River Basin (Fish and Wildlife Service, August 1983)
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ECONOMIC AND SOCIAL ASSESSMENT - Volume 7

- Socioeconomic Conditions
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Electrical Terms and Factors for Converting
English Units to Metric Units

(International System, SI, units)

Electrical Terms

1 kilovolt	equals	1 thousand volts
1 kilowatt	equals	1 thousand watts
1 megawatt	equals	1 million watts
1 gigawatt	equals	1 billion watts

Factors for Converting English Units to Metric Units

Multiply English units	by	To obtain metric units
	Length	
inch (in)	* 2.54	centimeter (cm)
	*25.4	millimeter (mm)
	* 0.0254	meter (m)
foot (ft)	* 0.3048	meter (m)
yard (yd)	* 0.9144	meter (m)
rod	* 5.0292	meter (m)
mile (mi)	* 1.609344	kilometer (km)
	Area	
acre	4.04686×10^3	1/ square meter (m^2)
	0.404686	hectare (ha)
	0.404686	square hectometer (hm^2)
	0.004047	square kilometer (km^2)
square mile (mi^2)	2.589988	square kilometer (km^2)
	Volume	
gallon (gal)	3.785412	2/ liter (l)
	3.785412	cubic decimeter (dm^3)
	3.785412×10^{-3}	cubic meter (m^3)
million gallons (10^6 gal)	3.785412×10^3	cubic meter (m^3)
	3.785412×10^{-3}	cubic hectometer (hm^3)
cubic foot (ft^3)	28.31685	cubic decimeter (dm^3)
	2.831685×10^{-2}	cubic meter (m^3)
cubic foot per second-day (ft^3/s-day)	2.446576×10^3	cubic meter (m^3)
	2.446576×10^{-3}	cubic hectometer (hm^3)
acre-foot (acre-ft)	1.233482×10^3	cubic meter (m^3)
	1.233482×10^{-3}	cubic hectometer (hm^3)
	1.233482×10^{-6}	cubic kilometer (km^3)
	0.123348	3/ hectare-meter (ha.m)

Multiply English units	by	To obtain metric units
	Flow	
cubic foot per second (ft^3/s)	28.31685	liter per second (l/s)
	28.31685	cubic decimeter per second (dm^3/s)
	2.831685×10^{-2}	cubic meter per second (m^3/s)
gallon per minute (gpm)	6.309020×10^{-2}	liter per second (l/s)
	6.309020×10^{-2}	cubic decimeter per second (dm^3/s)
	6.309020×10^{-5}	cubic meter per second (m^3/s)
million gallons per day (mgd)	43.81264	cubic decimeter per second (dm^3/s)
	4.381264×10^{-2}	cubic meter per second (m^3/s)
4/cubic foot per square foot per day (ft^3/ft^2d)	3.527778×10^{-6}	cubic meter per square meter per second (m^3/m^2s)
	Velocity-Speed	
mile per hour (mi/h)	4.470400×10^{-1}	meter per second (m/s)
	Mass	
ton (short)	9.071847×10^{2}	kilogram (kg)
	0.907185	tonne (t)
	Temperature	
degrees Fahrenheit (°F)	$(°F-32)\frac{5}{9}$	degrees Celsius (°C)
degrees Celsius (°C)	$(°C \times 1.8)+32$	degrees Fahrenheit (°F)

1/The unit hectare is approved for use with the International System (SI) for a limited time.
2/The unit liter is accepted for use with the International System (SI).
3/The unit hectare-meter (ha·m) is not approved for use with the International System (SI) at the present time.
4/Hydraulic conductivity-permeability.

CHAPTER I--INTRODUCTION

The Republican River is located along the Kansas-Nebraska border and drains portions of three states. The drainage area is approximately 24,900 square miles, of which 7,700 square miles are in Colorado, 9,700 square miles are in Nebraska, and 7,500 square miles are in Kansas. The river is formed by the junction of the Arikaree and North Fork Republican Rivers near Haigler, Nebraska. From Haigler, the river flows in an easterly direction to Junction City, Kansas, where it joins the Smoky Hill River to form the Kansas River. The watershed has an approximate length of 430 miles. The principal tributaries downstream from the confluence of the Arikaree and North Fork Republican Rivers are South Fork Republican River and Frenchman, Blackwood, Driftwood, Red Willow, Medicine, Sappa, Prairie Dog, and White Rock Creeks.

Four Reclamation (Bureau of Reclamation) water resource development divisions of the P-SMBP (Pick-Sloan Missouri Basin Program) are included in the study area. These include the Upper Republican, Frenchman-Cambridge, Kanaska, and Bostwick Divisions. The Upper Republican Division contains Bonny Dam and Reservoir, which is operated and maintained primarily for flood control. The State of Colorado purchased the conservation space in Bonny Reservoir for fish, wildlife, and recreation use. The other divisions primarily supply irrigation water.

The Frenchman-Cambridge Division includes the Frenchman Valley, H&RW, and Frenchman-Cambridge Irrigation Districts serving approximately 64,600 acres of irrigated land. Water supply and recreation are provided from four major reservoirs. The Kanaska Division includes the Almena Irrigation District, which includes approximately 5,200 irrigated acres with a water supply from Keith Sebelius Lake and ground-water wells. The Bostwick Division serves approximately 53,400 irrigated acres and includes the Bostwick Irrigation District in Nebraska and the Kansas-Bostwick Irrigation District. Water is supplied by Harlan County Lake and Lovewell Reservoir. The potential Scandia Unit, Kansas would also be included in the Bostwick Division.

The surface water area of the basin is nearly 41,000 acres. Over 40,000 acres are contained in reservoirs larger than 40 surface acres. Major reservoirs include Bonny (Colorado); Swanson Lake, Enders, Hugh Butler Lake, Harry Strunk Lake (Nebraska); Keith Sebelius Lake (Kansas); Harlan County Lake (Nebraska); and Lovewell Reservoir and Milford Lake (Kansas). All the reservoirs are Reclamation facilities, except Harlan County and Milford Lakes, which are Corps of Engineers facilities. Several of these reservoirs have experienced extreme water level fluctuations and long-term surface area declines in the past several years.

This report summarizes reconnaissance level investigations initiated in October 1977 in the Republican River Basin.

STUDY PERIOD

The surface water operations study period is 1949 to 1978. This period was selected due to availability of existing information. Comprehensive weather data for the entire basin is not available earlier than 1949. This study period appears adequate because it begins in an average year, contains a drought and a wet period, and ends in an average year.

PURPOSE AND GOALS

The purpose of this water management study was to identify existing and future uses of the limited water supply and associated land and environmental resources throughout the basin to determine ways to efficiently use the remaining available water.

Basic goals of the study were:

1. Identify water resource problems and water needs in the basin. These included multiple water uses such as municipal and industrial, irrigation, flood control, recreational, fish and wildlife, water quality, and environmental needs.

2. Define the causes of the declining water supplies for the existing reservoirs.

3. Define future water supply capability in the basin.

4. Develop alternative management plans, including both structural and nonstructural solutions, for the most effective use of present and projected water resources.

Investigations of structural methods to optimize water supplies considered canal automation, transbasin diversions, and canal and lateral lining.

Nonstructural conservation methods involved changes in reservoir operation, selective removal of streambank vegetation, and changes in irrigation techniques. Effects of no further well development and advances in farm conservation, tillage, and crop rotation practices, as well as possible precipitation changes were evaluated. Aerial photographic surveys were used to inventory land use and water resources.

5. Evaluate and document the economic, social, and environmental impacts associated with these alternative management plans.

AUTHORITY

The Republican River Basin Water Management Study was proposed by Reclamation because surface water supplies for existing projects within the upper portion of the basin have decreased within the last 10 years, while a demand for further development exists in the lower portion of the basin. The study was authorized by the Federal Reclamation Laws (Act of June 17, 1902, Stat. 388) and all Acts amendatory and supplementary thereto. The study was initially funded in fiscal year 1978 by Public Law 95-96 dated August 7, 1977.

PREVIOUS INVESTIGATIONS

Previous investigations conducted by Reclamation in the Republican River Basin include:

1946, June	Frenchman-Cambridge Unit, Comprehensive Plan
1951, February	Frenchman-Cambridge Division, Definite Plan Report
1953, June	Bostwick Division, Nebraska-Kansas, Definite Plan Report, Part 1
1954, April	St. Francis Unit (now Armel Unit), Definite Plan Report
1956, April	Bostwick Division, Nebraska-Kansas, Definite Plan Report, Part 2
1957, April	Almena Unit, Kansas, Definite Plan Report
1957, October	Red Willow Dam and Reservoir and Associated Works, Feasibility
1959, February	Nelson Buck Unit, Reconnaissance
1964, March	North Republican Unit, Concluding Report
1966, January	Phillipsburg-Smith Center Unit, Investigations Status Report (M&I water from Harlan County Dam, Bostwick Division)
1966, April	Scandia Unit, Kansas, Reconnaissance Report
1967, February	Nelson Buck Unit, Feasibility
1968, June	Scandia Diversion Damsite, Feasibility Geologic Report
1974, February	Colorado State Water Plan, Water for Tomorrow, Phase I
1974, April	Oberlin Unit, Appraisal
1974, August	Colorado State Water Plan, Legal and Institutional Considerations, Phase II
1974, October	Kansas State Water Plan Studies, Phase I
1976, December	Frenchman-Cambridge Irrigation District, Rehabilitation and Betterment Program
1977, January	Frenchman Unit, Appraisal Report
1977, March	Armel Unit, Concluding Report
1978, July	Frenchman Unit, Rehabilitation and Betterment Program, Concluding Report
1979, December	Kansas State Water Plan Studies, Phase II
1982, April	Courtland Unit, Bostwick Division, Kansas, Inventory of Remaining Subsurface Drainage Requirements, Special Report

PUBLIC INVOLVEMENT AND COORDINATION WITH PARTICIPATING AGENCIES

Public input information for this report is the same as that for the Solomon River Basin Water Management Study completed in 1984. The Solomon River Basin is an adjoining basin. The primary areas of concern in both basins are:

1. The causes of decline in the surface water supply.

2. The outlook for future water supplies for municipal, industrial, recreational, and fish and wildlife uses.

3. The alternatives available.

Local, state and Federal agencies have assisted Reclamation in addressing these concerns.

The Kansas State University, Department of Civil Engineering investigated changes in precipitation to determine potential impacts on watershed yield in the Republican River Basin.

The Colorado Division of Wildlife, Nebraska Game and Parks Commission, Kansas Fish and Game Commission, and Fish and Wildlife Service participated in the environmental assessment of the basin.

Study progress and interim results were presented to the Southwest Nebraska Irrigators Association and the Republican River Compact Administration. The membership of the Compact Administration consists of the State Engineer, Colorado; the Director, Department of Water Resources, Nebraska; and the Chief Engineer-Director, Division of Water Resources, State Board of Agriculture, Kansas. In addition, interim study results were reviewed by members of the Engineering Committee for the Compact Administration.

The Geological Survey made a reconnaissance hydrogeologic study, OF-81-531, of the Republican River Basin in Nebraska in July 1981. They completed a similar study, OF-82-79, of the Kansas portion of the basin in 1982.

The Bureau of Reclamation, with its ongoing responsibility for planning and operations, has maintained contacts with virtually all water-using entities in the basin. These contacts, either for this investigation or for other purposes, have led to an understanding of the basin's water-related problems and needs.

CHAPTER II--GENERAL DESCRIPTION

PHYSICAL CHARACTERISTICS

Topography and Drainage

The western three-fourths of the upper basin (figure 1) lies in the High Plains Section of the Great Plains Physiographic Province (Fenneman, 1931). This section is characterized by flat to gently rolling plains which are mildly dissected by the valleys of major streams. The eastern fourth of the upper basin lies within the Plains Border Section. In this section, dissection of the plains becomes more pronounced with steeper valley walls. The land surface slopes in an easterly direction from an elevation of 5650 feet near the headwaters of the Arikaree River to 2000 feet near Harlan County Dam with an average gradient of 14.5 feet/mile.

The uplands are dotted with many depressions ranging from a few feet to several thousand feet in diameter and depths from shallow to 40 feet. After a heavy rain, these depressions may retain water for weeks or months. The major topographic feature of the upper basin is the sandhills located in the northwest section. The sandhills are sand dunes that have been stabilized by a cover of grass. Local relief between dune troughs and crests ranges from 50 to 150 feet. During periods of high ground-water levels small lakes may form in the troughs of the dunes.

All of the lower basin (figure 2), except the portion southeast of Clay Center, Kansas, lies within the Border Section of the Great Plains Physiographic Province. This area is characterized by plateaus that are submaturely to maturely dissected (Fenneman, 1931). The area southeast of Clay Center lies in the Osage Plains Section of the Central Lowland Physiographic Province. This area has gently rolling uplands with entrenched streams. The lower Republican River valley in Nebraska is approximately 300 feet below the undissected uplands and in Kansas, it is 200-250 feet below the uplands. The Republican valley slopes in a southeasterly direction from an elevation of 2000 feet at Harlan County Dam to 1150 feet at Milford Dam with an average gradient of 5.2 feet/mile.

The drainage pattern of the Republican River Basin is dendritic, which is characterized by irregular branching of tributaries. This implies that the underlying strata is relatively flat, and there is a lack of structural controls such as faults and folds.

Soils

The soils of the Republican River Basin are very productive and are used primarily for growing both dryland and irrigated crops. The following is a general description of the major soil areas in the basin.

The alluvial soils along the Republican River and its tributaries are deep and lie on nearly level flood plains. The major portion of this group is well drained, but both poorly and excessively drained soils are common.

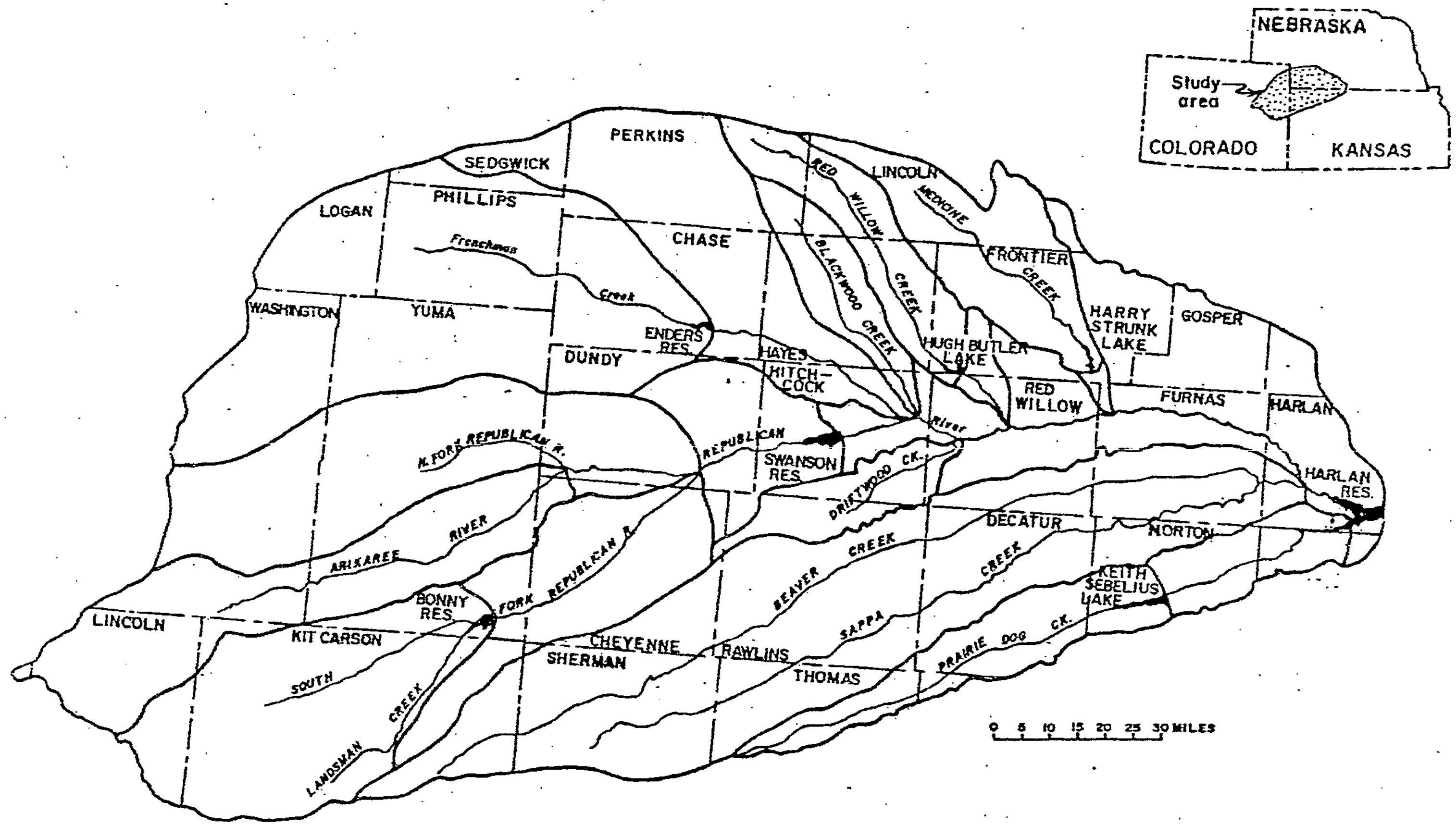


FIGURE 1 — Upper Republican River Basin divided into subbasins

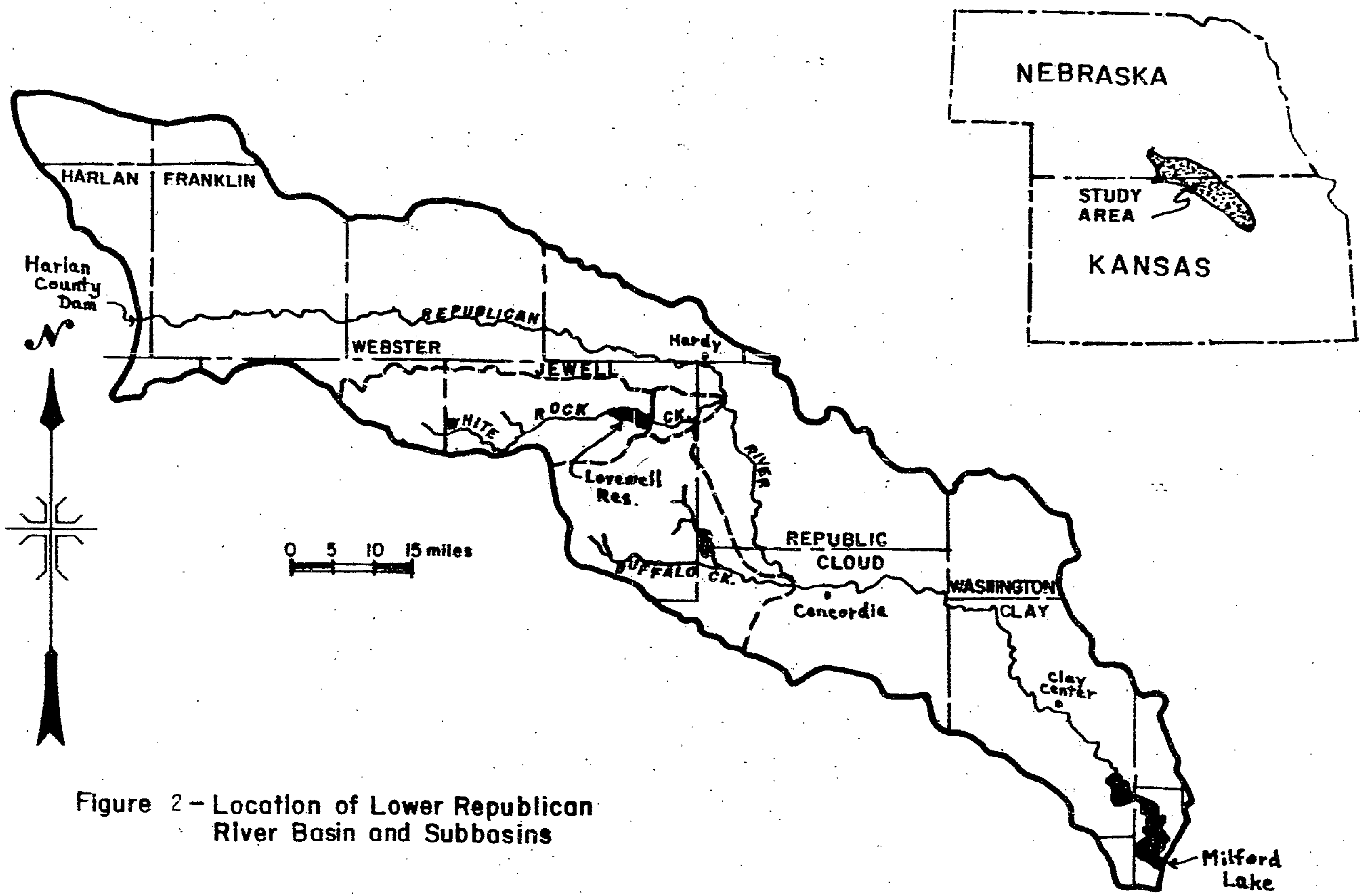


Figure 2 – Location of Lower Republican River Basin and Subbasins

Between the alluvial flood plains and the uplands are deep, near level to sloping well-drained soils formed in colluvial and eolian silts on terraces and footslopes. These soils are medium textured, but are generally more calcareous in their subsoils than are the soils on the uplands. Some moderately deep soils in this group occur in the western most portion of the basin as well as the north-central portion of the Kansas counties.

The loessial soils of the uplands are the most important both in areal extent and productivity. This group is comprised primarily of deep, nearly level to strongly sloping, well-drained silty soils. Generally, these soils are found in the eastern two-thirds of the Nebraska portion and to a smaller extent the northern portion of Kansas. Particularly in the Colorado portion and some of Perkins and Chase Counties of Nebraska are soils which contain dark fine-textured buried soils in their profiles.

Another important soils group includes the soils which are normally associated with the term "sandhills." These soils are generally deep, gently sloping to very steep, excessively drained, sandy soils formed in eolian sands on uplands. This group occupies two major areas: the first being Dundy County and the southwestern portion of Chase County and the second being Lincoln County, Nebraska, from Highway 83 west. Between these two sandhill areas is a group of soils which includes both deep and shallow, nearly level to gently sloping, well-drained loamy and silty soils formed in weathered sandstone and loess on uplands.

The soils in the lower reaches of the basin tend to be somewhat finer textured than the soils in the western portion. These uplands generally have a thin mantle of loess on the divides and are moderately deep over calcareous shales and sandstones.

Climate

The Republican River Basin has a subhumid to semiarid continental climate. The variable weather is typical of the interior of a large land mass in the temperate zone: light rainfall, low humidity, hot summers, and cold winters. Rapid weather changes are caused by invasions of larger masses of warm, moist air from the Gulf of Mexico; hot, dry air from the southwest; cool, dry air from the Pacific Ocean; and cold, dry air from Canada.

There is a large variation in precipitation from year-to-year and station-to-station within the basin (table 1). The mean annual precipitation varies from nearly 18 inches in the western part of the basin to 30 inches in the eastern part. Seventy-seven percent of the annual precipitation falls during the growing season (April through September).

Table 1.--Precipitation summary for representative climatological stations

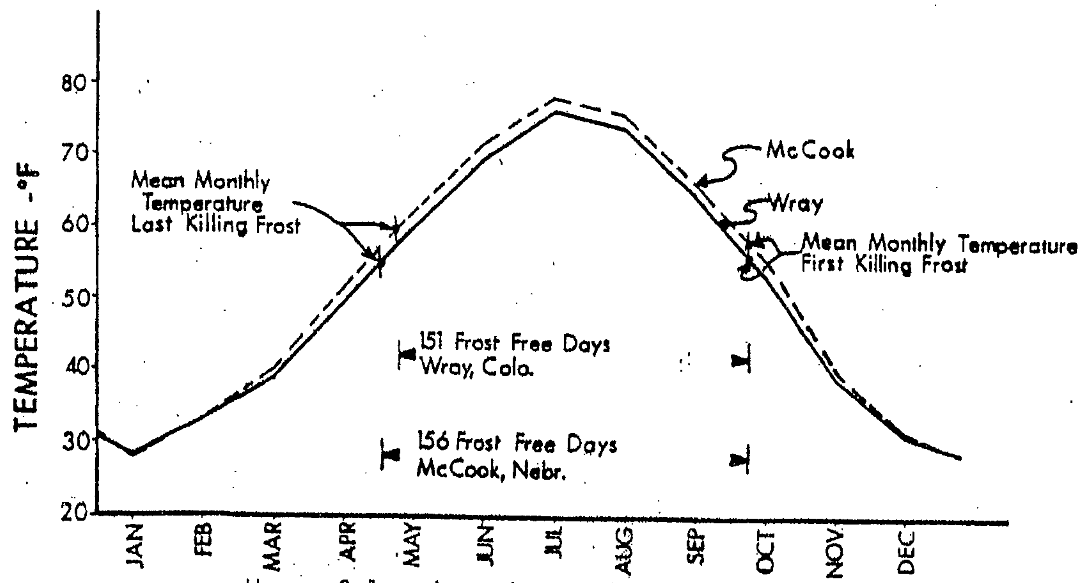
Station	1920-1978 mean annual (in)	Maximum annual (in)	Minimum annual (in)
Wray, CO	17.63	30.36	7.29
McCook, NE	20.15	38.26	9.69
Alma, NE	21.42	37.75	11.73
Red Cloud, NE	24.14	40.42	11.94
Clay Center, KS	29.68	53.86	13.88

Table 2 summarizes the annual, maximum, and minimum mean monthly temperatures for the 1920-1978 period.

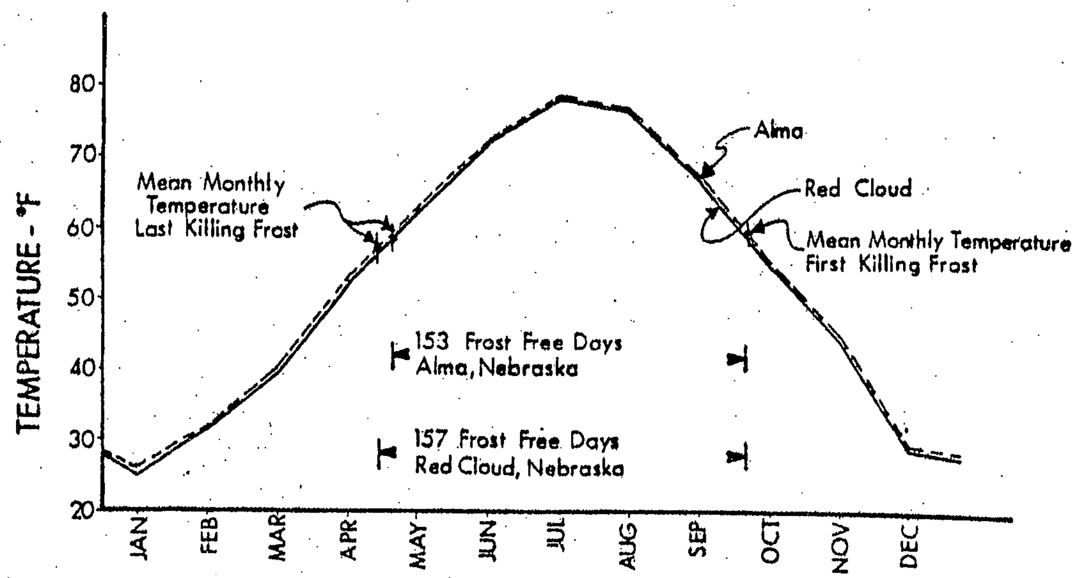
Table 2.--Temperature summary for representative climatological stations

Station	1920-1978 mean annual temperature (°F)	Maximum mean monthly temperature (°F)	Minimum mean monthly temperature (°F)
Wray, CO	51.2	81.8	10.8
McCook, NE	52.3	84.6	13.3
Alma, NE	52.8	86.8	10.1
Red Cloud, NE	52.6	87.6	10.0
Clay Center, KS	55.5	89.6	13.2

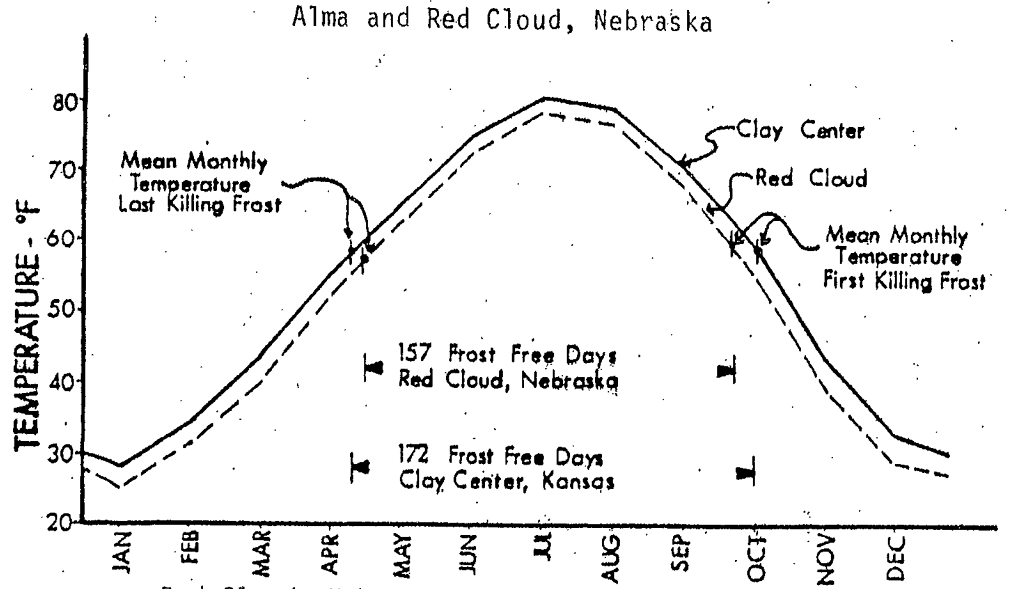
Figure 3 depicts average monthly temperatures, last and first killing frost dates, and frost-free days for the five stations.



Wray, Colorado and McCook, Nebraska



Alma and Red Cloud, Nebraska



Red Cloud, Nebraska and Clay Center, Kansas

Figure 3.--Average Monthly Temperature

Geology

Upper Republican Basin

The major geologic formations are the Ogallala Formation, alluvium, and eolian deposits that make up the aquifer system. The base for the aquifer system is comprised of the Niobrara Formation, Pierre Shale, and White River Group.

The Niobrara Formation and the Pierre Shale of late Cretaceous age, and the White River Group of Tertiary age are relatively impermeable consolidated deposits, which restrict the downward movement of water from the overlying aquifer system. The Niobrara and Pierre Shale are of marine origin. The Niobrara Formation (the aquifer base in the eastern part of the upper basin) consists of massive chalk beds, chalky shales and limestones, and thin beds of bentonite. The Niobrara Formation has a thickness of approximately 650 feet in Phillips County, Kansas. The Pierre Shale (the aquifer base in the western part of the upper basin) lies conformably on the Niobrara Formation. It is a thinly bedded shale with thin beds of bentonite and numerous concretionary zones. The Pierre Shale in the Frenchman Creek area is more than 2,000 feet thick. The Niobrara Formation and Pierre Shale slope to the east with an average gradient of 14.7 feet/mile. The White River Group (Brule and Chadron Formations) of Oligocene age, lies unconformably on the Pierre Shale in the northwestern portion of the upper basin. It appears to be of fluviatile origin and consists of siltstone, clay, and localized channel deposits of sand and gravel that may or may not be cemented. Although the deposit is considered impermeable, minor amounts of water could be obtained from unconsolidated sand and gravel deposits within the formation. It has a maximum thickness of ± 450 feet.

The semiconsolidated Ogallala Formation of Pliocene age is the major source of ground water due to its areal extent, accessibility, and extent of saturation. The formation is present throughout the upper basin, except where major streams have eroded through it to the bedrock. The Ogallala is believed to have been formed by eastward flowing streams whose sediment filled pre-existing valleys in the bedrock. Eventually, lateral constraints were eliminated, and the streams coalesced to form a broad alluvial plain. The formation consists of a poorly sorted mixture of clay, silt, sand, and gravel that is loosely cemented; the material becomes coarser or less cemented in the lower part (McGovern and Coffin, 1963). Also present are beds of soft limestone, bentonite, and volcanic ash. The top of the formation consists of a few feet of a dense, sandy limestone known as the "Algal limestone." Maximum thickness is about 500 feet in the northern Medicine Creek subbasin in Nebraska. Depth to the top of the formation varies from 0 to 200 feet, averaging less than 100 feet. The surface of the Ogallala slopes to the east with an average gradient of 12 feet/mile.

Pleistocene loess deposits (wind deposited silt and clay) are present throughout the upland areas and valley walls. These deposits, varying in thickness from 0 to 200 feet, lie above the water table and yield little water.

Sand deposited by the wind during the Pleistocene and Holocene epochs is present in the northwest section of the upper basin with a maximum thickness of 170 feet. These deposits are an important element of the aquifer system because of their high permeability, which allows rapid recharge to the underlying Ogallala Formation.

The next most important sources of ground water are alluvium and terrace deposits of Holocene age. They are found in the valleys and under the flood plains of the larger streams and are comprised of varying mixtures of clay, silt, sand, and gravel. Thickness of these deposits varies from 0 to 90 feet.

Lower Republican Basin

The principal aquifer system in the lower basin is comprised of alluvium and terrace deposits and the Ogallala, Grand Island, and Dakota Formations. The base of the aquifer system consists of Pierre Shale, the Niobrara and Wellington Formations, and the Chase Group.

The alluvium and terrace deposits of recent and Pleistocene age are a major source of municipal and irrigation water. They are made up of unconsolidated clay, silt, sand, and gravel that have been deposited in the valleys and flood plains of the major streams. The deposits generally become more coarse with depth. Thickness of the alluvium ranges up to 130 feet. The terrace deposit thickness ranges up to 125 feet.

Covering the uplands of the lower basin are undifferentiated deposits, consisting loess, volcanic ash, and gravels formed locally by weathering or stream action. Where saturated, these deposits will provide small to moderate amounts of water for domestic and stock wells. Thickness ranges up to 100 feet.

The Grand Island Formation is a major source of irrigation water in northeastern Jewell and northwestern Republic Counties, Kansas. It consists of coarse sand and medium-to-coarse gravel interbedded with silty clay deposited during the Pleistocene age in a former channel of the Republican River (Dunlap, 1982). Thickness ranges up to 120 feet.

The Ogallala Formation is found in the Nebraska portion of the lower basin. It is comprised of sandstone and siltstone interbedded with sand, gravel, and clay and has various degrees of cementation by calcium carbonate and silica. Thickness ranges over 100 feet and thins in an easterly direction. The base of the formation slopes to the southeast with an average gradient of 7 feet/mile.

Underlying the Ogallala and forming a relatively impermeable base are the Pierre Shale and Niobrara Formation. These formations were deposited in a marine environment during the late Cretaceous age. The Pierre is a dark-gray fissile shale, and the Niobrara consists of chalky shale and limestone. The Niobrara has a thickness of about 400 feet in Harlan County, Nebraska, and thins in an easterly direction.

Underlying the Niobrara Formation in the northern part of the lower basin, in descending stratigraphic order, are the Carlile Shale, Greenhorn Limestone, and Graneros Shale. They crop out at the surface in the central portion of the lower basin. Of these formations, the Greenhorn Limestone has the most potential for yielding small quantities of water for domestic purposes. Maximum total thickness of these deposits is about 430 feet.

The Dakota Formation is one of the principal aquifers in the vicinity of Cloud and Clay Counties (Kansas) for supplying municipal, domestic, and stock wells. Thickness ranges up to 350 feet. The quality of water varies from good-to-bad with a better quality generally obtained where the formation crops out or is near the surface. Water obtained from the Dakota Formation in most of northwestern Cloud County, Kansas contains high chloride concentrations, 250 p/m (parts per million) or higher (Fader 1968, pg 14). Walters and Bayne (1959) reported that samples obtained from the Dakota Formation in Clay County, Kansas show chloride concentrations below 250 p/m.

The Wellington Formation and Chase Group underlie the Dakota Formation to the north and crop out at the surface in Clay County, Kansas. Total thickness of these deposits ranges up to 480 feet. Small-to-moderate amounts of water for domestic and stock use may be obtained from several formations within the Chase Group. Better quality water can be obtained where the formations are not deeply buried.

ENVIRONMENT

Vegetation

The basin encompasses the Steppe and Prairie Divisions of Bailey's ecoregions. General environmental conditions found in these two divisions are shown in table 3.

Table 3.--General environmental conditions associated with the Steppe and Prairie Divisions

Division	Temperature	Rainfall	Vegetation	Soils
Prairie	Variable	Adequate all year except during dry years, maximum in summer	Tall grass, parklands	Prairie soils Chernozems (Mollisols)
Steppe	Variable winters cold	Rain 19.7 in/yr	Short grass, shrubs	Chestnut, brown soils and Sierozems (Mollisols and Aridosols)

Figure 4 shows where the irrigation lands and reservoirs lie in relation to Bailey's ecoregions. The Steppe and Prairie Divisions can be divided into separate provinces, which contain the various species of the Great Plains. The grama-buffalo grass prairie (3113) is part of the Great Plains-short grass prairie province. The bluestem-grama prairie (2533), wheatgrass-bluestem-needlegrass prairie (2532), and the bluestem prairie (2531) are all part of the tall grass prairie province. Over 90 percent of the area in the basin is used for agricultural purposes with over 50 percent cropland and less than 1 percent in forest land. The balance of the land is pasture and rangeland, farmsteads, wildlife areas, water, and miscellaneous areas.

Principal crops grown in the basin include corn, grain sorghum, wheat, soybeans, and alfalfa hay. The pastureland consists of introduced grasses and legumes on smaller tracts of mostly irrigated soils. Rangeland, which is dominated by climax communities of native grasses and associated forbs, is used for grazing livestock. Forested land occurs mainly along river bottoms in narrow bands. Common species are cottonwood, boxelder, green ash, willow, and oaks.

Field shelterbelts and farmstead windbreaks include species such as Rocky Mountain juniper, eastern redcedar, russian olive, locusts, elms, ponderosa pine, and various shrubs. All of these areas are important for their ability to trap snow and soil, stabilize stream courses and streambanks, and provide wildlife habitat and forage, and to provide shade and shelter to livestock. Significant areas of forest land have been cleared for agricultural purposes in the last three decades. Decreased numbers of farmsteads and increased farming intensity have been among the factors contributing to forest land decline.

Fish and Wildlife

There are nearly 17,000 acres of wildlife habitat adjacent to the river, its tributaries, and ponds. The ponds include small structures built for livestock watering, irrigation reuse, erosion control, fish and wildlife, and local flood control. In 1978, it was estimated that approximately 9,000 ponds, averaging 1.4 acres in size, were in the basin.

The most sought after fish in the river basin are the trout, stocked near Wray, Colorado, and the channel catfish in Nebraska and Kansas. Other fish in the streams and reservoirs sought by anglers in the basin include smallmouth and largemouth bass, flathead catfish, white bass, walleye, black bullhead, white and black crappie, and carp. Most of the fishing pressure in the basin occurs in public areas on or adjacent to the reservoir lands.

Ring-necked pheasant, bobwhite quail, cottontail rabbits, and fox squirrels are the most important small game species hunted in the basin. Limited numbers of sharp-tailed grouse and prairie chickens are also pursued. Waterfowl hunted in the area consists mainly of mallards and Canada geese followed by green-winged and blue-winged teal, American widgeon, gadwall, wood duck, pintail, ring-necked duck, redhead, canvasback lesser scoup,

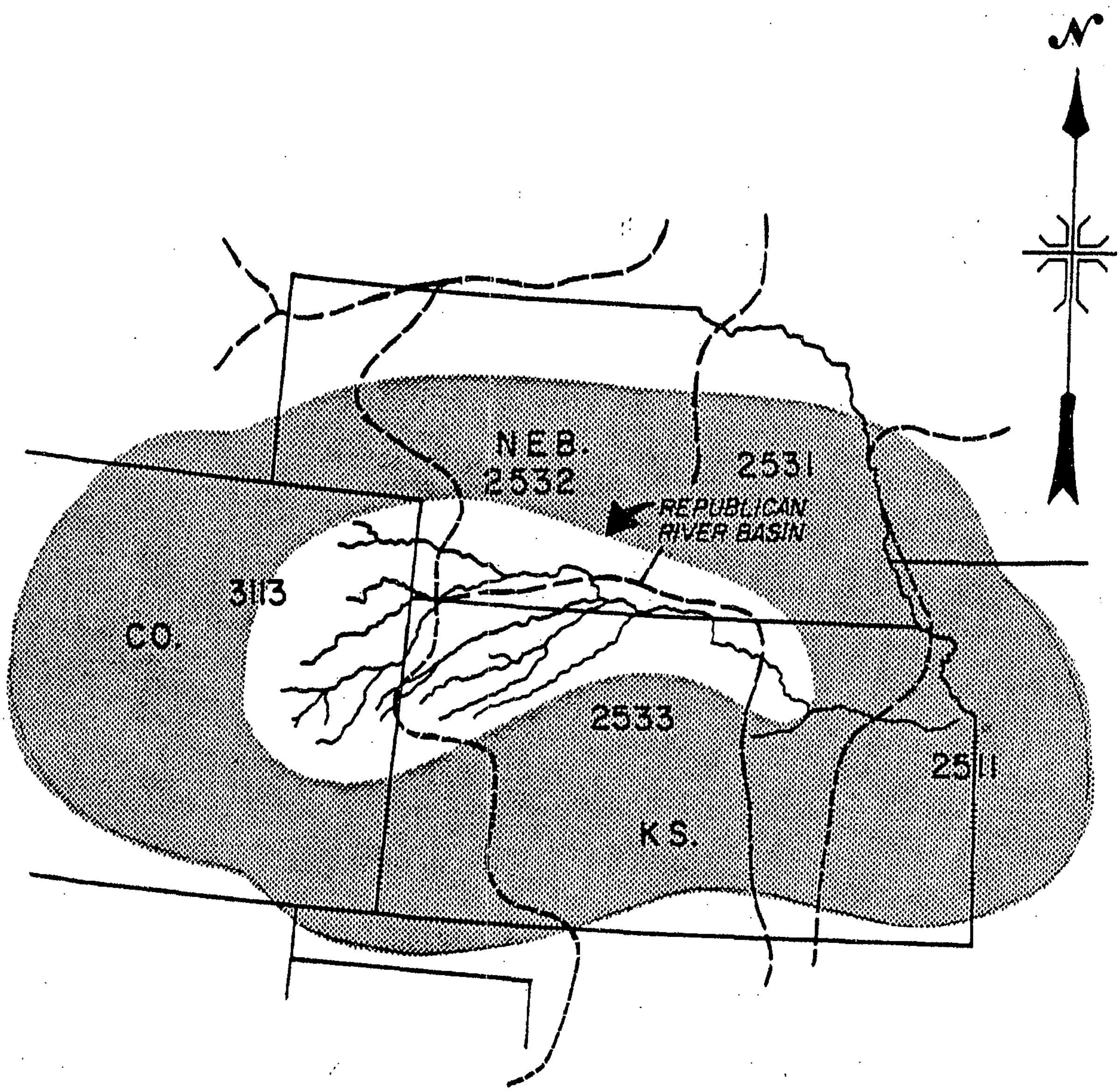


Figure 4.--Republican River Basin showing Bailey's Ecoregions

bufflehead, American goldeneye, ruddy duck, and white-fronted geese. Migratory mourning doves are also heavily hunted. Big game species pursued by archers and firearm hunters include mule deer, white-tailed deer, antelope, and turkey.

Public lands, managed for fish and wildlife resources, comprise only 0.8 percent of the 24,900 mi^2 (square miles) of the basin. There are 45 public areas which include over 82,500 acres of upland habitat, over 4,700 acres of wetlands, over 40,000 surface acres of reservoirs and lakes, and 2.75 miles of river. Nine public areas (16,300 acres) are located in Colorado, 30 areas (65,500 acres) in Nebraska, and 6 areas (46,500 acres) are located in Kansas.

HISTORY

Settlers began arriving in the region after 1873. Completion of the railroad in 1882, connecting the Republican Valley with Omaha and Denver, stimulated homesteading. Few "choice" tracts of land remained after 1886. The droughts of the 1890's and 1930's and the 1935 flood brought widespread disappointment. The recurrent cycles of wet and dry years caused a corresponding fluctuation from farm settlement to abandonment. Many enterprising farmers built distribution systems using horse-drawn slips and hand labor to irrigate with stream water.

Today, dryland farming is still common with wheat as the primary crop. The introduction of irrigation from both surface and ground-water sources has diversified crops and increased livestock production. Irrigation development also has stabilized the population by reducing the effect of droughts and floods. Corn, grain sorghum, and alfalfa are the main irrigated crops grown today. Grazing lands are utilized for beef cattle. Hog production also plays an important role in the economy. Agriculture continues to be the dominant economic sector in the basin.

Historical Floods

Flooding of the tributaries and main stem of the Republican River has occurred periodically, beginning with the legendary flood of 1876. Other major floods occurred in 1915, 1923, 1935, 1947, and 1957.

The flood of May-June 1935 is the largest of record. This flood was the result of a cloudburst in the upper portion of the watershed, mainly on the Arikaree and South Fork Republican Rivers. Local residents measured as much as 20 inches of rainfall during the night of May 30. Flood stage was exceeded for 8 days in Franklin, Nebraska. Some of the peak discharges measured were: 280,000 ft^3/s (cubic feet per second) at Cambridge, Nebraska, 200,000 ft^3/s at the gage near Stratton, Nebraska, and 168,000 ft^3/s near Junction City, Kansas. These flows were as large as any recorded since 1876. Losses included 150 lives, bridges, highways, and $1 million in property and crops.

The second largest flood in the basin occurred in June 1947. A storm over the entire Republican Basin dropped 5 inches of rain over a 3-day period.

The Medicine Creek area received intense rainfall during the onset of the storm and was the largest tributary watershed affected. The largest residential area affected was Cambridge, Nebraska. Thirteen people were killed and approximately $16 million damage to agricultural lands, roads, bridges, and municipal property occurred. Peak flows for this flood were: 30,000 ft^3/s at Red Willow Dam, 140,000 ft^3/s at Harlan County Dam, and 116,400 ft^3/s at Medicine Creek Dam. These compare to 45,000 ft^3/s at Red Willow Dam and 260,000 ft^3/s at Harlan County Dam during the 1935 flood.

Flood Potential

The Kansas City District, Corps of Engineers, has completed a study that examined the potential for increased benefits or degree of flood protection resulting from modification of flood control operations at Reclamation projects in the Republican River Basin. Areas between Harlan County Lake, Nebraska, and Wray, Colorado, were examined. The reach between Wray, Colorado, and Benkelman, Nebraska, was inspected and did not appear to warrant further study. The analysis for the remaining portions of the Republican River included developing water surface profiles for 100-and 500-year events as well as some preliminary economic analyses of the associated floods.

The study concluded there would be no apparent increase in the benefits or degree of flood protection by changing the flood control operations of the reservoirs. The dams in existence function adequately to control flooding on the rivers and tributaries they serve. However, a potential exists for flooding on the uncontrolled portions of the rivers and tributaries in the study area.

SOCIOECONOMIC

The socioeconomic characteristics of the basin were derived using data from 4 counties in Colorado, 14 counties in Nebraska, and 10 counties in Kansas. Data derived from these counties, including the cities and towns, were representative of the basin.

Agriculture has been a major influence on both past trends and present conditions in almost every area of socioeconomic concern because the basin is located in one of the most agriculturally productive regions of the United States.

Population

Agricultural areas are often characterized by low population density and a relatively high proportion of persons living in rural areas. Although the Republican River Basin accounted for 10.1 percent of the total land area in the Tri-State Area in 1980, the 169,025 people represented only 2.5 percent of the total population in all three states. The Republican Basin had 6.4 persons per square mile in 1980 compared to 26 persons per square mile in the Tri-State Area, and 64 persons per square mile in the Nation.

A much larger proportion of the people live in rural areas in the basin as compared to the Tri-State Area as a whole with 69.4 and 28.3 percent, respectively. This proportion has been decreasing and corresponds to national trends. For example, between 1950 and 1980, the percentage of the basin's population living in rural areas decreased from 80.8 to 69.4 percent. The rural population of the Tri-State Area as a whole decreased by an even greater amount, from 46.3 percent to 28.3 percent. Between 1970-1980, the basin rural population has decreased only 1.6 percent.

Another pattern of change has been a slow but steady decline in the actual size of the population. Between 1930 and 1980, the population of the basin decreased from 266,457 to 169,025. Between 1970-1980, nine counties in the basin experienced growth; however, only Phelps County in Nebraska and Sherman and Thomas Counties in Kansas had 1980 populations larger than their 1930 populations. These population changes are typical of many rural/agricultural areas in the Nation. As agriculture becomes more mechanized, fewer jobs exist and rural residents either leave or migrate to urban areas in search of employment and higher education. Table 4 shows population changes from 1930 to 1980.

Median age in the basin is higher than either the Tri-State Area or the Nation. The median age in the Republican Basin in 1980 was 35.5 as compared to 29.4 in the Tri-State Area and 30 in the United States. Since 1970, the median age decreased in the basin and increased in both the Tri-State Area and the Nation.

Ethnic and racial minorities made up less than 2 percent of the basin's population in 1980. The largest minority group was of Spanish origin.

Employment, Income, and Earnings

Between 1970 and 1978, per capita income in the Republican Basin increased 192 percent from $2,483 to $7,253. This was greater than the 165 percent increase in the Tri-State Area.

Employment and earnings are concentrated in the agricultural and related industries in the basin. In 1978, 28.9 percent of employment and 30.8 percent of earnings were generated by the agricultural industry in the basin compared to 7.2 percent of employment and 5.6 percent of earnings for the Tri-State Area. Other sectors accounting for high proportional amounts included retail and wholesale trade, Government, and services. Mining was the smallest sector.

ECONOMIC BASE

Basic sectors answer demands that are external to the area's economy, and are usually export sectors. Nonbasic (service) sectors answer demands from within the area and usually serve the local population. These distinctions are built around the concept of comparative advantage - a region produces goods and services for which it is most efficient and then exchanges them for goods and services of other regions. A single industrial sector may include both basic and nonbasic activities, but one type of activity is usually dominant.

Table 4.--Population - 1930, 1950, 1970, 1980
Republican River Basin

State/county	1930	1950	1970	1980	Growth rate 1970-1980 (percent)
Nebraska					
Chase	5,484	5,176	4,129	4,758	15.2
Dundy	5,610	4,354	2,926	2,861	- 2.2
Franklin	9,094	7,096	4,566	4,377	- 4.1
Frontier	8,114	5,282	3,982	3,647	- 8.4
Furnas	12,140	9,385	6,897	6,486	- 6.0
Gosper	4,287	2,734	2,178	2,140	- 1.7
Harlan	8,957	7,189	4,357	4,292	- 1.5
Hayes	3,603	2,404	1,530	1,356	-11.4
Hitchcock	7,269	5,867	4,051	4,079	0.7
Nuckolls	12,629	9,609	7,404	6,726	- 9.2
Perkins	5,834	4,809	3,423	3,637	6.3
Phelps	9,261	9,048	9,553	9,769	2.3
Red Willow	13,859	12,977	12,191	12,615	3.5
Webster	10,210	7,395	6,477	4,858	-10.0
Kansas					
Cheyenne	6,948	5,668	4,256	3,678	-13.6
Clay	14,556	11,697	9,890	9,802	- 0.9
Cloud	18,006	16,104	13,466	12,494	- 7.2
Decatur	8,866	6,185	4,988	4,509	- 9.6
Jewell	14,462	9,698	6,099	5,241	-14.1
Norton	11,701	8,808	7,279	6,689	- 8.1
Rawlins	7,362	5,728	4,393	4,105	- 6.6
Republic	14,745	11,478	8,498	7,569	-10.9
Sherman	7,400	7,373	7,792	7,759	- 0.4
Thomas	7,334	7,572	7,501	8,451	12.7
Colorado					
Kit Carson	9,725	8,600	7,530	7,599	0.9
Phillips	5,797	4,924	4,131	4,542	9.9
Washington	9,591	7,520	5,550	5,304	- 4.4
Yuma	13,613	10,827	8,544	9,682	13.3
Total	266,457	215,507	173,581	169,025	- 2.6

The 1978 basic sectors in the Republican River Basin were agriculture, construction, transportation, and retail and wholesale trade. Nonbasic sectors included mining, services, manufacturing, Government, finance, insurance and real estate, and communications and public utilities.

Agriculture

The basin's agricultural output has both regional and national significance. Table 5 shows a selected crop comparison and table 6 presents crop value.

The Tri-State Area is among the Nation's top 10 producers of winter wheat, sorghum grain and silage, dry beans, corn, and sugar beets. The Republican River Basin accounted for significant amounts of many of these crops grown in the Tri-State Area as shown in the preceding tables.

Of the total crop value, corn accounted for 47.1 percent, wheat for 31.4 percent, and hay for 6.4 percent. The remaining 15.1 percent came from soybeans, barley, dry beans, sugar beets, and other crops. Phelps and Franklin Counties in Nebraska and Yuma County in Colorado led in corn production. Leading producers of wheat included Thomas and Cloud Counties in Kansas and Washington County in Colorado. Yuma and Washington Counties in Colorado led in the production of hay. Processing of these crops also makes a significant contribution to the economic base of the basin.

Livestock production makes a major contribution to the economy. Much of the livestock produced in the basin, as well as the by-products, are shipped to points all over the Nation for futher feeding and/or processing. Table 7 presents the 1978 livestock inventory.

Retail and Wholesale Trade

In 1978, retail and wholesale trade was the second largest employment and earning sector in the basin accounting for 16.8 percent of the labor force and 18.3 percent of total earnings.

The retail and wholesale trade sector is unique in that it has both strong basic and nonbasic qualities. The export of raw and finished agricultural products, as well as the sale of farm machinery and fertilizer, give it strong basic qualities. The import and purchase of commodities needed to support the local population makes this sector strongly nonbasic. Major nonbasic activities include automobile, service station, grocery, and restaurant sales.

Table 5.--Selected crop production 1978 1/
(units = 1,000)

Area	Wheat (bu)	Corn (bu)	Sugar beets (tons)	Sorghum for grain (bu)	Hay (tons)
United States	1,799,000	7,082,000	25,800	748,000	142,000
Tri-State Area	447,452	967,400	3,348	354,970	14,201
Percent of Nation	24.9	13.7	13.0	47.5	10.0
Republican River Basin	84,732	159,140	758	34,818	1,198
Percent of Tri-State Area	18.9	16.4	22.6	9.8	8.4
Percent of Nation	4.7	2.2	2.9	4.7	0.8

Table 6.--Value of crop production, 1978 1/
($1,000)

Crop	Republican River Basin	Tri-State Area
Wheat	$245,686	$1,264,851
Corn	367,927	2,227,046
Soybeans	4,396	448,510
Barley	1,793	41,711
Hay	50,360	623,600
Dry beans	10,218	59,888
Sugar beets	14,136	80,479
Other	86,814	1,505,194
Total	$781,330	$5,659,634

Table 7.--Selected livestock inventory, 1978 1/

Livestock	Republican River Basin	Tri-State Area
Cattle and calves	1,623,000	15,680,000
Hogs and pigs	603,800	5,980,000
Sheep and lambs	53,200	892,000

1/ Agricultural Statistics - 1979; Colorado, Nebraska, Kansas. Published by the Department of Agriculture in each respective state.

For the past decade, the retail and wholesale trade sector has been growing in its importance to the economy of the basin. Retail sales in the basin increased from over $310 million in 1967 to $491 million in 1977, and wholesale sales increased from $369 million to $990 million. Between 1967 and 1977, the number of retail establishments decreased 18 percent, and the number of wholesale establishments increased almost 14 percent.

Primary trade centers include Akron, Burlington, Holyoke, and Wray in Colorado; Goodland, Colby, Norton, Clay Center, Belleville, and Concordia in Kansas; and McCook, Holdredge, Superior, Franklin, and Red Cloud in Nebraska. Rural residents rely heavily on these centers as well as smaller local establishments to provide essential consumer goods and services. Travel to major cities such as Grand Island or Lincoln, Nebraska; Denver, Colorado; and even Kansas City for a better selection, more competitive prices, or major purchase of durable goods is not unusual.

Government

In 1978, Government was the third largest sector accounting for approximately 16.8 percent of total employment and 14.4 percent of total earnings. The majority of Government activities are of a local/service-type making this sector primarily nonbasic. Such activities include local education, law enforcement, and city and county administration. The basic state or Federal acitivities that exist are service-type such as post offices, state employment services, and several small state institutions of higher education.

Services

The services industry was the fifth largest employer and fourth largest earnings sector in the basin in 1978. This is one of the fastest growing sectors in the area's economy. Employment in the services sector increased 46 percent between 1968-1978. This growth accompanied both the migration of residents from rural to urban areas and the expansion of economic activity in the area as a whole. This created an increased demand for local personal and professional services such as automotive repair shops, dry cleaners, hair stylists, doctors, and dentists. The continued emphasis on providing local services makes this sector primarily nonbasic and this emphasis is likely to continue in the future as the area's economy grows. Basic services include hotels, motels, and restaurants that cater more to visitors.

Manufacturing

Manufacturing in 1978 was the sixth largest employment sector and fifth in earnings, accounting for 5.4 percent of total employment and 7.3 percent of total earnings. Manufacturing in the Republican River Basin is primarily nonbasic in nature.

Manufacturing establishments in 1977 totaled 199, an increase of almost 20 percent from 1972. Manufacturing employment is increasing, as is value added by manufacture. Census data for all counties are not available due to nondisclosure of operations by individual companies. Of those counties where information was available, value added by manufacture was $67.4 million in 1977, an increase of 174 percent from 1972.

Communities with the largest number of manufacturing establishments are: McCook and Holdrege in Nebraska; Colby, Clay Center, Concordia, Belleville, and Goodland in Kansas; and Burlington, Wray, and Holyoke in Colorado. Manufactured items are primarily agriculturally oriented.

Contract Construction

In 1978, contract construction employed 2.8 percent of the labor force and generated about 5.1 percent of total earnings. Contract construction is a nonbasic employment and earnings sector, because little or nothing is exported, and activity centers around local demand for commercial and residential structures. Contract construction supports the basic industry of agriculture as well as the manufacturing sector. Because of the support the construction sector makes toward end products that are exported from the area, it is also a basic sector.

Finance, Insurance, and Real Estate

Commercial banks, savings and loans, investment, and real estate companies are all typical establishments in this sector. This sector is primarily nonbasic. Almost every town has at least one local bank and several insurance and real estate companies that deal primarily with the day-to-day needs of the local residents. This sector has been growing and with this growth it has taken on more basic qualities as it facilitates the entry of new businesses and manufacturing in the area. This trend is expected to keep pace with continuing efforts to obtain greater diversification in the area's economic base.

Transportation, Communications, and Public Utilities

Communications, public utilities, and particularly transportation are extremely important to the area in terms of the support given other economic sectors. Economic prosperity in the basin is heavily dependent on the agricultural sector; transportation connections between rural points of farm production and urban points of processing and consumption throughout the Nation are vital to the uninterrupted flow of agricultural goods. Because of this support, as well as that given to other industries, this sector is primarily basic in nature.

Railroads and trucks are the primary modes for transporting commodities. Major railroads serving the area include the Burlington Northern and Union Pacific lines which, in combinations with other lines outside of the area, provide commodity transportation to the west coast in approximately 4 days, and to the east coast in 4 to 5 days. Trucks also play an important role. Lines using the major interstate highways such as I-70 (east-west) through the southern portion of the basin can transport goods to the west coast in 3 days, and the east coast in 4 days. Interstate I-80, just north of the basin, is also used.

There is no well-developed public transit system and rural residents usually travel by car. Several inter- and intrastate bus lines provide service to cities along the major highways. AMTRAK provides rail service through part of the basin.

Commercial air service is available only in Goodland, Kansas, and McCook, Nebraska. Several towns outside of the area (Hays, Kansas and Grand Island, Nebraska) also have commercial facilities. There are smaller airfields offering varying levels of services to charter and private flights.

The major source of local information is the weekly newspaper, although daily publications from larger cities are available. Several radio and television stations also serve the area. Mountain Bell serves a small part of the basin with telecommunications services and several small independent companies serve the majority of the rural areas.

Public utilities such as water, sewer, sanitation, and electrical power are provided through individual communities or larger utilities serving the area. Because communications and public utilities are a service and are not involved in exporting products, they are primarily nonbasic.

Mining

In 1978, the mining sector was the smallest employment sector in the basin and is primarily nonbasic. Most activity centers around the production of sand and gravel and stone for use in local construction and highway maintenance. All counties in the basin produce some sand and gravel for local use. Mineral value and production statistics for the basin are not available due to nondisclosure of individual firm information. Basic activity exists because a small amount of the petroleum produced in the area is exported. According the 1976 Minerals Yearbook; Volume II (Bureau of Mines), Washington County was the fourth largest petroleum producing county in the State of Colorado. Also, Great Western Sugar's lime plant in Sherman County, Kansas, was the state's leading producer of lime. The mining industry plays a relatively small role in the industrial resource base of the basin's economy.

CHAPTER III--EXISTING CONDITIONS

WATER SUPPLY AND USES

The surface water supply for the Republican River Basin originates as rainfall, accumulates as surface water runoff, and runs downstream to the confluence of the tributaries. Base flow from the alluvial aquifers and return flows from surface irrigation are other surface water sources.

Since the mid-to-late 1960's, significant decreases in instream flow have occurred. This has reduced the water supply for irrigation or other demands.

Historical Streamflows

Figure 5 shows locations of gaging stations and reservoirs, as well as the assumed locations of the section gains from base flow accretions. Also shown are the 1949-1978 average annual reservoir inflows, section gains, and gaging station flows.

The historical streamflows for the Republican River Basin were examined in a point flow study and the results are shown in figure 6. The locations of the tributary inflows and gages in the basin are shown schematically. Included are the mean annual flows, based on average monthly flows, for the 1946-1978 and 1968-1978 periods of record. Also included are the average flows for the 1978 calendar year. The dashed lines on figure 6 indicate there may be other gaging stations in these reaches. However, due to incomplete data they were not included in the point flow study.

Diversions

Table 8 shows each division and its respective conveyance system, acres supplied, average annual net supply, and minimum and maximum diversions for the 1969-1978 study period.

Farm Water Requirments

The basin was divided into three study areas using mean annual precipitation as a basis for the divisions. Figure 7 shows the farm water management study areas. Average precipitation in Area I ranges between 16-20 inches per year, while Areas II and III receive between 20-24 and 24-28 inches per year, respectively.

Consumptive Use

The consumptive use for the 1920-1978 study period has been calculated using the modified Blaney-Criddle method. The Blaney-Criddle method is explained in the Soil Conservation Service's Technical Release No. 25, entitled "Irrigation Water Requirements." Data required for estimating the consumptive use include temperature, precipitation, crop planting and

Figure 5

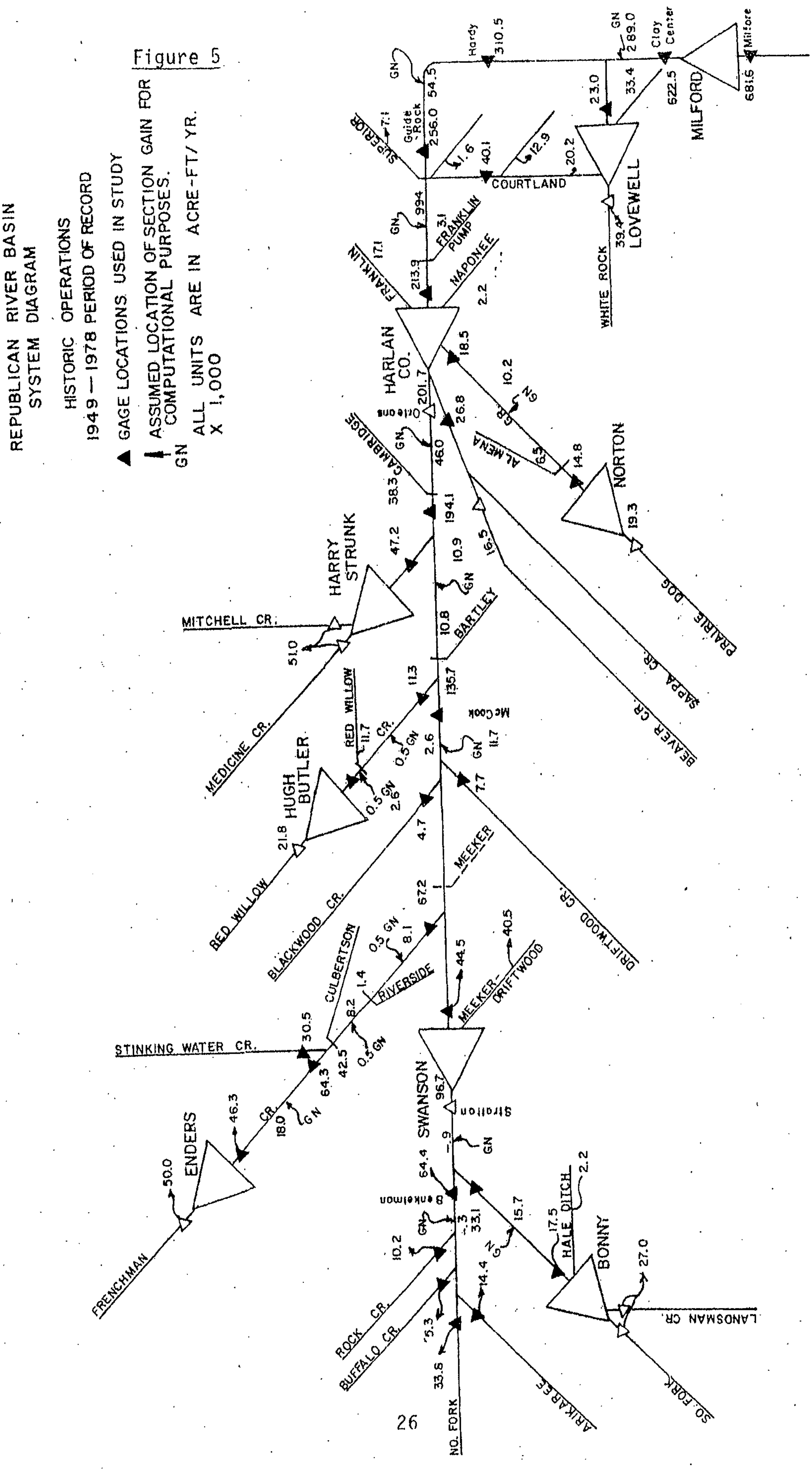

REPUBLICAN RIVER BASIN
SYSTEM DIAGRAM
HISTORIC OPERATIONS
1949 — 1978 PERIOD OF RECORD
GAGE LOCATIONS USED IN STUDY
GN ASSUMED LOCATION OF SECTION GAIN FOR COMPUTATIONAL PURPOSES.
ALL UNITS ARE IN ACRE-FT/YR.
X 1,000
MILFORD
Milford
681.6
622.5
Clay Center
GN 289.0
33.4
23.0
Hardy
310.5
GN
54.5
Guide Rock
256.0
SUPERIOR
7.1
1.6
40.1
12.9
20.2
COURTLAND
LOVEWELL
39.4
WHITE ROCK
GN
99.4
FRANKLIN PUMP
3.1
FRANKLIN
17.1
213.9
NAPONEE
2.2
HARLAN CO.
18.5
10.2
GN
Orleans
201.7
26.8
ALMENA
6.5
14.8
NORTON
19.3
PRAIRIE DOG
CAMBRIDGE
GN
46.0
58.3
194.1
16.5
SAPPA CR.
BEAVER CR.
HARRY STRUNK
47.2
10.9
GN
10.8
BARTLEY
MITCHELL CR.
51.0
MEDICINE CR.
11.3
135.7
McCook
GN 11.7
RED WILLOW CR.
11.7
0.5 GN
2.6
HUGH BUTLER
0.5 GN
2.6
21.8
RED WILLOW
7.7
4.7
BLACKWOOD CR.
DRIFTWOOD CR.
MEEKER
67.2
0.5 GN
8.1
1.4
RIVERSIDE
CULBERTSON
44.5
40.5
MEEKER-DRIFTWOOD
8.2
30.5
STINKING WATER CR.
64.3
42.5
0.5 GN
18.0
GN
46.3
ENDERS
50.0
FRENCHMAN
SWANSON
96.7
Stratton
-.9
GN
64.4
Benkelman
GN
-.3
33.1
GN
15.7
HALE DITCH
2.2
17.5
BONNY
27.0
LANDSMAN CR.
10.2
GN
ROCK CR.
14.4
5.3
BUFFALO CR.
33.8
NO. FORK
ARIKAREE
SO. FORK

Figure 6

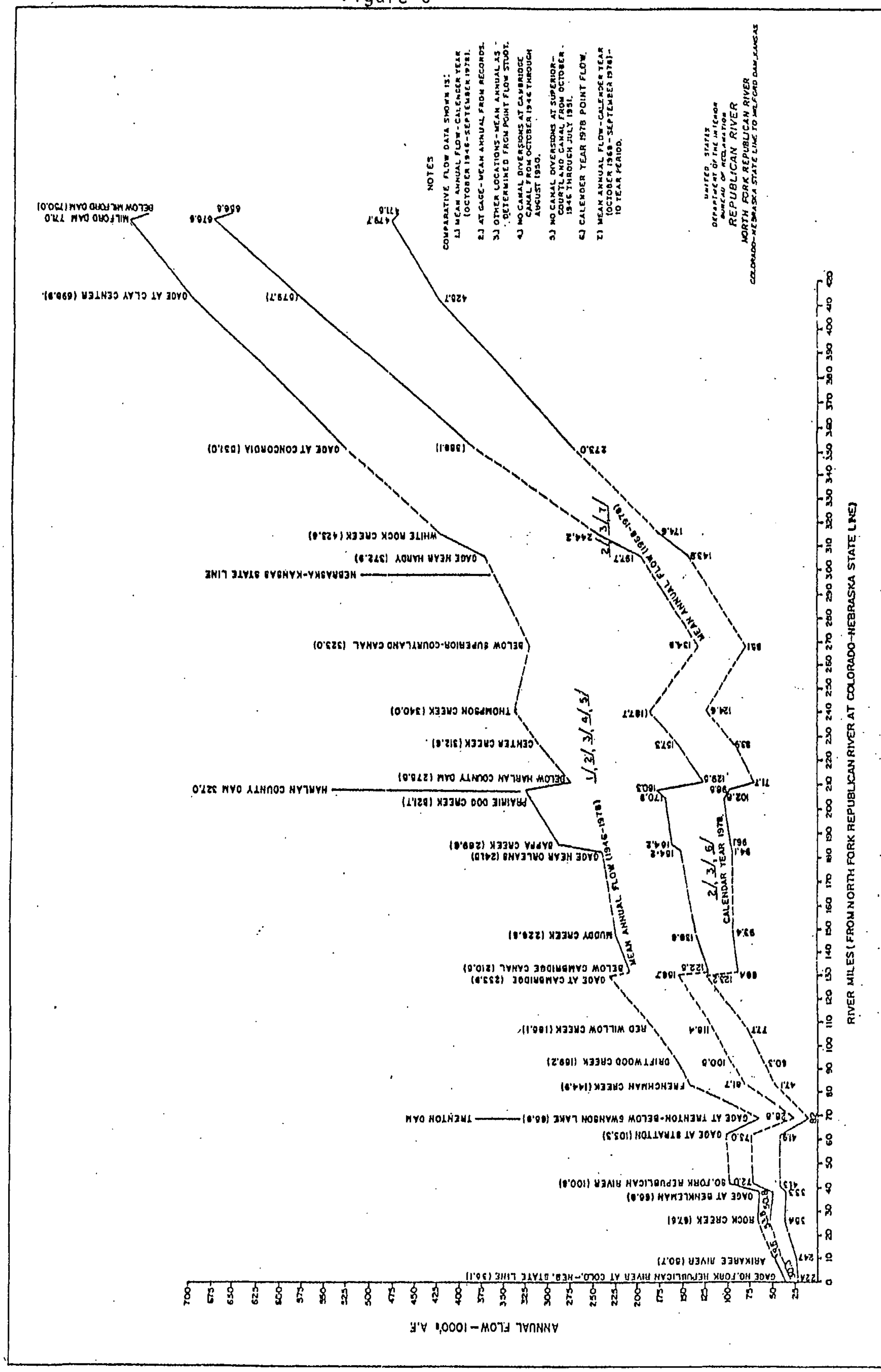


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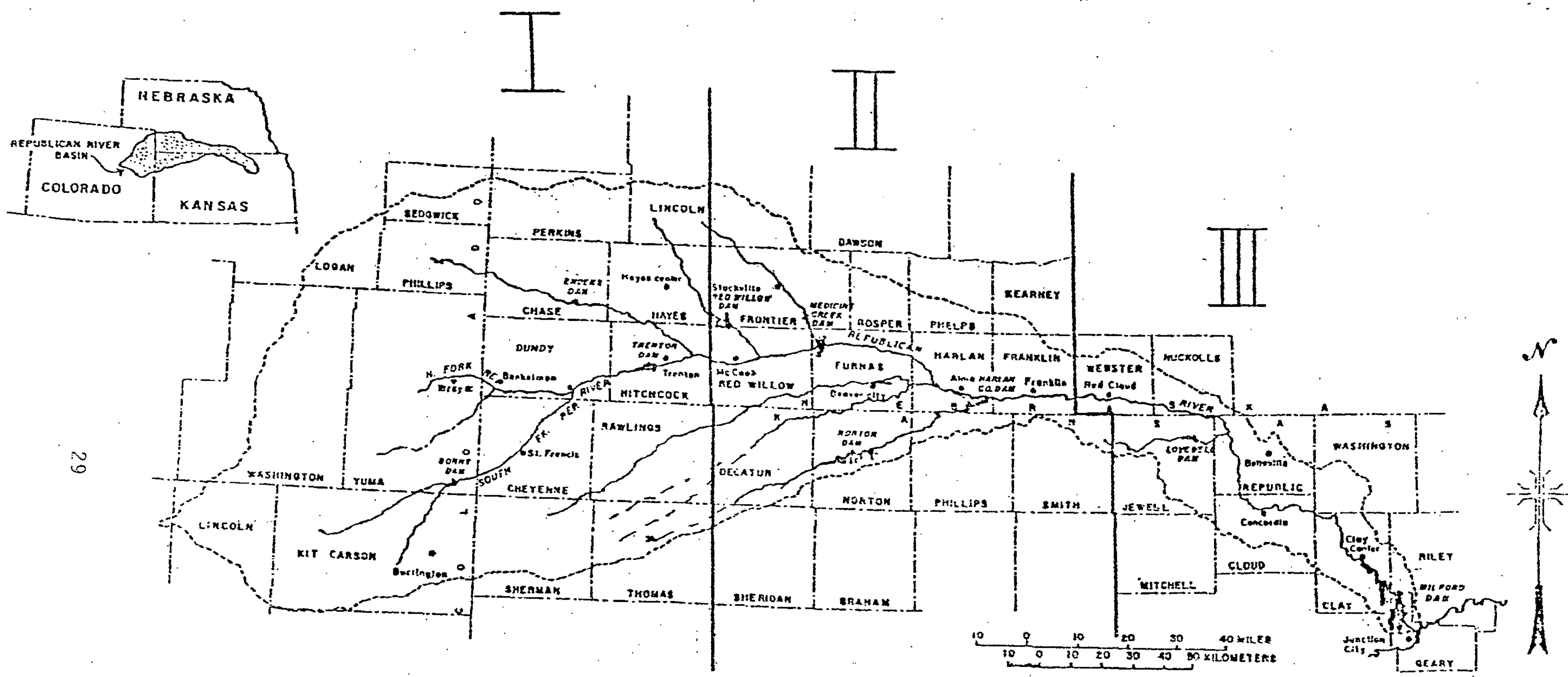
Table 8.--Conveyance systems and diversions

Conveyance system	Point of diversion	Acres supplied	1969-1978 Average annual net supply (acre-ft)	Diversion Minimum (acre-ft)	Year	Maximum (acre-ft)	Year
Upper Republican Division							
Hale Ditch	Bonny Dam	743	2,543	1,600	1978	3,950	1969
Frenchman-Cambridge Division							
Meeker-Driftwood	Trenton Dam	15,112	38,036	28,425	1977	42,960	1970
Red Willow	Red Willow Creek Diversion Dam	4,439	9,759	7,539	1977	12,037	1976
Bartley Canal	Bartley Diversion Dam	5,925	12,395	9,828	1969	14,935	1976
Cambridge	Cambridge Diversion Dam	15,958	34,787	15,088	1971	32,089	1976
Culbertson	Culbertson Diversion Dam	8,249	19,330	15,687	1978	22,333	1971
Culbertson Extension	Culbertson Diversion Dam	10,846	21,441	15,953	1978	26,980	1969
Total		60,529	135,748				
Kanaska Division							
Almena	Almena Diversion Dam	5,118	5,758	2,576	1972	10,091	1970
Bostwick Division							
Franklin	Harlan County Dam	9,806	29,229	21,554	1969	34,665	1976
Naponee	Harlan County Dam	1,472	3,530	2,222	1969	4,661	1976
Franklin South Side Pump	Franklin South Side Pumping Plant	1,978	3,408	1,806	1969	4,312	1971
Superior	Superior-Courtland Diversion Dam	5,125	14,589	10,262	1969	20,199	1976
Courtland-Nebraska	Superior-Courtland Diversion Dam	1,575	10,008	1,015	1969	3,261	1976
Courtland-Kansas	Superior-Courtland Diversion Dam	10,049	67,405	18,343	1972	38,614	1976
Courtland below Lovewell	Lovewell Dam	19,439	45,803	30,206	1973	71,792	1976
Total		49,444	173,972				



REPUBLICAN RIVER BASIN

Figure 7- Farm water management study areas

harvest dates, percent of daylight hours per day, and crop distribution patterns. Corn is the predominant irrigated crop in the basin; however, silage, winter wheat, alfalfa, grass pasture, and small grain are also irrigated. Table 9 shows the average consumptive use for the crop distribution in the basin.

Table 9.--Republican River Basin
Consumptive use, Blaney-Criddle method, 1920-1978

(inches)

Month	Area I	Area II	Area III
January	0.02	0	0
February	0.03	0	0
March	0.06	0	0.01
April	0.40	0.28	0.43
May	2.25	2.29	2.63
June	4.75	5.30	5.91
July	8.10	8.89	9.22
August	7.09	7.55	7.75
September	3.29	2.88	2.27
October	0.37	0.17	0.09
November	0.05	0.01	0.01
December	0.02	0	0
Total	26.43	27.37	28.32

Crop Irrigation Requirement

The water supply to meet the consumptive use demand does not come from irrigation only. Both precipitation and nongrowing season soil moisture carryover can be effective toward meeting crop growth demands. Effective precipitation is the amount of rainfall that is effective in meeting the consumptive use. The soil moisture carryover is the water stored within the root zone during the winter, when the crop is dormant or before planting. The crop irrigation requirement is the amount of irrigation water required for crop production. Crop irrigation requirements were determined by subtracting the monthly effective precipitation and the carryover soil moisture from the monthly consumptive use.

The crop irrigation requirements for the 1920-1978 study period are:

Area I	13.73 inches
Area II	13.84 inches
Area III	12.98 inches

Farm Delivery Requirement

The onfarm irrigation practice determines farm delivery requirement. Losses can occur from the farm turnout on the main canal system to the irrigated field. The greatest loss is seepage from the ditches. Seepage can be reduced by lining the canals or placing these ditches in buried pipe. Conveyance losses are spillage, phreatophyte use, and leaky farm gates. Other factors determining onfarm efficiencies are field characteristics and irrigation methods. Land surface contour, slope, soil type and intake rates, method of irrigation, and timing of water deliveries are important in determining the onfarm efficiency.

Table 10 shows the farm delivery requirement by area while table 8 presents the total acres irrigated from each of the canal and lateral systems.

Existing Water Conveyance System

Three irrigation districts in the Republican River Basin were analyzed. They include the Frenchman-Cambridge Irrigation District, the Bostwick Irrigation District in Nebraska, and the Kansas-Bostwick Irrigation District. The canal seepage rates were computed using the 1971-1980 average monthly volumetric losses, which were reported by the districts, and the calculated wetted perimeter from dimensions in the construction specifications. Table 11 shows the calculated average seepage rate of canals. Canal seepage losses as reported by the districts, is the difference between diverted and recorded deliveries less recorded waste. Analyses were not made for overdelivery and/or unrecorded delivery, which could significantly change the estimated canal seepage losses by as much as 50 percent. The four canals calculated to have the highest seepage rates are in the Bostwick Irrigation District in Nebraska and the Kansas-Bostwick Irrigation District. They are the Naponee, Franklin, Franklin South Side Pump, and the Courtland below Lovewell.

Table 10.--Farm delivery requirement by area

Area I
(units-inches)

	Existing (55% efficiency)	Attainable (65% efficiency)
Consumptive use	26.43	26.43
Effective precipitation	10.71	10.71
Carryover soil moisture	2.0	2.0
Crop irrigation requirement	13.73	13.72
Onfarm losses	11.22	7.38
Farm delivery requirement	24.94 or 2.07 ft	21.10 or 1.75 ft

Area II
(units-inches)

	Existing (58% efficiency)	Attainable (65% efficiency)
Consumptive use	27.36	27.36
Effective precipitation	11.31	11.31
Carryover soil moisture	2.2	2.2
Crop irrigation requirement	13.84	13.85
Onfarm losses	9.95	7.45
Farm delivery requirement	23.80 or 1.98 ft	21.30 or 1.76 ft

Area III
(units-inches)

	Existing (61% efficiency)	Attainable (65% efficiency)
Consumptive use	28.32	28.32
Effective precipitation	12.53	12.53
Carryover soil moisture	2.80	2.80
Crop irrigation requirement	12.98	12.99
Onfarm losses	8.31	6.99
Farm delivery requirement	21.30 or 1.76 ft	19.98 or 1.66 ft

Table 11.--Canal seepage rates

Irrigation district and canal	Average annual seepage 1971-1980 (acre-ft/yr)	Average July seepage 1971-1980 (acre-ft/mo)	Average seepage rate 1/ ($ft^3/ft^2/day$)
Kansas-Bostwick			
Courtland above Lovewell in Kansas	6,110	1,030	0.27
Courtland below Lovewell	6,130	2,720	1.20
Bostwick in Nebraska			
Courtland to state line	8,060	2,290	0.70
Franklin	11,040	4,530	1.05
Franklin South Side Pump	660	360	1.47
Naponee	880	450	1.61
Superior	4,940	1,940	0.78
Frenchman Cambridge			
Bartley	2,910	1,030	0.41
Cambridge	9,990	3,150	0.78
Meeker-Driftwood	8,850	3,220	0.93
Red Willow	2,460	780	0.58

1/ Calculated using average July seepage for 1971-1980, less high and low months.

Open ditch laterals were the standard design when the irrigation systems were constructed. The open ditch systems have high seepage losses, high annual maintenance costs, and associated drainage costs.

Harlan County Lake is the principal storage reservoir of the Kansas-Bostwick Irrigation District. Water is released from Harlan County Lake into the Republican River for diversion at the Superior-Courtland Diversion Dam. Water is then delivered through the Courtland Canal for secondary storage in Lovewell Reservoir. River fluctuations have occurred in the 44 miles between Harlan County Dam and the diversion dam due to precipitation. There is no opportunity to store the resulting peak flows and much of this water is unable to be diverted into the Courtland Canal at the diversion dam (bypassed).

Except for the five canal gates at the diversion dam, none of the control gates in the canal structures are motorized. Normal regulation of flows in the canal occurs during daylight hours, with only emergency situations dictating afterhours operation. In order to maintain near constant turnout flows for laterals and farm deliveries, along with accurate measurement and accounting of these flows, the water surface elevation in the canal must be maintained relatively constant. Consequently, present manual operations preclude the conservation of the erratic fluctuating bypass flows.

Surface Water Irrigation

Surface water supply for irrigation is affected by the amounts of water available for diversion to the canals and laterals that comprise the irrigation districts in the Republican River Basin. Significant changes have occurred in the watershed runoff characteristics during the past 3 decades. Several factors that are affecting surface water supply in the basin are: development and addition of soil and water conservation practices, changes in base flow due to increased ground-water pumping for irrigation, and cyclical variations in the precipitation regime.

Recharge from surface water irrigation practices has contributed a significant amount of water to the ground-water system in several areas of the basin. Deep percolation from applied surface water and seepage from canals and reservoirs in the Platte River Basin have caused water level rises up to 50 feet along the northern edge of the study area in Nebraska. In Kansas, water level rises due to surface water irrigation have occurred in the Grand Island Formation east of Lovewell Reservoir and in Pleistocene and Cretaceous deposits to the southwest. Small areas of rising water tables have also occurred near several reservoirs in the basin as a result of seepage.

Return flows from surface water have also increased the base flows in several of the major streams. Streams showing large increases in base flow include Driftwood and Blackwood Creeks, and the Republican River reach from Hardy, Nebraska, to Concordia, Kansas.

The estimated average annual recharge from surface water irrigation in the Republican River Basin (including seepage from the Platte River Basin) for the historic period is 211,300 acre-ft.

Ground-Water Pumping

Well development in the study area since the mid-1950's to 1960 has increased at a significant rate. Figures 8 and 9 graphically show the increase in well development by subbasin for the historic period. The number of irrigation, municipal, and industrial wells registered with the three states and acres irrigated with ground water as of May 1, 1978, are:

Figure 8.--Annual number of registered wells as of May 1, 1978, in each subbasin of the Upper Republican River Basin

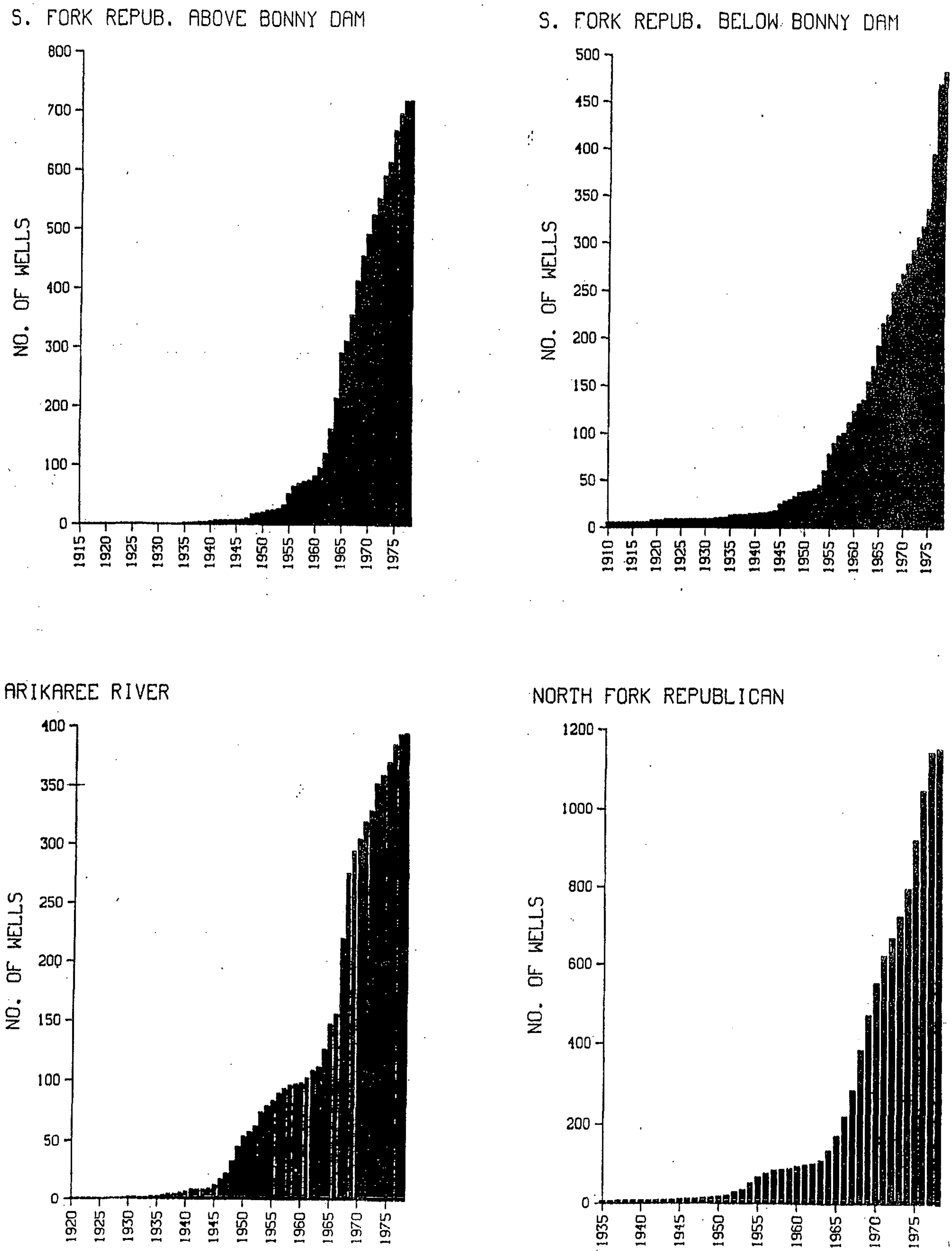


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Figure 8 (con.).--Annual number of registered wells as of May 1, 1978, in each subbasin of the Upper Republican River Basin

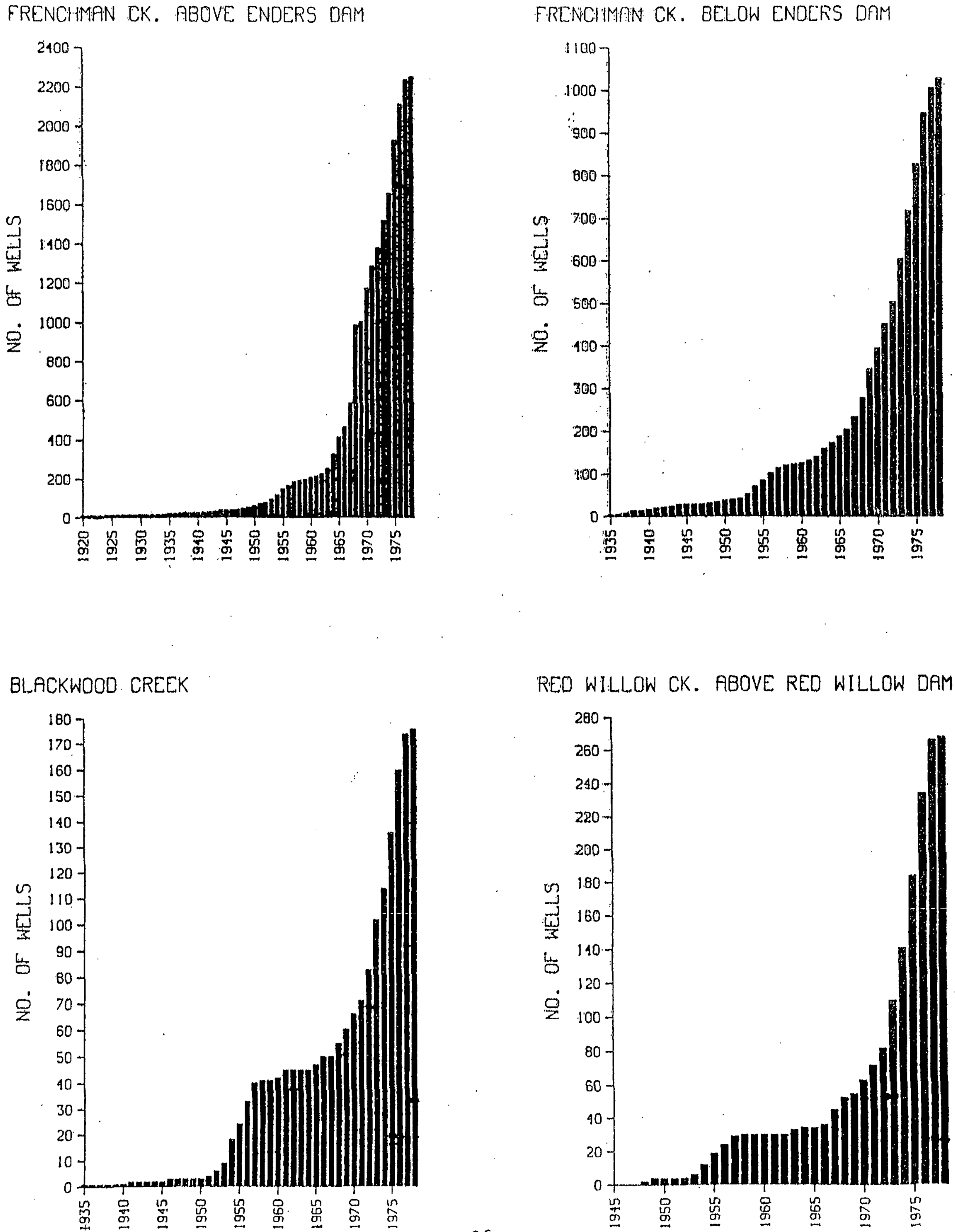


Figure 8 (con.).--Annual number of registered wells as of May 1, 1978, in each subbasin of the Upper Republican River Basin

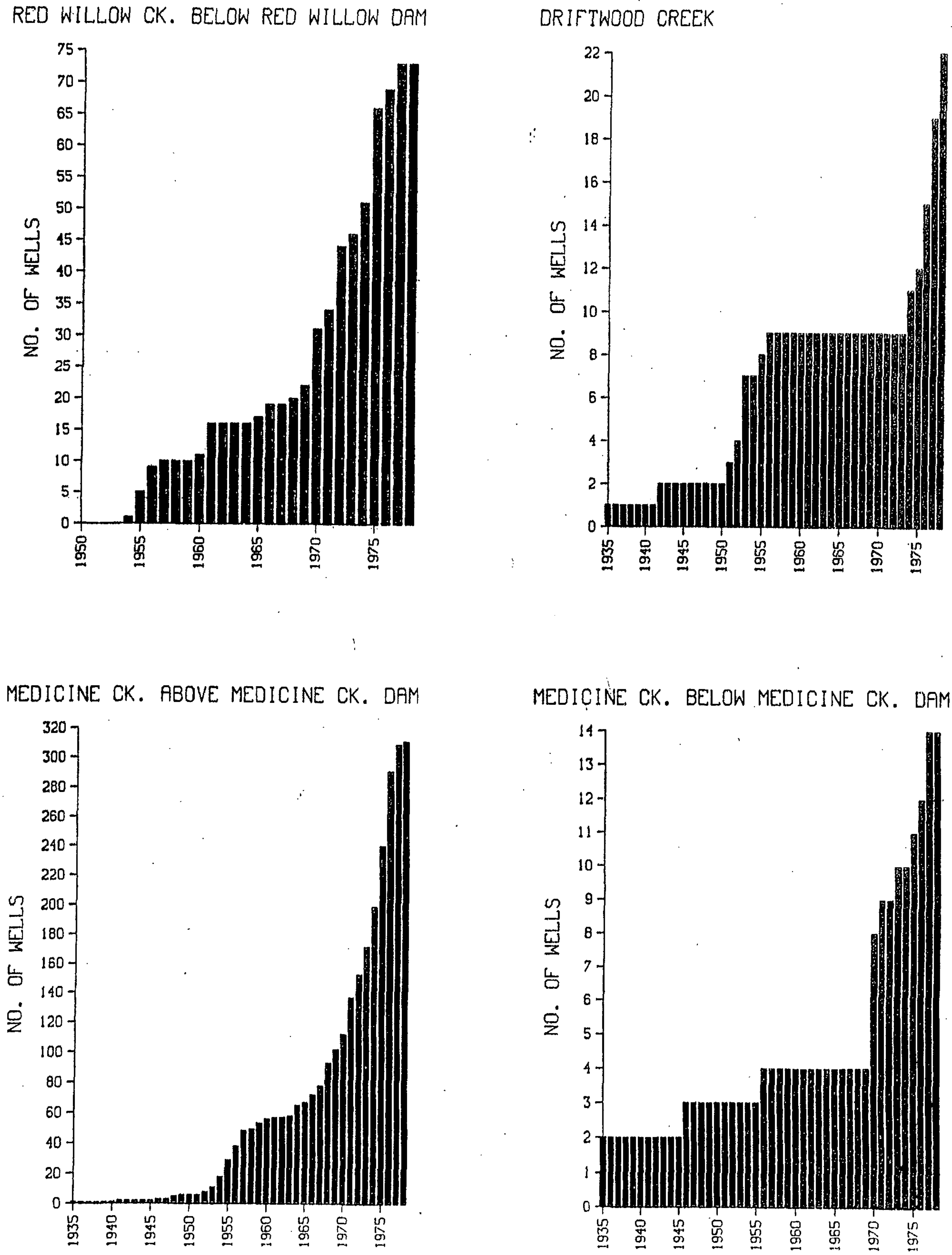
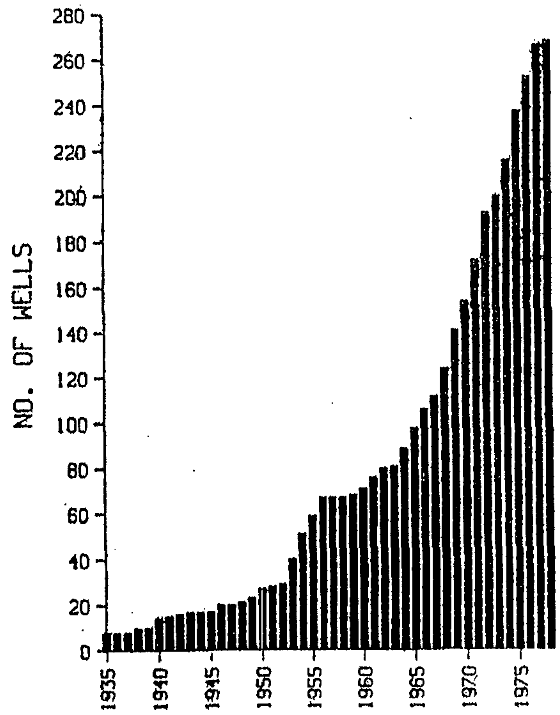
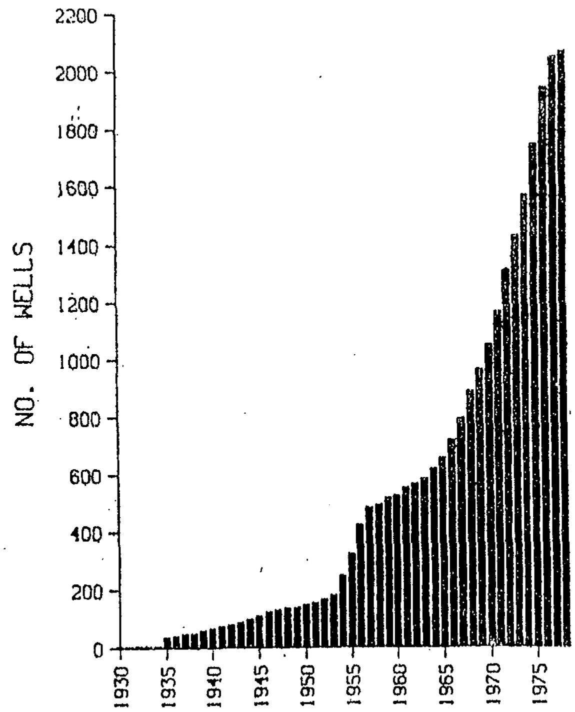


Figure 8 (con.).--Annual number of registered wells as of May 1, 1978, in each subbasin of the Upper Republican River Basin

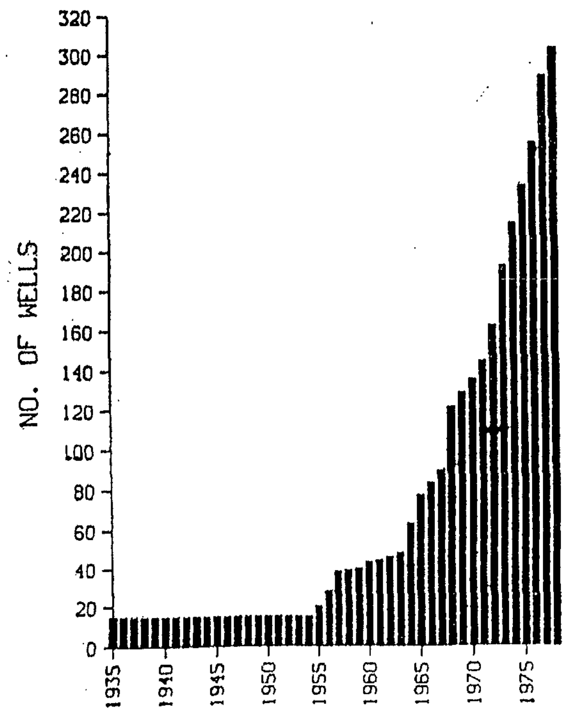
REPUBLICAN RIVER ABOVE TRENTON DAM



REPUBLICAN RIVER BELOW TRENTON DAM



PRAIRIE DOG CK. ABOVE NORTON DAM



PRAIRIE DOG CK. BELOW NORTON DAM

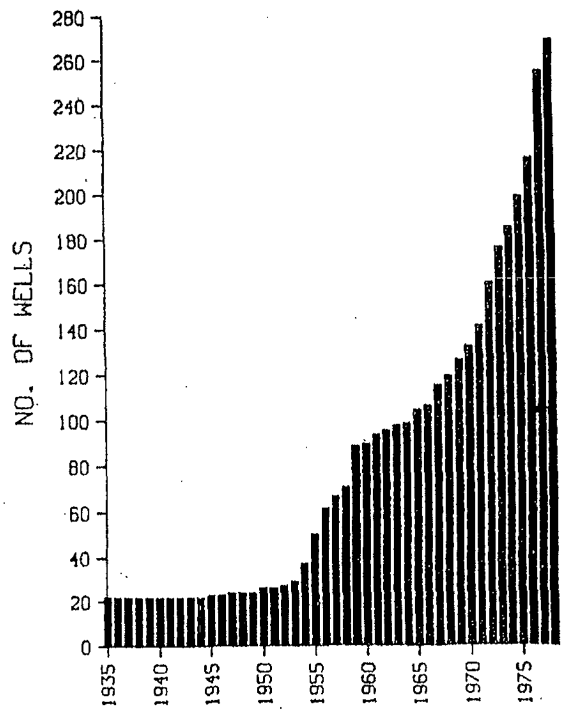


Figure 8 (con.).--Annual number of registered wells as of May 1, 1978, in each subbasin of the Upper Republican River Basin

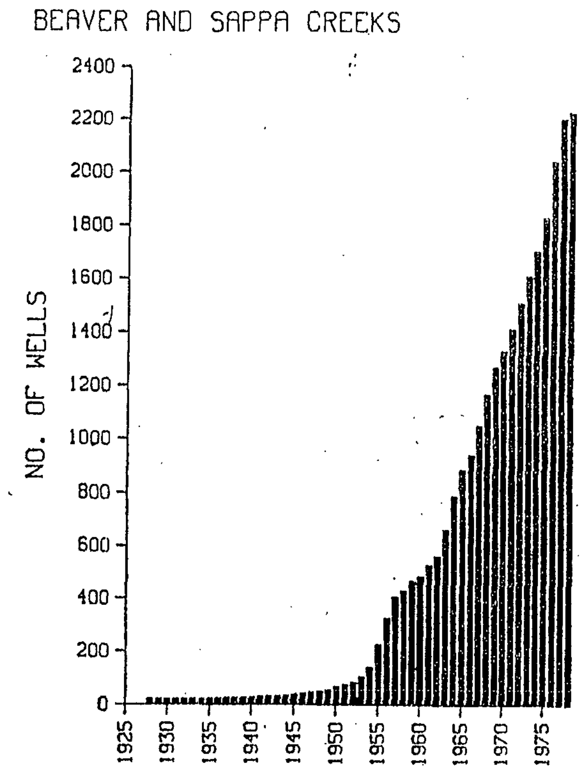
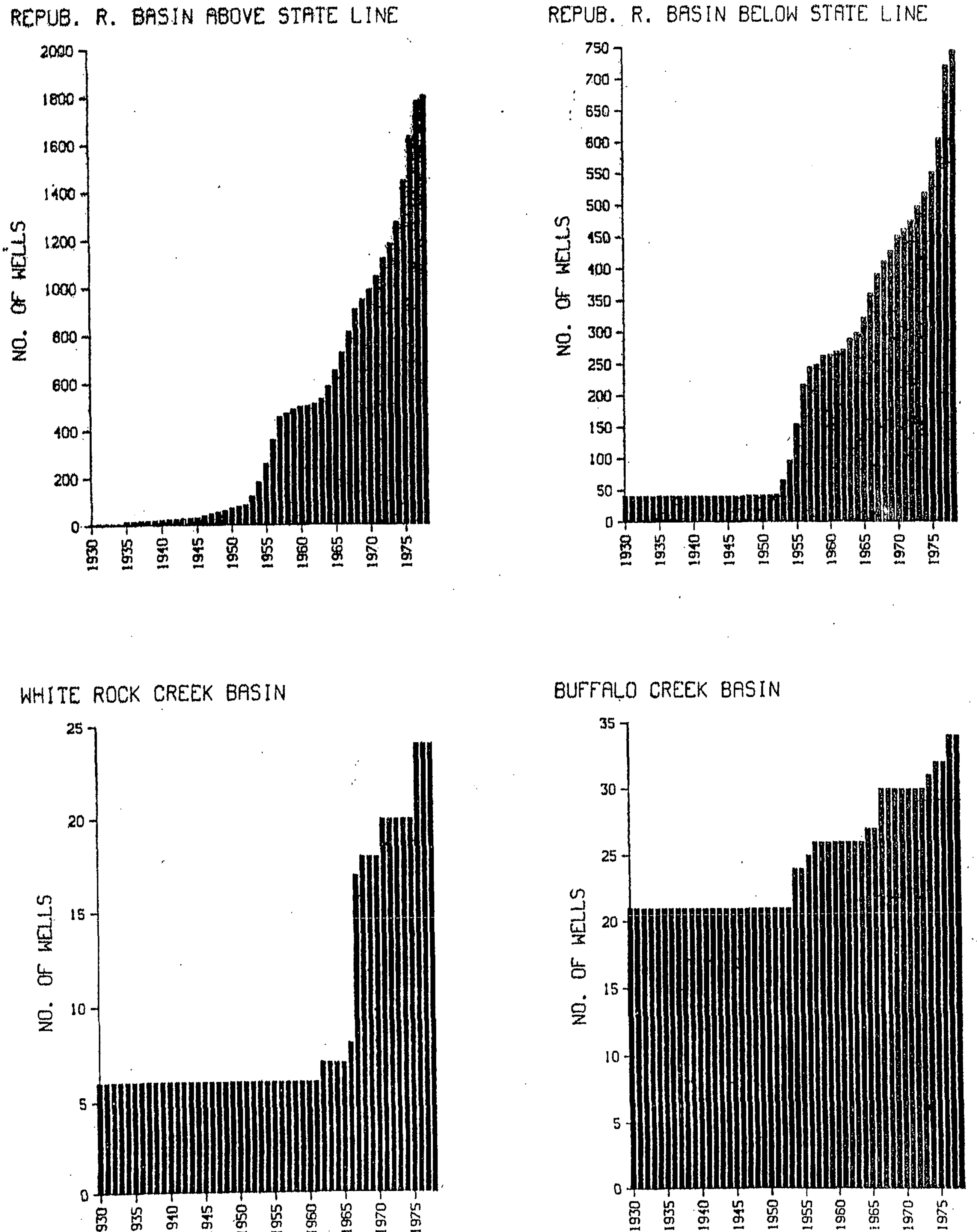


Figure 9 -- Annual number of registered wells as of May 1, 1978 in each subbasin of the Lower Republican River Basin



	Number of wells	Acres irrigated
South Fork Republican	1,202	112,300
Arikaree	395	42,900
North Fork Republican	1,152	145,600
Frenchman	3,287	441,600
Blackwood	176	19,600
Red Willow	341	40,400
Medicine	325	53,200
Driftwood	22	2,300
Beaver and Sappa	2,228	225,300
Prairie Dog	572	31,200
Mainstem Republican above Harlan County Dam	2,339	159,000
Republican from Harlan County Dam to Nebraska-Kansas State line	1,807	187,000
State line to Milford Dam	803	72,700
Total	14,649	1,533,100

In 1978, these wells were estimated to have pumped 2,131,400 acre-feet. This pumping caused an extensive amount of water level declines. The areas showing the greatest amount of water level declines are generally those portions of the basin adjacent to the Colorado State line. Declines of up to 40 feet have occurred in the areas along the southern half of the Colorado State line, mainly in the upper reaches of the Beaver and Sappa Creeks subbasin. Along the northern half of the state line declines have not been as great, ranging up to 20 feet. This is probably due to the sandier soils found in the upper half of the study area which allows for an increased recharge rate.

Although there has been a significant decline of water levels in certain areas, the overall reduction in volume of ground water in storage has not been as significant. This is mainly due to a saturated thickness that is generally quite large. The greatest saturated thickness, over 500 feet, occurs in the Ogallala Formation in the upper reach of the Medicine Creek subbasin in Nebraska. Saturated thickness in the northern half of the study area averages about 200 feet and decreases in a southerly direction. Average saturated thickness in the southern half of the basin is about 100 feet. The total predevelopment (pre-1950's) volume of ground water in storage for the Republican River Basin above Harlan County Dam and the section of the basin from Harlan County Dam down to the Nebraska-Kansas State line was determined to be 347,893,300 acre-feet. The 1977-1978 storage volume for the same area was 341,396,000 acre-feet. This represents a historic decline in storage of 6,497,300 acre-feet, which is 2 percent of the predevelopment storage volume. Table 12 shows storage changes that have occurred from predevelopment to 1977-1978 by subbasin. The 1977 storage volume of the lower Republican River Basin in Kansas for alluvium and terrace deposits was calculated to be 1,173,700 acre-feet.

Ground-water pumping has also had a significant effect on base flow contributions to streams in the basin. When a pumping well operates near a

Table 12.--Predevelopment and 1977-1978 volumes of ground water in storage and change in storage

Subbasin	Predevelopment volume in storage (acre-ft)	1977-1978 volume in storage (acre-ft)	Change in storage (acre-ft)	Percent change
South Fork Republican	21,201,900	19,357,700	-1,844,200	-9
Arikaree	10,528,700	9,776,200	- 752,500	-7
North Fork Republican	30,341,500	29,170,100	-1,171,400	-4
Frenchman	105,830,700	103,986,000	-1,844,700	-2
Blackwood	13,887,500	13,892,900	5,400	0
Red Willow	27,182,400	28,001,900	819,500	3
Medicine	35,522,000	36,592,200	1,070,200	3
Driftwood	1,270,300	1,271,000	700	0
Beaver and Sappa	42,166,800	38,351,300	-3,815,500	-9
Prairie Dog	7,211,500	6,946,700	- 264,800	-4
Republican above Harlan County Dam	38,002,600	38,903,000	900,400	2
Republican from Harlan County Dam to Nebraska-Kansas State line	14,747,400	15,147,000	399,600	3

stream it can either reverse the water table gradient between the well and the stream, which induces streamflow to seep to the aquifer, or it can decrease the former gradient towards the stream which in turn decreases the aquifer to stream discharge. These effects do not instantaneously affect the stream, but rather lag behind the operation of the well depending upon aquifer properties and distance from the well to the stream.

The base flow used in this report is actually the mean wintertime streamflow for the months of November to February for the upper Republican Basin and November to January for the lower Republican Basin. This mean streamflow was assumed to represent the annual average base flow and was calculated for every year of available record. These annual values were then plotted into a single-mass diagram to determine if there were any significant changes in the long-term base flow regime. Note that in several instances the estimated base flow is greater than the average annual flow (Buffalo Creek), figure 5 and table 13). This occurs because diversions in the spring and summer months reduce the average annual flows to values lower than the base flows calculated by averaging streamflows over the winter months.

Several streams in the upper Republican River Basin have been experiencing significant declines in base flow and are listed in table 13. Beaver Creek at Cedar Bluffs, Kansas, has experienced the greatest decline with 98 percent reduction in base flow since 1968. Probable maximum streamflow depletions caused by pumping wells were calculated by the Glover method. The results of those calculations, listed in table 14 by subbasin, show that wells are significantly stressing the streamflow in the basin.

It should be noted that the above derived streamflow depletions were not verifiable and based on the assumptions needed to use the Glover method, they are probably higher than the actual depletions. Since the calculated depletions were used to project the future water supply in the basin, the results will probably show a smaller future water supply than will actually exist.

Soil and Water Conservation Practices

Soil and water conservation practices (residue management, terracing, and farm ponds) contribute the largest depletions to the basin water supply.

During the past 3 decades, soil and water conservation practices have increased dramatically. The purpose of the practices is to reduce soil erosion and increase the available soil moisture for plant growth by holding more moisture in the soil profile. Changes in runoff have reduced the inflows to the reservoirs in the Republican River Basin. Table 15 shows how the farm water pond distribution has developed over the study period. Figure 10 graphically shows the development of the land terrace and contouring, crop residue management, and farm ponds based on percentages of the 1979 levels. Table 16 presents the total acres terraced and total acres of crop residue management in use as of 1979. There are two curves for lands treated with crop residue management practices. These imply that lands with higher percentages of row crops historically have had lower levels of crop residue management.

Table 13.--Streams with significant changes in base flow

Stream	Approximate year of change	Average base flow before change (acre-ft/yr)	Average base flow after change (acre-ft/yr)	Change in base flow (acre-ft)	Percent change
Streams with decreasing base flow					
Landsman Creek near Hale	1962	1,200	700	- 500	- 42
Arikaree River at Haigler	1953	11,700	5,800	- 5,900	- 50
Buffalo Creek near Haigler	1959	7,400	6,300	- 1,100	- 15
Frenchman Creek near Imperial	1968	56,900	40,700	-16,200	- 28
Frenchman Creek from Palisade to Culbertson	1969	13,600	9,700	- 3,900	- 29
Beaver Creek at Cedar Bluffs	1968	4,500	100	- 4,400	- 98
Sappa Creek near Beaver City	1955	5,700	3,200	- 2,500	- 44
Prairie Dog Creek above Keith Sebelius Lake	1970	2,900	1,000	- 1,900	- 66
Sappa Creek near Stamford	1968	14,300	2,100	-12,200	- 85
Streams with increasing base flow					
Blackwood Creek near Culbertson	1961	600	1,600	1,000	+167
Driftwood Creek near McCook	1959	300	2,800	2,500	+833

Table 14.--Historic streamflow depletions due to pumping wells in the Upper Republican River Basin

	S. FORK REPUB. ABOVE BONNY DAM (ACRE-FT)	S. FORK REPUB. BELOW BONNY DAM (ACRE-FT)	ARIKAREE (ACRE-FT)	N. FORK REPUB. (ACRE-FT)	FRENCHMAN ABOVE ENDERS (ACRE-FT)	FRENCHMAN BELOW ENDERS (ACRE-FT)	BLACK-WOOD (ACRE-FT)	RED WILLOW ABOVE R.W. DAM (ACRE-FT)
1940	300.	200.	0.	0.	900.	1400.	0.	0.
1941	300.	200.	0.	0.	1000.	1700.	0.	0.
1942	300.	200.	0.	100.	1100.	1900.	0.	0.
1943	300.	200.	0.	200.	1200.	2100.	0.	0.
1944	300.	200.	0.	300.	1400.	2400.	0.	0.
1945	300.	400.	0.	500.	1500.	2500.	0.	0.
1946	300.	700.	0.	600.	1600.	2600.	0.	0.
1947	300.	800.	0.	600.	1600.	2600.	100.	0.
1948	400.	900.	0.	600.	1700.	2700.	100.	0.
1949	400.	1100.	0.	700.	1800.	2700.	100.	0.
1950	400.	1200.	0.	1000.	2000.	2900.	100.	0.
1951	600.	1300.	100.	1200.	2200.	3000.	100.	0.
1952	700.	1400.	100.	1700.	2500.	3100.	100.	0.
1953	800.	1500.	100.	1900.	3000.	3400.	300.	0.
1954	800.	2000.	300.	2400.	3800.	4200.	900.	400.
1955	800.	2300.	300.	2900.	4700.	5000.	1400.	700.
1956	1000.	2500.	600.	3500.	6000.	6000.	1900.	1000.
1957	1200.	2900.	700.	4100.	6800.	6600.	2200.	1200.
1958	1300.	3000.	800.	4200.	7300.	7200.	2400.	1400.
1959	1400.	3500.	800.	4400.	7800.	7520.	2500.	1500.
1960	1600.	4200.	800.	4700.	8400.	7720.	2600.	1600.
1961	1800.	4500.	900.	5000.	8900.	8300.	2800.	1600.
1962	2300.	4700.	1000.	5100.	9300.	8800.	3000.	1700.
1963	2500.	4900.	1200.	5400.	9500.	10000.	3000.	1800.
1964	2600.	5200.	1300.	5600.	10900.	[illegible]	3100.	2000.
1965	3100.	5600.	1400.	5800.	11800.	11500.	3100.	2100.
1966	3300.	6300.	1500.	6200.	13200.	12000.	3200.	2200.
1967	3400.	6600.	1800.	6500.	15200.	12600.	3300.	2300.
1968	3600.	7000.	2100.	7500.	18100.	13800.	3400.	2500.
1969	3800.	7500.	2300.	8700.	21700.	15800.	3400.	2600.
1970	4000.	7900.	2500.	9800.	25200.	18000.	3500.	2900.
1971	4400.	8300.	2700.	11100.	28900.	19400.	3700.	3100.
1972	4700.	8800.	2900.	12400.	32900.	21000.	4100.	3300.
1973	4900.	9200.	3100.	13400.	37400.	22600.	4400.	3500.
1974	5100.	9600.	3300.	14400.	41900.	24300.	5000.	3800.
1975	5400.	10000.	3600.	15900.	46600.	25900.	5300.	4600.
1976	5800.	10800.	4000.	17500.	51300.	27900.	5600.	5500.
1977	6200.	12600.	4400.	18900.	56300.	30400.	6100.	6500.
1978	6700.	13900.	4700.	20200.	60400.	32300.	6400.	7400.

	RED WILLOW BELOW R.W. DAM (ACRE-FT)	MEDICINE CREEK ABOVE MED. DAM (ACRE-FT)	MEDICINE CREEK BELOW MED. DAM (ACRE-FT)	DRIFT-WOOD (ACRE-FT)	BEAVER AND SAPPA (ACRE-FT)	P. DOG ABOVE NORTON DAM (ACRE-FT)	P. DOG BELOW NORTON DAM (ACRE-FT)	REPUB. ABOVE TRENTON DAM (ACRE-FT)	REPUB. BELOW TRENTON DAM (ACRE-FT)
1940	0.	0.	200.	100.	900.	0.	700.	800.	3000.
1941	0.	0.	200.	100.	1200.	0.	700.	1000.	3300.
1942	0.	0.	200.	100.	1300.	0.	700.	1000.	3600.
1943	0.	0.	200.	100.	1400.	0.	700.	1100.	4000.
1944	0.	0.	200.	200.	1600.	0.	700.	1100.	4400.
1945	0.	0.	200.	200.	1800.	0.	700.	1200.	4800.
1946	0.	100.	200.	200.	2100.	0.	700.	1400.	5300.
1947	0.	100.	300.	200.	2300.	0.	700.	1400.	5700.
1948	0.	100.	300.	200.	2700.	0.	700.	1600.	6200.
1949	0.	300.	300.	200.	3000.	0.	700.	1800.	6400.
1950	0.	300.	300.	200.	3300.	0.	800.	2000.	6800.
1951	0.	400.	300.	200.	3700.	0.	800.	2200.	7100.
1952	0.	400.	300.	300.	4500.	0.	800.	2300.	7500.
1953	0.	700.	300.	500.	5100.	0.	800.	2800.	7300.
1954	0.	1000.	300.	600.	6400.	0.	900.	3400.	9400.
1955	200.	1400.	300.	700.	9400.	0.	1200.	3800.	11000.
1956	400.	2200.	400.	800.	13200.	100.	1500.	4000.	12700.
1957	500.	2600.	400.	800.	16900.	300.	1800.	4100.	14400.
1958	600.	3000.	400.	800.	18600.	300.	2000.	4200.	15400.
1959	600.	3500.	400.	900.	20600.	300.	2500.	4400.	16200.
1960	700.	4000.	400.	900.	21800.	300.	2800.	4600.	16900.
1961	1100.	4300.	400.	900.	23300.	300.	2900.	4900.	17800.
1962	1200.	4500.	400.	900.	24200.	300.	3100.	5100.	18600.
1963	1200.	4700.	400.	900.	25400.	300.	3200.	5300.	19300.
1964	1200.	5300.	400.	900.	26800.	400.	3300.	5700.	19900.
1965	1300.	5700.	400.	900.	28000.	400.	3500.	5900.	20700.
1966	1500.	6200.	500.	900.	29500.	500.	3600.	6100.	21500.
1967	1500.	6700.	500.	900.	31100.	500.	3800.	6400.	22400.
1968	1600.	7100.	500.	900.	32700.	500.	4000.	6600.	23400.
1969	1700.	7600.	500.	900.	34800.	600.	4100.	7000.	24400.
1970	1900.	8100.	700.	900.	36500.	700.	4400.	7300.	25600.
1971	2100.	8700.	900.	900.	38500.	800.	4500.	7600.	27400.
1972	2400.	9600.	1000.	900.	41000.	1000.	5000.	8200.	29000.
1973	2600.	10500.	1000.	900.	43500.	1100.	5500.	8600.	31100.
1974	2800.	11400.	1100.	1000.	45900.	1200.	5900.	8700.	33200.
1975	3200.	12400.	1100.	1100.	49400.	1300.	6100.	9200.	35400.
1976	3500.	13700.	1300.	1400.	54500.	1500.	6400.	9500.	38400.
1977	3800.	15100.	1500.	1700.	59400.	1800.	7100.	9800.	41200.
1978	4000.	16600.	1600.	2000.	63200.	1900.	7800.	10000.	43400.

Table 14.--Historic streamflow depletions due to pumping wells in the Lower Republican River Basin (continued)

YEAR	REPUB. R. SUBBASIN ABOVE NEB.-KS. STATE LINE (ACRE-FT)	REPUB. R. SUBBASIN BELOW NEB.-KS. STATE LINE (ACRE-FT)	WHITE ROCK CREEK SUBBASIN (ACRE-FT)	BUFFALO CREEK SUBBASIN (ACRE-FT)
1930	0	1300	100	100
1931	0	1600	200	100
1932	0	1700	200	100
1933	0	1800	200	100
1934	0	1800	200	100
1935	400	1800	200	100
1936	500	1800	200	100
1937	600	1800	200	100
1938	700	1800	200	100
1939	800	1800	200	100
1940	900	1800	200	100
1941	1000	1800	200	100
1942	1100	1900	200	100
1943	1100	1900	200	100
1944	1200	1900	200	100
1945	1400	1900	200	100
1946	1500	1900	200	100
1947	1700	1900	200	100
1948	2200	1900	200	100
1949	2600	1900	200	100
1950	3100	1900	200	100
1951	3300	2000	200	100
1952	3600	2000	200	100
1953	4200	3600	200	100
1954	5400	5600	200	300
1955	6500	10000	200	400
1956	7600	14500	200	400
1957	8400	17500	200	500
1958	9100	18900	200	500
1959	9600	20100	200	500
1960	10000	20700	200	500
1961	10400	21300	200	500
1962	10800	21700	200	500
1963	11100	22500	200	500
1964	11700	23400	200	500
1965	12400	24600	200	600
1966	13100	26600	300	600
1967	14100	28600	600	800
1968	15200	30500	800	800
1969	16100	32000	800	800
1970	17200	33300	800	800
1971	18600	34400	800	800
1972	20000	35600	800	800
1973	21600	36900	800	800
1974	23200	38400	800	800
1975	24700	40500	800	900
1976	26900	43300	800	900
1977	29300	48300	900	1000
1978	31100	51600	900	1000

Table 15.--Number of farm water ponds, Republican River Basin

Subbasin		1949	1954	1959	1964	1969	1974	1979
Above Harlan County Dam								
Frenchman Creek	(CO)	237	354	472	539	607	640	674
	(NE)	388	581	775	886	996	1,052	1,107
North Fork Republican	(CO)	54	81	109	124	140	147	155
	(NE)	37	56	75	85	96	101	107
	(KS)	6	10	13	15	17	18	18
Arikaree Rvr	(CO)	102	153	204	233	262	277	291
	(NE)	1	2	2	2	3	3	3
	(KS)	8	12	16	18	20	22	23
South Fork Republican	(CO)	111	166	222	253	285	301	317
	(NE)	1	2	2	3	3	3	3
	(KS)	117	175	233	267	300	317	333
Blackwood Crk	(NE)	50	75	100	114	129	136	143
Red Willow Crk	(NE)	145	217	289	331	372	393	414
Driftwood Crk	(NE)	80	120	160	183	206	217	229
	(KS)	28	42	57	65	73	77	81
Sappa Crk	(CO)	39	59	78	90	101	106	111
	(NE)	550	825	1,100	1,257	1,414	1,492	1,571
	(KS)	466	699	932	1,066	1,199	1,266	1,332
Prairie Dog Crk	(NE)	56	84	113	129	145	153	161
	(KS)	232	347	463	529	596	629	662
Medicine Crk	(NE)	260	391	521	595	670	707	744
Main Stem Republican Rvr	(NE)	1,264	1,896	2,528	2,889	3,250	3,431	3,611
	(KS)	36	54	72	82	92	98	103
Below Harlan County Dam								
Main Stem Republican Rvr	(NE)	1,335	2,002	2,669	3,050	3,432	3,622	3,813
	(KS)	1,636	2,453	3,271	3,739	4,206	4,440	4,673
White Rock Crk	(KS)	415	620	827	945	1,063	1,123	1,182
Buffalo Crk	(KS)	362	543	724	827	930	982	1,033

FIGURE 10— TIME DISTRIBUTION OF CONSERVATION PRACTICES

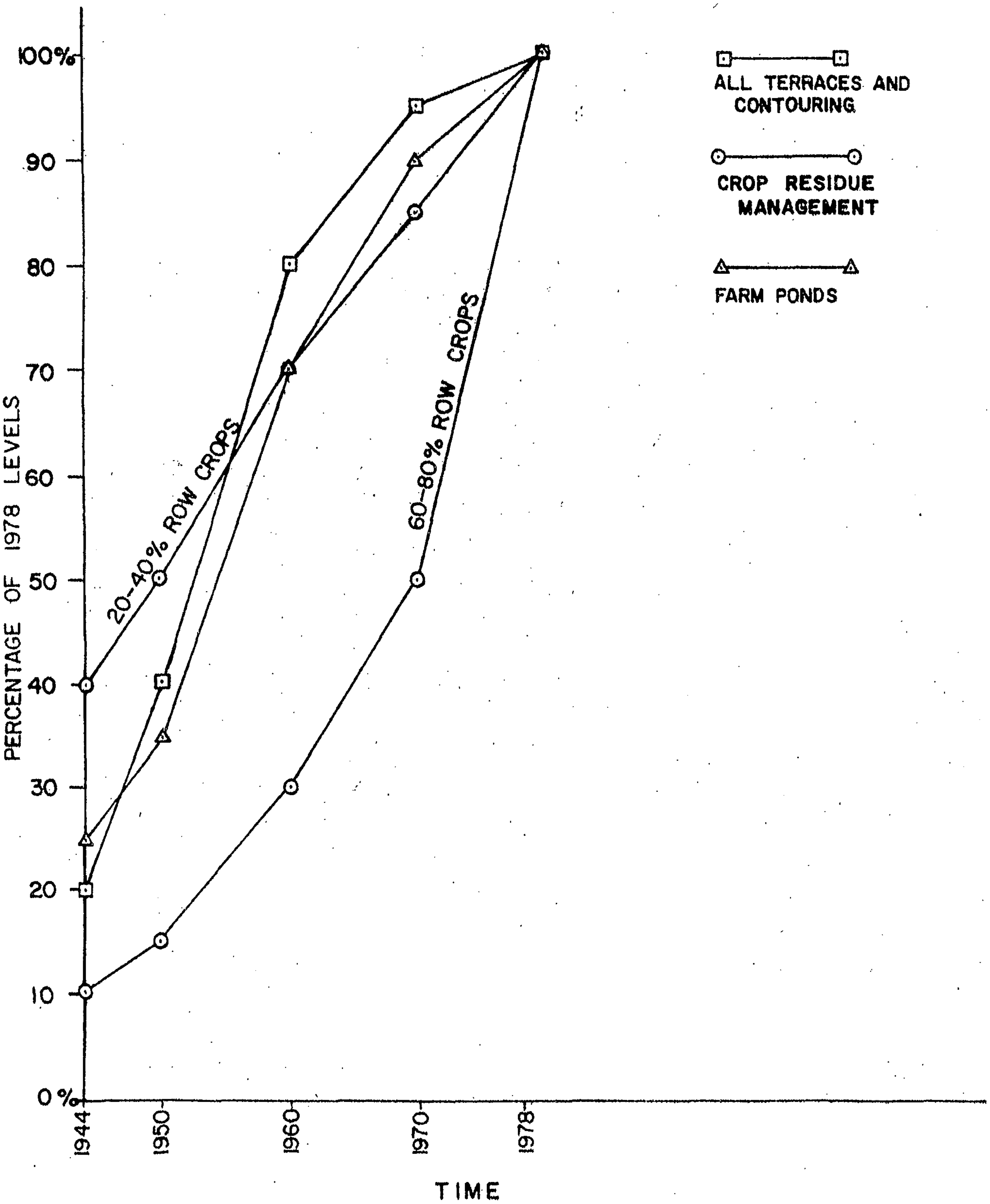


Table 16.--Conservation Practices - 1979 - Republican River Basin

Subbasin		Terraced (total acres)	Crop residue mgmt (total acres)
Above Harlan County Dam			
Frenchman Creek	(CO)	185,555	1,454,373
	(NE)	213,925	926,953
North Fork Republican River	(CO)	8,776	791,325
	(NE)	60,110	301,000
	(KS)	27,312	123,647
South Fork Republican River	(CO)	174,706	1,350,768
	(NE)	27,312	123,647
	(KS)	128,504	696,000
Blackwood Creek	(NE)	170,904	730,210
Red Willow Creek	(NE)	469,757	858,614
Driftwood Creek	(NE)	287,635	435,014
	(KS)	234,211	575,592
Sappa Creek	(CO)	83,685	530,000
	(NE)	447,747	459,474
	(KS)	790,246	1,387,012
Prairie Dog Creek	(NE)	256,299	259,474
	(KS)	975,091	1,520,268
Arikaree River	(CO)	174,706	1,350,768
	(NE)	27,312	123,647
	(KS)	60,110	301,000
Medicine Creek	(NE)	587,348	1,004,614
Main Stem Republican River	(NE)	833,240	1,277,554
	(KS)	377,497	770,592
Below Harlan County Dam			
Main Stem Republican River	(NE)	209,878	242,088
	(KS)	631,764	1,371,300
White Rock Creek	(KS)	310,769	768,485
Buffalo Creek	(KS)	276,898	789,159

The impacts of the various soil and water conservation practices have been estimated using an adapted version of the SCS (Soil Conservation Service) method described in the SCS National Engineering Handbook, section 4 (1972).

To assess these impacts, two computer models have been developed. The first model simulates the surface hydrology of the basin by segregating the conservation practice water uses into each factor contributing to runoff (land uses). This program also models the water budget of a typical farm pond. The second model uses the precipitation excess as calculated by the first program to determine runoff depletions in the watershed. Depletions are segregated into those attributed to terraces, crop residue management, and farm/stock ponds.

The subbasins of the upper Republican River Basin have an average annual historic conservation practice depletion of 197,300 acre-feet/year while the subbasins below Harlan County Lake are depleted by 129,500 acre-feet/year.

If conservation practice development remains at a level consistent with those of 1978, 238,200 acre-feet/year of depleted inflow may be expected above Harlan County Dam. Depletions in the lower basin may be expected to occur at a rate of 97,300 acre-feet/year.

Table 17 shows the depletions on an average annual basis for each of the subbasins in the Republican River Basin. Table 18 presents the historic and present level of development depletions for the entire basin.

In several of the subbasins in the lower basin, depletions are lower than expected when compared to historic rates. This is because levels of development are less as a result of decreased acreages harvested in 1978 than they have been historically. For example, in 1978 there were 1.6 million acres harvested in the Kansas portion of the lower Republican River Basin versus 1.75 million acres in 1974.

Based on future rates of development, it is estimated that depletions will be 15 percent larger than what currently exists. This implies that depletions of 273,900 and 111,900 acre-feet would occur annually in the upper and lower basins, respectively.

Conservation is an important factor. If the future water supply of the basin is to be assured, conservation practices need to be recognized as a major source of depletion to the flows in the Republican River Basin and managed accordingly.

The conservation practice depletions are not easily verifiable. The methodology used is empirically derived and is data intensive. In all fairness, the depletions are probably high and should be used with caution. Any estimates of future water supply are probably not as low as the results indicate.

Table 17.--Average annual conservation practice depletions 1949-1978

Basin and subbasin	Level of development: Historic (acre-ft)	Present 1978 (acre-ft)
Upper Republican		
Frenchman Creek	26,500	33,900
North Fork Republican	4,200	5,900
Arikaree	3,600	5,300
South Fork Republican	9,400	11,800
Blackwood Creek	2,300	3,000
Red Willow Creek	6,000	7,400
Driftwood Creek	6,100	7,000
Beaver and Sappa Creeks	66,500	76,400
Prairie Dog Creek	19,000	20,400
Medicine Creek	9,600	12,200
Main Stem Republican River	44,100	54,900
Lower Republican		
Buffalo Creek	13,800	18,400
Lower Republican River - NE	36,500	22,300
Lower Republican River - KS	65,300	38,100
White Rock Creek	13,900	18,500
Total depletion	326,800	335,500

Table 18.--Total Republican River Basin conservation practice depletions

Year	Level of development: Historic (1,000 acre-ft)	Level of development: Present (1978) (1,000 acre-ft)
1949	203.52	414.97
1950	157.08	298.72
1951	318.09	639.16
1952	60.58	115.21
1953	112.26	240.63
1954	67.59	82.88
1955	90.57	122.68
1956	45.43	60.26
1957	342.54	472.13
1958	226.59	304.32
1959	237.82	233.63
1960	302.92	289.63
1961	374.91	360.59
1962	476.59	551.11
1963	248.59	274.00
1964	252.29	219.57
1965	851.00	834.15
1966	167.28	175.21
1967	457.46	425.74
1968	310.55	277.25
1969	453.40	407.03
1970	270.89	197.74
1971	583.17	484.68
1972	480.51	385.02
1973	791.49	639.62
1974	205.40	186.91
1975	549.01	459.35
1976	177.73	146.16
1977	704.01	566.01
1978	282.33	195.29
Total depletion	9,799	10,062

Precipitation Changes

In an arid to semiarid basin, such as the Republican, agriculture is extremely sensitive to any changes in the precipitation regime. These changes must be analyzed as a possible source of declining water supply in the Republican River Basin.

Precipitation patterns in the Republican River Basin are quite variable and spotty, especially the highly localized thunderstorms that are so frequent. Because of the storms, the conclusions presented below are based on trends and changes which occurred over a period of 5 or more years.

In the upper portion of the basin above Harlan County Lake, Thiessen-weighted annual precipitation has averaged 0.50 and 2.60 inches for 1966-1973 and 1974-1978, respectively, below a 59-year (1920-1978) average of 18.64 inches. The 1957-1978 precipitation is 18.54 inches.

For the lower portion below Harlan County Lake, Thiessen-weighted precipitation averaged 2.86 inches (1966-1973) above and 1.25 inches (1974-1978) below a 59-year average of 26.74 inches. The 1957-1978 precipitation is 2.54 inches greater than the 59-year average.

In the upper basin, from Thiessen-weighted precipitation averages, it is apparent that predevelopment precipitation was not significantly greater than what has occurred historically since 1957. However, since 1974, Thiessen-weighted precipitation has been reduced for both the upper and lower basins.

The amounts of surface water runoff in a basin are not as much a function of the total annual precipitation as the frequency, duration, and intensity at which this precipitation occurs. The number of storms with amounts greater than 1 inch and with durations of 24 hours or less have been declining since the 1957-1965 period. Compared to the 1957-1965 period, 1966-1973 and 1974-1978 had only 77 and 70 percent as many storms per year, respectively.

Such a marked decrease in these events coincides with decreases in precipitation. Since these events are the ones that likely cause much of the surface runoff in the basin, it would follow that inflows to reservoirs would be decreasing with time as well.

In substantial parts of the basin, soils have high infiltration rates leaving insignificant amounts of surface runoff. Where surface runoff is an important component of inflow and with soil and water conservation practices in recent times, little runoff is expected unless daily precipitation exceeds 1.25 inches.

Over the period of record precipitation exhibits cyclic variations. This is substantiated by the droughts of the 1930's, 1950's, and mid-to-late 1970's. Whether or not the precipitation trends of the late 1970's are permanent or merely part of a cycle remains to be seen. More recent records of precipitation would indicate that a return to the cyclic fluctuations more common in the past 60 years would be a probable future condition. With the addition of soil and water conservation practices, the relative amount of precipitation and the magnitude, frequency, intensity, and duration required to produce runoff may have increased.

Riparian Vegetation

Consumption of ground water by riparian vegetation is significant. The consumption by riparian vegetation is estimated to be 18 percent of the total outflow of ground water from the aquifer system over the historic period in the Upper Republican River Basin. It is not known if the amount of riparian vegetation has changed over the historic period. The installation and filling of reservoirs has eliminated some streamside vegetation, but this could have been partially offset by an increase in vegetative growth along reservoir shorelines. There has probably been some decline in vegetation in areas where the water table has declined. Increases in vegetative growth could have occurred in areas where the water table has risen and along streams where the streamflow has increased or stabilized to a more consistent annual flow such as below reservoirs. It also is not known how much vegetation has been removed to make space for agricultural land development.

Riparian vegetation has provided protection to numerous species of wildlife and enabled increases in their numbers. Many of these species provide numerous hours of recreational activity as well as economic benefits to the area. The amount of riparian vegetation in the Upper Republican River Basin in 1978 was determined to be 53,200 acres from Landsat photos. Fader (1968) determined (from aerial photos) that the Lower Republican River Valley between Hardy, Nebraska, and the Clay County line in Kansas contained 3,800 acres of cottonwoods and willows. The remainder of the Lower Republican River Valley below Harlan County Dam was estimated (from 1:250,000 USGS topographic maps) to have 11,700 acres of riparian vegetation. Table 19 shows the riparian acreage by subbasin for the Republican River Basin. Assuming that the riparian vegetation consists essentially of cottonwoods and willows, the estimated average annual depth of consumptive use of the vegetation determined by the Blaney and Criddle (1949) method is 4.1 feet, or a total basin average consumption of 281,500 acre-feet/year of ground water.

Republican River Compact

The Republican River Compact of 1942 is an agreement between the States of Colorado, Nebraska, and Kansas governing the waters of the Republican River and its tributaries and provides for their most efficient use and equitable division. Specific allocations in acre-feet are made to each state derived from the computed average annual virgin water supply originating in each of the designated drainage subbasins of the Republican River Basin.

If the computed annual virgin water supply of any source varies more than 10 percent from the original compact virgin water supply, the allocations made from the water sources in the following years are increased or decreased in relative proportions so that the yearly computed virgin water

Table 19.--Acres of riparian vegetation per subbasin in the Republican River Basin

Subbasin	Acres
South Fork Republican	3,625
Arikaree	941
North Fork Republican	2,528
Frenchman	2,313
Blackwood	365
Red Willow	1,186
Medicine	2,458
Driftwood	254
Beaver and Sappa	9,261
Prairie Dog	3,300
Republican above Harlan County Dam	26,949
Republican from Harlan County Dam to Nebraska-Kansas State line	9,920
Republican from Nebraska-Kansas State line to Milford Dam	5,568

supply is proportional to the original compact computed virgin water supply.

Within Colorado, Nebraska, and Kansas, a total of 54,100 acre-feet, 234,500 acre-feet, and 190,300 acre-feet, respectively, of water is allocated for beneficial consumptive use annually. The water is to be derived from the sources in the amounts specified, subject to such quantities being physically available from the sources.

Water Rights Law

Each state containing the Republican River Basin has specific water rights laws which govern the use of both surface and ground water. The following summarizes the laws by which each state appropriates its surface water and ground water supply.

Colorado

Surface Water.--Colorado is an appropriation doctrine state. Since Colorado was the first state to adopt a pure appropriation system and having never followed the riparian rights theory, the doctrine early became known as the Colorado doctrine. The state engineer is charged with the administration and distribution of the State's waters. As chief of the Division of Water Resources, Department of Natural Resources, he has control over measurement, record keeping, and distribution of the public water of the State.

The State constitution declares that the unappropriated water of every natural stream is the property of the public, subject to appropriation, and that the right to divert unappropriated waters of any natural stream to beneficial uses shall never be denied. The state engineer and division engineers administer and distribute water to water rights holders in accordance with court adjudicated decrees for certain amounts of water and priorities for each right. Administration, distribution, and regulation of the use of water, both surface and ground water, is accomplished through the declaration of rules and regulations, and through the issuance of orders to individual owners and users of water rights.

Ground Water.--Ground water in the State of Colorado is, like surface water, subject to the law of appropriation. This water is characterized as either tributary or not tributary to a major stream.

Tributary ground water includes seepage, underflow, or percolating water, if that water would eventually become a part of a natural stream. A natural stream's waters include water in the unconsolidated alluvial aquifer of sand, gravel, and other sedimentary materials, and other waters hydraulically connected which can influence the rate or direction of movement of the water in that stream. Water rights for tributary water wells must be adjudicated in order to be given priority as to their actual dates of initiation. Ground water is classified as tributary if its withdrawal will significantly deplete any adjacent streams within 100 years at its adjudicated rate of withdrawal as specified on the well permit application.

Nontributary ground water includes all subsurface waters which are not hydraulically connected to any adjacent surface streams and whose withdrawal will not affect the rate or direction of movement of the water in those surface streams. Nontributary ground-water appropriation is based on the area of an applicant's property to which the water is to be put to beneficial use, the estimated quantity of water stored in the aquifer(s) underlying the applicant's property, the estimated annual rate of recharge, the estimated use of ground water in the area, and the number of users drawing water at the time of determination. If there are no unappropriated waters in the designated source, or if the appropriation would unreasonably impair existing water rights, then the application is denied. If the proposed appropriation will not unreasonably impair existing rights, then the permit is granted, subject to any specified conditions or limitations.

Kansas

Surface Water.--As part of the initial settlement and development of the State, Kansas adopted the riparian system of water rights. It was not until 1945 that legislation was enacted which implemented the appropriation system as the exclusive method of acquiring water rights in the State. Under the water code, unallocated water is subject to appropriation while all prior rights, whether appropriation or riparian, are preserved and protected.

The general administrative control of Kansas water resources is vested in the Division of Water Resources, State Board of Agriculture. This division is administered by the chief engineer, who is responsible for administering the statutes governing the appropriation and distribution of the water. All water within the State is dedicated to the use of the people of the State. No person may acquire an appropriation right for the use of water of the State for other than domestic purposes without making an application to the chief engineer for a permit to make such appropriation.

Ground Water.--Kansas ground water, since the adoption of the water code of 1945, is now subject to State administration and control. Prior to this enactment, ground water belonged to the owner of the land overlying it for use as he wished. However, ground water hydraulically connected to a surface stream never belonged to the overlying landowner, but has always been governed by appropriation. The 1945 act dedicated all of the unallocated water to the use of the people of the State and provided that rights, except for domestic use, could only be acquired by filing an application for a permit with the State Chief Engineer. All prior water rights were protected if the ground water was previously put to beneficial use or put to beneficial use within a reasonable time after the act was passed. The owner of an existing right did not acquire a vested right to the existing water level. In considering the effect of new applications on existing ground-water rights, the act specified that impairment is limited to the unreasonable raising or lowering of the static water level. The approval of each application is subject to the express condition that the water right must allow for a reasonable raising or lowering of the static water level.

Special provisions relate to artesian rights. Water obtained by an artesian well and put to beneficial use is considered to be appropriated. In addition, regulation of the drilling, construction, and use of artesian water is specified.

Nebraska

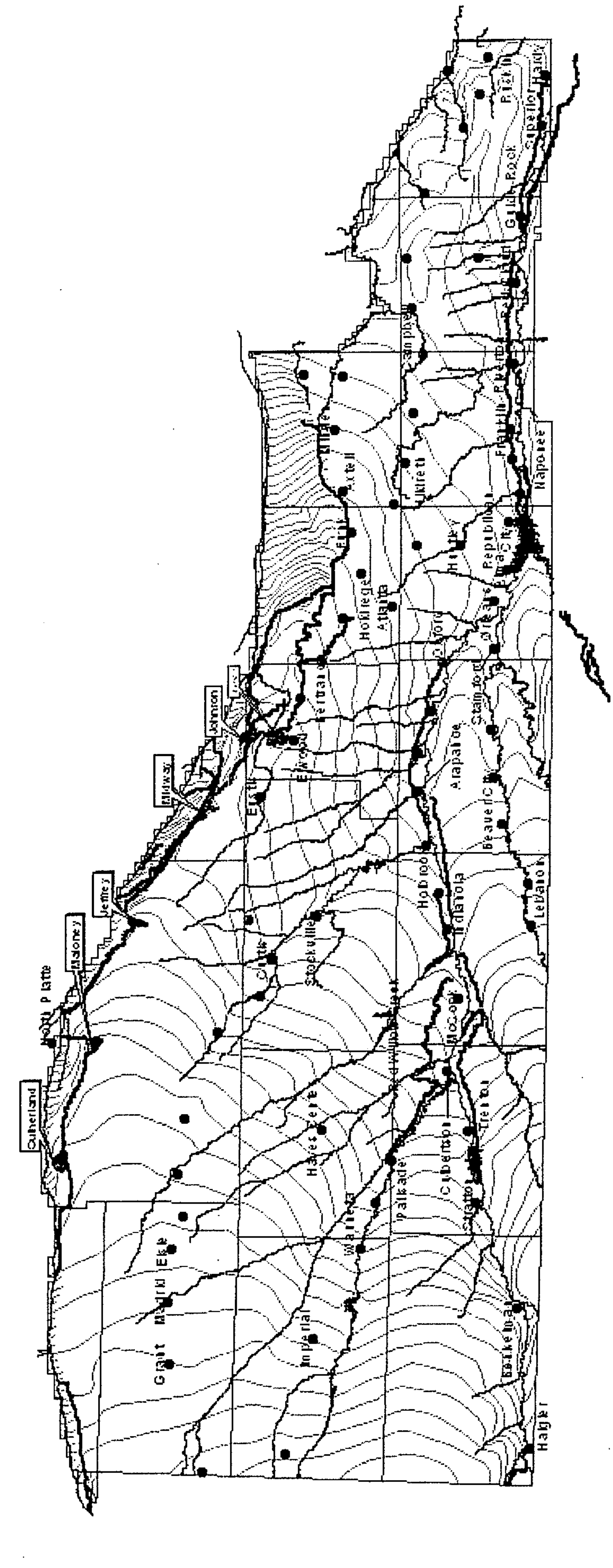
Surface Water.--Early decisions in the 1890's recognized the riparian system in Nebraska. In 1895, a more comprehensive irrigation law was enacted. Under it, the water of every natural stream not already appropriated was declared to be the property of the public and subject to appropriation for a beneficial use. Between users for the same purpose, priority in time of appropriation was recognized as conferring a prior right. However, a preference was accorded to domestic uses which were considered to be the highest value. The Department of Water Resources has supervisory power over all waters of the state, and acts upon all applications to appropriate or store water.

Riparian rights are confined to pre-1895 grants. Between riparians, the common-law doctrine of reasonable use governs their relative rights to the water. Between a riparian and an appropriator, early Nebraska court decisions found the appropriator superior. In 1966, the courts ruled differently. They now consider and decide water right disputes between riparians and appropriators on the basis of equality, having now recognized that both sides possess equally protected interests. Since the preference system applies only to appropriators, riparians may seek the protection of equitable remedy regardless of the contesting use.

Ground Water.--Before 1963, the Nebraska Court followed the "reasonable use" rule as a guide to a landowner's right to appropriate ground water. There was no requirement that a permit be obtained by an appropriator of ground water. A ground-water code adopted in 1963 defines this water as water which occurs, seeps, filters, or percolates through the ground under the surface. Due to the fact that pumping water for irrigation near streams may affect those streams, the legislature required that appropriators secure a permit in such a situation from the Nebraska Department of Water Resources before initiating such use. The department may take into consideration the effect of the pumping on the amount of water in the stream, and the ability of the stream to meet the requirements of appropriators from the stream. Municipalities receive a special preference for domestic use.

Nonproject Water Rights for the Republican River Basin

Applications for permit to appropriate surface water for beneficial use in the Republican River drainage have been summarized from records of the Kansas State Board of Agriculture, Division of Water Resources; Colorado State Engineer's Office; and the Nebraska State Department of Water Resources. Table 20 summarizes the applications for the use of surface water in the Republican River Basin by non-Federal entities. The water right summaries have been grouped according to their location within either


Sutherland
North Platte
Maloney
Jeffrey
Midway
Johnson
Naponee
Lebanon
Indianola
Imperial
Grant
Culbertson
Trenton
McCook
Stockville
Palisade
Wauneta
Arapahoe
Axtell
Holdrege
Haigler
Guide Rock
Franklin
Republican
Alma City
Stamford
Beaver City
Bertrand
Elwood
Eustis
Curtis
Hayes Center
Madrid
Elsie