SYNOPSIS OF GROUND-WATER AND SURFACE-WATER RESOURCES OF NORTH DAKOTA

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FOREWARD

The Garrison Diversion Unit Commission, created "to examine the water needs of North Dakota and propose development alternatives which will lead to the early resolution of the problems identified," was implemented by P.L. 98-360, signed by President Reagan on July 16, 1984. The authorizing statutory language cites the economic, environmental and international issues and concerns which have been raised regarding completion of the Garrison Diversion Unit Project. Mr. James C. Wiley, Director of the Garrison Diversion Unit Commission staff, requested the U.S. Geological Survey to provide expertise in hydrology to the Commission members. Based on available information, this report describes the ground waters and surface waters of North Dakota and, importantly, the limitations of existing data. This report is aimed at providing a technical understanding of the water resources of North Dakota as a basis for decisionmaking with regard to the Garrison Diversion Unit Project and alternatives to the Project. The discussions of uncertainties with regard to existing knowledge highlight the complex hydrologic setting of North Dakota and the lack of reliable information on certain aspects of water resources, particularly on ground water.

Comments regarding the content of this report are welcome and may be addressed to the Chief Hydrologist, U.S. Geological Survey, 409 National Center, Reston, Virginia 22092.

Director, U.S. Geological Survey

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METRIC CONVERSIONS

Multiply inch pound unit	By	To obtain metric unit
foot (ft)	0.3048	meter (m)
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
inch (in.)	25.40	millimeter (mm)
mile per hour (mi/h)	1.609	kilometer per hour (km/h)
mile (mi)	1.609	kilometer (km)
gallon per minute (gal/min)	0.06308	liter per second (L/s)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
cubic feet per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
acre-foot per year (acre-ft/y)	1,233	cubic meter per year (m^3/y)
ton, short	0.9072	megagram (Mg)
foot per mile (ft/mi.)	0.3048	meter per mile (m/mi.)

EXECUTIVE SUMMARY

This report describes the surface- and ground-water resources of North Dakota and the limitations of our understanding of these resources. Ground water and surface water are actually one resource, because they are often hydraulically interconnected. They are discussed separately for convenience. In general, the surface-water resources of the mainstem of the Missouri river are abundant and suitable for most uses. Other rivers may be important locally as water-supply sources, but the quantities of flow are small, quite variable in time, and generally of an unsuitable quality for most uses. Streamflow characteristics of North Dakota reflect its arid to semiarid climate (annual precipitation varies from 13 to 20 inches from west to east across the State), cold winters (usually including a significant snowpack available for spring snowmelt runoff), and the seasonal distribution of annual precipitation (almost 50 percent falls from May to July).

Significant volumes of shallow ground water, of variable quality are found in the glacial-drift aquifers in parts of central, northern, and eastern North Dakota. Existing information provides only a limited capability to assess the long-term reliability of these scattered aquifers. There are significant indications, however, of water-quality problems related to sustained production of wells if long-term utilization of these aquifers is planned. A summary of the general suitability for use of surface water and ground water is given in Table E1.

Surface-Water Resources

The accompanying text, summarizes quantitative and qualitative characteristics of streamflow for the Missouri River and tributaries, and for each of the major streams of central, eastern, and northern North Dakota--the James River, the Red River and tributaries, the Souris River, and the Devils Lake basin surface waters. A summary of daily-flow statistics and dissolved-solids concentrations at selected streamflow-gaging and water-quality stations in the State is given in tables E2 and E3.

The Missouri River is the most significant source of surface water in North Dakota: the mean annual flow at Bismarck of 17,220,000 acre-feet is more than 80 percent of the total measured mean annual streamflow of the State. Streamflow of the Missouri River at Bismarck is equal to or greater than 11,700 cubic feet per second, 90 percent of the time.

The quality of water in the Missouri River mainstem is equalized by Lakes Sakakawea and Oahe, behind mainstem dams, and is only minimally affected by more mineralized water from the intervening tributaries. As indicated by table E1, Missouri River water is suitable for most uses. In terms of nitrate-nitrogen and certain key trace constituents, Missouri River water more than meets the drinking-water standards of the North Dakota State Department of Health and the U.S. Environmental Protection Agency (interim primary standards).

The rivers in the central, eastern, and northern parts of the State tend to have relatively flat gradients and, therefore, generally have slow velocities and are prone to flooding from snowmelt, but have zero or near-zero flow seasonally or during droughts. Flood potential is lessened in some locations by flood-control reservoirs, such as Jamestown and Pipestem on the James River. However, on rivers such as the Red River, there are few potential sites for the large reservoirs required for flood control or maintenance of low flows. The low flows of rivers are enhanced in some locations by reservoir releases, but there appears to be limited base flow from ground water during droughts. The Souris River is a very limited source of supply for extractive uses of water, not only because of the variable streamflow, but also because the existing storages are dedicated primarily to wildlife-refuge management.

In much of northern and central North Dakota, the surface drainage is poorly developed and the river basins include areas replete with thousands of lakes and wetlands. The interrelationship of these water bodies with rivers and with aquifers is only partially understood. In the closed Devils Lake basin, runoff is contained by lakes and wetlands, which fluctuate in response to seasonal and long-term climatic trends.

The water quality of the tributaries to the Missouri River and the rivers in the central, eastern, and northern parts of the State varies by river, season, volume of flow, and location. The lowest mineral concentrations are found in the Red River, but concentrations of cadmium, lead, mercury, and selenium in excess of that allowed by drinking-water standards have been detected at certain water-quality stations on the Red River. Concentrations of selenium in excess of drinking-water standards also have been detected in the Souris River.

The surface-water resources of North Dakota consist of complex hydraulic and hydrologic systems. Because of limitations of our understanding of the systems, the results of existing hydrologic studies may be inadequate for predicting, for example, the water-quality effects of return flow from irrigation and the effects on streamflow of large-scale pumping of ground water.

Ground-Water Resources

Glacial-drift aquifers, which may store large quantities of ground water, have been delineated and are being developed in areas of central, northern, and eastern North Dakota. These glacial-drift aquifers (fig. 5) are the only significant source of shallow ground water that is not excessively mineralized. These aquifers are distributed widely in linear patterns and may be of limited utility as a long-term supply source. Recharge to some aquifers is impaired by overlying silt and clay. Withdrawals of ground water may cause inflow into the glacial-drift aquifers of more mineralized ground water from the adjacent or underlying sedimentary bedrock, which generally contains large concentrations of dissolved solids and sodium.

The ground-water systems of North Dakota are even more complex than the surface-water systems. Quantitative analyses, based on existing information, may contain uncertainties which limit the capability for (1) predicting the success of artificial recharge, (2) determining the relationships between streamflow and aquifers, and (3) predicting the effects of artificial recharge and of irrigation return flows on the quality of ground water.

TABLE E1.--General suitability for use of surface and ground water

[S = suitable; M = marginal; U = unsuitable]

Aquifer or basin	Public supply	Domestic	Irrigation
	Surface water		
Missouri			
Main stem	S	S	S
Tributaries	M	M	M to U
James	M	M	M
Red			
Main stem	S	S	S
Tributaries	S to M	S to M	S to M
Souris	M	M	M
Devils Lake	M	S	M
	Ground water		
Glacial drift			
Shallow	S	S	S
Deep	M	S	M to U
Bedrock	U	U	U

TABLE E2.--Summary of daily flow statistics at selected streamflow-gaging stations

Station number	Station name	Drainage area (square miles)		Period of record (water years)	Daily discharge (cubic feet per second)				
		Total	Contributing		Mean	Median	Maximum	Minimum	90-percent duration value
Missouri River basin:									
06330000	Missouri River near Williston	164,500	--	1898-1964	20,180	15,600	180,000	1,320	7,340
06338490	Missouri River at Garrison Dam	181,400	--	1970-83	25,380	25,000	65,200	6,000	16,600
06342500	Missouri River at Bismarck	186,400	--	1954-83	23,770	23,400	68,800	4,000	11,700
06337000	Little Missouri River near Watford City	8,310	--	1935-82	593	73.1	55,000	0	.32
06340500	Knife River at Hazen	2,240	--	a/1929-83	181	31.9	21,800	0	9.4
06349000	Heart River near Mandan	3,310	--	a/1929-83	268	48.6	28,400	0	5
06354000	Cannonball River at Breien	4,100	--	1935-83	254	27	63,100	0	.57
James River basin:									
06468500	James River near Pingree	1,670	680	1954-63	17.1	.02	1,400	0	0
06470000	James River at Jamestown	2,820	1,170	a/1929-53	68.9	2.4	6,170	0	.82
06470000	James River at Jamestown	2,820	1,170	1954-83	60.8	9	5,280	0	2.4
06470500	James River at LaMoure	4,390	1,790	1951-83	97.5	23	6,420	0	7.2
Red River basin:									
05051500	Red River at Wahpeton	4,010	--	1943-83	519	334	8,940	1.7	102
05054000	Red River at Fargo	6,800	--	1902-83	552	281	24,800	0	32.9
05082500	Red River at Grand Forks	a/26,300	--	1883-1982	2,513	1,240	80,900	1.8	240
05102500	Red River at Emerson	a/36,400	--	1930-83	3,313	1,340	94,400	.9	239
050530000	Wild Rice River near Abercrombie	2,080	1,490	1933-83	72	1.5	9,360	0	0
05057000	Sheyenne River near Cooperstown	b/2,670	b/1,270	1945-82	104	20	5,130	0	3.7
05059000	Sheyenne River near Kindred	b/5,000	b/3,020	1950-82	196	73.2	4,600	13	33.9
05066500	Goose River at Hillsboro	1,203	1,193	1932-83	68.5	4.3	14,400	0	.1
05100000	Pembina River at Neche	3,410	--	a/1904-83	192	39.7	9,950	0	1.6
Souris River basin:									
05114000	Souris River near Sherwood	8,940	3,040	1931-83	143	7.3	13,700	0	.01
05124000	Souris River near Westhope	16,900	6,600	1931-83	268	25.6	12,400	0	.01
Devils Lake basin:									
05056100	Mauvais Coulee near Cando	387	377	1957-82	19.1	.05	2,580	0	0
05056200	Edmore Coulee near Edmore	382	282	1958-82	13.3	.01	1,090	0	0
05056400	Big Coulee near Churchs Ferry	2,510	1,820	1951-82	40.8	.01	1,400	0	0

a/Period of record not continuous.
b/Does not include the closed basin of Devils Lake.

TABLE E3.--Summary of dissolved-solids concentrations, in milligrams per liter, at selected water-quality stations

Basin and station	Number of samples	Percent of samples in which values were less than or equal to those shown: 90	50 (median)	10
Missouri				
Main stem				
near Williston	162	550	460	300
at Garrison Dam	134	500	430	400
at Bismarck	70	509	435	400
Tributaries				
Little Missouri River near Watford City	100	2000	1300	550
Knife River at Hazen	104	1500	1000	585
Heart River near Mandan	72	1200	890	458
Cannonball River at Breien	122	2100	1200	593
James				
near Grace City	22	919	450	163
at Jamestown	74	890	510	200
at LaMoure	180	890	542	252
Red				
Main stem				
at Hickson	62	431	320	240
below Fargo	120	450	330	250
at Grand Forks	204	483	310	230
at Emerson, Manitoba	60	561	375	262
Tributaries				
Wild Rice River near Abercrombie	181	1200	880	382
Sheyenne River near Cooperstown	273	720	590	320
Sheyenne River near Kindred	137	632	520	362
Goose River at Hillsboro	60	1590	995	418
Pembina River at Neche	23	596	440	214
Souris				
near Sherwood	120	1300	720	340
above Minot	59	830	520	370
near Verendrye	239	1000	650	380
near Bantry	67	922	620	348
near Westhope	272	1100	630	400
Devils Lake				
Mauvais Coulee near Cando	28	938	610	294
Edmore Coulee near Edmore	19	640	360	210
Big Coulee near Churchs Ferry	141	1100	520	292

INTRODUCTION

North Dakota's surface-water resources range from an abundance in Lakes Sakakawea and Oahe in the west-central part of the State to shortages in other parts of the State. In addition to Lakes Sakakawea and Oahe, numerous smaller reservoirs have been constructed in the State. However, because of the lack of facilities to transport water, even areas a short distance from the large reservoirs do not make extensive use of the available surface-water resources. Use of the available resources also is limited by the quality of the water. The water in many natural lakes and even some reservoirs is too saline for general use.

Some large, productive aquifers have been delineated in many parts of the State. However, many are overlain by less permeable materials that retard rapid recharge. Although large quantities of ground water may be available from storage, the withdrawals may be accompanied by excessive drawdown in the well fields and degradation of quality. As is the case with surface-water resources, use of ground-water resources also is affected by the quality of the water. In some parts of the State the ground-water reservoirs contain substantial quantities of water generally not usable because of excessive salinity.

The purposes of this report are to provide a technical synopsis of the ground- and surface-water resources of North Dakota, their interrelations, and present use, and the current understanding of the hydrologic processes that affect the resources. The report was compiled at the request of the staff of the Garrison Diversion Unit Commission, which was established by Public Law 98- 360 in July 1984.

The report addresses all of North Dakota but it emphasizes those areas of the State that have been part of the Garrison Diversion Project plans. Information in this report was compiled from currently available publications and data. The ground- and surface-water resources of North Dakota are discussed separately in parts of the report for convenience. However, glacial drift and near-surface bedrock are commonly connected hydraulically to surface-water systems. Ground water and surface water are actually one resource; therefore, development or contamination of one nearly always affects the other.

Physiography and Climate

North Dakota is located in two provinces of the Interior Plains. Fenneman (1931) defined the boundary between these provinces (fig. 1); the Great Plains lie to the west and the Central Lowland to the east. The line that separates these provinces passes through the middle of the State along the base of the eastern escarpment of the Great Plains.

The drainage patterns in the Great Plains province generally are well defined except in the Coteau du Missouri, an area of complex glacial moraines. Much of this area does not have integrated drainage and does not contribute surface runoff to the streams.

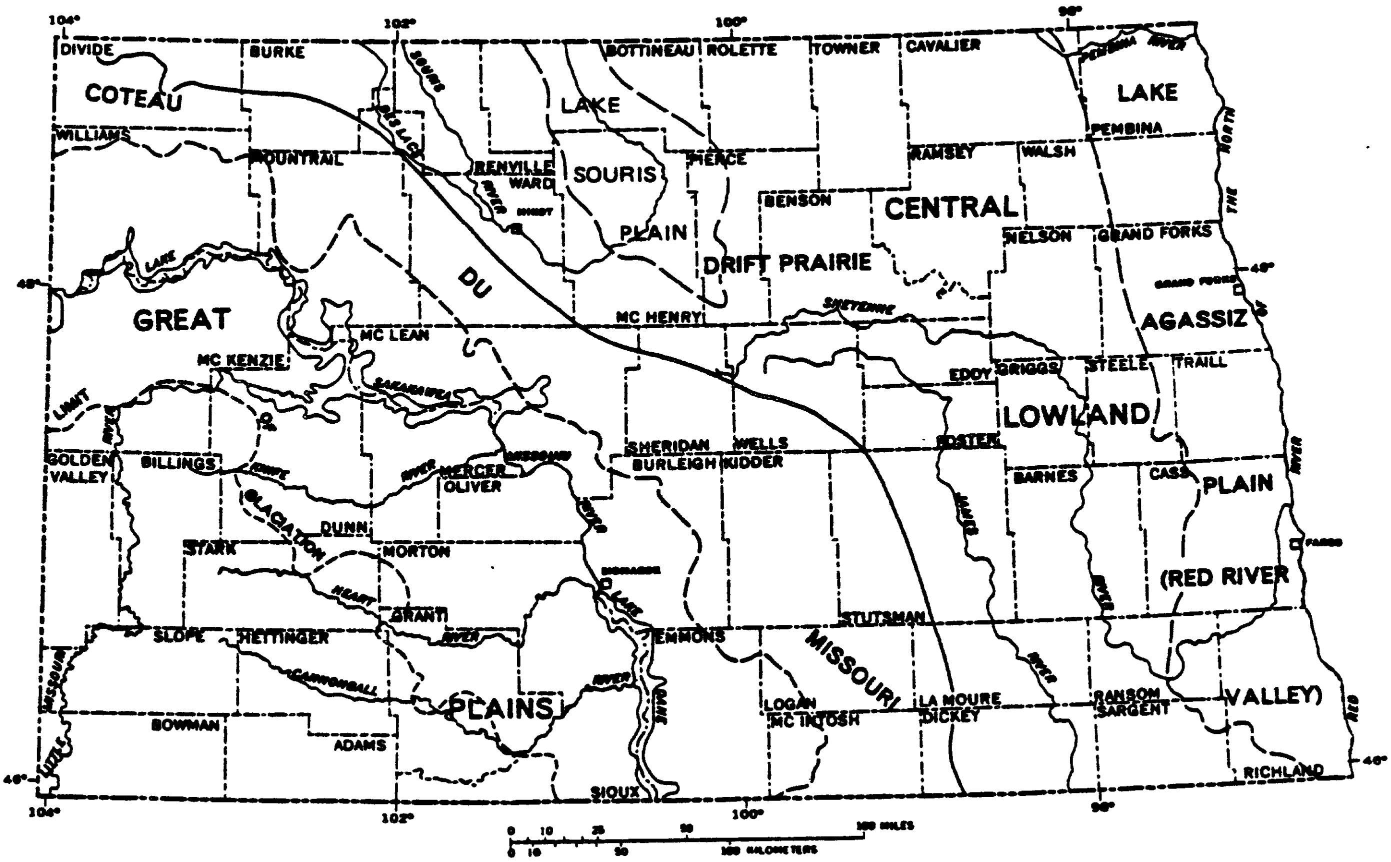


FIGURE 1.—Physiographic divisions of North Dakota. (Modified from Fennemen, 1946, and Clayton, 1962.)

The Central Lowland is a glaciated area; it is covered with glacial till, fine-grained lake sediments, and glaciofluvial drift consisting mainly of sand and gravel deposits. The land slopes slightly to the northeast from about 2,000 feet above sea level along the western border of the lowland, to 800 feet above sea level at the northeast corner of the State. Much of the drainage is poorly developed and includes closed basins varying from a few acres to as much as 3,900 square miles in the closed Devils Lake basin.

A major drainage divide transects the State from the northwest corner, near the eastern edge of the morainal part of the Great Plains, to the center of the State, then southeast between the James and Sheyenne Rivers. The southwestern part of the State is drained by the Missouri River, a tributary of the Mississippi River. The northeastern part is drained by the Red River of the North (hereafter refered to as Red River) which flows to Hudson Bay.

The average annual precipitation ranges from about 13 inches in the western part of the State to about 20 inches along the eastern border. The areal distribution of average annual precipitation based on data for 1931-60 is shown in figure 2. Recent records indicate that data for the years shown may not provide an accurate representation of the long-term average. However, more recent data have not yet been compiled. Average annual evaporation ranges from about 32 inches in the northeast part of the State to about 40 inches in the southwest part of the State (fig. 3).

Precipitation is derived chiefly from airmasses from the Gulf of Mexico. Most of the summer rainfall is from local thunderstorms. Cold winters usually result in an accumulation of snow from November or December through March.

Even though North Dakota has a relatively short growing season and little precipitation, agriculture is the main industry. This is possible, in part, because of climatic factors that are described by some statistics provided by Bavendick (1959, p. 811-812). About 75 percent of the annual precipitation falls during the crop-growing and freeze-free season, April to September, and almost 50 percent falls during May, June, and July. The average growing season is about 120 days. The growing season is comparatively short but includes more than 15 hours of daylight each day from the middle of May to the end of July. The prevailing direction of the wind in all months of the year is from the northwest, unless it is affected by local conditions. Average annual wind speed is about 11 miles an hour.

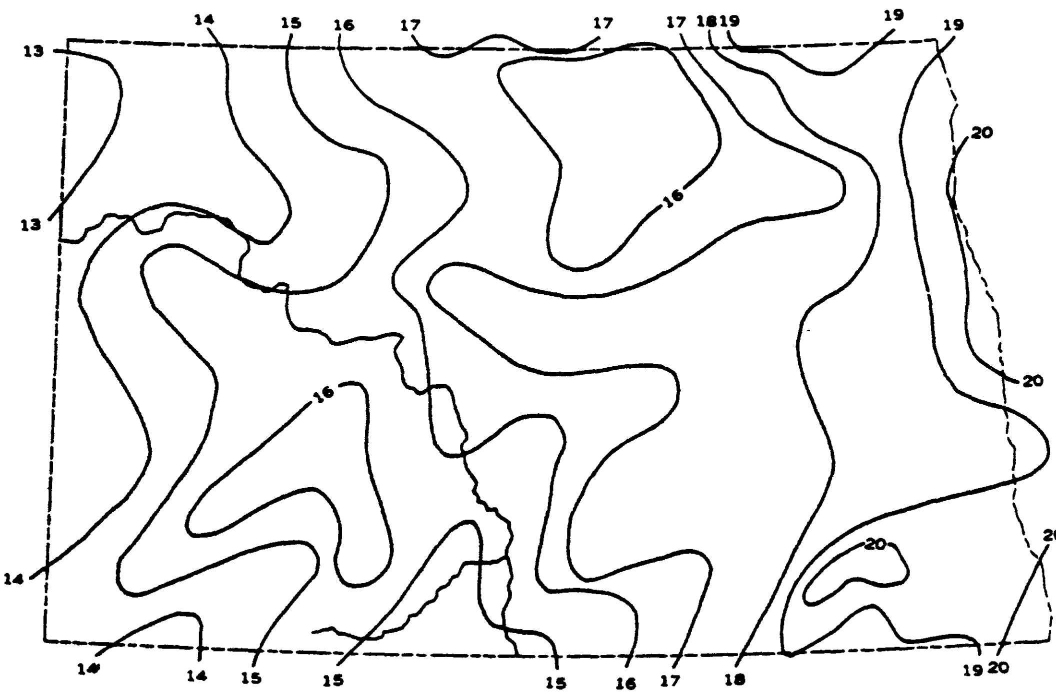


FIGURE 2.—Average annual precipitation in North Dakota (1931-60), in inches. (Data from National Weather Service.)

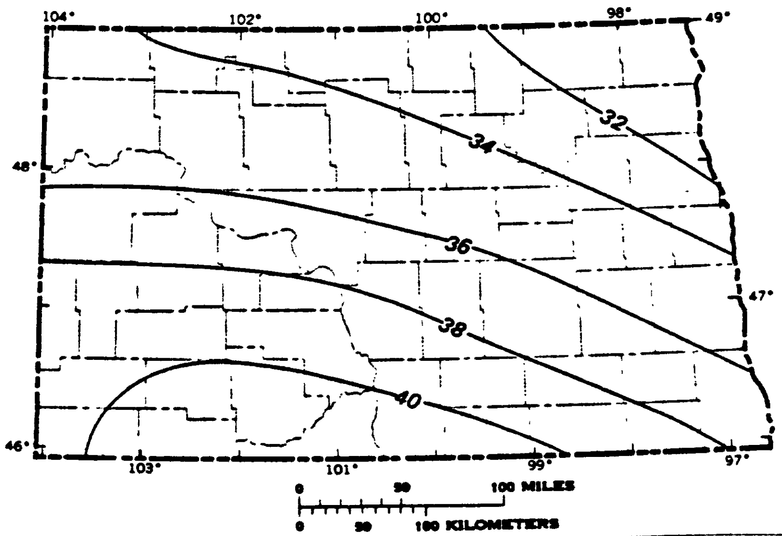


FIGURE 3.—Average annual free-water-surface evaporation (shallow lake) in North Dakota, in inches. (From U.S. Department of Commerce, 1982.).

Water-Quality Standards and Criteria

Limitations exist on the surface- and ground-water resources as a result of water-quality. The suitability of water for various uses is addressed in this report by comparing measurements of water quality in surface and ground water with water-quality standards and criteria.

Water-quality standards and criteria have been established for certain toxic and aesthetically undesirable constituents or properties both by the U.S. Environmental Protection Agency (EPA) and by the State of North Dakota. The purpose of these standards and criteria is to protect the users of the water, including humans and animals, aquatic life, and crops. Water-quality standards are developed through State and Federal rulemaking procedures and may be defined as maximum contaminant levels that, if exceeded in a water source, may be grounds for rejection of the source as a supply of drinking water or for other uses. In contrast, water-quality criteria do not provide a legal basis for enforcement, but specify concentrations of constituents which, if not exceeded, are expected to result in water suitable for the intended uses.

Water-quality standards and criteria for the major water uses in North Dakota are listed in table 1. The National Interim Primary Drinking Water Regulations that specify the maximum permissable level of a contaminant in water for public supplies, are health related and legally enforceable. If these concentrations are exceeded or if required monitoring is not performed, the public must be notified. The National Secondary Drinking Water Regulations pertain to constituents that affect the aesthetic qualities related to public acceptance of drinking water. They are guidelines and are not federally enforceable. Not included in the table are several standards or criteria for organic, microbiological, or radiological constituents, either because data concerning these constituents are lacking, or they will not be considered in this report.

The North Dakota standards in table 1 apply to class I streams. This is the most stringent classification of streams in North Dakota (North Dakota State Department of Health, 1977) and is defined as follows: "The quality of waters in this class shall be such as to permit the propagation and/or life of resident fish species and shall be suitable for boating, swimming, and other water recreation. The quality shall be such that after treatment consisting of coagulation, settling, filtration, and chlorination, or equivalent treatment processes, the treated water shall meet the bacteriological, physical, and chemical requirements of the State Health Department for municipal use. The quality of water shall be such as to permit its use for irrigation, stock watering, and wildlife use without injurious effects." Where State standards are more restrictive than Federal standards, the State standards apply to water in North Dakota.

These standards and criteria will be compared to the water quality of the ground and surface water of North Dakota. U.S. Environmental Protection Agency standards will be referred to as "Federal" standards. North Dakota State Health Department Class I standards will be referred to as "State" standards.

TABLE 1.--Water-quality standards and criteria

[mg/L, milligrams per liter; ug/L, micrograms per liter]

		Standards		Criteria		
Constituent	Units	National interim primary drinking-water regulations (U.S. Environmental Protection Agency, 1982a)	National secondary drinking-water regulations (U.S. Environmental Protection Agency, 1982b)	North Dakota class I streams (North Dakota State Health Department, 1977)	Freshwater aquatic life (U.S. Environmental Protection Agency, 1976,1980)[a]	Irrigation (National Academy of Sciences, 1972)
Alkalinity, as $CaCO_3$	mg/L	--	--	--	>20	--
Ammonia, unionized as NH_3	mg/L	--	--	0.02	.02	--
Arsenic	ug/L	50	--	50	440	100
Barium	ug/L	1000	--	1000	--	--
Beryllium	ug/L	--	--	--	5.3	100
Boron	ug/L	--	--	500	--	750
Cadmium	ug/L	10	--	10	6.3	10
Chloride	mg/L	--	250	100	--	--
Chlorine, residual	mg/L	--	--	.01	.01	--
Chromium	ug/L	50	--	50	[b]21	100
Copper	ug/L	--	1000	50	43	200
Cyanide	ug/L	--	--	.005	.052	--
Dissolved solids	mg/L	--	500	--	--	--
Fluoride	mg/L	[c]1.4 - 2.4	--	--	--	1000
Iron	ug/L	--	300	--	--	5000
Lead	ug/L	50	--	50	400	5000
Manganese	ug/L	--	50	--	--	200
Mercury	ug/L	2	--	2	.0017	--
Nickel	ug/L	--	--	--	3100	200
Nitrate, as N	mg/L	10	--	[d]1	--	--
Oxygen, dissolved	mg/L	--	--	>5	>5	--
pH	standard units	--	6.5 - 8.5	7 - 8.5	6.5 - 9	--
Phosphorus, dissolved as P	mg/L	--	--	[d].1	--	--
Selenium	ug/L	10	--	10	260	20
Silver	ug/L	50	--	--	13	--
Sulfate	mg/L	--	250	250	--	--
Zinc	ug/L	--	5000	1000	570	2000

[a]Criterion for concentrations that should not be exceeded at any time; trace-metal criteria are for hard water (hardness greater than 200 milligrams per liter as $CaCO_3$).

[b]Hexavalent chromium.

[c]Temperature related standard; mimimum 1.4 milligrams per liter when annual average maximum daily temperatures exceed 26.3 degrees Celsius.

[d]Standards are intended as guideline limits based on unique characteristics for each lake and stream that determine concentrations of these constituents that cause excessive algal growth (eutrophication). In no case shall the standard for nitrate as nitrogen exceed 10 milligrams per liter in water used for drinking-water supply.

GROUND WATER RESOURCES

North Dakota is underlain by extensive deposits of water-bearing sedimentary bedrock. The rocks are thickest, about 17,000 feet, in the Williston Basin. They gradually thin eastward across North Dakota; then become only a few hundred feet thick, or are totally absent, beneath the Red River.

Glacial drift overlies the bedrock throughout much of the State, north and east of the Missouri River. Glacial drift deposits range in thickness from less than 100 feet in much of this area to more than 400 feet in parts of the Coteau du Missouri and in a few drift-filled bedrock valleys (Bluemle, 1971). Southwest of the Missouri River, glacial drift is thin and discontinuous.

Location and Extent of Aquifers

Bedrock

Bedrock in North Dakota consists of sandstone, siltstone, shale, limestone, and dolomite (Bluemle and others, no date). Sandstone and limestone are the principal aquifers and readily yield water to wells. Shale and siltstone generally are confining beds and do not readily yield water to wells.

In a regional study of the ground-water resources of the northern Great Plains, Downey (1984) grouped the bedrock formations into aquifer units and confining beds. He classified five aquifer units within the bedrock underlying North Dakota, from deepest to shallowest: (1) Cambrian-Ordovician; (2) Mississippian (Madison); (3) Pennsylvanian-Permian; (4) Lower Cretaceous; and (5) Upper Cretaceous and Tertiary. Downey (1984) states that the aquifers consist of rocks with variable permeability, but that he grouped them because hydraulic head differences within each unit were much smaller than hydraulic-head differences between an aquifer and adjacent confining beds. The term aquifer is used in this part of the report to refer to water yielding properties; the term makes no implication relative to water quality.

The Cambrian-Ordovician aquifer principally consists of the Deadwood, Winnipeg, Red River, Stony Mountain, and Interlake (lower part) Formations. These rocks principally are limestone and dolomite, except for the Deadwood Formation, which is sandstone and shale. The Mississippian aquifer in the Madison Limestone principally is limestone and dolomite. The Pennsylvanian aquifer principally consists of the Minnelusa Formation, which is mostly sandstone and dolomite. The Lower Cretaceous aquifer is known as the Dakota aquifer in North Dakota. It consists of the Inyan Kara Group, Skull Creek Shale, Newcastle or Muddy Sandstone, and Mowry Shale. These formations principally are sandstones, but they contain considerable interbedded shale. The Upper Cretaceous and Tertiary aquifer consists of the Fox Hills Sandstone and Hell Creek Formation (Upper Cretaceous) and the Fort Union Formation, Golden Valley Formation, and White River Group (Tertiary). All these rocks have sand and lignite beds interbedded with silt and clay.

Relative positions, extents, and thicknesses of the five aquifer zones, and the confining beds separating them, are shown in figure 4. The figure includes a larger area than North Dakota to put North Dakota's ground-water resources in perspective with the northern Great Plains regional aquifer systems as a whole, especially with respect to overall ground water movement and water quality.

Glacial drift

Glacial drift overlying bedrock in much of North Dakota is perhaps the most complex system of geologic deposits in the State. The geologic materials were deposited in a variety of regional and local environments associated with glacial ice: (1) Water-deposited sand and gravel (outwash) that underlie areas ranging in size from a few acres to many square miles. These deposits are in outwash plains, bedrock valley fill, and present river valleys; and (2) glacial till, an unsorted mixture of clay through boulder size particles, associated with the melting of stagnant ice.

Glacial till generally is poorly sorted and has minimal permeability. Therefore, the only glacial drift deposits that are permeable enough to readily yield water to wells are water-deposited sand and gravel.

A large number of sand and gravel aquifers in the glacial drift have been delineated through cooperative a Statewide drilling program by the North Dakota State Water Commission, North Dakota Geological Survey, and U.S. Geological Survey. The extent of known glacial-drift aquifers in the State are included in a series of county reports published by the North Dakota State Water Commission and the North Dakota Geological Survey (fig. 5). In figure 5 surficial aquifers are not distinquished from those buried beneath till and (or) fine-grained alluvial deposits.

The principal glacial drift aquifers in North Dakota can be divided into surficial and buried aquifers. Buried aquifers are discussed separately from surficial aquifers, because they have significantly different hydrologic properties. The upper surface of a surficial aquifer is the water table, which is in equilibrium with atmospheric pressure; thus, the surficial aquifer is unconfined. Buried aquifers, in contrast, generally are confined by a less permeable overlying deposit and contain water under artesian pressure.

The two types of glacial drift aquifers also are different in the following ways: (1) Recharge to surficial aquifers principally is from infiltration of precipitation; whereas, recharge to buried aquifers principally is from leakage from adjacent rocks; (2) because of the direct connection to the land surface, surficial aquifers are more easily contaminated from various land uses, or accidental spills, than are buried aquifers; (3) surficial aquifers are hydraulically connected to surface water, such as streams, lakes, and wetlands; therefore, development of ground water, or use of land over a surficial aquifer, usually has a direct and at times rapid effect on contiguous surface water. The presence of a confining bed over a buried aquifer does not completely isolate surface water from such aquifers; however the effect generally is less, or is greatly delayed..

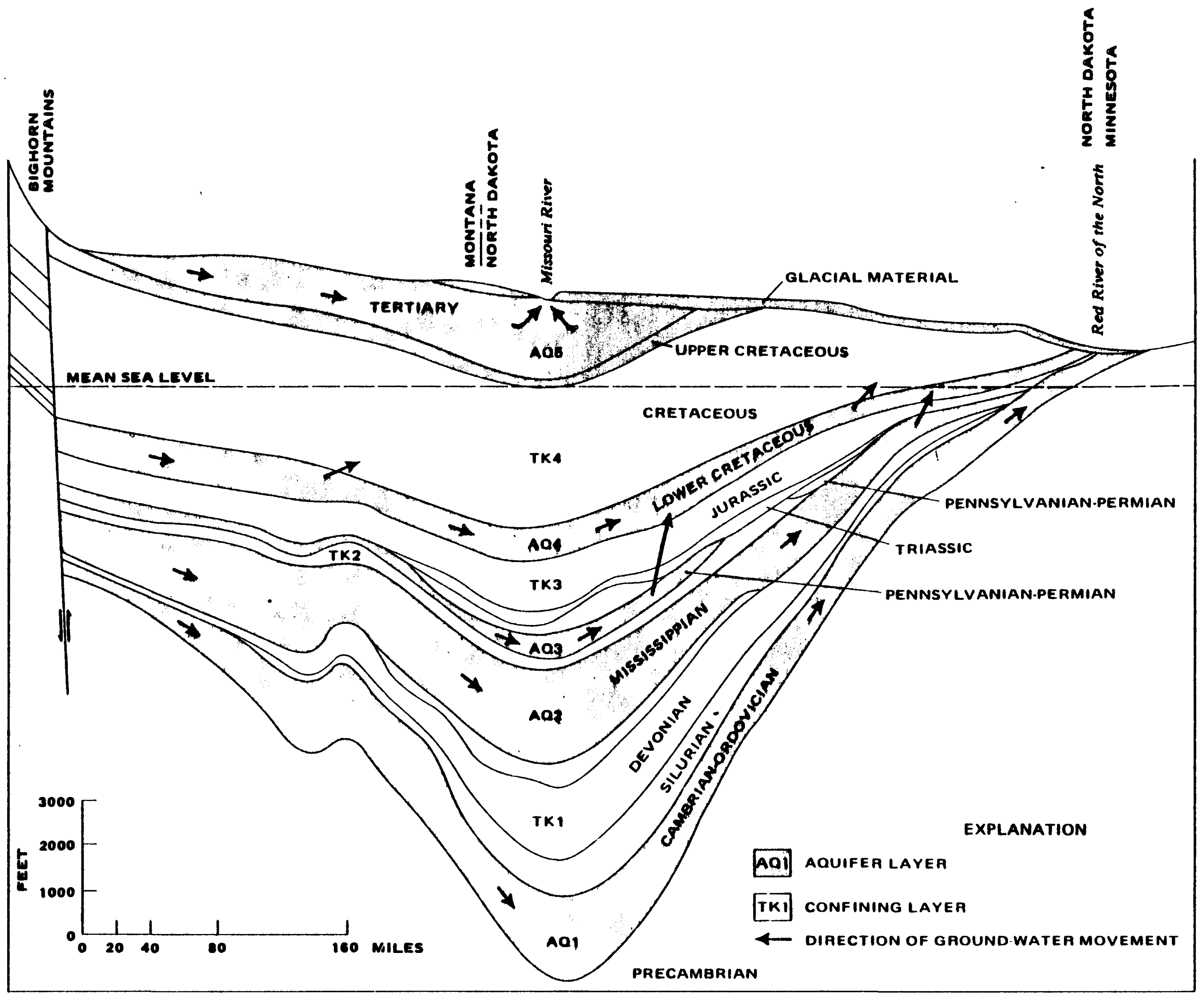


FIGURE 4.—Generalized geohydrologic section showing bedrock aquifers and direction of ground-water flow. (Modified from Downey, 1984. Line of section begins at Bighorn Mountains in Montana, arcs across eastern Montana, then trends eastward across North Dakota.)

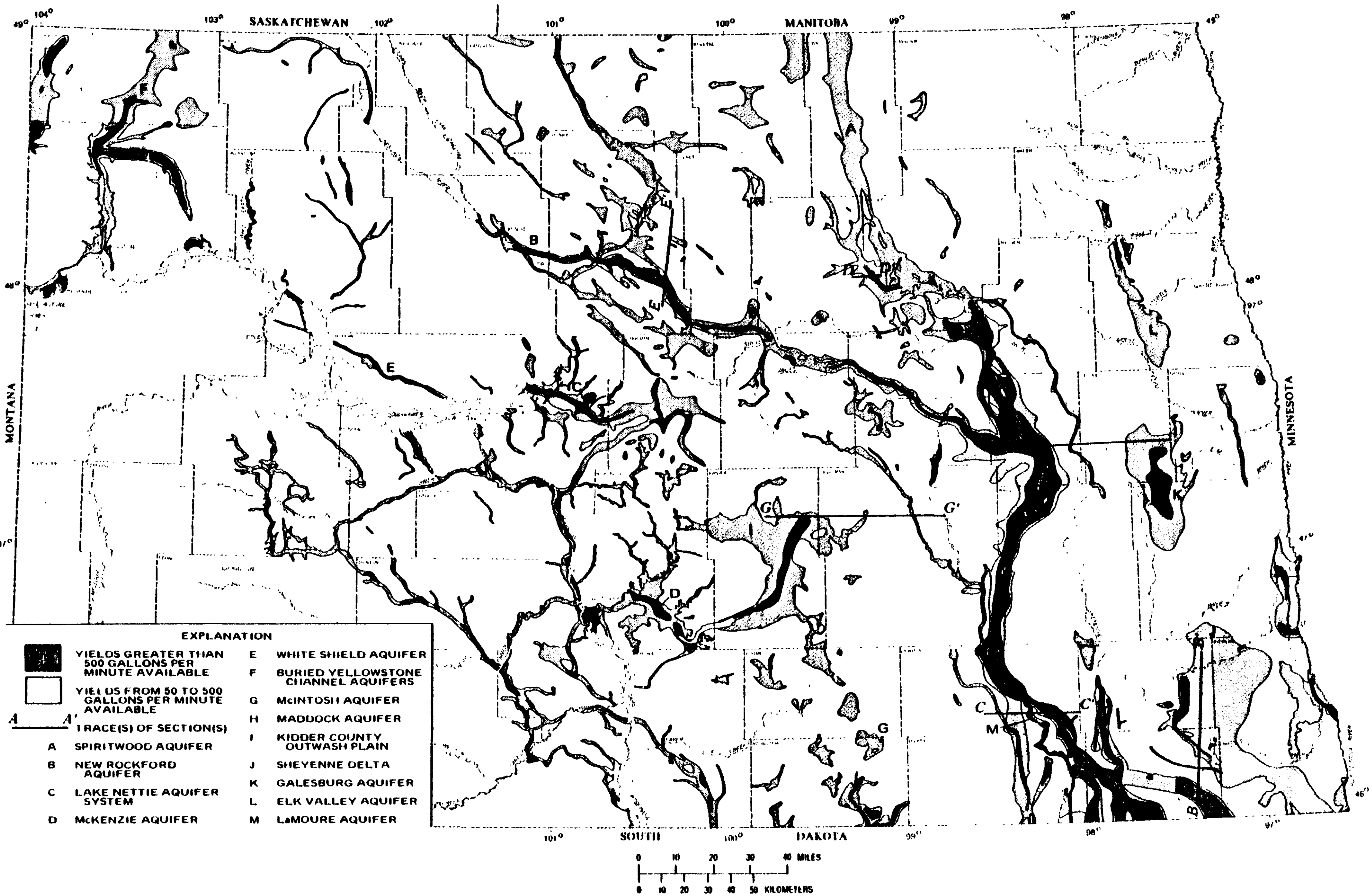


FIGURE 5.–Location of major drift aquifers in North Dakota. (Modified from North Dakota State Water Commission, 1982.)

Separation of glacial drift aquifers into surficial aquifers and buried aquifers is not easily done, because of the complexity of glacial deposits. This problem is illustrated in figure 6 that shows a geologic section through the Spiritwood and Galesburg aquifers in Griggs and Steele Counties. Sand and gravel deposits within the aquifer systems occur both at the surface and buried beneath fine-grained material. Therefore, the classification of surficial and buried, is based on the dominant aquifer. The scope of this report permits discussion of only the major aquifers shown in figure 5. Minor aquifers shown on this map, as well as the numerous small sand lenses buried within glacial till deposits, are not considered.

Buried glacial drift aquifers.--Buried glacial drift aquifers are the most important aquifers in North Dakota and consist of sand and gravel deposits within drift-filled valleys and buried outwash. Nearly all the major, buried glacial-drift aquifers occur within drift-filled valleys that were eroded as much as several hundred feet into bedrock prior to and during the Pleistocene ice age. In addition, many of the smaller, linear, buried aquifers shown in figure 5 also occur in bedrock valleys. The major aquifers of this type are the Spiritwood (A), New Rockford (B), Lake Nettie (C), McKenzie (D), White Shield (E), and Yellowstone Channel (F).

The deposits within the drift-filled valleys are interbedded and interfingered layers of gravel, sand, silt, clay, and till. The resulting complexity of such depositional processes can be seen in a number of geologic sections through the Spiritwood and nearby aquifers (figs. 6, 7, 8, 9), New Rockford aquifer (B) (fig. 10), and the Lake Nettie aquifer (C) (fig. 11). The data in these figures indicate that the aquifers shown in figure 5 vary greatly in depth and thickness and are not clearly-defined deposits of sand and gravel. The map (fig. 5) only delineates zones in which there is a significant probability of locating sand and gravel units. The figures (figs. 6-11) also show that correlation of glacial drift deposits within the buried valleys is highly uncertain, even if test holes are closely spaced.

Buried outwash aquifers generally are much smaller in extent than are aquifers within buried drift-filled valleys, Outwash deposits generally consist of well-sorted sand and gravel; however, silt and clay beds are common. Outwash deposits can be very large, such as the surficial outwash plain in central Kidder County, but delineation of buried outwash plains requires extensive test drilling. Examples of buried outwash aquifers are the McIntosh aquifer (G) in Logan and McIntosh Counties, and the Maddock aquifer (H) in Benson County (fig. 5).

Surficial glacial drift aquifers.--Surficial glacial drift aquifers in North Dakota are of three general types: (1) Outwash plains; (2) alluvium and terraces along ancestral and present drainage courses; and (3) deltas and beach ridges associated with Glacial Lake Agassiz.

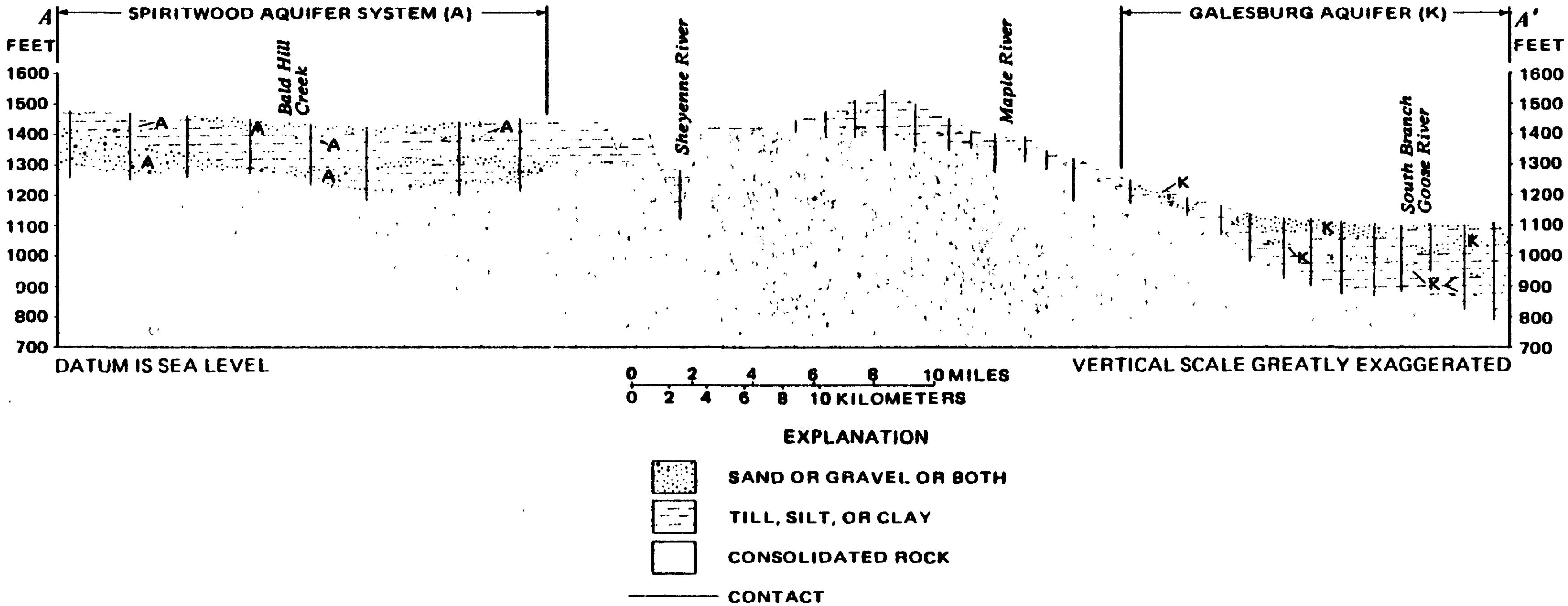


FIGURE 6.—Generalized geologic section (A-A') showing configuration of geologic units in buried (Spiritwood (A)) and surficial (Galesburg (K)) aquifers in Griggs and Steele Counties, North Dakota. (Modified from Downey and Armstrong, 1976.)

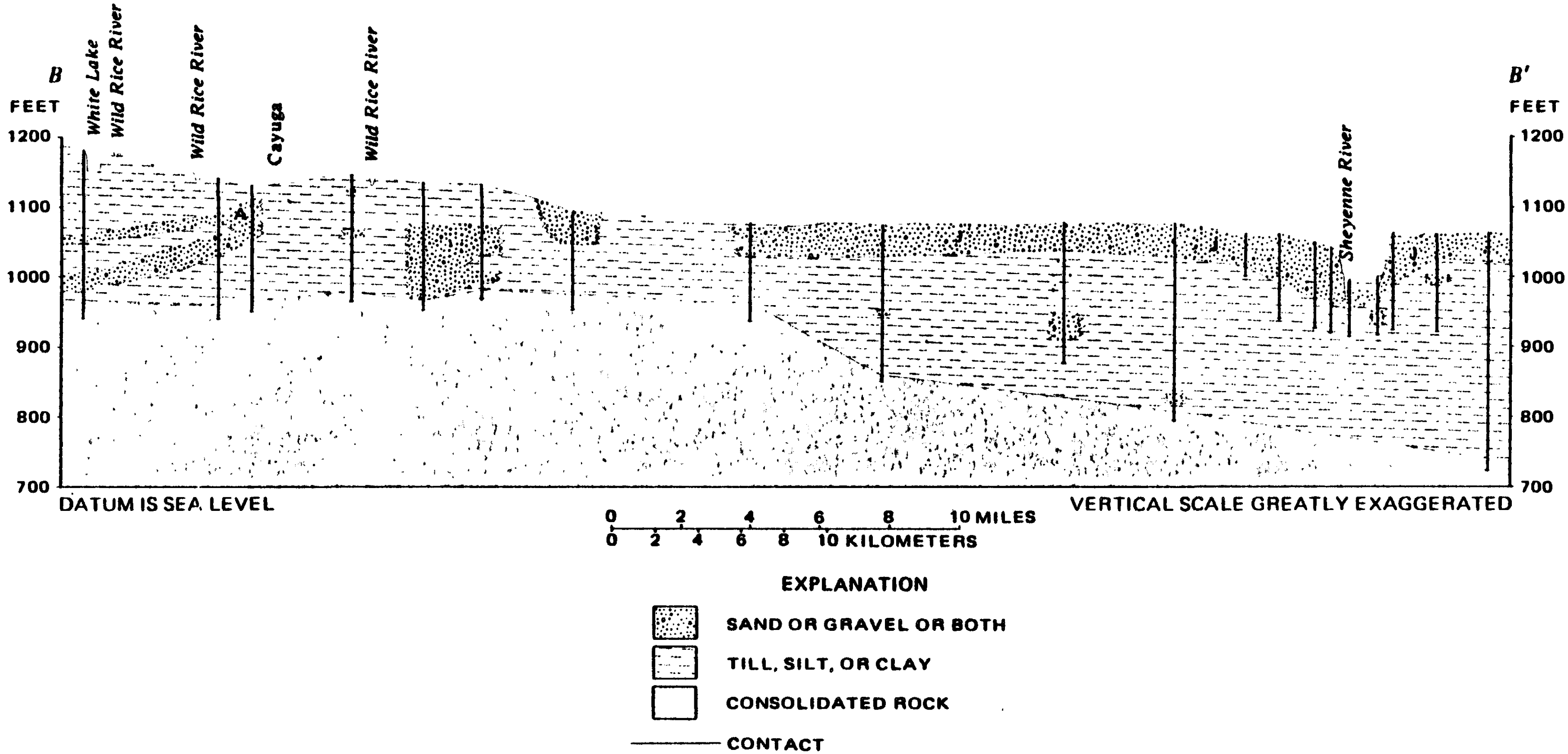


FIGURE 7.—Generalized geologic section (B-B') showing configuration of geologic units in Spiritwood (A) and Sheyenne-delta (J) aquifers in Ransom and Sargent Counties, North Dakota. (Modified from Armstrong, 1982.)

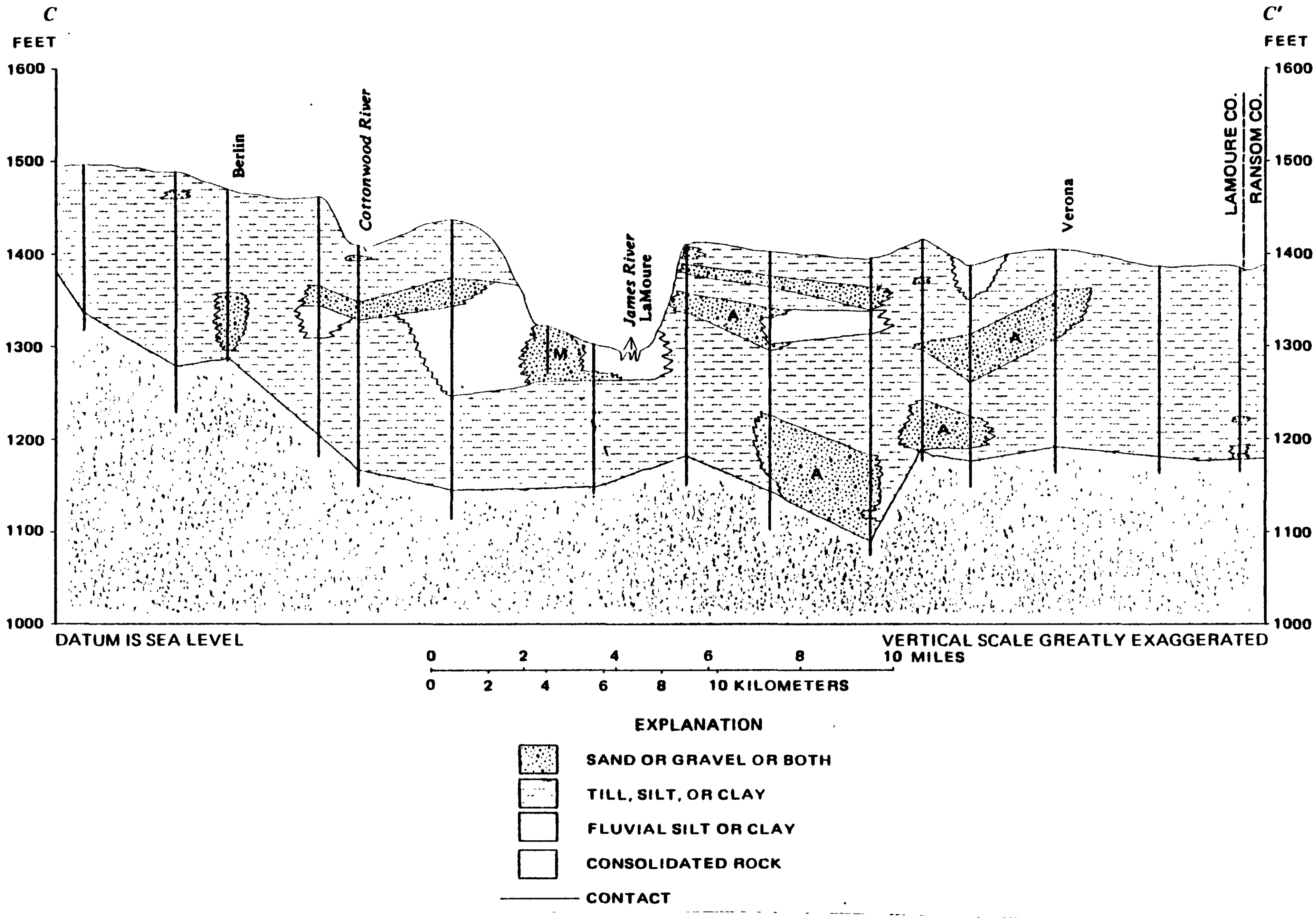


FIGURE 8.—Generalized geologic section (C-C′) showing configuration of geologic units in Spiritwood (A) and LaMoure (M) aquifers in LaMoure County, North Dakota. (Modified from Armstrong, 1980.)

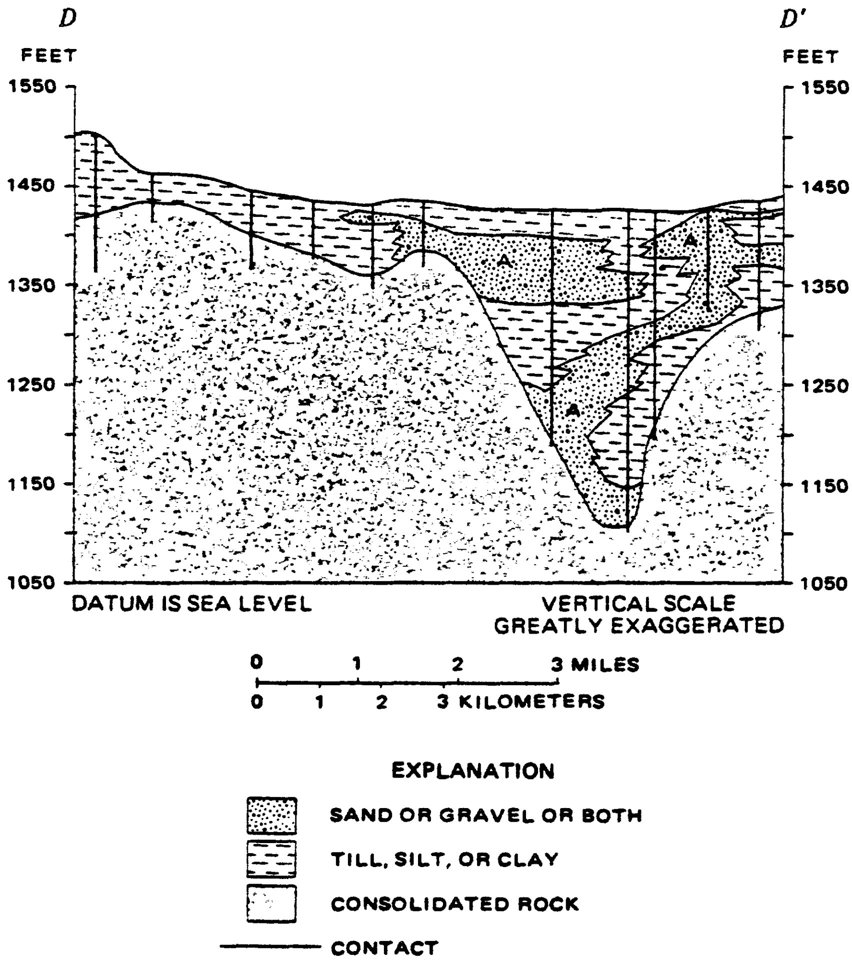


FIGURE 9.—Generalized geologic section (D-D') showing configuration of geologic units in Spiritwood (A) aquifer in Benson and Pierce Counties, North Dakota. (Modified from Randich, 1977.)

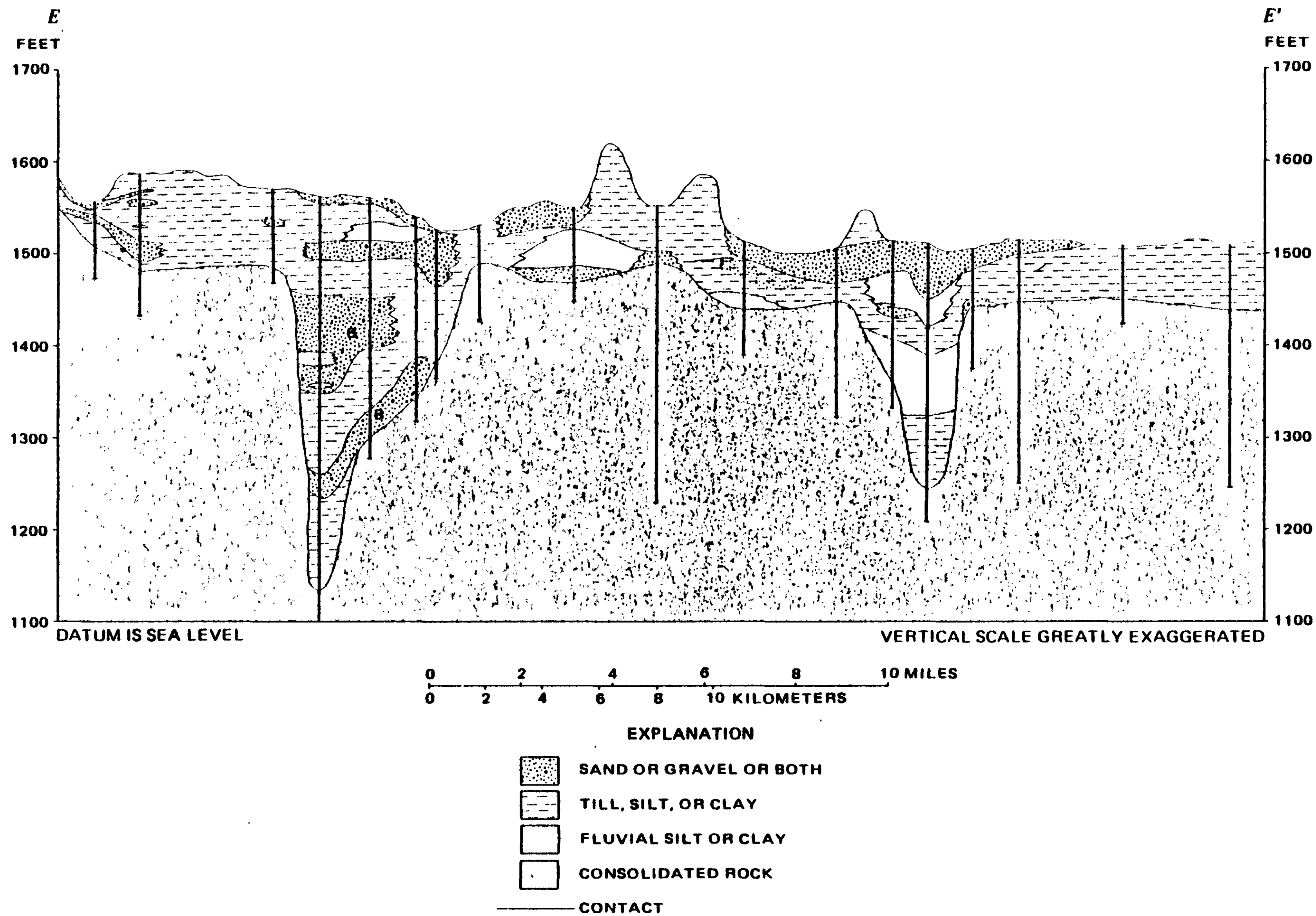


FIGURE 10.—Generalized geologic section (E-E') showing configuration of geologic units in New Rockford (B) aquifer in McHenry County, North Dakota. (Modified from Randich, 1981.)

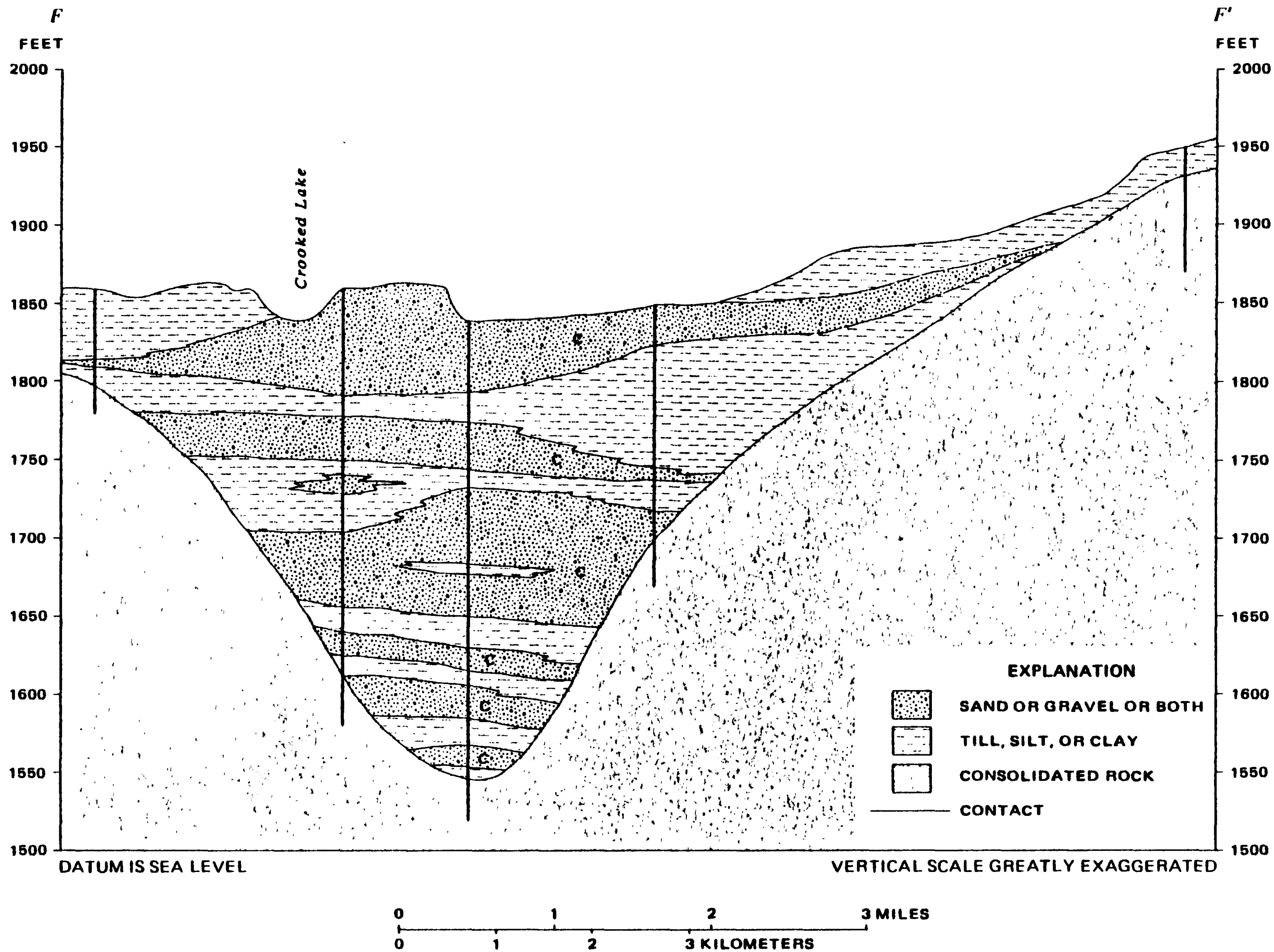


FIGURE 11.—Generalized geologic section (F-F') showing configuration of geologic units in Lake Nettie (C) aquifer in McLean County, North Dakota. (Modified from Klausing, 1974.)

The most prominent surficial outwash deposit in the State is that in central Kidder County (fig. 5). The outwash is as much as 85 feet thick and consists principally of stratified layers of sand and gravel, but it also includes layers of silt and clay. A buried glacial-drift aquifer underlies and is hydraulically connected to the outwash in places. The buried valley containing the glacial-drift aquifer is shown in figure 5 as the linear feature that trends northeast across Kidder County. The total thickness of outwash and glacial drift in the buried valley is greater than 100 feet in places.

Alluvium and terraces along ancestral and present drainage courses contain deposits similar to those in buried valleys; that is, they were deposited by flowing rivers that continually shifted course, which resulted in complex deposits of interbedded and interfingered clay, silt, sand, and gravel. Deposits of this type occur in virtually all existing river valleys. Most alluvial and terrace deposits are not thick, generally less than 40 feet. They usually are connected hydraulically to contiguous rivers.

Three major deltas were formed in Glacial Lake Agassiz: the Sheyenne delta (J), Galesburg-Page (K), and Elk Valley (L) aquifers (fig. 5). The Sheyenne delta underlies about 750 square miles, mostly in Richland and Ransom Counties. The deposit is as much as 200 feet in the western part, and it thins eastward. The western part of the delta, in Ransom County, has the coarsest-grained deposits; the deposits become progressively finer- grained from west to east across the delta.

The Galesburg Page (K) aquifer underlies about 320 square miles in Steele and Cass Counties (fig. 5). The aquifer is a complex deposit of interbedded and interfingered clay, silt, and sand, as are other deltaic deposits, but it is further complicated by having several glacial till units within it (fig. 6). The aquifer actually is covered by till throughout much of the extent, but it is included in the surficial section of this report because it is a delta, and because the till cover is thin and discontinuous. Although the aquifer unit is as much as 400 feet thick, and averages about 200 feet thick, the average thickness of permeable material is only about 40 feet.

The Elk Valley (L) aquifer underlies about 200 square miles in Grand Forks County. The deposit is somewhat lenticular, ranging in thickness from a few feet to about 60 feet; average thickness is about 34 feet. Grain sizes are largest in the northern part of the deposit; and the material becomes finer toward the south.

Water movement

Water movement in the four deepest bedrock aquifers--the Cambrian-Ordovician, Mississippian (Madison), Pennsylvanian-Permian, and Lower Cretaceous aquifers--is east-northeast across North Dakota. The rocks are recharged in mountainous areas of Montana, Wyoming, and South Dakota (fig. 4). In North Dakota water moves through the aquifer systems and, because of the very high hydraulic heads in the aquifers, discharges to overlying rock units, and ultimately to the base of the glacial drift (Downey, 1984). The hydraulic heads in the deeper bedrock aquifers are particularly high in eastern North Dakota. The Lower Cretaceous aquifer discharges upward to overlying rock units throughout much of its extent in North Dakota (fig. 4).

The Upper Cretaceous and Tertiary bedrock aquifers, as well as glacial drift aquifers, have a more complex flow system than that in deeper bedrock units. These upper bedrock systems have a regional component of flow similar to the deeper units, where they are confined by overlying rocks of minimal permeability. However, where they are unconfined, ground-water flow is controlled by recharge and discharge processes at the land surface.

On a regional scale it generally can be assumed that ground water is recharged at topographic highs and discharged at topographic lows (streams, lakes, and wetlands) in the glacial drift and the near-suface parts of the bedrock aquifers. Ground-water discharge maintains the permanence of many surface-water features. Generally in North Dakota, regional flow systems are recharged in major morainal areas, such as the Coteau du Missouri and Turtle Mountain areas north and east of the Missouri River. Southwest of the Missouri River, where drift is thin and discontinuous, topographically high areas of bedrock probably are recharge areas. All principal rivers and many large lakes and wetlands that are topographically low are features of regional ground-water discharge.

On a local scale, generalizations that were made for regional ground-water flow may not always apply. Ground water in local flow systems in terrane such as the Coteau du Missouri generally moves only a short distance from areas of localized recharge to adjacent low areas, generally occupied by headwater streams, lakes, or wetlands. In a study of a group of wetlands within an area of recharge to regional ground-water flow systems, near the eastern edge of the Coteau du Missouri (fig. 12), LaBaugh and others, (1984) showed that local flow systems are complex and dynamic. Their study showed that, within a 160-acre area on this regional topographic high, some wetlands recharged ground water; some wetlands receive ground-water inflow in some parts of the bed and wetland water seeps out in other parts; and other wetlands are principally areas of ground-water discharge. LaBaugh and others (1984) also showed that ground-water recharge in areas of hummocky glacial till is focused in lowlands (a conclusion also reached by Lissey (1971) in the Canadian prairies), and that, on a local scale, water-table highs do not always underlie land-surface highs. These authors also showed that reversals of ground-water flow between some wetlands is common on a seasonal basis, and that the flow directions are not the same from year to year. The study also showed that much of the ground-water recharged in some wetlands remains in local flow systems, to be discharged into nearby wetlands. Thus, ground-water recharge to some wetlands does not necessarily become recharge to regional flow systems.

To put regional and local flow systems into perspective for a North Dakota setting, Winter and Carr (1980) determined, and numerically simulated, ground-water flow systems in a 50-mile cross section through parts of Stutsman and Kidder Counties (fig. 12). The cross section extends westward from the James River across a high ridge of the Coteau du Missouri to the lowland occupied by the Kidder County outwash plain. The data indicate that, within the glacial drift, many individual intermediate and regional flow systems extend deep into the ground-water system. As expected, intermediate and regional flow systems are recharged in the topographic high areas and they

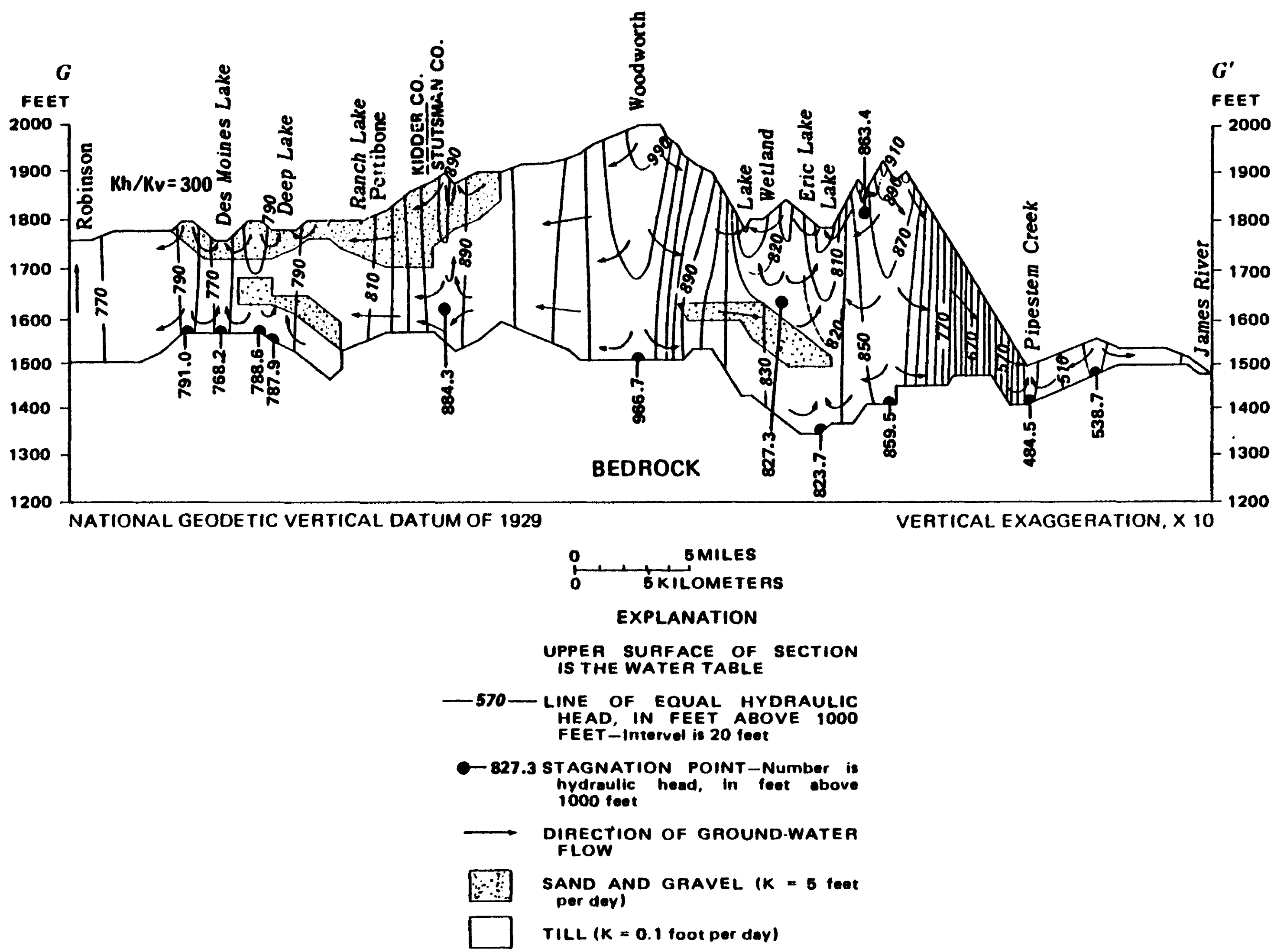


FIGURE 12.—Hydrologic section showing numerical simulation of ground-water flow in the Coteau du Missouri in Stutsman and Kidder Counties, North Dakota. (Modified from Winter and Carr, 1980.)

discharge to major streams. In addition, the data indicate that the numerous lakes in the topographic lows also are discharge points for large ground-water flow systems, which is partly the reason those lakes are so saline.

The cross section in figure 12 does not indicate the upward seepage from bedrock into the glacial drift. This upward leakage does not significantly change the configuration of the flow systems, but it does have an effect on ground-water chemistry deep in the drift. Because of the scale of the regional section, the data also do not indicate the numerous, small, local flow systems in the uppermost part of the ground-water system.

The studies discussed previously indicate that a great deal of local ground-water discharge occurs within areas that are considered to be areas of regional ground-water recharge. Conversely, considerable evidence exists that a great deal of local ground-water recharge occurs within areas that are considered to be areas of regional ground-water discharge. An example of such evidence is the common occurrence of fresh-water springs that flow into saline lakes. Much of the above discussion on flow systems applies particularly to studies that have been done in the Coteau du Missouri. It is believed that the results apply generally to areas within the Coteau, or to similar areas of hummocky topography.

Ground-water movement in areas of the relatively flat ground moraine such as that between the Coteau du Missouri and the Red River Valley, is probably dominated by deep local flow systems. Modeling studies by Toth (1963) and Winter (1976) indicate that in areas where the water table has slight regional slope and low to high local relief, ground water moves in deep, isolated, local flow systems.

Ground-water quality

Ground-water quality is determined by geochemical reactions between rocks and water moving through those rocks. Generally, ground water contains small concentrations of dissolved solids near recharge areas. Water in these areas usually is the calcium bicarbonate type. As ground water moves farther along flow paths, dissolved solids concentration increases, and the water becomes dominated by different ions.

Geochemical processes unique to certain rock types greatly affect water type. For example, because of ion-exchange, water in contact with shales, such as the Pierre Shale, commonly are a sodium bicarbonate type.

In many all extensive ground-water systems, ground water eventually evolves to a sodium chloride type. Water in these systems may have very large concentrations of dissolved solids.

Water in the four deepest bedrock aquifers (Cambrian-Ordovician, Mississippian (Madison), Pennsylvanian-Permian, and Lower Cretaceous aquifers) in North Dakota is characterized by high dissolved solids concentrations; thus, the aquifers are not a useful source of water for domestic, municipal or irrigation purposes. For example, dissolved solids concentrations greatly exceed 1,000 milligrams per liter over much of areal extent of each aquifer (fig. 13), and areas in which the ground water is considered to be a brine (dissolved solids concentrations are in excess of 100,000 milligrams per liter) varies in each aquifer as shown in figure 14.

Water in the Upper Cretaceous and Tertiary aquifers, has a wide range in dissolved-solids concentrations and water type because of near-surface interaction of recharge and discharge. However, in general, water in shallower parts of these rocks is sodium bicarbonate type. Water from these bedrock aquifers is used for some domestic purposes, although dissolved-solids concentrations usually are greater than 1,000 milligrams per liter. The water generally is unsuitable for irrigation, because of high sodium and salinity hazards.

The quality of water in glacial drift in North Dakota is quite variable. As indicated previously, water chemistry depends on whether the water is in till or outwash, and it depends on the position of a sampling point within ground-water flow systems. An additional factor is the relationship of glacial drift in a given area to flow direction and chemistry of water in the underlying bedrock.

In general, water in glacial till near recharge areas contains small concentrations of dissolved solids and is a calcium bicarbonate type. As it moves along ground-water flow paths, it becomes more mineralized, and changes to a calcium magnesium sulfate type. Therefore, much water in till has large concentrations of dissolved solids and sulfate.

Ground water in outwash tends to have smaller dissolved solids concentrations, and to persist as a calcium bicarbonate type for longer distances along flow paths. Therefore, much water in outwash, particularly at shallower depths, tends to be suitable for most uses. Even in outwash, however, ground water at greater depths can be very mineralized, because of mixing with water that moves into the outwash from adjacent glacial till deposits.

The effect of discharge of highly mineralized water from bedrock on ground water in the deep glacial drift also is especially significant in North Dakota. As discussed earlier in this section, water in the bedrock has very high hydraulic head, and is very mineralized, compared to water in the drift. Because of this, ground water in the deep drift mixes with water that moves upward from the bedrock into the drift. The result of this mixing is that water deep in the drift commonly is very mineralized and consists of mixed chemical types. In some areas, such as in low areas of the Red River Valley, the upward movement of water from bedrock is great enough that even shallow drift, and some lakes (Downey, 1984), are saline.

The effect of these hydrological and geochemical processes on the suitability of ground water for use varies considerably throughout North Dakota. In general, most bedrock water is unsuitable for all domestic, municipal, and irrigation uses. The only exception is ground water from some Tertiary aquifers in western North Dakota. This water is sometimes used for domestic purposes, but most of it is marginally suitable, or unsuitable, for irrigation.

The least mineralized, and therefore the best, ground water in North Dakota is in surficial glacial-drift aquifers. This water is suitable for nearly all domestic uses and for irrigation. In deeper parts of surficial aquifers, and especially in buried valley aquifers, the water can be very mineralized. Unfortunately, the deep aquifers, which tend to be the most

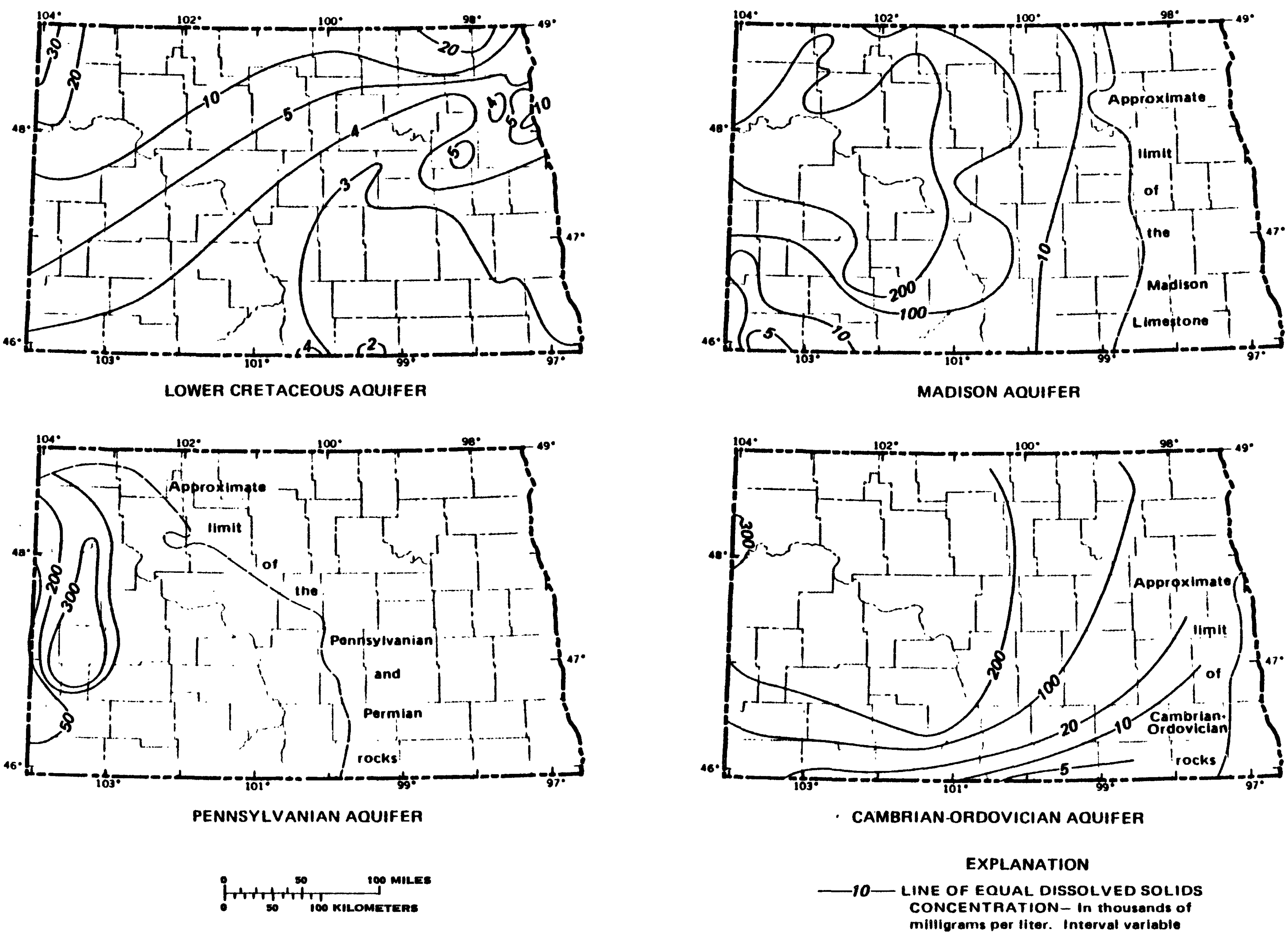


FIGURE 13.–Distribution of dissolved-solids concentration and physical limits of bedrock aquifers in North Dakota. (Modified from Downey, 1984.)

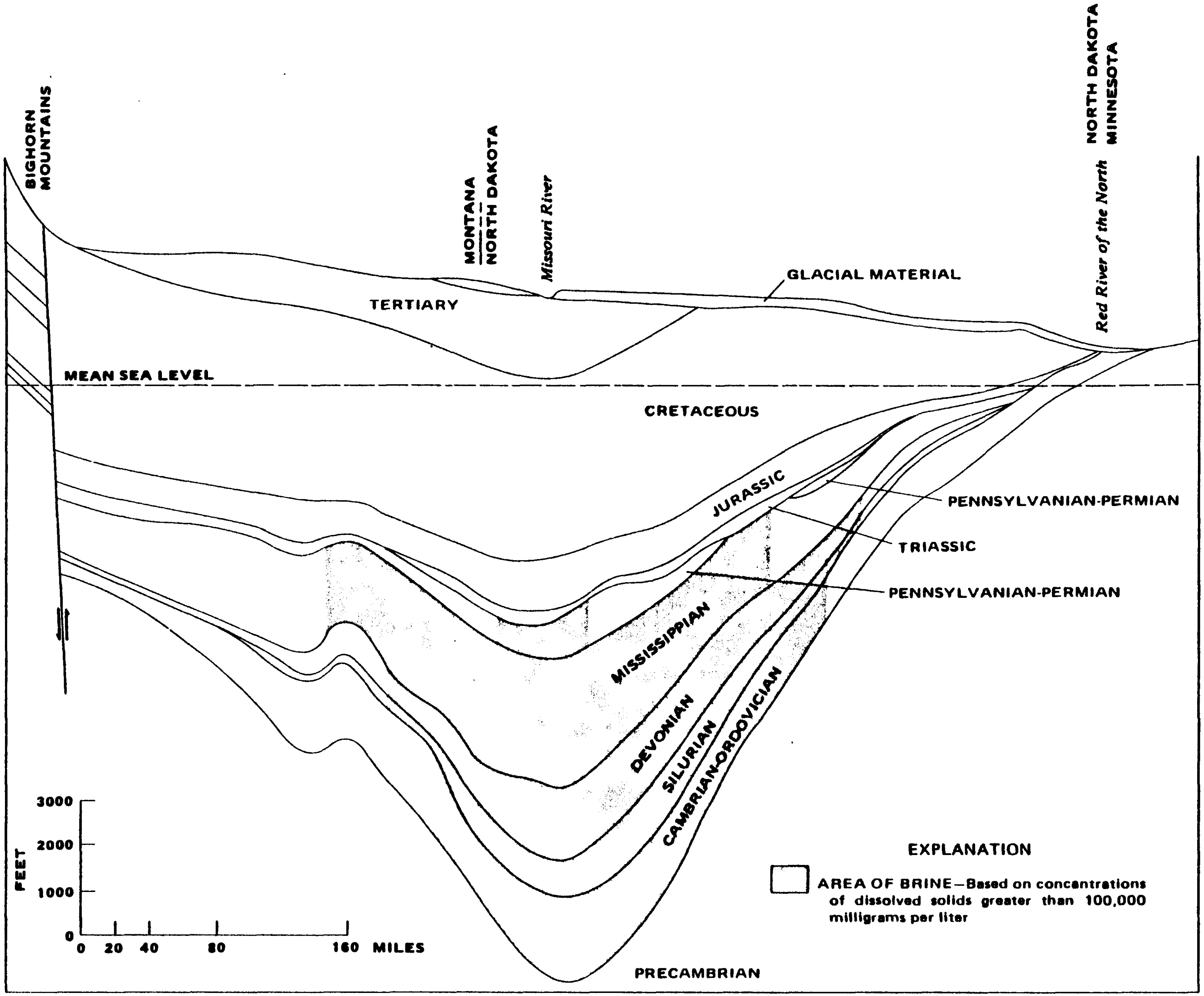


FIGURE 14.—Diagrammatic geochemical section showing distribution of brine in bedrock aquifers. (From Downey, 1984. Line of section begins at Bighorn Mountains in Montana, arcs across eastern Montana, then trends eastward across North Dakota.)

promising for development of large water supplies, are also in a position to be the most affected by seepage of very mineralized water from the till, and from the adjacent bedrock into which the valleys are eroded. Because of this situation, water from bedrock valley aquifers generally is suitable for domestic use, although some constituents exceed recommended drinking-water standards. However, it is commonly marginal for irrigation use, because it either has high sodium hazard, high salinity hazard, or both.

Limited information is available on the occurrence and magnitude of trace constituents in ground water in North Dakota. However, arsenic concentrations of about 100 micrograms per liter have been detected in ground water in a glacial drift aquifer at a U.S. Environmental Protection Agency Superfund site in the southeast part of the State (R. L. Houghton, U.S. Geological Survey, oral commun., 1984). These concentrations probably are not from natural sources but were derived from arsenic-bearing pesticides that were extensively used in the 1930's and that since have been leached into the ground water.

Naturally-occurring amounts of selenium ranging from 50-600 micrograms per liter have been detected in water from aquifers in the Sentinel Butte Member of the Fort Union formation and in water from aquifers in hydrologic connection with the Pierre Shale (R. L. Houghton, U.S. Geological Survey, oral commun., 1984). Except for limited information from the Oakes area, data are not available for selenium concentrations in irrigation return flow in North Dakota. In that area, selenium concentrations did not exceed Federal drinking water standards.

Water Yield of Aquifers

Water yield generally is thought of as the quantity of ground water that can be pumped from wells. In this sense, North Dakota has a significant amount of ground water. However, two other factors, the concept of sustained yield and water quality, need to be considered when evaluating the potential for long-term development of useable ground water in the State.

When considering short-term yield, sustained yield, and water quality, virtually none of the water in bedrock is available for large-scale development. Although some individual wells completed in bedrock aquifers in the western part of the State have been pumped at a rate of several hundred gallons per minute, most wells yield far less water. The reason for this is that large-capacity wells cannot be developed in the generally fine-grained and thin-bedded rocks. In addition, the poor potential for significant recharge and the very mineralized water further restrict the usefulness of the water for anything other than small, individual, farm supplies.

From both water yield and water quality perspectives, some potential exists for development of large ground-water supplies from local areas within glacial-drift aquifers. First consider what is known about yields from drift aquifers, using figure 5. This map delineates areas in North Dakota, where a good probability exists to develop wells that will yield 50 to 500 gallons per minute and wells that will yield greater than 500 gallons per minute. In addition, local areas within the greater-than-500 gallons per minute zones will probably yield greater than 1,000 gallons per minute to individual wells.

Glacial-drift aquifers generally are lenticular in cross section and the largest yields are obtainable usually from the central and therefore the thickest parts. Wells penetrating aquifers in narrow valleys generally have lower yields than wells tapping aquifers of comparable thickness but having large areal extent. Where several aquifers are superimposed, the maximum yield indicated is obtained only by tapping all aquifers.

Delineation of aquifers and estimates of well yield (figure 5) is based on the result of reconnaissance studies and should be used only as a generalized guide to the location of glacial-drift aquifers. Only a few pumping tests were made in each county, and some aquifers were not test-pumped at all. Figure 5 provides a guide to yields expected from individual wells, but it does not indicate yields from well fields. The impact of actually developing well fields to produce the yields shown, on surface water, recharge, and evapotranspiration has been evaluated in only a few small surficial aquifers.

The sustained yield from all glacial drift aquifers has not been determined. To determine this yield, the impact of ground-water development on the remainder of the hydrologic system, especially on surface-water resources needs to be studied. It is commonly assumed that the volume of water that can be safely pumped from an aquifer over the long term is dependent on the volume of water that recharges the aquifer. Several factors invalidate this assumption: First, any pumping will affect the natural flow system. For example, if a surface-water feature, such as a stream, lake or wetland, exists because it is maintained by a given amount of ground-water discharge, any development that disrupts the flow system will effect the discharge area. If the volume of ground water taken for development equals recharge, that amount of recharge will not be available to the flow system and the natural discharge area could be severely effected. Therefore, sustained yields need to be related to pumping rates and volumes that prevent unacceptable effects on surface water.

Recharge rates to aquifers are not independent of development. As an example, Freeze (1971) did a theoretical study of a transient hydrologic budget for a ground-water system. His study used three-dimensional simulation of an unconfined aquifer, which was similar to surficial aquifers discussed in this report. Using successive step increases in pumping, each equal to the natural recharge rate, he showed that each increase in pumping is balanced by a lowering of the water table. After a period of time a new equilibrium is established, and the unsaturated zone is induced to deliver greater flow rates to the ground-water system. Freeze cautioned that if increases in pumpage continue indefinitely, an unstable condition may arise, in which the maximum rate of recharge is exceeded, and the water table declines continuously. Freeze defines the value of total ground-water withdrawal at which this instability occurs as the maximum stable basin (aquifer) yield. Freeze states that, because of uncertainty in climate, an aquifer should not be developed to its maximum stable basin yield. Also, if an aquifer is developed to near this limit, potential yield of surface water would be reduced. In North Dakota, few, if any, aquifers have been studied sufficiently to know their maximum stable basin yield.

In the case of buried glacial drift aquifers, much of the ground water is pumped from storage. In these aquifers, large-scale pumping will eventually induce leakage from and disrupt natural flow in adjacent rocks. Extensive development of ground water from buried aquifers, with the attendant changes of flow in and through confining beds, may eventually affect surface-water resources. However, these effects are less noticeable for buried aquifers than they are for surficial aquifers.

The decline of hydraulic head is a noticeable impact of large scale, long-term pumping of glacial-drift aquifers on long term development of those aquifers. If water is pumped at greater rates than the amount of recharge or of leakage from confining beds, hydraulic head within the aquifer will decline. Declining heads are already being felt locally within some of the major drift aquifers, such as that reported by Randich (1981) for the New Rockford aquifer in McHenry County.

Water quality is an additional limit to determining sustained yield for an aquifer. Especially for deep, buried valley aquifers, there is great potential for water-quality deterioration with development. Large-scale pumping of these glacial drift aquifers very likely will induce more very mineralized water to move into them from adjacent till and bedrock units.

Effects of ground-water development on the hydrologic system can be demonstrated through the use of simulation models. Downey and Paulson (1974) used a simulation model of the Sheyenne delta to assess the impact of the surface water pool created by Kindred dam on ground-water levels in the Sheyenne delta aquifer. Christensen and Miller (1984) recently completed a simulation model of the interaction of the James River with a contiguous surficial glacial drift aquifer in LaMoure County. The North Dakota State Water Commission has developed, or is currently developing simulation models of a few other surficial aquifers; such as, the Pleasant Lake aquifer near Rugby in Pierce County, and the Edgeley aquifer near Edgeley in LaMoure County. There have been no simulation models developed for buried drift aquifers in North Dakota.

In summary, North Dakota has the potential to develop relatively large quantities of water from local areas within its glacial-drift aquifers. However, caution must be exercised, and considerably more study needs to be done in order to efficiently develop ground-water resources. The studies need to include an evaluation of tradeoffs between ground-water development and effects of that development on surface-water flow and availability, and on water quality in the aquifers. Generally, the most effective method to assess various water management alternatives is to develop simulation models of hydrologic systems. Unfortunately, simulation models have been developed for only a few aquifers in North Dakota.

Artificial Recharge

The possibility of recharging aquifers by some engineering mechanism devised by man, referred to as artificial recharge, is commonly suggested as a means to supplement natural recharge to aquifers. Generally, the goal, is to pump excess surface water through wells or let it seep through beds of surface ponds into aquifers, then, pump the water out of the aquifer later, as needed.

Although artificial recharge appears to be an attractive solution to many water management problems, the process involves a number of complex conditions and interactions that plague some experiments and programs. Among them are: (1) inadequate definition or understanding of the hydraulic characteristics of aquifers. (2) inadequate understanding of geochemical processes. The injected, or ponded, water must be chemically compatible with water in the aquifer. If the waters are not chemically compatible, precipitates might form that will clog the pores in the aquifer, causing failure of the artificial recharge program; and (3) inadequate understanding of biological processes. Surface water injected into ground water commonly contains organisms that clog the pores in the aquifer. Inspite of these physical, chemical, and biological problems, some artificial recharge experiments and programs succeed.

In the 1960's and 1970's the City of Minot attempted to artificially recharge the New Rockford aquifer with untreated water pumped from the Souris River and introduced into gravel-packed, porous concrete-cased wells. The attempt was abandoned because of persistent plugging of the wells, and, the city, instead, developed a well field in another location.

SURFACE-WATER RESOURCES

Two major river systems drain North Dakota -the Missouri River system and the Hudson Bay system. The Missouri River system includes the Missouri and James Rivers; the Hudson Bay system includes the Souris and Red Rivers, plus the noncontributing Devils Lake basin. These five major drainage basins are shown in fig. 15.

Runoff is extremely variable, both seasonally and annually, as well as areally. The average annual runoff varies from less than 0.25 inch to about 1 inch (fig. 16). A large proportion of runoff occurs in the spring as a result of snowmelt. Average annual runoff in eastern North Dakota is minimal because a large quantity of water is retained in noncontributing areas (lakes, ponds, and wetlands). Delineation of noncontributing areas is very subjective. It is based on estimates of areas of water stored in lakes, ponds, and wetlands which ultimately reaches streams and rivers. In addition, the actual contributing drainage area may vary greatly with the magnitude of the runoff.

Two types of floods, primarily affected by different weather conditions, occur in North Dakota. The spring flood is the result of several factors, including snow cover, antecedent soil-moisture conditions, temperatures and precipitation during spring thaw, and ice jams. The other type of flood is caused by thunderstorms in the spring, summer, or fall that produce intense rainfall in a short time over small areas. The annual maximum flood on the larger streams (drainage areas greater than about 100 square miles) usually occurs during the spring. On the smaller streams (drainage areas less than about 100 square miles), about one-half the annual peaks are due to thunderstorms. Long periods of no flow occur on most of the smaller tributary streams, and occasionally no-flow periods occur on many of the larger streams. The average discharge of the principal rivers in North Dakota is shown in figure 17.

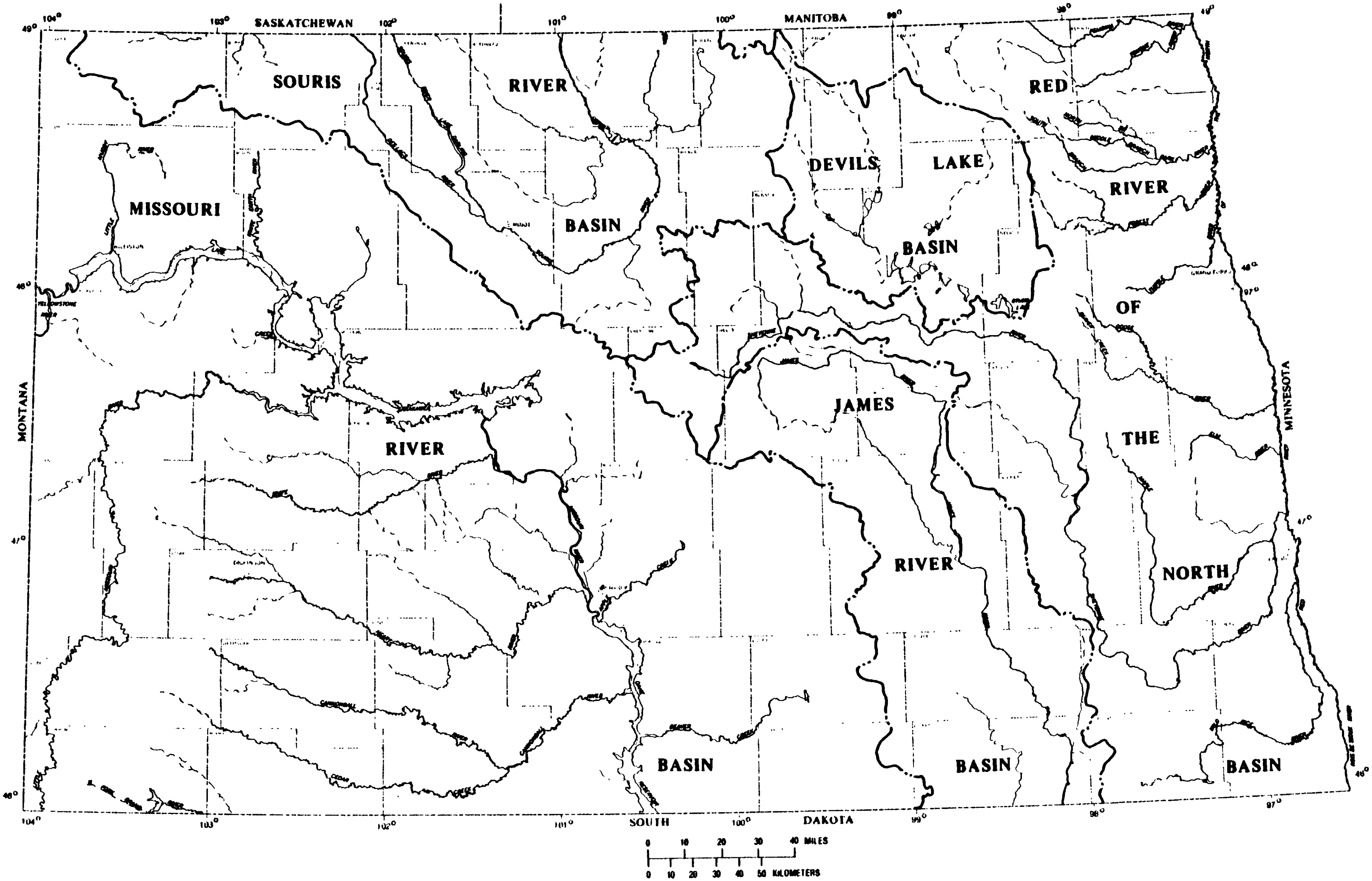


FIGURE 15.—Location of major drainage basins of North Dakota.

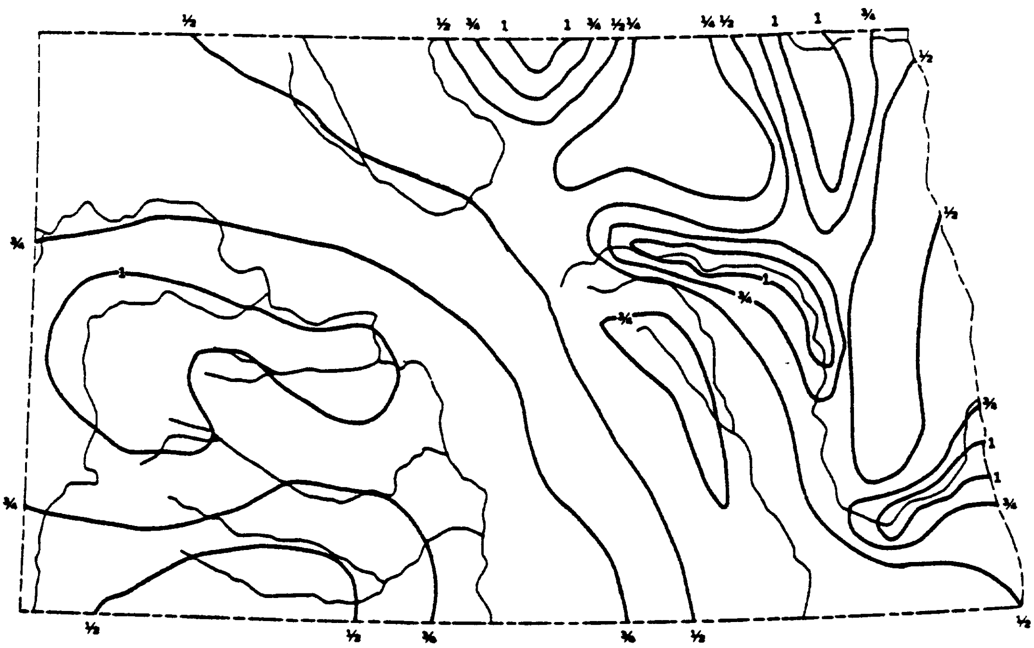


FIGURE 16.—Average annual runoff in North Dakota, in inches.

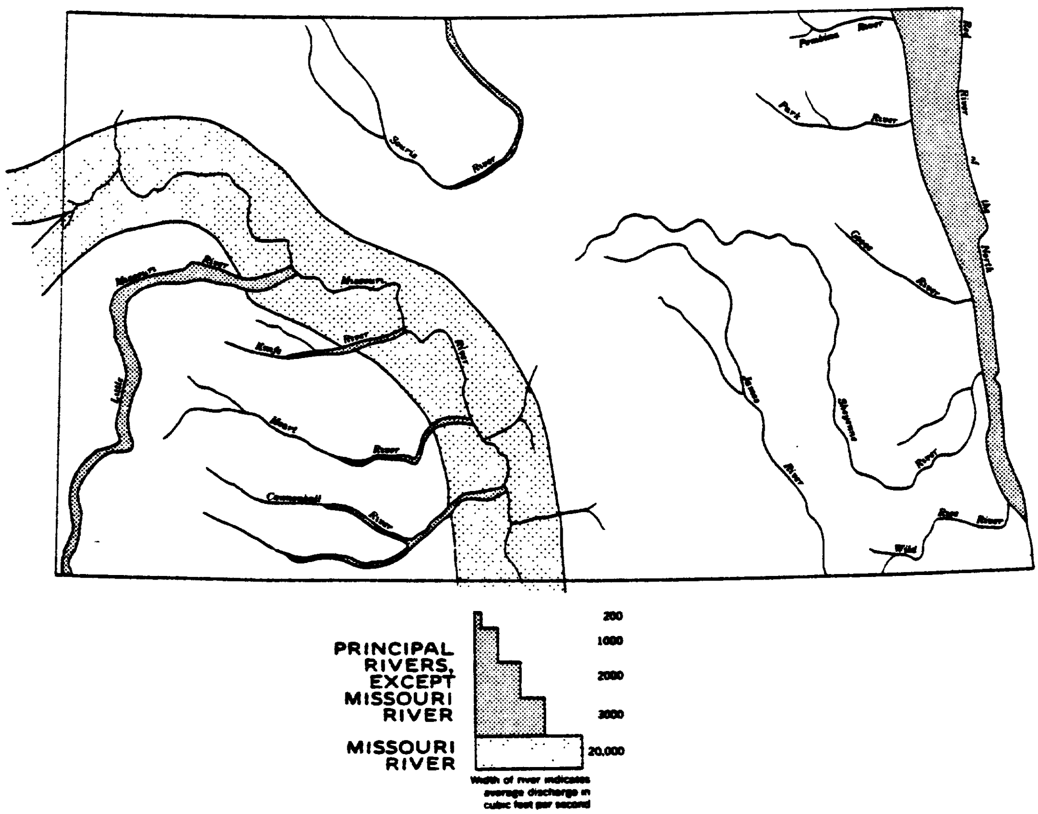


FIGURE 17.—Average discharge of the principal rivers of North Dakota.

Based on the above considerations, streamflow at selected gaging stations in North Dakota has been examined in this report by the tabulation of selected daily flow statistics (minimum, maximum, mean, median, and 10-percentile value) and by plotting of monthly minimums, maximums, and means. This presentation was selected to best illustrate the temporal distribution of streamflow in North Dakota. The 10-percentile value included in the tabulations is used to differentiate low-flow characteristics of the different streams. Streamflow is less than this value during 10 percent of the time. The period of record and drainage-area data (total and contributing) are presented in the tabulations to facilitate comparisons of data. In certain instances, the period of record is split when major control works were constructed on the stream.

The quality of North Dakota streamflow is affected by many hydrologic factors. Climate affects surface-water quality through variations in temperature and precipitation. Topography and drainage affect surface-water quality by influencing magnitude and rate of runoff. Sources and regulation of streamflow also cause water-quality variations. For example, when streamflow principally is derived from runoff, stream quality tends to be quite variable, whereas when streamflow is derived principally from ground-water seepage, stream quality generally is less variable. Likewise, stream quality generally is more variable in unregulated streams than in regulated streams. Furthermore, dissolved-solids concentrations generally are inversely related to stream discharge; that is, dissolved-solids concentrations are greater during low-flow conditions and lesser during high-flow conditions.

Surface-water quality has been examined in this report primarily by use of statistics. Statistical summaries for 27 stations in 5 basins are provided for 22 constituents or properties. These summaries include four descriptive statistics—maximum, minimum, mean, and standard deviation about the mean—and duration tables. Duration tables show the percentage of samples in which concentrations were less than or equal to those given. Because data for individual constituents or properties commonly vary considerably within a given range, the duration tables usually provide more information about this variation than do descriptive statistics.

The U.S. Geological Survey, and Federal, State and local agencies in North Dakota, have had cooperative agreements for the systematic collection of surface-water records since 1903. Surface-water record collection in North Dakota actually began in the 1870's and was conducted by the U.S. Army, Corps of Engineers. The location of U.S. Geological Survey stream-gaging and water-quality stations operated in North Dakota during 1983 is shown in figures 18 and 19. Streamflow and water-quality data from some of these stations are presented in the following discussions of the five major drainage basins.

Missouri River Mainstem Basin

The Missouri River mainstem drainage area within North Dakota (fig. 15) consists of about 48 percent of the State. The Missouri River is the most significant source of surface water in the State, as evidenced by the fact that the mean recorded flow at Bismarck is more than 80 percent of the total measured streamflow for the State. The major tributaries are the Yellowstone,

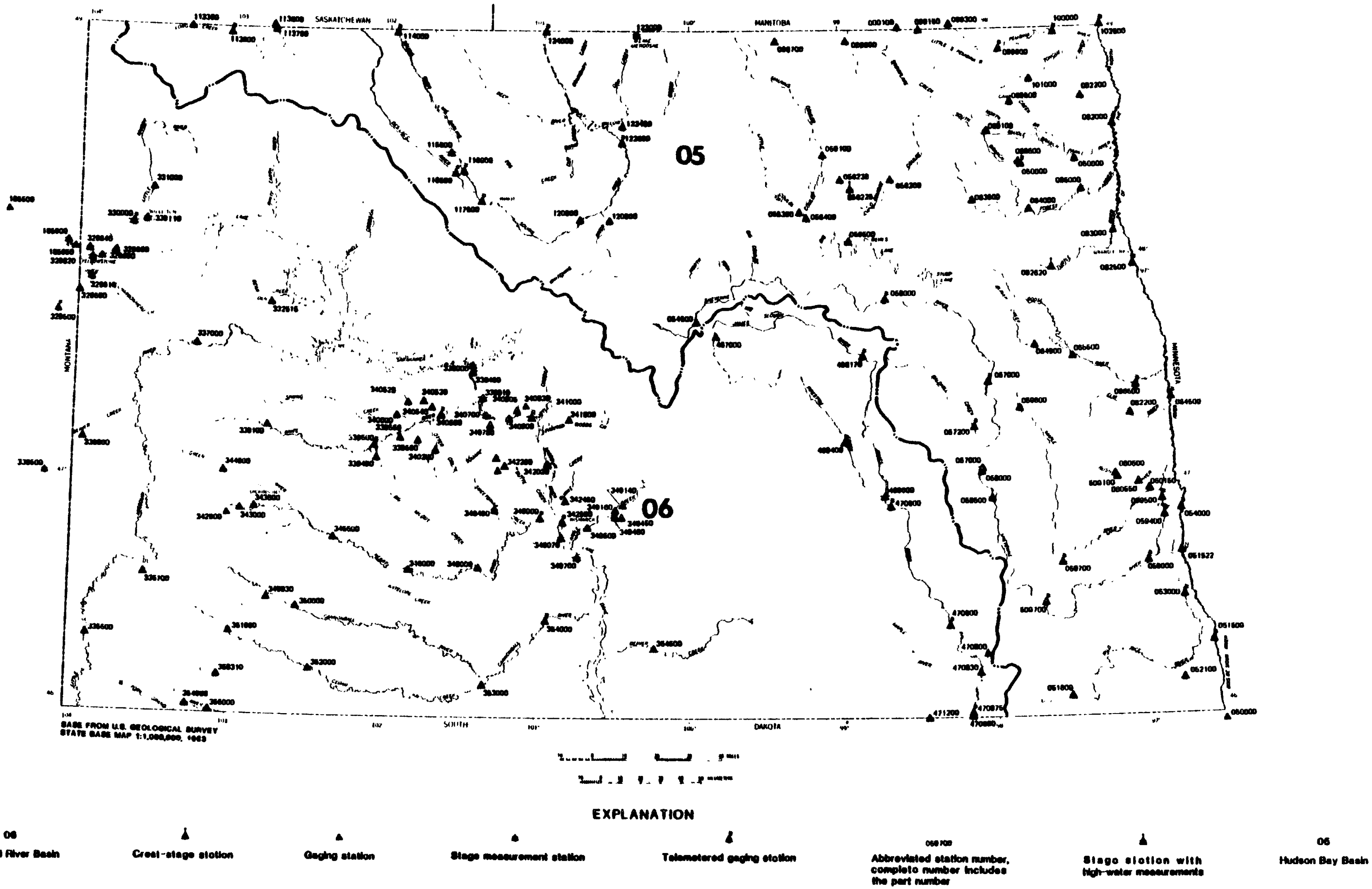


FIGURE 18.—Locations of lake, crest-stage, and stream-gaging stations in North Dakota.

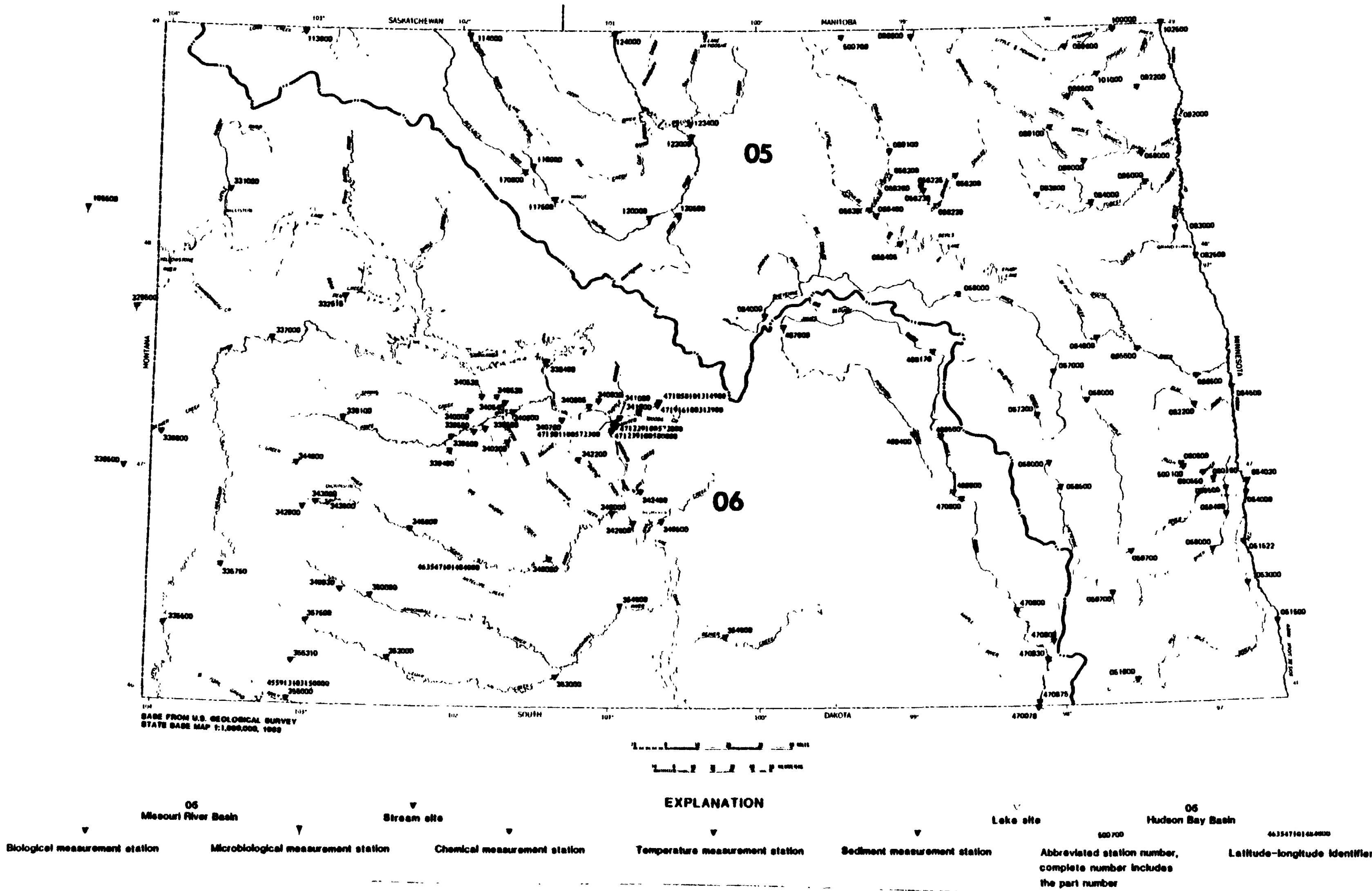


FIGURE 19.—Locations of water-quality stations in North Dakota.

Little Missouri, Knife, Heart, and Cannonball Rivers, which drain the area to the west and south of the Missouri River. Smaller tributaries, generally occupying large valleys of glacial origin, drain the area to the east and north.

About 32,800 square miles of drainage area contribute to the Missouri River mainstem in North Dakota. The river is almost entirely regulated in its course through the State. Of the original 390 miles of river in the State, only the 90-mile reach between Garrison Dam (Lake Sakakawea) and the upstream end of Lake Oahe near Bismarck, has not been inundated. Useable storage within Lake Sakakawea is slightly less than 19 million acre-feet (U.S. Army, Corps of Engineers, written commun., 1984).

General Description of Major Tributaries

Yellowstone River.--The Yellowstone River originates in Wyoming and all but about 750 square miles of its drainage of 70,000 square miles is in Wyoming and Montana. However, its importance to North Dakota is evidenced by the fact that it contributes about the same quantity of water as the mainstem Missouri River at their confluence in North Dakota. Some water from the Yellowstone River is being used to irrigate land in North Dakota.

Little Missouri River.--The Little Missouri River, which originates in northeastern Wyoming, enters the southwestern corner of North Dakota, and flows in a northerly direction and then easterly to its confluence with Lake Sakakawea, near Killdeer. Its drainage area within North Dakota is about 4,750 square miles. The treeless and barren slopes of the basin produce rapid and excessive overland runoff, and tributary streams flood frequently. Two communities--Marmarth and Medora--are subject to occasional damage by floods although property damage within the basin is generally minor because of the lack of development along the streams. The stream channels of the basin are in the easily eroded shale and sandstone of the badlands and, as a result, transport large quantities of sediment. There are no major flood-control works in the basin. The principal uses of water from the river are stock watering and irrigation.

Knife River.--The Knife River originates in badland areas in west-central North Dakota and flows easterly for about 200 miles to its confluence with the Missouri River. The drainage area is about 2,510 square miles. The communities of Beulah, Zap, Hazen, Stanton, and Hebron are periodically subject to damage by floods from the Knife River or its tributaries. The principal uses of water from the river are stock watering, recreation, and irrigation.

Heart River.--The Heart River originates in the same part of North Dakota as does the Knife River. The Heart River is about 270 miles long with a drainage area of about 3,340 square miles located in smooth to undulating plains. Two major storage structures on the mainstem (Dickinson Dam and Heart Butte Dam) provide about 234,000 acre-feet of storage for flood control, irrigation, municipal supply, and recreation (U.S. Bureau of Reclamation, written commun., 1984). These two structures generally provide adequate flood protection along the mainstem, although the communities of Dickinson, Almont, and Mandan can be flooded. The principal uses of water from the river are stock watering, recreation, and irrigation.

Cannonball River.--The Cannonball River generally parallels the Heart River along its 320-mile course from its headwaters in southwestern North Dakota to its confluence with the Missouri River. The total drainage area is about 4,310 square miles. Severe floods resulting from thunderstorms can occur along the tributaries of the Cannonball and the mainstem can occasionally flood during the spring runoff period. The communities of Mott, Breien, and Solen are subject to flood damage. Erosion has resulted in a series of local badlands along the Cannonball. Surface water in the basin is used primarily for stock watering and irrigation.

General Description of Minor Tributaries

Several small tributaries, draining about 2,800 square miles, flow directly into the Missouri River from the west. The area drained by these tributaries is characterized by steep ravines and gullies, with principal land use being farming and grazing.

The total drainage area of the eastern tributaries is about 14,300 square miles. However, the tributaries originate in the lake wetlands area of the Coteau du Missouri where drainage is poorly integrated and approximately 6,200 square miles is noncontributing. The communities of Williston, on Little Muddy River, and Linton, on Beaver Creek, are subject to minor flood damage.

Streamflow Statistics

Daily flow statistics for three mainstem and four tributary stations within the Missouri River basin in North Dakota are included in table 1a:

TABLE 1a.--Daily streamflow statistics for three mainstem and four tributary stations within the Missouri River basin in North Dakota

Station number	Station name	Drainage area (square miles)		Period of record (water years)	Daily discharge (cubic feet per second)				
		Total	Contributing		Mean	Median	Maximum	Minimum	10-percentile value
06330000	Missouri River near Williston	164,500	--	1898-1964	20,180	15,600	180,000	1,320	7,340
06337000	Little Missouri River near Watford City	8,310	--	1935-83	593	73.1	55,000	0	.32
06338490	Missouri River at Garrison Dam	181,400	--	1970-83	25,380	25,000	65,200	6,000	16,600
06340500	Knife River at Hazen	2,240	--	1929-33, 1938-83	181	31.9	21,800	0	9.4
06342500	Missouri River at Bismarck	186,400	--	1954-83	23,770	23,400	68,800	4,000	11,700
06349000	Heart River near Mandan	3,310	--	1929-32, 1938-83	268	48.6	28,400	0	5
06354000	Cannonball River at Breien	4,100	--	1935-83	254	27	63,100	0	.57

The statistics for the mainstem stations clearly indicate the reliability of the Missouri River as a source of surface water. The statistics for the Garrison Dam and Bismarck stations are very similar, indicating the regulation effects of Garrison Dam (Lake Sakakawea). Using the statistics for the Bismarck station as an example, the median flow is virtually equal to the mean flow (23,770 cubic feet per second or about 17,220,000 acre-feet per year) indicating that flows greater than the mean occur about as frequently as flows less than the mean. The 90-percent duration flow at Bismarck is 11,700 cubic feet per second indicating that flows less than 11,700 cubic feet per second only occur 10 percent of the time.

The daily flow statistics for the tributary stations show the variability of discharge of all four tributaries. The median flows are substantially less than the mean flows, the minimum flows are all equal to zero, and the 10-percentile flows are quite small. Rather substantial maximum flows, resulting from snowmelt and from thunderstorms, have been measured on all four rivers and can be attributed to the well defined drainage patterns within the respective basins.

Monthly streamflow data are presented in fig. 20. The bar graphs illustrate the respective characteristics of streamflow in the mainstem and tributaries discussed above. The temporal distribution of flows on the tributaries is such that storage is necessary to provide a dependable, year-round supply.

Flooding

The most extreme flood recorded on the Missouri River mainstem occurred in April of 1952 as a result of spring snowmelt. An instantaneous peak discharge of 500,000 cubic feet per second was recorded at Bismarck, and an instantaneous peak discharge of 348,000 cubic feet per second was recorded at the Garrison Dam station. Garrison Dam, which provides slightly less than 19-million acre-feet of flood control and multiple use storage, was completed in 1955. The instantaneous peak discharge recorded at Williston in 1952 was 170,000 cubic feet per second. The peak discharge recorded at Williston occurred in 1930, prior to construction of Fort Peck Dam, and was determined to be 231,000 cubic feet per second. Fort Peck Dam, located near Glasgow, Montana and completed in 1940, provides about 14.6-million acre-feet of flood control and multiple use storage.

The instantaneous peak discharges on the tributaries do not necessarily coincide with mainstem major floods. This is attributable, in part, to the regulation of the mainstem and the fact that a considerable part of the Missouri River drainage area is outside North Dakota. Following are the instantaneous peak discharges, and the date of occurrence, which have been recorded at the tributary stations:

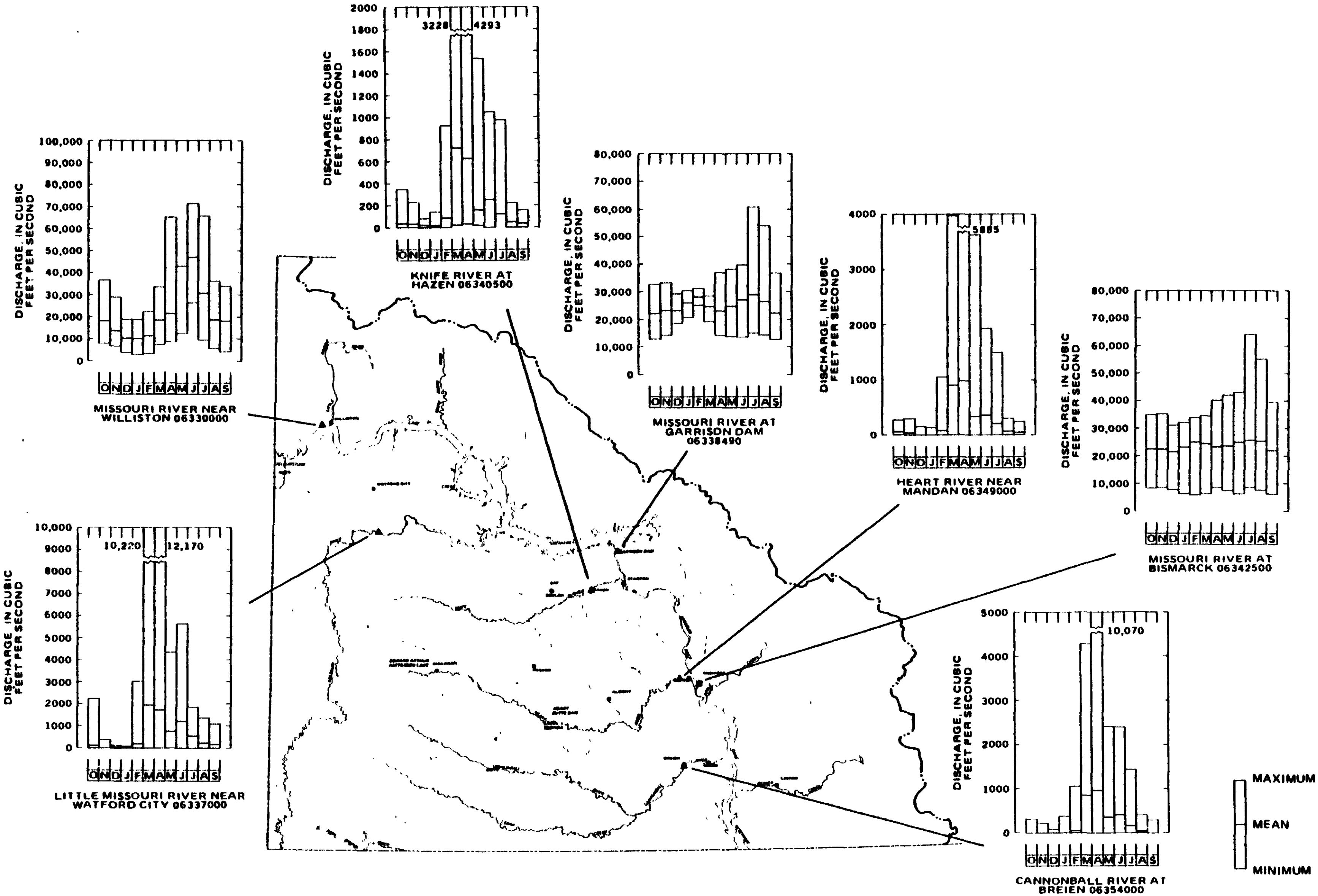


FIGURE 20.—Monthly discharge for period of record at selected gaging stations, Missouri River basin North Dakota.

Station	Date	Instantaneous peak discharge (cubic feet per second)
Little Missouri River near Watford City -	March 1947	110,000
Knife River at Hazen --------------------	June 1966	35,300
Heart River near Mandan------------------	April 1950	30,500
Cannonball River at Breien --------------	April 1950	94,800

Quality of Water

Chemical composition and variation.--Water quality in the Missouri River in North Dakota generally reflects the quality of water from both the Missouri River and the Yellowstone River. The chemical composition of water in the Missouri River mainstem in North Dakota changes very little from the upstream station near Williston to the downstream station at Bismarck. Like discharge, water quality is controlled by the reservoir system starting with Fort Peck Reservoir in Montana and including Lakes Sakakawea and Oahe in North Dakota. Water quality is affected very little by the more mineralized water from four major tributaries--the Little Missouri, Knife, Heart, and Cannonball Rivers--because the lakes stabilize the water quality through dilution and because the volume of water contributed by the tributaries is very small compared to the volume of mainstem streamflow or the lake volumes.

Sodium, calcium, and magnesium are all significant cations (positively charged ions), and sulfate and bicarbonate are the principal anions (negatively charged ions) in water in the Missouri River mainstem. Sodium is the principal cation and sulfate is the principal anion in water from each of the four principal tributaries. In the tributary basins, sodium and sulfate are derived from soils developed from, and deposits of, the Fort Union Formation. Gypsum is the principal source for sulfate and sodium is derived principally through cation exchange (calcium exchanged for sodium). Mean dissolved-solids concentrations are 440 milligrams per liter at the Williston station, 441 milligrams per liter at the Garrison Dam station, and 442 milligrams per liter at the Bismarck station. In contrast, mean dissolved-solids concentrations for the four tributaries range from 856 milligrams per liter in water from the Heart River near Mandan to 1,319 milligrams per liter in water from the Little Missouri River near Watford City. Descriptive statistics and duration tables for specific conductance, seven principal chemical constituents, and dissolved solids in water at the three Missouri River mainstem stations and at the four tributary stations are given in table 2. These data are based on the following periods of record:

TABLE 2.--SUMMARY OF WATER-QUALITY DATA, MISSOURI RIVER BASIN
[UMHOS, MICROMHOS PER CENTIMETER AT 25° CELSIUS; MG/L, MILLIGRAMS PER LITER]

STATION NUMBER: 06330000 STATION NAME AND LOCATION: MISSOURI RIVER NR WILLISTON, ND

DRAINAGE AREA: 164500 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
SPECIFIC CONDUCTANCE (UMHOS)	446	1090.00	314.00	668.31	128.84	807.30	763.25	695.50	578.75	470.00
BICARBONATE FET-FLD (MG/L AS HCO3)	407	322.00	20.00	186.20	30.51	221.00	208.00	191.00	166.00	143.80
NITROGEN, NO2+NO3 TOTAL (MG/L AS N)	94	1.50	0.00	0.18	0.18	0.32	0.25	0.16	0.07	0.01
CALCIUM DISSOLVED (MG/L AS CA)	195	430.00	32.00	57.22	28.74	67.40	64.00	57.00	49.00	39.00
MAGNESIUM, DISSOLVED (MG/L AS MG)	195	39.00	8.50	21.50	5.53	28.00	26.00	23.00	18.00	13.00
SODIUM, DISSOLVED (MG/L AS NA)	435	100.00	4.40	57.12	14.93	75.00	67.00	59.00	47.00	35.00
POTASSIUM, DISSOLVED (MG/L AS K)	162	17.00	2.00	4.16	1.25	5.00	4.60	4.10	3.70	3.20
CHLORIDE, DISSOLVED (MG/L AS CL)	201	24.00	0.70	9.91	3.13	13.00	12.00	10.00	8.00	5.52
SULFATE DISSOLVED (MG/L AS SO4)	248	290.00	54.00	184.37	47.56	240.00	220.00	190.00	155.25	111.90
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	162	660.00	190.00	442.27	92.44	550.00	510.00	460.00	380.00	300.00

STATION NUMBER: 06337000 STATION NAME AND LOCATION: LITTLE MISSOURI RIVER NR WATFORD CITY, ND

DRAINAGE AREA: 8310 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
SPECIFIC CONDUCTANCE (UMHOS)	198	5000.00	400.00	1690.97	705.65	2523.00	2150.00	1620.00	1080.00	812.60
BICARBONATE FET-FLD (MG/L AS HCO3)	53	947.00	127.00	336.70	146.66	493.40	422.00	310.00	230.00	157.60
NITROGEN, NO2+NO3 TOTAL (MG/L AS N)	77	2.40	0.00	0.38	0.56	1.22	0.55	0.10	0.02	0.01
CALCIUM DISSOLVED (MG/L AS CA)	100	160.00	21.00	70.32	30.68	100.00	89.00	72.00	45.25	30.00
MAGNESIUM, DISSOLVED (MG/L AS MG)	100	95.00	3.70	35.75	18.75	60.90	47.00	35.00	20.00	12.00
SODIUM, DISSOLVED (MG/L AS NA)	100	720.00	66.00	314.35	145.82	499.00	400.00	300.00	212.50	121.00
POTASSIUM, DISSOLVED (MG/L AS K)	100	25.00	4.80	10.36	3.30	14.00	12.75	9.90	7.93	6.90
CHLORIDE, DISSOLVED (MG/L AS CL)	100	35.00	0.00	11.65	6.61	21.70	16.00	10.00	7.13	4.93
SULFATE DISSOLVED (MG/L AS SO4)	100	1500.00	170.00	690.70	308.41	1100.00	860.00	665.00	472.50	290.00
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	100	2900.00	370.00	1318.60	573.28	2000.00	1600.00	1300.00	897.50	550.00

STATION NUMBER: 06338490 STATION NAME AND LOCATION: MISSOURI RIVER AT GARRISON DAM, ND

DRAINAGE AREA: 181400 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
SPECIFIC CONDUCTANCE (UMHOS)	171	810.00	570.00	678.09	50.28	751.60	710.00	665.00	640.00	625.00
BICARBONATE FET-FLD (MG/L AS HCO3)	106	201.00	171.00	184.19	7.12	192.60	189.00	184.00	179.00	175.00
NITROGEN, NO2+NO3 TOTAL (MG/L AS N)	89	0.28	0.00	0.13	0.07	0.23	0.18	0.13	0.09	0.03
CALCIUM DISSOLVED (MG/L AS CA)	159	65.00	41.00	52.94	3.99	58.00	56.00	53.00	50.00	48.00
MAGNESIUM, DISSOLVED (MG/L AS MG)	159	28.00	16.00	21.31	2.21	25.00	23.00	21.00	20.00	19.00
SODIUM, DISSOLVED (MG/L AS NA)	159	82.00	48.00	61.65	7.12	73.00	65.00	60.00	57.00	54.00
POTASSIUM, DISSOLVED (MG/L AS K)	159	8.20	3.10	4.15	0.47	4.60	4.30	4.10	3.90	3.80
CHLORIDE, DISSOLVED (MG/L AS CL)	135	19.00	3.80	9.59	1.53	11.00	10.00	9.70	8.80	8.16
SULFATE DISSOLVED (MG/L AS SO4)	135	250.00	120.00	190.07	26.67	230.00	210.00	180.00	170.00	160.00
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	134	540.00	330.00	441.27	38.57	500.00	470.00	430.00	410.00	400.00

STATION NUMBER: 06340500 STATION NAME AND LOCATION: KNIFE RIVER AT HAZEN, ND

DRAINAGE AREA: 2240 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
SPECIFIC CONDUCTANCE (UMHOS)	292	3100.00	170.00	1317.24	524.46	2000.00	1607.50	1305.00	1100.00	472.00
BICARBONATE FET-FLD (MG/L AS HCO3)	72	778.00	66.00	456.36	199.48	725.50	579.50	495.00	296.50	114.90
NITROGEN, NO2+NO3 TOTAL (MG/L AS N)	91	0.96	0.00	0.18	0.21	0.49	0.30	0.08	0.02	0.01
CALCIUM DISSOLVED (MG/L AS CA)	130	130.00	14.00	65.08	22.86	97.00	80.00	67.00	51.00	30.20
MAGNESIUM, DISSOLVED (MG/L AS MG)	130	67.00	2.20	36.18	14.11	54.00	45.25	38.00	28.75	13.40
SODIUM, DISSOLVED (MG/L AS NA)	119	410.00	17.00	234.69	89.81	350.00	308.00	235.00	190.00	110.00
POTASSIUM, DISSOLVED (MG/L AS K)	116	12.00	1.60	8.24	1.52	10.00	9.10	8.50	7.50	6.57
SULFATE DISSOLVED (MG/L AS SO4)	135	860.00	26.00	389.35	162.43	594.00	500.00	390.00	301.00	147.00
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	104	1700.00	190.00	1033.99	337.95	1500.00	1300.00	1000.00	870.00	585.00

TABLE 2.--SUMMARY OF WATER-QUALITY DATA, MISSOURI RIVER BASIN--Continued
[UMHOS, MICROMHOS PER CENTIMETER AT 25° CELSIUS; MG/L, MILLIGRAMS PER LITER]

STATION NUMBER: 06342500 STATION NAME AND LOCATION: MISSOURI RIVER AT BISMARCK, ND

DRAINAGE AREA: 186400 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
SPECIFIC CONDUCTANCE (UMHOS)	208	822.00	500.00	673.17	51.43	741.00	700.00	670.00	640.00	620.00
BICARBONATE FET-FLD (MG/L AS HCO3)	50	220.00	162.00	187.06	9.79	199.90	191.00	188.50	180.00	175.20
NITROGEN, NO2+NO3 TOTAL (MG/L AS N)	144	0.80	0.03	0.14	0.08	0.22	0.18	0.13	0.10	0.07
CALCIUM DISSOLVED (MG/L AS CA)	70	61.00	46.00	54.34	3.12	58.00	56.25	54.00	52.75	50.10
MAGNESIUM, DISSOLVED (MG/L AS MG)	71	26.00	18.00	21.82	2.10	24.80	23.00	22.00	20.00	19.00
SODIUM, DISSOLVED (MG/L AS NA)	71	80.00	53.00	63.07	7.77	76.00	67.00	61.00	57.00	54.20
POTASSIUM, DISSOLVED (MG/L AS K)	71	5.00	2.70	4.21	0.32	4.68	4.40	4.20	4.00	3.90
CHLORIDE, DISSOLVED (MG/L AS CL)	72	13.00	7.20	9.62	1.24	11.00	10.00	9.50	8.80	8.20
SULFATE DISSOLVED (MG/L AS SO4)	73	260.00	150.00	189.85	28.80	230.00	210.00	180.00	170.00	160.00
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	70	530.00	370.00	443.57	40.76	509.00	470.00	435.00	417.50	400.00

STATION NUMBER: 06349000 STATION NAME AND LOCATION: HEART RIVER NR MANDAN, ND

DRAINAGE AREA: 3310 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
SPECIFIC CONDUCTANCE (UMHOS)	208	3499.99	205.00	1222.38	437.37	1641.00	1467.50	1182.50	1040.00	658.00
BICARBONATE FET-FLD (MG/L AS HCO3)	22	550.00	90.00	326.23	134.30	518.80	439.25	308.00	223.00	149.30
NITROGEN, NO2+NO3 TOTAL (MG/L AS N)	38	0.81	0.00	0.20	0.23	0.59	0.31	0.10	0.02	0.00
CALCIUM DISSOLVED (MG/L AS CA)	73	100.00	18.00	61.11	19.49	91.00	71.00	59.00	46.50	35.00
MAGNESIUM, DISSOLVED (MG/L AS MG)	73	64.00	5.40	38.13	13.14	55.00	47.50	39.00	28.50	19.00
SODIUM, DISSOLVED (MG/L AS NA)	72	320.00	19.00	179.08	67.97	267.00	230.00	180.00	140.00	88.60
POTASSIUM, DISSOLVED (MG/L AS K)	72	13.00	5.50	8.51	1.33	10.00	9.35	8.45	7.70	6.90
CHLORIDE, DISSOLVED (MG/L AS CL)	73	32.00	0.00	10.46	5.63	18.00	13.00	10.00	7.10	3.54
SULFATE DISSOLVED (MG/L AS SO4)	73	670.00	55.00	376.10	126.04	520.00	460.00	410.00	295.00	210.00
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	72	1500.00	160.00	864.86	288.64	1200.00	1100.00	890.00	660.00	458.00

STATION NUMBER: 06354000 STATION NAME AND LOCATION: CANNONBALL RIVER AT BREIEN, ND

DRAINAGE AREA: 4100 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
SPECIFIC CONDUCTANCE (UMHOS)	274	3799.99	190.00	1697.38	752.13	2680.00	2350.00	1600.00	1180.00	690.00
BICARBONATE FET-FLD (MG/L AS HCO3)	70	951.00	106.00	428.97	212.94	734.50	611.25	350.00	286.50	213.20
NITROGEN, NO2+NO3 TOTAL (MG/L AS N)	81	2.50	0.00	0.23	0.36	0.66	0.35	0.10	0.02	0.00
CALCIUM DISSOLVED (MG/L AS CA)	125	160.00	23.00	78.78	32.11	130.00	95.50	72.00	59.00	38.60
MAGNESIUM, DISSOLVED (MG/L AS MG)	125	150.00	2.60	59.06	28.00	99.00	79.50	55.00	39.00	22.60
SODIUM, DISSOLVED (MG/L AS NA)	122	630.00	39.00	267.61	126.78	447.00	350.00	260.00	170.00	103.00
POTASSIUM, DISSOLVED (MG/L AS K)	122	18.00	2.30	9.94	2.31	13.00	11.00	9.85	8.30	7.23
CHLORIDE, DISSOLVED (MG/L AS CL)	125	62.00	0.80	13.22	9.27	25.20	16.50	11.00	7.30	4.36
SULFATE DISSOLVED (MG/L AS SO4)	125	1500.00	120.00	649.56	285.00	1040.00	865.00	610.00	440.00	280.00
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	122	3000.00	280.00	1301.39	550.13	2100.00	1700.00	1200.00	917.50	593.00

Station	Period of record
Main-stem stations	
Missouri River near Williston ----------	1951-65, 1969-70, 1974-83
Missouri River at Garrison Dam ---------	1972-83
Missouri River at Bismarck -------------	1969-72, 1974-80
Tributary stations	
Little Missouri River near Watford City	1972-83
Knife River at Hazen -------------------	1950-51, 1969-83
Heart River near Mandan ----------------	1946-50, 1971-76, 1978-83
Cannonball River at Breien -------------	1970-72, 1974-83

Although maximum and minimum concentrations define the overall range of occurrence of the constituents, the 90th and 10th percentiles in the duration tables generally define a more effective range for general examination of stream quality. Constituent values greater than the 90th percentile or less than the 10th percentile are outliers that may represent extraordinary events or occasionally may indicate random errors in the data base. While it is extremely important to understand the significance of individual outliers for specific projects or users, they are less important for general knowledge of the range of the stream quality. Likewise, when outlying values are significantly greater than the 90th percentile or significantly less than the 10th percentile, the median (50th percentile) may provide better information about average constituent concentrations than does the mean. The mean may be affected unduly by the outliers whereas the median is not. The 75-percentile value representing the group of higher constituent concentrations may be used as an indicator of concentrations during low-flow conditions. Likewise, the 25-percentile value may be used as an indicator of concentrations during high-flow conditions.

Dissolved-solids concentrations show little seasonal variation at the Missouri River mainstem stations but vary greatly seasonally at the tributary stations (fig. 21). Most of the streamflow at the tributary stations occurs either in March and April and consists of snowmelt and ice breakup, or in early summer and consists mostly of overland runoff from thunderstorms. Because of limited contribution of ground water to streamflow, the tributaries may be nearly dry at other times of the year. Period-of-record mean dissolved-solids concentrations for high flows during snowmelt (March-April) are compared to those from low flows(August-September) in figure 21. Dissolved-solids concentrations are less in water from the Heart River near Mandan than in water at the other three tributary stations, both at high and low flows, even though, geochemically, the source material is nearly the same for all four tributaries. Two reservoirs on the Heart River, Edward Arthur Patterson Lake (Dickinson Dam) and Lake Tschida (Heart Butte Dam) substantially decrease the overall variation in dissolved-solids concentrations in the Heart River. No major reservoirs are located on the other three tributaries.

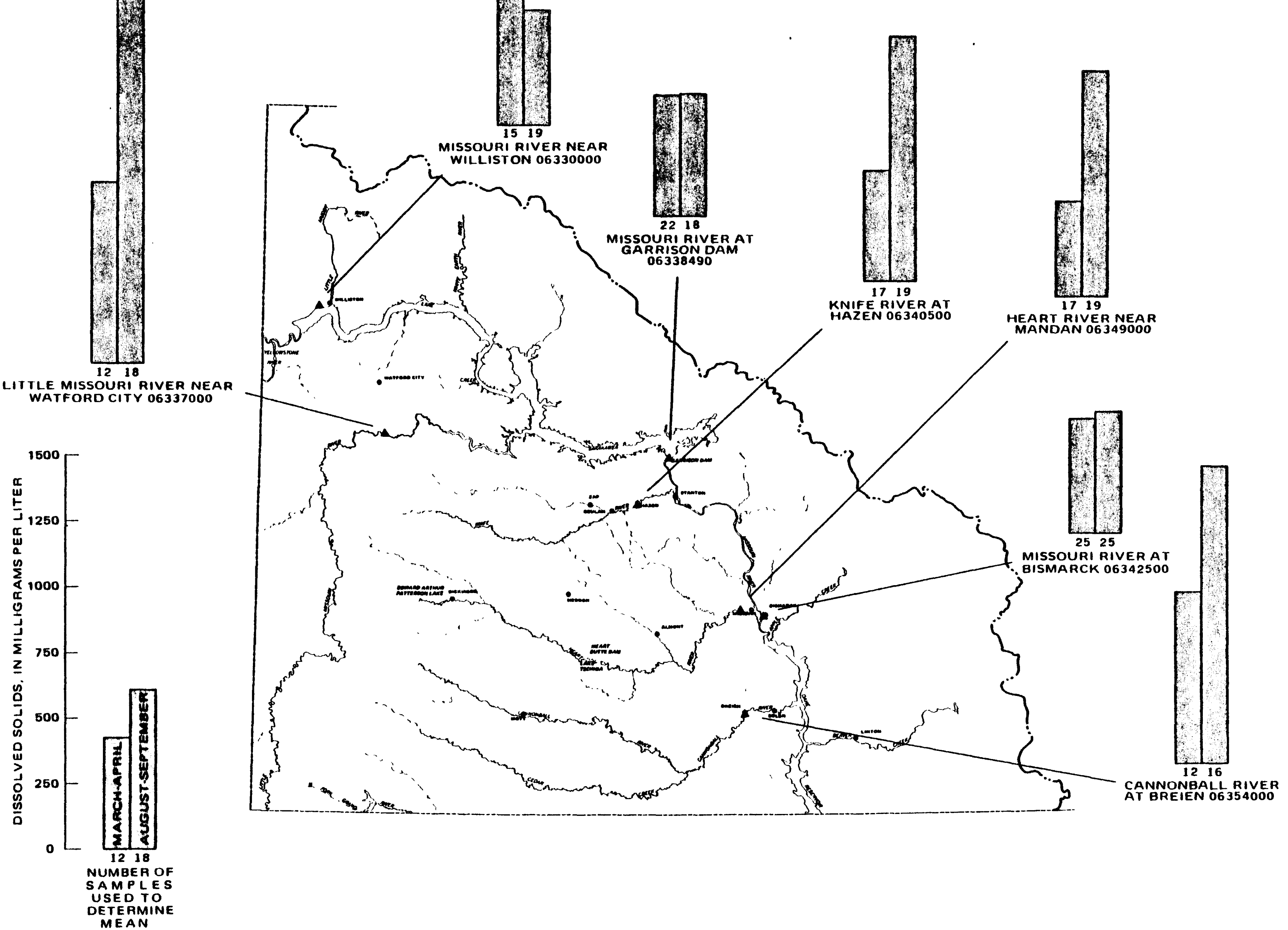


FIGURE 21.—Period-of-record mean dissolved-solids concentrations for high flows (March-April) and low flows (August-September) at selected stations, Missouri River basin, North Dakota.

Concentrations of five principal constituents in water at the three Missouri River main-stem stations are compared in figure 22 and are compared at the four tributary stations in figure 23. These box plots show maximum, minimum, mean, median (50th percentile), and 75th and 25th percentiles for each constituent in downstream order, left to right. Mean constituent-concentrations in water from the mainstem stations display little variation, but ranges are slightly greater in water at the Williston station than in water at the other two stations. Variations in concentrations and ranges are greater at the tributary stations. For all stations, data are not directly comparable between constituents because scales are different and concentration data are not chemically equivalent.

Time trend analyses for dissolved-solids concentration data were performed by the residuals method on dissolved-solids data for the four tributary stations (Wells and Schertz, 1983). Trends were detected if the regression between adjusted residuals and time was significant at the 95 percent confidence level. Results of these analyses are summarized below:

Station	Period of record (water years)	Magnitude of trend (milligrams per liter per year)
Little Missouri River near Watford City	1972-82	None
Knife River near Hazen	1970-82	None
Heart River near Mandan	1972-82	+14.3
Cannonball River at Breien	1971-81	None

The reasons for the statistically-significant trend at the Heart River station are not known.

Suitability for use. -Water in the reservoirs and at the mainstem Missouri River stations generally is suitable for drinking-water supplies or domestic use. Mean dissolved solids concentrations are less than 500 milligrams per liter at all main-stem stations, and 90th-percentile dissolved-solids concentrations are 550 milligrams per liter at the Williston station, 500 milligrams per liter at the Garrison Dam station, and 509 milligrams per liter at the Bismarck station. Nitrate-nitrogen 90th-percentile concentrations are all much less than the State standard of 1 milligram per liter.

Mercury is the only trace constituent for which the maximum value exceeded Federal drinking water standards at any Missouri River mainstem station (table 3). A concentration of 30 micrograms per liter was measured in a sample from the Williston station and probably is the result of a single contamination event or random error because the 90th-percentile concentration in 23 samples collected at this station is 2.0 micrograms per liter, which is the Federal maximum limit for mercury in drinking water.

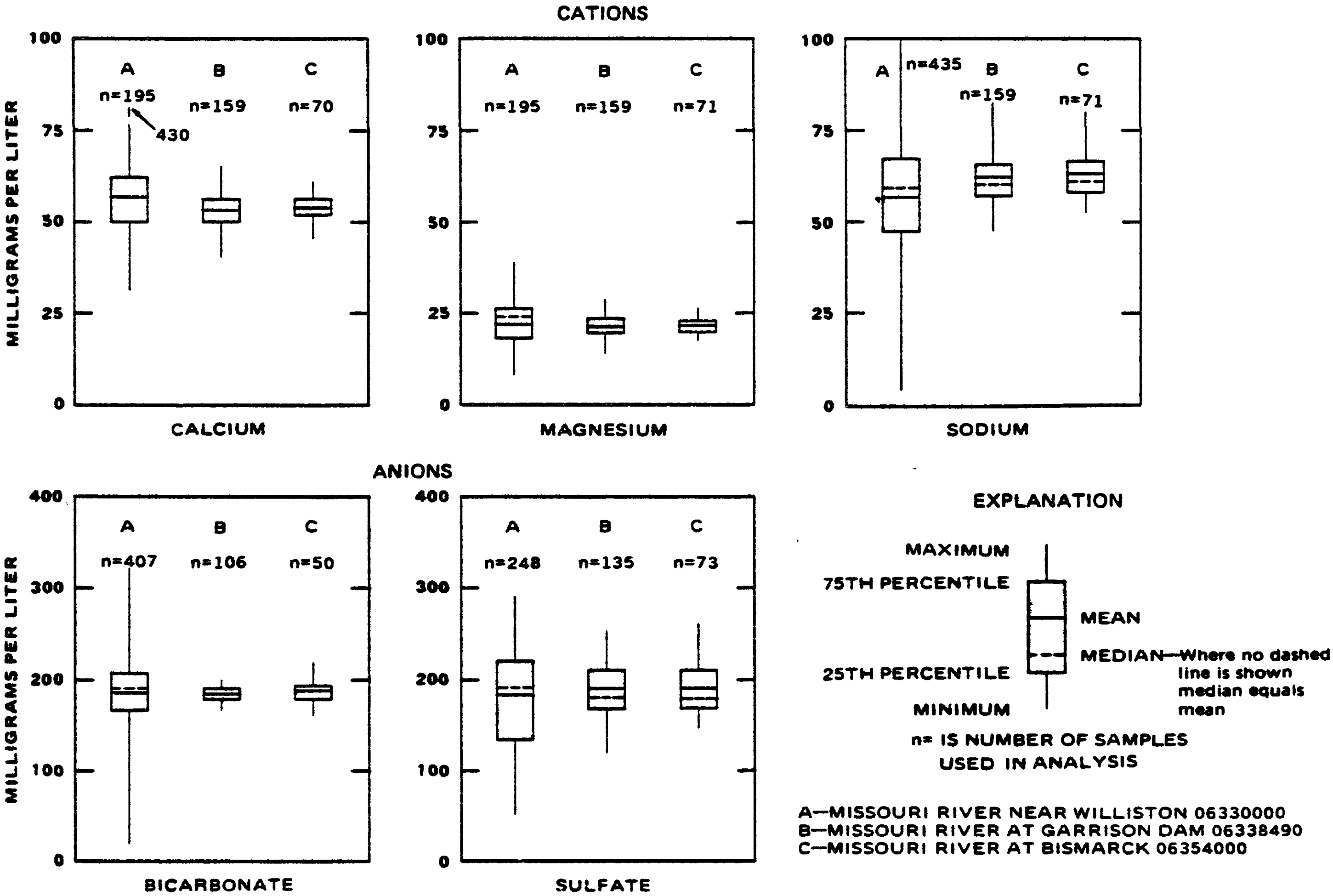


FIGURE 22.—Statistical comparisons of concentrations of principal cations and anions at selected main stem stations, Missouri River basin, North Dakota.

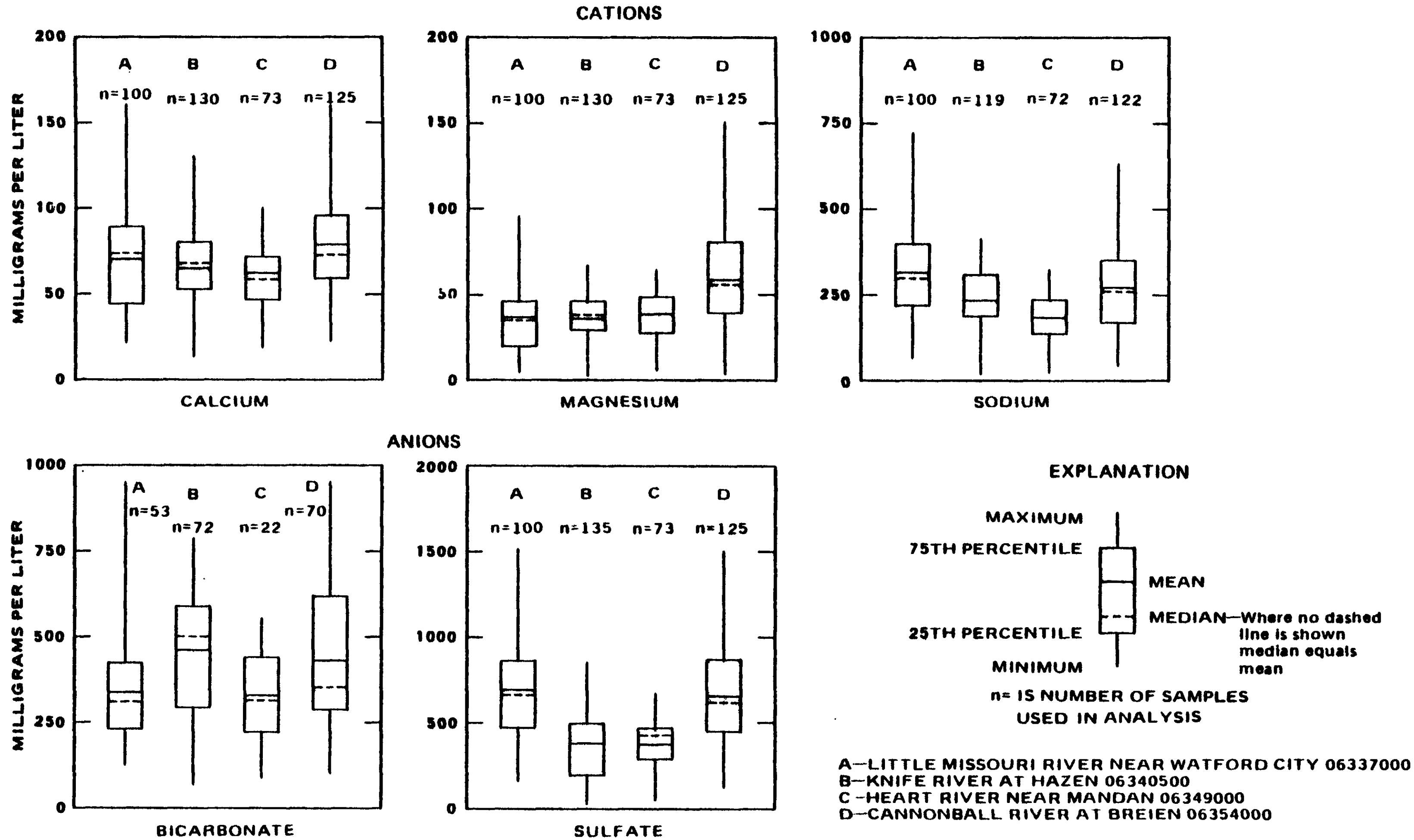


FIGURE 23.—Statistical comparisons of concentrations of principal cations and anions at selected major tributary stations, Missouri River basin, North Dakota.

TABLE 3.--SUMMARY OF TRACE CONSTITUENT DATA, MISSOURI RIVER BASIN
[UG/L, MICROGRAMS PER LITER]

STATION NUMBER: 06330000 STATION NAME AND LOCATION: MISSOURI RIVER NR WILLISTON, ND

DRAINAGE AREA: 164500 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
ARSENIC DISSOLVED (UG/L AS AS)	17	40.00	1.00	4.82	9.12	11.20	3.50	3.00	2.00	1.00
BARIUM, DISSOLVED (UG/L AS BA)	5	100.00	100.00							
BORON, DISSOLVED (UG/L AS B)	169	350.00	10.00	132.78	42.64	170.00	150.00	130.00	110.00	90.00
CADMIUM DISSOLVED (UG/L AS CD)	17	2.00	0.00	0.59	0.87	2.00	1.50	0.00	0.00	0.00
CHROMIUM, DISSOLVED (UG/L AS CR)	17	20.00	0.00	1.53	4.87	7.20	0.00	0.00	0.00	0.00
COPPER, DISSOLVED (UG/L AS CU)	20	56.00	0.00	12.70	15.22	41.10	19.50	5.50	2.00	2.00
IRON, DISSOLVED (UG/L AS FE)	33	820.00	0.00	49.30	141.36	50.00	30.00	20.00	10.00	10.00
LEAD, DISSOLVED (UG/L AS PB)	20	7.00	0.00	1.90	1.68	3.00	3.00	2.00	0.00	0.00
MANGANESE, DISSOLVED (UG/L AS MN)	18	40.00	0.00	15.00	10.43	31.00	22.50	10.00	10.00	9.00
ZINC, DISSOLVED (UG/L AS ZN)	22	120.00	0.00	31.82	28.72	77.00	42.50	20.00	20.00	0.00
SELENIUM, DISSOLVED (UG/L AS SE)	22	3.00	0.00	1.09	0.53	1.70	1.00	1.00	1.00	1.00
MERCURY DISSOLVED (UG/L AS HG)	22	30.00	0.00	1.83	6.31	2.04	0.50	0.50	0.10	0.10

STATION NUMBER: 06337000 STATION NAME AND LOCATION: LITTLE MISSOURI RIVER NR WATFORD CITY, ND

DRAINAGE AREA: 8310 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
ARSENIC DISSOLVED (UG/L AS AS)	38	5.00	1.00	1.53	0.80	2.00	2.00	1.00	1.00	1.00
BARIUM, DISSOLVED (UG/L AS BA)	24	300.00	0.00	95.46	79.32	250.00	100.00	83.50	41.25	29.00
BORON, DISSOLVED (UG/L AS B)	13	570.00	40.00	240.77	156.60	510.00	330.00	290.00	90.00	60.00
CADMIUM DISSOLVED (UG/L AS CD)	38	6.00	0.00	1.37	1.40	3.00	2.00	1.00	0.00	0.00
CHROMIUM, DISSOLVED (UG/L AS CR)	37	20.00	0.00	3.54	6.14	12.00	7.00	0.00	0.00	0.00
COPPER, DISSOLVED (UG/L AS CU)	38	50.00	2.00	10.58	10.32	27.30	13.00	7.50	4.00	2.00
IRON, DISSOLVED (UG/L AS FE)	49	5500.00	0.00	249.88	798.24	440.00	165.00	50.00	25.00	10.00
LEAD, DISSOLVED (UG/L AS PB)	38	19.00	0.00	3.00	3.62	6.20	3.25	2.00	1.00	0.00
MANGANESE, DISSOLVED (UG/L AS MN)	49	190.00	0.00	24.86	32.14	60.00	35.00	10.00	9.00	3.00
SILVER, DISSOLVED (UG/L AS AG)	24	1.00	0.00	0.46	0.51	1.00	1.00	0.00	0.00	0.00
ZINC, DISSOLVED (UG/L AS ZN)	38	100.00	0.00	23.39	22.23	51.00	32.50	20.00	10.00	3.00
SELENIUM, DISSOLVED (UG/L AS SE)	38	4.00	0.00	1.32	0.87	3.00	1.25	1.00	1.00	0.90
MERCURY DISSOLVED (UG/L AS HG)	38	1.00	0.00	0.31	0.24	0.60	0.50	0.25	0.10	0.09

STATION NUMBER: 06338490 STATION NAME AND LOCATION: MISSOURI RIVER AT GARRISON DAM, ND

DRAINAGE AREA: 181400 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
ARSENIC DISSOLVED (UG/L AS AS)	88	9.00	0.00	2.03	1.22	3.10	2.00	2.00	1.00	1.00
BARIUM, DISSOLVED (UG/L AS BA)	46	200.00	0.00	80.43	37.50	100.00	100.00	100.00	55.00	49.70
BORON, DISSOLVED (UG/L AS B)	83	270.00	0.00	112.89	29.20	130.00	120.00	110.00	110.00	100.00
CADMIUM DISSOLVED (UG/L AS CD)	88	3.00	0.00	0.67	0.85	2.00	1.00	0.00	0.00	0.00
CHROMIUM, DISSOLVED (UG/L AS CR)	47	20.00	0.00	3.30	6.33	16.00	1.00	0.00	0.00	0.00
COPPER, DISSOLVED (UG/L AS CU)	49	12.00	0.00	2.67	2.29	6.00	3.00	2.00	2.00	0.00
IRON, DISSOLVED (UG/L AS FE)	63	160.00	4.00	21.02	26.22	48.00	20.00	10.00	10.00	9.00
LEAD, DISSOLVED (UG/L AS PB)	49	6.00	0.00	1.41	1.46	3.00	2.00	1.00	0.00	0.00
MANGANESE, DISSOLVED (UG/L AS MN)	50	67.00	0.00	7.26	9.72	10.00	10.00	8.00	1.00	1.00
SILVER, DISSOLVED (UG/L AS AG)	45	20.00	0.00	0.71	2.98	1.00	1.00	0.00	0.00	0.00
ZINC, DISSOLVED (UG/L AS ZN)	49	80.00	0.00	14.76	16.17	30.00	20.00	10.00	3.00	0.00
SELENIUM, DISSOLVED (UG/L AS SE)	48	8.00	0.00	1.35	1.47	2.20	1.00	1.00	1.00	1.00
MERCURY DISSOLVED (UG/L AS HG)	48	1.10	0.00	0.29	0.24	0.50	0.50	0.20	0.10	0.00

STATION NUMBER: 06340500 STATION NAME AND LOCATION: KNIFE RIVER AT HAZEN, ND

DRAINAGE AREA: 2240 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
ARSENIC DISSOLVED (UG/L AS AS)	39	4.00	1.00	1.49	0.76	2.00	2.00	1.00	1.00	1.00
BARIUM, DISSOLVED (UG/L AS BA)	35	200.00	42.00	106.06	42.23	200.00	100.00	100.00	89.00	56.80
BORON, DISSOLVED (UG/L AS B)	76	1300.00	0.00	285.00	192.23	395.00	350.00	295.00	190.00	70.00
CADMIUM DISSOLVED (UG/L AS CD)	38	3.00	0.00	0.92	0.85	2.00	2.00	1.00	0.00	0.00
CHROMIUM, DISSOLVED (UG/L AS CR)	39	20.00	0.00	4.97	7.50	20.00	10.00	0.00	0.00	0.00
COPPER, DISSOLVED (UG/L AS CU)	40	40.00	0.00	4.35	6.73	8.70	4.00	2.00	2.00	2.00
IRON, DISSOLVED (UG/L AS FE)	71	740.00	0.00	95.55	142.06	270.00	100.00	40.00	20.00	0.00
LEAD, DISSOLVED (UG/L AS PB)	40	16.00	0.00	2.07	2.90	4.90	3.00	1.00	0.00	0.00
MANGANESE, DISSOLVED (UG/L AS MN)	56	220.00	0.00	47.55	50.40	133.00	70.00	30.00	10.00	9.70
SILVER, DISSOLVED (UG/L AS AG)	26	1.00	0.00	0.42	0.50	1.00	1.00	0.00	0.00	0.00
ZINC, DISSOLVED (UG/L AS ZN)	40	190.00	0.00	21.75	33.80	29.50	20.00	20.00	4.25	3.00
SELENIUM, DISSOLVED (UG/L AS SE)	42	6.00	0.00	0.93	0.89	1.00	1.00	1.00	1.00	0.00
MERCURY DISSOLVED (UG/L AS HG)	42	0.80	0.00	0.25	0.23	0.50	0.50	0.10	0.10	0.00

TABLE 3.--SUMMARY OF TRACE CONSTITUENT DATA, MISSOURI RIVER BASIN--Continued
[UG/L, MICROGRAMS PER LITER]

STATION NUMBER: 06342500 STATION NAME AND LOCATION: MISSOURI RIVER AT BISMARCK, ND

DRAINAGE AREA: 186400 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
	SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS									
ARSENIC DISSOLVED (UG/L AS AS)	10	2.00	2.00	2.00	0.00	2.00	2.00	2.00	2.00	2.00
BARIUM, DISSOLVED (UG/L AS BA)	6	100.00	100.00							
BORON, DISSOLVED (UG/L AS B)	49	540.00	9.00	133.86	65.19	160.00	130.00	120.00	120.00	110.00
CADMIUM DISSOLVED (UG/L AS CD)	9	2.00	0.00							
CHROMIUM, DISSOLVED (UG/L AS CR)	10	20.00	0.00	4.00	8.43	20.00	5.00	0.00	0.00	0.00
COPPER, DISSOLVED (UG/L AS CU)	10	4.00	0.00	2.20	1.03	3.90	3.00	2.00	2.00	0.20
IRON, DISSOLVED (UG/L AS FE)	10	400.00	10.00	56.00	121.03	363.00	22.50	20.00	10.00	10.00
LEAD, DISSOLVED (UG/L AS PB)	9	3.00	0.00							
MANGANESE, DISSOLVED (UG/L AS MN)	10	30.00	4.00	11.40	6.80	28.00	10.00	10.00	10.00	4.60
SILVER, DISSOLVED (UG/L AS AG)	1	0.00	0.00							
ZINC, DISSOLVED (UG/L AS ZN)	10	30.00	0.00	15.80	9.82	29.00	20.00	20.00	6.00	0.00
SELENIUM, DISSOLVED (UG/L AS SE)	10	2.00	1.00	1.10	0.32	1.90	1.00	1.00	1.00	1.00
MERCURY DISSOLVED (UG/L AS HG)	10	1.20	0.10	0.41	0.34	1.13	0.50	0.50	0.10	0.10

STATION NUMBER: 06349000 STATION NAME AND LOCATION: HEART RIVER NR MANDAN, ND

DRAINAGE AREA: 3310 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
	SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS									
ARSENIC DISSOLVED (UG/L AS AS)	26	4.00	1.00	1.35	0.69	2.00	2.00	1.00	1.00	1.00
BARIUM, DISSOLVED (UG/L AS BA)	26	200.00	9.00	78.54	33.36	100.00	92.50	79.50	59.75	38.80
BORON, DISSOLVED (UG/L AS B)	17	1700.00	0.00	387.65	392.15	876.00	505.00	270.00	130.00	56.00
CADMIUM DISSOLVED (UG/L AS CD)	24	3.00	0.00	1.25	0.61	2.00	1.75	1.00	1.00	1.00
CHROMIUM, DISSOLVED (UG/L AS CR)	25	20.00	0.00	3.48	5.42	10.00	10.00	1.00	0.00	0.00
COPPER, DISSOLVED (UG/L AS CU)	25	35.00	0.00	3.40	6.65	4.00	3.00	2.00	1.50	1.00
IRON, DISSOLVED (UG/L AS FE)	41	270.00	0.00	52.76	71.38	184.00	85.00	20.00	7.50	0.00
LEAD, DISSOLVED (UG/L AS PB)	23	7.00	0.00	1.52	1.65	4.00	2.00	1.00	1.00	0.00
MANGANESE, DISSOLVED (UG/L AS MN)	41	230.00	0.00	20.15	41.56	46.00	13.00	10.00	5.50	0.00
SILVER, DISSOLVED (UG/L AS AG)	26	1.00	0.00	0.46	0.51	1.00	1.00	0.00	0.00	0.00
ZINC, DISSOLVED (UG/L AS ZN)	26	34.00	0.00	11.85	8.83	23.00	20.00	10.50	3.75	3.00
SELENIUM, DISSOLVED (UG/L AS SE)	26	1.00	0.00	0.77	0.43	1.00	1.00	1.00	0.75	0.00
MERCURY DISSOLVED (UG/L AS HG)	26	0.70	0.00	0.11	0.13	0.13	0.10	0.10	0.10	0.00

STATION NUMBER: 06354000 STATION NAME AND LOCATION: CANNONBALL RIVER AT BREIEN, ND

DRAINAGE AREA: 4100 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
	SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS									
ARSENIC DISSOLVED (UG/L AS AS)	42	3.00	0.00	1.48	0.83	3.00	2.00	1.00	1.00	1.00
BARIUM, DISSOLVED (UG/L AS BA)	28	200.00	37.00	90.79	38.32	128.00	100.00	95.00	74.00	40.00
BORON, DISSOLVED (UG/L AS B)	25	860.00	0.00	370.40	255.99	708.00	575.00	350.00	115.00	42.00
CADMIUM DISSOLVED (UG/L AS CD)	41	3.00	0.00	0.98	0.85	2.00	1.50	1.00	0.00	0.00
CHROMIUM, DISSOLVED (UG/L AS CR)	42	20.00	0.00	4.02	6.86	20.00	10.00	0.00	0.00	0.00
COPPER, DISSOLVED (UG/L AS CU)	43	28.00	0.00	3.67	4.80	5.00	4.00	2.00	2.00	1.40
IRON, DISSOLVED (UG/L AS FE)	66	1700.00	0.00	76.29	237.27	93.00	60.00	20.00	0.00	0.00
LEAD, DISSOLVED (UG/L AS PB)	41	8.00	0.00	2.02	2.02	4.00	3.00	2.00	0.00	0.00
MANGANESE, DISSOLVED (UG/L AS MN)	66	210.00	0.00	25.70	32.03	70.00	27.75	20.00	10.00	4.70
SILVER, DISSOLVED (UG/L AS AG)	29	1.00	0.00	0.48	0.51	1.00	1.00	0.00	0.00	0.00
ZINC, DISSOLVED (UG/L AS ZN)	42	120.00	0.00	20.57	27.98	69.70	20.00	10.00	5.75	0.00
SELENIUM, DISSOLVED (UG/L AS SE)	42	5.00	0.00	1.12	0.80	2.00	1.00	1.00	1.00	0.00
MERCURY DISSOLVED (UG/L AS HG)	42	0.50	0.00	0.22	0.20	0.50	0.50	0.10	0.10	0.00

Water in the four tributary streams appears to be at best marginally suitable for domestic supplies because mean sulfate concentrations exceed the Secondary drinking water standard criterion of 250 milligrams per liter at all stations. Water containing sulfate in excess of 250 milligrams per liter may have a laxative effect on infrequent users. In contrast, nitrate-nitrogen concentrations are much less than the Federal drinking water standard of 10 milligrams per liter. In fact, the 90th-percentile concentration of 1.22 milligrams per liter nitrate-nitrogen for the Little Missouri River near Watford City is the only 90th-percentile concentration at any of the Missouri River basin stations that exceed the State standard for class I streams.

Maximum concentrations for trace constituents for which Federal primary drinking water standards are established are not exceeded in water from any of the tributary streams. Maximum and 90th-percentile concentrations for iron and manganese however have exceeded Secondary drinking water standards of 300 and 50 micrograms per liter, at most stations. Because these criteria are based on esthetic considerations, water in which concentrations of iron and manganese exceed the standard can be used for most domestic uses as long as the effects are understood by the users.

Specific conductance (conductivity) and sodium-adsorption ratio (SAR) ranges at the three Missouri River stations and at the four tributary stations are shown on irrigation suitability diagrams (fig. 24). SAR is an index that relates calcium and magnesium concentrations to the sodium concentration in water; generally the greater the sodium concentration the greater the SAR. On the diagrams, water types classified in the lower left area (C1-S1) are most suitable and those in the upper right (C4-S4) are least suitable. Water types classed along the right side of the diagrams (C4) have the greatest salinity hazard, whereas water types classed along the top of the diagram (S4) have the greatest sodium hazard. Water classed as C4 generally is unsatisfactory for irrigation use because it is too saline for most crops. Water classed as S4 is unsatisfactory for irrigation use because large SAR values indicate that sodium may replace adsorbed calcium and magnesium in the soil causing swelling and damage to its structure. Water classed as C3 can only be used on soils with unrestricted drainage; water classed as S3, if used for irrigation, may require special management of soils.

Ninetieth-percentile values for specific conductance in water at the three Missouri River stations are about 750 micromhos per centimeter at 25 degrees Celsius which means that 90 percent of the time the specific conductance does not exceed C2 on the diagrams. Likewise, 90th-percentile SAR values are about 2 units which does not exceed S1 on the diagrams. Normally, C2-S1 water is safe for irrigation use.

In contrast, water from the tributaries is marginal for irrigation. The sodium hazard potentially is only S2 or S3 at 90th percentile SAR, but the salinity hazard is C3 or C4 at 90th percentile specific conductance at all tributary stations. Because of this, water at low-flow conditions (90th percentile) possibly would be dangerous for prolonged irrigation use.

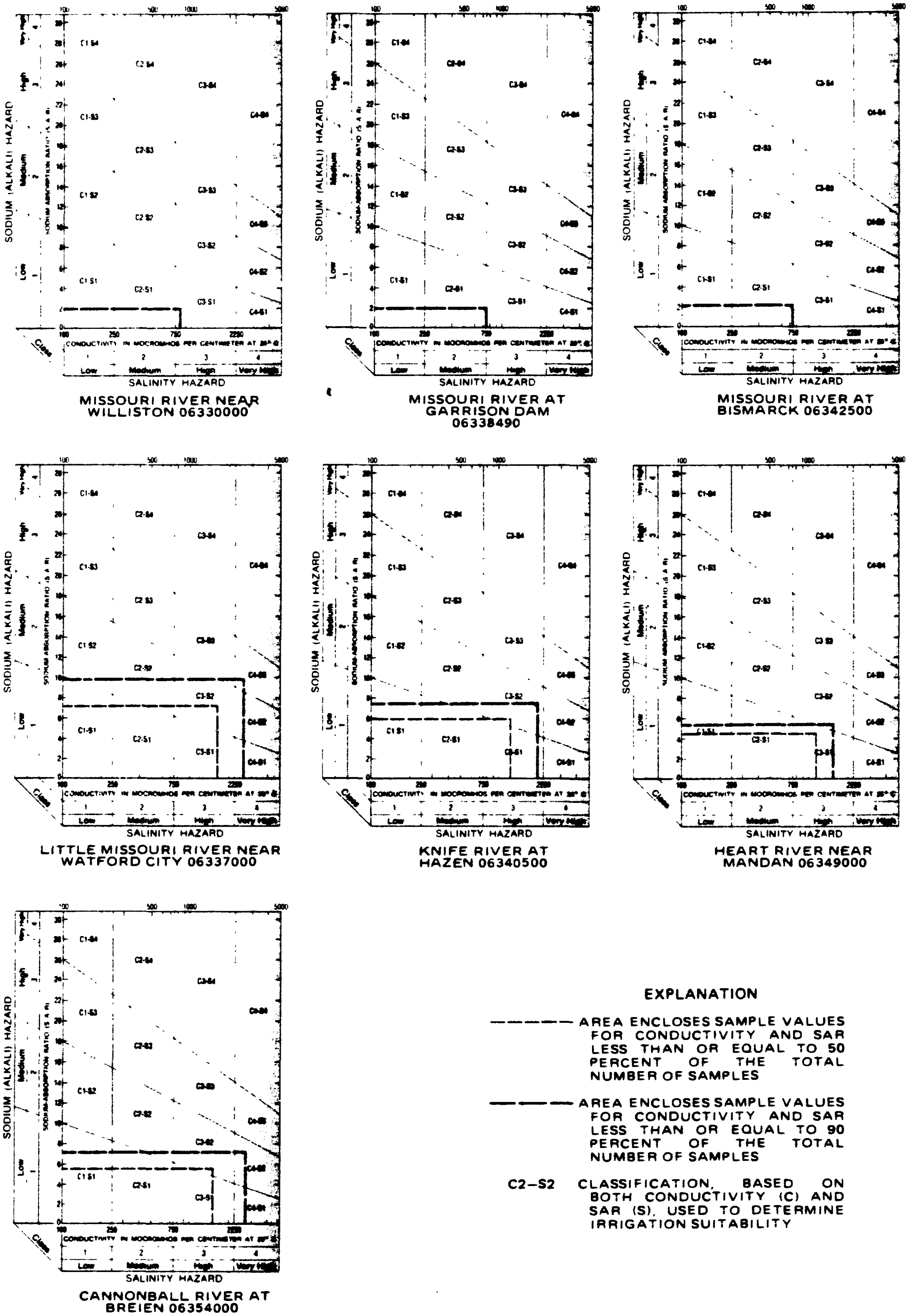


FIGURE 24.—Comparison of irrigation suitability of water at selected stations, Missouri River basin, North Dakota. (Diagram from U.S. Salinity Laboratory Staff, 1954.)

Boron concentrations at 90th-percentile values indicate that water at all stations except the Heart River near Mandan would be safe for crops. This information is of little value for the other three tributaries, however, because the large SAR values previously discussed make this water unsuitable for irrigation.

Sediment

Daily-fluvial-sediment discharge data are available for four of the stations in the Missouri River basin. Annual sediment discharge based on these data are summarized in table 4.

For uncontrolled streams, large quantities of sediment are transported by the streams during high flow, particularly during snowmelt runoff and early summer thunderstorms. More than one-half the sediment transported by a stream during a year may be transported during 1 month in the spring. For example, in April of 1975, more than 6 million tons of sediment were transported past the Little Missouri River near Watford City station. In fact, 842,000 tons were transported past the station in one day, April 29.

The Little Missouri River flows through easily erodeable badland topography of the Fort Union Formation which accounts for the large sediment concentrations during high flow. Although the Heart and Cannonball Rivers also drain areas underlain by the Fort Union Formation, the headwater drainage of these rivers has a fairly resistant topsoil. Therefore, even during high flow, these streams generally transport smaller sediment loads than does the Little Missouri River.

Most sediment from the Missouri and Little Missouri Rivers settles to the bottom of Lake Sakakawea, and the concentration of sediment at the Garrison Dam station is negligible. The sediment load in the Missouri River at Bismarck, therefore, is contributed by tributary inflow between Garrison Dam and Bismarck or is eroded from the channel. Because the streamflow is regulated by releases from Garrison Dam in that reach, sediment concentrations at the Bismarck station tend to remain fairly constant throughout each year. Rarely is more than about one-sixth of the annual sediment load transported past the Bismarck station during any single month.

TABLE 4.--Summary of daily sediment data at four stations, Missouri River basin

Station	Water year	Annual sediment discharge (tons)	Annual sediment yield (tons per square mile)	Maximum monthly sediment discharge (tons)	Maximum monthly sediment discharge (month)
Little Missouri River near Watford City	1972	11,236,200	1,350	3,270,000	March
	1973	3,259,450	392	1,290,000	June
	1974	3,274,050	394	1,906,500	May
	[a]1975	14,125,500	1,700	6,030,000	April
	1976	2,898,720	349	1,827,000	June
Missouri River at Bismarck[b]	1972	14,383,800	2,880	4,140,000	April
	1973	3,942,000	788	592,000	March
	1974	4,380,000	876	533,200	August
	1975	6,606,500	1,320	1,190,400	July
	1976	6,405,000	1,280	705,000	April
	1977	2,346,950	469	372,000	November
	1978	4,416,500	883	573,500	August
	1979	4,343,500	869	886,600	May
	1980	2,522,150	504	387,500	July
	1981	3,062,350	612	384,400	July
Heart River near Mandan[c]	1972	660,000	412	474,300	March
	1974	2,190	1.4	420	April
	1975	646,050	404	414,000	April
	1976	11,315	7.1	5,670	March
Cannonball River at Breien	1972	1,471,320	359	933,100	March
	1973	95,995	23	61,070	March
	1974	25,185	6.1	13,110	April
	1975	905,500	221	492,900	May
	1976	58,560	14	29,310	June

[a]842,000 tons on April 29.
[b]Drainage area used in computing annual sediment yield was only the intervening drainage area downstream from Garrison Dam (5,000 square miles).
[c]Drainage area used in computing annual sediment yield was only the intervening drainage area downstream from Lake Tschida (1,600 square miles).

James River Basin

The James River originates in Wells County in central North Dakota and follows a meandering course east and south for 260 miles to the North Dakota-South Dakota border. Near its headwaters, the channel is poorly defined, consisting of a series of small ponds or sloughs. The drainage area within North Dakota is 5,480 square miles, of which about 3,300 square miles is considered noncontributing. Relief throughout the basin is extremely slight, consisting of low hills, scattered lakes, and low bluffs along the river. The average slope of the James River in North Dakota is 1.2 feet per mile, although the slope in the downstream 85 miles of the State is only 0.35 foot per mile. The channel capacity downstream from Jamestown generally ranges from 1,000 to 2,000 cubic feet per second, although in short, isolated reaches, flows in excess of 200 to 300 cubic feet per second will cause flooding (Missouri River Basin Commission, 1980a). The slow movement of flows, caused by the flat slope and obstructions in the downstream reach, in conjunction with restricted channel capacities, results in occasional prolonged inundation during spring snowmelt.

Two major storage structures (Jamestown Dam on the mainstem and Pipestem Dam on Pipestem Creek) provide about 368,500 acre-feet of total storage for flood control, fish and wildlife, recreation, irrigation, and municipal use (Missouri River Basin Commission, 1980b and U.S. Water and Power Resources Service, 1981). Two National Wildlife Refuges on the mainstem (Arrowwood located upstream from Jamestown Reservoir and Dakota Lake located upstream from the North Dakota-South Dakota border) provide a normal storage of about 32,000 acre-feet for waterfowl propogation (Missouri River Basin Commission, 1980b). Numerous other small dams have been constructed to impound water for recreation, small-scale irrigation, stock watering, and other uses.

Streamflow Statistics

Flow statistics for five gaging stations within the James River basin are included in table 4a:

TABLE 4a.--Daily streamflow statistics for five gaging stations within the James River basin, North Dakota

Station number	Station name	Drainage area (square miles)		Period of record (water years)	Daily discharge				
		Total	Contributing		Mean	Median	Maximum	Minimum	10-percentile value
06468500	James River near Pingree	1,670	680	1954-63	17.1	0.02	1,400	0	0
06469400	Pipestem Creek near Pingree	700	260	1974-83	27.9	.27	2,200	0	0
06469500	Pipestem Creek near Buchanan	758	298	1951-74	19.5	1.1	4,620	0	0
06470000	James River at Jamestown	2,820	1,170	1929-34, 1938-39, 1944-53	68.9	2.4	6,170	0	.82
06470000	James River at Jamestown	2,820	1,170	1954-83	60.8	9	5,280	0	2.4
06470500	James River at LaMoure	4,390	1,790	1951-83	97.5	23	6,420	0	7.2

Data for two stations on Pipestem Creek are presented because the station near Buchanan was relocated to near Pingree in 1973 due to the construction of Pipestem Dam. The record for the James River at Jamestown is split to reflect the construction of Jamestown Dam in 1953.

Streamflow in the James River and its tributaries in North Dakota is highly variable. Comparison of the statistics for the Pipestem Creek stations would indicate the expected effects of regulation by Pipestem Dam, although the differences also may be affected by the differing periods of record. Comparison of the statistics for the two periods of record for the James River at Jamestown indicates the effects of regulation by Jamestown Dam, although the differences in the median and 10-percentile flows are not as great as might be expected. Again, the differing periods of record could be affecting these comparisons. Zero flow occurs in the James River near Pingree and the Pipestem Creek stations for at least 10 percent of the time. Comparison of the statistics for the Jamestown and LaMoure stations indicates significant increases in the median and 10-percentile flows. The contributing drainage area between these two stations increases by about 620 square miles.

Monthly streamflow data are presented in fig 25. The bar graphs illustrate that the stream may go dry, or near dry, during any month of the year at all stations. The bar graphs also indicate that a large percentage of the annual runoff in the basin results from snowmelt. Although mean daily streamflow in the lower basin is substantial (greater than 60 cubic feet per second at Jamestown and almost 100 cubic feet per second at LaMoure), the temporal distribution illustrated in fig. 25 indicates that storage is necessary to provide a dependable year-round supply.

Flooding

Flooding along the James River usually results from spring snowmelt and these floods may be amplified by spring rains. Flooding in the summer months is the result of intense thunderstorms. Spring floods generally are much more severe than summer floods.

Flooding along the James River usually is caused by a relatively rapid accumulation of runoff from the tributaries, resulting in tributary inflows that may exceed the main-stem channel capacity. The steeper slopes of the tributaries result in floods that are characterized by high discharges of relatively short duration. However, because of the flatter slope of the mainstem, the floods of the James River, except for a few miles downstream of the major tributaries, are characterized by slow rises and prolonged recession periods.

Major floods occurred along the James River in North Dakota in 1950 and 1969. At Jamestown, the maximum recorded instantaneous peak discharge is 6,390 cubic feet per second and occurred on May 13, 1950. An instantaneous peak of 6,330 cubic feet per second was recorded on April 11, 1969. These peaks represent the maximum recorded discharges before and after construction of Jamestown Dam. At LaMoure, the maximum recorded instantaneous peak

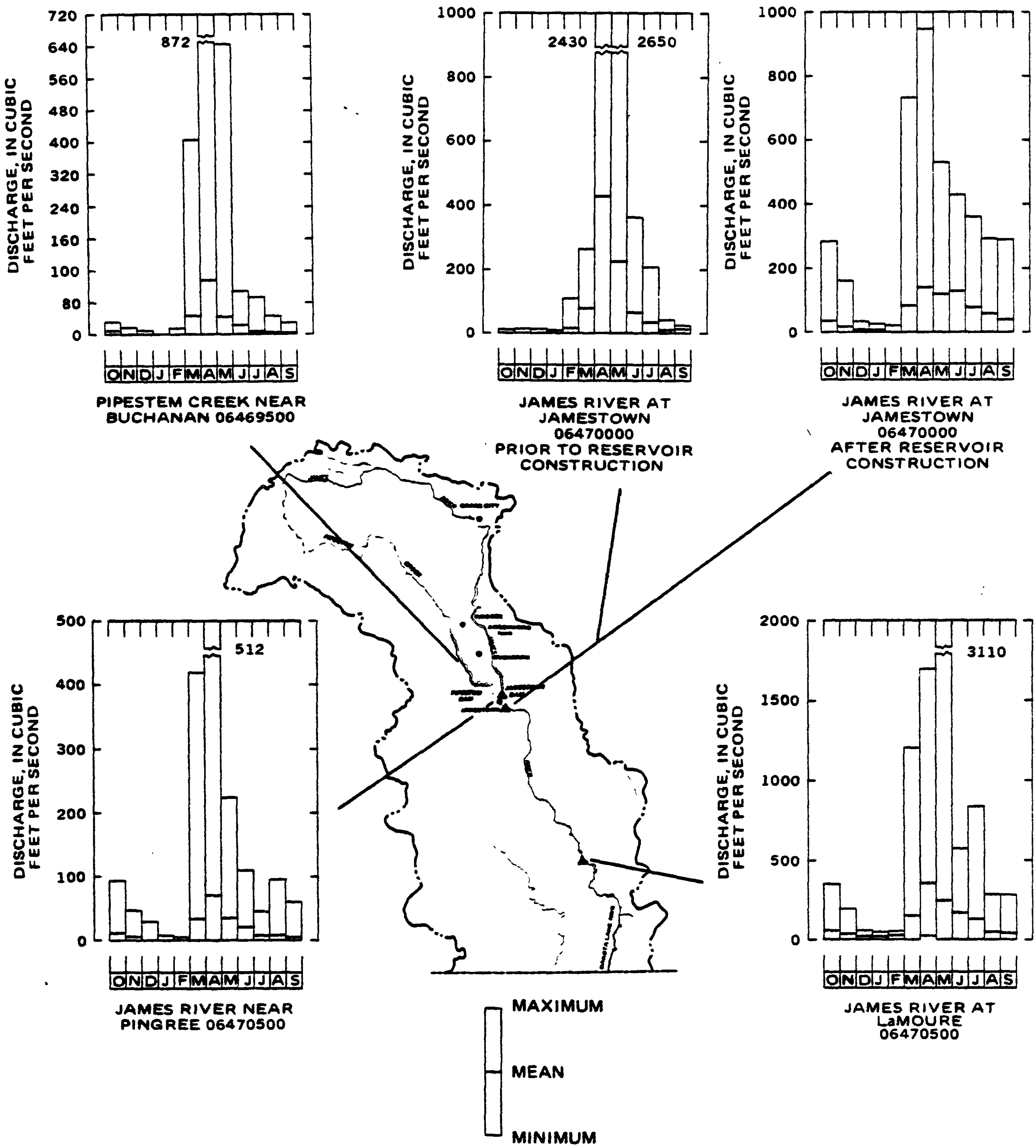


FIGURE 25.—Monthly discharge for period of record at selected gaging stations, James River basin, North Dakota.

discharge is 6,800 cubic feet per second and occurred on April 14, 1969. In 1950, the peak was 5,730 cubic feet per second on May 16. Lesser floods that occurred along the downstream reach of the river in 1972, 1975, and 1978 are reflected in the discharge records for the James River at LaMoure.

Quality of Water

Chemical composition and variation.--The James River throughout most of its North Dakota reach flows in a glacial-drift prairie, and the quality of water in the James River generally is controlled by the chemical composition of the glacial drift. Runoff from snowmelt or thunderstorms contacts soils and subsoils developed on the glacial drift and dissolves the material that ultimately determines the chemical composition of water in the James River. The glacial drift contains large quantities of carbonate minerals and, in the water in the James River, bicarbonate is the predominant anion. In the reach upstream from Jamestown Reservoir, sodium is the predominant cation. Downstream from Jamestown Reservoir, calcium becomes nearly equal in occurrence with sodium, and magnesium occurs in significant concentrations.

Descriptive statistics and duration tables for specific conductance, seven principal chemical constituents, and dissolved solids, in water at three stations on the James River are given in table 5. Explanation of information presented in the duration tables is in the section on water quality in the Missouri River basin. These data are based on the following periods of record:

Station	Period of record
James River near Grace City ----------	1972-83
James River at Jamestown -------------	1950-51, 1958-65, 1972-83
James River at LaMoure ---------------	1957-83

Water quality varies with water discharge in the James River. Most of the flow in the James River occurs during March and April when the winter snowpack melts and during the early summer when thunderstorms occasionally produce large quantities of rain in the basin. At other times of the year, the James River may be dry upstream from Jamestown Reservoir. Small releases from the reservoir maintain low flow during these periods downstream from the reservoir. Period-of-record mean dissolved-solids concentrations for highflows and lowflows at three stations on the James River are compared in figure 26. The high-flow means increase slightly in a downstream direction, whereas the low-flow mean near Grace City is greater than the means for the two stations downstream from Jamestown Reservoir. This indicates that, for most of the year, the reservoir provides some limited stabilization of water quality downstream.

Concentrations of five principal constituents in water at three stations are compared in figure 27. These plots show maximum and minimum, mean and

TABLE 5.--SUMMARY OF WATER-QUALITY DATA, JAMES RIVER BASIN
[UMHOS, MICROMHOS PER CENTIMETER AT 25° CELSIUS; MG/L, MILLIGRAMS PER LITER]

STATION NUMBER: 06468170 STATION NAME AND LOCATION: JAMES RIVER NR GRACE CITY, ND

DRAINAGE AREA: 1060 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
	SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS									
SPECIFIC CONDUCTANCE (UMHOS)	122	2440.00	130.00	939.98	525.01	1757.00	1300.00	830.00	510.00	303.00
BICARBONATE FET-FLD (MG/L AS HCO3)	17	526.00	85.00	265.24	143.25	476.40	399.00	252.00	120.50	97.00
CALCIUM DISSOLVED (MG/L AS CA)	22	53.00	13.00	33.05	12.03	50.00	41.50	34.50	21.50	15.60
MAGNESIUM, DISSOLVED (MG/L AS MG)	22	45.00	8.90	26.09	11.48	41.00	36.75	23.50	17.50	9.46
SODIUM, DISSOLVED (MG/L AS NA)	22	310.00	11.00	88.68	84.28	257.00	112.50	67.00	29.50	15.10
POTASSIUM, DISSOLVED (MG/L AS K)	22	24.00	5.40	10.75	4.64	17.70	12.75	9.50	7.15	5.63
CHLORIDE, DISSOLVED (MG/L AS CL)	22	110.00	0.30	24.72	30.33	90.60	29.25	16.50	6.05	2.04
SULFATE DISSOLVED (MG/L AS SO4)	22	270.00	35.00	112.64	68.36	231.00	160.00	104.00	56.25	36.20
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	22	1000.00	130.00	458.18	256.60	919.00	582.50	450.00	245.00	163.00

STATION NUMBER: 06470000 STATION NAME AND LOCATION: JAMES RIVER AT JAMESTOWN, ND

DRAINAGE AREA: 2820 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
	SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS									
SPECIFIC CONDUCTANCE (UMHOS)	210	1590.00	111.00	833.41	323.12	1250.00	1100.00	805.00	580.00	430.60
BICARBONATE FET-FLD (MG/L AS HCO3)	86	600.00	38.00	336.48	131.46	484.30	441.50	353.00	246.00	129.80
CALCIUM DISSOLVED (MG/L AS CA)	87	118.00	9.50	62.67	25.61	99.20	83.00	59.00	42.00	29.00
MAGNESIUM, DISSOLVED (MG/L AS MG)	88	48.00	3.00	27.87	10.34	40.00	35.75	29.00	21.25	11.90
SODIUM, DISSOLVED (MG/L AS NA)	74	200.00	2.70	82.68	49.76	154.00	116.50	77.00	45.00	16.50
POTASSIUM, DISSOLVED (MG/L AS K)	72	18.00	5.30	9.43	2.77	14.00	11.00	8.90	7.63	6.20
CHLORIDE, DISSOLVED (MG/L AS CL)	88	155.00	0.00	33.38	25.96	62.10	47.75	30.00	13.00	6.09
SULFATE DISSOLVED (MG/L AS SO4)	88	372.00	13.00	146.13	73.91	253.20	199.25	136.00	90.25	55.90
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	74	1010.00	58.00	530.78	238.82	890.00	705.00	510.00	345.00	200.00

STATION NUMBER: 06470500 STATION NAME AND LOCATION: JAMES RIVER AT LAMOURE, ND

DRAINAGE AREA: 4390 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
	SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS									
SPECIFIC CONDUCTANCE (UMHOS)	241	1720.00	2.20	839.85	356.65	1276.00	1080.00	800.00	600.00	344.00
BICARBONATE FET-FLD (MG/L AS HCO3)	125	721.00	65.00	339.06	140.85	552.80	407.00	336.00	270.00	128.20
CALCIUM DISSOLVED (MG/L AS CA)	179	160.00	15.00	67.44	30.13	115.00	79.00	63.00	46.00	32.00
MAGNESIUM, DISSOLVED (MG/L AS MG)	179	68.00	5.50	31.28	12.96	49.00	40.00	31.00	23.00	14.00
SODIUM, DISSOLVED (MG/L AS NA)	180	260.00	7.90	78.99	42.20	132.90	107.25	76.00	46.25	25.20
POTASSIUM, DISSOLVED (MG/L AS K)	179	17.00	4.90	10.89	2.19	14.00	12.00	11.00	9.60	8.30
CHLORIDE, DISSOLVED (MG/L AS CL)	180	196.00	0.10	35.61	26.47	59.00	49.75	31.00	16.00	8.40
SULFATE DISSOLVED (MG/L AS SO4)	180	360.00	0.00	149.14	72.32	263.60	190.00	143.50	98.25	62.10
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	180	1200.00	110.00	554.13	242.74	890.00	697.50	542.00	382.50	252.00

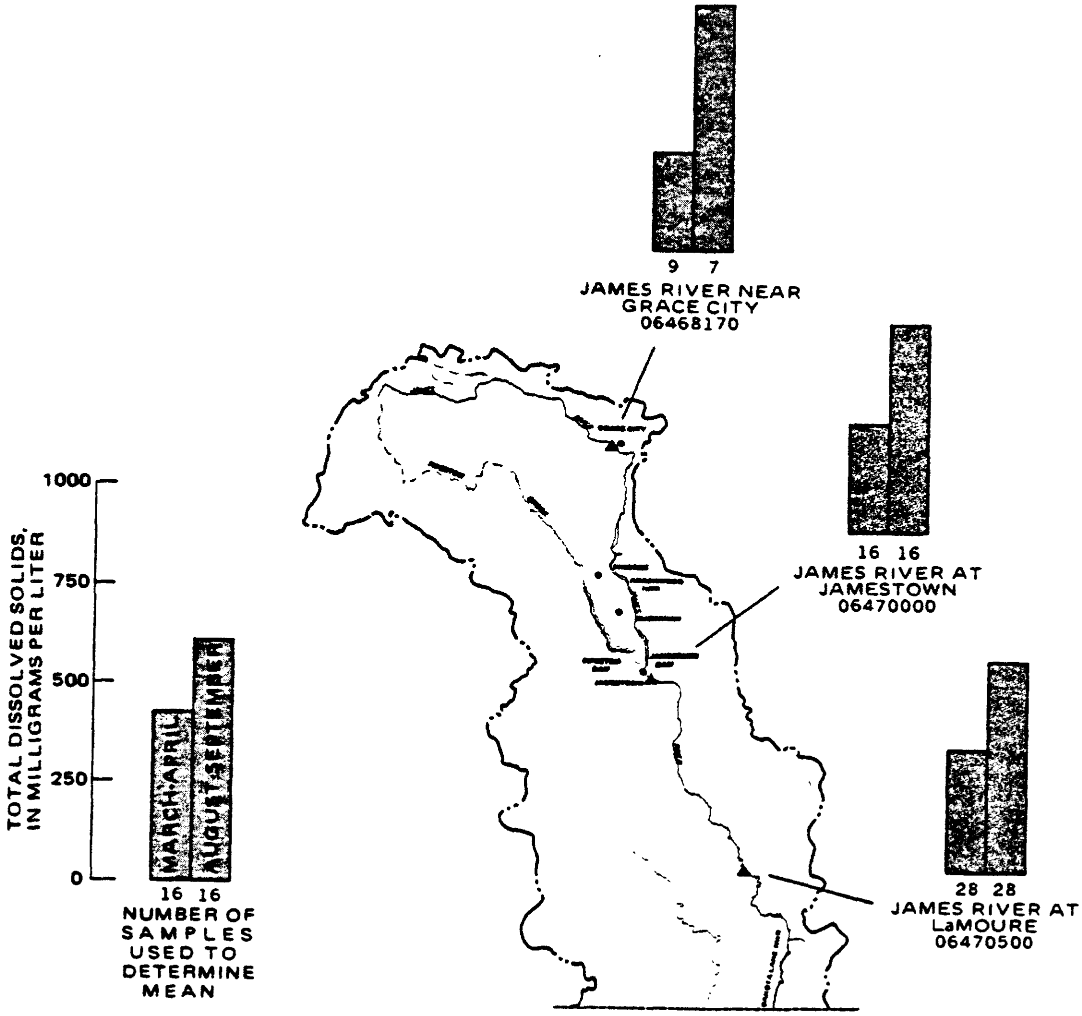


FIGURE 26.—Period-of-record mean dissolved-solids concentrations for high flows (March-April) and low flows (August-September) at selected stations, James River basin, North Dakota.

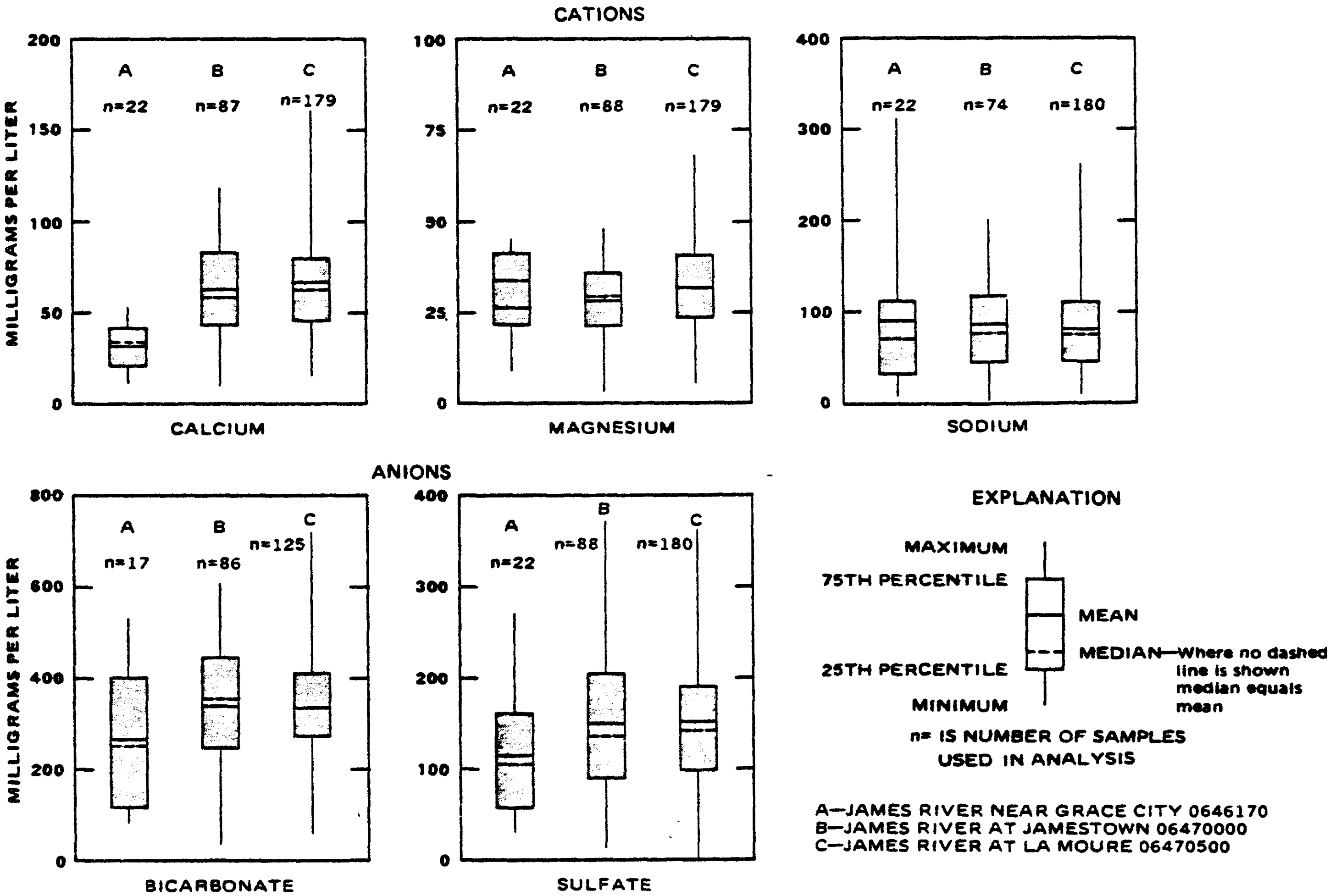


FIGURE 27.—Statistical comparisons of concentrations of principal cations and anions at selected stations, James River basin, North Dakota.

median (50th percentile), and 75th and 25th percentiles in downstream order, left to right. Variations from station to station for any of these statistics are apparent. For example, mean calcium concentrations double from Grace City to LaMoure, whereas mean sodium concentrations decrease slightly. Small variations also may be related to the differing periods of record for the stations.

No trend information is available for individual stations in the James River basin.

Suitability for use.--Water in the James River, based on chemical composition, appears to be generally suitable for domestic use although data confirming this are somewhat limited. No information is available for nitrate-nitrogen, but limited sources of nutrients in the basin indicate that nitrate-nitrogen is not a problem. Few data are available for those trace constituents for which Federal drinking-water standards exist (table 6). Mercury concentrations exceeded the Federal standard in one of four samples collected from the James River at Jamestown, and the maximum selenium value among 8 samples from the James River at LaMoure exceeded the Federal standard of 10 micrograms per liter.

Water from the James River may only be suitable for irrigation if used with caution. The diagrams in figure 28 indicate the ranges of specific conductance and sodium-adsorption ratio (SAR) at 90th-percentile concentrations.

Boron concentrations at all stations for the 90th percentile are less than the irrigation use criterion of 750 micrograms per liter indicating that, if water from the James River is used for irrigation, boron concentrations should not be toxic to crops.

Sediment

Little information is available on fluvial sediment for the James River. Because of the slight slopes in the basin and the relatively flat gradient of the stream downstream from Jamestown Reservoir, the stream transports relatively small quantities of sediment.

Red River of the North basin

The Red River basin is a part of the Hudson Bay drainage system and includes parts of North Dakota, South Dakota, and Minnesota in the United States, and parts of the Provinces of Ontario, Saskatchewan, and Manitoba in Canada. Of the total drainage area of 39,200 square miles in the United States at the international boundary, 20,820 square miles is in North Dakota, 570 square miles is in South Dakota, and 17,810 square miles is in Minnesota (Souris-Red-Rainy River Basins Commission, 1972, p. D-37). This includes 3,800 square miles of the closed Devils Lake basin.

The Ottertail and Bois de Sioux Rivers combine at Wahpeton, North Dakota, and Breckenridge, Minn., to form the Red River. The river flows northward

TABLE 6.--SUMMARY OF TRACE CONSTITUENT DATA, JAMES RIVER BASIN
[UG/L, MICROGRAMS PER LITER]

STATION NUMBER: 06468170 STATION NAME AND LOCATION: JAMES RIVER NR GRACE CITY, ND

DRAINAGE AREA: 1060 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
ARSENIC DISSOLVED (UG/L AS AS)	4	8.00	2.00							
BORON, DISSOLVED (UG/L AS B)	22	320.00	0.00	138.18	97.43	304.00	210.00	135.00	62.50	0.00
IRON, DISSOLVED (UG/L AS FE)	22	330.00	0.00	98.64	92.24	258.00	165.00	55.00	20.00	13.00
LEAD, DISSOLVED (UG/L AS PB)	4	3.00	0.00							
MANGANESE, DISSOLVED (UG/L AS MN)	22	190.00	10.00	50.45	47.05	139.00	62.50	40.00	10.00	10.00
SELENIUM, DISSOLVED (UG/L AS SE)	4	0.00	0.00							
MERCURY DISSOLVED (UG/L AS HG)	4	0.50	0.20							

STATION NUMBER: 06470000 STATION NAME AND LOCATION: JAMES RIVER AT JAMESTOWN, ND

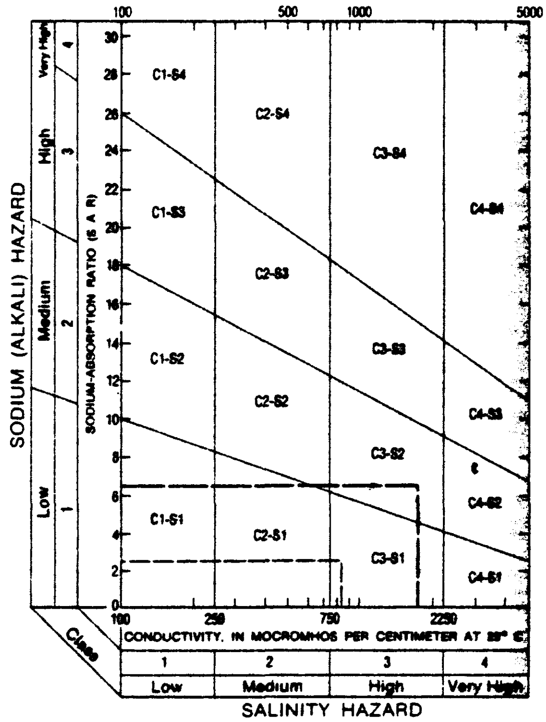
DRAINAGE AREA: 2820 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
ARSENIC DISSOLVED (UG/L AS AS)	4	4.00	0.00							
BORON, DISSOLVED (UG/L AS B)	79	1000.00	0.00	296.71	216.33	550.00	440.00	240.00	110.00	40.00
CHROMIUM, DISSOLVED (UG/L AS CR)	1	0.00	0.00							
IRON, DISSOLVED (UG/L AS FE)	24	480.00	0.00	98.33	123.94	330.00	135.00	50.00	20.00	10.00
LEAD, DISSOLVED (UG/L AS PB)	4	0.00	0.00							
MANGANESE, DISSOLVED (UG/L AS MN)	24	1500.00	0.00	476.25	424.09	1350.00	700.00	335.00	177.50	50.00
SELENIUM, DISSOLVED (UG/L AS SE)	4	0.00	0.00							
MERCURY DISSOLVED (UG/L AS HG)	4	5.00	0.20							

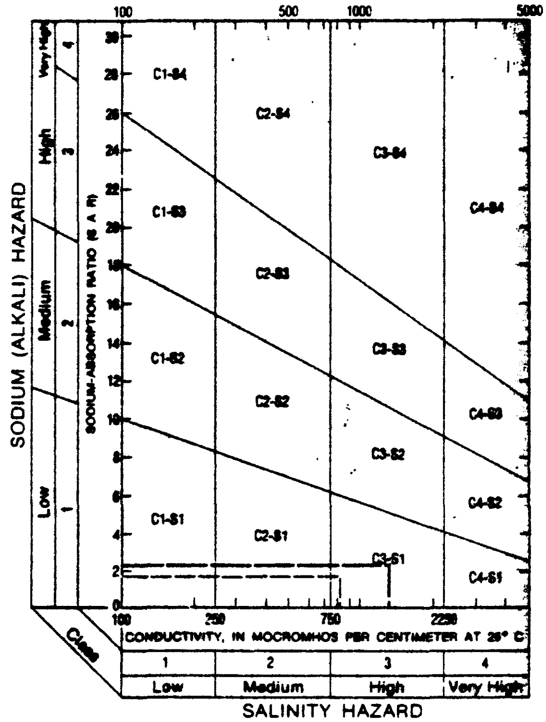
STATION NUMBER: 06470500 STATION NAME AND LOCATION: JAMES RIVER AT LAMOURE, ND

DRAINAGE AREA: 4390 SQUARE MILES

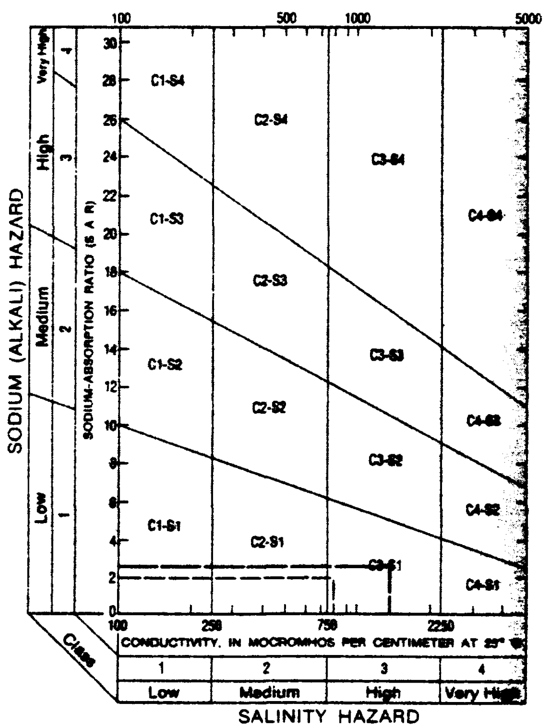
WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
ARSENIC DISSOLVED (UG/L AS AS)	9	4.00	0.00							
BARIUM, DISSOLVED (UG/L AS BA)	9	500.00	0.00							
BORON, DISSOLVED (UG/L AS B)	180	2600.00	10.00	259.58	222.44	440.00	350.00	230.00	140.00	90.00
CADMIUM DISSOLVED (UG/L AS CD)	9	2.00	0.00							
CHROMIUM, DISSOLVED (UG/L AS CR)	9	20.00	0.00							
COPPER, DISSOLVED (UG/L AS CU)	10	30.00	0.00	7.00	12.16	30.00	9.00	2.00	0.00	0.00
IRON, DISSOLVED (UG/L AS FE)	40	570.00	0.00	69.12	102.80	169.00	80.00	35.00	20.00	10.00
LEAD, DISSOLVED (UG/L AS PB)	8	2.00	0.00							
MANGANESE, DISSOLVED (UG/L AS MN)	37	1600.00	30.00	387.62	366.40	1012.00	555.00	310.00	120.00	40.00
SILVER, DISSOLVED (UG/L AS AG)	2	0.00	0.00							
ZINC, DISSOLVED (UG/L AS ZN)	11	200.00	0.00	28.55	58.20	168.00	20.00	10.00	0.00	0.00
SELENIUM, DISSOLVED (UG/L AS SE)	8	18.00	1.00							
MERCURY DISSOLVED (UG/L AS HG)	7	0.50	0.00							



JAMES RIVER NEAR GRACE CITY 06468170



JAMES RIVER AT JAMESTOWN 06470000



JAMES RIVER AT LaMOURE 06470500

EXPLANATION

– – – – – AREA ENCLOSES SAMPLE VALUES FOR CONDUCTIVITY AND SAR LESS THAN OR EQUAL TO 50 PERCENT OF THE TOTAL NUMBER OF SAMPLES

——— AREA ENCLOSES SAMPLE VALUES FOR CONDUCTIVITY AND SAR LESS THAN OR EQUAL TO 90 PERCENT OF THE TOTAL NUMBER OF SAMPLES

C2–S2 CLASSIFICATION, BASED ON BOTH CONDUCTIVITY (C) AND SAR (S), USED TO DETERMINE IRRIGATION SUITABILITY

FIGURE 28.—Comparison of irrigation suitability of water at selected stations, James River basin, North Dakota. (Diagram from U.S. Salinity Laboratory Staff, 1954.)

394 miles to the United States-Canadian boundary, forming the North Dakota-Minnesota boundary. The river follows a meandering course through the broad, very flat bed of glacial Lake Agassiz, called the Red River valley. About one-half of the basin consists of the extremely flat lake plain that slopes northward at an average of about 0.4 foot per mile, and the other one-half of the basin consists of an upland area with greater local relief. The principal tributaries on the North Dakota side of the basin are the Wild Rice, Sheyenne, Goose, and Pembina Rivers.

The communities of Wahpeton, Fargo, Grand Forks, and Pembina, as well as large tracts of agricultural land, are subject to flood damage by the Red River. Although there are no reservoirs for flood control on the mainstem, there are several reservoirs of considerable capacity on the tributaries.

General Description of Major Tributaries

Wild Rice River.--The Wild Rice River originates in the south-central part of Sargent County. Stream slopes of the different reaches of the Wild Rice River vary from about 4 feet per mile upstream from Lake Tewaukon to about 0.8 foot per mile near the mouth. The drainage area of Wild Rice River basin is 2,230 square miles of which 2,020 square miles is in North Dakota. The flow of the Wild Rice River is used primarily for stock watering, fish and wildlife propagation, irrigation, and recreation. There is some regulation of flow, with Lake Tewaukon (usable capacity 7,200 acre-feet) having the greatest effect. There is very little control of major floods that can cause extensive damage to agricultural areas.

Sheyenne River.--The Sheyenne River originates in northwestern Sheridan County and flows eastward to Nelson County, then southward to south-central Ramsey County, and then loops to flow northeastward to its confluence with the Red River north of Fargo. The river is about 550 miles long, with an average slope of about 1.5 feet per mile on the drift prairie, about 2 feet per mile as it enters the Red River valley, and about 1 foot per mile on the valley floor. The drainage area of the Sheyenne River basin is 6,910 square miles (not including the closed Devils Lake basin). The only major impoundment in the Sheyenne River basin is Lake Ashtabula (normal full-pool capacity 70,700 acre-feet) formed by Baldhill Dam. The lake stores floodwater (flood capacity 116,500 acre-feet) for flood control, municipal supplies, stream-pollution abatement, and recreation. The major cities that can be flooded are Valley City, Lisbon, West Fargo, Enderlin, and Amenia. Large areas of agricultural land within the Sheyenne River drainage in the Red River Valley also sustain considerable flood damage.

Goose River.--The Goose River originates in eastern Nelson County and flows southeasterly, then easterly, about 150 miles to its confluence with the Red River. The average slope is 3.7 feet per mile, and the drainage area is 1,280 square miles. The principal uses of water from the river are stock watering, fish and wildlife propagation, irrigation, recreation, and municipal supplies. The major cities that can be flooded are Mayville and Hillsboro.

Pembina River.--The Pembina River originates in the northern part of the Turtle Mountains in Manitoba, Canada. The river approximately parallels the international boundary until it enters North Dakota east of Maida in Cavalier County. From there, the river flows easterly to its confluence with the Red River at Pembina. The slopes of the Turtle Mountains and Pembina Escarpment are relatively steep, but the average slope of the river through the Red River Valley is only about 1.6 feet per mile. The drainage area of the Pembina River is 3,950 square miles of which 1,960 square miles is in North Dakota. The principal uses of water from the river are for stock watering, municipal supply, and recreation. The major communities that can be flooded are Walhalla, Neche, and Pembina. There are no flood-control structures on the mainstem, but several flood-retarding structures have been constructed on the Tongue River, a tributary.

Streamflow Statistics

Flow statistics for gaging stations within the Red River basin and its major tributaries in North Dakota are included in table 6a:

TABLE 6a.--Daily streamflow statistics for the Red River of the North and major tributaries, North Dakota

Station number	Station name	Drainage area (square miles)		Period of record (water years)	Daily discharge (cubic feet per second)				
		Total	Contributing		Mean	Median	Maximum	Minimum	10-percentile value
05051500	Red River at Wahpeton	4,010	--	1943-83	519	334	8,940	1.7	102
05053000	Wild Rice River near Abercrombie	2,080	1,490	1933-83	72	1.5	9,360	0	0
05054000	Red River at Fargo	6,800	--	1902-83	552	281	24,800	0	32.9
05057000	Sheyenne River near Cooperstown	a/2,670	a/1,270	1945-82	104	20	5,130	0	3.7
05059000	Sheyenne River near Kindred	a/5,000	a/3,020	1950-82	196	73.2	4,600	13	33.9
05066500	Goose River at Hillsboro	1,203	1,193	1932-83	68.5	4.3	14,400	0	.1
05082500	Red River at Grand Forks	a/26,300	--	1883-1982	2,513	1,240	80,900	1.8	240
05100000	Pembina River at Neche	3,410	--	1904-08, 1910-15, 1920-83	192	39.7	9,950	0	1.6
05102500	Red River at Emerson	a/36,400	--	1930-83	3,313	1,340	94,400	.9	239

a/Does not include the closed basin of Devils Lake.

Streamflow is quite variable on a yearly basis as well as seasonally during each year. The relatively large difference between the mean daily discharge and the median daily discharge indicates that the mean discharge is significantly affected by relatively few high-flow days.

Flow in the Red River at Wahpeton is regulated by Orwell Reservoir, capacity 14,100 acre-feet, located 42 miles upstream from the mouth of the Ottertail River; Lake Traverse, capacity 137,000 acre-feet, located 28 miles upstream from the mouth of the Bois de Sioux River; and numerous other controlled lakes and ponds. The streamflow statistics for the Wahpeton station are somewhat reflective of this regulation. Whereas the mean and maximum daily discharge statistics for the Red River at Fargo indicate an increase in flows during high flow from Wahpeton to Fargo, the stream statistics of median, minimum, and 10-percentile values indicate a decrease in flow during low flow. These decreases can be attributed to diversions and natural losses. The Red River at Fargo station is the only station on the mainstem at which zero flow has been recorded. The minimum flow recorded at the Red River at Grand Forks station was caused by unusual regulation during the repair of a low dam at Grand Forks. The Red River from Fargo to Emerson is a gaining stream, with most of the gain obtained between Fargo and Grand Forks where the increase in contributing drainage area is 19,500 square miles.

Zero flow has been recorded at all streamflow stations on the North Dakota tributaries of the Red River except the Sheyenne River near Kindred station. The Sheyenne River is sustained almost wholly by rainfall runoff and snowmelt runoff except for a 70-mile reach just upstream from Kindred where the river flows through the Sheyenne delta. The Sheyenne delta (fig. 5) is a sand deposit from which 28.8 cubic feet per second of ground-water discharge has been measured (Paulson, 1964, p. D181). Since 1949, when Lake Ashtabula was created by the completion of Baldhill Dam, the flow of the river downstream from the dam has been regulated by the releases from the lake.

The monthly maximum, mean, and minimum flows for selected streamflow stations in the Red River basin are shown in fig. 29. The bar graphs illustrate the monthly distribution of flows, with most of the runoff occurring during the spring. The minimum flows for the mainstem and tributaries are not large enough for a reliable supply for any major use unless storage is provided.

Flooding

The flood response of the the Red River basin has been analyzed by Miller and Frink (1984). They point out that large numbers of floods at fairly frequent intervals were reported prior to 1900. The 1897 flood (peak instantaneous discharge of 85,000 cubic feet per second at Grand Forks) was larger than any flood that has occurred since then. Floods of the same magnitude as those prior to 1900 did not occur again until recent years (since the 1950s). These recent floods have caused concern that land-use changes and man-made drainage have increased flooding. However, little indication of significant change in flood response of the basin can be identified. A change in response is difficult to identify because the flooding problem of the Red River basin is complex hydrologically, highly variable historically and follows a regional pattern.

The flooding problems of the Red River mainstem are particularly severe because of the large area that is inundated when the Red River overflows its banks. Unlike most river valleys the Red River valley was not shaped by the stream that presently drains and erodes its surface. Its shape is, instead, almost entirely the product of glacial Lake Agassiz. Therefore, the floodplain is poorly defined and extends without easily recognizable relief across the lakebed. During high water the inundated area along the Red River is often several miles wide.

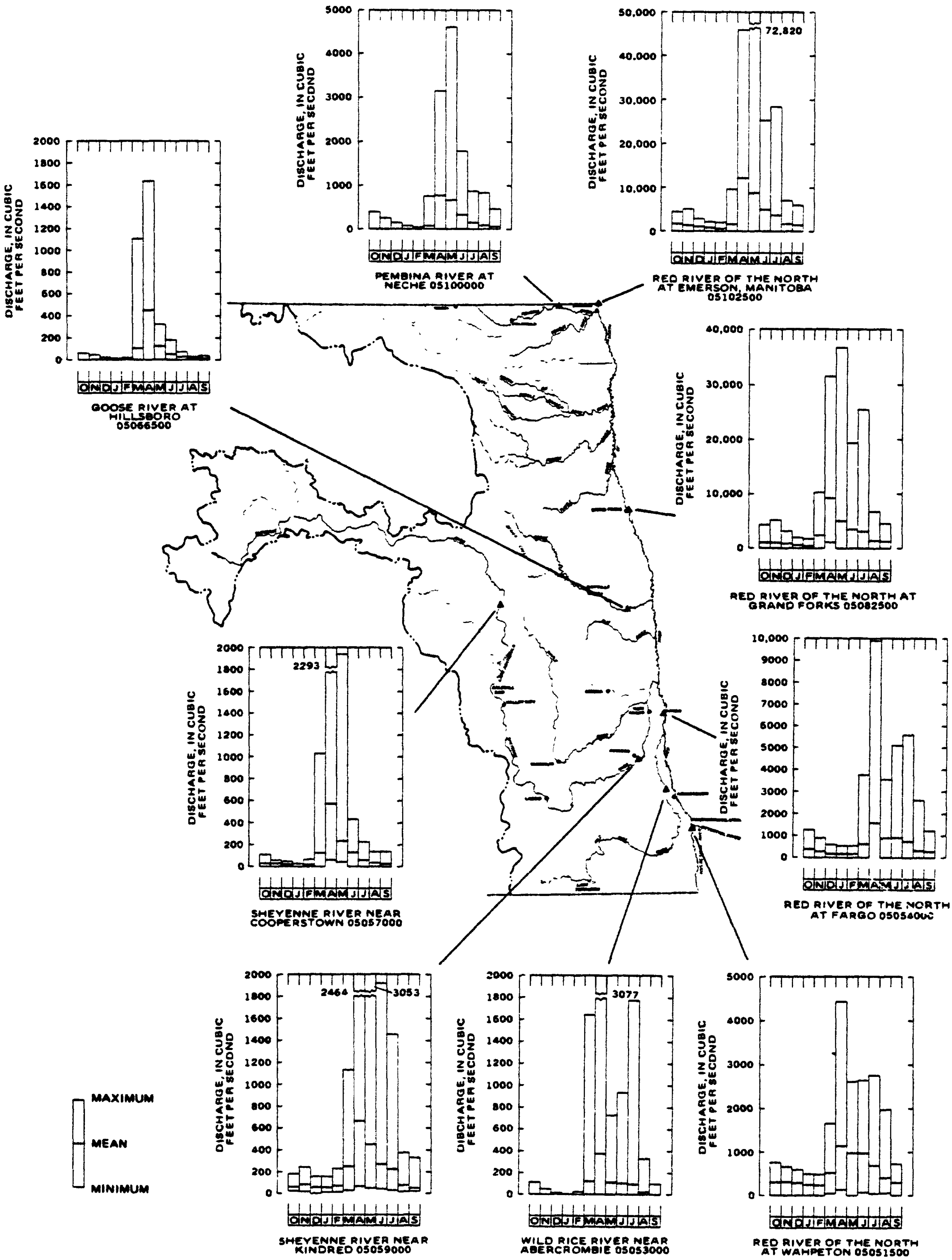


FIGURE 29.—Monthly discharge for period of record at selected gaging stations, Red River basin North Dakota.

The instantaneous peak discharges and the date of occurrence that have been recorded at the mainstem and tributary stations are included in the table below:

Station	Date	Instantaneous Peak Discharge (cubic feet per second)
Red River at Wahpeton	April 1969	9,200
Wild Rice River near Abercrombie	April 1969	9,540
Red River at Fargo	April 1969	25,300
Sheyenne River near Cooperstown	April 1950	7,830
Sheyenne River near Kindred	April 1969	4,690
Goose River at Hillsboro	April 1979	14,800
Red River at Grand Forks	April 1897	85,000
Pembina River at Neche	April 1950	10,700
Red River at Emerson	May 1950	95,500

Quality of Water

Chemical composition and variation.--The Red River flows over lacustrine deposits of glacial Lake Agassiz through its entire length in North Dakota. Water quality in the Red River is affected by these deposits and by inflow from major tributaries from both North Dakota and Minnesota. Because precipitation is greater in eastern North Dakota than in western North Dakota, much of the soluble material has been leached from source deposits. Therefore, concentrations of material available to dissolve into the river are small, with the result that the Red River is the least mineralized of the major rivers in North Dakota. Mean dissolved-solids concentrations range from 347 milligrams per liter at the upstream station at Hickson to 406 milligrams per liter at the international boundary near Emerson, Manitoba. Throughout this reach, calcium and magnesium are the principal cations and bicarbonate is the principal anion. This indicates that source material in the lacustrine deposits in the valley, in the glacial-drift deposits in the headwater drainage, and in soils in both areas contains soluble carbonate material (dolomite and calcite).

Water is more highly mineralized in principal tributaries originating in North Dakota than in the Red River. Mean dissolved-solids concentrations are 957 milligrams per liter in water from the Wild Rice River near Abercrombie; 561 and 508 milligrams per liter, respectively, in water near Cooperstown and near Kindred on the Sheyenne River; 1,036 milligrams per liter in water from the Goose River near Hillsboro; and 433 milligrams per liter in water from the Pembina River at Neche. Calcium is the principal cation in water from the Pembina River, whereas calcium, magnesium, and sodium in varying ratios are all important cations in water from the other tributaries. Bicarbonate is the principal anion in water from the Sheyenne River, whereas bicarbonate and sulfate are the principal anions in water from the other three streams. This indicates that calcite, dolomite, gypsum and mirabilite-derived material probably controlled by solubilities rather than ratios of occurrence in the soils and drift are sources for the principal ions in the major North Dakota tributaries. Sulfate also may dissolve from Cretaceous bedrock which crops out in downstream areas of most Red River tributaries originating in North Dakota.

Descriptive statistics and duration tables for specific conductance, seven principal chemical constituents and dissolved solids in water at four Red River main-stem stations and at five stations on major tributaries originating in North Dakota are given in table 7. Explanation of information presented in the duration tables is in the section on water quality in the Missouri River basin. These data are based on the following periods of record:

Station	Period of record
Red River at Hickson	1976-1983
Wild Rice River near Abercrombie	1967-1983
Red River below Fargo	1969-1983
Sheyenne River near Cooperstown	1960-1983
Sheyenne River near Kindred	1972-1983
Goose River at Hillsboro	1969-1983
Red River at Grand Forks	1949, 1956-1983
Pembina River at Neche	1972-1983
Red River at Emerson, Manitoba	1978-1983

Dissolved-solids concentrations in streamflow in the Red River basin are least during high flows and greatest during low flows. Period-of-record mean dissolved-solids concentrations for high flows (snowmelt in March-April) are compared with those for low flows (August-September) for 9 stations on the Red River and its major North Dakota tributaries in figure 30. Concentrations of dissolved solids in the Sheyenne River are affected by Lake Ashtabula, which is located between the Cooperstown and Kindred stations. The lake, which regulates flow in the Sheyenne River, also reduces variation in dissolved-solids concentrations downstream. The difference between the mean low-flow and mean high-flow dissolved-solids concentrations at the Kindred station, therefore, is much smaller than the respective difference at the Cooperstown station. Water quality at the Kindred station also is affected by base flow from Sheyenne River delta deposits upstream from the station.

Concentrations of five principal constituents in water at four Red River main-stem stations are compared in figure 31. Concentrations of the same constituents in water at five tributary stations are compared in figure 32. These diagrams contain a combination of descriptive statistics and percentile data for each constituent in downstream order from left to right. Variations in any of the statistics or percentiles are apparent. For example, mean concentrations of calcium tend to increase in a downstream direction at the Red River main-stem stations, whereas mean values for sulfate tend to remain almost constant. Tributary data for individual constituents could be

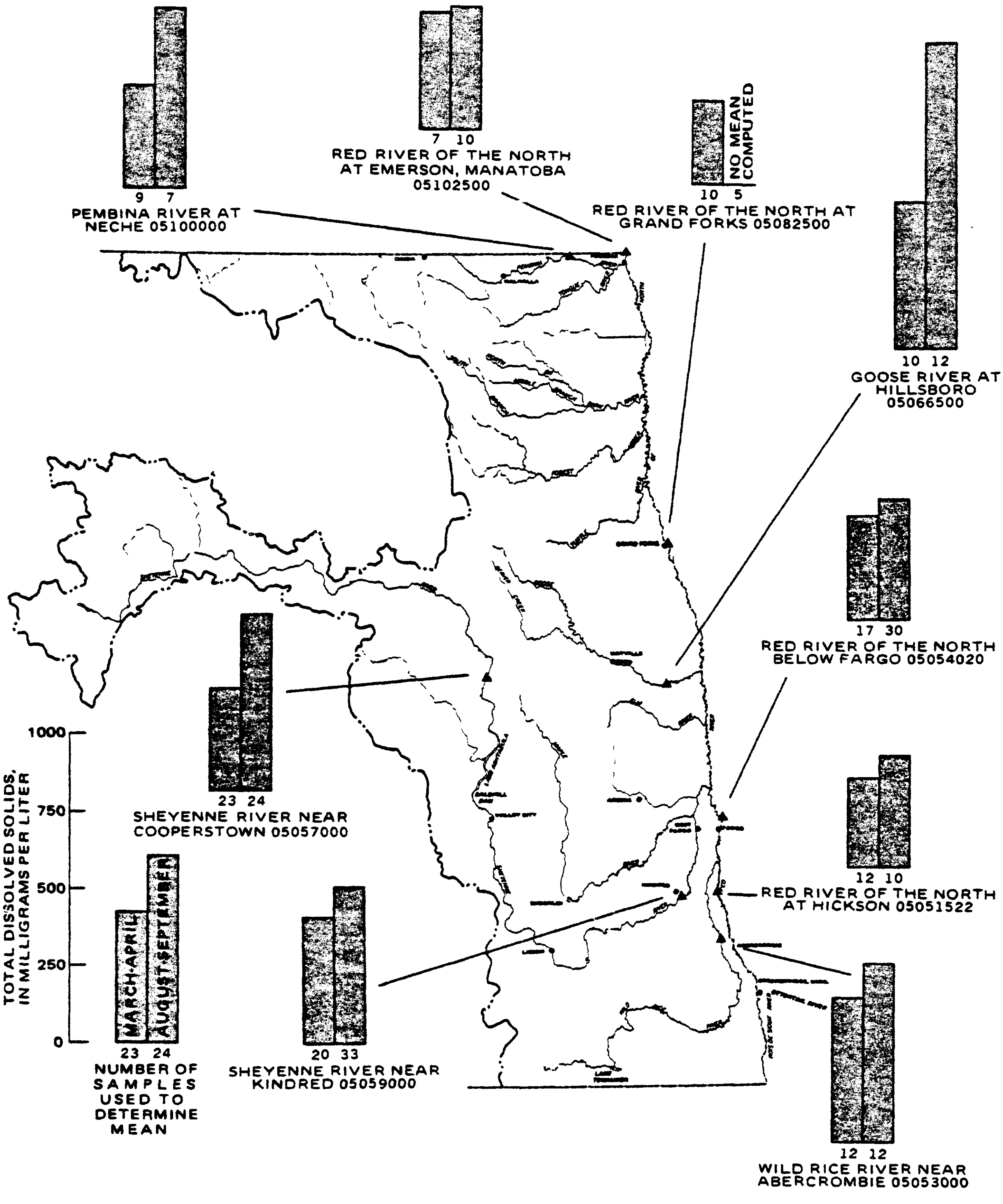


FIGURE 30.—Period-of-record mean dissolved-solids concentrations for high flows (March-April) and low flows (August-September) at selected stations, Red River of the North basin, North Dakota.

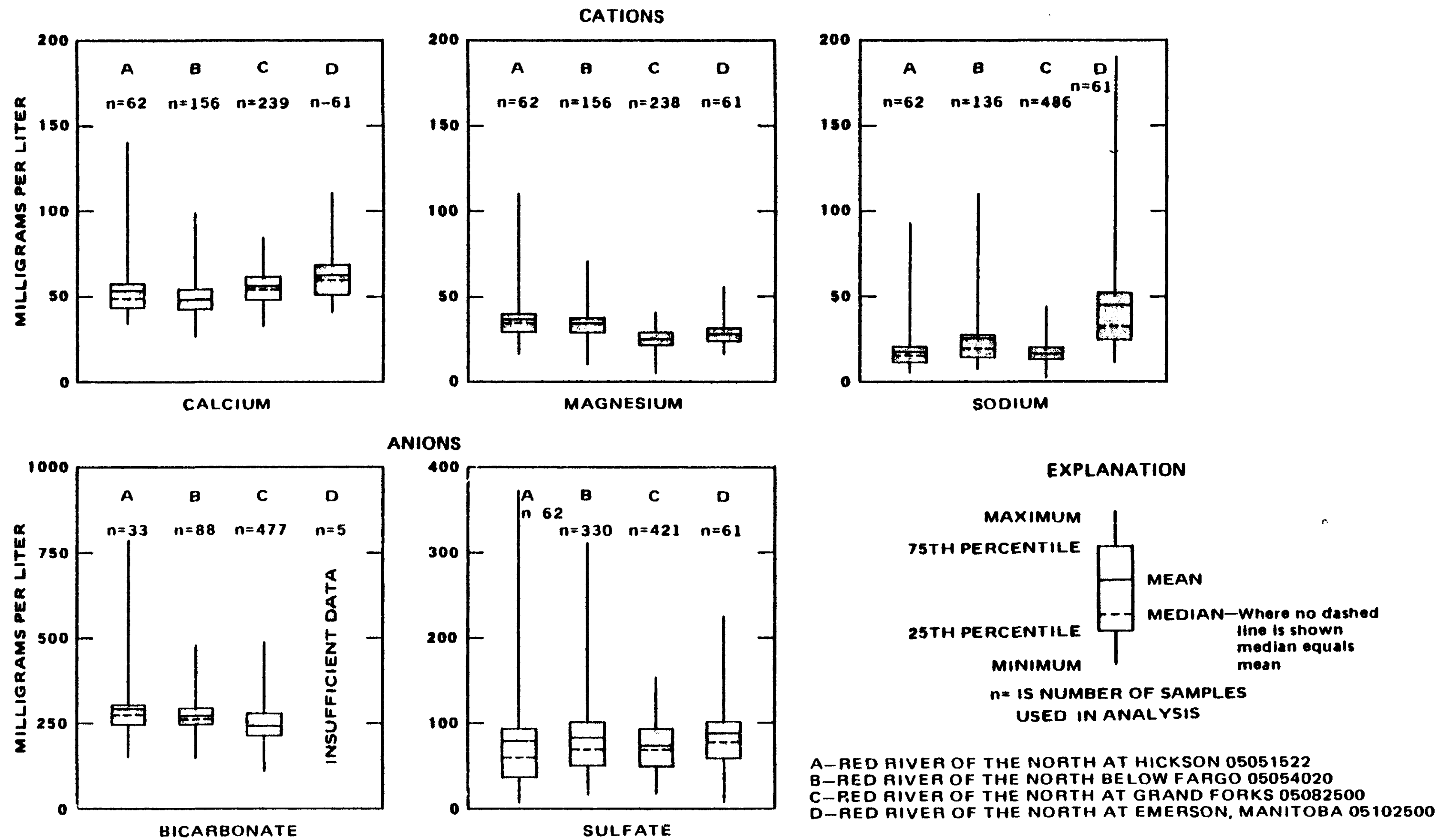


FIGURE 31.—Statistical comparisons of concentrations of principal cations and anions at selected main stem stations, Red River of the North basin, North Dakota.

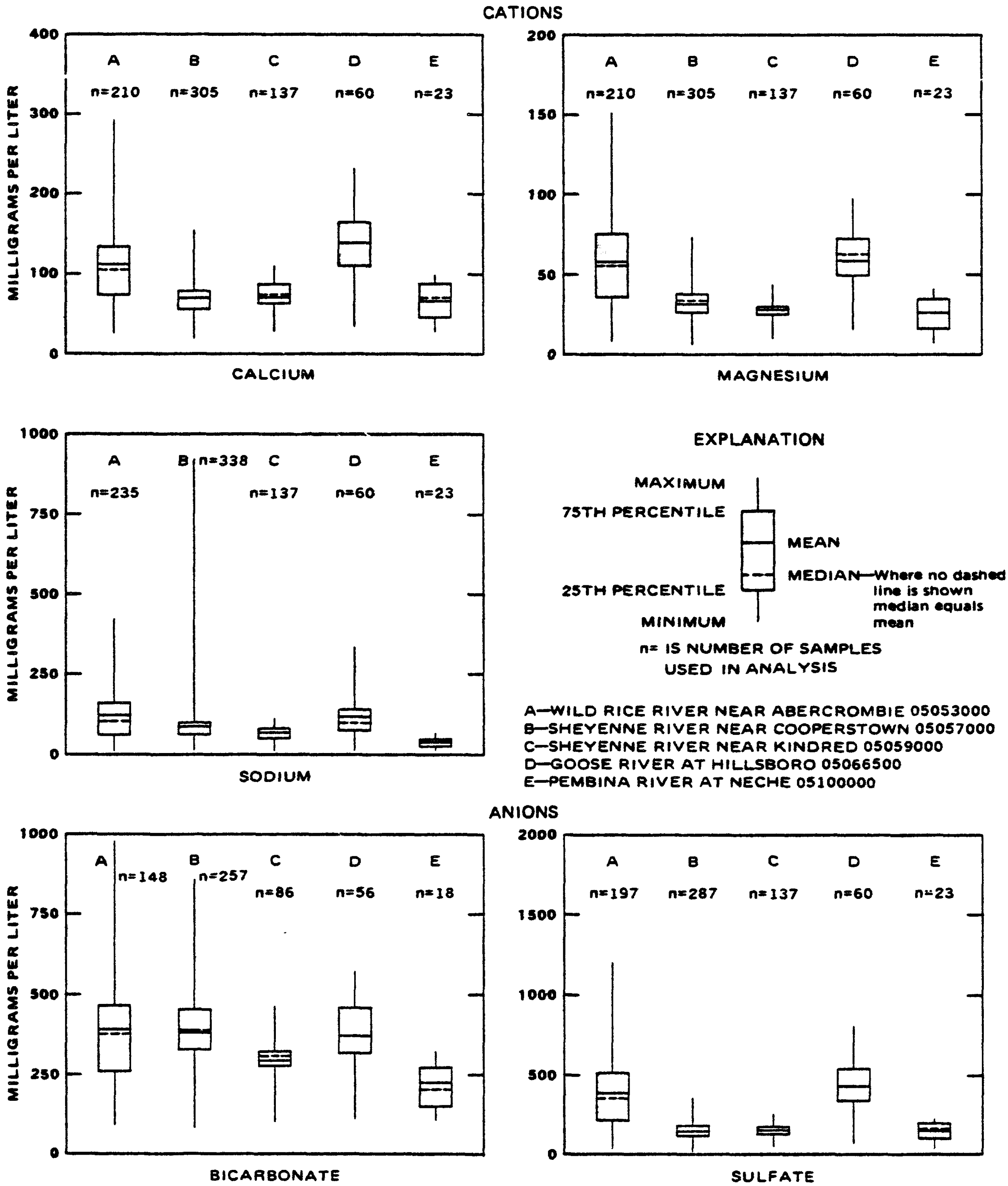


FIGURE 32.—Statistical comparisons of concentrations of principal cations and anions at selected major tributary stations, Red River of the North basin, North Dakota.

TABLE 7.--SUMMARY OF WATER-QUALITY DATA, RED RIVER OF THE NORTH BASIN
[UMHOS, MICROMHOS PER CENTIMETER AT 25° CELSIUS; MG/L, MILLIGRAMS PER LITER]

STATION NUMBER: 05051522 STATION NAME AND LOCATION: RED RIVER OF THE NORTH AT HICKSON, ND

DRAINAGE AREA: SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
SPECIFIC CONDUCTANCE (UMHOS)	107	1590.00	47.00	541.31	173.68	690.00	593.00	520.00	468.00	399.60
BICARBONATE FET-FLD (MG/L AS HCO3)	33	786.00	150.00	290.06	111.34	317.20	300.00	274.00	246.50	210.00
NITROGEN, NO2+NO3 TOTAL (MG/L AS N)	62	2.30	0.01	0.24	0.39	0.49	0.30	0.10	0.03	0.01
CALCIUM DISSOLVED (MG/L AS CA)	62	140.00	35.00	54.05	17.23	68.70	58.00	50.50	44.00	39.30
MAGNESIUM, DISSOLVED (MG/L AS MG)	62	110.00	16.00	35.65	13.43	41.00	38.00	34.00	29.00	27.00
SODIUM, DISSOLVED (MG/L AS NA)	62	92.00	7.60	17.26	12.06	24.40	20.00	15.00	11.00	9.83
POTASSIUM, DISSOLVED (MG/L AS K)	62	16.00	1.30	5.75	2.00	7.38	6.30	5.30	4.60	4.13
CHLORIDE, DISSOLVED (MG/L AS CL)	62	44.00	1.30	9.48	5.53	13.00	11.00	8.50	6.80	5.50
SULFATE DISSOLVED (MG/L AS SO4)	62	340.00	5.40	78.01	62.70	147.00	93.00	59.00	36.75	26.30
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	62	1100.00	220.00	346.77	137.25	431.00	380.00	320.00	280.00	240.00

STATION NUMBER: 05053000 STATION NAME AND LOCATION: WILD RICE RIVER NR ABERCROMBIE, ND

DRAINAGE AREA: 2082 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
SPECIFIC CONDUCTANCE (UMHOS)	284	3430.00	125.00	1277.83	670.38	2220.00	1670.00	1200.00	790.25	425.00
BICARBONATE FET-FLD (MG/L AS HCO3)	198	979.00	96.00	389.75	173.00	641.00	461.25	373.50	256.00	178.90
CALCIUM DISSOLVED (MG/L AS CA)	210	290.00	25.00	111.71	54.21	190.00	133.50	104.50	74.00	49.00
MAGNESIUM, DISSOLVED (MG/L AS MG)	210	150.00	9.30	58.41	30.22	100.00	74.00	55.50	35.00	23.00
SODIUM, DISSOLVED (MG/L AS NA)	235	420.00	8.30	121.20	79.12	225.20	160.00	103.00	63.00	38.00
POTASSIUM, DISSOLVED (MG/L AS K)	217	47.00	1.90	15.03	4.62	21.00	18.00	15.00	12.00	9.80
CHLORIDE, DISSOLVED (MG/L AS CL)	181	180.00	3.60	47.75	33.01	92.80	64.00	40.00	23.50	16.00
SULFATE DISSOLVED (MG/L AS SO4)	197	1200.00	32.00	387.87	221.98	713.60	501.00	360.00	210.00	110.00
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	181	2700.00	160.00	956.63	507.43	1700.00	1200.00	880.00	555.00	382.00

STATION NUMBER: 05054020 STATION NAME AND LOCATION: RED RIVER OF THE NORTH BELOW FARGO, ND

DRAINAGE AREA: 6820 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
SPECIFIC CONDUCTANCE (UMHOS)	223	1200.00	290.00	581.55	144.21	720.00	631.00	557.00	501.00	430.00
BICARBONATE FET-FLD (MG/L AS HCO3)	88	471.00	145.00	267.77	46.61	328.20	288.75	258.00	248.25	219.00
NITROGEN, NO2+NO3 TOTAL (MG/L AS N)	54	4.60	0.01	0.70	0.85	1.90	0.90	0.37	0.18	0.08
CALCIUM DISSOLVED (MG/L AS CA)	156	98.00	27.00	49.07	9.96	61.00	53.75	48.00	43.00	38.00
MAGNESIUM, DISSOLVED (MG/L AS MG)	156	70.00	11.00	33.17	6.71	40.00	36.00	33.00	29.00	26.70
SODIUM, DISSOLVED (MG/L AS NA)	135	110.00	6.80	24.73	19.47	45.00	24.75	19.50	15.00	11.70
POTASSIUM, DISSOLVED (MG/L AS K)	126	20.00	3.70	6.86	2.53	11.00	7.45	6.10	5.30	4.37
CHLORIDE, DISSOLVED (MG/L AS CL)	155	96.00	4.40	15.06	13.87	28.40	15.00	11.00	8.40	6.96
SULFATE DISSOLVED (MG/L AS SO4)	167	330.00	19.00	80.66	49.18	150.00	100.00	69.00	49.00	31.80
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	120	740.00	160.00	351.67	106.58	450.00	380.00	330.00	290.00	250.00

STATION NUMBER: 05057000 STATION NAME AND LOCATION: SHEYENNE RIVER NR COOPERSTOWN, ND

DRAINAGE AREA: 6470 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
SPECIFIC CONDUCTANCE (UMHOS)	380	1760.00	213.00	851.98	243.39	1100.00	994.00	892.50	741.25	483.70
BICARBONATE FET-FLD (MG/L AS HCO3)	257	853.00	80.00	380.98	117.15	516.40	453.50	389.00	329.00	210.00
NITROGEN, NO2+NO3 TOTAL (MG/L AS N)	69	1.30	0.00	0.17	0.28	0.56	0.16	0.08	0.02	0.00
CALCIUM DISSOLVED (MG/L AS CA)	305	154.00	19.00	67.53	21.13	96.00	78.50	67.00	57.00	34.60
MAGNESIUM, DISSOLVED (MG/L AS MG)	305	72.00	6.50	31.10	9.18	40.00	37.00	33.00	27.00	17.00
SODIUM, DISSOLVED (MG/L AS NA)	338	920.00	10.00	84.34	53.57	114.10	99.00	84.00	66.00	40.90
POTASSIUM, DISSOLVED (MG/L AS K)	320	28.00	0.00	8.67	1.98	10.00	9.50	8.45	7.63	7.10
HLORIDE, DISSOLVED (MG/L AS CL)	273	39.00	0.10	16.20	5.55	22.00	19.00	17.00	13.00	7.94
ULFATE DISSOLVED (MG/L AS SO4)	287	360.00	21.10	142.32	44.42	190.00	168.00	140.00	120.00	82.60
OLIDS, SUM OF CONSTITUENTS, DISSOLVED	273	1400.00	120.00	560.66	167.12	720.00	650.00	590.00	490.00	320.00

TABLE 7.--SUMMARY OF WATER-QUALITY DATA, RED RIVER OF THE NORTH BASIN--Continued
[UMHOS, MICROMHOS PER CENTIMETER AT 25° CELSIUS; MG/L, MILLIGRAMS PER LITER]

STATION NUMBER: 05059000 STATION NAME AND LOCATION: SHEYENNE RIVER NR KINDRED, ND

DRAINAGE AREA: 8800 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
SPECIFIC CONDUCTANCE (UMHOS)	268	1210.00	180.00	769.95	176.83	971.00	900.00	770.00	691.25	520.00
BICARBONATE FET-FLD (MG/L AS HCO3)	86	414.00	110.00	291.64	62.09	356.30	330.00	310.00	260.00	190.00
NITROGEN, NO2+NO3 TOTAL (MG/L AS N)	111	1.00	0.00	0.27	0.31	0.78	0.52	0.10	0.02	0.01
CALCIUM DISSOLVED (MG/L AS CA)	137	110.00	28.00	72.26	16.37	89.00	84.00	76.00	63.00	47.80
MAGNESIUM, DISSOLVED (MG/L AS MG)	137	42.00	11.00	27.22	5.98	34.00	30.00	28.00	25.00	19.20
SODIUM, DISSOLVED (MG/L AS NA)	137	110.00	9.50	61.55	18.64	85.40	74.00	62.00	51.00	34.80
POTASSIUM, DISSOLVED (MG/L AS K)	136	13.00	3.80	8.56	1.47	10.00	9.30	8.45	7.80	6.87
CHLORIDE, DISSOLVED (MG/L AS CL)	137	74.00	5.70	30.31	13.34	48.00	37.00	30.00	20.00	14.00
SULFATE DISSOLVED (MG/L AS SO4)	137	240.00	50.00	144.58	33.62	180.00	170.00	150.00	120.00	100.00
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	137	780.00	190.00	508.34	108.95	632.00	580.00	520.00	450.00	362.40

STATION NUMBER: 05066500 STATION NAME AND LOCATION: GOOSE RIVER AT HILLSBORO, ND

DRAINAGE AREA: 1203 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
SPECIFIC CONDUCTANCE (UMHOS)	176	3400.00	260.00	1379.99	601.45	2115.00	1750.00	1370.00	1007.50	452.50
BICARBONATE FET-FLD (MG/L AS HCO3)	56	566.00	111.00	368.09	112.11	525.90	452.75	371.00	312.50	184.00
CALCIUM DISSOLVED (MG/L AS CA)	60	230.00	34.00	137.52	46.94	209.00	163.00	140.00	110.00	62.00
MAGNESIUM, DISSOLVED (MG/L AS MG)	60	98.00	16.00	59.67	18.89	79.90	72.75	62.50	50.50	27.50
SODIUM, DISSOLVED (MG/L AS NA)	60	330.00	9.20	118.27	72.28	239.00	135.75	100.00	76.25	44.10
POTASSIUM, DISSOLVED (MG/L AS K)	60	20.00	5.90	11.25	3.00	15.90	13.00	11.00	9.20	7.84
CHLORIDE, DISSOLVED (MG/L AS CL)	60	310.00	5.40	87.52	65.00	190.00	104.25	71.50	44.00	24.10
SULFATE DISSOLVED (MG/L AS SO4)	60	800.00	70.00	421.62	153.35	599.00	531.25	420.00	350.00	174.00
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	60	2100.00	210.00	1035.83	385.14	1590.00	1200.00	995.00	875.00	418.00

STATION NUMBER: 05082500 STATION NAME AND LOCATION: RED RIVER OF THE NORTH AT GRAND FORKS, ND

DRAINAGE AREA: 30100 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
SPECIFIC CONDUCTANCE (UMHOS)	683	976.00	200.00	517.86	106.82	640.00	579.00	520.00	455.00	375.00
BICARBONATE FET-FLD (MG/L AS HCO3)	477	480.00	112.00	243.53	49.86	296.00	269.00	243.00	215.00	187.00
CALCIUM DISSOLVED (MG/L AS CA)	239	83.00	33.00	54.97	9.39	68.00	61.00	54.00	49.00	43.00
MAGNESIUM, DISSOLVED (MG/L AS MG)	238	40.00	5.70	25.18	5.88	33.00	29.25	25.00	21.75	18.00
SODIUM, DISSOLVED (MG/L AS NA)	486	43.00	2.60	17.08	6.00	25.00	20.00	16.00	13.00	10.00
POTASSIUM, DISSOLVED (MG/L AS K)	207	20.00	0.80	5.08	1.86	6.80	5.70	4.80	4.10	3.60
CHLORIDE, DISSOLVED (MG/L AS CL)	208	34.00	0.00	9.01	4.34	14.00	10.00	8.60	6.33	4.99
SULFATE DISSOLVED (MG/L AS SO4)	421	152.00	18.00	71.85	28.12	110.00	94.00	68.00	48.50	37.00
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	206	1890.00	160.00	318.54	127.08	400.00	360.00	310.00	270.00	230.00

STATION NUMBER: 05100000 STATION NAME AND LOCATION: PEMBINA RIVER AT NECHE, ND

DRAINAGE AREA: 3410 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
SPECIFIC CONDUCTANCE (UMHOS)	152	1350.00	250.00	774.24	253.89	1098.50	947.50	807.50	610.50	410.00
BICARBONATE FET-FLD (MG/L AS HCO3)	18	339.00	107.00	224.67	85.03	330.90	318.25	203.50	148.25	121.40
CALCIUM DISSOLVED (MG/L AS CA)	23	98.00	26.00	66.30	23.84	96.60	90.00	69.00	46.00	32.00
MAGNESIUM, DISSOLVED (MG/L AS MG)	23	40.00	8.00	25.89	10.62	38.60	35.00	26.00	17.00	9.10
SODIUM, DISSOLVED (MG/L AS NA)	23	53.00	19.00	37.43	10.84	51.20	48.00	39.00	28.00	19.40
POTASSIUM, DISSOLVED (MG/L AS K)	23	13.00	3.20	7.06	2.66	11.60	8.80	6.60	4.90	3.72
CHLORIDE, DISSOLVED (MG/L AS CL)	23	34.00	3.40	12.80	6.94	20.20	17.00	12.00	6.60	5.40
SULFATE DISSOLVED (MG/L AS SO4)	23	210.00	56.00	146.22	48.56	206.00	190.00	160.00	110.00	64.60
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	23	600.00	200.00	432.61	141.78	596.00	570.00	440.00	300.00	214.00

TABLE 7.--SUMMARY OF WATER-QUALITY DATA, RED RIVER OF THE NORTH BASIN--Continued
[UMHOS, MICROMHOS PER CENTIMETER AT 25° CELSIUS; MG/L, MILLIGRAMS PER LITER]

STATION NUMBER: 05102500 STATION NAME AND LOCATION: RED RIVER AT EMERSON, MANITOBA

DRAINAGE AREA: 40200 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
SPECIFIC CONDUCTANCE (UMHOS)	194	1810.00	400.00	621.06	170.50	764.00	648.00	594.00	530.00	527.00
BICARBONATE FET-FLD (MG/L AS HCO3)	5	350.00	160.00							
NITROGEN, NO2+NO3 TOTAL (MG/L AS N)	44	1.80	0.00	0.35	0.36	0.88	0.43	0.29	0.08	0.01
CALCIUM DISSOLVED (MG/L AS CA)	61	110.00	40.00	60.88	12.51	78.00	68.50	60.00	51.00	48.00
MAGNESIUM, DISSOLVED (MG/L AS MG)	61	54.00	16.00	27.45	6.89	36.60	31.00	26.00	23.00	19.00
SODIUM, DISSOLVED (MG/L AS NA)	61	190.00	11.00	44.92	36.30	94.20	51.00	33.00	24.00	20.20
POTASSIUM, DISSOLVED (MG/L AS K)	61	13.00	3.80	6.28	1.95	8.62	6.90	5.80	5.20	4.30
CHLORIDE, DISSOLVED (MG/L AS CL)	61	240.00	9.80	53.64	50.12	126.00	67.50	35.00	22.50	15.40
SULFATE DISSOLVED (MG/L AS SO4)	61	220.00	6.00	84.44	38.02	140.00	99.50	77.00	59.00	47.00
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	60	1100.00	230.00	406.17	147.32	561.00	450.00	375.00	322.50	262.00

compared, but the comparisons mean little because of possible differences in source material for the constituents in each tributary basin.

A trend analysis of dissolved solids for the Sheyenne River near Kindred station using data for 1972-81 indicates that no time trend in dissolved-solids concentration could be detected (Wells and Schertz, 1983).

Suitability for use.--Water in the Red River mainstem, the Sheyenne River, and the Pembina River is suitable for drinking-water supply and domestic use. Mean dissolved-solids concentrations slightly exceed the secondary drinking water standards of 500 milligrams per liter in water from the Sheyenne River but are less than 500 milligrams per liter in water from the Red and Pembina Rivers. Water from the Wild Rice and Goose Rivers probably is not suitable for drinking-water supply because mean sulfate concentrations of 388 and 422 milligrams per liter, respectively, exceed the secondary drinking water standard for sulfate of 250 milligrams per liter. Water containing sulfate in excess of 250 milligrams per liter may have a laxative effect on infrequent users.

Nitrate-nitrogen concentrations are substantially less than the Federal primary drinking water standard of 10 milligrams per liter at all stations for which data are available in the Red River basin. In fact, 90th-percentile data indicate that the State standard of 1.0 milligrams per liter nitrate-nitrogen for class I streams in North Dakota is exceeded only at the Red River below Fargo station. This station is located downstream from the Fargo sewage-treatment plant and the sampled reach may be slightly enriched with nitrate-nitrogen derived from treated sewage effluent.

Four trace constituents have been detected in concentrations that exceed the Federal primary drinking water standards at several stations in the Red River basin (table 8). Most of the excessive concentrations of mercury,

TABLE 8.--SUMMARY OF TRACE CONSTITUENT DATA, RED RIVER OF THE NORTH BASIN
[UG/L, MICROGRAMS PER LITER]

STATION NUMBER: 05051522 STATION NAME AND LOCATION: RED RIVER OF THE NORTH AT HICKSON, ND

DRAINAGE AREA: SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
ARSENIC DISSOLVED (UG/L AS AS)	9	5.00	1.00							
BARIUM, DISSOLVED (UG/L AS BA)	9	200.00	40.00							
BORON, DISSOLVED (UG/L AS B)	61	530.00	3.00	102.34	72.28	154.00	120.00	90.00	70.00	50.00
CADMIUM DISSOLVED (UG/L AS CD)	8	3.00	0 00							
CHROMIUM, DISSOLVED (UG/L AS CR)	9	30.00	0.00							
COPPER, DISSOLVED (UG/L AS CU)	9	20.00	2.00							
IRON, DISSOLVED (UG/L AS FE)	9	300.00	10.00							
LEAD, DISSOLVED (UG/L AS PB)	8	7.00	0.00							
MANGANESE, DISSOLVED (UG/L AS MN)	9	90.00	2.00							
SILVER, DISSOLVED (UG/L AS AG)	4	0.00	0.00							
ZINC, DISSOLVED (UG/L AS ZN)	9	140.00	0.00							
SELENIUM, DISSOLVED (UG/L AS SE)	9	1.00	1.00							
MERCURY DISSOLVED (UG/L AS HG)	9	11.00	0.10							

STATION NUMBER: 05053000 STATION NAME AND LOCATION: WILD RICE RIVER NR ABERCROMBIE, ND

DRAINAGE AREA: 2082 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
ARSENIC DISSOLVED (UG/L AS AS)	23	15.00	0.00	5.91	4.20	12.20	10.00	5.00	3.00	0.40
BARIUM, DISSOLVED (UG/L AS BA)	19	170.00	0.00	68.42	52.52	100.00	100.00	100.00	0.00	0.00
BORON, DISSOLVED (UG/L AS B)	181	840.00	40.00	310.51	148.90	520.00	400.00	300.00	200.00	122.00
CADMIUM DISSOLVED (UG/L AS CD)	19	18.00	0.00	1.95	4.03	3.00	2.00	2.00	0.00	0.00
CHROMIUM, DISSOLVED (UG/L AS CR)	19	20.00	0.00	5.26	9.05	20.00	20.00	0.00	0.00	0.00
COPPER, DISSOLVED (UG/L AS CU)	19	36.00	0.00	9.21	10.17	35.00	11.00	7.00	3.00	0.00
IRON, DISSOLVED (UG/L AS FE)	45	1400.00	0.00	145.13	277.25	354.00	128.00	50.00	20.50	0.00
LEAD, DISSOLVED (UG/L AS PB)	23	480.00	0.00	22.96	99.67	9.20	5.00	2.00	0.00	0.00
MANGANESE, DISSOLVED (UG/L AS MN)	34	2290.00	0.00	310.03	489.90	860.00	293.25	115.00	47.50	25.00
SILVER, DISSOLVED (UG/L AS AG)	8	2.00	0.00							
ZINC, DISSOLVED (UG/L AS ZN)	19	73.00	0.00	21.58	14.58	30.00	23.00	20.00	15.00	8.00
SELENIUM, DISSOLVED (UG/L AS SE)	23	13.00	0.00	3.00	3.75	10.60	4.00	1.00	1.00	0.00
MERCURY DISSOLVED (UG/L AS HG)	20	9.00	0.00	0.90	1.97	2.24	0.50	0.50	0.13	0.10

STATION NUMBER: 05054020 STATION NAME AND LOCATION: RED RIVER OF THE NORTH BELOW FARGO, ND

DRAINAGE AREA: 6820 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
ARSENIC DISSOLVED (UG/L AS AS)	44	10.00	0.00	3.89	2.44	7.50	5.00	3.50	2.00	0.50
BARIUM, DISSOLVED (UG/L AS BA)	17	230.00	0.00	94.00	69.22	206.00	125.00	100.00	41.50	0.00
BORON, DISSOLVED (UG/L AS B)	77	421.00	40.00	106.43	62.23	169.20	115.00	90.00	70.00	60.00
CADMIUM·DISSOLVED (UG/L AS CD)	45	26.00	0.00	1.76	3.81	2.00	2.00	1.00	0.00	0.00
CHROMIUM, DISSOLVED (UG/L AS CR)	46	20.00	0.00	3.48	6.40	13.00	10.00	0.00	0.00	0.00
COPPER, DISSOLVED (UG/L AS CU)	44	140.00	0.00	12.70	26.20	20.00	9.00	5.00	4.00	2.00
IRON, DISSOLVED (UG/L AS FE)	36	70.00	6.00	28.31	18.98	58.60	50.00	20.00	10.00	10.00
LEAD, DISSOLVED (UG/L AS PB)	44	15.00	0.00	2.68	3.55	8.50	3.75	2.00	0.00	0.00
MANGANESE, DISSOLVED (UG/L AS MN)	44	190.00	2.00	40.25	45.04	118.50	50.00	30.00	10.00	4.50
SILVER, DISSOLVED (UG/L AS AG)	13	2.00	0.00	0.62	0.77	2.00	1.00	0.00	0.00	0.00
ZINC, DISSOLVED (UG/L AS ZN)	45	194.00	0.00	25.27	31.07	51.20	25.00	20.00	9.00	3.60
SELENIUM, DISSOLVED (UG/L AS SE)	41	135.00	0.00	4.85	20.92	5.80	1.00	1.00	1.00	0.00
MERCURY DISSOLVED (UG/L AS HG)	39	8.00	0.00	0.51	1.27	0.50	0.50	0.30	0.10	0.00

STATION NUMBER: 05057000 STATION NAME AND LOCATION: SHEYENNE RIVER NR COOPERSTOWN, ND

DRAINAGE AREA: 6470 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
ARSENIC DISSOLVED (UG/L AS AS)	27	12.00	0.00	4.26	3.27	10.20	5.00	4.00	2.00	1.00
BARIUM, DISSOLVED (UG/L AS BA)	23	200.00	0.00	67.61	61.86	160.00	100.00	100.00	0.00	0.00
BORON, DISSOLVED (UG/L AS B)	273	890.00	20.00	179.00	75.48	260.00	210.00	180.00	138.00	100.00
CADMIUM DISSOLVED (UG/L AS CD)	23	11.00	0.00	1.52	2.27	2.00	2.00	2.00	0.00	0.00
CHROMIUM, DISSOLVED (UG/L AS CR)	22	20.00	0.00	2.73	7.03	20.00	0.00	0.00	0.00	0.00
COPPER, DISSOLVED (UG/L AS CU)	22	34.00	0.00	8.59	9.26	27.40	12.50	5.50	2.00	0.00
IRON, DISSOLVED (UG/L AS FE)	115	700.00	0.00	54.43	84.41	124.00	60.00	30.00	10.00	10.00
LEAD, DISSOLVED (UG/L AS PB)	26	200.00	0.00	14.85	42.50	50.40	5.25	2.00	0.00	0.00
MANGANESE, DISSOLVED (UG/L AS MN)	103	5000.00	0.00	648.11	1092.52	2200.00	460.00	250.00	100.00	48.00
SILVER, DISSOLVED (UG/L AS AG)	13	4.00	0.00	0.46	1.20	3.20	0.00	0.00	0.00	0.00
ZINC, DISSOLVED (UG/L AS ZN)	23	400.00	0.00	34.39	80.26	37.20	20.00	20.00	10.00	4.00
SELENIUM, DISSOLVED (UG/L AS SE)	27	18.00	0.00	3.26	4.52	10.90	4.00	1.00	1.00	0.00
MERCURY DISSOLVED (UG/L AS HG)	24	0.90	0.00	0.33	0.24	0.55	0.50	0.40	0.10	0.00

TABLE 8.--SUMMARY OF TRACE CONSTITUENT DATA, RED RIVER OF THE NORTH BASIN--Continued
[UG/L, MICROGRAMS PER LITER]

STATION NUMBER: 05059000 STATION NAME AND LOCATION: SHEYENNE RIVER NR KINDRED, ND

DRAINAGE AREA: 8800 SQUARE MILES

SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS

WATER QUALITY CONSTITUENT	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
ARSENIC DISSOLVED (UG/L AS AS)	31	10.00	1.00	4.35	2.44	9.80	5.00	4.00	3.00	2.00
BARIUM, DISSOLVED (UG/L AS BA)	31	300.00	56.00	129.48	57.60	208.00	200.00	100.00	100.00	77.00
BORON, DISSOLVED (UG/L AS B)	31	20000.00	70.00	935.16	3573.40	1291.99	220.00	170.00	110.00	80.00
CADMIUM DISSOLVED (UG/L AS CD)	27	27.00	0.00	2.19	5.00	2.20	2.00	1.00	1.00	0.80
CHROMIUM, DISSOLVED (UG/L AS CR)	31	20.00	0.00	3.13	5.18	10.00	10.00	0.00	0.00	0.00
COPPER, DISSOLVED (UG/L AS CU)	31	28.00	0.00	5.13	6.15	16.20	5.00	3.00	2.00	2.00
IRON, DISSOLVED (UG/L AS FE)	125	1400.00	3.00	52.31	136.01	94.00	40.00	20.00	10.00	10.00
LEAD, DISSOLVED (UG/L AS PB)	25	350.00	0.00	15.52	69.71	6.40	2.50	1.00	0.00	0.00
MANGANESE, DISSOLVED (UG/L AS MN)	125	500.00	4.00	119.43	105.68	284.00	185.00	90.00	35.00	16.80
SILVER, DISSOLVED (UG/L AS AG)	31	1.00	0.00	0.35	0.49	1.00	1.00	0.00	0.00	0.00
ZINC, DISSOLVED (UG/L AS ZN)	31	100.00	3.00	23.23	26.48	68.00	20.00	14.00	7.00	3.00
SELENIUM, DISSOLVED (UG/L AS SE)	31	1.00	0.00	0.77	0.43	1.00	1.00	1.00	1.00	0.00
MERCURY DISSOLVED (UG/L AS HG)	38	20.00	0.00	1.64	4.19	8.20	0.33	0.10	0.07	0.00

STATION NUMBER: 05066500 STATION NAME AND LOCATION: GOOSE RIVER AT HILLSBORO, ND

DRAINAGE AREA: 1203 SQUARE MILES

SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS

WATER QUALITY CONSTITUENT	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
ARSENIC DISSOLVED (UG/L AS AS)	3	19.00	3.00							
BORON, DISSOLVED (UG/L AS B)	60	1100.00	0.00	279.18	232.64	555.00	367.50	235.00	120.00	40.00
IRON, DISSOLVED (UG/L AS FE)	49	880.00	0.00	84.29	136.55	210.00	95.00	50.00	15.00	0.00
LEAD, DISSOLVED (UG/L AS PB)	3	2.00	0.00							
MANGANESE, DISSOLVED (UG/L AS MN)	49	2800.00	10.00	455.92	663.68	1799.99	620.00	200.00	80.00	20.00
SELENIUM, DISSOLVED (UG/L AS SE)	3	1.00	0.00							
MERCURY DISSOLVED (UG/L AS HG)	3	0.30	0.10							

STATION NUMBER: 05082500 STATION NAME AND LOCATION: RED RIVER OF THE NORTH AT GRAND FORKS, ND

DRAINAGE AREA: 30100 SQUARE MILES

SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS

WATER QUALITY CONSTITUENT	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
ARSENIC DISSOLVED (UG/L AS AS)	20	13.00	0.00	3.10	2.97	6.80	4.00	3.00	1.25	0.00
BARIUM, DISSOLVED (UG/L AS BA)	14	300.00	0.00	55.43	82.02	200.00	100.00	26.00	0.00	0.00
BORON, DISSOLVED (UG/L AS B)	201	760.00	0.00	91.80	85.08	130.00	100.00	80.00	60.00	30.00
CADMIUM DISSOLVED (UG/L AS CD)	20	7.00	0.00	0.65	1.60	1.90	1.00	0.00	0.00	0.00
CHROMIUM, DISSOLVED (UG/L AS CR)	20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COPPER, DISSOLVED (UG/L AS CU)	25	20.00	0.00	4.88	7.23	20.00	9.00	0.01	0.00	0.00
IRON, DISSOLVED (UG/L AS FE)	63	1500.00	0.00	95.92	198.73	211.40	80.00	47.00	24.00	7.60
LEAD, DISSOLVED (UG/L AS PB)	27	5.00	0.00	0.74	1.29	2.40	1.00	0.00	0.00	0.00
MANGANESE, DISSOLVED (UG/L AS MN)	51	820.00	0.00	47.14	118.19	79.40	40.00	20.00	10.00	0.00
SILVER, DISSOLVED (UG/L AS AG)	10	5.00	0.00	1.60	1.78	4.90	2.50	1.50	0.00	0.00
ZINC, DISSOLVED (UG/L AS ZN)	25	46.00	0.00	11.10	12.95	31.00	20.00	10.00	0.00	0.00
SELENIUM, DISSOLVED (UG/L AS SE)	20	23.00	0.00	4.38	5.70	9.96	8.00	2.00	0.00	0.00
MERCURY DISSOLVED (UG/L AS HG)	15	1.40	0.00	0.31	0.36	0.92	0.50	0.20	0.10	0.00

STATION NUMBER: 05100000 STATION NAME AND LOCATION: PEMBINA RIVER AT NECHE, ND

DRAINAGE AREA: 3410 SQUARE MILES

SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS

WATER QUALITY CONSTITUENT	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
ARSENIC DISSOLVED (UG/L AS AS)	4	12.00	0.00							
BORON, DISSOLVED (UG/L AS B)	23	550.00	0.09	133.92	129.85	328.00	200.00	100.00	40.00	20.00
IRON, DISSOLVED (UG/L AS FE)	23	410.00	10.00	110.43	105.72	288.00	200.00	80.00	30.00	14.00
LEAD, DISSOLVED (UG/L AS PB)	4	1.00	0.00							
MANGANESE, DISSOLVED (UG/L AS MN)	23	760.00	30.00	152.17	148.93	286.00	170.00	100.00	80.00	54.00
SELENIUM, DISSOLVED (UG/L AS SE)	4	1.00	0.00							
MERCURY DISSOLVED (UG/L AS HG)	4	0.70	0.10							

TABLE 8.--SUMMARY OF TRACE CONSTITUENT DATA, RED RIVER OF THE NORTH BASIN--Continued
[UG/L, MICROGRAMS PER LITER]

STATION NUMBER: 05102500 STATION NAME AND LOCATION: RED RIVER AT EMERSON, MANITOBA

DRAINAGE AREA: 40200 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS: SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN: 90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
ARSENIC DISSOLVED (UG/L AS AS)	27	11.00	1.00	3.33	1.92	5.00	4.00	3.00	2.00	1.80
BARIUM, DISSOLVED (UG/L AS BA)	26	230.00	42.00	106.04	53.47	203.00	100.00	100.00	67.50	44.00
BORON, DISSOLVED (UG/L AS B)	1	160.00	160.00							
CADMIUM DISSOLVED (UG/L AS CD)	26	3.00	0.00	1.08	0.69	2.00	1.00	1.00	1.00	0.00
CHROMIUM, DISSOLVED (UG/L AS CR)	26	10.00	0.00	2.15	3.93	10.00	1.00	0.00	0.00	0.00
COPPER, DISSOLVED (UG/L AS CU)	26	13.00	0.00	4.35	2.77	8.30	5.25	4.00	2.00	1.70
IRON, DISSOLVED (UG/L AS FE)	27	70.00	10.00	25.41	16.75	51.00	36.00	20.00	10.00	10.00
LEAD, DISSOLVED (UG/L AS PB)	23	4.00	0.00	1.04	1.02	2.60	1.00	1.00	0.00	0.00
MANGANESE, DISSOLVED (UG/L AS MN)	27	60.00	2.00	15.15	15.63	44.40	21.00	10.00	4.00	3.00
SILVER, DISSOLVED (UG/L AS AG)	26	2.00	0.00	0.42	0.58	1.00	1.00	0.00	0.00	0.00
ZINC, DISSOLVED (UG/L AS ZN)	26	60.00	3.00	18.77	14.52	40.90	29.25	20.00	6.75	3.00
SELENIUM, DISSOLVED (UG/L AS SE)	27	1.00	0.00	0.76	0.42	1.00	1.00	1.00	0.50	0.00
MERCURY DISSOLVED (UG/L AS HG)	26	0.30	0.00	0.09	0.06	0.13	0.10	0.10	0.10	0.00

cadmium, and lead appear to be related to individual contamination events or random errors as geochemical sources for these constituents probably do not exist in the basin. However, a geochemical source for selenium is present in Cretaceous bedrock in the basin, and the potential exists for concentrations of selenium to slightly exceed the Federal primary drinking water standard of 10 micrograms per liter. Maximum concentrations of mercury exceed the Federal standard of 2 micrograms per liter in water from the Red River at Hickson and below Fargo and in water from the Wild Rice River near Abercrombie; maximum concentrations of cadmium exceed the Federal standard of 10 micrograms per liter in water from the Red River below Fargo, the Wild Rice River near Abercrombie, and the Sheyenne River both near Cooperstown and near Kindred; maximum concentrations of lead exceed the Federal standard of 50 micrograms per liter in water from the Wild Rice River near Abercrombie and in water from both the Sheyenne River near Cooperstown and near Kindred; and maximum concentrations of selenium exceed the Federal standard of 10 micrograms per liter in water from the Red River below Fargo and at Grand Forks, Wild Rice River near Abercrombie, and the Sheyenne River near Cooperstown.

Quality of water in the Red River mainstem, the Pembina River, and the Sheyenne River generally is suitable for irrigation based on specific conductance and SAR values. Expected ranges of these values are indicated on irrigation suitability diagrams (fig. 33). Ninetieth percentile SAR values do not exceed S2 in water for any of these stations. Specific conductance may be C3 to C4 in the Sheyenne, Pembina Wild Rice and Goose Rivers; special management for salinity control may be required if water from the streams at low flow were used for irrigation.

Ninetieth percentile boron concentrations in water at all stations except Sheyenne River near Kindred are less than the EPA criterion of 750 micrograms per liter. This indicates that if water in the Red River basin was used for irrigation, boron concentrations potentially might be toxic to crops only in the downstream reaches of the Sheyenne River basin.

Sediment

Little information is available on fluvial sediment for the Red River basin in North Dakota. Sediment transported by the Red River is derived principally from sheet and wind erosion of glacial-drift and lacustrine deposits and predominantly is fine grained.

Souris River Basin

The Souris River originates in southeastern Saskatchewan, Canada, flows southeasterly to enter North Dakota west of Sherwood, forms a loop in North Dakota, re-enters Canada near Westhope, and then flows to the Red River via the Assiniboine River in Canada. The topography in North Dakota varies from hilly moraines in the southwest part of the basin to gently rolling moraines and a flat glacial lake plain in the northeast part of the basin. East of the international crossing near Westhope, a forested topographic high, the Turtle Mountains, rises about 900 feet above the flat valley of the Souris River. Large areas within the Souris River basin have a poorly defined drainage pattern and are noncontributing to the streamflow. The drainage area at the western crossing of the international boundary near Sherwood is 8,940 square miles, of which about 5,900 square miles is considered noncontributing. About 1,350 square miles of the 8,940-square-mile area is from tributaries in the United States flowing into Canada. The drainage area at the eastern crossing of the international boundary near Westhope is 16,900 square miles of which about 10,300 square miles is considered noncontributing. The total drainage area in North Dakota is 9,130 square miles. Major tributaries (fig. 34) are the Des Lacs, Wintering, and Deep Rivers, and Willow and Boundary Creeks.

Because the Souris River flows through Saskatchewan, North Dakota, and Manitoba, the apportionment of flow has been placed under the jurisdiction of an International Joint Commission. Two of the interim measures from the Commission's Docket No. 41 adopted March 19, 1958, are: (1) Saskatchewan will not decrease the annual streamflow to North Dakota at the western crossing by more than one-half that which would have occurred in a state of nature, and (2) North Dakota has the right to use this streamflow plus that which originates in North Dakota provided that, except during severe drought, a regulated flow of not less than 20 cubic feet per second be permitted to flow into Manitoba from June 1 through October 31. Saskatchewan exercises some regulation on flows through several on-stream and tributary reservoirs for municipal, thermal-electric power generation, and irrigation supplies. Flood control is not a design function of the reservoirs.

Uses of water from the Souris River in North Dakota are for municipal supply, stock watering, irrigation, recreation, and fish and wildlife

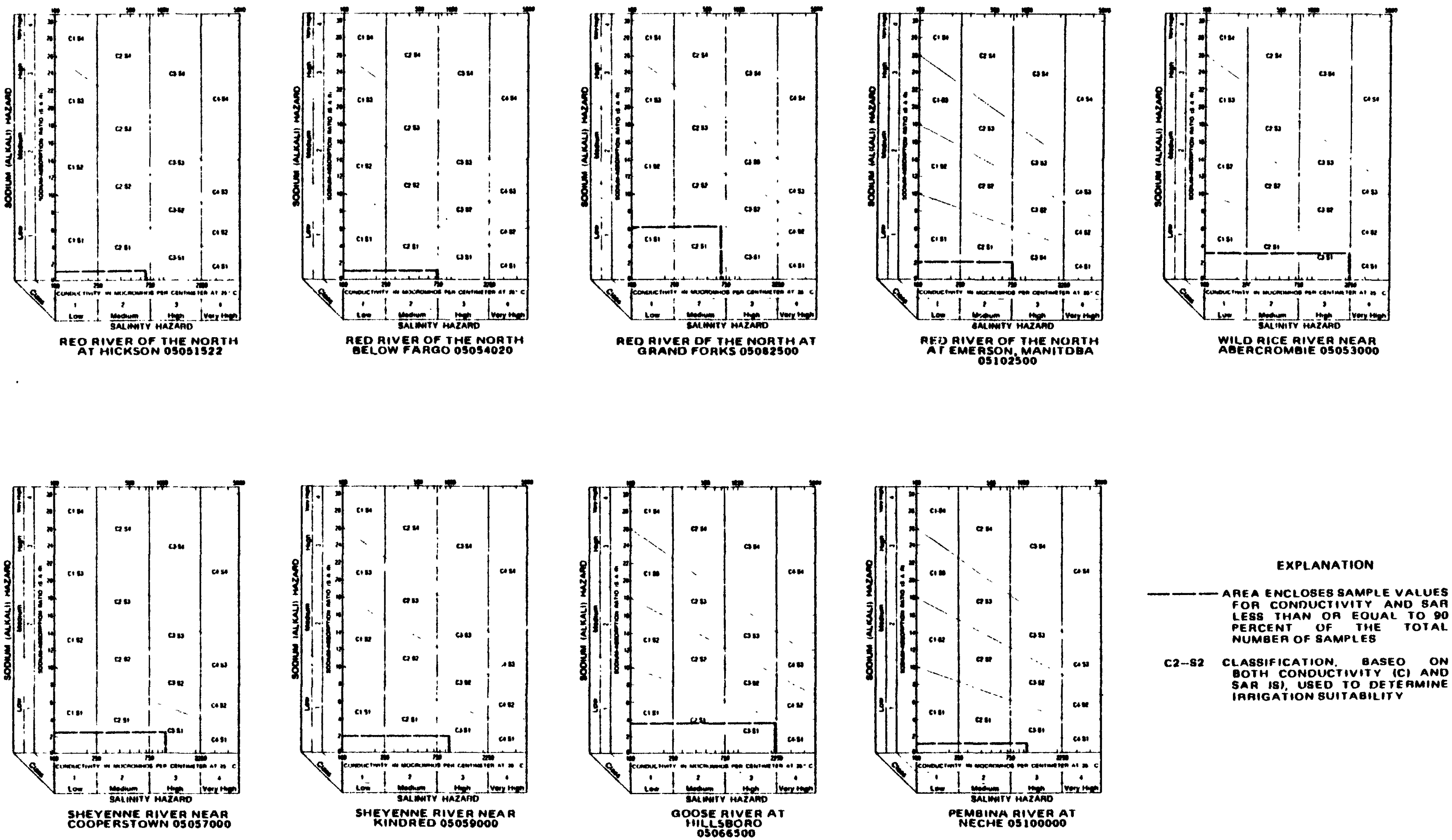


FIGURE 33.—Comparison of irrigation suitability of water at selected stations, Red River of the North basin, North Dakota. (Diagram from U.S. Salinity Laboratory Staff, 1954.)

propagation. Major storage is affected by Lake Darling, which contains 114,000 acre-feet at spillway level, and the J. Clark Salyer Refuge Pools, which contain 43,700 acre-feet at spillway level. Though not a design function, these and several smaller reservoirs partly regulate flood flows.

Streamflow Statistics

Flow data for the Souris River and its major tributaries are given in figure 34 and in table 8a:

TABLE 8a.--Daily streamflow statistics for five gaging stations on the Souris River, North Dakota

Station number	Station name	Drainage area (square miles)		Period of record (water years)	Daily discharge (cubic feet per second)				
		Total	Contributing		Mean	Median	Maximum	Minimum	10-percentile value
05114000	Souris River near Sherwood	8,940	3,040	1931-83	143	7.3	13,700	0	0.01
05117500	Souris River above Minot	10,600	3,900	1905-83	171	24.6	11,400	0	.27
05120000	Souris River near Verendrye	11,300	4,400	1938-83	220	45.1	9,700	0.1	3.9
05122000	Souris River near Bantry	12,300	4,700	1938-83	239	56.2	9,260	0	5.9
05124000	Souris River near Westhope	16,900	6,600	1931-83	268	25.6	12,400	0	.01

Streamflow is quite variable on a yearly basis as well as seasonally during each year. As indicated in the table, the Souris River has been observed to be dry at all stations except near Verendrye. The 10-percentile flows are 5.9 cubic feet per second or less for all stations, and are equal to 0.01 cubic foot per second for the boundary stations.

The Souris River near Sherwood (fig. 34) has only moderate regulation in Saskatchewan at high flows, but low flows are augmented by releases from several reservoirs. The monthly variability is greatest in April when the monthly flow has ranged from 11 to 6,739 cubic feet per second.

The streamflow record above Minot reflects the added effect of Lake Darling and tributary inflow. The major tributary inflow is from the Des Lacs River which, in turn, has flows moderated by wildlife refuge reservoirs in the upper reaches. Lake Darling generally is drawn down during the winter months and filled to maximum storage during the spring runoff. Releases are made later in the summer and fall to augment flows in the refuge reservoirs in the downstream reaches of the Souris River and to dilute effluent from Minot sewage lagoons. This results in greater-than-natural flows during July through October.

The streamflow record near Verendrye reflects the flow above Minot, tributary inflow, treated sewage effluent from Minot, and a major contribution of ground water from the New Rockford aquifer (fig. 10). Downstream from the

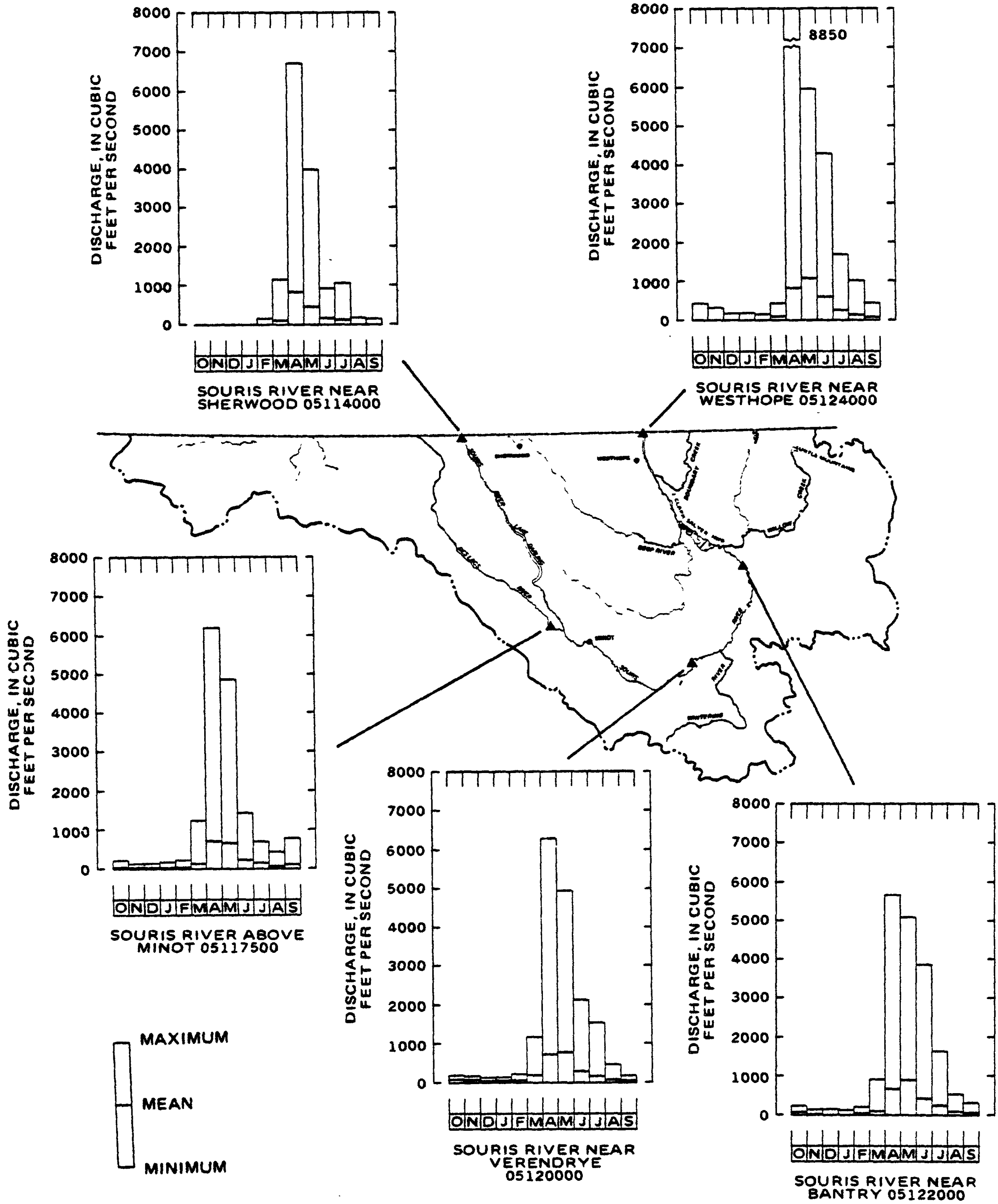


FIGURE 34.—Monthly discharge for period of record at selected gaging stations, Souris River basin, North Dakota.

station near Verendrye and the mouth of the contributing Wintering River, water is diverted from the channel for flood irrigation of 7,600 acres of hayland. This water (as much as 10,000 acre-feet annually) is diverted during spring runoff and generally is held on the land about 2 weeks, after which it is returned to the stream.

The streamflow record near Bantry reflects the irrigation activity, as well as tributary inflow. High flows are attenuated by diversions. Streamflow during June, especially, shows the effects of this diversion of water. The streamflow station near Bantry is at the upstream end of the J. Clarke Salyer National Wildlife Refuge.

Streamflow records near Westhope reflect the effects of the wildlife refuge and tributary inflow. More than 50 percent of the contributing drainage area of the Souris River in North Dakota is between the stations near Bantry and near Westhope. There is attenuation of the peak flows due to storage, and there is prolonged low flow due to the commitment to Manitoba.

Flooding

The most extreme floods recorded in the 20th century on the Souris River occurred in 1904, 1969, and 1976. There is little information about the 1904 flood except at Minot, where it is the maximum of record. Newspaper reports in 1904 stated the 1881 flood stage was at least 3 feet higher at Minot. Of the 7 highest floods in Minot since 1904, 4 of them have occurred in the last 15 years.

The only flood control on the Souris is by reservoir structures built for other purposes. The higher floods cause extensive damage to rural and municipal property and necessitate large expenditures to protect municipal areas from floods.

Following are the instantaneous peak discharges and date of occurrence for the larger floods:

Station	Date	Instantaneous peak discharge (cubic feet per second)
Souris River near Sherwood -	April 1976	14,800
	April 1969	12,400
Souris River above Minot ---	April 1904	12,000
	April 1976	9,350
Souris River near Verendrye	April 1976	9,900
Souris River near Bantry ---	April 1976	9,330
Souris River near Westhope -	April 1976	12,600
	May 1975	6,700

Quality of Water

Chemical composition and variation.--The Souris River flows through hilly to gently rolling morainal deposits in the western part of its basin in North Dakota and across glacial lake-plain deposits in the eastern part of its basin. The quality of water in the Souris River is affected partly by the soluble material in these deposits. The glacial deposits contain significant quantities of carbonate material. Generally sodium is the predominant cation but calcium and magnesium also are significant. Bicarbonate is the predominant anion. Mean concentrations of calcium plus magnesium in equivalents per liter are nearly equal to mean bicarbonate concentrations in equivalents per liter. Likewise, the sodium and sulfate concentrations are about equivalent at the five stations. This indicates that dolomite- and mirabilite-derived material in the soils and glacial drift are likely sources for the principal ions in water in the Souris River basin.

Descriptive statistics and duration tables for specific conductance, seven principal chemical constituents and dissolved solids in water at five stations on the Souris River are given in table 9. Explanation of information presented in the duration tables is in the section on water quality in the Missouri River Basin. These data are based on the following periods of record:

Station	Period of record
Souris River near Sherwood-----	1973-83
Souris River above Minot ------	1969-83
Souris River near Verendrye --	1950-51, 1957-83
Souris River near Bantry ------	1971-83
Souris River near Westhope ----	1954-64, 1966-83

TABLE 9.--SUMMARY OF WATER-QUALITY DATA, SOURIS RIVER BASIN
[UMHOS, MICROMHOS PER CENTIMETER AT 25° CELSIUS; MG/L, MILLIGRAMS PER LITER]

STATION NUMBER: 05114000 STATION NAME AND LOCATION: SOURIS RIVER NR SHERWOOD, ND

DRAINAGE AREA: 8940 SQUARE MILES

	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
WATER QUALITY CONSTITUENT	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
	SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS									
SPECIFIC CONDUCTANCE (UMHOS)	239	2770.00	128.00	1132.69	472.10	1830.00	1420.00	1100.00	840.00	515.00
BICARBONATE FET-FLD (MG/L AS HCO3)	64	804.00	99.00	407.37	179.65	696.50	501.00	404.00	280.25	173.00
NITROGEN, NO2+NO3 TOTAL (MG/L AS N)	173	2.10	0.00	0.21	0.28	0.53	0.27	0.10	0.05	0.02
CALCIUM DISSOLVED (MG/L AS CA)	120	140.00	19.00	74.97	30.00	120.00	91.75	76.00	50.00	33.30
MAGNESIUM, DISSOLVED (MG/L AS MG)	120	91.00	7.40	40.74	17.95	63.90	54.00	39.00	27.25	18.00
SODIUM, DISSOLVED (MG/L AS NA)	120	360.00	20.00	134.37	73.32	239.00	167.50	120.00	87.25	55.20
POTASSIUM, DISSOLVED (MG/L AS K)	120	14.00	6.50	10.49	1.87	13.00	12.00	10.00	9.20	8.11
CHLORIDE, DISSOLVED (MG/L AS CL)	121	190.00	4.40	50.43	34.75	90.80	68.00	47.00	22.50	10.40
SULFATE DISSOLVED (MG/L AS SO4)	121	650.00	45.00	245.60	119.03	394.00	315.00	220.00	160.00	112.00
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	120	1800.00	160.00	772.83	345.72	1300.00	950.00	720.00	550.00	340.00

STATION NUMBER: 05117500 STATION NAME AND LOCATION: SOURIS RIVER ABOVE MINOT, ND

DRAINAGE AREA: 10600 SQUARE MILES

	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
WATER QUALITY CONSTITUENT	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
	SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS									
SPECIFIC CONDUCTANCE (UMHOS)	202	1900.00	330.00	911.73	307.97	1347.00	1060.00	870.00	697.25	565.00
BICARBONATE FET-FLD (MG/L AS HCO3)	41	436.00	139.00	285.46	73.60	406.20	321.00	291.00	227.50	183.40
NITROGEN, NO2+NO3 TOTAL (MG/L AS N)	18	0.51	0.10	0.13	0.10	0.23	0.10	0.10	0.10	0.10
CALCIUM DISSOLVED (MG/L AS CA)	59	92.00	26.00	55.17	13.99	74.00	63.00	53.00	45.00	40.00
MAGNESIUM, DISSOLVED (MG/L AS MG)	59	74.00	13.00	30.81	12.11	46.00	37.00	27.00	22.00	20.00
SODIUM, DISSOLVED (MG/L AS NA)	59	210.00	35.00	89.68	37.03	140.00	110.00	83.00	63.00	49.00
POTASSIUM, DISSOLVED (MG/L AS K)	59	19.00	5.20	11.89	2.71	16.00	13.00	11.00	10.00	8.70
CHLORIDE, DISSOLVED (MG/L AS CL)	59	71.00	7.40	19.59	12.40	34.00	20.00	16.00	12.00	10.00
SULFATE DISSOLVED (MG/L AS SO4)	59	570.00	100.00	194.64	80.90	300.00	230.00	172.00	140.00	123.00
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	59	1200.00	290.00	560.00	192.70	830.00	650.00	520.00	420.00	370.00

STATION NUMBER: 05120000 STATION NAME AND LOCATION: SOURIS RIVER NR VERENDRYE, ND

DRAINAGE AREA: 11300 SQUARE MILES

	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
WATER QUALITY CONSTITUENT	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
	SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS									
SPECIFIC CONDUCTANCE (UMHOS)	463	2430.00	260.00	1022.84	325.32	1456.00	1150.00	1010.00	811.00	642.00
BICARBONATE FET-FLD (MG/L AS HCO3)	305	772.00	88.00	380.14	122.65	550.00	445.00	377.00	303.00	227.20
NITROGEN, NO2+NO3 TOTAL (MG/L AS N)	8	1.00	0.10							
CALCIUM DISSOLVED (MG/L AS CA)	302	136.00	17.00	64.20	20.65	92.00	75.00	62.50	50.00	42.00
MAGNESIUM, DISSOLVED (MG/L AS MG)	301	66.00	6.30	33.81	10.86	47.00	40.00	34.00	27.00	20.00
SODIUM, DISSOLVED (MG/L AS NA)	318	390.00	15.00	120.54	55.99	188.10	144.25	113.00	83.75	58.00
POTASSIUM, DISSOLVED (MG/L AS K)	240	20.00	5.20	12.28	2.55	16.00	14.00	12.00	10.00	9.20
CHLORIDE, DISSOLVED (MG/L AS CL)	308	234.00	1.60	34.68	29.24	63.20	40.00	27.00	18.00	12.00
SULFATE DISSOLVED (MG/L AS SO4)	308	500.00	31.00	204.39	81.80	310.00	250.00	194.50	150.00	110.00
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	239	1500.00	140.00	677.38	243.45	1000.00	780.00	650.00	520.00	380.00

STATION NUMBER: 05122000 STATION NAME AND LOCATION: SOURIS RIVER NR BANTRY, ND

DRAINAGE AREA: 12300 SQUARE MILES

	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
WATER QUALITY CONSTITUENT	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
	SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS									
SPECIFIC CONDUCTANCE (UMHOS)	171	1660.00	355.00	934.67	275.93	1326.00	1080.00	933.00	750.00	561.00
BICARBONATE FET-FLD (MG/L AS HCO3)	48	594.00	163.00	361.90	102.77	489.00	439.50	365.50	286.00	225.30
NITROGEN, NO2+NO3 TOTAL (MG/L AS N)	16	0.50	0.09	0.15	0.11	0.36	0.12	0.10	0.10	0.10
CALCIUM DISSOLVED (MG/L AS CA)	67	110.00	27.00	65.19	20.08	98.20	81.00	61.00	50.00	40.00
MAGNESIUM, DISSOLVED (MG/L AS MG)	67	58.00	12.00	34.94	10.69	50.20	41.00	34.00	27.00	19.00
SODIUM, DISSOLVED (MG/L AS NA)	67	190.00	31.00	99.81	36.62	160.00	120.00	98.00	76.00	47.40
POTASSIUM, DISSOLVED (MG/L AS K)	67	14.00	2.00	9.59	2.14	13.00	11.00	9.40	8.50	7.34
CHLORIDE, DISSOLVED (MG/L AS CL)	67	92.00	7.50	28.10	18.00	55.00	32.00	22.00	18.00	9.42
SULFATE DISSOLVED (MG/L AS SO4)	67	350.00	69.00	193.85	60.93	282.00	230.00	190.00	160.00	110.00
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	67	1100.00	240.00	624.03	194.29	922.00	730.00	620.00	490.00	348.00

TABLE 9.--SUMMARY OF WATER-QUALITY DATA, SOURIS RIVER BASIN--Continued
[UMHOS, MICROMHOS PER CENTIMETER AT 25° CELSIUS; MG/L, MILLIGRAMS PER LITER]

STATION NUMBER: 05124000 STATION NAME AND LOCATION: SOURIS RIVER NR WESTHOPE, ND

DRAINAGE AREA: 16900 SQUARE MILES

	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
WATER QUALITY CONSTITUENT	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
SPECIFIC CONDUCTANCE (UMHOS)	566	4540.00	239.00	1094.25	542.19	1785.99	1290.00	940.50	770.00	600.50
BICARBONATE FET-FLD (MG/L AS HCO3)	334	2380.00	88.00	429.02	272.45	683.50	483.25	349.00	287.25	227.50
NITROGEN, NO2+NO3 TOTAL (MG/L AS N)	161	1.10	0.00	0.12	0.18	0.32	0.13	0.05	0.01	0.01
CALCIUM DISSOLVED (MG/L AS CA)	305	190.00	17.00	62.27	32.82	110.00	75.00	51.00	40.00	31.00
MAGNESIUM, DISSOLVED (MG/L AS MG)	306	153.00	7.50	45.70	23.41	77.90	54.25	39.00	31.00	24.00
SODIUM, DISSOLVED (MG/L AS NA)	387	672.00	18.00	126.17	77.90	213.60	150.00	110.00	82.00	55.80
POTASSIUM, DISSOLVED (MG/L AS K)	273	61.00	4.10	15.01	5.80	22.00	17.00	14.00	12.00	9.80
CHLORIDE, DISSOLVED (MG/L AS CL)	326	108.00	4.60	29.70	18.36	57.00	36.00	26.00	17.00	11.00
SULFATE DISSOLVED (MG/L AS SO4)	379	1100.00	33.00	229.67	145.02	420.00	280.00	180.00	139.00	115.00
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	272	2100.00	150.00	723.12	349.86	1100.00	850.00	630.00	500.00	400.00

Dissolved-solids concentrations in the Souris River basin generally are least during high flows and greatest during low flows. Period-of-record mean dissolved-solids concentrations for high flows (snowmelt in March-April) are compared with those for low flows (August-September) for five stations on the Souris River in figure 35. These concentrations are affected somewhat by Lake Darling, located on the Souris River between the Sherwood and Minot stations. The lake decreases mean concentrations of dissolved solids from 773 milligrams per liter at the Sherwood station to 560 milligrams per liter at the Minot station. Likewise, the mean low-flow dissolved-solids concentration (fig. 35) at Minot is greater, but the mean high-flow dissolved-solids concentration is less than the respective mean dissolved-solids concentration at Sherwood. This indicates that Lake Darling also tends to decrease the variation in dissolved solids.

A similar situation occurs between the Bantry and Westhope stations. Between these stations, water flows over a series of dams in the J. Clarke Salyer National Wildlife Refuge. These impoundments tend to attenuate changes in water quality between the Bantry and Westhope stations.

Concentrations of five principal constituents in water at five stations are compared in figure 36. These diagrams show a combination of descriptive statistics and percentile data for each constituent in downstream order, left to right. Variations from station to station are apparent. For example, mean sulfate concentrations decrease by about 25 percent from the Sherwood station to the below Minot station. Attenuation in Lake Darling decreases the variation in the concentration of sulfate and other dissolved constituents.

A trend analysis of dissolved solids in water from the Souris River near Westhope (Wells and Schertz, 1983) for 1969-82 indicates that no time trend in dissolved-solids concentration could be detected.

Suitability for use.--Water in the Souris River, based on chemical composition, appears to be marginally suitable for domestic use. Mean dissolved-solids concentrations at the five stations in the Souris basin range from 560 milligrams per liter to 723 milligrams per liter. The secondary drinking water standard is 500 milligrams per liter.

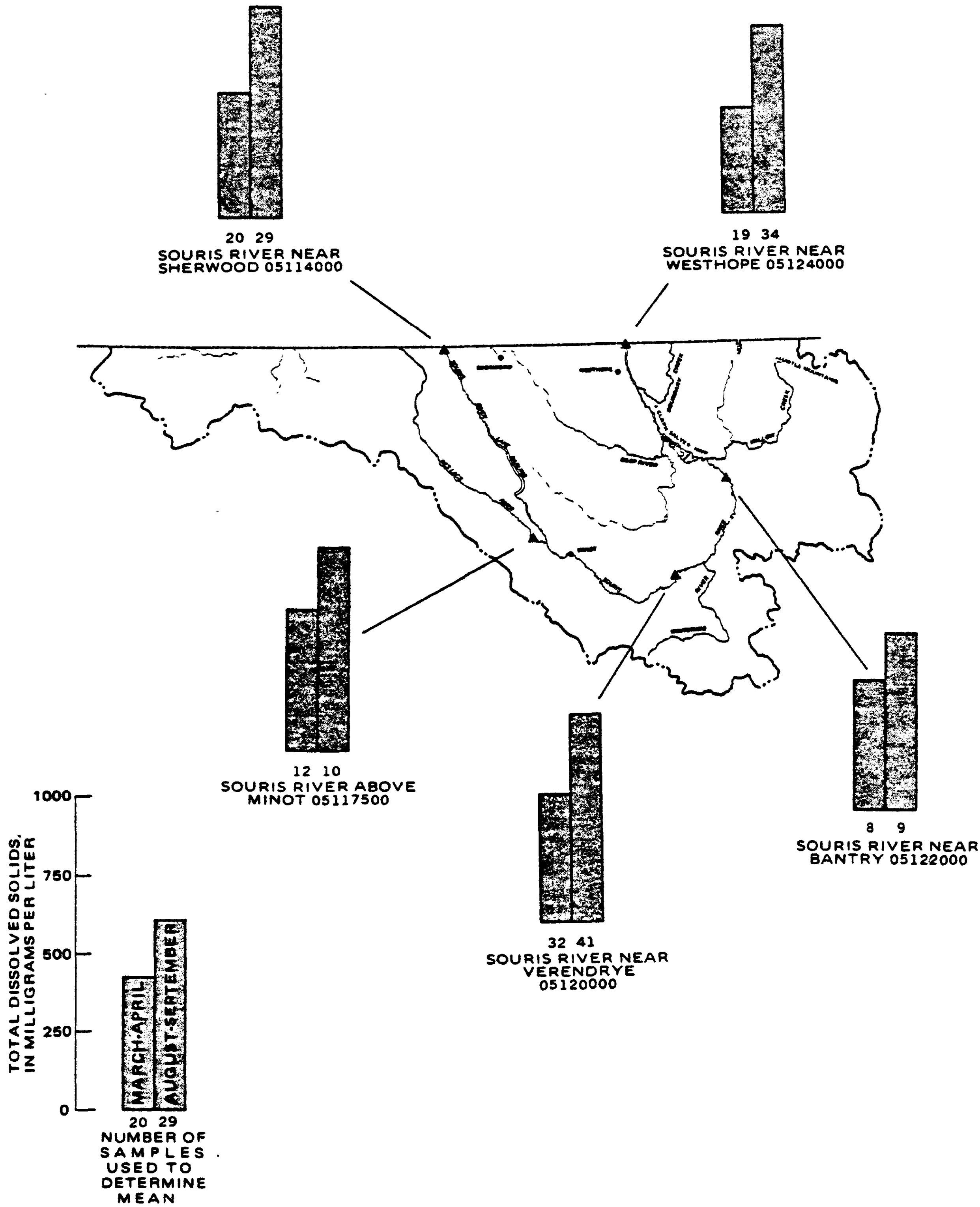


FIGURE 35.—Period-of-record mean dissolved-solids concentrations for high flows (March-April) and low flows (August-September) at selected stations, Souris River basin, North Dakota.

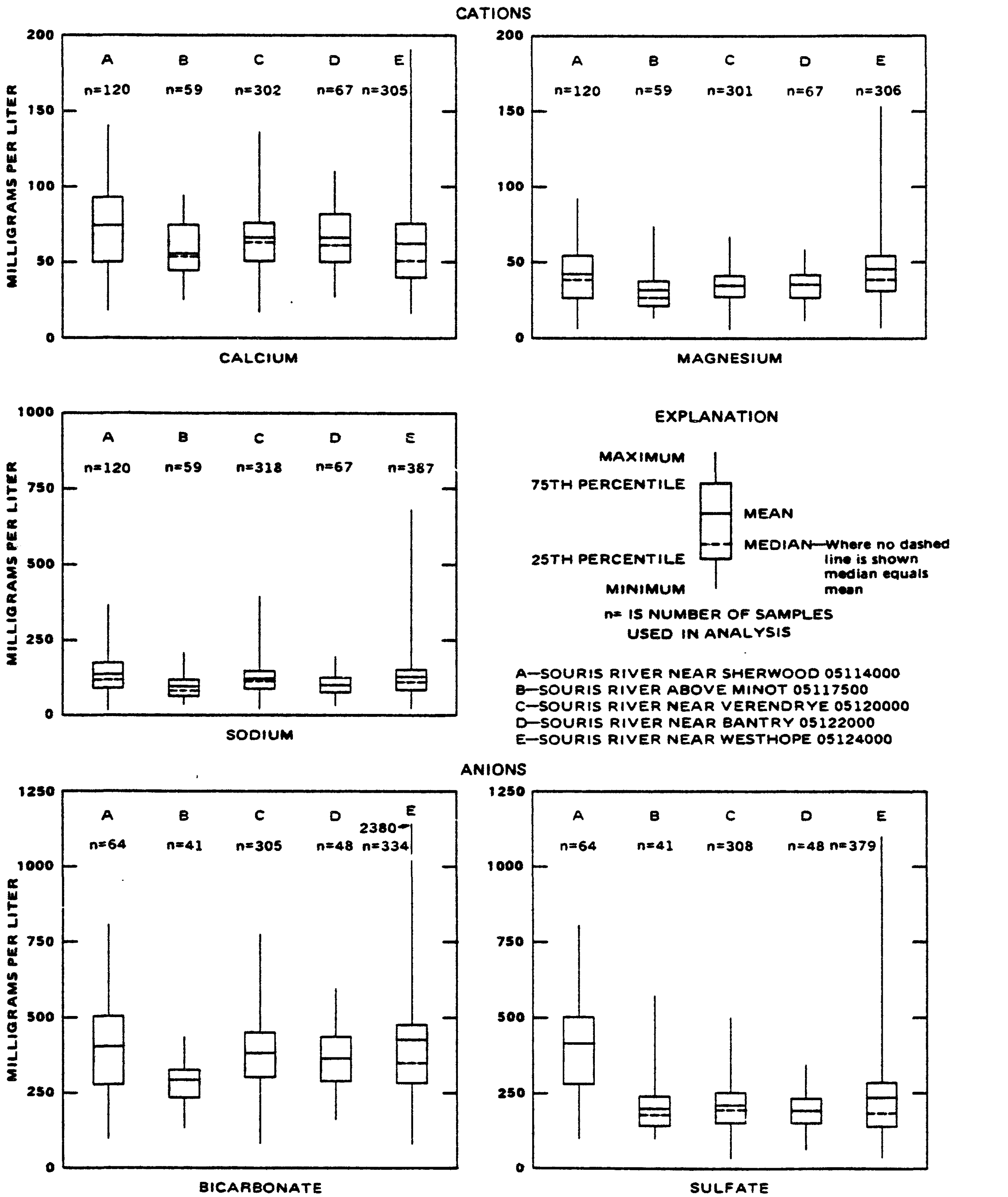


FIGURE 36.—Statistical comparisons of concentrations of principal cations and anions at selected stations, Souris River basin, North Dakota.

Nitrate-nitrogen concentrations are much less than the Federal primary drinking water standard at all stations in the Souris River basin (table 10). In fact, the 90th-percentile concentrations for nitrate-nitrogen are all considerably less than the more restrictive State standard for class I streams.

Lead and selenium are the only trace constituents for which maximum concentrations have exceeded the Federal standards in water from the Souris basin (table 10). A lead concentration of 200 micrograms per liter was measured in water at the Sherwood station. Because the 90th-percentile concentration for lead in water at the Sherwood station is 9.2 micrograms per liter as compared to the Federal drinking water standard of 50 micrograms per liter, the concentration of 200 micrograms per liter for lead is thought to be related to an isolated contamination event or to random error. Maximum selenium concentrations of 12 micrograms per liter at Verendrye and 20 micrograms per liter at Westhope exceeded the Federal standard of 10 micrograms per liter. However, the 90th-percentile concentrations for selenium at each station are less than the standard.

Water from the Souris River may be suitable for irrigation if used with caution. Specific-conductance and SAR values are indicated in the diagrams (fig. 37) for each of the five stations on the Souris River. At times, specific-conductance values may be in the C3 category at each station. This means that the water could be used only with adequate leaching on sandy soils if salinity problems are to be avoided. In contrast, 90th-percentile values for SAR do not exceed S1.

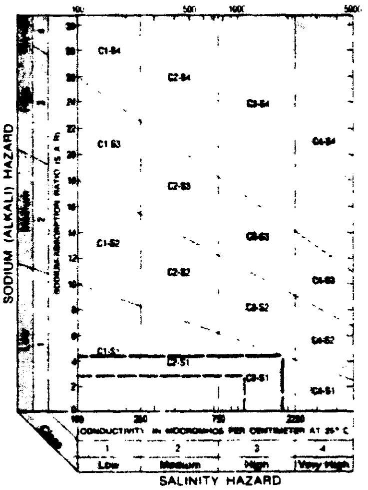
Boron concentrations at all stations for the 90th percentile are less than the irrigation use criterion of 750 micrograms per liter indicating that if water from the Souris River was used for irrigation, boron concentrations probably would not be toxic to crops.

Sediment

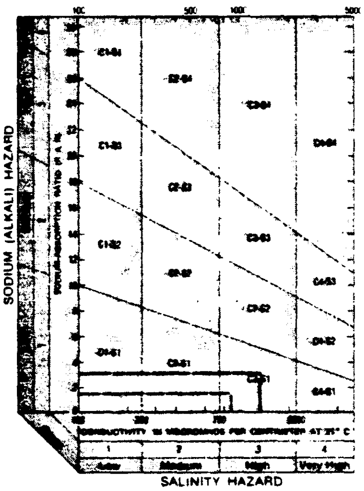
Little daily information is available on fluvial sediment for the Souris River. However, most of the sediment movement would occur in March-May during high flows associated with snowmelt and ice breakup. Available data are not indicative of total sediment loads in the stream.

Devils Lake Basin

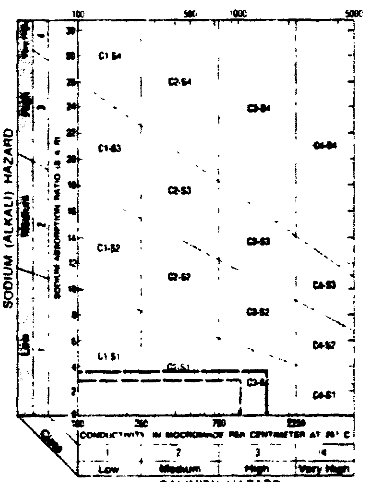
The Devils Lake basin is a closed or noncontributing basin in the Sheyenne River basin, which is a tributary of the Red River (fig. 15). The total drainage area is about 3,900 square miles, and 3,130 square miles of the total area is tributary to Devils Lake; the remainder is tributary to East Devils Lake and Stump Lake. The topographic relief and surficial landforms are of glacial origin, and there are numerous wetland depressions throughout the basin; many connected by poorly defined channels and swales.



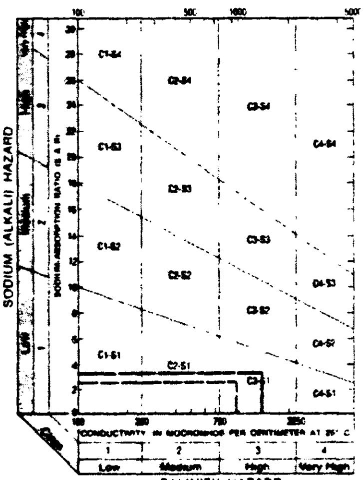
SOURIS RIVER NEAR SHERWOOD 05114000



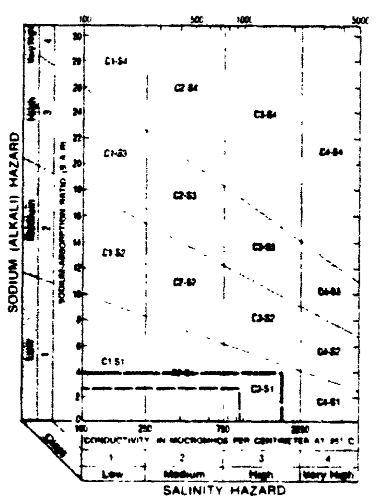
SOURIS RIVER ABOVE MINOT 05117500



SOURIS RIVER NEAR VERENDRYE 05120000



SOURIS RIVER NEAR BANTRY 05122000



SOURIS RIVER NEAR WESTHOPE 05124000

EXPLANATION

- - - - - AREA ENCLOSES SAMPLE VALUES FOR CONDUCTIVITY AND SAR LESS THAN OR EQUAL TO 50 PERCENT OF THE TOTAL NUMBER OF SAMPLES

— — — AREA ENCLOSES SAMPLE VALUES FOR CONDUCTIVITY AND SAR LESS THAN OR EQUAL TO 90 PERCENT OF THE TOTAL NUMBER OF SAMPLES

C2–S2 CLASSIFICATION, BASED ON BOTH CONDUCTIVITY (C) AND SAR (S), USED TO DETERMINE IRRIGATION SUITABILITY

FIGURE 37.—Comparisons of irrigation suitability of water at selected stations, Souris River basin, North Dakota. (Diagram from U.S. Salinity Laboratory Staff, 1954.)

TABLE 10.--SUMMARY OF TRACE CONSTITUENT DATA, SOURIS RIVER BASIN
[UG/L, MICROGRAMS PER LITER]

STATION NUMBER: 05114000 STATION NAME AND LOCATION: SOURIS RIVER NR SHERWOOD, ND

DRAINAGE AREA: 8940 SQUARE MILES

	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
WATER QUALITY CONSTITUENT	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
ARSENIC DISSOLVED (UG/L AS AS)	23	8.00	1.00	2.61	1.92	5.60	4.00	2.00	1.00	1.00
BARIUM, DISSOLVED (UG/L AS BA)	23	200.00	48.00	96.91	29.05	110.00	100.00	100.00	93.00	51.20
BORON, DISSOLVED (UG/L AS B)	120	1100.00	40.00	279.58	160.34	470.00	347.50	250.00	180.00	110.00
CADMIUM DISSOLVED (UG/L AS CD)	22	3.00	0.00	1.05	0.79	2.00	1.25	1.00	0.75	0.00
CHROMIUM, DISSOLVED (UG/L AS CR)	23	10.00	0.00	5.65	5.07	10.00	10.00	10.00	0.00	0.00
COPPER, DISSOLVED (UG/L AS CU)	24	20.00	0.00	2.54	3.95	4.50	2.75	2.00	1.00	0.00
IRON, DISSOLVED (UG/L AS FE)	51	3200.00	4.00	162.92	462.39	298.00	100.00	59.00	37.00	10.00
LEAD, DISSOLVED (UG/L AS PB)	23	200.00	0.00	10.61	41.37	9.20	3.00	1.00	0.00	0.00
MANGANESE, DISSOLVED (UG/L AS MN)	51	4000.00	6.00	413.63	749.15	1560.00	260.00	140.00	40.00	11.40
SILVER, DISSOLVED (UG/L AS AG)	13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ZINC, DISSOLVED (UG/L AS ZN)	24	60.00	0.00	11.62	12.15	20.00	18.25	8.50	5.25	1.00
SELENIUM, DISSOLVED (UG/L AS SE)	24	2.00	0.00	0.87	0.45	1.00	1.00	1.00	1.00	0.00
MERCURY DISSOLVED (UG/L AS HG)	23	0.50	0.00	0.17	0.18	0.50	0.10	0.10	0.10	0.00

STATION NUMBER: 05117500 STATION NAME AND LOCATION: SOURIS RIVER ABOVE MINOT, ND

DRAINAGE AREA: 10600 SQUARE MILES

	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
WATER QUALITY CONSTITUENT	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
ARSENIC DISSOLVED (UG/L AS AS)	9	11.00	2.00							
BARIUM, DISSOLVED (UG/L AS BA)	9	140.00	47.00							
BORON, DISSOLVED (UG/L AS B)	59	1100.00	0.00	229.84	223.50	480.00	280.00	180.00	80.00	30.00
CADMIUM DISSOLVED (UG/L AS CD)	9	3.00	1.00							
CHROMIUM, DISSOLVED (UG/L AS CR)	9	10.00	10.00							
COPPER, DISSOLVED (UG/L AS CU)	9	4.00	1.00							
IRON, DISSOLVED (UG/L AS FE)	39	760.00	0.00	88.13	142.08	230.00	120.00	40.00	8.00	0.00
LEAD, DISSOLVED (UG/L AS PB)	9	3.00	1.00							
MANGANESE, DISSOLVED (UG/L AS MN)	39	6500.00	0.00	331.77	1035.55	480.00	240.00	100.00	20.00	10.00
ZINC, DISSOLVED (UG/L AS ZN)	9	34.00	3.00							
SELENIUM, DISSOLVED (UG/L AS SE)	9	1.00	1.00							
MERCURY DISSOLVED (UG/L AS HG)	9	0.10	0.10							

STATION NUMBER: 05120000 STATION NAME AND LOCATION: SOURIS RIVER NR VERENDRYE, ND

DRAINAGE AREA: 11300 SQUARE MILES

	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
WATER QUALITY CONSTITUENT	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
ARSENIC DISSOLVED (UG/L AS AS)	26	20.00	0.00	4.1[illegible]	4.21	8.60	6.00	3.50	1.75	0.00
BARIUM, DISSOLVED (UG/L AS BA)	24	400.00	0.00	77.92	93.06	200.00	100.00	100.00	0.00	0.00
BORON, DISSOLVED (UG/L AS B)	191	590.00	20.00	214.08	[illegible].34	360.00	270.00	200.00	130.00	100.00
CADMIUM DISSOLVED (UG/L AS CD)	26	2.00	0.00	0.27	0.67	2.00	0.00	0.00	0.00	0.00
CHROMIUM, DISSOLVED (UG/L AS CR)	26	20.00	0.00	0.77	3.92	0.00	0.00	0.00	0.00	0.00
COPPER, DISSOLVED (UG/L AS CU)	22	60.00	0.00	11.50	16.84	44.60	20.00	3.00	1.50	0.00
IRON, DISSOLVED (UG/L AS FE)	39	1800.00	2.10	133.22	296.74	350.00	96.00	50.00	30.00	10.00
LEAD, DISSOLVED (UG/L AS PB)	26	9.00	0.00	1.31	2.33	5.60	2.00	0.00	0.00	0.00
MANGANESE, DISSOLVED (UG/L AS MN)	28	700.00	0.00	177.43	158.39	379.00	249.25	160.00	36.00	19.00
SILVER, DISSOLVED (UG/L AS AG)	22	2.00	0.00	0.50	0.80	2.00	1.00	0.00	0.00	0.00
ZINC, DISSOLVED (UG/L AS ZN)	27	120.00	0.00	18.11	22.98	30.20	20.00	20.00	0.00	0.00
SELENIUM, DISSOLVED (UG/L AS SE)	23	12.00	0.00	3.48	3.93	10.00	7.00	1.00	1.00	0.00
MERCURY DISSOLVED (UG/L AS HG)	21	0.70	0.00	0.31	0.22	0.50	0.50	0.40	0.10	0.00

STATION NUMBER: 05122000 STATION NAME AND LOCATION: SOURIS RIVER NR BANTRY, ND

DRAINAGE AREA: 12300 SQUARE MILES

	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
WATER QUALITY CONSTITUENT	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
ARSENIC DISSOLVED (UG/L AS AS)	9	10.00	2.00							
BARIUM, DISSOLVED (UG/L AS BA)	8	190.00	64.00							
BORON, DISSOLVED (UG/L AS B)	66	1600.00	0.00	232.42	232.41	389.00	290.00	210.00	100.00	20.00
CADMIUM DISSOLVED (UG/L AS CD)	9	3.00	1.00							
CHROMIUM, DISSOLVED (UG/L AS CR)	9	10.00	10.00							
COPPER, DISSOLVED (UG/L AS CU)	9	3.00	1.00							
IRON, DISSOLVED (UG/L AS FE)	60	1400.00	0.00	112.77	198.75	275.00	137.50	60.00	12.50	0.00
LEAD, DISSOLVED (UG/L AS PB)	9	2.00	1.00							
MANGANESE, DISSOLVED (UG/L AS MN)	59	3000.00	0.00	255.76	597.41	820.00	160.00	40.00	10.00	8.00
ZINC, DISSOLVED (UG/L AS ZN)	9	24.00	3.00							
SELENIUM, DISSOLVED (UG/L AS SE)	9	1.00	1.00							
MERCURY DISSOLVED (UG/L AS HG)	9	0.10	0.10							

TABLE 10.--SUMMARY OF TRACE CONSTITUENT DATA, SOURIS RIVER BASIN--Continued
[UG/L, MICROGRAMS PER LITER]

STATION NUMBER: 05124000 STATION NAME AND LOCATION: SOURIS RIVER NR WESTHOPE, ND

DRAINAGE AREA: 16900 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS										
ARSENIC DISSOLVED (UG/L AS AS)	56	12.00	0.00	4.70	2.94	10.00	6.00	4.00	2.25	1.70
BARIUM, DISSOLVED (UG/L AS BA)	48	400.00	0.00	96.77	84.00	200.00	100.00	99.50	46.75	0.00
BORON, DISSOLVED (UG/L AS B)	220	480.00	40.00	195.73	79.46	280.00	240.00	190.00	140.00	100.00
CADMIUM DISSOLVED (UG/L AS CD)	56	3.00	0.00	0.86	0.82	2.00	1.00	1.00	0.00	0.00
CHROMIUM, DISSOLVED (UG/L AS CR)	56	20.00	0.00	2.13	5.15	10.00	1.00	0.00	0.00	0.00
COPPER, DISSOLVED (UG/L AS CU)	56	52.00	0.00	4.50	10.50	10.60	2.00	2.00	1.00	0.00
IRON, DISSOLVED (UG/L AS FE)	67	340.00	0.00	63.64	66.82	157.20	80.00	40.00	20.00	10.80
LEAD, DISSOLVED (UG/L AS PB)	56	14.00	0.00	1.52	2.53	5.00	2.00	1.00	0.00	0.00
MANGANESE, DISSOLVED (UG/L AS MN)	61	2700.00	0.00	308.18	539.36	1070.00	420.00	47.00	10.50	8.00
SILVER, DISSOLVED (UG/L AS AG)	49	2.00	0.00	0.35	0.60	1.00	1.00	0.00	0.00	0.00
ZINC, DISSOLVED (UG/L AS ZN)	57	150.00	0.00	15.02	21.58	32.00	20.00	10.00	3.00	0.00
SELENIUM, DISSOLVED (UG/L AS SE)	53	20.00	0.00	2.58	4.61	8.80	1.00	1.00	1.00	0.00
MERCURY DISSOLVED (UG/L AS HG)	50	0.50	0.00	0.22	0.19	0.50	0.50	0.10	0.10	0.00

Big Coulee is the principal tributary to Devils Lake and has its headwaters on the eastern slopes of the Turtle Mountains. Edmore, Starkweather and Calio Coulees flow into a chain of lakes north of Devils Lake (fig. 38). Formerly, in the wetter years, discharge from these tributaries reached Devils Lake via Chain Lake, Lake Alice, Lake Irvine, and Big Coulee. In 1979, channel A (fig. 38) was constructed from the southern shore of Dry Lake to the northern shore of Devils Lake. Channel A was constructed to provide a means of diverting discharge from Edmore and Starkweather Coulees, thereby bypassing the longer drainage network through the downstream lakes and Big Coulee.

There are no major flood-storage structures in Devils Lake basin. Drainage of wetlands to increase agricultural production has increased concerns as to the possible hydrologic effect on water-surface altitudes of Devils Lake (see for example, Miller and Frink, 1984, p 16-17). The majority of water used in the basin is for stock watering and wildlife production.

Streamflow Statistics

Streamflow statistics for tributaries in the Devils Lake basin are presented in figure 38 and in table 10a:

TABLE 10a.--Daily streamflow statistics for three gaging stations on tributaries to Devils Lake, North Dakota

Station number	Station name	Drainage area (square miles)		Period of record (water years)	Daily discharge (cubic feet per second)				
		Total	Contributing		Mean	Median	Maximum	Minimum	10-percentile value
05056100	Mauvais Coulee near Cando	387	377	1957-82	19.1	0.05	2,580	0	0
05056200	Edmore Coulee near Edmore	382	282	1958-82	13.3	.01	1,090	0	0
05056400	Big Coulee near Churchs Ferry	2,510	1,820	1951-82	40.8	.01	1,400	0	0

The relatively large difference between the mean daily discharge and the median daily discharge indicates that the mean daily discharge is significantly affected by relatively few high-flow days. This is further emphasized by the fact that there is no flow on at least 10 percent of the days. At each of the three stations listed in the table above there have been as many as 330 days with no flow during a year.

The streamflow at the Big Coulee gage near Churchs Ferry is affected by a large quantity of natural storage in the lakes upstream from the gage. In the Devils Lake basin, the major tributaries such as Edmore, Starkweather, Calio, and Mauvais Coulees flow through a series of poorly connected lakes (fig. 38) and enter Devils Lake via Channel A or Big Coulee. Large losses, especially in the dryer years, occur in these upstream lakes. These losses are a result of evaporation from the lake surface, storage required to reach the spill altitude to the next lake, and ground-water recharge.

The 1965 water year provides a good example of these losses when a combined discharge of 29,900 acre-feet was recorded at the Mauvais Coulee and Edmore Coulee gaging stations. A discharge of 1,310 acre-feet was recorded at the Big Coulee near Churchs Ferry for the 1965 water year. Thus, the two gaging stations that account for 36 percent of the contributing drainage area at Big Coulee near Churchs Ferry had a combined discharge that was 28,600 acre-feet greater than the recorded flow at the downstream gage. Analysis of the annual discharge data indicates that losses occur in many years. Therefore, the discharge entering Devils Lake from year to year varies not only according to the volume of flow from the upstream tributaries but also varies according to the hydrologic interaction of the upstream lakes which is a function of variation in climate.

The timing, as well as the quantity, of flow entering Devils Lake is affected by the upstream lakes. The upstream lakes and interconnected channels tend to attenuate the discharge as indicated in the bar graphs in figure 38. The mean monthly discharge for Mauvais and Edmore Coulees is greatest in April, decreases significantly in May, and the combined mean monthly flow is less than 17 cubic feet per second in June. Downstream at the Big Coulee near Churchs Ferry gage, the mean monthly discharge is greatest in May and decreases slowly from 117 cubic feet per second in June to 13.2 cubic feet per second in September.

Water-Level Fluctuations and Flooding

Rising lake levels of Devils Lake (fig. 38) pose a flood threat to the community of Devils Lake, a National Guard Camp, roads, and sewer and lagoon systems of several other communities. Water-surface altitudes of Devils Lake were recorded, albeit somewhat sporadically, from 1867 to 1901, and these records have been authenticated by the U.S. Geological Survey. In 1901, the U.S. Geological Survey established a gage at Devils Lake. The maximum recorded water-surface altitude of 1,438 feet above sea level for the period of record at Devils Lake occurred in 1867 when the lake had a surface area of about 140 square miles. From 1867, the water-surface altitude of Devils Lake declined almost continuously until 1940 when it reached a recorded low of 1,400.9 feet above sea level, resulting in a shallow, brackish body of water covering 10.2 square miles (North Dakota State Engineer, 1944). From 1940 to 1956, Devils Lake generally rose; from 1956 to 1968, it again generally

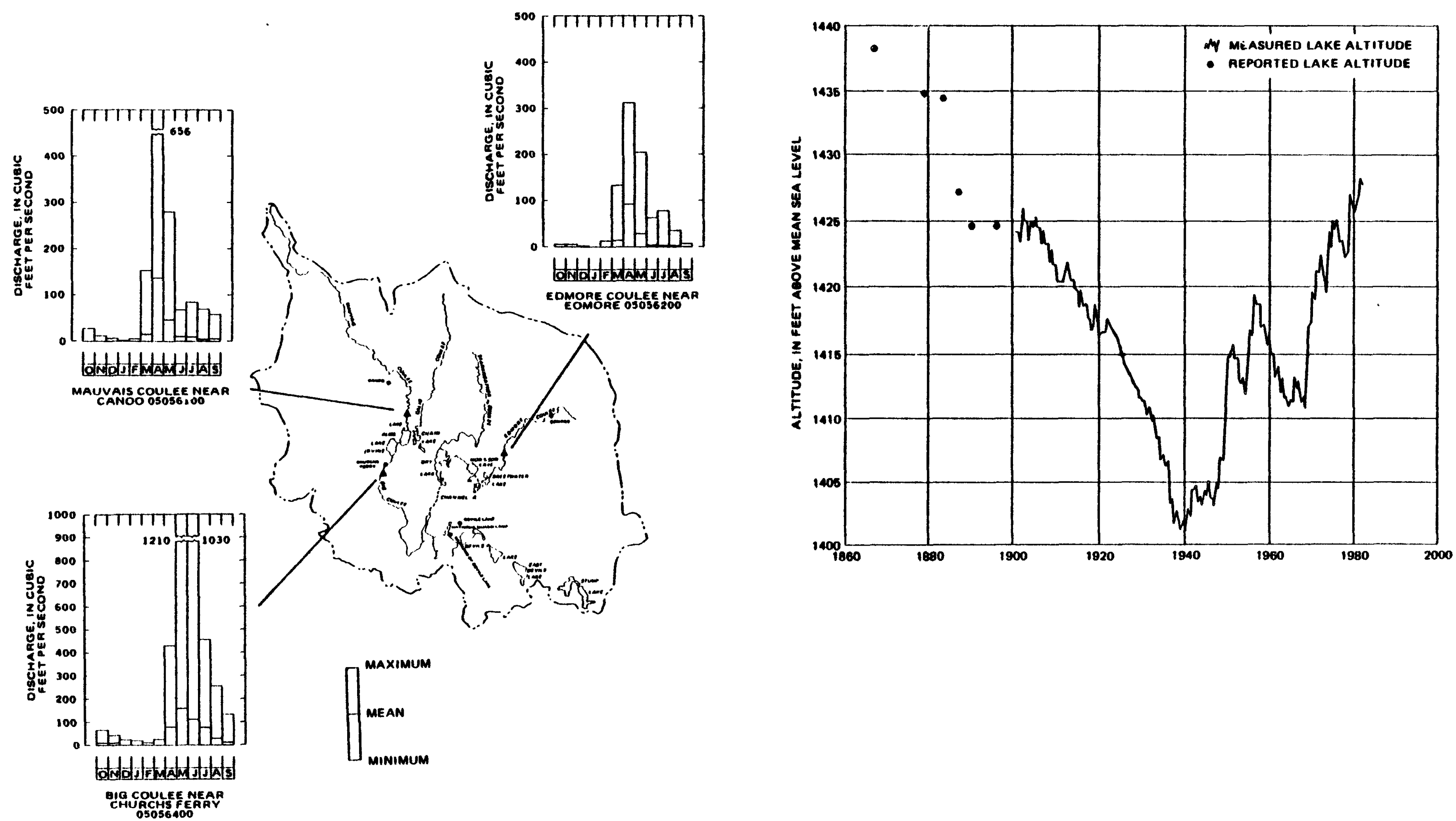


FIGURE 38.—Monthly discharge for period of record at selected gaging stations, Devils Lake basin, and historic water levels for Devils Lake.

declined; and in 1982 reached to a peak of 1,426.9 feet. Lake levels have remained fairly stable during 1983 and 1984, and the surface area of the lake is about 84 square miles.

In addition to the flood problems associated with rising lake levels, extensive areas of agricultural land are prone to flood damage in the wetter years because the poorly defined tributaries have limited channel capacities.

Quality of Water

Chemical composition and variation.--The quality of water at the three stream stations in the Devils Lake basin is not unusual, although the closed basin in which the streams are located is unique among the principal drainage basins in North Dakota. Morainal and glacial-drift deposits blanket the basin and affect the quality of water in the three principal flowing streams. Bicarbonate and sulfate are the principal anions in about equivalent concentrations in each stream. Calcium, magnesium, and sodium are the principal cations, occurring in about equivalent concentrations in water from each stream. Gypsum-, dolomite-, and mirabilite-derived materials in soils, glacial drift, and morainal deposits probably are sources for these constituents. The Devils Lake chain located in the southern part of the basin not only stores discharge from the streams but also is an evaporation basin.

Descriptive statistics and duration tables for specific conductance, seven chemical constituents, and dissolved solids, for three flowing streams in the Devils Lake basin are given in table 11. Explanation of information presented in the duration tables is in the section of water quality in the Missouri River basin. These data are based on the following periods of record:

Station	Period of record
Mauvais Coulee near Cando -------	1972-83
Edmore Coulee near Edmore -------	1972-83
Big Coulee near Churches Ferry --	1958, 1961-83

Dissolved-solids concentrations generally are least during high flows and are greatest during low flows. Period-of-record mean dissolved-solids concentrations for high flows (snowmelt in March-April) are compared with mean dissolved-solids concentrations for low flows (August-September) at the three stations in figure 39. Dissolved-solids concentrations at low flow are nearly double those at high flow at both the Mauvais and Big Coulee stations.

Concentrations of five principal constituents in water at the three stations are compared in figure 40. These diagrams include a combination of descriptive statistics and percentile data for each constituent in downstream order, left to right. For each constituent, concentrations generally are least for all statistics or percentiles at the Edmore Coulee station.

Trend analyses for dissolved solids are not available for the three stream stations in the Devils Lake basin.

TABLE 11.--SUMMARY OF WATER-QUALITY DATA, DEVILS LAKE BASIN
[UMHOS, MICROMHOS PER CENTIMETER AT 25° CELSIUS; MG/L, MILLIGRAMS PER LITER]

STATION NUMBER: 05056100 STATION NAME AND LOCATION: MAUVAIS COULEE NR CANDO, ND

DRAINAGE AREA: 387 SQUARE MILES

WATER QUALITY CONSTITUENT	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
	SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS									
SPECIFIC CONDUCTANCE (UMHOS)	112	2899.99	275.00	1060.85	543.79	1735.00	1300.00	960.00	672.50	420.00
BICARBONATE FET-FLD (MG/L AS HCO3)	23	481.00	67.00	262.74	110.94	422.00	363.00	261.00	159.00	117.60
CALCIUM DISSOLVED (MG/L AS CA)	28	170.00	26.00	75.96	32.40	131.00	88.25	75.50	49.50	40.60
MAGNESIUM, DISSOLVED (MG/L AS MG)	28	100.00	8.50	48.38	23.54	78.10	66.75	49.00	26.25	20.30
SODIUM, DISSOLVED (MG/L AS NA)	28	120.00	11.00	53.00	31.14	101.00	70.25	55.50	22.50	16.00
POTASSIUM, DISSOLVED (MG/L AS K)	28	22.00	4.90	10.46	3.87	15.20	13.75	9.50	7.52	6.38
CHLORIDE, DISSOLVED (MG/L AS CL)	28	55.00	4.10	23.74	14.28	46.30	33.50	22.00	13.25	4.74
SULFATE DISSOLVED (MG/L AS SO4)	28	610.00	61.00	248.32	141.60	461.00	377.50	225.00	125.00	86.80
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	28	1300.00	160.00	609.64	273.72	938.00	785.00	610.00	335.00	294.00

STATION NUMBER: 05056200 STATION NAME AND LOCATION: EDMORE COULEE NR EDMORE, ND

DRAINAGE AREA: 382 SQUARE MILES

WATER QUALITY CONSTITUENT	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
	SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS									
SPECIFIC CONDUCTANCE (UMHOS)	75	1510.00	225.00	693.35	299.95	1092.00	920.00	725.00	400.00	344.00
BICARBONATE FET-FLD (MG/L AS HCO3)	15	451.00	72.00	206.87	120.64	420.40	293.00	152.00	120.00	82.20
CALCIUM DISSOLVED (MG/L AS CA)	19	86.00	20.00	51.37	21.41	84.00	76.00	42.00	34.00	28.00
MAGNESIUM, DISSOLVED (MG/L AS MG)	19	40.00	7.80	22.50	10.94	36.00	34.00	19.00	13.00	9.70
SODIUM, DISSOLVED (MG/L AS NA)	19	99.00	15.00	47.21	26.86	89.00	74.00	34.00	25.00	19.00
POTASSIUM, DISSOLVED (MG/L AS K)	19	27.00	4.50	11.34	5.68	19.00	13.00	11.00	6.40	5.00
CHLORIDE, DISSOLVED (MG/L AS CL)	19	40.00	4.10	17.62	10.45	37.00	24.00	16.00	7.10	5.50
SULFATE DISSOLVED (MG/L AS SO4)	19	270.00	51.00	130.26	70.67	220.00	200.00	100.00	67.00	53.00
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	19	680.00	150.00	404.74	178.21	640.00	600.00	360.00	250.00	210.00

STATION NUMBER: 05056400 STATION NAME AND LOCATION: BIG COULEE NR CHURCHS FERRY, ND

DRAINAGE AREA: 2510 SQUARE MILES

WATER QUALITY CONSTITUENT	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
	SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS									
SPECIFIC CONDUCTANCE (UMHOS)	208	2800.00	229.00	955.21	489.15	1568.00	1107.50	830.50	652.00	435.00
BICARBONATE FET-FLD (MG/L AS HCO3)	133	989.00	52.00	309.54	142.81	477.60	368.50	302.00	226.50	128.20
CALCIUM DISSOLVED (MG/L AS CA)	146	229.00	19.00	71.75	38.32	118.30	79.00	62.50	49.00	38.00
MAGNESIUM, DISSOLVED (MG/L AS MG)	146	130.00	6.10	40.72	22.44	75.30	47.00	37.00	26.00	16.00
SODIUM, DISSOLVED (MG/L AS NA)	146	298.00	9.40	74.98	58.26	170.00	88.00	54.00	37.75	26.10
POTASSIUM, DISSOLVED (MG/L AS K)	143	65.00	5.30	21.23	9.51	31.60	25.00	20.00	14.00	11.00
CHLORIDE, DISSOLVED (MG/L AS CL)	146	117.00	6.20	30.67	22.12	59.60	39.25	23.50	16.00	11.70
SULFATE DISSOLVED (MG/L AS SO4)	146	850.00	36.00	226.42	172.23	463.00	260.00	170.00	120.00	96.00
SOLIDS, SUM OF CONSTITUENTS, DISSOLVED	141	1900.00	130.00	627.30	359.84	1100.00	715.00	520.00	405.00	292.00

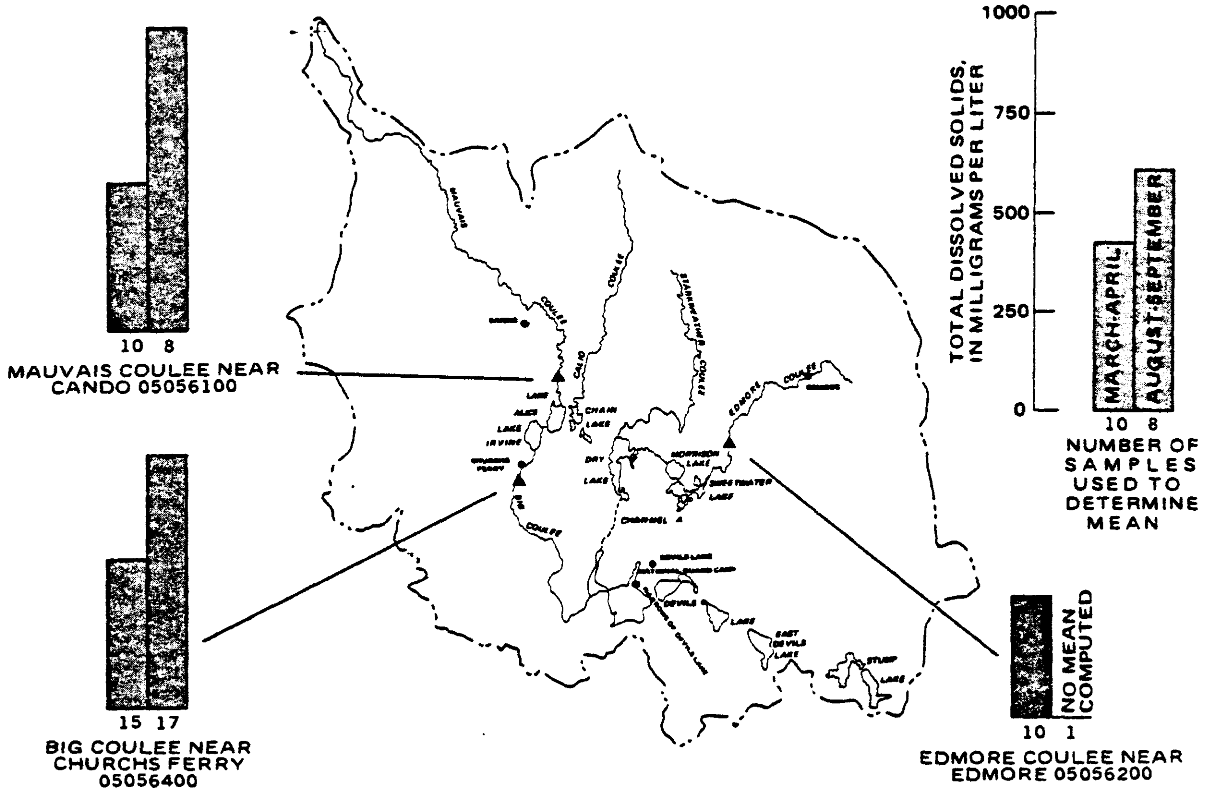


FIGURE 39.—Period-of-record mean dissolved-solids concentrations for high flows (March-April) and low flows (August-September) at selected stations, Devils Lake basin, North Dakota.

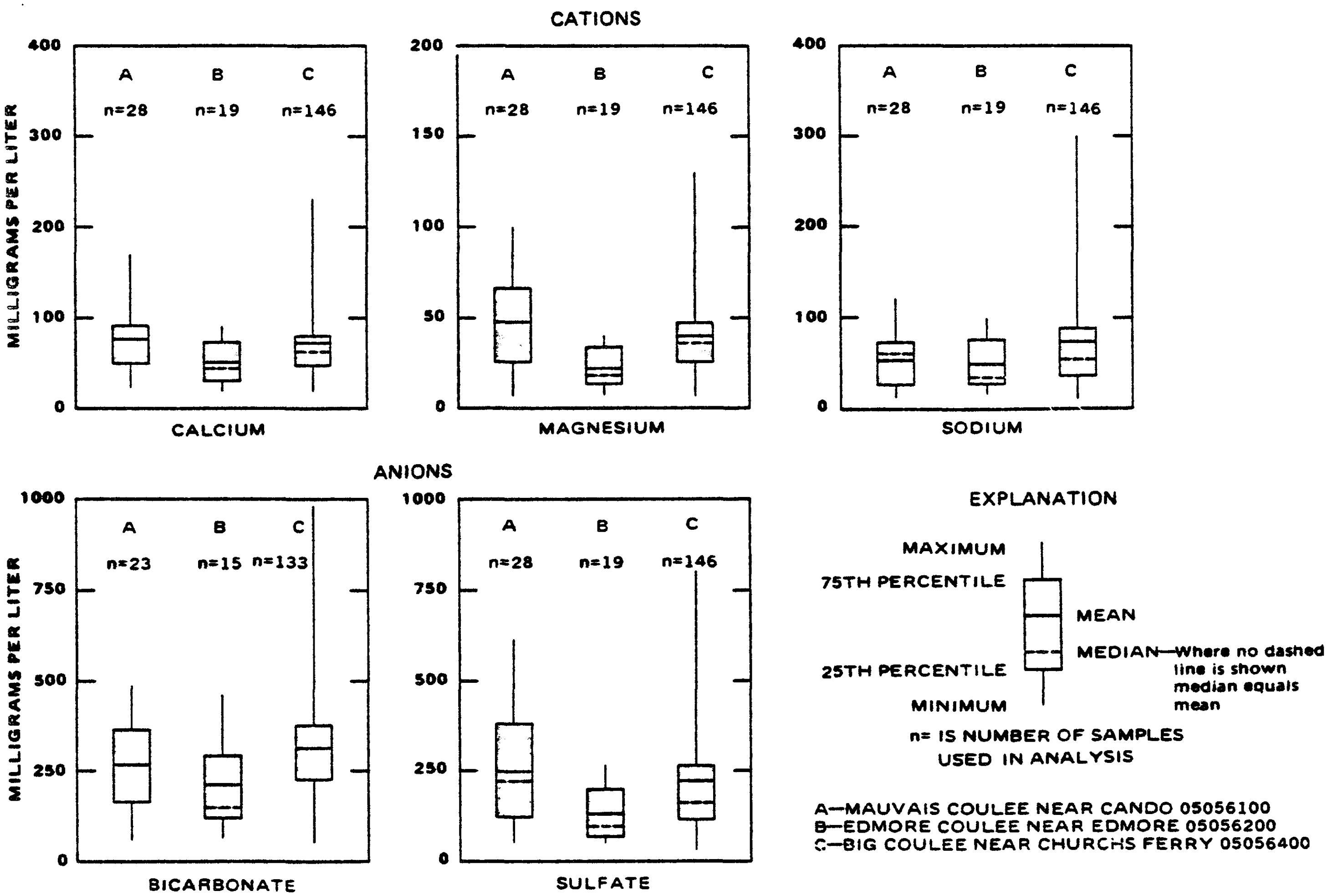


FIGURE 40.—Statistical comparisons of concentrations of principal cations and anions at selected stations, Devils Lake basin, North Dakota.

The Devils Lake chain in the southern part of the basin is the terminus for all streamflow in the basin. Water quality in Devils Lake is related to the lake level which, in turn, depends on the volume of flow delivered to the lake by Big Coulee and Channel A. During extended dry periods, flow decreases in Big Coulee and Channel A, the lake level declines, and concentrations of dissolved constituents increase. During extended wet periods, flow increases in Big Coulee and Channel A, the lake-level rises, and concentrations of dissolved constituents decrease. During water years 1961-69, relatively minor fluctuations occurred in the lake levels, and dissolved-solids concentrations in the lake remained relatively constant, averaging 11,400 milligrams per liter. During water year 1970, the beginning of a decade of wet years, flow into Devils Lake increased substantially and the lake surface began to rise at an average rate of 1.4 feet per year. Associated with this, dissolved-solids concentrations began to decrease. Mean dissolved-solids concentrations for two samples collected in water year 1969 at the Narrows of Devils Lake was 12,100 milligrams per liter. Mean dissolved-solids concentration for four samples collected in water year 1979 at the same station was 2,430 milligrams per liter. Mean dissolved-solids concentrations for samples collected at the Narrows for 19 water years are as follows:

Water year	Number of samples	Mean dissolved solids (milligrams per liter)
1961	4	9,160
1962	3	10,000
1963	2	10,900
1964	1	11,700
1965	2	12,100
1966	4	11,100
1967	2	12,900
1968	1	12,400
1969	2	12,100
1970	2	7,860
1971	3	5,880
1972	4	5,070
1973	3	4,970
1974	4	4,780
1975	2	3,100
1976	4	2,840
1977	4	2,890
1978	4	3,130
1979	4	2,430

Sodium was the principal cation and sulfate was the principal anion in water samples collected during the 19 years at the Narrows station. During the 1960's when the lake altitude was relatively low, chloride concentrations were as much as 1,000 milligrams per liter. During the late 1970's, after the lake surface had risen by about 15 feet, calcium comprised a larger overall percentage of the cation composition even though sodium remained the dominant cation. These determinations are understandable because calcium concentrations probably are controlled by the solubility of calcite, whereas sulfate, chloride and sodium are not limited by mineral solubilities until much larger concentrations are reached.

Suitability for use.--Water at the three streamflow stations in the Devils Lake basin probably would be suitable for domestic use if sufficient supplies were available. For most of the year, streamflow at each station is less than 5 cubic feet per second and the streams may freeze completely in January and February. Mean dissolved-solids concentrations are 610 milligrams per liter at the Mauvais station, 405 milligrams per liter at the Edmore station, and 627 milligrams per liter at the Big Coulee station. No nitrate-nitrogen information is available at the three stations.

No information regarding trace constituents that have Federal primary drinking water standards is available at the Mauvais and Edmore Coulee stations. Boron, iron, and manganese are the only trace constituents for which information is available (table 12). Maximum values of selenium, 23 micrograms per liter, and mercury, 4.4 micrograms per liter, exceeded Federal standards of 10 micrograms per liter for selenium and 2 micrograms per liter for mercury in water from Big Coulee near Churches Ferry. The 90th percentile selenium concentration of 15 micrograms per liter also exceeded the Federal standard.

Water from all stations might be suitable for irrigation use (fig. 41) if sufficient supplies were available and the soil to which the water was applied could be adequately leached. Ninetieth percentile specific conductance values are C3 for water from all stations.

Sediment

No daily sediment information is available at stations in the Devils Lake basin. Most sediment movement would occur in March-May associated with snowmelt. Sediments transported by the streams during this period would be predominantly silt and clay.

INTERRELATIONSHIP OF GROUND WATER AND SURFACE WATER

Glacial drift and near-surface bedrock aquifers and surface water are actually one resource; development or contamination of either nearly always will effect the other, particularly for shallow aquifers. The challenge to water managers is to determine acceptable tradeoffs between development and resulting effects.

TABLE 12.--SUMMARY OF TRACE CONSTITUENT DATA, DEVILS LAKE BASIN
[UG/L, MICROGRAMS PER LITER]

STATION NUMBER: 05056100 STATION NAME AND LOCATION: MAUVAIS COULEE NR CANDO, ND

DRAINAGE AREA: 387 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
	SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS									
ARSENIC DISSOLVED (UG/L AS AS)	4	8.00	1.00							
BORON, DISSOLVED (UG/L AS B)	28	480.00	0.00	114.65	121.67	336.00	150.00	85.00	20.00	0.07
IRON, DISSOLVED (UG/L AS FE)	28	700.00	0.00	133.57	163.12	296.00	140.00	75.00	40.00	28.00
LEAD, DISSOLVED (UG/L AS PB)	4	1.00	0.00							
MANGANESE, DISSOLVED (UG/L AS MN)	28	1420.00	10.00	178.93	316.63	379.99	167.50	85.00	40.00	10.00
SELENIUM, DISSOLVED (UG/L AS SE)	4	1.00	0.00							
MERCURY DISSOLVED (UG/L AS HG)	4	0.90	0.10							

STATION NUMBER: 05056200 STATION NAME AND LOCATION: EDMORE COULEE NR EDMORE, ND

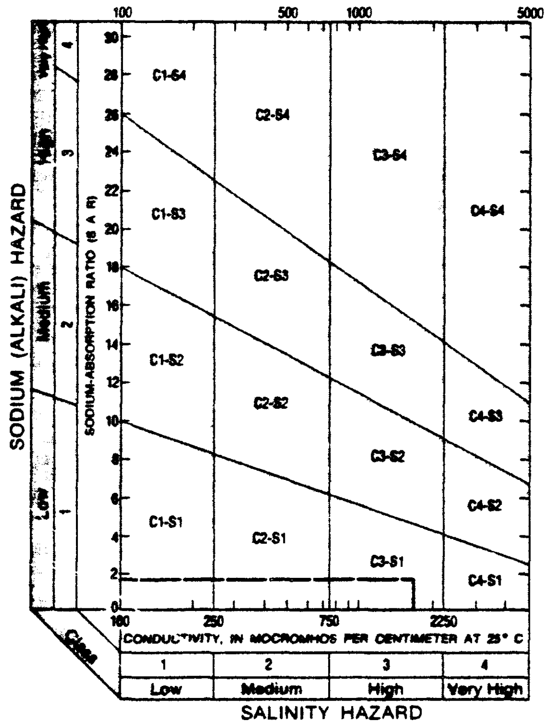
DRAINAGE AREA: 382 SQUARE MILES

WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
	SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS									
ARSENIC DISSOLVED (UG/L AS AS)	3	8.00	1.00							
BORON, DISSOLVED (UG/L AS B)	19	980.00	0.09	114.22	216.08	200.00	90.00	60.00	30.00	20.00
IRON, DISSOLVED (UG/L AS FE)	18	530.00	10.00	140.56	127.85	341.00	172.50	110.00	57.50	28.00
LEAD, DISSOLVED (UG/L AS PB)	3	1.00	0.00							
MANGANESE, DISSOLVED (UG/L AS MN)	18	890.00	10.00	133.33	221.97	557.00	110.00	70.00	17.50	10.00
SELENIUM, DISSOLVED (UG/L AS SE)	3	0.00	0.00							
MERCURY DISSOLVED (UG/L AS HG)	3	1.10	0.20							

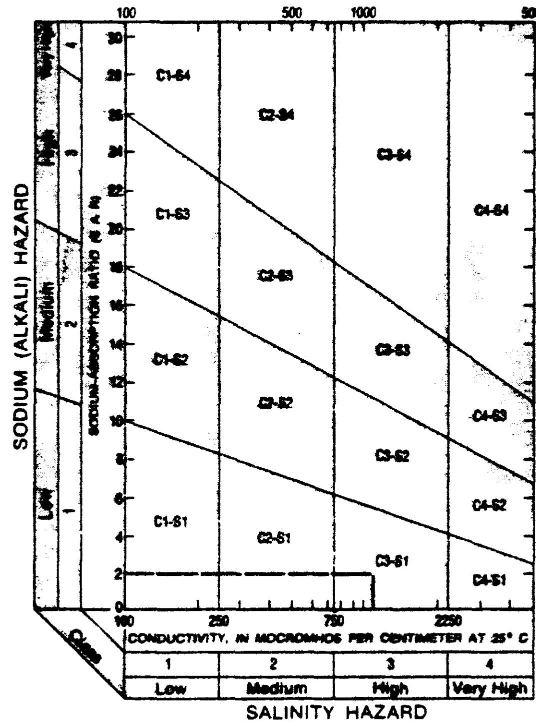
STATION NUMBER: 05056400 STATION NAME AND LOCATION: BIG COULEE NR CHURCHS FERRY, ND

DRAINAGE AREA: 2510 SQUARE MILES

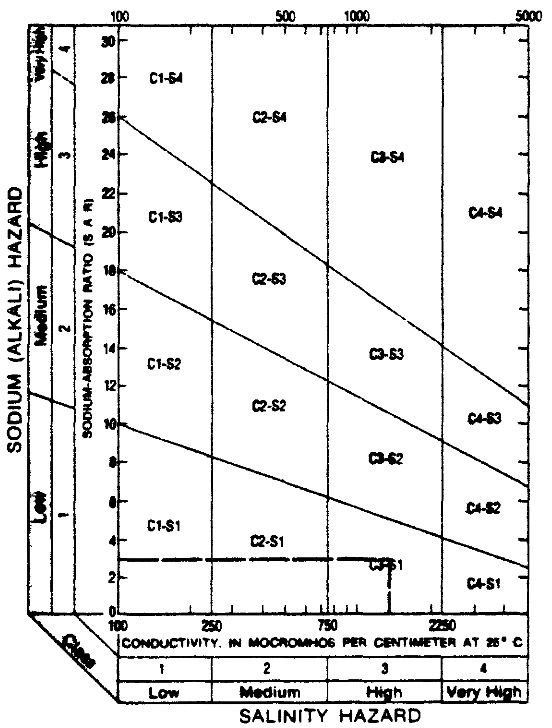
WATER QUALITY CONSTITUENT	DESCRIPTIVE STATISTICS					PERCENT OF SAMPLES IN WHICH VALUES WERE LESS THAN OR EQUAL TO THOSE SHOWN				
	SAMPLE SIZE	MAXIMUM	MINIMUM	MEAN	STANDARD DEVIATION	90	75	MEDIAN 50	25	10
	SUMMARY OF DATA COLLECTED AT PERIODIC INTERVALS									
ARSENIC DISSOLVED (UG/L AS AS)	24	17.00	0.00	7.50	5.00	14.50	11.75	6.50	4.00	0.50
BARIUM, DISSOLVED (UG/L AS BA)	20	200.00	0.00	75.00	62.11	190.00	100.00	100.00	0.00	0.00
BORON, DISSOLVED (UG/L AS B)	141	830.00	0.11	146.74	113.96	288.00	170.00	110.00	80.00	50.00
CADMIUM DISSOLVED (UG/L AS CD)	20	6.00	0.00	1.30	1.49	2.00	2.00	2.00	0.00	0.00
CHROMIUM, DISSOLVED (UG/L AS CR)	20	20.00	0.00	2.00	6.16	18.00	0.00	0.00	0.00	0.00
COPPER, DISSOLVED (UG/L AS CU)	20	40.00	0.00	9.65	11.44	35.30	12.00	6.00	2.00	0.00
IRON, DISSOLVED (UG/L AS FE)	39	461.00	0.00	87.85	101.05	226.00	102.00	54.00	30.00	10.00
LEAD, DISSOLVED (UG/L AS PB)	23	50.00	0.00	3.61	10.25	5.00	3.00	1.00	0.00	0.00
MANGANESE, DISSOLVED (UG/L AS MN)	37	1600.00	2.00	183.35	335.29	580.00	180.00	47.00	11.00	7.60
ZINC, DISSOLVED (UG/L AS ZN)	20	30.00	0.00	12.75	11.94	30.00	20.00	11.50	0.00	0.00
SELENIUM, DISSOLVED (UG/L AS SE)	24	23.00	0.00	3.54	6.22	15.00	1.75	1.00	1.00	0.00
MERCURY DISSOLVED (UG/L AS HG)	21	4.40	0.00	0.68	0.95	1.76	0.55	0.50	0.30	0.02



MAUVAIS COULEE NEAR CANDO 05056100



EDMORE COULEE NEAR EDMORE 05056200



BIG COULEE NEAR CHURCHES FERRY 05056400

EXPLANATION

——— AREA ENCLOSES SAMPLE VALUES FOR CONDUCTIVITY AND SAR LESS THAN OR EQUAL TO 90 PERCENT OF THE TOTAL NUMBER OF SAMPLES

C2–S2 CLASSIFICATION, BASED ON BOTH CONDUCTIVITY (C) AND SAR (S), USED TO DETERMINE IRRIGATION SUITABILITY

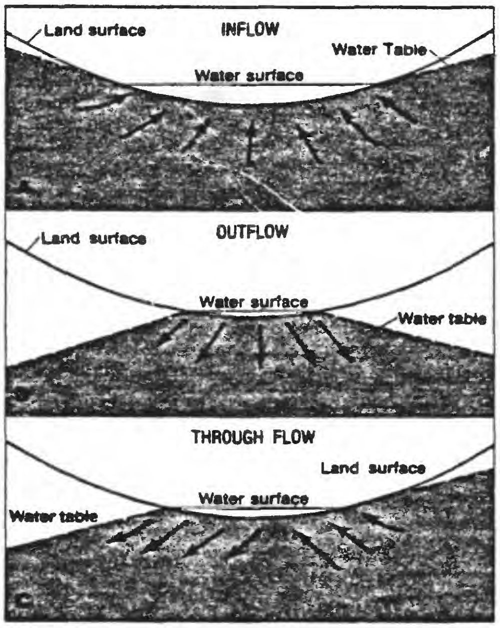
FIGURE 41.—Comparison of irrigation suitability of water at selected stations, Devils Lake basin, North Dakota. (Diagram from U.S. Salinity Laboratory Staff, 1954.)

Ground water interacts with surface water in three general ways: (1) Surface water has ground-water inflow, if the water table slopes toward the surface water; (2) surface water has outflow to ground water, if the water table slopes away from the surface water; and (3) surface water will have both inflow and outflow (through flow), if the water table slopes toward surface water in some parts and away from it in other parts (fig. 42).

Hydrologists have developed a considerable number of methods for analyzing and modeling the interaction of ground water and surface water. (See Hall, 1968, and Winter, 1984, for reviews of some of these methods.) In nearly all cases, the representations of the natural systems had to be greatly simplified so the analyses could be made. Toth (1963), Meyboom (1966) and Freeze and Witherspoon (1966), based on work of Hubbert (1940), began to study, and model more complex ground-water flow systems; their results had important implications for understanding how ground water interacts with surface water.

Following the above work, Winter (1976, 1978) used numerical simulation studies of ground-water flow near surface water to determine the sensitivity of seepage from surface water caused by differences in geologic setting. He found that seepage to and from surface water varies spatially across a stream, lake, or wetland bottom depending on: (1) depth of surface water; (2) distribution of bottom sediments; (3) directional differences in hydraulic conductivity (anisotropy); and (4) the relationship of aquifers to confining beds. Pfannkuch and Winter (1984) showed that differences in overall geometry of the ground-water system relative to geometry of surface water also causes seepage patterns to differ.

Of the factors that affect seepage patterns in surface-water beds, those mentioned before are all generally related to geology, and are therefore relatively stable. The boundary of ground-water flow systems that is dynamic is the water table, because it responds directly to the distribution of recharge and discharge, hence to changes in climate. In a recent study that considered models of flow in both the unsaturated and saturated zones, such that the water table could move freely in response to infiltration of water at the land surface, Winter (1983) indicated that recharge varies greatly in time and in space. The models showed that recharge commonly is focused quickly adjacent to surface water, resulting in: (1) Ground water moving very quickly into the surface water; and (2) recharge beneath uplands being delayed relative to that near surface water. Examples of the effect of focused recharge on flow systems and on changes in seepage patterns in a surface-water body are shown in figure 43. The resulting constantly changing recharge pattern causes very complex and constantly changing flow systems, which, in turn, cause seepage patterns in beds of surface water bodies to continually change. Field studies of flow systems and of seepage patterns relative to streams, lakes, and wetlands, using both hydraulic head and chemical data, and based on these recent theoretical studies, have verified the existence and dynamic character of the interaction of ground and surface water. Important implications of these studies relate to ground-water recharge, water quality, and water development.



From Sloan, 1972

FIGURE 42.—Diagrammatic sections showing three types of surface-ground water interrelationships; inflow, outflow, and through flow.

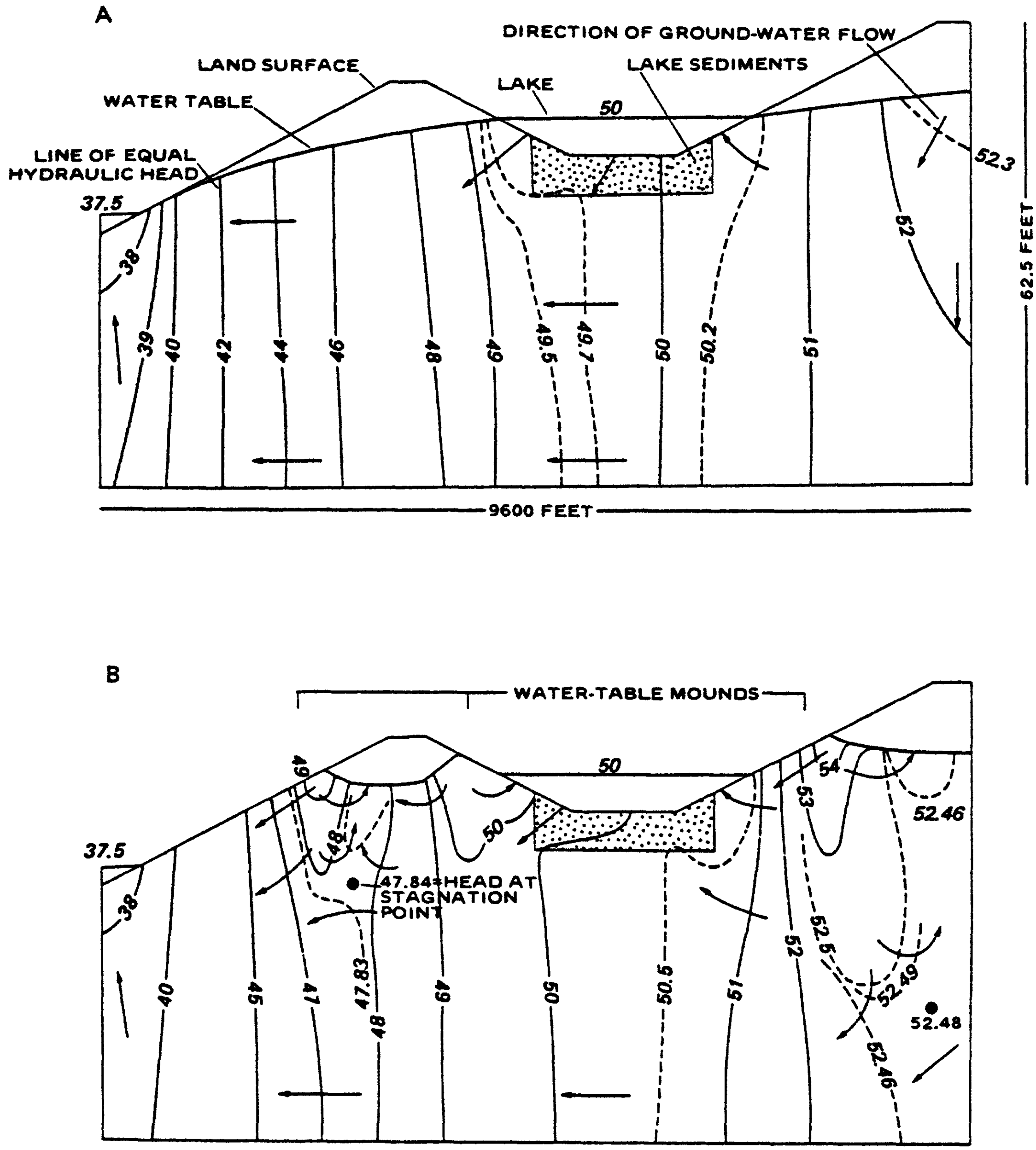


FIGURE 43.—Hydrologic sections showing numerical simulation of distribution of hydraulic head in variably-saturated porous media. (Modified from Winter, 1984.) Prior to a recharge event, the surface water has ground-water seepage in on one side and surface-water seepage out on the other (A). Focused recharge causes water-table mounds to form directly adjacent to the surface water, resulting in reversals of ground-water flow in several locations (B). Mound 2 causes seepage into the surface water, whereas the seepage was out of the surface water prior to recharge.

Implications for Ground-Water Recharge and Movement

The studies of saturated-unsaturated flow (Winter, 1983) can be extended further, with respect to the affect of surface water in ground-water recharge. The above example discussed only the effect of recharge directly adjacent to surface water. However, even throughout upland areas, if the thickness of the unsaturated zone is not uniform, the areal and temporal distribution of recharge will not be uniform. Water table mounds will increase in response to focused recharge, where infiltrated water has the shortest path through the unsaturated zone. Therefore, recharge sometimes will be focused beneath low points on the land surface, where the distance to the water table is less than beneath adjacent hills. This focused recharge can cause the formation of transient, local flow systems that will vary in size and permanence, depending on the rate and quantity of recharge.

These flow systems can last for a very short time, from a few hours to several months, in more permeable settings, or, in contrast, last for months, or even years, in less permeable settings. These small, transient local systems cause very complex movement of water in the uppermost parts of the ground-water system: the water moving one direction as a result of localized recharge, then moving the other direction as the water-table mound associated with that recharge dissipates.

Over the long term, months to years, a given quantity of infiltrating water will result in a somewhat uniform movement of water through the unsaturated zone to the water table. But lateral movement caused by the localized recharge and the rejected infiltration (overland runoff), where the subsurface is quickly saturated, does not justify the assumption of uniform areal recharge. Further, as noted by Lissey (1971), in areas where deep soil frost occurs, most of the overland runoff during the spring concentrates in land surface depressions before the frost melts. This concentration of water results in relatively little water being available for infiltration as vertical ground-water recharge beneath topographic highs.

The slow rate of water movement in less permeable materials and the long time needed to move water from localized recharge areas to low points on the water table, also possibly explains the complex configuration of the water table, including water table depressions beneath land surface highs, in parts of North Dakota. As discussed earlier in this report, study of a group of wetlands in Stutsman County (LaBaugh and others, 1984) has shown that lakes and wetlands interact with ground water in all three ways (fig. 42): (1) They receive ground-water inflow; (2) they outflow to ground water; or (3) an individual wetland can do both. The study shows some wetlands, generally temporary wetlands, serve a very critical ground-water recharge function. Ironically, these temporary wetlands commonly are those that are most easily destroyed by changing land uses.

Implications for Water Quality

Results of these studies have important implications for geochemical studies related to the interaction of surface water and ground water, as well as for ground-water geochemical studies in general. The possibility of small local ground-water flow systems forming and disappearing within the ground-water system could lead to very complex geochemical systems. With the reversals of flow that are possible, water might have significantly different residence times. In a given area, the water could be within a closed, local flow system for part of the year, then move in another direction toward a major discharge area the remainder of the year, only to reverse direction again during the next recharge. Similarly, in field studies, water samples from a given well might be from a small, local flow system one time, and from a large flow system at other times.

Perhaps the most important implications for water chemistry are for studies of chemical fluxes to and from surface water bodies. If localized recharge occurs adjacent to surface water, a very short flow path is immediately created for ground-water movement to surface water. This, in fact, already has been studied and observed in the field. Ragan (1968) observed the formation of ground-water ridges adjacent to streams as being related to rapid movement of infiltrated water to a stream in Vermont. Sklash and Farvolden (1979) observed rapid movement of chemical constituents to a stream in Ontario shortly after precipitation. In the wetland studies in Stutsman County, LaBaugh and others (1984) documented reversals of ground-water flow and their effect on ground-water quality and chemistry of wetlands. This discussion refers only to hydrologic systems in their natural state. Complex as natural water movement and related chemical processes might seem, the effects of water development further complicates the picture.

Implications for Water Development

Development of either ground water or surface water will have the greatest effect on their interaction in surficial aquifers, where the hydraulic connection between the two is direct. Paulson (1983) describes the degree of the interaction for the Sheyenne delta area, one of the largest surficial aquifers in the State.

> "Probably the best example of ground-water interaction with streamflow in North Dakota is along the Sheyenne River in the southeastern part of the State. Studies have shown that in a 52-mile reach southwest of Kindred, where the river flows through a large, thick sand aquifer (Sheyenne delta), ground-water discharge into the river is as much as 28.8 cubic feet per second during the fall.
>
> In contrast, records show that little or no ground water is discharged into the Sheyenne River in the reach from Kindred northeast to its confluence with the Red River. In fact, streamflow is decreased in this reach due to evapotranspiration losses."

Evapotranspiration refers not only to water loss by direct evaporation from the river, but also to water transpired by riparian vegetation, which can cause seepage from the river. The phenomenon of phreatophytes being similar to pumps in water wells, with related effects on seepage loss from surface water, has been observed by Meyboom (1966) in the prairie region of Canada.

Much more substantial effects on the interaction of ground water and surface water are caused by the activities of man. Manipulation of surface water can have a number of effects on ground water. As stated earlier in this section of the report, drainage of recharge-type wetlands can change the patterns and distribution of recharge to ground water. Drainage of discharge-type wetlands and lakes will increase ground-water gradients toward those surface water bodies, and that will actually increase the discharge of ground water to them.

If water-table gradients are slight, high stages in rivers, lakes or wetlands will cause water to seep from surface water body to ground water. This phenomenon is termed bank storage because, after surface water levels decline, the water will seep back into the river. However, if high stages of surface water persist, part of the surface water seepage will not return, but will recharge ground water. The implications for surface-water quality affecting ground-water quality in this situation is obvious; non-potable surface water will have deleterious effects on ground-water quality.

Development of ground water will affect, usually decrease, ground-water discharge to rivers. This effect will vary with the degree of hydraulic connection and the degree of development. Large-scale pumpage of deep, buried aquifers probably will have little effect on surface water, until the effect is transmitted through the confining beds. In the case of surficial aquifers, small-scale pumpage probably will have little noticeable effect on surface water. The exception would be if the well were close to the surface water (fig. 44). However, large-scale pumpage, especially if the volume approaches the maximum stable (sustained) yield (Freeze, 1971) (as defined earlier) will seriously decrease ground-water discharge to surface water, and very likely will induce surface water to seep to ground water, as shown in fig. 44. This could cause deterioration of ground-water quality, if the quality of surface water was degraded. An example of this being particularly serious is near saline lakes within outwash plains, where ground-water development could induce saline water into the ground-water system.

Because of the interrelationship of near-surface ground water and surface water, water-management plans and programs need to consider them as one resource. In some of the most extensively developed water systems in the western United States, studies of conjunctive use of ground water and surface water have been made. Some of these studies have evolved to the point that computer models of the ground water-surface water system are being used to manage the joint resource.

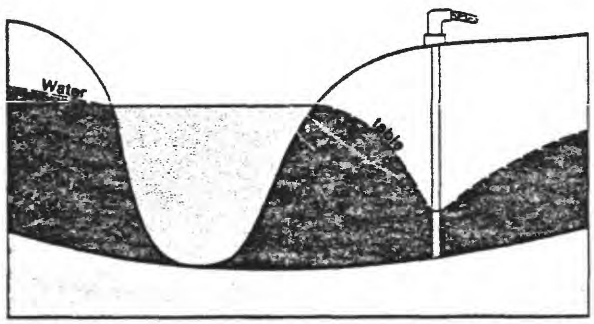


FIGURE 44.—Diagrammatic section showing seepage from surface water caused by pumping of ground water.

WATER USE

Estimated total water use in North Dakota during 1982 was about 1,140,000 acre-feet of which 77.5 percent, or 883,000 acre-feet, was nonconsumptive use (Patch and Haffield, 1982). Ninety-seven percent of the nonconsumptive water use was for thermoelectric power generation, primarily as cooling water. Most of the water withdrawn for thermoelectric power generation occurred in a four-County area (fig. 45) adjacent to the Missouri River and Lake Sakakawea. Surface water is the source of 99.9 percent of the water used for thermoelectric power generation.

Industrial water use during 1982 was 9,700 acre-feet, of which 4,770 acre-feet was nonconsumptive use, which was less than 1 percent of the total nonconsumptive use in North Dakota. Consumptive use of water for industrial purposes during 1982 equaled 4,930 acre-feet, which was less than 1 percent of the total water consumed. Seventy-five percent of the total water withdrawn for industrial use was obtained from surface-water sources, and the remaining 25 percent was obtained from ground-water sources (fig. 45).

About 150,000 acre-feet of water was used for irrigation in North Dakota during 1982; 85.2 percent was consumed which amounted to 49.6 percent of the total consumptive use of water in North Dakota during 1982. Sixty-three percent of all water used for irrigation was obtained from surface-water sources and 37 percent was obtained from ground-water sources.

Municipal and rural water use during 1982 was about 105,000 acre-feet. All water withdrawn for municipal and rural use was considered consumptive (Patch and Haffield, 1982). Thus, the municipal and rural water withdrawals equaled 41 percent of the total water used for consumptive purposes. As expected, the major withdrawals (fig.45) occurred in the Counties with the largest population centers. Forty-one percent of all water used for municipal and rural supplies was obtained from surface water sources, and 59 percent was obtained from ground-water sources.

Total water use increased more than 200 percent from 1970 to 1980 (Smith and Harkness, 1980). An increase in the number of thermoelectric powerplants was the major factor for the increased use. Water used for irrigation increased from 119,000 acre-feet during 1970 to 308,000 acre-feet during 1980, which is more than a 250 percent increase. Smith and Harkness (1980) indicated that a large increase in irrigation in the 1970's was due to the installation of center-pivot sprinklers that generally use ground water as the source of water. There were only minor increases in industrial and municipal and rural water use from 1970 to 1980. Thus, as a percentage, water withdrawal for irrigation had the largest increase of the four categories discussed above.

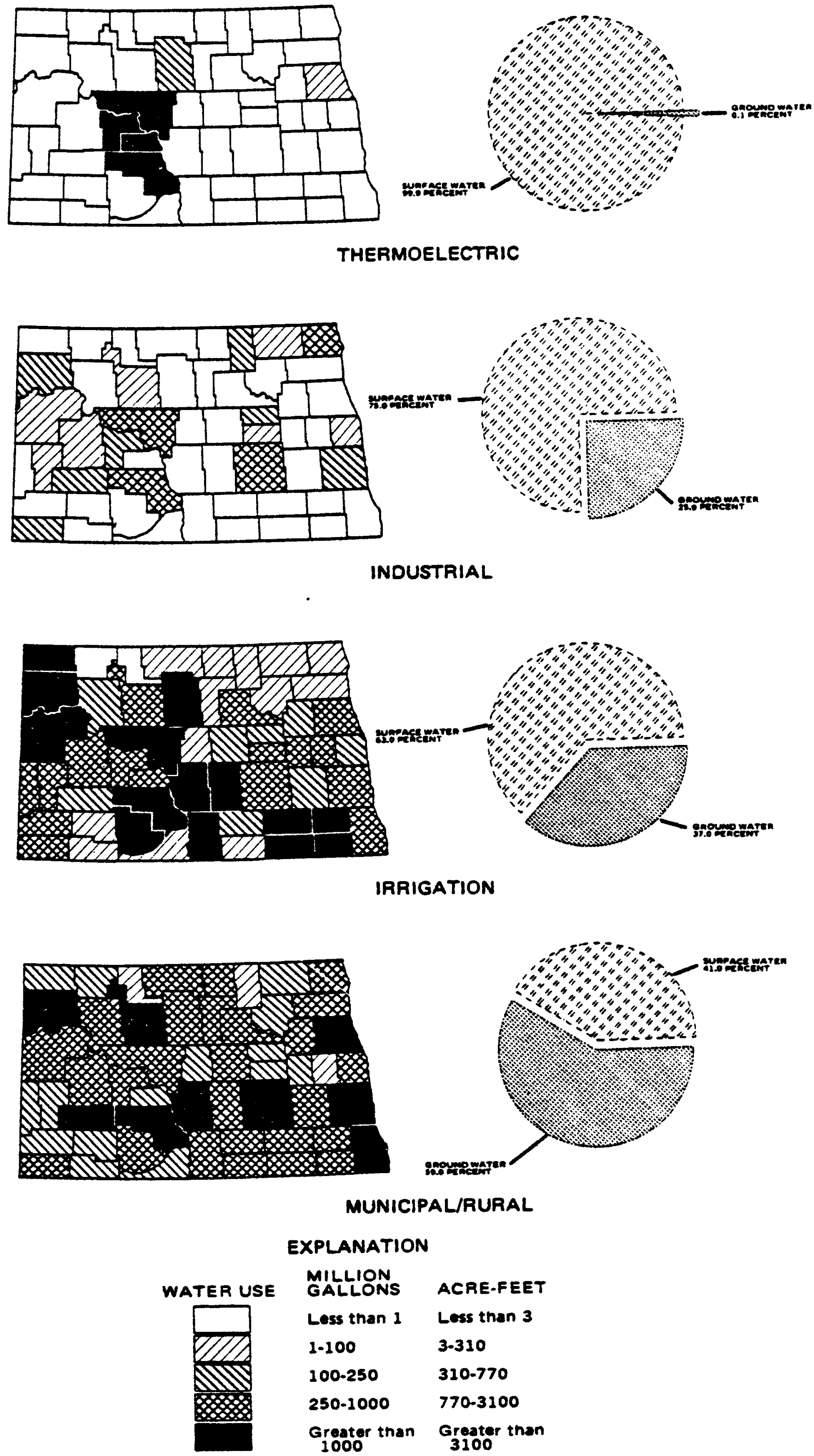


FIGURE 45.—Water use of North Dakota, 1982. (Modified from Patch and Haffield, 1982.)

LIMITATIONS OF DATA AND UNDERSTANDING OF HYDROLOGIC SYSTEMS

Ground Water

Efficient development of ground-water resources requires an understanding of the physics and chemistry of subsurface systems. Although it may appear at this point in the report that much is known about North Dakota's ground-water resources, there is considerable uncertainty in the estimates of water quantity and water quality reported herein. For example, limited information is available on concentrations in ground water of arsenic, cadmium, lead, mercury, selenium and other trace constituents, for which Federal primary drinking-water standards have been established. Further, some of the concepts, especially with respect to ground-water recharge and the interaction of ground water and surface water, have only recently been developed and are only beginning to be tested in the field. Considerably more research, field evaluation and data collection need to be done before effective water-management plans can be devised and implemented.

Hydraulic Parameters of Aquifers

North Dakota has progressed far, through its County ground-water studies, in delineating the principal glacial-drift aquifers in the State. Although figure 5 is useful for qualitative comparison of aquifer yields, it does not include information on the sustained yields. The County studies included some testing of aquifers, but generally only a few pumping tests were made in each County and some aquifers were not tested at all. Even for the aquifers tested, the great complexity of aquifer configuration and grain-size distribution, make the tests applicable to only a small part of the entire aquifer system. Without thorough understanding and definition of aquifer parameters, such as transmissivity and storage coefficient, aquifer geometry, as well as hydraulic characteristics of confining beds; it is impossible to accurately evaluate the ground-water resources. Evaluation should include not only determination of pumping rates and sustained yield that prevent unacceptable depletion of ground water, but also that prevent unacceptable effects on surface-water resources. It is premature to consider artificial recharge of aquifers without an understanding of aquifer parameters and geometry.

Ground-Water Recharge and Movement

The process of ground-water recharge is poorly understood, and definition of ground-water flow systems within the drift in North Dakota is even less well understood. Only very recently have many of the simple concepts of recharge and ground-water movement been critically evaluated from a theoretical perspective. Field studies to evaluate and test recently proposed concepts have begun in only a few localities, and the studies have been in progress for only a few years. Thus, understanding of the dynamic circulation of water in the subsurface, and its interrelationship with surface water is extremely limited. Much of the discussion in this report with respect to ground-water resources and especially with respect to the interaction of ground water and surface water is extrapolated from theory and from these few, detailed field studies.

Geochemical Processes

Much of the water-quality information presented in this report describes the distribution of chemical constituents. Although this information is useful, it does not indicate that understanding of geochemical processes is adequate. Some general geochemical processes are relatively well known, such as ion exchange, and these can be used to explain the distribution of some water-quality types. However, one of the greatest deficiencies in geochemical knowledge is the rate of many reactions between rocks and water. Knowledge of reaction rates, effects of mixing of water types, and knowledge of flow systems is essential if predictions are to be made concerning development of ground- and surface-water resources. Understanding of these processes is particularly critical to predicting the effects of irrigation return flow on surface-water quality, and to predicting the effects of artificial recharge on ground-water quality. With respect to artificial recharge, an inability to deal with geochemical and biological problems is one of the principal reasons many artificial recharge experiments fail.

Surface Water

Efficient development of water resources requires an understanding of the hydrology and hydraulics of the basins involved, based on accurate stream flow gaging records and hydrologic and hydraulic analysis. In general, the theoretical basis of one-dimensional, surface-water hydraulics is well developed and field tested. However, some stream systems in North Dakota are complex hydraulic systems that require careful analysis using nonstandard techniques to provide accurate results. In general, the theoretical basis for the rainfall runoff, snowmelt runoff (including the effects of frozen soils), processes is not well developed or field tested especially for the complex hydrology in many parts of the State.

Some of the hydrologic data that usually are available for stream basins have not yet been developed in the State because of some of the same complexities that require nonstandard hydraulic analysis. These complexities have been previously described for the Red River basin by Miller and Frink (1984, p44-45) and the James River basin by P. K. Christensen, North Dakota State Water Commission, and J. E. Miller, U.S. Geological Survey, (written commun., 1983) in a progress report on a study of the ground- and surface-water relationships of the lower James River in North Dakota.

Complexities of Hydraulic Systems

In many parts of North Dakota the streams consist of complex hydraulic systems that are difficult to analyse for both data collection and numerical prediction purposes. These complexities are caused by almost flat stream gradients, long and numerous storage areas, poorly defined channels, and wide exposed channels that result in slow velocities, poorly defined stage-discharge relationships, extremely wide overbank inundation at higher flows, and stream flows that are subject to wind effects. Because of these complexities the methods used in standard streamflow routing methods need to be tested on streams such as the lower James River in the State.

Because of these complexities, standard streamflow gaging methods and analysis techniques do not provide adequate results in many parts of the State. Special streamflow-gaging methods have been developed that can provide accurate results but are more complex and expensive than standard techniques. These include the installation of acoustic velocity meters and the application of dynamic-wave models to compute streamflow by simulating the flow (including the effects of almost flat gradients) between two stage measuring gages. Both of these methods have been recently implemented on the James River at the North Dakota-South Dakota State line.

Streamflow records in North Dakota are accurate, in general, because streamflow gages are located at those sites where accurate gaging records can be obtained. However, streamflow records have not always been obtained where needed for project development purposes or to define long-term streamflow characteristics. For example, there is a need for long-term records of inflows and outflows at Arrowwood and Dakota Lake National Wildlife Refuges on the James River to determine the effects of potential water development, but these data are difficult to obtain and are not now available.

Complexities of Hydrologic Systems

Commonly used rainfall-runoff and snowmelt-runoff models do not adequately describe the runoff processes in many parts of North Dakota. Because of the many processes involved, these models generally are very complex. In development of the models, certain assumptions are made to simplify them so that they can be programmed and be more readily understood. Significant research and alterations would be required to improve the model representations of the the prairie snow pack melting processes, water-excess processes such as infiltration (including the effects of frozen soils), and water-routing processes such as depressional storages and water routing involving almost flat gradients. These complexities limit the accuracy with which, for example, return flows from irrigation can be analysed.

Limited Drainage-Area Determinations

Another problem caused by the almost flat gradients, poorly defined drainage systems, and the many noncontributing and partly contributing areas, is that drainage-area determinations have not yet been completed in some parts of the State. Because drainage-area determinations are essential to most hydrologic analyses, a reasonable approach to the drainage-area-determination problem is needed. It may include a development of drainage-area-frequency curves to relate the contributing drainage area to the magnitude of the rainfall runoff or snowmelt runoff. This is a difficult problem because, among other reasons, runoff is caused by both rainfall and snowmelt that would have to be analysed differently.

Limited Data for Small Streams

There are few long-term streamflow gaging records on small streams in North Dakota. This greatly hampers the analysis and prediction of runoff from subbasins in any project development area. It also hampers the direct measurement of the effects of development on the water resources.

Predictive Capabilities of Effects of Development

The goal of nearly all scientific endeavor is to understand processes well enough so effects of stress on a system can be predicted within a needed degree of certainty. The limitations discussed above all relate to the ability to predict the effects of a stress on the hydrologic system. The ability to simulate hydrologic systems using computers offers a powerful tool for analysis and prediction of those systems. However, a computer model of a system is only as good as the ability of investigators to formulate the problem properly, and as good as the worth of the data used. For example, it is conceivable to model an aquifer according to the known boundaries at that time only to find that further test drilling results in changes in those boundaries. Further, concepts and related assumptions used to model the interaction of ground water and surface water may force a solution to a problem, when in fact the problem may have been defined incorrectly because of inadequate understanding and analytical treatment of the system.

Problems with simulating hydrologic systems are not only related to inadequate definition because of lack of understanding, but also are related to inability to solve extremely complex mathematical formulations. The science of simulating hydrologic systems is only in its infancy with respect to certain types of problems. The following two examples illustrate this point:

(1) To understand and model ground-water recharge it is necessary to be able to solve equations that describe unsaturated and saturated flow jointly. Few models of this type are available and documented, and fewer still have received rigorous field testing.

(2) To understand and model the transport of dissolved constituents in ground water, it is necessary to know reaction rates of complex and numerous rock-water interactions. Understanding of these reaction rates

is minimal for natural systems. Most transport models available are still at the stage of development where only conservative (nonreacting) constituents can be modeled.

The capability of predicting the hydraulic effects of changes in channel characteristics and stream discharge characteristics are needed both to design a water development project and to manage the operation of the project after it is constructed and operational. Because of the complexities in the surface-water hydraulic systems noted earlier, simulation of the surface-water systems in many parts of North Dakota will need carefully formulated predictive tools.

Changes in flow in the stream systems generally are significantly attenuated and dispersed by the channel-storage and dynamic effects of the flow-routing processes. Because of the many complexities of the stream systems (such as the James River), complex hydraulic flow models would be needed in many situations to provide an accurate model. Because of the extensive real-time simulation needed to manage the operation of a large water-development project, the least complex flow routing model that provides answers within acceptable accuracy needs to be used to simulate the hydraulic system involved. Therefore, significant testing is required to determine the best model to be used for various purposes.

Given the above limitations of understanding and data, water-management plans based on them also are subject to uncertainty. Organizations charged with implementing water-development programs need to be cognizant of the data bases and analytical methods on which determination of the quantity and quality of water resources are based.

SUMMARY AND CONCLUSIONS

Significant development of ground water in North Dakota is possible only from glacial-drift aquifers. Chemical quality of water from these aquifers is variable. In general, water in shallower parts of glacial-drift aquifers is chemically suitable for most uses. Water in deeper parts of glacial-drift aquifers, particularily in buried bedrock valleys, is marginal to unsuitable for irrigation, but the water may be used for domestic and stock purposes.

The Missouri River is the most significant source of surface water in North Dakota. The mean recorded flow at Bismarck is about 17,220,000 acre-feet per year which is more than 80 percent of the total measured streamflow in the State. Useable storage in Lake Sakakawea, formed by Garrison Dam on the mainstem, is slightly less than 19 million acre-feet. All other streams in the State generally do not provide dependable, year-round supplies of surface water unless storage is provided.

Quality of water in the Missouri River mainstem and Lake Sakakawea generally is suitable for public supply, domestic use, and irrigation. Quality of water in the principal Missouri River tributaries is marginally suitable for domestic use and marginally suitable to unsuitable for irrigation. Quality of water for other streams in the State is variable and these streams do not provide dependable supplies unless storage is provided.

Total water use has increased rapidly during the last 10 years. Much of the increase has been thermoelectric-powerplant use and further increases depend on the overall energy demands. Irrigation use has more than doubled during the past 10 years, however, further increases in irrigation use will depend on local availability of ground water or large-scale transport of surface water.

The water resources of North Dakota consist of complex hydraulic and hydrologic systems. Analyses of these systems require carefully formulated predictive tools that, because of limitations of our understanding of the systems, may contain considerable uncertainty in the results. It needs to be realized that any water-management plans based on analyses of these systems also are subject to uncertainty.

REFERENCES CITED

Armstrong, C. A., 1980, Ground water resources of Dickey and LaMoure Counties, North Dakota: North Dakota State Water Commission, County Ground Water Studies 28, Part III, 61 p.

--- 1982, Ground water resources of Ranson and Sargent Counties, North Dakota: North Dakota State Water Commission, County Ground Water Studies 31, Part III, 51 p.

Bavendick, F.J., 1959, The climate of North Dakota, in Climates of the States, Volume II--Western States (including Alaska and Hawaii): U.S. Department of Commerce, National Oceanic and Atmospheric Administration, p. 811-825.

Bluemle, J. P., 1971, Depth to bedrock in North Dakota: North Dakota Geological Survey, Miscellaneous Map 13, scale 1:500,000, 1 sheet.

Bluemle, J. P., Anderson, S. B., and Carlson, C. G., no date, North Dakota stratigraphic column: North Dakota Geological Survey, 1 sheet.

Clayton, Lee, 1962, Glacial geology of Logan and McIntosh Counties, North Dakota: North Dakota Geological Survey Bulletin 37, 84 p.

Clayton, Lee, Moran, S. R., Bluemle, J. P., and Carlson, C. G., 1980, Geologic map of North Dakota: U.S. Geological Survey, scale 1:500,000, 1 sheet.

Downey, J. S., 1984, Geohydrology of the bedrock aquifers in the northern great plains in parts of Montana, Wyoming, North Dakota and South Dakota: U.S. Geological Survey Professional Paper 1402-E, in press .

Downey, J. S., and Armstrong, C. A., 1977, Ground water resources of Griggs and Steele Counties, North Dakota: North Dakota State Water Commission, County Ground Water Studies 21, Part III, 33 p.

Fenneman, N. M., 1946, Physiographic divisions of the United States: U.S. Geological Survey map prepared in cooperation with Physiographic Committee, U.S. Geological Survey, scale 1:7,000,000 (reprinted 1964).

Freeze, R. A. and Witherspoon, P. A., 1967, Theoretical analysis of regional ground water flow, 2. Effect of water table configuration and subsurface permeability variation: Water Resources Research, v. 3, no. 2, p. 623-634.

Freeze, R. A., 1971, Three-dimensional, transient, saturated-unsaturated flow in a ground water basin: Water Resources Research, v. 7, no. 2, p. 347-366.

Hall, F. R., 1968, Base-flow recessions--A review: Water Resources Research, v. 4, no. 5, p. 973-983.

Hubbert, M. K., 1940, The theory of ground-water motion: Journal of Geology, v. 48, no. 8, p. 785-944.

Klausing, R. L., 1974, Ground-water resources of McLean County, North Dakota: North Dakota State Water Commission, County Ground-Water Studies 19, Part III, 73 p.

LaBaugh, J. W., Winter, T. C., Adomaitis, V., and Swanson, G. A., 1984, Geohydrology and chemistry of prairie wetlands, Stutsman County, North Dakota: U.S. Geological Survey Professional Paper, in press .

Landis, E. R., ed., 1973, Mineral and water resources of North Dakota: North Dakota Geological Survey Bulletin 63, 252 p.

Lissey, A., 1971, Depression-focused transient groundwater flow patterns in Manitoba: Geological Association of Canada Special Paper 9, p. 333-341.

Meyboom, Peter, 1966, Unsteady ground water flow near a willow ring in hummocky moraine: Journal of Hydrology, v. 4, p. 38-62.

Miller, J.E. and Frink, D.L., 1984, Changes in flood response of the Red River of the North basin, North Dakota-Minnesota: U.S. Geological Survey Water-Supply Paper 2243, 103 p.

Missouri River Basin Commission, 1980a, Flooding technical paper, James River basin subregional analysis, North Dakota-South Dakota: Omaha, Nebr., 74 p.

--- 1980b, Summary report, James River basin subregional analysis, North Dakota-South Dakota: Omaha, Nebr., 125 p.

National Academy of Sciences, National Academy of Engineering, 1972, Water Quality Criteria 1972: U.S. Government Printing Office, 594 p.

North Dakota State Engineer, 1944, Fourth report of State Water Conservation Commission and 22nd biennium report of State Engineer of North Dakota: Bismarck, 10 p.

North Dakota State Health Department, 1977, Standards of water quality for State of North Dakota: Bismarck, 20 p.

North Dakota State Water Commission, 1982, Map showing glacial drift aquifers in North Dakota and Estimated potential yields: North Dakota State Water Commission, scale 1:500,000, 1 sheet.

Patch, J. C. and Haffield, N. D., 1982, Types of water use in North Dakota: North Dakota State Water Commission, Information Series 33, 1 sheet.

Paulson, Q. F., 1964, Geological factors affecting discharge of the Sheyenne River in southeastern North Dakota, in Geological Survey Research 1964: U.S. Geological Survey Professional Paper 501-D, p. D177-D181.

--- 1983, Guide to the ground-water resources of North Dakota: U.S. Geological Survey Water-Supply Paper 2236, 25 p.

Pfannkuch, H. O. and Winter, T. C., 1984, Effect of anisotropy and ground-water system geometry on seepage through lakebeds, 1. Analog and dimensional analysis: Journal of Hydrology, v. 75, in press .

Ragan, R. M., 1968, An experimental investigation of partial area contributions: International Association of Scientific Hydrology Publication 76, p. 241-249.

Randich, P. G., 1977, Ground-water resources of Benson and Pierce Counties, North Dakota: North Dakota State Water Commission, County Ground Water Studies 18, Part III, 76 p.

--- 1981, Ground water resources of McHenry County, North Dakota: North Dakota State Water Commission, County Ground Water Studies 33, Part III, 47 p.

Sklash, M. G. and Farvolden, R. N., 1979, The role of ground water in storm runoff in Back, William, and Stephenson, D. A., cds., Contemporary Hydrogeology: New York, Elsevier Scientific, p. 45-65.

Smith, M. L., and Harkness, R. E., 1981, Water use in North Dakota, 1980: North Dakota State Water Commission Information Series 31, 1 plate.

Souris-Red-Rainy River Basins Commission, 1972, Souris-Red-Rainy River basins comprehensive study--Flood damage reduction and drainage, volume 3: 205 p.

Toth, Joseph, 1963, A theoretical analysis of ground water flow in small drainage basins, in Proceedings of Hydrology Symposium 3, Groundwater: Ottawa, Queen's Printer, p. 75-96.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, 1982, Evaporation atlas for the contiguous 48 United States: National Oceanic and Atmospheric Administration Technical Report NWS33, 27 p.

U.S. Environmental Protection Agency, 1980, Water quality criteria documents--Availability: Federal Register, v. 45, no. 231, Friday, November 28, 1980, Part V, p. 79318 79379.

--- 1982a, Maximum Contaminant Levels (subpart B of part 141, National Interim Primary Drinking Water Regulations): U.S. Code of Federal Regulations, Title 40, parts 100 to 149, revised as of July 1, 1982, p. 315 318.

--- 1982b, Secondary Maximum Contaminant Levels (section 143.3 of part 143, National Secondary Drinking Water Regulations): U. S. Code of Federal Regulations, Title 40, parts 100 to 149, revised as of July 1, 1982, p. 374.

U.S. Geological Survey, 1952, Floods of 1950 in the Red River of the North and Winnipeg River basins: U.S. Geological Survey Water-Supply Paper 1137-B, 325 p.

U.S. Water and Power Resources Service, 1981, Project data: Denver, Colo., 1463 p.

Wells, F. C., and Schertz, T. L., 1983, Statistical summary of daily values data at National Stream Quality Accounting Network (NASQAN) stations: U.S. Geological Survey Water Resources Investigations Report 83-4172, 526 p.

Winter, T. C., 1976, Numerical simulation analysis of the interaction of lakes and ground water: U.S. Geological Survey Professional Paper 1001, 45 p.

--- 1978, Numerical simulation of steady-state, three-dimensional ground water flow near lakes: Water Resources Research, v. 14, no. 2, p. 245-254.

--- 1983, The interaction of lakes with variably saturated porous media: Water Resources Research, v. 19, no. 5, p. 1203-1218.

--- 1984, Modeling the interrelationship of ground water and surface water, in Schnoor, J. L., ed., Modeling of total acid precipitation impacts: Boston, Butterworth Publishers, p. 89-119

Winter, T. C. and Carr, M. R., 1980, Hydrologic setting of wetlands in the Cottonwood Lake area, Stutsman County, North Dakota: U.S. Geological Survey Water-Resources Investigations WRI 80-99, 42 p.