SUMMARY APPRAISALS OF THE NATION'S GROUND-WATER RESOURCES--SOURIS-RED-RAINY REGION

by Harold O. Reeder, 1923-

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SUMMARY APPRAISALS OF THE NATION'S

GROUND-WATER RESOURCES- -

SOURIS-RED-RAINY REGION

by Harold O. Reeder

ABSTRACT

A broad-perspective analysis of the ground-water resources and present and possible future water development and management in the Souris-Red-Rainy Region is presented. The region includes the basins of the Souris River within Montana and North Dakota; the Red River of the North in South Dakota, North Dakota, and Minnesota; and the Rainy River within Minnesota. The region includes 59,645 square miles, mostly in North Dakota and Minnesota.

The terrain is relatively flat, but ranges in altitude from 2,541 to 750 feet. Annual average precipitation ranges from 14 inches in the west to 28 inches in the east and about 75 percent of it is rain. The mean annual snow fall ranges from 32 inches in the west to 64 inches in the east. Temperatures range from -55° to $118^{\circ}F$ (-48.3° to $47.8^{\circ}C$). Irrigation is needed at least part of the time to assure crop production, particularly in the western part of the region.

Sand and gravel deposits in the drift form the most important fresh-water aquifers. Other aquifers are found in at least parts of the region in the Precambrian, Paleozoic, Cretaceous, and Tertiary rocks. The potentiometric surface in the bedrock generally decreases in altitude toward the Red River of the North, indicating that the general direction of ground-water movement is toward the river.

Ground-water with less than 3,000 milligrams per liter dissolved solids is available throughout the region. Ground water with less than 1,000 milligrams per liter occurs in most of the region east of the Red River of the North and in most of the shallow aquifers west of the river. The total volume of water available from storage having less than 3,000 milligrams per liter dissolved solids is estimated to be 5×10^8 acre-feet. In addition to the fresh and slightly saline water, the region has abundant highly mineralized water that can be considered as a resource. Yields of wells in individual bedrock aquifers are generally less than 100 gallons per minute but locally yields may be as much as 500 gallons per minute and more. Yields in drift aquifers are frequently less than 100 gallons per minute but range from 5 to 1,000 gallons per minute. In a few places outwash yields more than 1,000 gallons per minute.

Ground water is the sole or a primary source of water supply in much of the region, including supplies for irrigation, domestic and livestock, municipal, and industrial needs. Reportedly, the potential irrigation development is 1,550,000 acres, as compared with 50,200 acres in 1975. Both ground- and surface-water supplies would be required to meet these demands. Rural domestic and livestock water supplies are derived almost entirely from ground-water sources. Smaller communities and towns generally rely on ground water, and the cities and industries use ground water, surface water, or both. The municipalities using surface water generally depend upon reservoir storage. Water quality rather than quantity is the greater water-supply problem for many communities in the region.

Increased demands on both ground-water and surface-water supplies likely will be made in the future. Storage of surface water in the ground-water reservoirs during times of surplus for withdrawal during times of scarcity would aid in meeting these demands. The surplus (flood) water is of better chemical quality than underlying ground water in parts of the western half of the region. Fresh water could be stored in saline- or fresh-water aquifers, and pumped out later, as needed. Thus, the ground-water reservoirs have a definite present and potential role in water management.

To understand the hydrologic system for management purposes there is a need to determine more adequately the geologic and hydrologic characteristics of existing aquifers and the location of new aquifers. Also, as pumping and other stresses on any part of the hydrologic system affect other parts of the system, monitoring programs ideally should be started and maintained to detect changes and determine effects of the stresses.

Many alternatives are available for managing water in the region. Some of these are operational and others are undergoing research. Adequate hydrologic information is needed to aid in solving problems of water supply, use, and pollution.

INTRODUCTION

Purpose and Scope of this Report

The purpose of this report is to present a broad-perspective analysis of ground-water resources in the Souris-Red-Rainy Region. The region's ground water is a large and manageable resource that could have a more significant role in regional water development. This report is one of a U.S. Geological Survey series that summarizes information on the Nation's ground water for the guidance of planners. New data were not collected for this appraisal, but information from many sources has been utilized.

In addition to summarizing the knowledge of ground-water resources of the region, the report points out deficiencies in knowledge. The primary objective of evaluating information deficiencies is to direct attention to types of studies and information that will lead to fuller understanding and description of ground-water reservoirs for better evaluation, planning, and management of the region's water resources. With proper knowledge, utilization, and conjunctive management of all water resources, ground water can assume greater significance in the region's development.

Most numbers in this report are given in English units, ~~followed by metric units in parentheses~~. The conversions to metric units ~~were~~ are made as follows:

English			Metric	
Unit	Abbreviation	Multiplied by	Unit	Abbreviation
Inches	in	25.4	millimeters	mm
Feet	ft	.3048	meters	m
Miles	mi	1.609	kilometers	km
Acres		.004047	square kilometers	km^2
Square miles	mi^2	2.590	square kilometers	km^2
Gallons	gal	.003785	cubic meters	m^3
Cubic feet	ft^3	.02832	cubic meters	m^3
Acre-feet	acre-ft	1233	cubic meters	m^3
Gallons per minute	gal/min	.06309	liters per second	l/s
Cubic feet per second	ft^3/s	28.32	liters per second	l/s
Million gallons per day	M gal/d	.04381	cubic meters per second	m^3/s

Chemical concentrations are given only in metric units -- milligrams per liter (mg/l). For concentrations less than 7,000 mg/l, the numerical value is practically the same as for concentrations in the English unit, parts per million.

Physical Setting

The region is located along the northern boundary of the United States in North Dakota and Minnesota and extends short distances into Montana and South Dakota (fig. 1).

Figure 1 belongs near here.

The region discussed in this report includes that part of the three river basins within the United States. The region, which includes 59,645 square miles in the United States, drains northward into Hudson Bay. The Red River of the North, hereafter referred to as the Red River, drains 39,199 square miles in the central part of the region and flows into Lake Winnipeg and Nelson River to Hudson Bay (all in Canada and not shown on map). The Souris River drains 9,142 square miles in the western part of the region, joins the Assiniboine River in Manitoba, Canada, and flows into the Red River. The Rainy River drains 11,304 square miles in the eastern part of the region, flows through Lake of the Woods to the Winnipeg River in Canada, and eventually joins the Nelson River in Canada. The three river basins in the United States are in the Western Lake section of the Central Lowland physiographic province (Fenneman, 1931).

Figure 1.--Location map of Souris-Red-Rainy Region showing subbasins.

The terrain is relatively flat. One of the most prominent features is the plain along the Red River from 30 to 50 miles wide and 315 miles long. During the glacial epoch the Red River was occupied by glacial Lake Agassiz (fig. 1a). Its outlet was

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Figure 1a belongs near here.

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southward into Big Stone Lake (outside the region) and through the present valley of the Minnesota River. Altitude ranges from 2,541 feet in north central North Dakota to 750 feet where the Red River crosses the Canadian boundary. Figure 1a Also shows the location of other former glacial lakes in the region.

Figure 1a.--Location of glacial lakes in the Souris-Red-Rainy Region.

Regional Water Supply

Precipitation is the ultimate source of water supply. Average annual precipitation in the region ranges from about 14 inches in the west to 28 inches in the east (fig. 2).

Figure 2 belongs near here.

About 75 percent of the annual precipitation is rain. The mean annual snowfall ranges from about 32 inches in the west to 64 inches in the east (fig. 3). Precipitation is adequate

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Figure 3 belongs near here.

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for crop production during normal years, although the western half of the region has occasional droughts. The average annual natural runoff originating within the region ranges from less than 0.2 inch in the western part of the Souris River basin to about 15 inches in the eastern part of the Rainy River basin (fig. 4) owing to less precipitation and

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Figure 4 belongs near here.

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higher evapotranspiration rate in the west than in the east. Generally, minimum flows occur during the winter under ice cover 2 to 4 feet thick. Maximum flows generally occur during the spring breakup, and about 50 percent of the annual flow occurs during April and May.

Figure 2.--Map showing average annual precipitation.

Figure 3.--Map showing average annual snowfall.

Figure 4.--Map showing average annual runoff.

The quantity and quality of water resources differ greatly from place to place, season to season, and year to year. In the Souris River basin, streamflow is normally inadequate to satisfy water needs, and the quality is marginally acceptable for most present uses. During normal years, streamflow in most of the Red River basin is adequate, and the quality is generally satisfactory for the predominantly agricultural demands of the basin. However, water quality in the main stem of the Red River is poor due to heavy sediment loads; periodic low flows with attendant increases in dissolved solids; and increasing municipal, industrial, and agricultural pollution. Water is abundant for the extent of present development in the Rainy River basin, and, except below International Falls and Shagawa Lake at Ely, its quality is excellent for most uses (U.S. Water Resources Council, 1968, p. 6-8-3).

The glacial aquifers and much of the bedrock are recharged by water from precipitation within the region. Some ground-water recharge is from surface-water bodies and from bedrock aquifers of adjacent regions. Recharge to the ground-water reservoirs from precipitation can occur only after the soil moisture deficiency is satisfied. Water requirements of plants and the intensity and duration of a rain, and certain additional factors such as soil type, also affect the amount of recharge. Consequently, recharge is not necessarily proportional to rates of precipitation, although, when the precipitation rate is large, recharge is generally greater than during relatively dry periods.

Recorded temperature extremes range from -55° to 118°F (-48.3° to 47.8°C, or Celsius); however, mean monthly temperatures range from a monthly minimum of about -10°F (-23.3°C) in January to a monthly maximum of about 85°F (29.4°C) in July (U.S. Geological Survey, 1970, p. 104-107). The occasional droughts, hot winds, and prolonged high temperatures that occur, particularly in the western half of the region, cause crop failure and create the need for irrigation at least part of the time. Large quantities of ground water evaporate through the swamps, marshes, lakes, and streams. The average annual lake evaporation rate ranges from 36 inches in the west to less than 24 inches in the east (fig. 5).

Figure 5 belongs near here.

Discharge from aquifers occurs naturally and by pumping. Natural discharge occurs by flow into adjacent rocks having lower hydraulic head, by seepage into streams, as springs, and by evapotranspiration. Trends in water levels reflect the balance or imbalance of ground-water recharge and discharge. Current pumping is not large enough to cause a significant general impact. Significant water-level declines are noted, however, in several areas (Kenmare, Minot, Fargo-West Fargo-Moorhead, and Hatton areas).

Ground water constitutes a major element of the region's water supply, as discussed in detail in the following section.

Figure 5.--Map showing average annual lake evaporation.

GROUND-WATER RESOURCES

Ground water in the Souris-Red-Rainy region is obtained mainly from aquifers in Pleistocene drift such as drainage-channel deposits, lake deltas, beach deposits, outwash deposits, and small bodies of sand and gravel interbedded with till. In addition, the Souris and Red River basins in North Dakota have aquifers of Precambrian and Paleozoic ages; the Dakota, Pierre, and Fox Hills-Hell Creek aquifers of Cretaceous age; and the Fort Union aquifer of Tertiary age (Crosby and others, 1973, p. 176). In the Red and Rainy River basins in Minnesota, aquifers are of Precambrian, Paleozoic, and Cretaceous ages. The total volume of water having less than 3,000 mg/l of dissolved solids available from storage in the region is estimated to be 5×10^8 acre-feet. The estimate is based on areas, estimated and known saturated thicknesses, and estimated and known specific yields of the various aquifer materials.

The Souris-Red-Rainy Region is underlain by a series of bedrock units that differ greatly in thickness and in hydrologic characteristics and that range in age from Precambrian to Quaternary. Precambrian crystalline rocks are at or near the land surface (about 1,300 feet (400 m) above mean sea level) locally in the eastern part of the region and about 15,000 feet (4,570 m) below the surface (about 12,000 feet (3,660 m) below mean sea level) in the center of the Williston Basin (figs. 5a and 5b). The central and deepest part of this basin is in

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Figures 5a and 5b belong near here.

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the westernmost part of North Dakota, southwest of and beyond the limits of the Souris River basin (fig. 5a). Most of North Dakota, including the Souris and the western part of the Red River basins, is in Williston Basin, which extends northward into Canada, southward into South Dakota, and westward into Montana. Sediments of Paleozoic, Cretaceous, and Tertiary age were deposited in the Williston Basin. Rocks formed from these sediments gradually thin in an eastward direction and are missing in the southern and eastern parts of the Red River basin and in the Rainy River basin, where Precambrian rocks directly underlie the glacial deposits (fig. 5b).

Figure 5a.--Map showing location of the Williston Basin.

Figure 5b.--Diagramatic section of North Dakota and Minnesota showing location of aquifers.

The oldest Paleozoic beds dip westward at an average slope of nearly 50 feet per mile (9.5 m/km) across the eastern three-fourths of North Dakota, but the Tertiary beds dip westward at ~~an average slope of~~ only a few feet per mile (Crosby and others, 1973, p. 176). Sedimentary rocks of Ordovician age overlie the crystalline rocks in most of the Red River and Souris River basins, sloping and thickening westward. Rocks of Jurassic and Cretaceous age, which thicken westward from the west border of Minnesota overlie the Paleozoic rocks. Tertiary rocks occur on the west edge of the Red River basin and in much of the Souris River basin (Glover and others, 1972).

The entire region has been glaciated, and most of it is covered with drift that ranges in thickness from less than a foot (0.3 m) to several hundred feet. The drift is ~~made up~~ largely ~~of~~ till, a heterogeneous mixture of clay, silt, sand, and gravel, but it also contains buried lenses of stratified sand, gravel, silt, and clay, which were deposited along the margin of the glacier or near it. The buried sand units, which range in thickness from a few inches to many feet, cover areas of many square miles.

Lake Agassiz sediments significantly affect the hydrologic system in the Red River basin because they are extremely fine grained, thick, and widespread. The thickness of these sediments in the Minnesota part of the lake deposits ranges from less than 1 foot (0.3 m) to more than 140 feet (43 m) (Maclay and others, 1972, p. 29).

Small yields of water are obtained from bedrock aquifers underlying the drift in the Souris and Red River basins. In parts of the Rainy River basin, where productive glacial deposits are thin or absent, small yields of water are obtained locally from fractures in the crystalline bedrock (Glover and others, 1972, p. B-27, B-52, B-77).

Yields of wells in individual bedrock aquifers are generally less than about 100 gal/min but may be as much as 500 gal/min locally, and more than 500 gal/min in a few places. Yields in drift aquifers average less than 100 gal/min but range from 5 to 1,000 gal/min. A few wells in outwash yield more than 1,000 gal/min. Table la is a list of aquifers and range of yields to wells.

Table 1a.--Aquifers and well yields in the Souris-Red-Rainy Region.

(Bedrock aquifers: adapted from Crosby and other, 1973, p. 176-185; and Glover and others, 1972, Tables B-10, B-16, B-24; glacial drift aquifers: adapted from Glover and others, 1972, Tables B-11, B-12, B-17, B-18, B-19, B-24, and Q. F. Paulson, written communi~~cation~~, 1976.)

Aquifer	Well yields (gal/min)		
	Common rate pumped	General range	Largest known
Drift	<100	5-1,000	more than 1,000
Fort Union	2-4	<1-50	100
Fox Hills-Hell Creek	<5	<1-30	150
Pierre	<5	<1-6	100
Dakota	2-3	<1-350	500
Paleozoic	<5	<1-60	700
Precambrian	<5	<1-10	

< less than

The potentiometric surface in the bedrock formations generally decreases in altitude toward the Red River, indicating that the regional direction of water movement is toward the river. In the Rainy River basin, some ground water probably migrates westward into the Red River basin; but most ground water moves northwestward and is discharged from the area through the Rainy River and Lake of the Woods (Glover and others, 1972, p. B-53, B-77). These regional patterns of movements of the ground water indicate that recharge from precipitation on upland areas, from surface water, and from ground water entering from adjacent regions moves regionally to discharge areas along the Red River Valley. The general ground-water flow system is much more complex because of the many local flow patterns within the regional system. Much of the ground-water discharge occurs near ~~the place of~~ recharge area within the ~~Souris-Red-Rainy~~ Region. (See Maclay and others, 1972, p. 104-113).

— much

Precambrian Aquifer

Precambrian crystalline rocks, which underlie all of the region, generally are poor aquifers, but locally are sources of small supplies. Along the southeastern edge of North Dakota, and in the eastern part of the Red River basin in Minnesota and in most of the Rainy River basin (fig. 6), small supplies of

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Figure 6 belongs near here.

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water can be obtained from the fractures or from weathered zones in the upper part of the crystalline rocks. Generally, wells in the Precambrian aquifer will not yield more than a few gallons per minute (Crosby and others, 1973, p. 176). The Precambrian rock surface also generally defines the base of the water-yielding zone of the hydrologic system. The general slope of the crystalline rock surface is from east to west (Maclay and others, 1972, p. 23). (See figure 5b.)

Figure 6.--Map showing areal extent of bedrock aquifers in the Souris-Red-Rainy Region.

Paleozoic Aquifer

Water occurs in the Paleozoic rocks in the Souris River basin and in most of the Red River basin (fig. 6). Although there are several water-bearing units within the Paleozoic rocks, data are insufficient to determine the areal extent, thickness (except locally), and degree of interconnection of the individual units; therefore, all water-bearing Paleozoic rocks are treated here as a single aquifer. The top of the aquifer occurs at depths of about 150 feet in eastern North Dakota and deepens westward to more than 13,500 feet at the bottom of the aquifer in western North Dakota, beyond the limits of the region (figs. 5a and 5b). It is composed of fine-grained sandstone which yields small dependable supplies of water; and porous, cavernous limestone, which yields large supplies of water. The salinity of the water, however, severly limits its usefulness. Production of water in eastern North Dakota is limited to one industrial well that flows, when not closed, at a rate of about 700 gal/min, and a few domestic wells that are used for sanitation. Water from the Paleozoic aquifer also is produced with oil in the western part of the region (Crosby and others, 1973, p. 177). Because of the highly saline water, the Paleozoic aquifers in Minnesota have never been used. Test holes into the Paleozoic rocks have flowed as much as 60 gal/min (Maclay and others, 1972, p. 60).

Dakota Aquifer

The Dakota aquifer, which is composed of basal Cretaceous sandstone and shale, underlies all of the souris River Basin and the western half of the Red River basin (fig. 6). Aquifers in Cretaceous rocks, which probably are equivalent to the Dakota aquifer, underly the northwestern Red River basin in Minnesota. The depth to the top of the Aquifer gradually increases from 100 feet (30 m) along the eastern limit of the aquifer in the Red River basin to more than 5,600 feet (1,700 m) in the deepest part of the Williston Basin southwest of the Souris River basin (fig. 5a). The aquifer materials differ from place to place, but generally consist of interbedded quartzose sand and shale. Sand predominates in the eastern part of North Dakota and shale predominates in the western part.

In the eastern part of North Dakota, the individual sand beds generally are less than 30 feet (9 m) thick, but locally are as much as 100 feet (30 m) thick. They generally are composed of fine, medium, or coarse sand that has very little interstitial silt or clay. Interstitial silt and clay decreases permeability of the aquifer and, thus, decreases well yields and the rate of flow of water through the aquifer. In the western part, individual beds generally are composed of fine sand and minor amounts of medium sand, and interstitial silt and clay are more common (Crosby and others, 1973, p. 178).

Numerous wells tap the Dakota aquifer in the eastern part of North Dakota. Most of these wells are for domestic and stock use but a few are for municipal and industrial purposes. Flowing wells in the Dakota have discharges that range from less than 1 to 100 gal/min and average 2 to 3 gal/min in most of the Souris-Red-Rainy Region. Pumping rates in excess of 500 gal/min are obtained from some wells (Crosby and others, 1973, p. 179). In the Souris basin part of the region potential well yields range from 50 to 350 gal/min. This water is used mostly by the oil industry for maintaining pressure in oil reservoirs (Glover and others, 1972, p. B-31).

Pierre Aquifer

The Pierre aquifer is in the upper part of the Pierre Shale of Cretaceous age in the eastern part of the Souris River basin and the western part of the Red River basin (fig. 6). The aquifer may extend westward for a short distance beneath the Fox Hills-Hell Creek aquifer, but no data are available to determine the western limit accurately.

The Pierre is composed of light-gray to black siliceous shale, marlstone, and claystone, and is locally fractured in the upper part. ~~Textural materials of the~~ Unfractured shale, marlstone, and claystone are nearly impermeable and will not yield a significant amount of water to wells; therefore, the fractured zones are the only sources of water. The fractures, where present, may extend several hundred feet below the land surface, but they generally are too small to yield significant quantities of water below depths of about 100 feet (30 m) (Crosby and others, 1973, p. 180).

Although the Pierre is not a major aquifer, it is the only source of water for many farms and a few municipal supplies. Most farm wells yield less than 6 gal/min ~~(0.4 l/s)~~. Locally, where the fracture zone is exceptionally thick or the fractures unusually large, pumping rates range from 50 to 100 gal/min (3 to 6 l/s) (Crosby and others, 1973, p. 180).

Fox Hills-Hell Creek Aquifer

The Fox Hills-Hell Creek aquifer of Cretaceous age underlies most of the Souris River basin (fig. 6). The depth to the top of the aquifer gradually increases from a few feet in topographically low areas near the eastern boundary of the aquifer to more than 1,400 feet (400 m) in topographically high areas near the center of the Williston Basin southwest of the Souris basin (fig. 5a). The aquifer is composed of interbedded sand, clay, silt, and lignite, but the lithology differs considerably from place to place. Many of the individual sandy layers in the aquifer are thin and lenticular and do not extend for more than a few miles. However, at least one and commonly more than one, sandy layer more than 20 feet (6 m) thick are present. Generally, the individual sandy layers are composed of fine to medium sand with interbedded silt and clay lenses, but locally the sandy layers may be either very fine sand or include considerable amounts of interstitial silt (Crosby and others, 1973, p. 180).

Wells in the Fox Hills-Hell Creek aquifer generally yield less than 30 gal/min (2 l/s); but locally where the sandy layers are unusually thick or contain very little interstitial or interbedded silt or clay, yields may be as much as 150 gal/min (9 l/s). Most of the water is used for rural domestic and stock purposes (Crosby and others, 1973, p. 181).

Fort Union Aquifer

Sand and lignite beds in the Fort Union Formation of Teritiary age form the Fort Union aquifer in the western two-thirds of the Souris River basin (fig. 6). The Fort Union, which may be as thick as 1,100 feet ~~(335 m)~~ near the center of the Williston Basin, is composed of beds of silty clay, clay, sand, and lignite. Individual beds in the formation generally cannot be traced as much as mile ~~(1.6 km)~~; however, ~~there are~~ a few exceptionally thick and extensive beds ~~that~~ extend many miles. Most sand beds are less than 10 feet ~~(3 m)~~ thick, but some are as much as 150 feet ~~(45 m)~~ thick. Lignite beds generally are 2 to 5 feet ~~(0.6 to 1.5 m)~~ thick, but thicknesses of as much as 40 feet ~~(12 m)~~ have been reported. The sand is generally fine, with medium sand reported locally. The sand also may contain considerable amounts of interstitial clay (Crosby and others, 1973, p. 181-182).

The nonmarine Tongue River Member of the Fort Union Formation, stratigraphically ~~occuring~~ in the upper part of the formation, is the principal bedrock aquifer in the Souris River basin. The underlying marine Cannonball Member yields water that is used for watering livestock but that is generally too salty for human consumption, according to Glover and others (1972, p. B-27). Although there may be several aquifers in the Fort Union Formation, data generally are insufficient to determine the areal extent, thickness, or degree of interconnection of the units; therefore, all water-bearing units in the Fort Union are considered here as a single aquifer.

The quantity of water the Fort Union aquifer will yield to wells depends on 1) the thickness, sorting, and grain size of the sand beds, and 2) the quantity of interstitial or interbedded clay ~~in the vicinity of~~ near each well. Properly constructed wells finished in sand beds ~~that are~~ as thick as 100 feet ~~(30 m)~~ will yield as much as 50 gal/min ~~(3 l/s)~~ with 20 feet (6 m) of drawdown. A few wells will yield as much as 100 gal/min ~~(6 l/s)~~, but drawdowns are greater than 20 feet ~~(6 m)~~. Most wells that tap the Fort Union aquifer are used for rural domestic and stock supplies. Some wells, however, are used for municipal and industrial supplies. Most farm wells are completed in the uppermost saturated sand lens. The wells commonly are equipped with cylinder pumps generally having capacities of only 2 to 4 gal/min ~~(0.1 to 0.2 l/s)~~ (Crosby and others, 1973, p. 182).

Drift Aquifers

Drift aquifers of Quaternary age, which are the most important sources of ground water in the ~~Souris-Red-Rainy~~ Region, are distributed throughout most of the Souris and Red River basins and part of the Rainy River basin. Although most of the drift in the region is composed of several tens to several hundred feet of till, which yields little or no water to wells, some of the drift consists of stratified ~~glaciofluvial deposits of~~ sand and gravel which form important sources of water supply (Crosby and others, 1973, p. 183). In the Rainy River basin, however, glacial erosion rather than deposition was the primary process shaping the surface of the land, and the deposits are thin or absent, except in the south and west parts of the basin where the glacial deposits thicken to nearly 250 feet ~~(76 m)~~ (Glover and others, 1972, p. B-77). Figure 7 shows the areal distribution of known major drift aquifers and the expected

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Figure 7 belongs near here.

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yields to wells of water having less than 3,000 mg/l of dissolved solids. Ranges in yields to wells in the various aquifers delineated in figure 7 have been simplified ~~in the illustration~~ from those tabulated by Glover and others (1972).

Figure 7.--Map showing expected yields of individual wells.

Most of the aquifers ~~were formed~~ are either ~~as~~ valley fill or outwash deposits. Melt water flowing from and along the ice front deposited outwash and ice-contact deposits in a network of channels. During subsequent periods of glacial advance and retreat, old channels were blocked and new ones formed. Each successive advance of glacial ice ~~tended to~~ smoothed the terrain by filling the valleys and eroding the hills. Parts of these channels were subsequently filled with sand, gravel, and till, such as the New Rockford aquifer in east-central North Dakota. ~~and~~ Some of these glacial channels are now occupied by modern streams, as illustrated by the Sheyenne River valley in southeastern North Dakota. Deposits in these channels form numerous aquifers scattered throughout the Red and Souris River basins and the western part of the Rainy River basin as shown by the long narrow patterns on figure 7. Many of the earlier channels were buried by subsequent glacial deposits, and most of the glacial channels exposed at the surface were formed during the most recent advance of glacial ice. Outwash deposits in these youngest channels are generally thin, and only locally form significant aquifers.

The deposits in Glacial Lake Agassiz, in the center of the Red River basin, occupy almost one-third of the area of the basin (fig. 1a). These deposits are generally too fine grained to be important as a source of ground water. However, some lakeshore deposits, such as deltas and beach ridges, are coarse grained and form important aquifers (Glover and others, 1972, p. B-29, B-53). The Sheyenne delta aquifer in the southeast corner of North Dakota is a notable example (Glover and others, 1972, p. B-62). Fine-grained sediments also were deposited in Glacial Lakes Cando, Dakota, and Devils Lake in the western part of the Red River basin and in Glacial Lake Souris in the Red and Souris River basins (fig. 1a).

Alluvium deposited after the glacial periods consists of silt, sand, and gravel in the valleys of some of the larger streams. These deposits generally are finer grained and less permeable than the outwash deposits, but locally they provide sources of water.

The ability of the deposits to yield water to wells depends on the grain size and thickness of the materials, but in broad view and ultimately the quantity of water that an aquifer will yield depends on the amount of water in storage and on the amount of recharge. If a sand or gravel deposit is small and enclosed in till or other fine-grained material, it receives little recharge; consequently, such deposits will not yield large quantities of water for sustained periods. Large deposits of saturated sand and gravel, however, contain large quantities of water in storage and may be capable of receiving sustained quantities of recharge over the large area of contact with the clay layers, even if they are enclosed within fine-grained deposits; consequently, such deposits form major aquifers that will yield substantial quantities of water for sustained periods (Crosby and others, 1973, p. 183).

Quality of Ground Water

The chemical quality of water can be classified according to its dissolved-solids concentration. The classification of Winslow and Kister (1956, p. 5) used by the U.S. Geological Survey is as follows:

Class	Dissolved solids (mg/l)
Fresh	less than 1,000
Slightly saline	1,000 - 3,000
Moderately saline	3,000 -10,000
Very saline	10,000 -35,000
Brine	more than 35,000

Figure 8 shows areas in the Souris-Red-Rainy Region where

Figure 8 belongs near here.

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ground water occurs with less than 1,000 mg/l and with 1,000 to 3,000 mg/l dissolved solids. Ground water with less than 3,000 mg/l dissolved solids is available throughout the region; however, yields may be small.

Figure 8.--Map showing dissolved solids in ground water.

In addition to the fresh and slightly saline water, the region has abundant highly mineralized water. Robinove and others (1958, p. 9) state that many of the formations in North Dakota are capable of yielding only very small supplies of water. The Pierre Shale, for example, yields only minor amounts of saline water to many wells in the eastern part of North Dakota. Table 1 lists and describes water-yielding formations and their water-quality and water-supply potential.

Table 1.--Description of aquifers, water quality, and water-supply potential in the Souris-Red-Rainy Region.
[Compiled from Crosby and others, 1973; Glover and others, 1972; and Robinove and others, 1958.]

(Small yields are 5 to 150 gal/min, moderate yields 150 to 350 gal/min, and large yields more than 350 gal/min.)

Aquifer	Character of Rocks	Water Quality	Water-Supply Potential and Aquifer Occurrence
Drift and alluvium	Drift: Till, outwash, and lacustrine deposits. Alluvium: gravel, sand, silt, and clay.	Extremely variable from place to place Dissolved solids generally 250 to 1,000 mg/l, but may be as high as 3,000 to 10,000 mg/l in a few places.	Extremely variable from place to place. Large potential for large supplies in sand and gravel aquifers. Large potential for small supplies almost everywhere in region.
Fort Union: Upper part of Fort Union	Sandstone, shale and lignite.	Sodium bicarbonate type and locally high sulfate. Dissolved solids 200 to 7,000 mg/l.	Small to moderate supplies. Occurs in western two-thirds of Souris basin.
Fort Union: Cannonball member of Fort Union	Marine sandstone and sandy shale.	Sodium chloride type. Dissolved solids less than 3,000 mg/l, most water ranges from 1,000 to 2,500 mg/l.	
Fox Hills-Hell Creek	Sandstone; sandstone and shale.	Sodium bicarbonate type generally, sodium sulfate type locally. Dissolved solids 300 to 3,700 mg/l, but most water contains 1,000 to 2,000 mg/l.	Small to moderate supplies. Occurs in most of Souris basin and extreme western parts of Red basin.
Pierre	Shale, brittle, fissile; upper part fractured.	Extremely variable from place to place . Sodium chloride, sodium sulfate type, or combination. Dissolved solids 700 to 12,500 mg/l but most is less than 3,000 mg/l.	Widely used for domestic and stock supplies. Occurs in eastern part of Souris basin and western two-thirds of Red basin.
Dakota	Sandstone and shale.	Souris basin: Sodium chloride type, dissolved solids 4,000 to 15,000 mg/l. Red basin: Sodium sulfate type, dissolved solids 2,000 to 8,000 mg/l in North Dakota, less than 2,000 mg/l in Minnesota.	Moderate to large supplies. Occurs in western two-thirds of region.
Paleozoic	Shale, sandstone, limestone, and dolomite.	Highly saline. Dissolved solids 14,000 to 54,000 mg/l in central part of Red basin, and as high as 330,000 mg/l in western North Dakota.	Potential for development of small to large supplies. Occurs in North Dakota and northwestern corner of Minnesota.
Precambrian	Crystalline rocks, upper part fractured and weathered.	Sodium bicarbonate sulfate type, depending largely on type in the adjacent aquifer. Dissolved solids about 1,000 mg/l or more in Red basin, less than 500 mg/l in Rainy basin.	Small supplies, low yields. Occurs in Minnesota and eastern North Dakota.

The quality of ground water in the Souris-Red-Rainy Region differs from place to place, even within an aquifer. Generally, water with the best quality is in or near recharge areas (p. 19, 28) or areas with flow sufficient to flush out saline water. Water in surficial outwash in or near recharge areas almost everywhere contains less than 1,000 mg/L dissolved solids and in many places less than 500 mg/L. Highly mineralized water is found in older, deeper rocks in much of the region and in shallow aquifers where water has migrated from mineralized aquifers. For example, in the north-central part of the Red River basin, highly mineralized water migrates upward into the drift from the underlying Paleozoic and Dakota aquifers. Water in the drift in these areas generally is a sodium chloride type, with many of the characteristics of the water in the underlying bedrock (Crosby and others, 1973, p. 195).

In the Pierre aquifer, water is a sodium chloride or sodium sulfate type or a combination of the two. The dissolved-solids concentration ranges from 700 to 12,500 mg/L, and the shallow fractured zone generally yields water with 2,000 to 4,000 mg/L dissolved solids. Most of the water in the Pierre aquifer contains greater quantities of chloride or sulfate, or both, than the limits for drinking water recommended by the U.S. Public Health Service (1962). The Pierre is not a highly productive aquifer, but it is the only source of water for many farms and a few municipalities (Crosby and others, 1973, p. 194).

Water in the Fox Hills-Hell Creek aquifer generally is a sodium bicarbonate type, but locally the water is a sodium sulfate type. Although water from the Fox Hills-Hell Creek aquifer ranges from about 300 to 3,700 mg/l dissolved solids, water containing less than 1,000 mg/l dissolved solids occurs near outcrop areas, where little drift overlies the aquifer. Most of the water that contains more than 2,500 mg/l of dissolved solids occurs where significant thicknesses of drift cover the Fox Hills-Hell Creek aquifer. The drift probably contributes much of the dissolved-solids concentration to recharge water that reaches the Fox Hills-Hell Creek aquifer (Crosby and others, 1973, p. 194).

Water in the Fort Union aquifer is a sodium bicarbonate or sodium sulfate type in different places. However, some of the water from the deeper parts of the aquifer in the northern part of North Dakota is a sodium chloride type, with chloride concentrations as high as 3,830 mg/l. Elsewhere, the water in the Fort Union aquifer generally contains less than the U.S. Public Health Service recommended limit for chloride of 250 mg/l.

The quality of water differs greatly among shallower (300 feet or less) wells in the Fort Union aquifer. Dissolved-solids concentrations range from about 200 to 6,700 mg/L in North Dakota. Most water in the Fort Union aquifer that contains more than 3,000 mg/L dissolved solids is in areas covered with drift. The dissolved-solids concentrations in most of the deeper part of the aquifer is in the 1,000- to 2,500-mg/L range. The high sodium and dissolved-solids concentrations generally make the water from the Fort Union aquifer unsuitable for irrigation (Crosby and others, 1973, p. 194).

In most of the Red River basin in Minnesota the dissolved-solids concentrations in the drift are between 300 and 600 mg/L (Maclay and others, 1972, p. 62, 63). In the Rainy River basin and in the northeastern part of the Red River basin, the dissolved-solids concentrations in the drift are less than 300 mg/L. The dissolved solids in drift aquifers in the Red and Souris River basins in North Dakota are generally greater than 600 mg/L. Dissolved solids in the drift in North Dakota are as high as 26,200 mg/L, although most water in areas where flow is upward from bedrock aquifers contains less than 10,000 mg/L (Crosby and others, 1973, p. 195).

ROLE OF GROUND WATER IN WATER-RESOURCES MANAGEMENT

Increased demands on ground-water and surface-water supplies of the Souris-Red-Rainy region will be made in the future (Souris-Red-Rainy River Basins Commission, 1972, p. 15; and Ferris and others, 1972, p. G-3, G-5). The population is expected to increase 20 percent between 1960 and 2020 but the municipal and rural domestic water uses are expected to increase 90 percent. Increased irrigation and industrial uses will cause even greater demands on the water supply. Municipal and industrial growth in an area generally depend directly upon the availability of adequate supplies of water of suitable quality. Anticipated usage may result in ground-water shortages. Little difficulty is expected in meeting this need in the eastern part of the Souris-Red-Rainy Region, but in the western part, particularly in the Souris basin, good quality water from known sources is in short supply.

Most of the anticipated additional needs for water in the western half of the region probably can be met from the Garrison Diversion Unit and through greater use of ground- and surface-water supplies. The Garrison Diversion Unit is a large-scale water redistribution project. It is planned to divert initially 2,000 ft^3/s and eventually 8,850 ft^3/s from the Missouri River at Garrison Reservoir to the Red and Souris River drainages and the James River (tributary to the Missouri) drainage for irrigation and municipal-industrial uses. Also included as part of the Garrison Diversion Unit plan are measures for flood control, drainage of nonirrigable lands, pollution abatement, and recreation.

Maclay and others (1972, p. 47-84) discussed water-resource management in the Red River basin, including ground water. A summary of their discussion of ground water in the Red River basin applies as well to the Souris-Red-Rainy Region.

Water management before 1967 included major flood-control projects, local flood-protection projects, watershed-protection projects, fish and wildlife developments, land drainage, and irrigation. Many manmade reservoirs have been constructed, particularly in North Dakota. The largest of these is Lake Ashtabula on the Sheyenne River, which has about 69,000 acre-feet of usable storage.

Primary considerations in the managment of water supply are: 1) location and amount of the supply, 2) accessibility, 3) dependability, and 4) quality. Table 2 shows the advantages and disadvantages of ground water and surface water in regard to these four considerations. Ground water is important to the region's future development because of its large total quantity and general availability in most of the region; however, careful planning will be required in developing ground-water supplies because of its different quality from place to place and with depth, and the limited geographic extent of many of the Quaternary aquifers. Adapting McGuinness' (1963) discussion of the role of ground water in the Nation's water situation (p. 119) to the Souris-Red-Rainy Region:

1. Ground-water reservoirs are important and indispensable in securing the region's future water supply.
2. Existing knowledge is grossly inadequate to form a basis for effective development and management of the ground-water reservoirs.
3. The region must overcome informational inadequacies in ground-water hydrology as well as in techniques of planning and water management.

Table 2.--Advantages and disadvantages of ground water and surface water as sources of water supply in the Souris-Red-Rainy Region (After Maclay, Winter, and Bidwell, 1972)

	SURFACE WATER	GROUND WATER
Location and amount	Surface water is easily located.	Ground water can be easily located where surficial deposits are water bearing.
	Amount of surface water available is not large, **in some areas**, even with storage.	In most places exploration by test drilling or other methods is generally necessary to locate sources capable of supplying high-yield wells. Locally, even obtaining a small supply is difficult.

Table 2.--Continued

	SURFACE WATER	GROUND WATER
Accessibility	Surface water is readily accessible to riparian land owners in Minnesota.	Ground water is generally accessible by drilling wells.
	Surface water is not accessible to riparian land owners in North Dakota. Users must obtain State permits in North Dakota and Minnesota. For the large number of people not living along streams and lakes, surface water is generally not available. The cost of physically storing and transporting water is an important economic factor.	~~A State permit is required for larger than domestic supplies.~~ Locally, an aquifer capable of supplying high-yield wells may not be in the immediate vicinity and a municipality may have to go several miles to obtain a supply. A State permit is required for larger than domestic supplies.

Table 2.--Continued

	SURFACE WATER	GROUND WATER
Dependability	Because streamflow can be observed and measured it is possible to calculate and project the amount of water that will probably be available in the future. Data are already available for some locations on many of the streams.	Ground-water sources are ususally very dependable. If discharge does not exceed recharge ground water can normally be used virtually indefinitely, including periods of extended droughts.
	Streamflow is highly variable in most streams in the region. Dependable water supplies require storage reservoirs as a rule.	Determining the yield of an aquifer is difficult. Data are not available for many areas and they are costly to obtain. Shallow surficial aquifers are generally not dependable during drought years.

Table 2.--Continued

	SURFACE WATER	GROUND WATER
Quality	Surface water is generally low in dissolved solids and is fairly uniform east of the Red River but variable west of the Red River.	Ground-water quality ~~varies~~ differs over the region but generally does not vary at any location with time. Temperature is constant throughout the year.
	Treatment is generally necessary to remove suspended sediment and organic matter. Quality, temperature, and color vary widely over the year at any location.	Certain chemical characteristics, such as hardness and iron content, are high in many places.

Fresh-Water Use

Ground water is the sole or a primary source of supply in much of the Souris-Red-Rainy Region. In areas distant from streams and in uplands, where surface water is not available physically, legally, or in the quality required for a particular use, ground water is the sole source of supply.

Ground water and surface water are used conjunctively in part of the region, but conjunctive use is not fully exploited to meet quantity and quality requirements of water supplies. For example, water of good quality from one source could be mixed with mineralized water from another source in some areas to get a greater quantity within specified quality requirements. Also during times of low or no streamflow, ground water could supplement or replace surface water. Distribution systems could be used for surface water or ground water.

Estimates of water use in the United States according to categories of use are listed by State and region by MacKichan and Kammerer (1961), Murray (1968), and Murray and Reeves (1972). Water-use projections to 2020 are given for the Souris-Red-Rainy Region by Ferris and others (1972) and Weber and others (1972) in the Souris-Red-Rainy River Basins Comprehensive Study. The U.S. Bureau of Reclamation (1973) summarizes water-resources development in North Dakota, with emphasis on surface-water supplies, and includes a brief description of the Garrison Diversion Unit which was mentioned earlier.

Irrigation

About 15,700 acres of land was irrigated in the region in 1967 and 1968, including about 12,000 acres in the Souris River basin, about 3,500 acres in the Red River basin, and about 200 acres in the Rainy River basin. Irrigated land in the Red River basin increased to about 38,000 acres in 1975 but remained about the same in the Souris and Rainy River basins. The total land irrigated in 1975 was 50,200 acres.

The largest potential use of water in the Souris-Red-Rainy Region is for irrigation. Forecasts of irrigation development were described by Weber and others (1972) in the Souris-Red-Rainy River Basins Comprehensive Study for optimum utilization of land and water resources. Potentially irrigable lands were considered to be suitable for development by either private (small-scale) or project (large-scale) methods, depending on availability of water. Private methods considered are farm-size systems irrigated primarily with ground water. Project methods considered would use surface-water storage and distribution works, which probably could be constructed only with public funds.

Sources of water in quantity for irrigation include ground water in the Souris and Red River basins and water from the Missouri River (Garrison Diversion Unit) and the Rainy River. The Souris and Red River basins have large areas of potentially irrigable land (fig. 10), but water is not available from

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Figure 10 (caption on next page) belongs near here.

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the Souris River for irrigation and the Red River can supply only small parts of the potentially irrigable area in the basin, such as the irrigated area east of Moorhead where several irrigators tap tributaries to the Red River. Surface water for potential irrigation development in the Souris and Red basins must be supplied from other sources, such as the Missouri and Rainy Rivers. In the Rainy River basin the abundance of surface water of good quality and apparent absence of large aquifers preclude the consideration of ground water for major irrigation.

The ultimate potential irrigation development in the region totals 1,550,000 acres ~~(6,270 km^2)~~, table 3. It is predicted that irrigated lands will reach 530,000 acres (2,145 km^2) by ~~the year~~ 2000 and 1,404,000 acres ~~(5,680 km^2)~~ by 2020. Ground-water ~~(or private)~~ development is projected to decrease between 2000 and 2020, and surface-water ~~(or project)~~ development is projected to increase nearly 400 percent in the same period.

Figure 10.--Map showing areas with irrigation potential.

Table 3.--Projected irrigation in Souris, Red, and Rainy River Basins

(From Souris-Red-Rainy River Basins Comprehensive Study by Weber and others, 1972, Tables F-17, F-20)

River basin	Water source	Year 2000	Year 2020	Ultimate
		(thousand acres)		
Souris:	Ground water	20	16	16
	Surface water	134	369	369
Red:	Ground water	200	180	180
	Surface water	169	824	970
Rainy:	Surface water	7	15	15
Total:	Ground water	220	196	196
	Surface water	310	1,208	1,354
Total irrigation		530	1,404	1,550

Note: Does not include 190,700 acres as initial stage of Garrison Diversion Unit.

The source of water and the irrigable area for the ultimate irrigation development within each State in the region is shown in table 4. It is estimated that 579,000 acres could be irrigated from the Missouri River (Garrison Diversion Unit), 775,000 acres could be irrigated from the Rainy River, and 196,000 acres from ground-water supplies. The estimate of potential irrigation development is 1,203,500 acres in North Dakota, 343,000 acres in Minnesota, and 3,500 acres in South Dakota.

Table 4.--Ultimate ~~potential~~ irrigation in each State in the Souris-Red-Rainy Region

(From Souris-Red-Rainy River Basins Comprehensive Study by Weber and others, 1972, p. F-51 to F-60)

Development plan	Potential irrigation development			
	North Dakota	Minnesota	South Dakota	Total
	(thousand acres)			
Souris River basin				
from ground water 1/	16	-	-	16
from Missouri River 2/	369	-	-	369
Red River basin				
from ground water 1/	122	58	-	180
from Missouri River 2/	206.5	-	3.5	210
from Rainy River 2/	490	270	-	760
Rainy River basin				
from Rainy River 1/	-	15	-	15
Totals	1,203.5	343	3.5	1,550

1/ Private development

2/ Project development

Not necessary?? Could we convert to use the figure?

The projections in the Souris-Red-Rainy River Basins Comprehensive Study (Weber and others, 1972) show that most of the near future irrigation will be with ground water. By 2000, 41 percent of the acreage will be irrigated from ground water, but by 2020 surface-water development will account for 86 percent of the irrigated area. These projections are based on present knowledge of the availability of ground water and do not allow for methods of water management such as artificial recharge, salvage of water for beneficial use, and use of saline aquifers. Also, with continued ground-water investigations, additional aquifers probably will be found. When water-management possibilities are fully utilized, ground water may become increasingly important to irrigation.

Municipal

The region is primarily rural, with few population centers of more than a few thousand persons. Only 11 cities are projected to have a population of greater than 10,000 by 2020 (Ferris and others, 1972, p. G-7). Ten are in the Red River basin and one in the Souris basin.

Of the 208 cities or towns in the region, 178 have ground-water supplies, 21 have surface-water supplies, and 9 have combined supplies. Table 5 lists the number of cities and towns and population served in each of the river basins. The smaller communities and towns of the region generally rely on ground water, and the larger cities and industries rely on ~~surface water, ground water, or both. The municipalities~~ using surface water generally depend on reservoir storage.

Municipalities with water-distribution systems have a per capita use of about 100 gallons ~~(0.38 m^3)~~ of water per day. The per capita use is 108 gallons ~~(0.41 m^3)~~ per day in the Souris basin, 98 gallons ~~(0.37 m^3)~~ in the Red basin, and 79 gallons ~~(0.30 m^3)~~ per day in the Rainy basin. Projections indicate a per capita use of about 140 gallons ~~(0.53 m^3)~~ per day by ~~the year~~ 2020 for the Souris-Red-Rainy Region. Projection for the Souris, Red, and Rainy basins are 152, 138, and 119 gallons ~~(0.58, 0.52, and 0.45 m^3)~~ per day per person, respectively, in 2020. Table 6 lists the 1960 population and water withdrawal, and projections of population and withdrawal to 2020 for each of the basins.

Table 5.--Municipal water supplies in the Souris-Red-Rainy Region (From Souris-Red-Rainy River Basins Comprehensive Study by Ferris and others, 1972, p. G-19, G-36, G-75)

Source of water	Ground	Surface	Combined
Souris River basin			
Number of cities or towns	31	0	2
Population served 1/	23,019	0	35,800
Red River basin			
Number of cities or towns			
North and South Dakota	69	8	5
Minnesota	69	8	1
Population served 1/			
North and South Dakota	62,620	104,317	13,903
Minnesota	50,355	42,590	22,935
Rainy River basin			
Number of cities or towns	9	5	1
Population served 1/	9,915	14,705	465
Totals			
Number of cities or towns	178	21	9
Population served 1/	145,909	161,612	73,103

1/ 1960 census

Table 6.--Municipal, domestic, livestock, and industrial water supply in the Souris-Red-Rainy Region

(From Souris-Red-Rainy River Basins Comprehensive Study by Ferris and others, 1972, Tables G-12, G-15, G-36, G-39 G-49, G-52)

	Population served		Withdrawal	
	1960	2020	1960 M gal/d	2020 M gal/d
Municipalities				
Souris	58,819	121,899	6.36	18.50
Red	296,720	507,709	29.11	69.87
Rainy	25,085	36,511	1.98	4.36
Total	380,624	666,119	37.45	92.73
Domestic				
Souris	44,852	20,701	2.11	1.15
Red	244,393	135,791	13.12	7.25
Rainy	15,323	8,152	.65	.36
Total	304,568	164,644	15.88	8.76
Livestock				
Souris			4.50	8.18
Red			52.63	100.06
Rainy			2.35	4.25
Total			59.48	112.49

Table 6.--Continued

Industrial		
Souris	2.33	4.75
Red	151.38	92.78
Rainy	54.23	157.62
Total	207.94	255.15

According to Ferris and others (1972) in the Souris-Red-Rainy River Basins Comprehensive Study (p. G-2), for a few communities the threat of water shortages persists or may develop as requirements increase. These communities include Minot, in the Souris River basin, and several other cities (such as Neche, Pembina, Grafton, and Mayville, N. Dak., and Crookston, Minn.) that depend on tributaries of the Red River. The largest municipal water-supply demands of the region are along the main stem of the Red River. The Red River and its tributary storage can meet the present municipal and industrial requirements. Shortages in some areas, however, have occurred during prolonged drought. Communities that depend on ground water have solved such problems by deepening wells or constructing additional wells. As water use along the main stem of the Red River increases, additional storage for water supply may be required, or ground water may be needed as a supplement. Water supplies in the Rainy River basin exceed present and forseeable requirements.

Domestic and Livestock

Domestic and livestock water supplies are almost entirely from ground-water sources. Withdrawals are small and well distributed and~~, therefore, no~~ shortages are not expected. About two-thirds of the 305,000 rural population is served by pressurized water systems, and per capita use is 60 gallons ($0.23\ m^3$) per day. By ~~the year~~ 2020, the rural population is expected to be about half the present number and to have the same per capita use, according to Ferris and others (1972) in the Souris-Red-Rainy River Basins Comprehensive Study. The 2020 water-use projections (~~see~~ table 6) are intended to indicate the trend of water requirements based on population projections and the general water-use criteria developed for the basinwide projections. These projections do not reflect the individual circumstances for a given community.

In the Souris River basin, about half the domestic and livestock wells tap bedrock aquifers. Drift aquifers supply the other half. Surface water, where available, is used for livestock. Some water, which is too mineralized for human consumption, can be tolerated by livestock. In the Red River basin, drift aquifers, where available, are generally tapped by domestic and livestock wells. Well yields and water quality from the bedrock aquifers are generally poorer than from the drift. Bedrock aquifers can be tapped nearly anywhere on the Dakota side of the Red River basin, but are not present in parts of northwestern Minnesota. As a result, local water shortages exist where drift aquifers are also absent. Livestock production has been inhibited due to lack of adequate water resources in parts of northwestern Minnesota. Rural domestic water in the Rainy River basin is supplied by wells. Livestock supplies are mostly from surface-water sources.

In the last several years, water districts have been formed in North Dakota to supply water to rural and small-city residents for domestic and stock uses. In general, the rural water districts are formed as a consequence of county-wide ground-water studies which delineated aquifers and identify ground-water resources available for development. Water supplies of about 100 gal/min ~~(6.3 l/s)~~ are developed from glacial outwash, buried sand and gravel channels, and delta aquifers such as are found along the east edge of North Dakota in the Red River valley. The water districts are formed ~~in order~~ to ~~better~~ utilize good-quality water from these aquifers and to supply nearby rural areas where water quality and quantity are inadequate.

Industrial

The economy of the Souris and Red River basins is based primarily on agriculture and related food-processing industries. The food-processing industries, which include sugar-beet refining, potato processing, meat packing, and creameries, account for a large part of the industrial water demands. Most soils in the Rainy River basin and in the northern Minnesota part of the Red River basin, however, are unsuitable for cultivation but valuable for forestry. In these areas forestry resources and recreation are the economic foundation, and the pulp and paper industry is the primary water user. Manufacturing is increasing in the Souris basin. The large decrease in water requirements indicated in the Red River basin from 1960 to 2020 (table 6) is due to a shift in the power industry from flow-through to cooling-tower operation. Table 6 reflects only water use by self-supplied industry. Some industries obtain water from municipal supplies. A rough guideline is that municipal water use in excess of 80 to 90 gallons per day per person is attributable to commercial and industrial use.

Ferris and others (1972) in the Souris-Red-Rainy River Basins Comprehensive Study assumed that future industrial food processing in the region would increase at about the same rate as agricultural production. Figures in table 6 reflect the expected increase in the Souris and Rainy River basins. A similar increase in the Red River basin is overshadowed by the expected decrease in water requirements of the power industry. That is, future water use was derived by applying the projected production to current water use. Where appropriate, adjustments were made to reflect changing trends, such as the anticipated increase of water recycling.

Saline-Water Use

Highly mineralized ground water is plentiful in the western part of the region. Feth and others (1965) show the availability of water containing more than 1,000 mg/L dissolved solids at depths less than 500 feet throughout the western half. In the northeastern and northwestern corners of North Dakota, water containing 10,000 to 35,000 mg/L dissolved solids lies at depths of less than 500 feet. At greater depths the water is generally more mineralized. Such water can be considered a resource or asset rather than a liability. The water can be used for a number of purposes, including cooling and oil-field repressuring. Possibly this highly mineralized water could be utilized by the chemical industry as a source of minerals and chemicals. Mineralized water from the Dakota aquifer is being used for washing sugar beets and potatoes.

In the western part of the region highly mineralized water is being used to some extent to repressure oil fields to increase production. Saltwater produced with the oil must be disposed of so that it does not damage the environment and contaminate surface water and fresh ground water. About 94 percent of the oil-field brine produced in North Dakota is returned to saline ground-water reservoirs. Most of the brine is returned to the reservoirs from which it was withdrawn (Folsom, 1973, p. 102). Where oil-field brines are insufficient for repressuring oil fields, highly mineralized water available from other ground-water sources ideally should be used to conserve freshwater supplies.

A large part of the available water supply of the western part of the region is saline. Robinove and others (1958) state that a large proportion of the available water supply of North Dakota is saline. Water-resources investigations in the region have been principally oriented to municipal, industrial, domestic, and irrigation uses requiring fresh water. However, saline water can be treated to increase its usability for these purposes. Congress, in 1952, passed the Saline Water Act that provided for research into and development of practicable and economic means to produce fresh water from saline water to conserve and increase the water resources of the Nation. Considerable progress has been made in developing desalinization processes. The former Office of Saline Water (Dept. Interior) (now Office of Water Research and Technology) once operated an electrodialysis desalting plant at Webster, S. Dak.. Although only a small number of desalinization plants are in operation throughout the Nation, they may be used more extensively in the future.

In some areas of the region water of acceptable quality for a particular purpose may be inadequate in quantity. Where saline water is available, it could be diluted with the fresh water to create an adequate supply of usable water.

Feth (1965) prepared a map of the United States showing distribution of saline ground water. His report includes a large number of references. Several reports for North Dakota and Minnesota are listed and the reader is referred to these reports for a more detailed discussion of saline ground water in the region.

Artificial Recharge

Artificial recharge is the process of increasing the storage of water in an aquifer system by artificial means. Storage in the ground has several advantages over surface storage: 1) the sand and gravel would filter the water; 2) the water would be kept at a relatively constant temperature; and 3) there would be no evaporation. Care is necessary, however, to avoid pollution or physical impairment of the underground system. For example, recharge waters must be chemically compatible with the native ground water to prevent formation of precipitates that would reduce hydraulic conductivity. Suspended solids must be removed before injection, and pollution by bacteria must be prevented. Storage of surface water in aquifers, during times of surplus, for withdrawal during times of scarcity would aid in meeting increased demands. Flood water is chemically better in most respects than underlying ground water in parts of the western half of the region. Fresh water could be stored in saline-water aquifers, as well as fresh-water aquifers, and pumped out as needed.

Artificial recharge may be accomplished by direct and indirect methods. Direct methods of recharge include water spreading by means of ponds, check dams, pits, furrows, or ditches to increase the amount of water infiltrating from the surface into the ground-water reservoir, and injection of water directly into the ground-water body by means of wells or shafts (fig. 11). Indirect methods of recharge include

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inducing movement of water from streams or lakes into underground formations (fig. 12-A), and preventing the natural flow

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Figure 12 (caption on next page) belongs near here.

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of ground water to the land surface by lowering ground-water levels (fig. 12-B). Further information is available in the published literature on methods, case studies, and other aspects of artificial recharge. See Todd (1959), Signor, Growitz, and Kam (1970), and Knapp (1973) for listings of literature to 1973.

Figure 11.--Diagrams of direct methods of recharge.

Figure 12.--Diagrams of indirect methods of recharge.

Replenishing Fresh-Water Aquifers

In the Souris~~-Red=Rainy Region~~, surplus s~~upplies of~~ water ~~are~~ is available during winter and spring ~~months~~ from surface-water sources, principally the larger rivers and tributaries, which could be used to recharge ground water. Utilization of flood water to replenish ground-water supplies would also diminish flooding to some extent. Additionally, water injected into the ground in winter or early spring would be cold and well suited for air conditioning and as a process coolant. This technique could probably be used near Moorhead where high flows from the Buffalo River could be injected into the aquifer and pumped out later in the year. Artificial recharge is not new to the region, as shown by the following two examples.

Artificial recharge has been in operation at Minot, N. Dak. since 1965. The Souris River has been a source of part of Minot's municipal water supply for many years. In 1961, Minot constructed eight wells to supplement the stream supply. Excessive water-level declines in the following years indicated that a ground-water shortage was developing. Although the Souris River is not a reliable source of direct supply, relatively large peak flows in the spring indicated that the river was a potential source of water for recharge to the aquifer. A ground-water recharge facility was designed and constructed in 1965 to ~~utilize~~ use both direct and indirect recharge methods, (Ferris and others, 1972, p. G-22).

Kelly (1967, p. 20) reports that Valley City, N. Dak. had an average daily water use of 750,000 gallons (2,840 m^3) in 1966, which was obtained from wells tapping partly confined gravel deposits in the Sheyenne River valley. These deposits at Valley City have a maximum thickness of more than 50 feet (15 m) and an areal extent of about 1 square mile (2.6 km^2). The aquifer has been artificially recharged successfully since 1932 by diversion of water from the Sheyenne River to an abandoned gravel pit. During this time the potentiometric surface in the aquifer has risen more than 22 feet (6.7 m).

Before 1958, the recharge system was operated annually from January until June; however, when the potentiometric surface rose to within 8 feet (2.4 m) of the surface, the recharge operation was discontinued. Between June and January the potentiometric surface declined as ground water was withdrawn. During the recharge-discharge cycle, the average annual fluctuation of the potentiometric surface was 10 feet (3 m), amounting to a change in storage of about 1,000 acre-feet (1,200,000 m^3) of water. Since 1958, the recharge system has been operated throughout the year. The quality of water in the aquifer has gradually improved since the installation of the recharge system.

Fresh-Water Storage in Saline Aquifers

Saline aquifers can be used to store fresh water during times of abundant surface supply and pumped out as needed. Tests and experiments by the U.S. Geological Survey at Norfolk, Va., recovered about 85 percent of the injected fresh water (Brown and Silvey, 1973). The fresh water displaces the saline water and forms a ~~globular~~ fresh-water body that can be recovered. The success of such projects would depend on knowledge of the hydrologic system in the vicinity of the projects, favorable site conditions, and on the operation of adequate monitoring systems.

This possibility might be investigated in the Minot area, N. Dak., the Fargo-Moorhead area, N. Dak. and Minn., the Hallock area, Minn. and other population centers or areas of central rural supplies where spring floodwater might be retained temporarily in upland reservoirs until it can be treated and stored underground. In the Red River basin, the Dakota Sandstone or the Pierre Shale might be used in North Dakota for this purpose; in Minnesota aquifers in Cretaceous or Ordovician rocks might be so used. In the Souris River basin, the Fox Hills-Hell Creek aquifer or the Fort Union aquifer might be so used. The Dakota Sandstone in the Souris basin probably is too deep to be used economically for this purpose. To use these aquifers for storage of surplus surface water, suitable site conditions would have to be located.

Liquid-Waste Disposal in Saline Aquifers

Saline aquifers can be used for liquid waste disposal. Much has been written concerning underground waste disposal (Rima and others, 1971). A knowledge of the geology, ground-water hydraulics, and geochemistry would aid in determining whether or not injected wastes could be contained and isolated, or recovered later if it is warranted. (Injection of waste underground can present serious hazards to water supplies and the local environment.)

GROUND-WATER DEVELOPMENT

Water use has had a rapid upward trend in the Souris-Red-Rainy region. As the gross water supply is constant and water demands are rising, the answer to problems of supply is the development of untapped sources of water and the possible reuse of water.

Problems of Development

The problems of development differ widely with the intended use of the water. Problems inherent in development of most small wells are chiefly the availability, quantity, and quality of the water. Water quality is a serious problem in parts of the Souris and Red River basins where supplies of potable water are scarce. The development of large supplies has additional problems related to proper planning and administration of the development pattern.

Initial development generally involves haphazard drilling for water that is readily available. In some areas where the ground and surface waters are closely related, the development of ground-water supplies has depleted surface flow (Theis, 1941). Also, unplanned development may result in aquifer overdraft in one area and surpluses at another.

Ideally, the development of an aquifer would be designed to achieve the most optimum and economic recovery of the water. To achieve this, detailed information would be needed on the depth, quality, quantity, and annual recharge and discharge of the water in the various aquifers. Thus it is seen that water problems during initial development in much of the region are related to hydrologic and geologic conditions.

In general, investigations that would provide information about the geologic and hydrologic conditions of the aquifer are not undertaken until the degree of development has created problems that threaten the continued use of the aquifer. In this region, these problems are: changes in ground-water levels, depletion of streamflow, and deterioration of water quality. Also there are management problems relating to ground-water replenishment, ground-water conservation, and effects of the development on the environment.

Changes in Water Levels

Pumping necessarily causes water levels to decline near the pumped well, creating a gradient and flow toward the well. Water-level declines, although not yet alarming in most of the region, are increasing the cost of pumping. Declines of ground-water levels near West Fargo, due to municipal and industrial pumpage, indicate possible future supply problems from this aquifer. Large water-level declines in the Minot well field in the early 1960's indicated that a critical water shortage was developing rapidly. The problem was alleviated by artificial recharge of the aquifer. (See section on Replenishing Fresh-Water Aquifers.)

If the extraction of water continues until withdrawal exceeds recharge, significant depletion of water storage may occur in the area of overdraft. With time, the continued or increased water use may cause water-level declines in the entire aquifer.

In the late 19th century and early 20th century near the Red River, wells flowed that tapped the glacial drift below the lake deposits. Since then water levels in the western part of the lake plain have declined and ceased to flow. Serious water-level declines have occurred near West Fargo because of municipal and industrial pumpage of about 500 million gallons annually. Water levels have declined as much as 150 feet at Moorhead where buried sand and gravel aquifers have been tapped for a municipal water supply. Because of the declines in water levels in this area, the ground-water gradient has been reversed locally and the underlying drift aquifers are recharging rather than discharging upward toward the land surface (Maclay and others, 1972, p. 113).

Water-level rises can be caused by irrigation of land, leakage from canals, flooding, and construction of surface reservoirs. Percolation of irrigation water to the water table in time may cause the water table to rise. Infiltration of irrigation water additionally could cause deterioration of ground-water quality. Excessive water-level rises may cause other problems such as flooding of basements, damage to structures, and detrimental changes to vegetation.

An example of potential rising water levels is near the planned Kindred Dam and lake on the Sheyenne River in south-eastern North Dakota. Downey and Paulson (1974) have predicted that the maximum rise in water levels will occur about 50 years after filling of the lake.

Depletion of Streamflow

The withdrawal of ground water can decrease streamflow by decreasing ground-water discharge to the stream or by causing infiltration of water from the stream. The pumping effect on a stream depends on the pumping rate, distance of well from the stream, and the aquifer characteristics. The amount of ground-water pumpage derived from a nearby stream or drain can be computed by using methods developed by Theis (1941).

Decreased streamflow caused by pumping of ground water is generally considered an adverse effect. However, benefits may outweigh the disadvantages, as in the Minot area, where a dam on the Souris River augments the surface supply to the city and increases infiltration of ground water to the city's well field (Ferris and others, 1972, p. G-22).

Deterioration of Water Quality

Deterioration in chemical quality of the ground water may result when the natural equilibrium of the aquifer is disturbed by development. Intensive development can cause large-scale deterioration of quality by recirculation of water, interformational leakage, and pulling poor water from distant areas.

Where good quality water is being pumped from glacial aquifers, upward migration of deeper mineralized water may be caused by the lowered head due to pumping. The Paleozoic and Cretaceous rocks in the northwestern part of the Red River basin contain highly saline water that is discharging where these rocks pinch out against crystalline rocks in Minnesota. Upward migration of saline water has resulted in contamination of ground water in the overlying drift in northwestern Minnesota and northeastern North Dakota (Maclay and others, 1972, p. 113; and Crosby and others, 1973, p. 195). To the west of the area, wells tapping the better water in the overlying drift aquifers could induce upward migration of the saline water if the heads are lowered sufficiently by the pumping.

Water may leak vertically between aquifers if the seal between them is broken by improperly constructed wells. If the quality of water is poorer in the aquifer having the higher head, the quality of water in the receiving aquifer will deteriorate.

Municipalities and industry have waste for disposal. The important types of waste in the region are chemicals from food and industrial processing, sewage, concentrated chemicals in cooling water, oil-field brines, mine discharge, and return flow of irrigation water. Any of these wastes may cause deterioration of ground-water quality if they enter the aquifer. Other types of waste, such as the effluent from saline-water conversion plants may be added in the future.

The use and reuse of water for irrigation results in the dissolved mineral concentrations in the water. Each time water is applied to the land, some returns to the surface stream or to the ground-water reservoir. This return flow is wastewater, and its utility has been decreased because of the increase in dissolved-solids concentration.

Ground-Water Conservation

When intensive development reaches advanced stages, the conservation of water becomes important as a solution to pressing problems. Farm conservation could include reduction of irrigation losses between well and field; more efficient irrigation, planting crops with a smaller water requirement, and eradication of phreatophites. Leaky artesian wells could be repaired and artesian flow controlled by valves at the well head. Municipalities could repair leaky distribution systems, and limit lawn watering. Commercial users could return cooling water to the aquifer. Industry could process and return used water underground through injection wells or filter beds. All of these conservation measures could be used to various degrees in the Souri-Red-Rainy Region.

Elimination of phreatophytes would reduce consumptive use of the ground water. Phreatophytes, where found, are in areas where ground water is less than about 30 feet deep. Phreatophytes may intercept and waste ground water moving toward streams or lakes. They also may use enough water to induce recharge from surface-water bodies into shallow aquifers. Phreatophytes in some parts of the Nation are undesirable. However, in this region phreatophytes are desirable as wind breaks and ground cover to prevent erosion.

Water may be salvaged by use of evaporation suppressants on surface reservoirs in the western half of the region where evaporation rates are high. Experiments with evaporation suppressants (Magin and Randall, 1960) indicate suppression may not be practical or feasible on large reservoirs, but is promising for use on small ponds. Evaporation losses can be eliminated by storing water underground and pumping it out as needed. The underground storage could use known aquifers or permeable, unsaturated materials.

Another method of water conservation that could be used advantageously in the region is the salvage and recycling of water. Such recycling includes air conditioning or industrial water where the water can be treated to restore its usefulness. The possibility of reuse should be considered for as many different situations as possible. Under some circumstances ground water used for air conditioning can be returned to the reservoir without detrimental effects, thereby maintaining the ground-water supply.

Effects on the Environment

A Souris-Red-Rainy River Basins Commission report (1972, p. 215) states:

> "Although this Region is relatively small in comparison to other water resource planning regions in the Nation, its natural environment is characterized by a wide variety of physiographic and vegetative features. Over the years, public concern for maintaining and/or enhancing the quality of this natural environment has been increasing rapidly. Proper use and management of the water and land resources, which make up the Region's natural environment, will preserve and maintain a high quality environment."

Development of water supplies may have a detrimental effect on the environment. However, adequate monitoring programs can detect adverse effects in most situations. Declining water levels caused by pumping can cause migration of highly mineralized water, depletion of streamflow, or a change in natural vegetation in the case of near-surface ground-water levels. Irrigation can cause deterioration of water quality as natural minerals and fertilizers are dissolved in recycled irrigation water.

Long distance transportation of water may cause environmental changes. Such changes depend on (1) quality of the transported water in relation to the native water, (2) depth to the ground water along the path of transportation and in the area of use, and (3) effects of removing water from one area and its use in another.

Along much of the Red River in North Dakota and Minnesota, natural upward migration of highly mineralized water has reduced soil productivity. Pumping could lower heads of the mineralized water and improve the quality of the soils, but provision would have to be made to dispose of the mineralized water. Lowering the artesian heads is a drainage project that could be detrimental to wildlife and natural vegetation.

A broad-scale analysis of land resources and watershed management as related to economic development and certain aspects of the environment is presented for the region in the Souris-Red-Rainy River Basins Comprehensive Study (McClure and others, 1972).

Currently more than 2 million acres of pasture and range land is suitable for crop production. Conversely, one-half million acres of land currently used for crop production could be converted to more economical uses such as forest, pasture or range land. The projected land development depends largely on availability of water, and particularly on availability of ground water.

INFORMATION AND GROUND-WATER MANAGEMENT NEEDS

Few aquifers are so continuous and uniform that high-production wells may be assured without preliminary test drilling. In some places the aquifers are defined by data from scattered test holes; future work may modify interpretations. For example, very little is known about the Paleozoic rocks in the region owing to a lack of drill-hole data and information on depth to the rocks. Exploration, testing, and study may help to find water at depth in quantity and quality suitable for a particular purpose. Study and planning also are needed to determine best use of the water and land resources.

A properly designed and operated monitoring program can alert managers to approaching problems of diminishing supply or other detrimental effects. Monitoring programs ideally should be started before development, and continued to detect changes and determine effects of the development. For example, pumping ground water causes water-level declines near the pumped wells. As pumping continues or is increased, these declines generally spread. Return irrigation water, a new canal or reservoir, or excess precipitation can cause water-level rises. Monitoring water levels near pumped areas could give useful information on possible migration of inferior water toward the well field.

A ground-water quality monitoring program would detect changes in water quality such as migration of highly mineralized water or other pollution within or into the aquifer. Data from such a program could be used to suggest corrective action such as altering the pumping rates or patterns.

Reconnaissance and qualitative studies have been made for most of the region. Quantitative studies, including models, have been made for small parts of the region to define the hydrologic and geochemical aspects of the system. Where sufficient data are available for digital models, these would aid in better planned use of the ground- and surface-water supplies. All of the water in storage, both surface water and ground water, is not usable, and the amount of each fluctuates with changing conditions. Regulation of surface- and ground-water storage can increase the usable supply. Adequate surface storage possibly could eliminate the loss of floodwaters and reduce surface discharge to that amount required for downstream water users.

Some surface water is lost during floods when streams overflow onto adjacent lands and the water is lost to evapotranspiration. Additional surface storage could reduce these losses. These surplus waters could be conserved by artificial recharge through wells and infiltration beds. Data are needed to determine the amount of surface water that could be salvaged by artificial recharge. Also, data are needed in all areas to locate suitable recharge sites.

Some water in storage is not usable because of high mineral content. Information is needed to determine where desalinization could be effective to increase the usable water supply.

Information and inventories are needed to identify existing and potential sites of pollution and means of waste disposal. In a water-short area such as the western half of the region, the reduction of waste through intensive use and conservation would reduce problems of waste disposal. The increased concentration of chemical constituents that results from intensive reuse of water, however, may aggravate problems in other areas, such as restrictions on, or lack of, suitable disposal sites or methods. Wise and efficient use of water requires that waste problems be solved at the stage of prevention, rather than when the problem becomes one of correction. Further research may lead to better means of reducing agricultural processing wastes. Also, research may determine the efficiency and suitability of various types of soils for the land disposal of sewage sludges and effluent.

Information gained by continued monitoring could be effective in preventing pollution from oil-field waste. Water produced with oil in the western part of the Souris River basin is an important quality problem in North Dakota. The water is highly mineralized and is produced in relatively large volume. Pollution from petroleum production, however, does not appear to be a serious problem at this time. Surveillance of these activities is conducted by the State of North Dakota and prevention of pollution rather than curative measures are emphasized in the Souris-Red-Rainy River Basins Comprehensive Study (Young and others, 1972, p. H-16). Most of this water is disposed of by injection into deep wells, either for disposal, or for repressuring oil producing formations.

Data are required on water-level fluctuations in connection with the inventory of water supplies, and to minimize the possibility of water logging of the land, and the invasion of inferior water. Data also are needed on the quantity of return flow from existing irrigation areas and on the relation among crop type, water application practices, fertilizer use, and other factors causing increase in dissolved solids in the return flow.

Maclay, Winter, and Bidwell (1972, p. 71-73) discussed water-resource management alternatives and related information needs. Their discussion is summarized here with respect to ground water in the Souris-Red-Rainy Region. Many alternatives for managing water are available to planners, some of which could be applied to water problems in the region. Some of these are operational and others are currently undergoing research. Many of them require adaptation to each local situation.

Improved methods to locate ground-water supplies are greatly needed. This would assure that the best and nearest possible source is being used. Better methods of well drilling and construction could lead to better development of water supplies. More efficient well development is needed, particularly in small aquifers. Pumping water from the lower yielding aquifers by using several low-yield wells rather than one high-yield well might be desirable. This is particularly applicable to beach-ridge aquifers associated with deposits of former glacial lakes. Also, special types of well construction such as infiltration galleries may be useful for developing thin but widespread aquifers, for example those composed of beach deposits.

Special uses of saline or other poor quality water could be beneficial in part of the region where this type of water is abundant. Desalinization might be considered for these areas when it becomes economical.

Joint use of ground water and surface water also offers many management possibilities, particularly in the lake plain. Mixing of good quality water with poor quality water may provide an intermediate type that is acceptable for a particular use. This might be considered where poor quality water is abundant.

The storage capacity of aquifers would determine the possibility of storing surface water in them. Ground-water pumpage could greatly exceed natural recharge if stream water could be injected into ground-water reservoirs during periods of high flow. This technique probably could be used near Moorhead, where high flows from the Buffalo River could be injected into the aquifer and pumped out later.

More efficient and less costly methods are needed for transporting water from source to central distribution system, and then to individual users. Better metering and more realistic water billing in some of the communities could reduce water demands.

Many alternatives in the managment of water supplies are possible. The selection of methods would depend upon their economic and hydrologic feasibility. In selecting any one or a set of these alternatives, the development of a water resource should be considered in the context of the total hydrologic system, with the realization that hydrologic changes in one part of a system will cause changes at other places.

McGuinness (1969, p. 1) states, "...management of aquifers requires vast amounts of data plus a much better understanding of aquifer-system behavior than now exists. Implicit in this deficiency of knowledge is a need for much new research, lest aquifers be managed according to ineffective rule-of-thumb standards, or even abandoned as unmanageable."

SUMMARY

The Souris-Red-Rainy Region is underlain by a series of bedrock units that differ greatly in thickness and hydraulic characteristics and that range in age from Precambrian to Quaternary. Precambrian rocks are at or near the surface locally in the eastern part of the region and more than 15,000 feet below the surface in the center of the Williston Basin in western North Dakota . The Paleozoic, Cretaceous, and Tertiary deposits of the Williston Basin gradually thin eastward and are missing in the Rainy River basin and in the southern and eastern parts of the Red River basin. The entire region has been glaciated, and most of the region is covered with glacial deposits that range in thickness from less than a foot to several hundred feet. Sand and gravel deposits in the drift form the most important fresh-water aquifers. Other aquifers in the region are in the Precambrian, Paleozoic, Cretaceous, and Tertiary rocks. The potentiometric surface in the bedrock formations generally decreases in altitude toward the Red River, indicating that the general direction of ground-water movement is toward the Red River.

Ground water with less than 3,000 mg/l dissolved solids is available throughout the Souris-Red-Rainy Region; however, yields are small in places because some aquifers contain highly mineralized water. Ground-water quality in the Rainy River basin generally is better than in the Souris or Red River basins. Ground water with less than 1,000 mg/l of dissolved solids occurs in most of the region east of the Red River and in most of the shallow aquifers west of the Red River. The dissolved-solids concentration generally is less than 500 mg/l in water from the fractured crystalline rock and outwash-delta aquifers and less than 1,000 mg/l in other aquifers in the glacial deposits. The total volume of water available from storage having less than 3,000 mg/l of dissolved solids is estimated to be 5 x 10^{8} acre-feet. In addition to the fresh and slightly saline water, the region has abundant more highly mineralized water that also can be considered as a resource.

Yields of wells in individual bedrock aquifers are generally less than 100 gal/min but locally yields may be as much as 500 gal/min and more. Yields in drift aquifers are commonly less than 100 gal/min but range from 5 to 1,000 gal/min. In a few places outwash yields more than 1,000 gal/min.

Water quality rather than quantity is the greater water-supply problem for many communities in the region. Excessive natural concentrations of dissolved solids, sulfate, and chloride are common in the western parts. Iron and manganese concentrations also are excessive in many supplies throughout the region. However, at the natural concentration levels none of these constituents are hazardous to health.

Ground water is the sole or a primary source of water supply in much of the Souris-Red-Rainy Region. In areas distant from streams, and in upland areas where surface water is not available physically, legally, or in the quality required for a particular use, ground water is the sole source of supply.

Reportedly, the potential irrigation development is 1,550,000 acres as compared with 50,200 acres irrigated in 1975. Both ground- and surface-water supplies will be required to meet these potential demands.

Rural domestic and livestock water supplies are derived almost entirely from ground-water sources. Small communities and towns generally rely on ground water, and the cities and industries use ground water, surface water, or both. The municipalities using surface water generally depend upon reservoir storage.

The quantity of water available to most municipalities has been adequate. Shortages in some areas, however, have occurred during prolonged drought. Communities depending upon ground water have solved such problems by deepening wells or constructing additional ones. For a few communities, potential water shortages persist or may develop in the future as requirements increase. Included are Minot in the Souris River basin, and several cities (such as Neche, Pembina, Grafton, and Mayville, N. Dak., and Crookston, Minn.) that depend on tributaries of the Red River. The largest municipal and industrial water-supply demands are in areas along the main stem of the Red River. As water use increases, however, additional reservoir storage or ground water may be required. Careful analysis and management of this complex water-supply system is warranted. Water supplies in the Rainy River basin are abundant in terms of present and foreseeable requirements.

Increased demands on both ground-water and surface-water supplies will be made in the future. Storage of water in the ground-water reservoir during times of surplus for withdrawal during times of scarcity would aid in meeting these demands. Similarly the surplus (flood) water is of better chemical quality than underlying ground water in parts of the western half of the region. Fresh water could be stored in saline-water aquifers as well as in fresh-water aquifers, and pumped out as needed. The ground-water reservoir has a definite potential in water management. This reservoir is larger than all of the surface reservoirs in the region and should be more fully used.

Supplies of water adequate for recharging the ground water reservoir are available in the region during the spring months from several rivers and tributaries. Use of floodwater for replenishing ground-water supplies also could diminish flooding to some extent. Examples of artificial recharge projects that are operational in the region are at Minot and Valley City, N. Dak.

To understand the hydrologic system for management purposes there is a need to determine more adequately the hydrologic and geologic characteristics of existing aquifers, to determine the feasibility of providing treatment for improvement of the quality of water contained in those aquifers, and to locate new, undeveloped aquifers. As pumping and other stresses on any part of the hydrologic system affect other parts, monitoring programs ideally should be started before development and continued to detect changes and determine effects of the stress. Monitoring water-level changes, withdrawals, and ground-water quality can alert managers to approaching problems of diminishing supply, waterlogging of land, or other detrimental effects. A water-quality monitoring program could detect migration of highly mineralized water or of other pollution in the aquifer and aid in determining corrective action. Information is needed to locate and identify pollution sources. Further research may lead to better means of reducing wastes derived from product processing.

Many alternatives are available to planners for managing water. Some of these are operational and others are undergoing research. Many of them require adaptation to specific local situations. Adequate hydrologic information is needed by the water manager or planner to aid in solving problems of water supply, use, and pollution.

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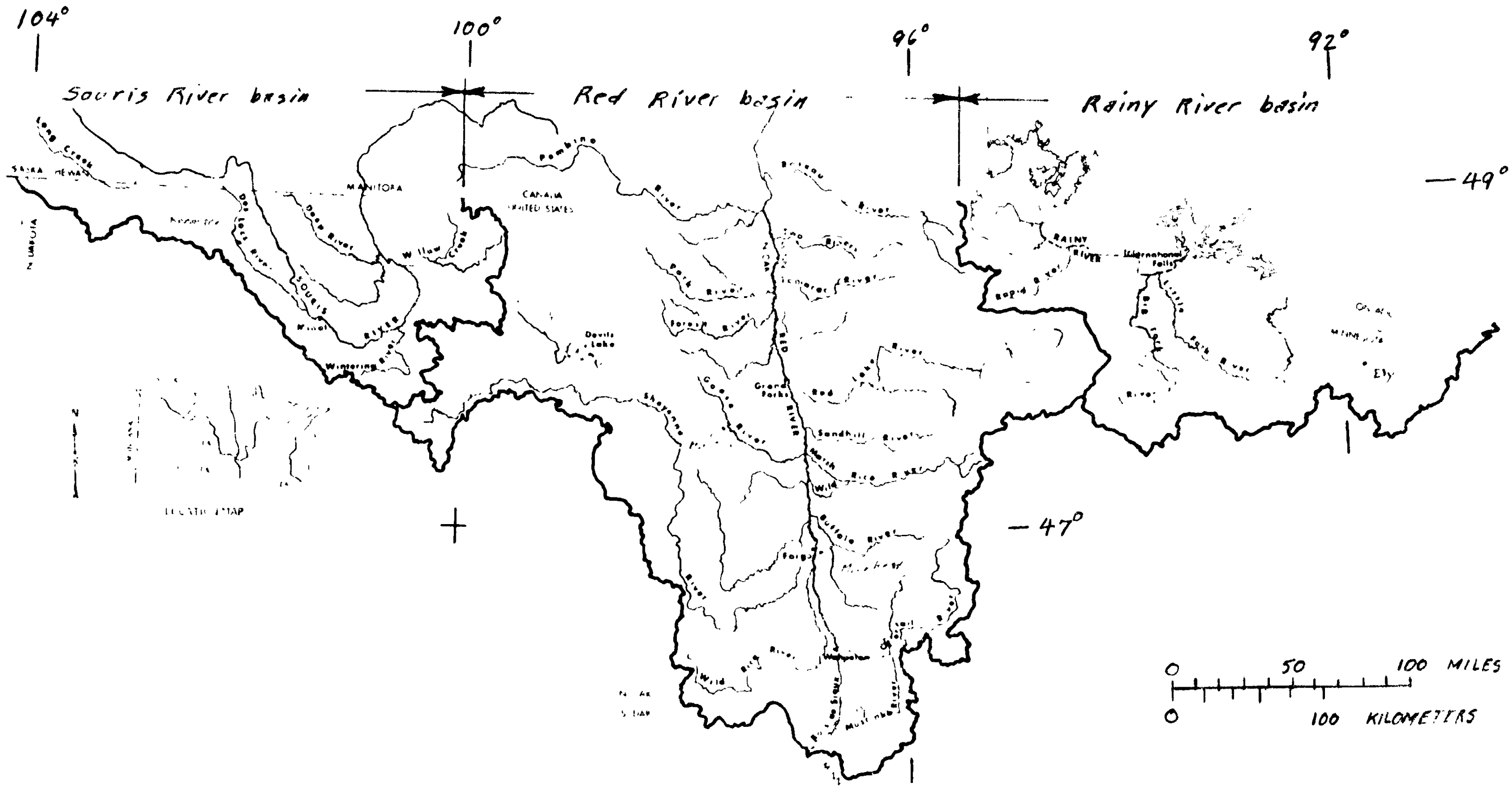
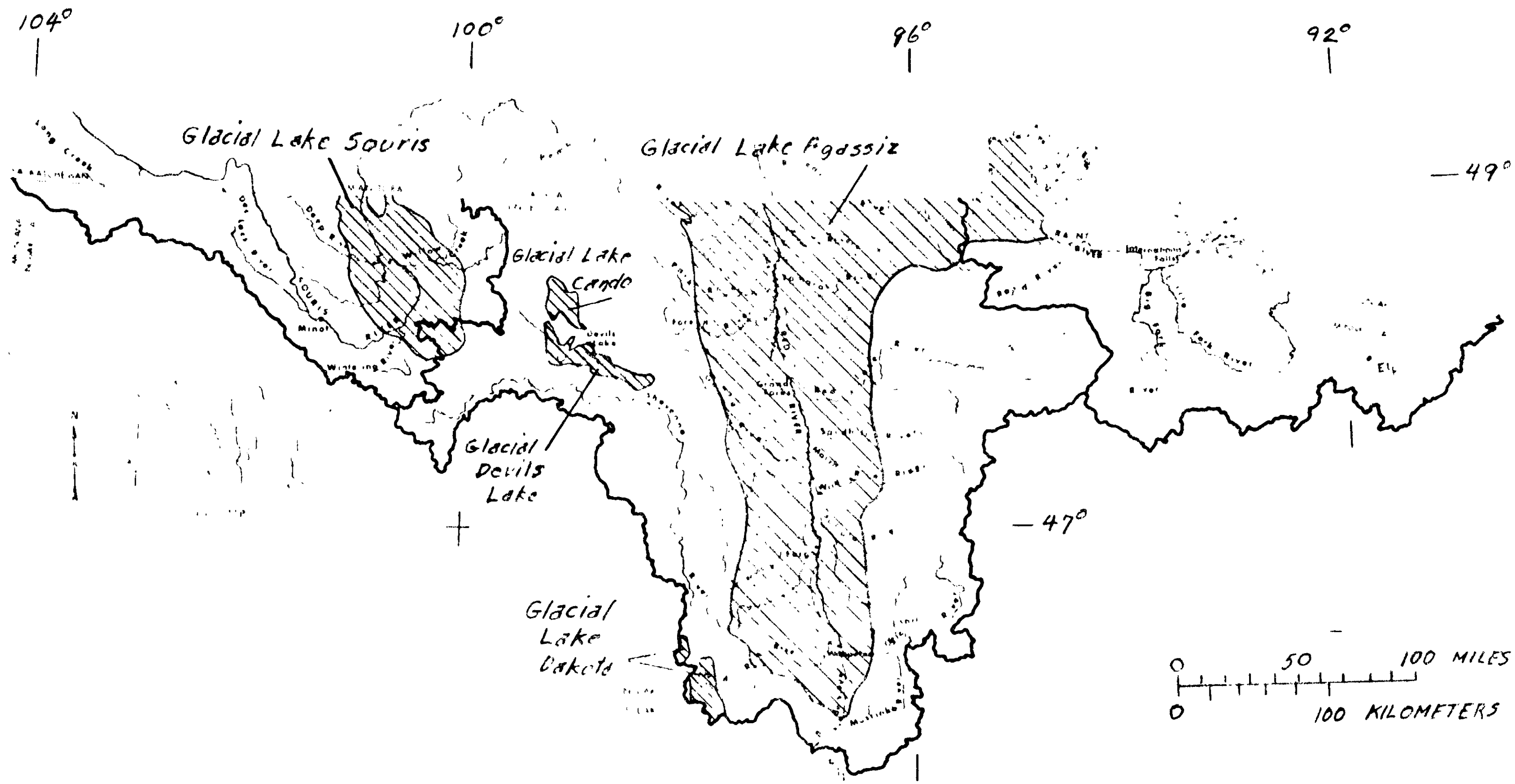


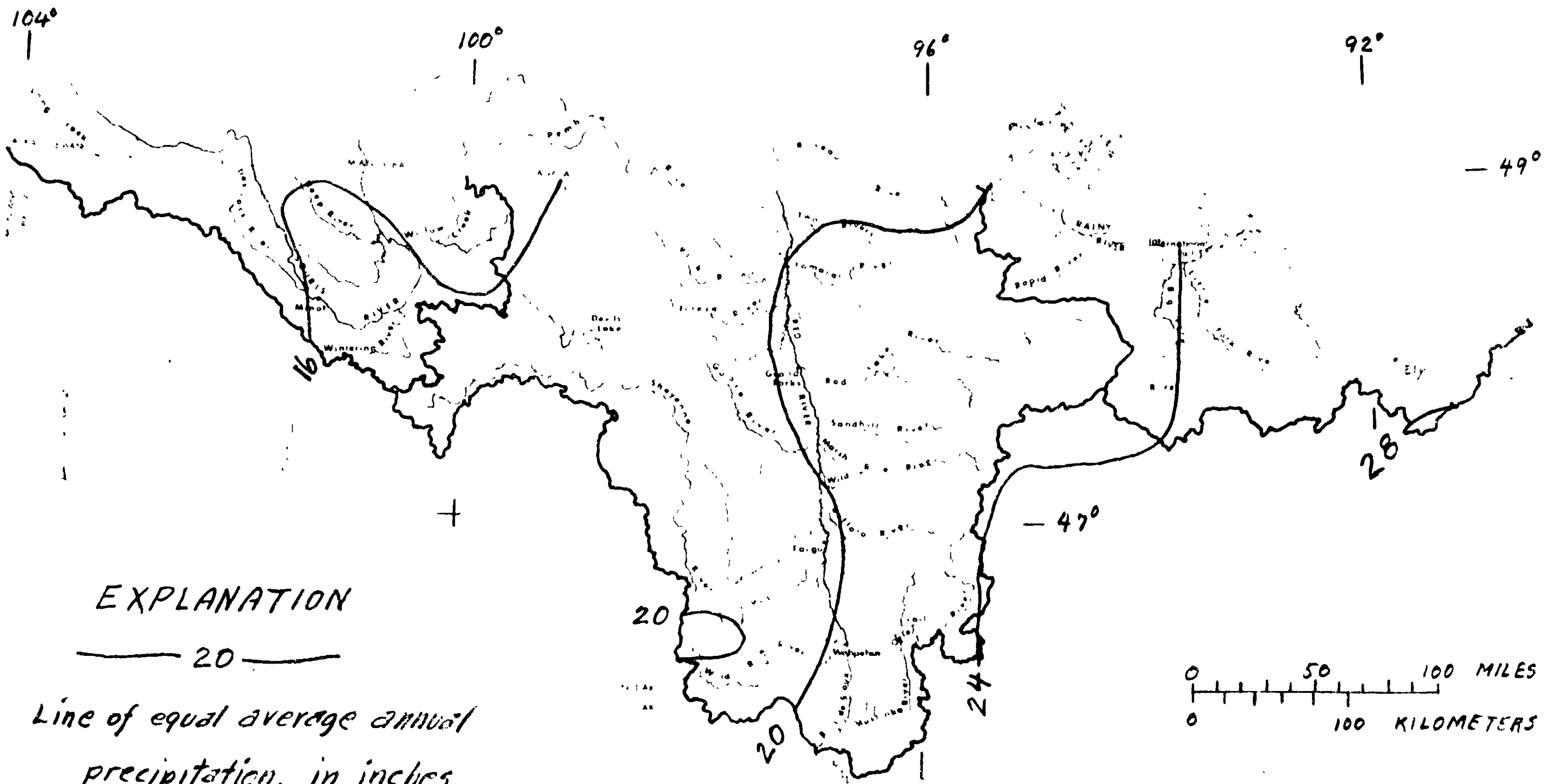
Page from Souris-Red Rainy River Basin Commission [illegible]

Figure 1.-- Location m[illegible] of So[illegible]ris-Red-Rainy Region showing subbasins



From Souris-Red-Rainy ... Commission, 1972.

Figure 1a.-- Location of former ... Rainy Region



EXPLANATION

——— 20 ———

Line of equal average annual precipitation, in inches. Interval 4 inches.

From U.S. Department of Commerce, Environmental Science Services Administration, 1968

Figure 2.-- Average annual precipitation

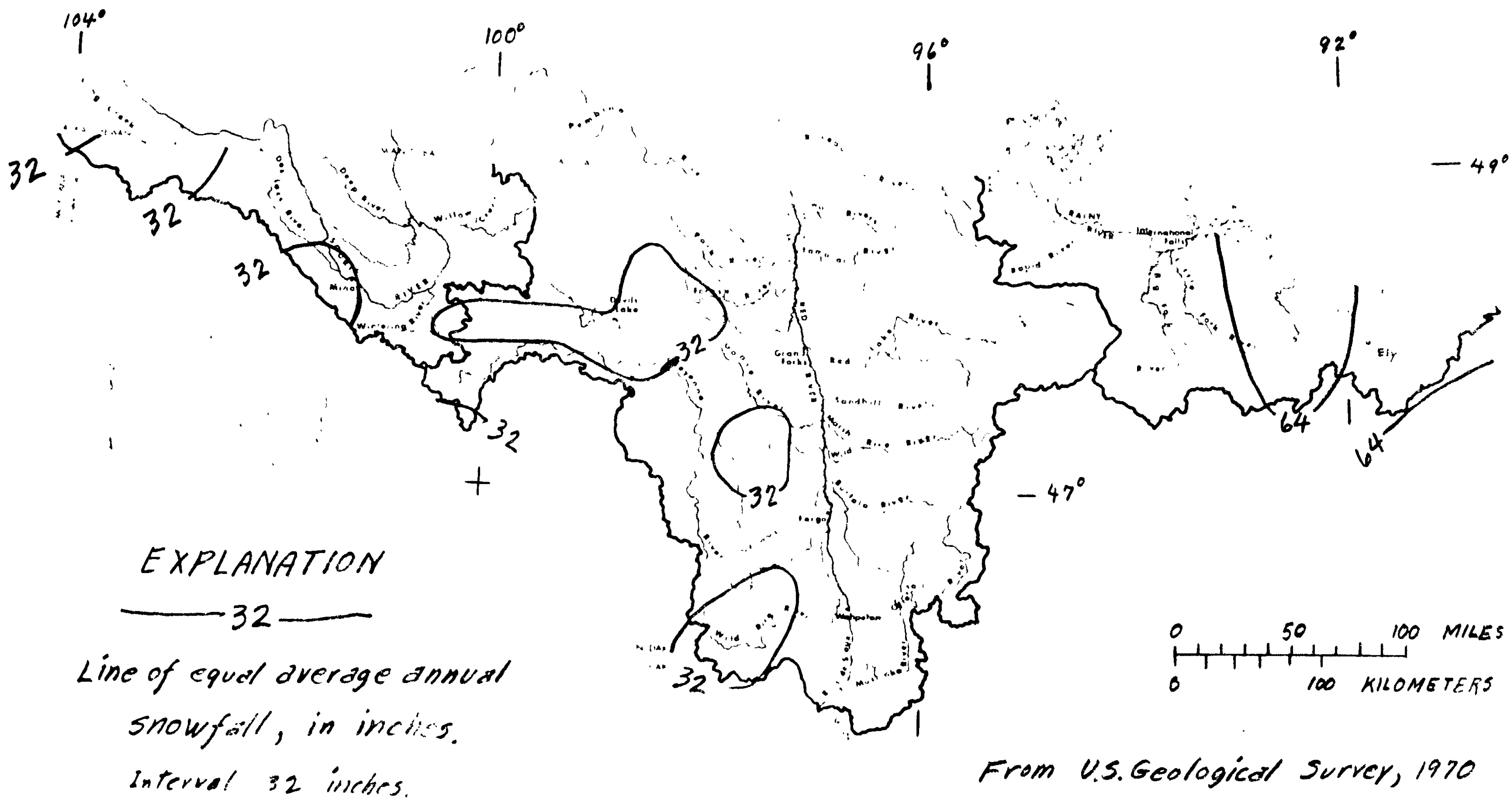


Figure 3.-- Average annual snowfall

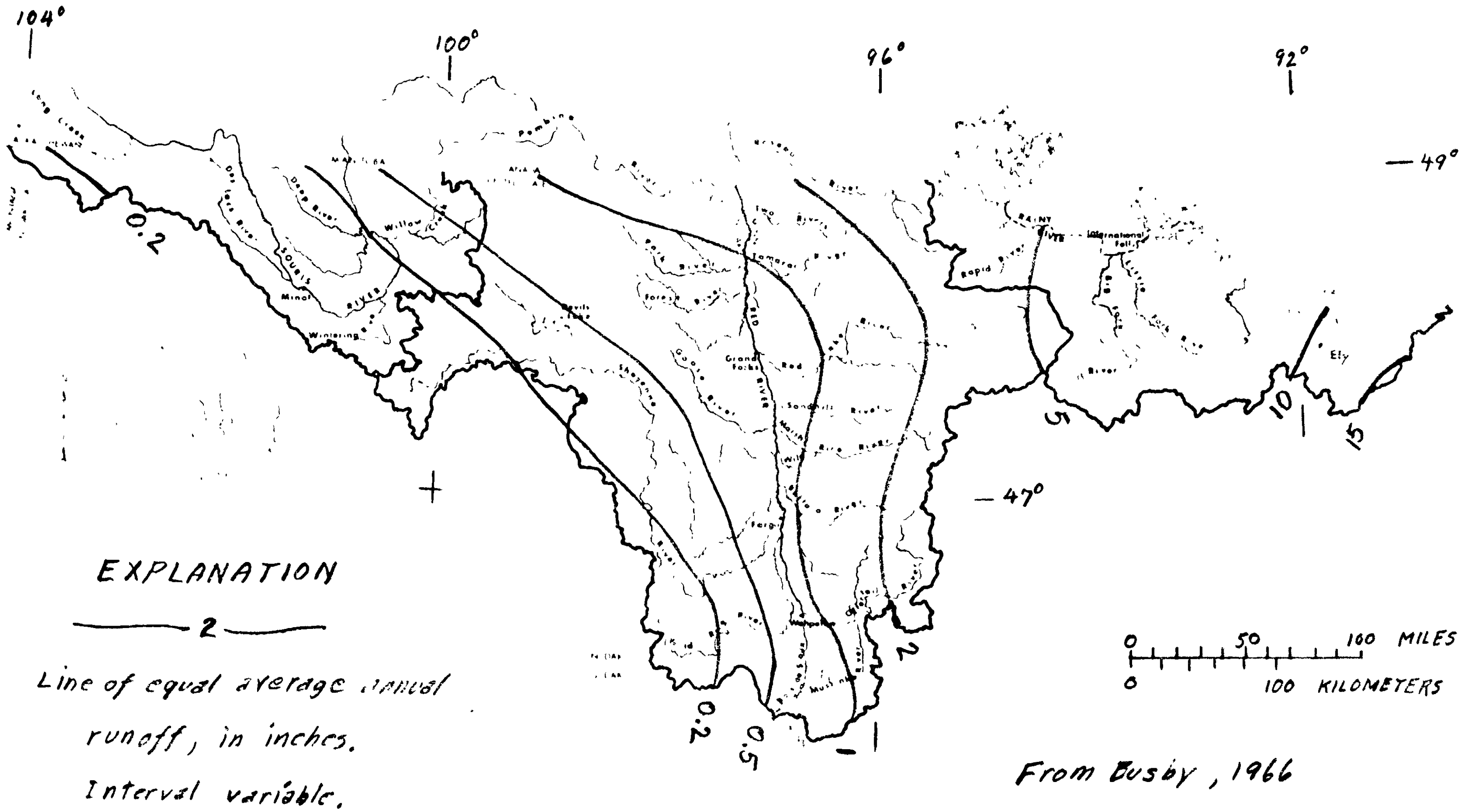


Figure 4.-- Average annual runoff

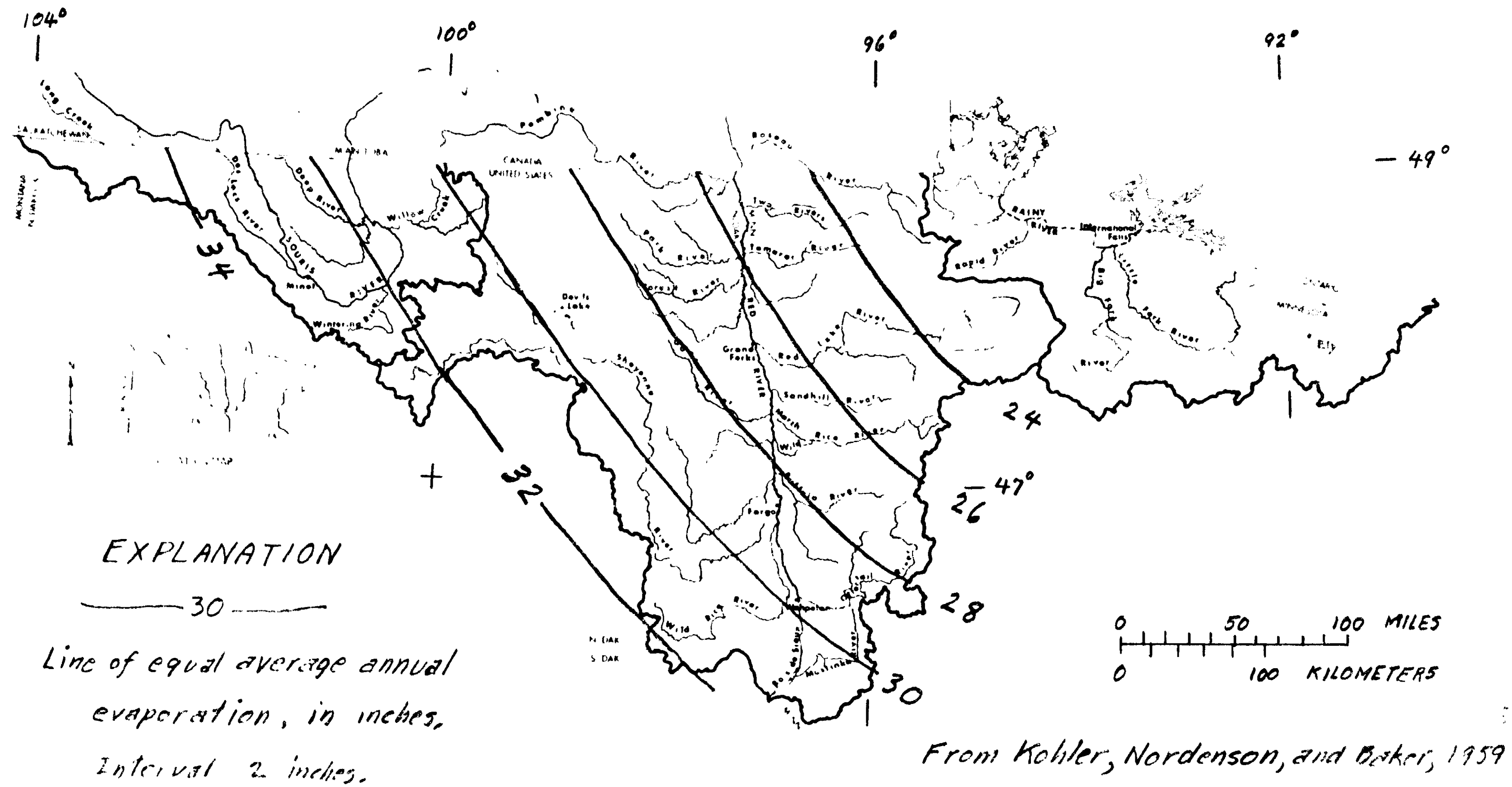
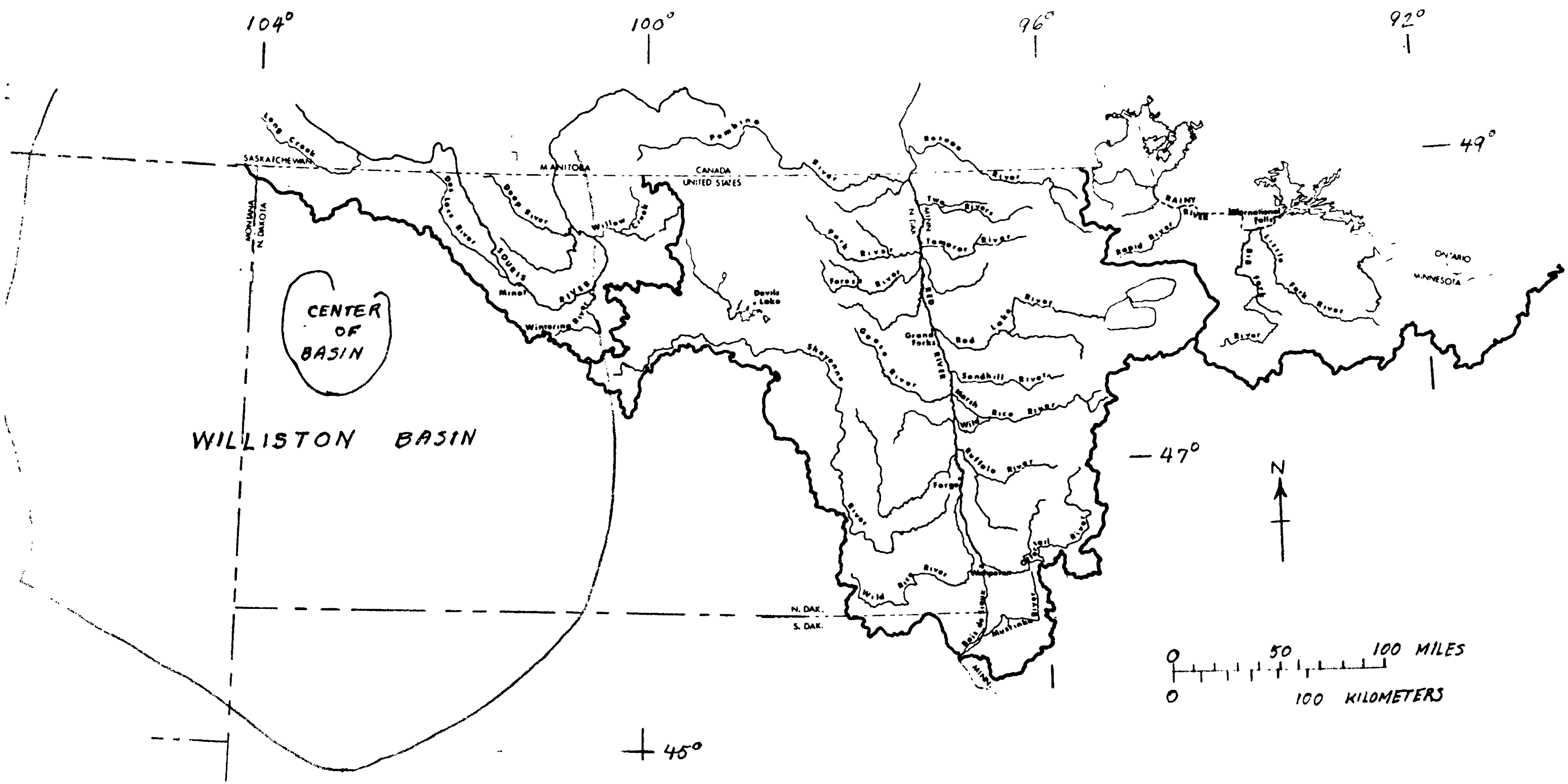


Figure 5.-- Average annual lake evaporation



Base from Souris-Red-Rainy River Basins Commission, 1972

Figure 5a.--Map showing location of the Williston Basin

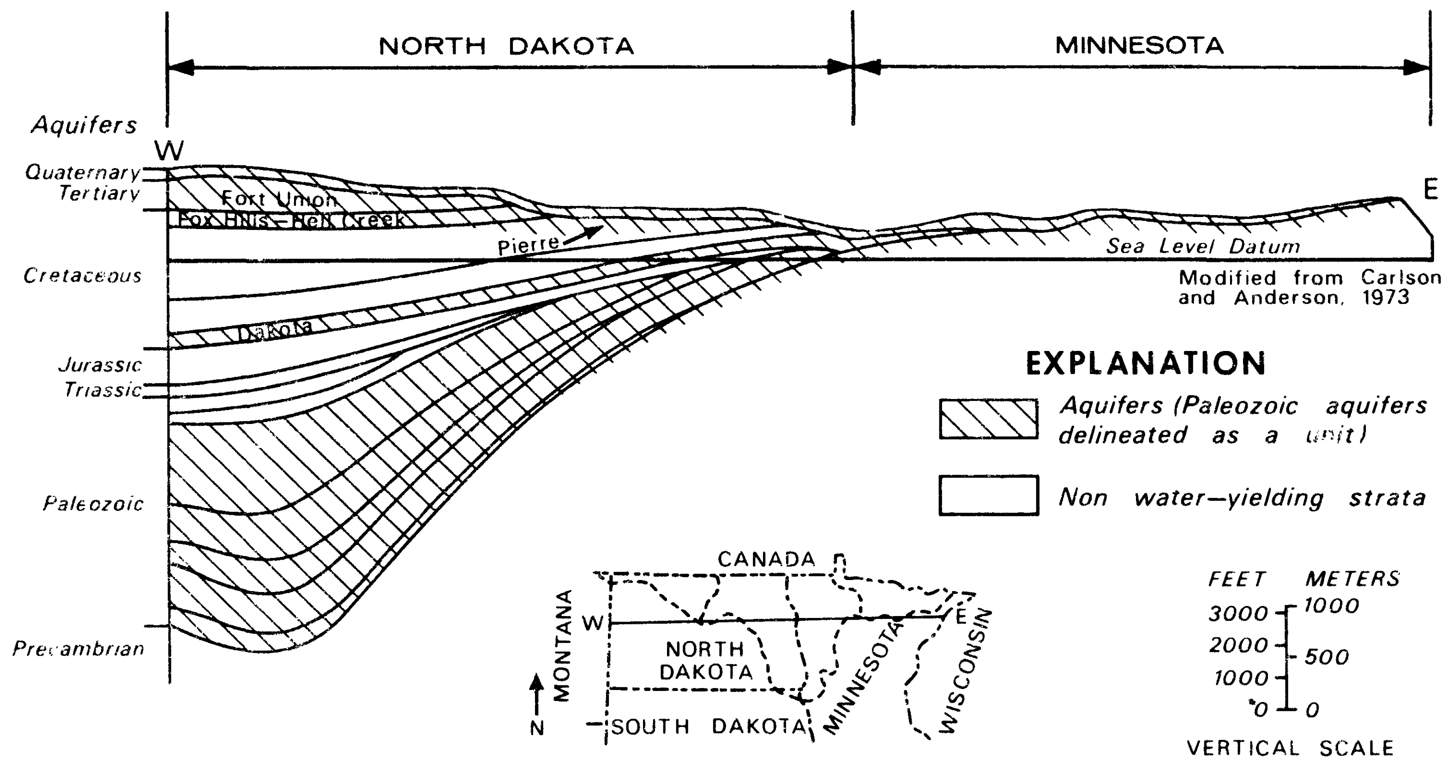


Figure 5b.--Diagrammatic section of North Dakota and Minnesota showing location of aquifers.

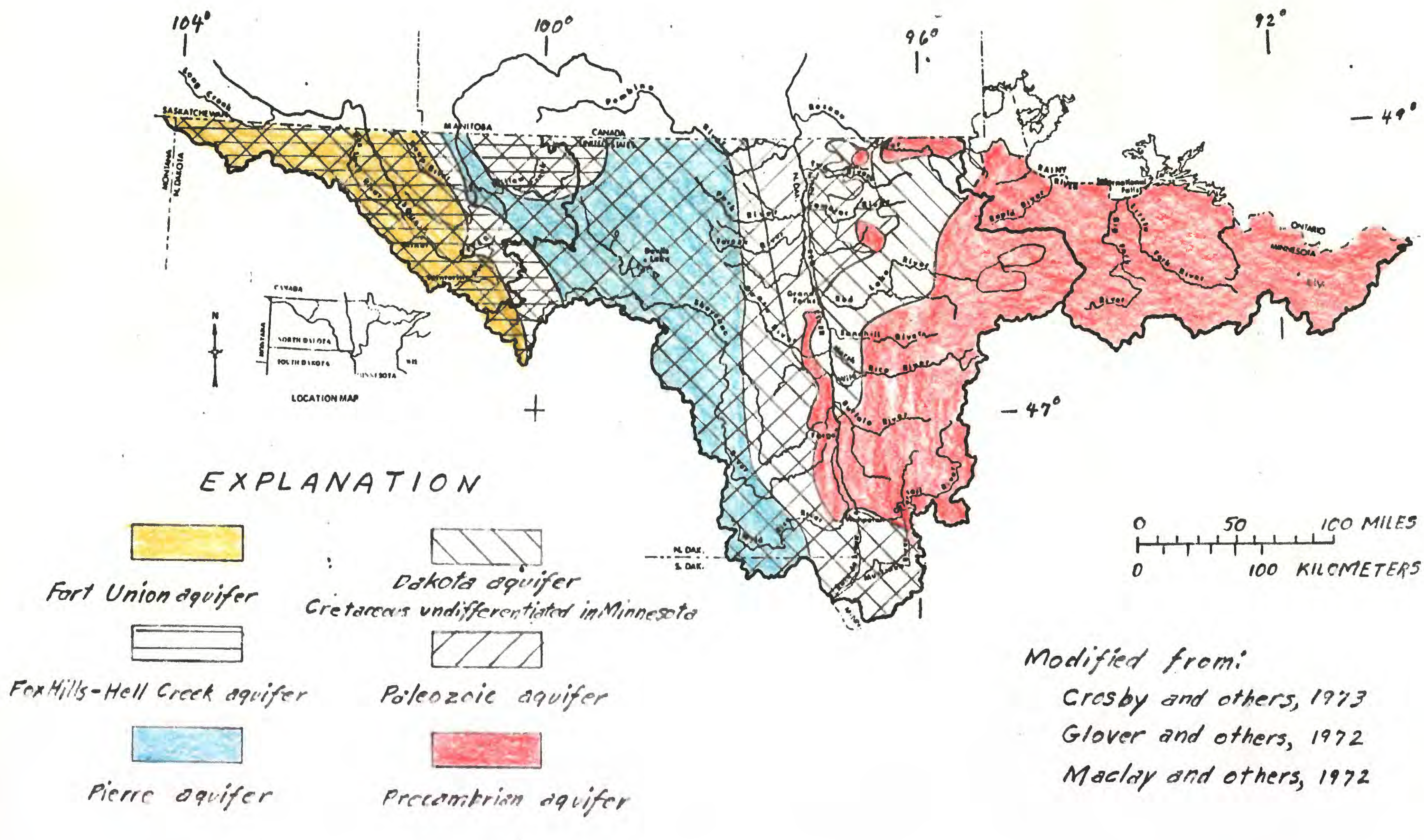
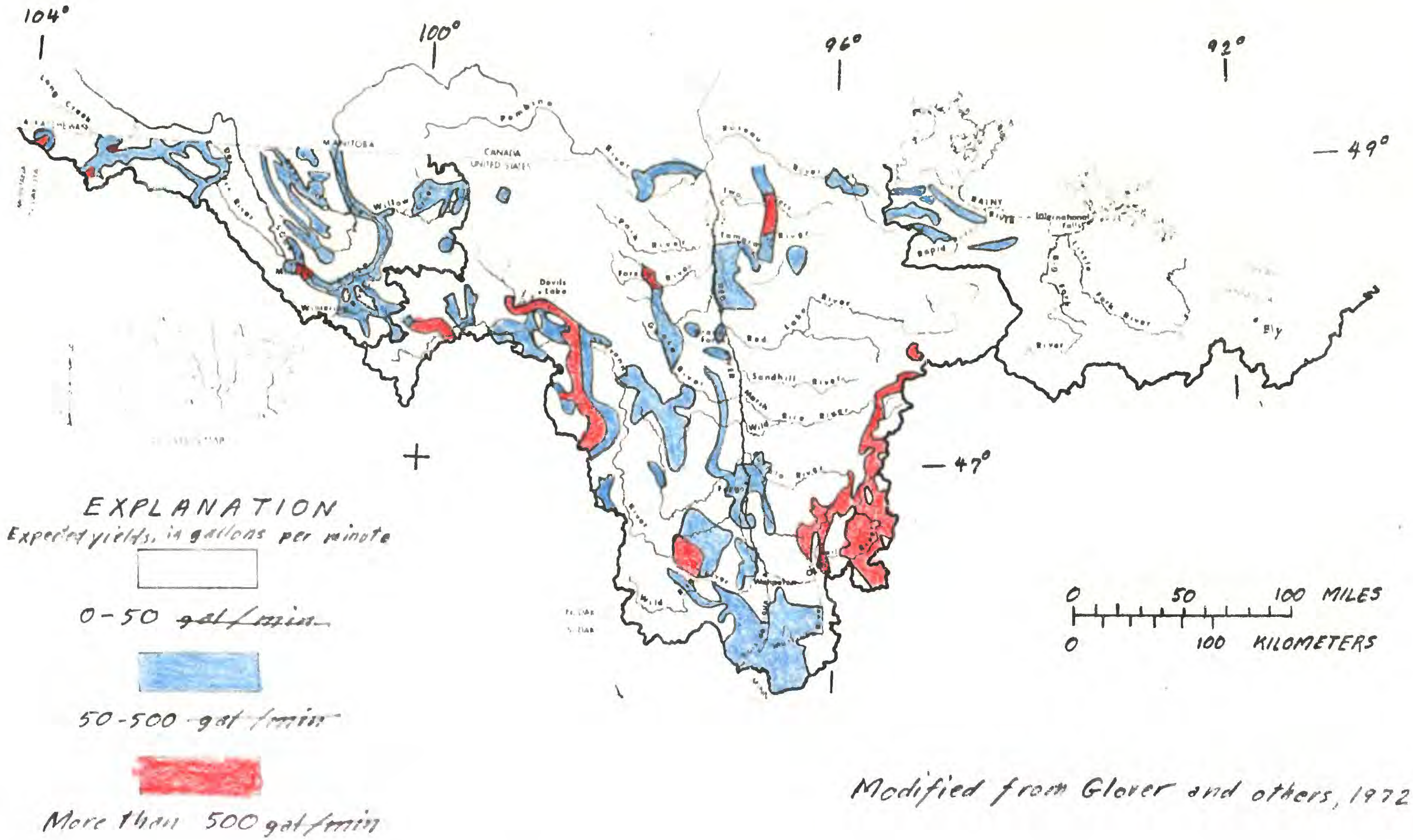
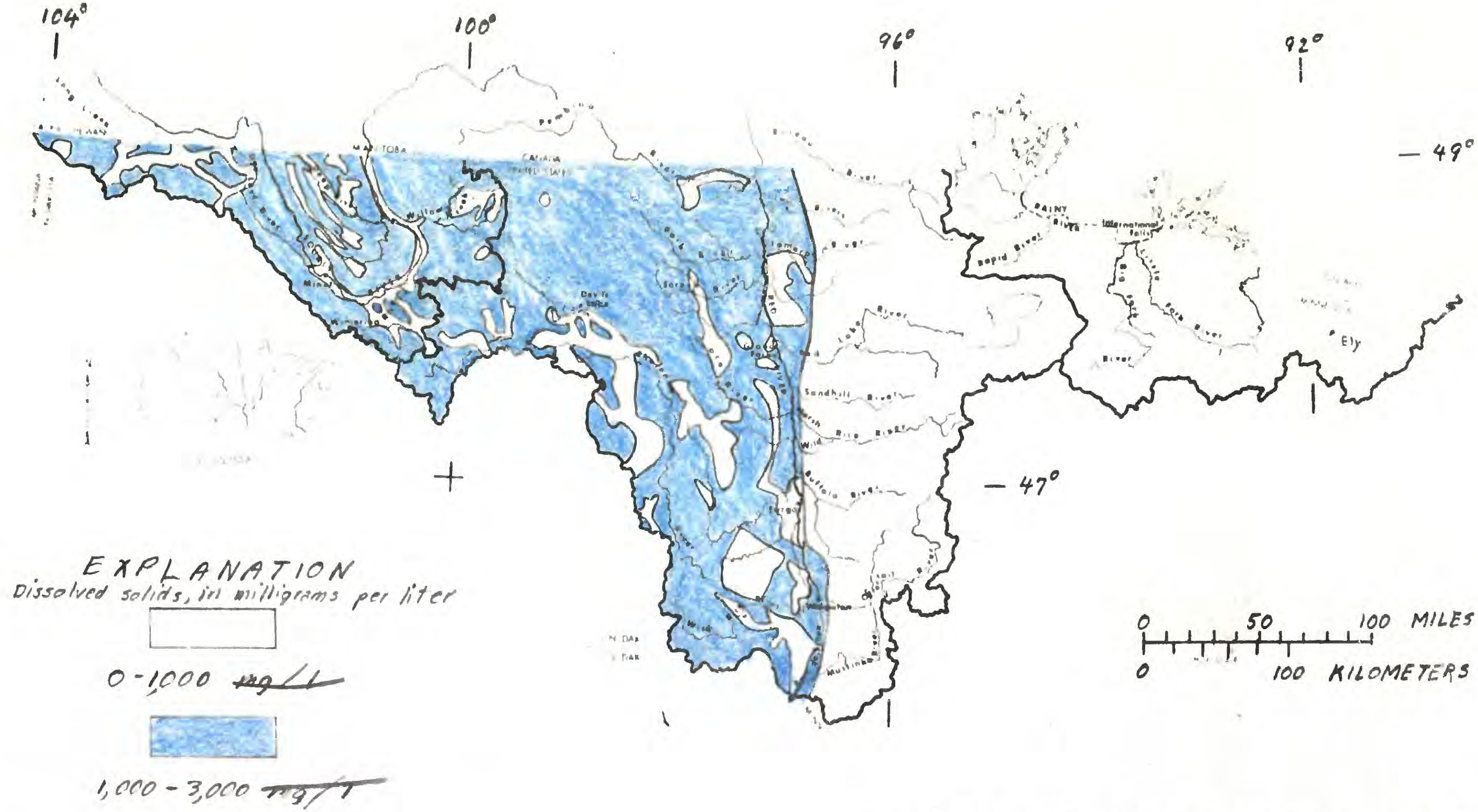


Figure 6.-- Areal extent of bedrock aquifers in the Souris-Red-Rainy Region



Modified from Glover and others, 1972

Figure 7.-- Expected yields of individual wells completed in ~~glacial~~ drift.



Modified from Glover and others, 1972

Figure 8.-- Dissolved solids in ground water

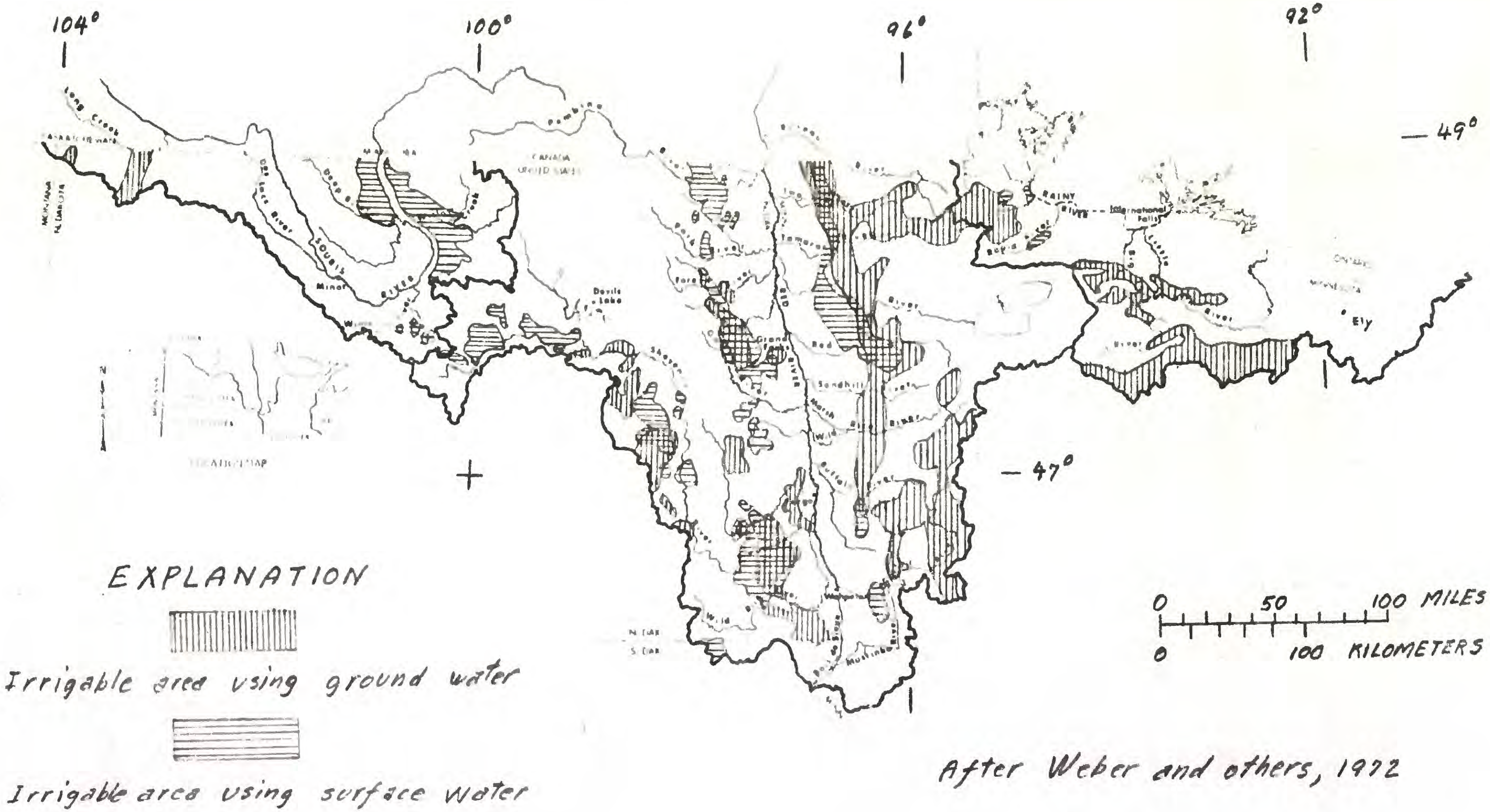
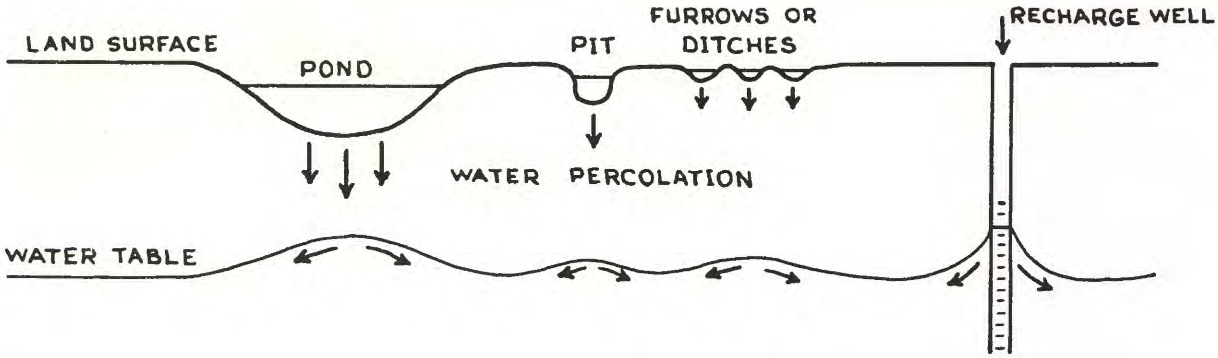
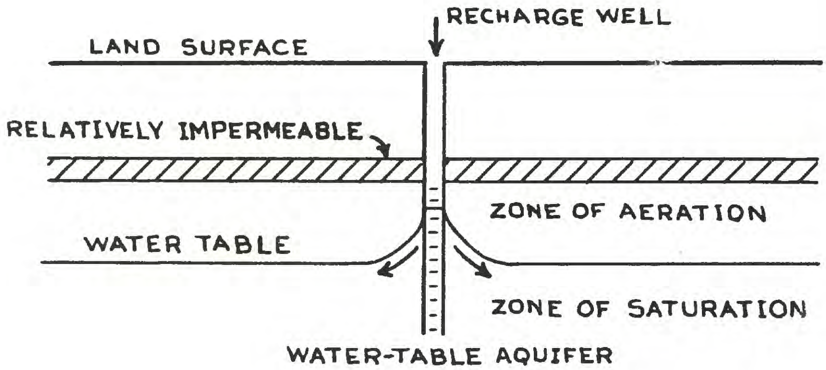


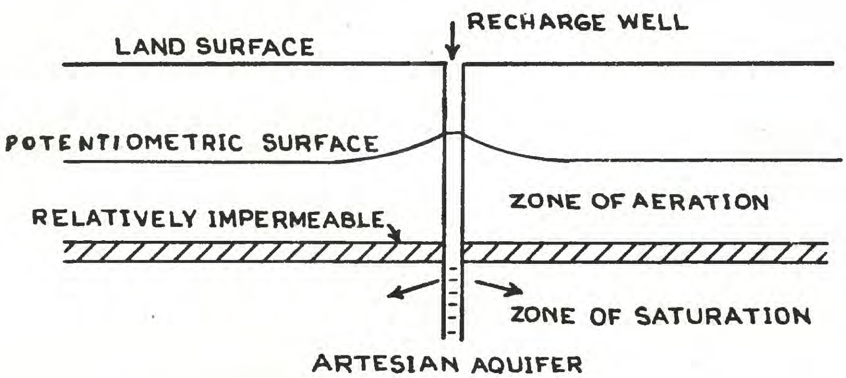
Figure 10.-- Areas with irrigation potential in Souris-Red-Rainy Region



No impermeable layer or zone between ground surface and aquifer



Impermeable layer or zone between ground surface and water-table aquifer



Impermeable layer or zone between ground surface and artesian aquifer

Figure 11.-- Direct methods of recharge

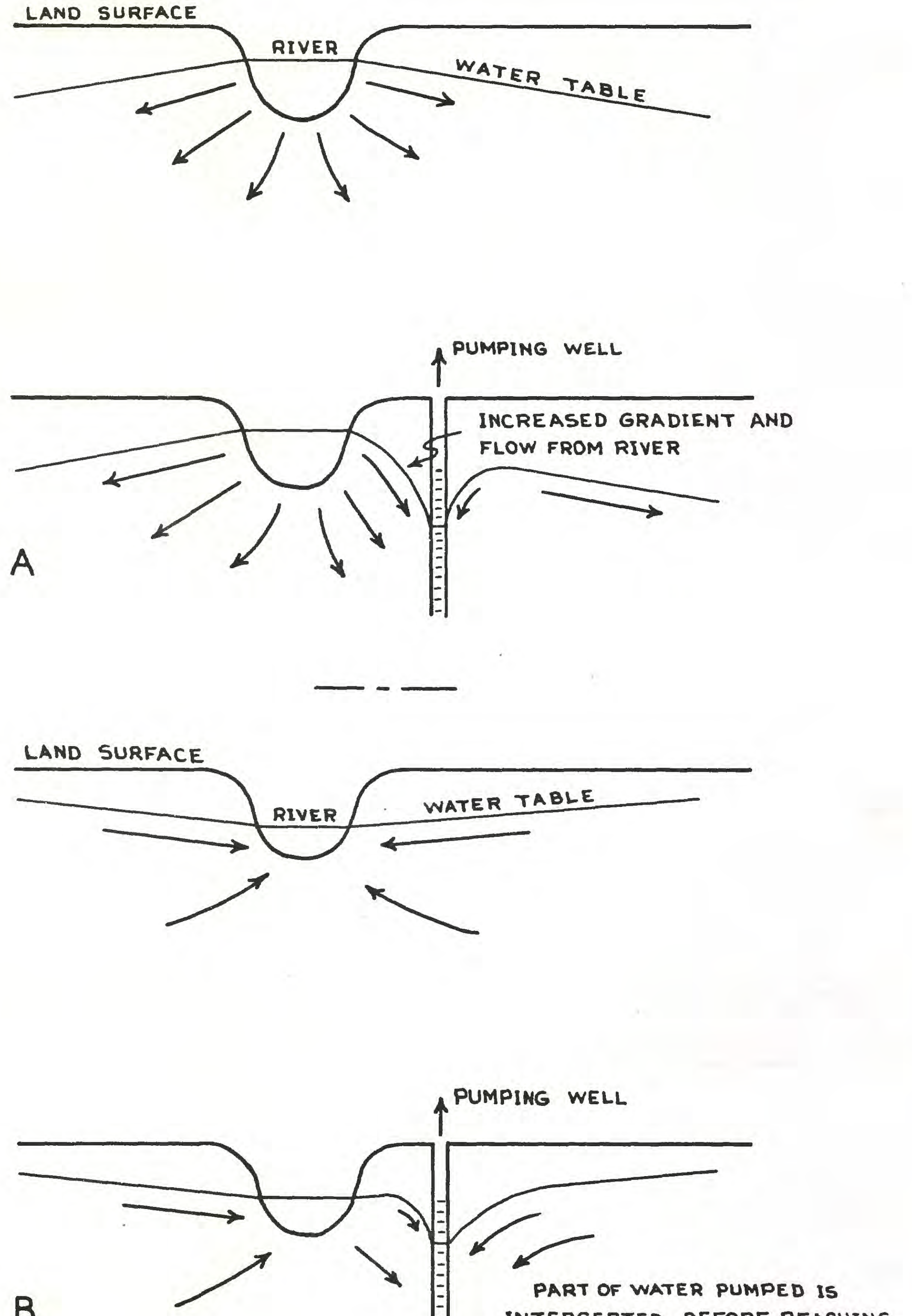


Figure 12.-- Indirect ~~(induced)~~ methods of recharge.