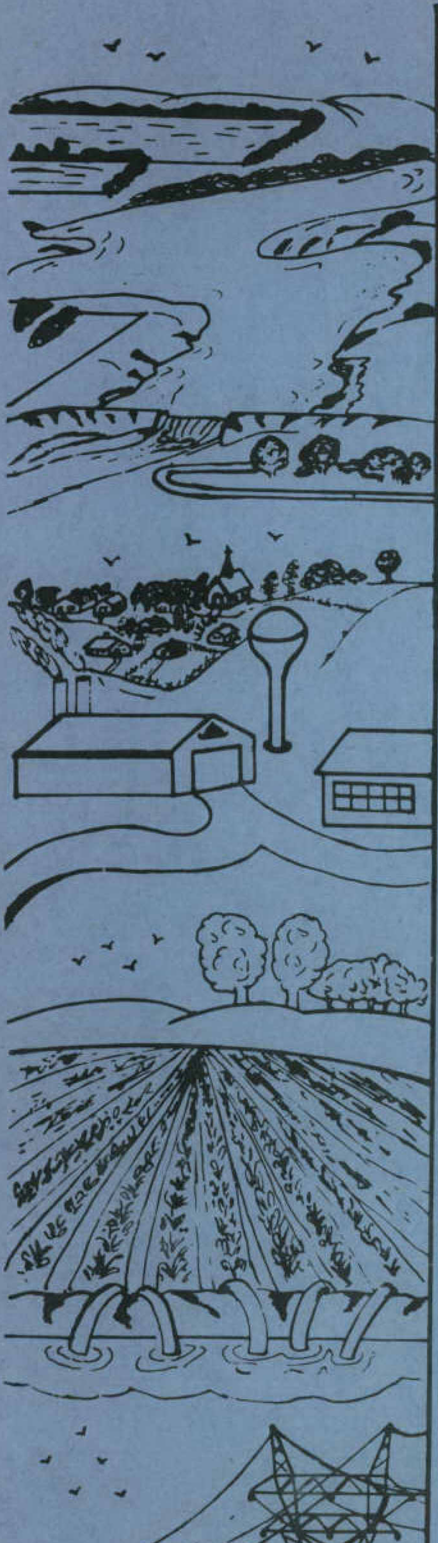


Ground Water In The Crosby-Mohall Area, North Dakota

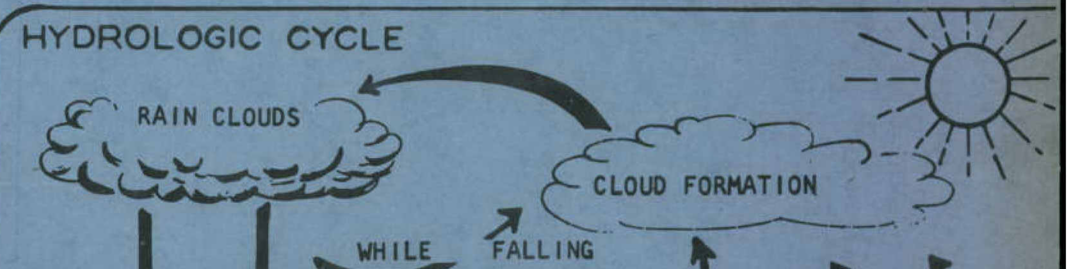
By
G. A. LaRocque, Jr., H. A. Swenson,
and D. W. Greenman

NORTH DAKOTA GROUND-WATER STUDIES NO. 54

Prepared by the U.S. Geological Survey as a part of the program
of the Department of the Interior for the development of the
Missouri River Basin

Published by
NORTH DAKOTA STATE WATER CONSERVATION COMMISSION
1301 State Capitol, Bismarck, North Dakota

1963



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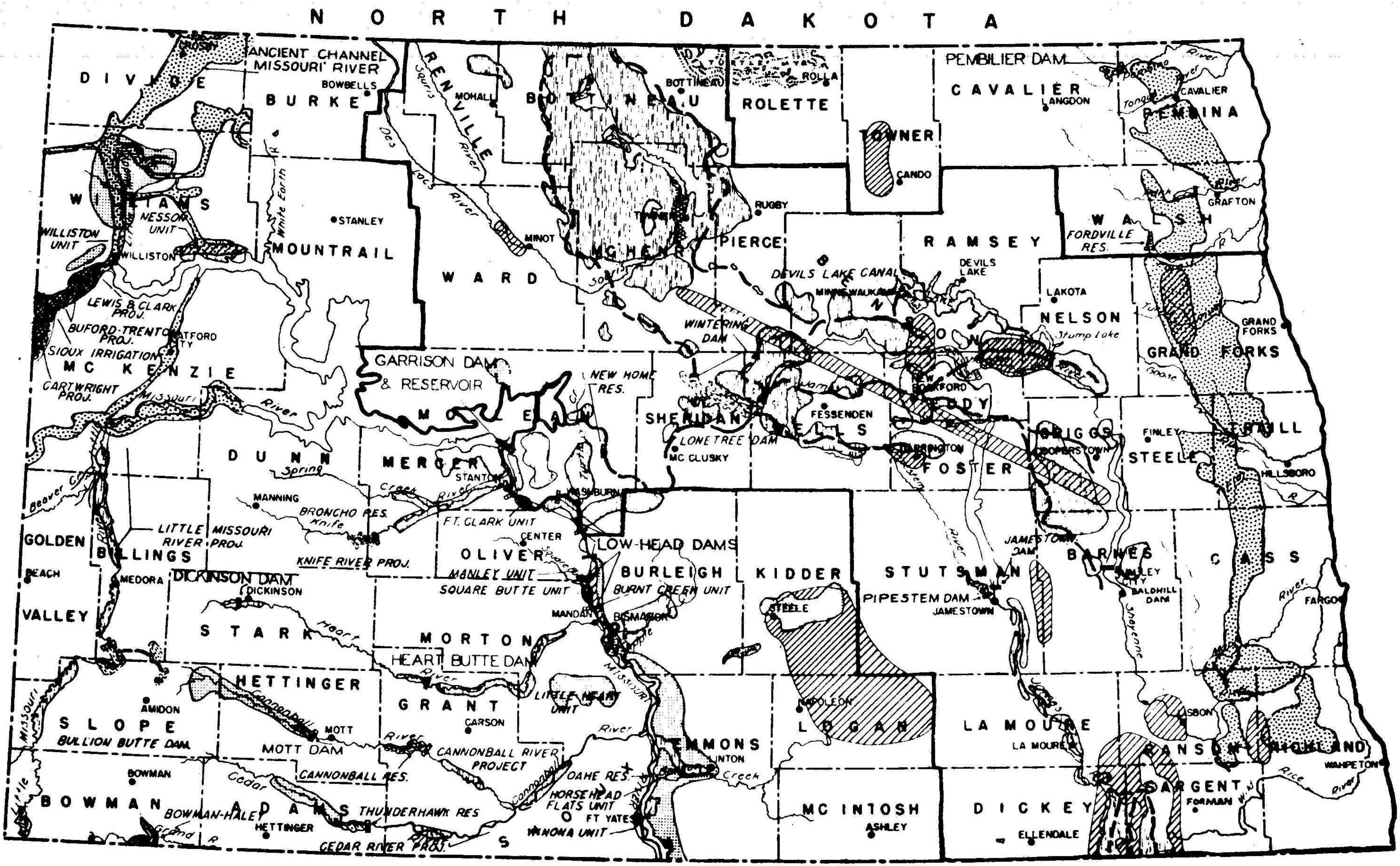

NORTH DAKOTA STATE WATER CONSERVATION COMMISSION

WATER RESOURCES DEVELOPMENT PLAN

- ▩ LANDS UNDER IRRIGATION
- ▥ AREAS CONSIDERED IRRIGABLE
- ▒ AREAS BEING INVESTIGATED
- ░ PROPOSED FOR INVESTIGATION

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GROUND WATER IN THE CROSBY-MOHALL AREA, NORTH DAKOTA

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GROUND WATER IN THE CROSBY-MOHALL AREA, NORTH DAKOTA

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ABSTRACT

The Fort Union Formation of Tertiary (Paleocene) age is the principal bedrock aquifer in the Souris River drainage basin in North Dakota. The lower part of the formation consists of two members, which probably intertongue, the nonmarine Ludlow and the marine Cannonball. The Ludlow underlies the western and central parts of the area, and the Cannonball underlies much of the eastern part. The upper part of the Fort Union is the nonmarine Tongue River Member, which completely covers the Ludlow and much of the Cannonball. Wells tapping the Fort Union may derive water from nonmarine strata only, from both nonmarine and marine strata, or from marine strata only.

The composition of water from the Cannonball Member is similar to that of ocean water although its average mineral content is only one-tenth as great. The water is used for watering livestock but generally is too salty for human consumption. Two types of water are present in the nonmarine members, one a hard calcium sulfate water and the other a soft sodium bicarbonate water; the hard water is obtained more commonly from the shallow wells and the

soft water from deep wells.. Although both types are suitable for most domestic purposes, the water from the deeper wells is less palatable and contains more fluoride than is considered desirable in drinking water, in some parts of the area. None of the water from the Fort Union is suitable for irrigation.

Except near the outcrop of the Fort Union, the water in the formation is under artesian pressure. In some places artesian or gas pressure is sufficient to cause water to flow from wells.

Most of the wells that were not drilled deep enough to enter the Fort Union Formation derive water from lenses and stringers of sand and gravel in the glacial drift. Some wells tap bodies of sand and gravel that are exposed at the land surface. The water in the deposits of Quaternary age is extremely variable in chemical quality. The least mineralized is that in the valley fill of the Souris and Des Lacs Rivers, in the glacial outwash deposits in the surficial melt-water channels, in surficial ice-contact deposits, and in the sediments deposited in ancient Lake Souris. The most mineralized is that derived from glacial till. The water generally is very hard and commonly contains sulfate as the principal constituent.

Recharge to the unconsolidated deposits underlying the report area is almost wholly from snowmelt and rain. Under the natural hydrologic regimen, in the area underlain by glacial drift, it is believed that about 60 to 70 percent of the recharge is from water that accumulates in numerous surface depressions, and about 30 to 40 percent is from the direct infiltration of available surface moisture on the upland areas tributary to the depressions. The greatest percentage of recharge is through the undrained depressions. Many of the undrained depressions, plus the drained depressions, account for about 70 to 80 percent of the natural ground-water discharge from the glacial drift. In these sinks, ground water is largely discharged through evapotranspiration. Irrigated areas may become waterlogged because the application of additional water to the surface will augment recharge. In the depressions, additional recharge will occur from (1) runoff from excessive applications of irrigation water; and (2) water-wastage caused by untimely and unavoidable deliveries of irrigation water in excess of immediate demands. In the upland areas, a significant quantity of additional recharge will occur from (1) precipitation, after soil-moisture requirements are satisfied by irrigation water, and (2) irrigation water in excess of crop requirements and soil-moisture deficiencies. Open-ditch or tile drains probably will be an uneconomical means for the prevention of widespread waterlogging in areas underlain by glacial drift. However, if runoff to the depressions were to be intercepted by a system of shallow drains and conducted to surface drainage courses, total recharge to ground water probably could be kept within the natural capacity of the land to drain itself.

INTRODUCTION

Purpose and scope of the investigation

The investigation upon which this report is based was made between September 1945 and September 1951 by the U.S. Geological Survey as part of the program of the Department of the Interior for the development of the water resources of the Missouri River basin. According to the original plan for development, a dam was to be constructed on Big Muddy Creek, a tributary of the Missouri River in northeastern Montana, and the water stored in the reservoir created by the dam was to be used for irrigating several areas in North Dakota (U.S. Congress, 1944). The largest of these proposed areas, sometimes called the Crosby-Mohall area, is described in this report. The area is almost wholly in the drainage basin of the Souris River in North Dakota, which is outside the Missouri River drainage basin. (See fig. 1.) Under the original plan for development, about a million acres in the report area was to be irrigated. Funds for completion of the investigation and for publication of the results were exhausted in 1953. In an effort to reduce the publication costs, this report has been modified slightly and some illustrations and tables have been removed.

The purpose of the investigation was to collect and interpret basic data concerning the occurrence and movement of ground water and to determine measures whereby waterlogging, an anticipated result of recharge by infiltrating irrigation water, could be prevented.

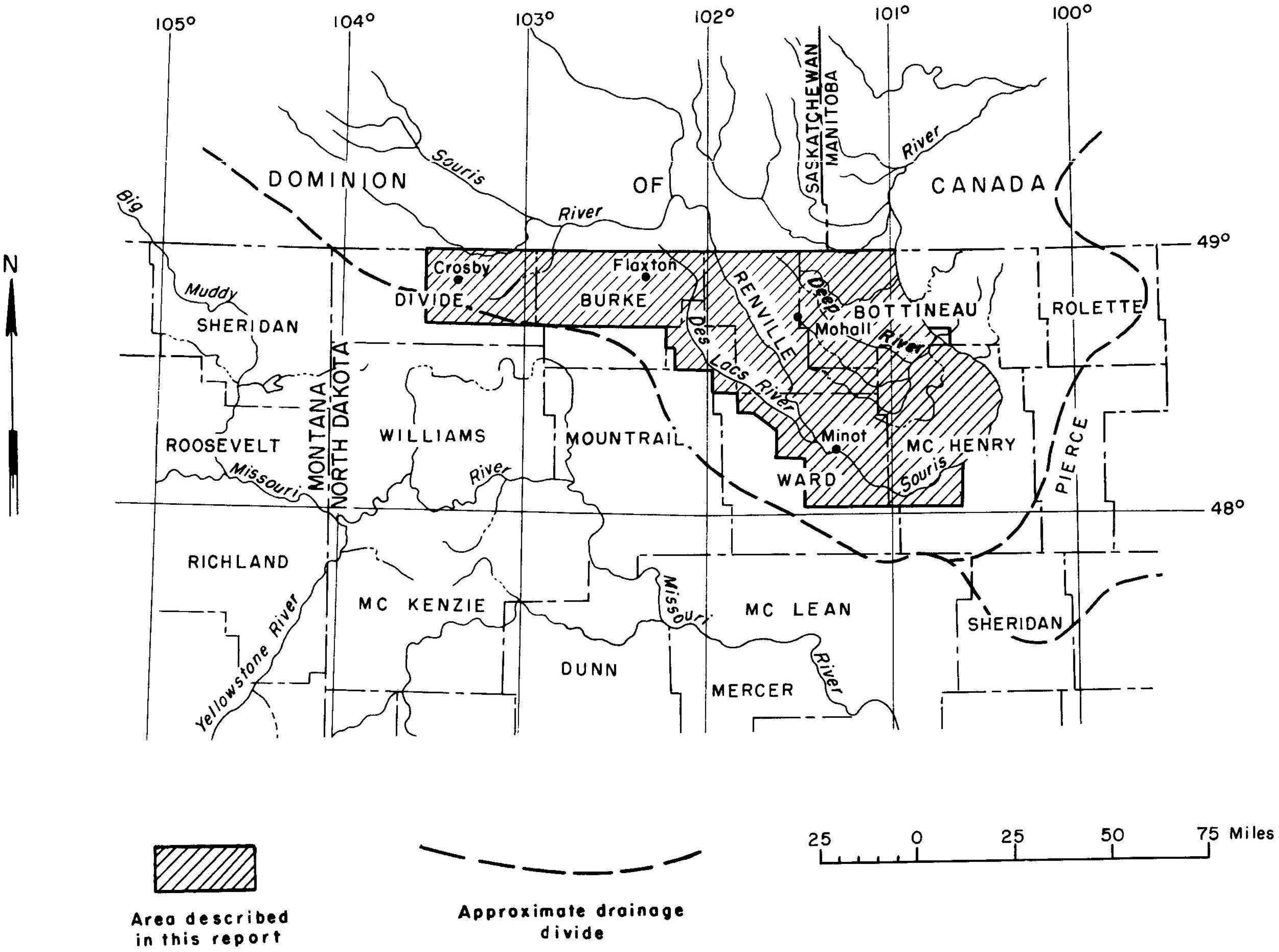


Figure 1.--Map showing the area described in this report.

The investigation included a study of rock formations, the occurrence of ground water in them, and the chemical character of the water. This report is an interpretation of basic data included in an open-file companion report (LaRocque, Swenson, and Greenman, 1963) available for inspection at the Water Resources Division offices of the U.S. Geological Survey in North Dakota and Denver, Colorado, and in the office of the North Dakota State Water Conservation Commission in Bismarck, N. Dak. The field work included an inventory of about 6,700 wells, summarized in table 1, the periodic measurement of the water level in about 570 wells, the contracted drilling of 92 test holes and collection of lithologic information on an additional 122 wells and test holes, the collection of about 2,000 samples of ground water for chemical analysis, and a detailed study of occurrence of shallow ground water in a test area 3 miles square near Flaxton in Burke County (figs. 1, 10).

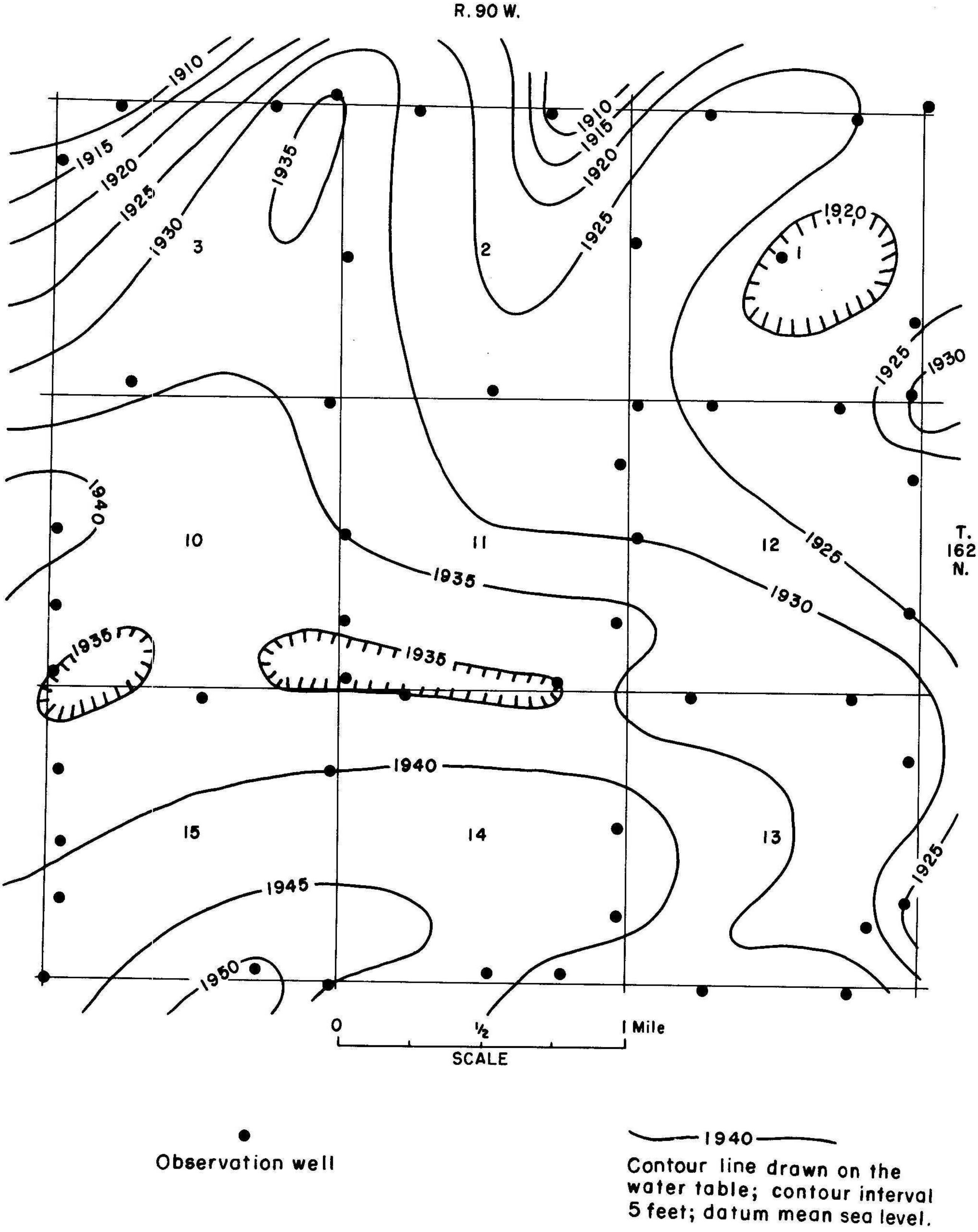


Figure 10 --Map of the Flaxton test area, Burke County, N. Dak., showing the configuration of the water table.

TABLE 1.--Distribution of wells and test holes by geologic formation, depth, and county, Crosby-Mohall area

(Detailed well records are given by LaRocque, Swenson, and Greenman, 1963, table 2.)

Geologic source	Depth of wells (Range, in feet)	Bottineau		Burke		Divide		McHenry		Renville		Ward		Total	
		Number	Cumulative percent	Number	Cumulative percent	Number	Cumulative percent	Number	Cumulative percent	Number	Cumulative percent	Number	Cumulative percent	Number	Cumulative percent
Undifferentiated	0 - 50	16	5.3	49	26.9	14	13.7	1	0.7	8	4.0	9	4.4	97	8.6
	50 - 100	62	25.9	48	53.3	32	45.1	24	17.7	4	6.0	44	25.9	214	27.5
	100 - 150	76	51.2	19	63.7	17	61.8	67	65.2	6	9.0	26	38.5	211	46.1
	150 - 200	62	71.8	31	80.8	11	72.5	35	90.1	4	10.9	40	58.0	183	62.3
	200 - 250	19	78.1	10	86.3	3	75.5	6	94.3	7	14.4	18	66.8	63	67.8
	More than 250	66	100	25	100	25	100	8	100	172	100	68	100	364	100
	Unknown	81	.....	86	.....	58	.....	34	.....	86	.....	110	.....	455	.....
Total		382		268		160		175		287		315		1,587	
Quaternary Glacial drift	0 - 50	522	78.3	426	75.3	218	74.9	767	80.7	424	90.6	480	76.3	2,837	79.4
	50 - 100	126	97.2	68	87.3	52	92.8	175	99.1	32	97.4	118	95.1	571	95.4
	100-- 150	9	98.5	26	91.9	3	93.8	6	99.7	1	97.6	15	97.5	60	97.1
	150 - 200	6	97.4	35	98.1	6	95.9	2	99.9	4	98.5	11	99.2	64	98.9
	200 - 250	13	99.9	7	99.3	3	96.9	1	100	3	99.1	1	99.4	18	99.4
	More than 250	1	100	4	100	9	100	0	100	4	100	4	100	22	100
	Unknown	82	.....	40	.....	23	.....	100	.....	122	.....	72	.....	439	.....
Total		749		606		314		1,051		590		701		4,011	
Tertiary Fort Union Formation Ludlow and Tongue River Members, undifferentiated	0 - 100	0	0	64	28.1	7	9.3	2	4.9	0	0	11	10.6	84	16.1
	100 - 150	0	0	37	44.3	16	30.7	20	53.7	0	0	18	27.9	91	33.6
	150 - 200	1	14.3	50	66.2	6	38.7	15	90.2	3	4.5	17	44.2	92	51.2
	200 - 300	5	85.7	53	89.5	20	65.3	3	97.6	22	37.9	32	75.0	135	77.2
	300 - 400	1	100	16	96.5	20	92.0	1	100	28	80.3	18	92.3	84	93.3
	More than 400	0	100	8	100	6	100	0	100	13	100	8	100	35	100
	Unknown	1	.....	8	.....	0	.....	0	.....	5	.....	16	.....	30	.....
Total		8		236		75		41		71		120		551	
Composite Tongue River-Cannonball Members	0 - 100	0	0	0	0	0	0	1	2.9	1	2.9	0	0	2	1.8
	100 - 150	0	0	0	0	0	0	15	47.1	0	2.9	1	3.2	16	16.4
	150 - 200	1	10.0	0	0	0	0	10	76.5	1	5.9	5	19.4	17	31.8
	200 - 300	6	70.0	0	0	0	0	8	100	6	23.5	5	35.5	25	54.5
	300 - 400	3	100	0	0	0	0	0	100	5	38.2	15	83.9	23	75.5
	More than 400	0	100	1	100	0	0	0	100	21	100	5	100	27	100
	Unknown	0	.....	0	.....	0	.....	0	.....	10	.....	1	.....	11	.....
Total		10		1		0		34		44		32		121	
Cannonball Member	0 - 100	0	0	0	0	0	0	4	5.0	0	0	0	0	4	1.1
	100 - 150	0	0	0	0	0	0	18	27.5	0	0	1	1.4	19	6.1
	150 - 200	4	5.5	0	0	0	0	32	67.5	5	3.3	13	19.2	54	20.3
	200 - 300	25	39.7	0	0	0	0	22	95.0	23	18.3	29	58.9	99	46.4
	300 - 400	37	50.7	0	0	0	0	4	100	56	54.9	18	83.6	115	76.8
	More than 400	7	100	0	0	0	0	0	100	69	100	12	100	88	100
	Unknown	8	.....	0	.....	0	.....	4	.....	43	.....	1	.....	56	.....
Total		81		0		0		84		196		74		435	
Total inventoried		1,230		1,111		549		1,385		1,188		1,242		6,705	

The Flaxton test area was selected by the U.S. Bureau of Reclamation and the U.S. Geological Survey for study of drainage problems because it was considered to be representative of the soil type and topography of that part of the report area west of the Des Lacs River. Small-diameter observation wells, ranging in depth from 10 to 26 feet, were installed on the section lines at intervals of a quarter of a mile and one well was installed at the center of each section (fig. 10).[1] Measurements of the water level in these 97 wells were made periodically and water samples for analysis were collected from many of them both in October 1949 and in July 1950.[1]

1/ Basic data for Flaxton test area given in tables 3, 4, 7, and 8 of the companion open-file report (LaRocque, Swenson, and Greenman, 1963).

Well-numbering system

The well-numbers used in this report show the location of wells according to the U.S. Bureau of Land Management's survey of the area. The first numeral of a well number indicates the township, the second the range, and the third the section in which the well is located. The lowercased letters following the section number show the position of the well within the section. The first letter indicates the quarter section, the second the quarter-quarter section, and the third the quarter-quarter-quarter section (10-acre tract). The letters are assigned in a counterclockwise direction, beginning in the northeast quarter of the section, quarter section, or quarter-quarter section. Where two or more wells are located in the same tract, they are distinguished by serial numbers, beginning with 1, added after the lowercased letters. (See fig. 2.)

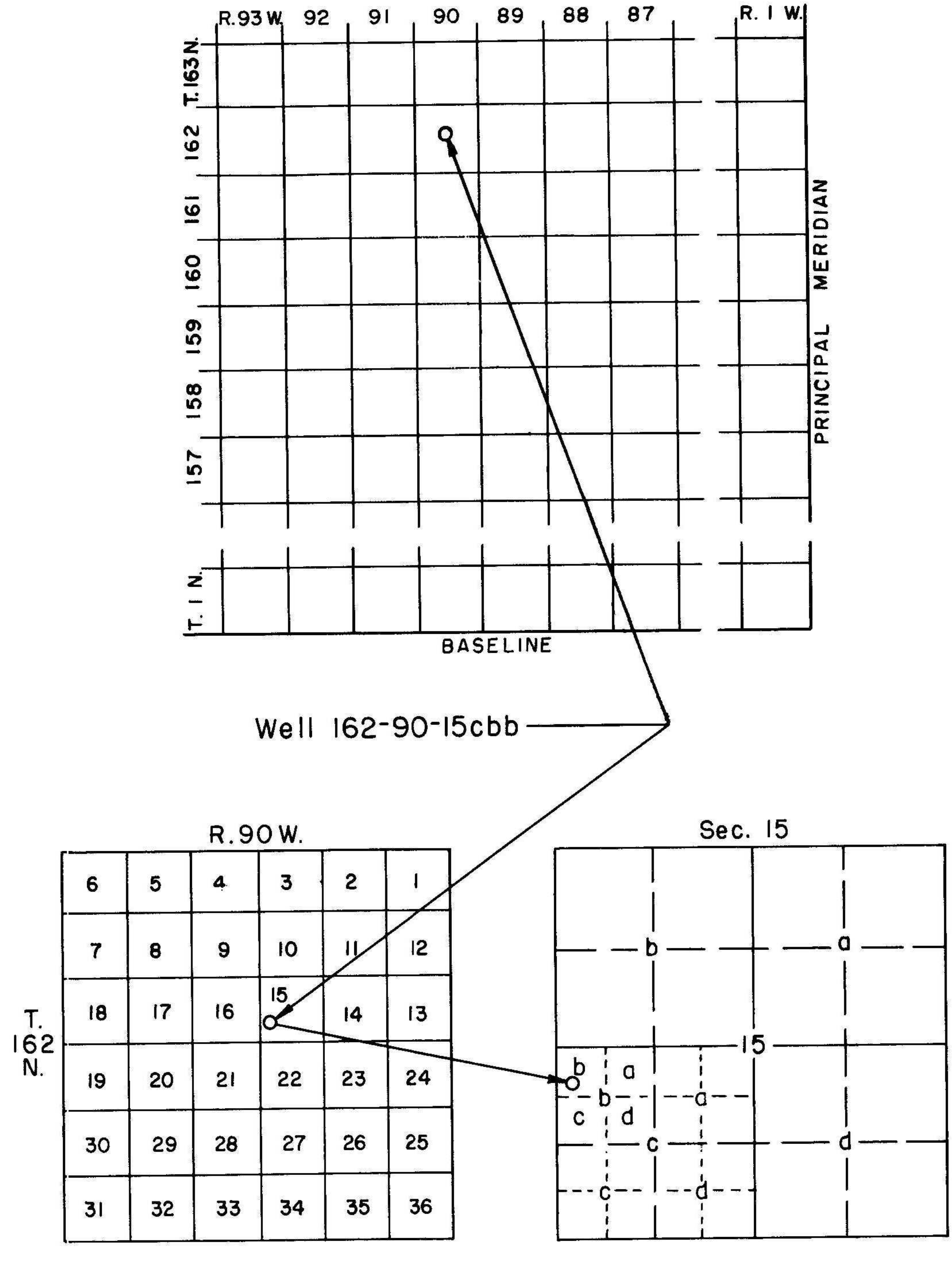


Figure 2.--Well-numbering system.

GEOGRAPHY

Location and extent of area

The area described in this report is in northwestern North Dakota adjacent to the Canadian boundary. It is wholly north of the 48th parallel of latitude and is between $100^{\circ}25'$ and $103^{\circ}30'$ west longitude. The area contains about 4,300 square miles, is about 130 miles long in a southeast-northwest direction, and ranges in width from 15 to 65 miles. It comprises all of Renville County and parts of Bottineau, Burke, Divide, McHenry, and Ward Counties. (See fig. 1.)

Agricultural and economic development

The agricultural economy of the area was established and developed when the precipitation was above average. By 1920 most of the area had been divided into homesteads of 160 acres. During the subsequent prolonged period of drought, many homesteads were sold or relinquished and the population decreased to about one-fourth of its earlier total. Meanwhile, many homesteads were consolidated into larger holdings, some consisting of several thousand acres. Since 1940, with the aid of labor-saving machinery and several years of good crops, farming again has become profitable.

Most of the area is dry farmed. Much of the sandy land in the southeastern part of the area and some of the rough and stony land elsewhere in the area is used for pasture. Meadowlands in shallow valleys and in the valleys of the Des Lacs and Souris Rivers are used either for grazing or for growing forage. Wheat and flax are the principal crops. Dairying and the raising of beef cattle, hogs, sheep, turkeys, and chickens are other important sources of farm income.

Minot, which is in the valley of the Souris River near the south border of the area, is the principal city and has a population of about 20,000. No other town in the area has a population greater than 2,000. Towns of more than 500 are Bowbells, Columbus, Crosby, Kenmare, Mohall, Noonan, Portal, Towner, and Velva (fig. 2). These and several smaller towns are supply points for the farmers and shipping points for grain and livestock.

Lignite is mined extensively. Several large strip mines are in operation near Noonan and Columbus in the western part of the area and near Velva in the southeastern part. The overburden is as much as 100 feet thick in some of the mines, but more generally it is less than 50 feet thick. Gravel from deposits in the Souris River valley was used for concrete aggregate in the construction of Garrison Dam in central North Dakota.

Most of the roads in the area are on section lines. A few have been hard surfaced or graveled, and many of the dirt roads have been graded. The latter dry quickly after summer rains but are muddy and rutted in the thawing period during March and April.

Every point within the report area is within about 15 miles of the main or a branch line of either the Great Northern Railway or the Minneapolis, St. Paul and Sault Ste. Marie Railroad. The main lines of both railroads pass through Minot.

Physiography

The report area is in the northwestern part of the Western lake section of the Central Lowland physiographic province (Fenneman, 1931) and lies almost wholly within the drainage basin of the Souris River, which is known locally by its English equivalent, Mouse River. The Souris River rises in Canada, flows southeastward across the boundary of the United States into North Dakota, and at the town of Velva, McHenry County, veers northeastward for about 35 miles and thence flows northwestward back into Canada. Within North Dakota the Souris River drains about 9,250 square miles. Its largest tributary, the Des Lac River, also flows southeastward from Canada and drains the central part of the report area. Another tributary, the Deep River, drains most of the Souris loop, which is the part of North Dakota enclosed by the Souris River.

The report area is an eastward-sloping, gently undulating plain, which has been relatively unchanged by erosion since the melting of the last great ice sheet. It is dissected by the deep, narrow valleys of the Souris and Des Lacs Rivers and their principal tributaries, by the abandoned channels of ice-marginal streams, and by the shallow channels of streams that flowed off the melting ice sheet. Except in the eastern part of the area, which was once covered by ancient Lake Souris, oval or circular depressions called kettles are common. Most of these depressions, generally about 5 to 10 feet deep and about 100 to 300 yards across, were formed by the melting of residual blocks of ice that were wholly or partly buried in the glacial deposits. The altitude of the land surface ranges from nearly 2,300 feet at the west border to about 1,420 feet along the Souris River at the east border of the area.

Climate

The climate of northwestern North Dakota is rigorous. The winters are characterized by strong winds, extremely low temperatures, and little snowfall. Summer rains are frequent but are of short duration, and storms of cloudburst proportion are not uncommon. Precipitation is uniform (see figs. 3 and 4) and, as in many other semiarid areas, the annual total varies widely -- from about 40 to about 200 percent of the average. These extreme departures generally are the result of wide variations in the frequency and intensity of rainstorms. Because the arithmetic average of the annual precipitation recorded at a given station gives too much weight to infrequent extreme departures from average, the expected annual precipitation based on frequency of occurrence also was calculated. (See fig. 5.) The amounts of annual precipitation calculated by both methods checked closely. The arithmetic average of the annual precipitation at Bismarck for the period 1875-1947 was 16.34 inches, and the expected annual precipitation, based on frequency of occurrence, was 16.02 inches.

The cumulative departure from expected annual precipitation at Bismarck for the period 1875-1950 and the average cumulative departure from the average of the expected precipitations at Crosby, Bottineau, Minot, and Mohall for the period 1905-50 are shown in figure 6. Both curves have

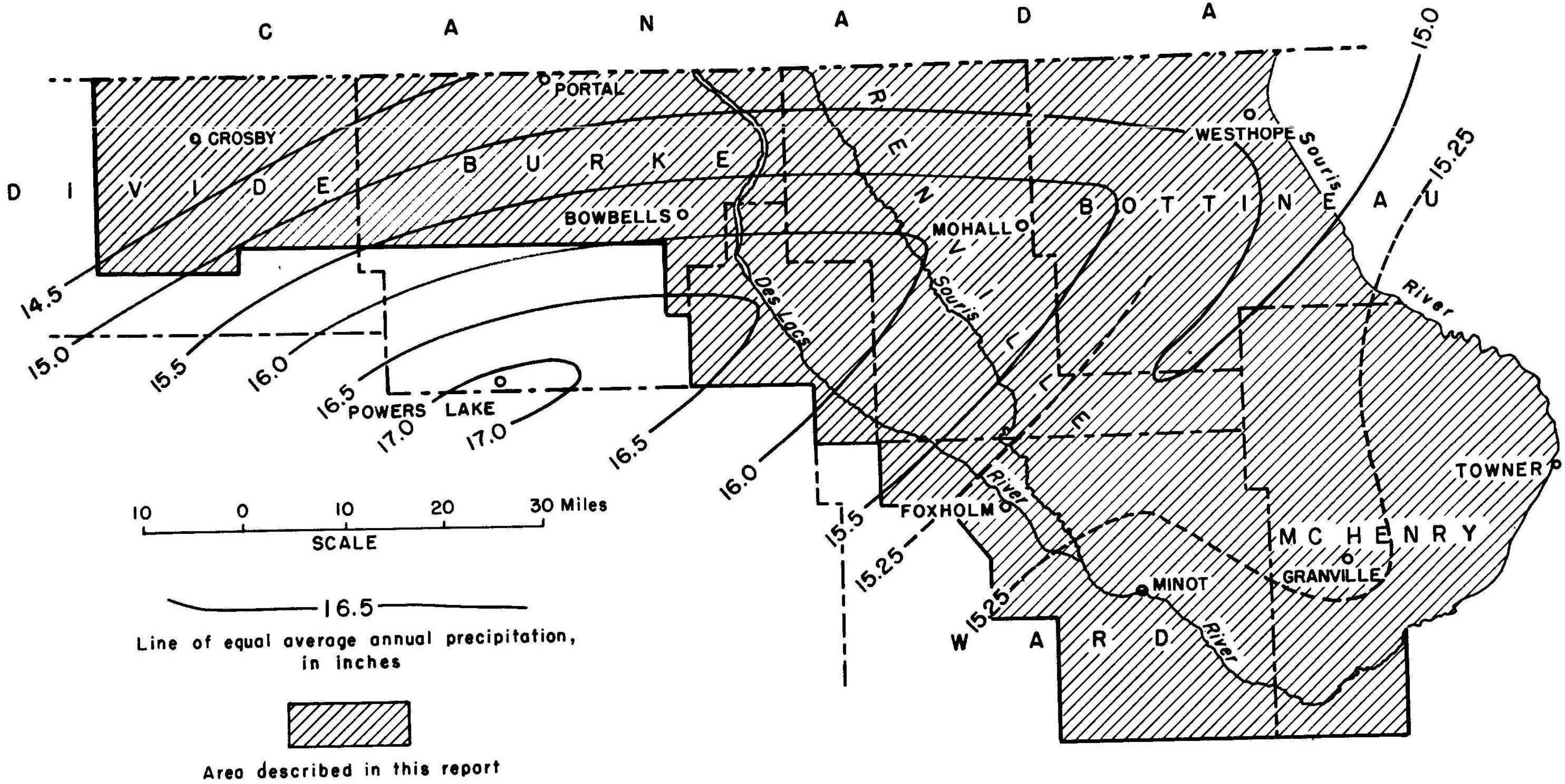


Figure 3.-- Map of Crosby-Mohall area showing average annual precipitation, in inches, 1907-45. (Based on records of the U. S. Weather Bureau)

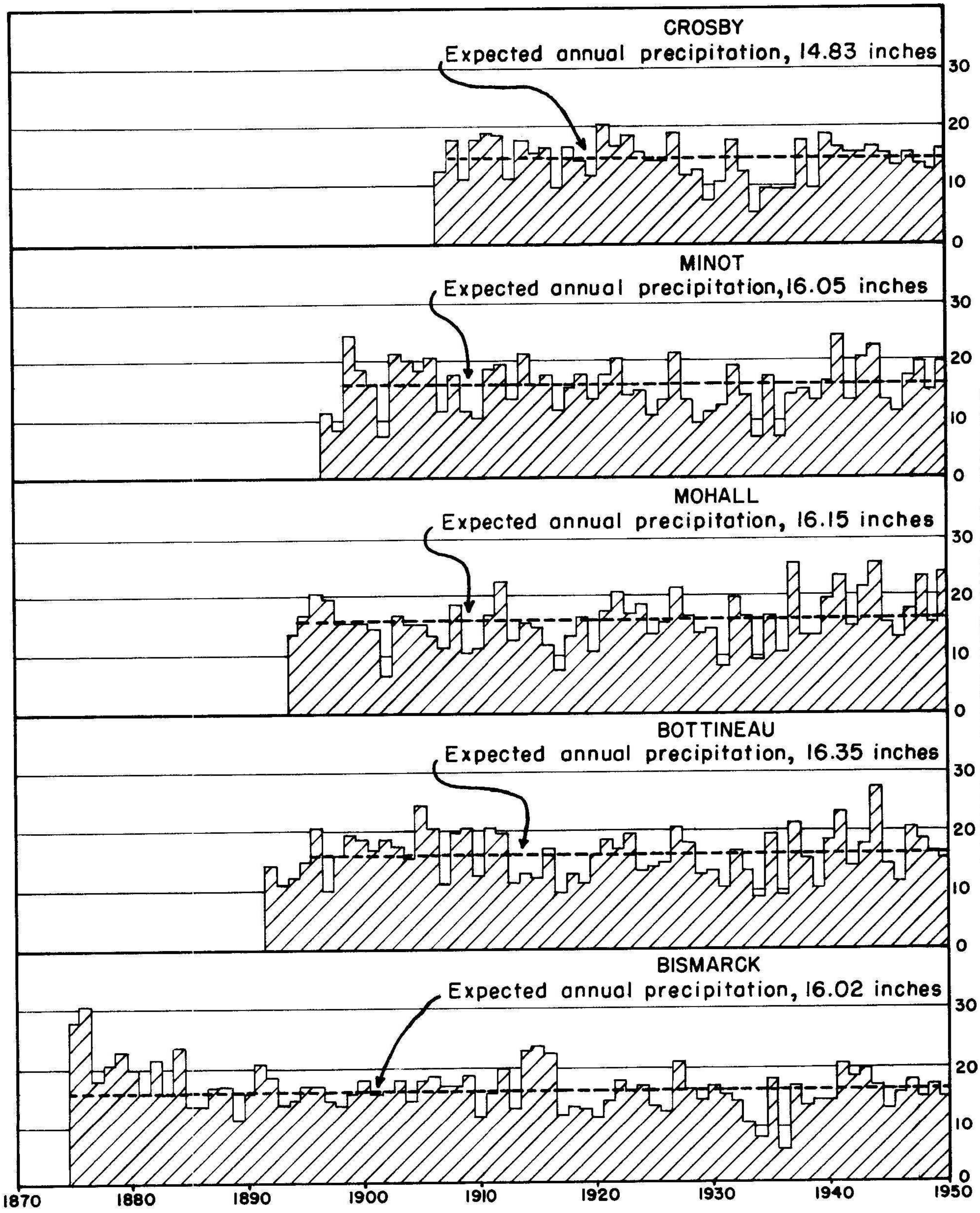


Figure 4.--Annual precipitation at five stations in North Dakota, 1875-1950.

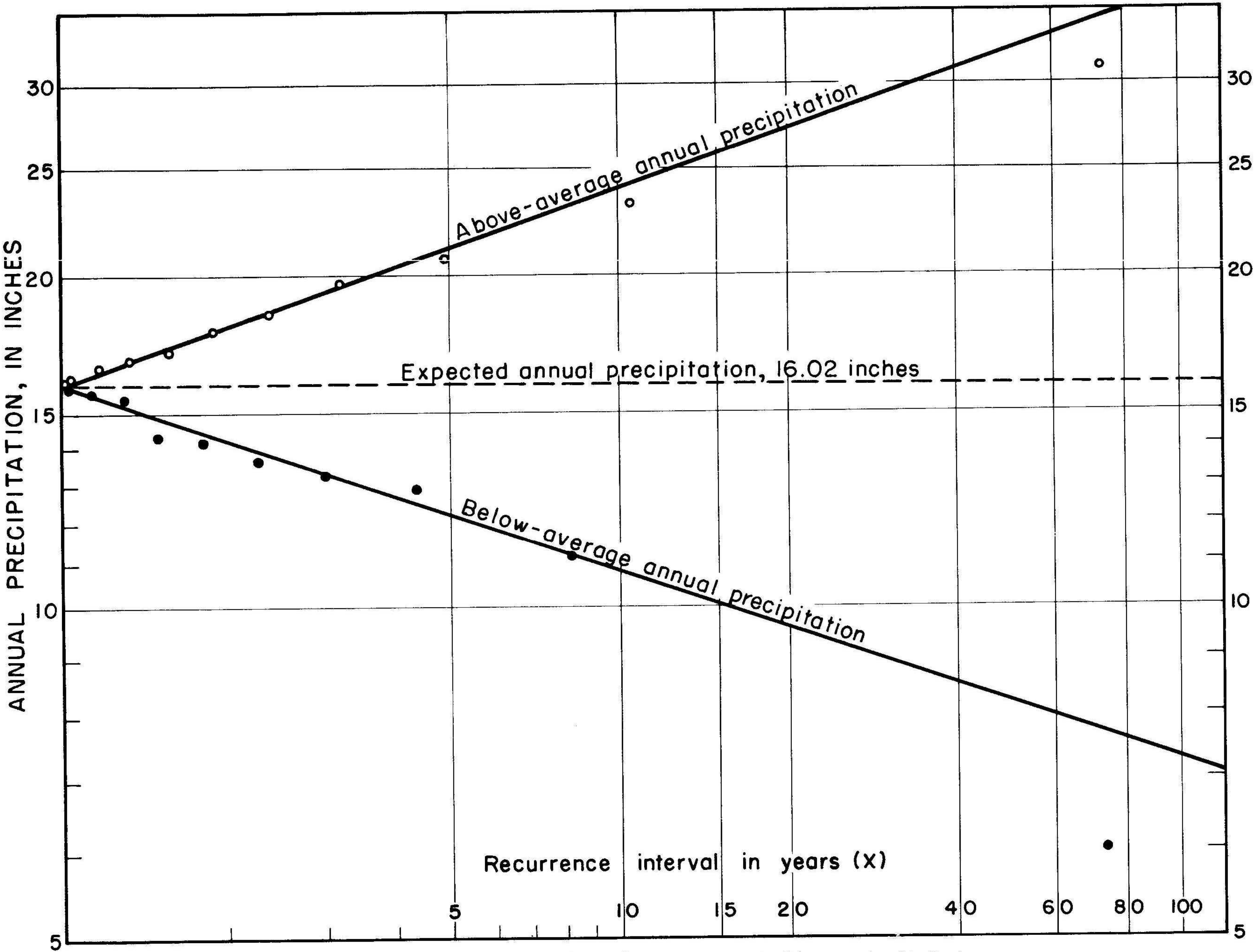


Figure 5.– Annual precipitation frequency at Bismarck, N. Dak.

been smoothed by using 5-year moving averages. The rising parts of the curves indicate that actual precipitation exceeded the expected precipitation, and the declining parts indicate the opposite. Although many references are made to the drought of the 1930's, inspection of the graph shows that the drought period in this area actually began about 1916 and continued with but slight break until 1940.

Because the surficial earth materials do not freely transmit water downward to the zone of saturation, and because such a large part of the precipitation generally comes from storms of relatively short duration rather than from several successive days of rainfall, increases in the amount of ground water in storage in this area probably are not related directly to the amount of precipitation. Instead, the amount of rise and the duration of the period of rise in ground-water levels are governed largely by how much water collects in the undrained depressions during the period of snowmelt and spring rains and how long before all the water either sinks into the ground or is evaporated.

The average growing season in the report area is about 110 days. In general, about 77 percent of the annual average precipitation falls during the growing season, and about 50 percent falls during May, June, and July. As the economy of the region is related closely to the wheat crop, a succession of dry years is disastrous to the prosperity of the whole area and affects the entire population.

GEOLOGY

Previous investigations

Simpson (1929), in a report on the geology and ground-water resources of North Dakota, gave much information on ground water in the report area. The glacial deposits in the western part of the area were described by Alden (1932), and a somewhat more detailed geologic description, as well as information on the water supply in the western part of the area, was presented in an unpublished report (Alpha, A. G., 1935, Geology and ground-water resources of Burke, Divide, Mountrail, and Williams Counties in North Dakota: North Dakota Univ. M.S. thesis). Geologic information for much of the report area is included in a comprehensive report on the Souris River area by Lemke (1960) and in published quadrangle maps by Townsend (1954a, b, c). Several reports of the North Dakota Geological Survey (Abbott and Voedisch, 1938; Akin, 1947, 1951; Laird, 1941; and Simpson, 1932, 1935, 1937) contain well logs and other detailed information.

The principal deposits of lignite have been described in reports by Andrews (1939), Brant (1953), Leonard and others (1925), and Lemke (1960). A report on land use and erosion in the vicinity of Minot was made by Holowaychuck and Boatright (1938).

Summary of stratigraphy

Only rocks above the top of the Pierre Shale of Late Cretaceous age are described in this report because drilling for water below this horizon is considered to be infeasible. The Pierre is overlain, in ascending order, by the Late Cretaceous Fox Hills Sandstone and Hell Creek Formation, the Fort Union Formation of Tertiary age and glacial and alluvial deposits of Quaternary age. The principal water-bearing formations are the Tertiary Fort Union Formation and the Quaternary glacial deposits.

The Pierre Shale, a marine deposit, underlies the entire area and probably nowhere in the area is its thickness less than 1,000 feet. The log of the J. H. Kline well 1, in sec. 16, T. 157 N., R. 85 W., shows it to be 1,200 feet thick and to consist of gray clay that contains bentonite and ironstone (Lemke, 1960, p. 11-19). The Pierre is too fine grained to transmit significant quantities of water to wells, and the little water it might yield probably would be too highly mineralized for use (Simpson, 1929, p. 39). Northeast of a line roughly paralleling and 2 to 8 miles southwest of the Souris River in northern McHenry County and in Bottineau County, the top of the Pierre is within about 35 to 50 feet of the land surface. West and southwest of that line it is progressively deeper and at the west end of the area it is estimated to be 1,500 feet or more below the land surface.

Except in the 2 to 8 mile wide band along the northeast border of the area, the Pierre is overlain by the Fox Hills Sandstone, also of Late Cretaceous age. If the sandstone cropping out along the valley wall of the Souris River near Verendrye in McHenry County has been correctly identified, the Fox Hills is the oldest formation exposed in the report area. Because the outcropping sandstone contains both marine fossils and remains of land plants, the Fox Hills in this part of the area is believed to have been deposited close to the shoreline of a sea. Little is known of its lithology and thickness in the report area because so few holes have been drilled into or through it. Cuttings from the J. H. Kline well 1, in which the Fox Hills was 235 feet thick, show it to be composed of gray shale, siltstone, and fine-grained sandstone. The formation thins until it loses its identity along the northeastern limit of its extent, and, judging from measured thicknesses in northeastern Montana (Swenson, 1955, p. 37), it is probably no more than 50 feet thick at the western end of the report area. It probably would yield small quantities of water to wells, but no wells in the area are known to be sufficiently deep to tap it.

The Hell Creek Formation, the youngest formation of Late Cretaceous Age in the area, is believed to overlie the Fox Hills Sandstone throughout the western part of the report area and the southwestern half of the Souris loop. According to Lemke (1960, p. 24, 26), the Hell Creek possibly crops out in the valley wall of the Souris River near Verendrye. The log of the J. H. Kline well 1 shows it to be 235 feet thick and to consist of gray fine-grained sandstone, gray siltstone and mudstone, gray silty shale, and greenish-gray silty bentonite. Like the Fox Hills Sandstone, it thins to a zero thickness along the northeastern limit of its extent. Swenson (1955, p. 38) estimates a thickness of 130 to 150 feet for the Hell Creek in northeastern Montana and the thickness of this formation at the western end of the report area is assumed to be about the same or possibly a little greater. The Hell Creek is a source of water supply in eastern Montana and, if tapped, probably would yield water to wells in the report area also.

Except for the exposure of Late Cretaceous rocks near Verendrye, the Fort Union Formation of Tertiary (Paleocene) age is the only bedrock exposed in the report area. As shown on plate 2, bedrock crops out in many places along the Des Lacs River south from central T. 161 N., R. 88 W., to its confluence with the Souris River, and thence along the Souris River to the southeastern part of T. 154 N., R. 79 W. It also crops out in many places in eastern Divide County and western Burke County. The Fort Union is an eastward-thinning wedge that extends beyond the eastern limit of the Hell Creek Formation but not as far as the eastern limit of the Fox Hills Sandstone. The Fort Union lies unconformably on the underlying Cretaceous rocks which had been gently warped and beveled by erosion before the Fort Union was deposited.

The Fort Union has been subdivided into three members -- the Cannonball, which is marine, and the Ludlow and Tongue River Members, which are continental. The Cannonball and Ludlow Members compose the basal part of the formation. They were deposited contemporaneously, at least in part -- the Cannonball in a shallow sea and the Ludlow on a broad plain bordering that sea. During Cannonball time the sea advanced from the east and submerged the eastern part of the area. Because the ancient sea probably advanced and receded several times before it finally withdrew completely, the sediments of the Cannonball and Ludlow Members are assumed to intertongue in the report area in the same manner as they do where exposed in the south-central part of North Dakota. The members have not been mapped in the subsurface, but on the basis of chemical analysis of water from many wells drilled into bedrock, it is believed that the westernmost advance of the Cannonball sea was to a line almost coinciding with the course of the Des Lacs River. After the final retreat of the sea, deposition of continental deposits extended over the entire area and continued uninterrupted throughout Tongue River time, which lasted to the end of the Paleocene Epoch.

The Cannonball Member is exposed on the walls of the Souris River valley from a point about midway between Minot and Velva to a point about 9 miles downstream from Velva. The Cannonball is well exposed about 2 miles upstream from Velva in the SW$\frac{1}{4}$ sec. 16, T. 153 N., R. 80 W., where the Souris River has undercut a 40-foot bluff of grayish-black sandy shale. In most exposures the Cannonball is composed mainly of alternating thin beds of tan to brown sand and sandy shale. Small gypsum (selenite) crystals are moderately abundant, and a few fairly round, carbonate-rich concretions are present along some bedding planes.

The Ludlow Member is not exposed in the report area but underlies the western and central parts. Numerous wells have been drilled into it. Where the Ludlow Member is exposed in the valley of the Missouri River near Bismarck, N. Dak., it consists of gray to brown fine-grained sand interbedded with brown to black lignitic shale. The sand commonly is silty to shaly and is crossbedded.

The Tongue River Member consists of generally light-colored interbedded shale, clay, siltstone, sandstone, sand, and lignite beds. The sediments were deposited in large part in swamps, lagoons, and shallow lakes. The position and size of the shallow bodies of water gradually shifted and changed during the accumulation of the sediments, causing the resulting layers to be disconnected and uneven in thickness. Lush vegetation grew in swamps and shallow lagoons, and, in places, accumulations of organic matter were buried by subsequent sedimentary deposits. By the end of the Paleocene Epoch, the aggregate thickness of these sediments was about 1,000 feet in the western part of the area but may have been somewhat less in the eastern part. The Tongue River Member crops out in many places in the western part of the area and here and there along the valley walls of the Des Lacs River and along the valley of the Souris River between Burlington and Velva.

Because the nonmarine members have not been differentiated in the subsurface, and also because they apparently share similar hydrologic characteristics, they are treated in this report as a single hydrologic unit, the Ludlow and Tongue River Members undifferentiated.

Between the end of the Paleocene and the beginning of the last glaciation of the Pleistocene Epoch the Fort Union Formation was gently warped. Erosion removed much of the sediments of the Tongue River Member or the area within the Souris loop and produced a badlands topography in part if not throughout the entire area. The general configuration of the bedrock surface thus produced is shown on plate 1.

During the Pleistocene Epoch glaciers moved southward over the area at least three times and possibly four. The glaciers were heavily laden with rock fragments which had been picked up and transported by the ice as it advanced. Each successive advance of ice tended to smooth the terrain by filling the valleys and abrading the hills. When the margin of the glacier melted northward, the rock debris that had been transported within the ice was left as a mantle on the surface overridden by the ice. Also, the melt water flowing out from and along the ice front deposited glacial debris in a network of channels. The frequent changes in the ice front caused old melt-water channels to be abandoned and new ones to be formed. Turbulent streams flowing from the ice, or in crevasses or esker streams, washed coarse rock material into mounds and ridges. At its highest level, Lake Souris, which was formed in front of the ice margin during the retreat of the last ice sheet, inundated the east half of the Souris loop. The present ground surface is essentially as the ice and melt water left it.

The glacial deposits consist chiefly of ground and end moraine but also include ice-contact, outwash, and glacial lake deposits. Test drilling has revealed that the thickness of the glacial deposits ranges from less than a foot near bedrock outcrops to at least 520 feet where they fill a valley in the bedrock surface near Crosby, in Divide County. (See pl. 1, this report, and LaRocque, Swenson, and Greenman, 1963, table 3.)

Ground moraine is not only the most widespread exposed deposit in the report area but in most places underlies all the other exposed glacial deposits. It consists mainly of till, which is a nearly impervious mixture of clay, silt, sand, pebbles, and boulders. Its surface is a gently undulating plain pockmarked by numerous undrained saucer-shaped depressions, or kettles, many of which contain water. In some of the depressions, slopewash and windblown material have been deposited to a thickness of several feet. Rising above the general surface of the moraine are hummocky areas of recessional moraines, consisting of till intermixed with ice-contact deposits of silt, sand, and gravel. The finer-grained portion of the till was derived in part from the underlying bedrock. The pebbles and boulders, however, are fragments of stratified, metamorphic, and igneous rock transported from Canadian sources. On drying, the more clayey till cracks into vertical blocks having a pronounced prismatic structure.

Outwash from the wasting glacier not only carved a complex network of channels into the surface of the ground moraine but partially filled the channels with marly clay, silt, sand, and gravel. In the broader channels the thickness of these deposits is as much as 15 feet, but in the narrower channels it generally is less than 5 feet. Although fairly permeable, vertical and lateral drainage from these deposits is usually poor because the underlying and surrounding ground moraine is nearly impervious. The thin alluvial deposits in the Des Lacs and Souris River valleys are underlain by glacial outwash deposits which extend to a depth of as much as 150 feet in some places. As part of a study of ground water in the Mohall area (Akin, 1951), several test holes were drilled through the valley fill in the Souris River valley as well as in the nearby melt-water channels. The logs of these test holes are included in table 3 (LaRocque, Swenson, and Greenman, 1963). Glacial outwash deposits form terrace remnants along the valley walls.

The ice-contact deposits consist for the most part of kames, eskers, and crevasse fillings. Kames are mounds of poorly sorted silt, sand, and gravel carried by glacial melt water and deposited in holes in the glacier or in re-entrants at the ice margin. A few of the kames stand as much as 40 feet above the surrounding plain. The eskers are narrow, sinuous ridges of material deposited by streams in the ice or at the base of the ice; crevasse fillings were deposited in cracks in the ice. Although, in general, the ice-contact deposits are moderately to highly permeable, they commonly are easily drained except where they are so thin that the underlying ground moraine is close to the surface.

The lake sediments underlying the flat plain that is a part of the bed of ancient Lake Souris consist of well-sorted clay, silt, sand, and fine gravel and range in thickness from 0 to about 30 feet. In general, the deposits are coarsely textured in the southern half of the Souris loop and along the western shoreline of the lake. Deltaic deposits radiate from the points where streams of melt water entered the lake; these deposits grade laterally into the more typical lake deposits. In general, much of the area underlain by lake sediments is presently poorly drained, but is drainable.

Except for the deposits of sand, silt, and clay of Recent age, which form the valley floor of the Souris River and its larger tributaries, the deposits of Quaternary age are late Wisconsin. It is not known how much of the total thickness of unconsolidated deposits should be attributed to the Wisconsin stage of glaciation, but it is believed that possibly some of the buried layers of till and lenses of stratified silt, sand, and gravel penetrated in the drilling of wells and test holes may be associated with earlier glacial advances.

All available evidence indicates that the buried lenses and stringers of stratified silt, sand, and gravel are scattered throughout the mass of unconsolidated deposits without apparent system of orientation and that few, if any, are of more than local extent. Consequently, drilling a well in the hope of tapping one or more such layers within the zone of saturation generally is a "hit-or-miss" proposition.

The large streams in the report area have deposited alluvium in their valleys. The alluvium consists of fairly well sorted sand, silt, and clay, and cannot be readily distinguished from the glacial outwash deposits that underlie it in most places, although generally it is finer grained.

Windblown sand has accumulated in several places in the report area. Most dunes are of local extent, but several areas of dune sand are fairly large.

HYDROLOGIC PROPERTIES OF THE GLACIAL DEPOSITS

The hydrologic properties of the glacial deposits at 7 sites within the report area were determined by aquifer tests. Six of the tests were made as part of this investigation and one was made by consultants engaged by the thermoelectric plant at Voltaire. The results of the seven tests are summarized below. The specific conductance of water samples collected from the pumped wells during four of the tests is summarized in table 2, and the complete chemical analyses are given in LaRocque, Swenson, and Greenman (1963, table 5).

Results of aquifer tests

Pumped well	Thickness of aquifer (feet)	Coefficient of storage	Coefficient of transmissibility (gallons per day per foot)	Coefficient of permeability (gallons per day per square foot)
		Lake deposits		
157-75-31ca (McHenry County)	....	0.16	75,000	.....
158-77-35ada (McHenry County)	....	.09	2,000	110
159-80-35bbb (McHenry County)	18.9	0.0003	10	0.5
162-90-10cbc (Burke County)	12.8	.01	25	2.0
163-80-19ddd (Bottineau County)	16.5	.01	60	3.5
163-84-6ad (Renville County)	14.5	.003	8	.5
		Outwash deposits		
153-79-31ca 1/ (McHenry County)	67	0.15	43,000	650

1/ Data obtained from thermoelectric plant at Voltaire.

TABLE 2.--Specific conductance of water from wells used in aquifer tests

Well number	Depth of well (feet)	Date of collection	Time	Depth to water in pumped well (feet below land surface)	Specific conductance of pumped water (micromhos at 25° C)
158-77-35ada	27	8 -7-51	9:20 a.m.	.....	615
			12:00 m	.....	577
			4:00 p.m.	.....	627 [a]
159-80-35bbb	25	8-16-51	11:30 a.m.	8.00	1,230
			2:50 p.m.	15.40	1,300
			4:10 p.m.	16.65	1,340
162-90-10cbc	22.5	8-28-51	9:15 a.m.	9.5	13,900
			10:10 a.m.	10.5	13,900
			11:20 a.m.	13.5	15,800
			1:50 p.m.	16.5	18,000
			2:50 p.m.	20.75	18,400
163-84-6ad	22	8- 1-51	7:00 p.m.	13.90	10,100
		8- 2-51	12:30 a.m.[b]	13.35	11,100
		8- 2-51	3:05 a.m.	15.25	10,800

[a] Aquifer being recharged with water from pumped well.
[b] Pumping stopped 9:25 p.m., started 10:15 p.m. (8-1-51).

The coefficients of transmissibility and storage were computed from the test data by the nonequilibrium method of Theis (1935), and the coefficients of permeability were obtained by dividing the coefficient of transmissibility by the thickness of the aquifer, in feet.

The plot of s (drawdown) versus r^2/t (where r = distance of observation well from pumped well, in feet, and t = time, in days) for the test in which well 157-75-31ca was pumped is shown in figure 7. Because the data curve matched the well-function type curve almost perfectly, the computed results are considered to be reliable.

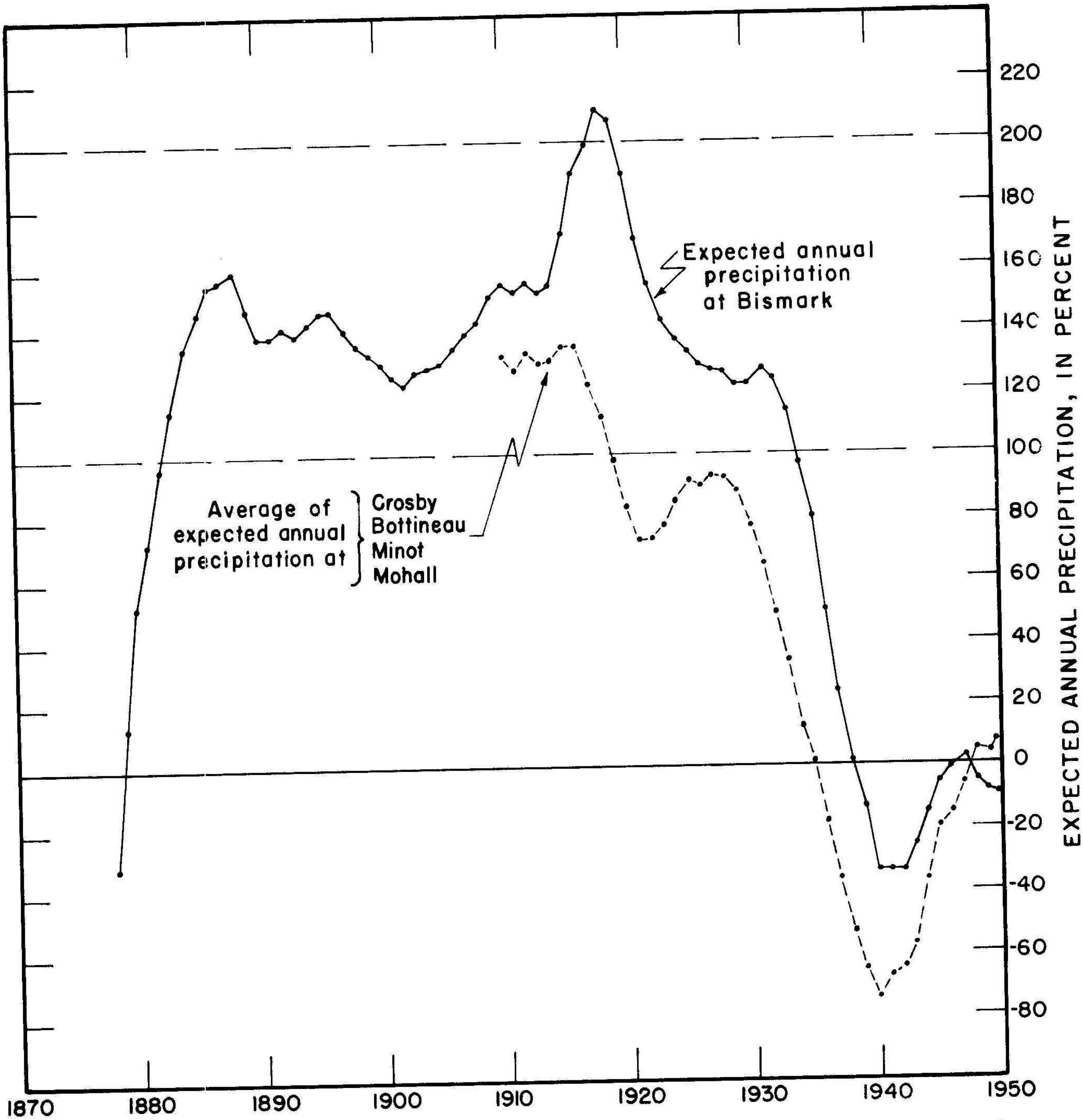


Figure 6.- Graph showing cumulative departure from the expected annual precipitation, smoothed by 5-year moving averages at five stations in North Dakota, 1875-1950.

During the later part of the test on well 158-77-35ada, the aquifer was recharged by water discharged from the pumped well. Accordingly, plotted data for that part of the test deviated from the type curve and the deviations when plotted, matched the type curve. (See fig. 8.) The coefficients computed from both curves are nearly equal.

Of the tests made on wells tapping the ground moraine, only the test on well 162-90-10cbc gave data that in part could be matched directly with the type curve. (See fig. 9.) As the coefficients computed from the matched curves could not be checked by plotting deviation curves, the coefficients are not considered to be mathematically precise. They are believed, however, to be of the correct order of magnitude.

No part of the plotted data from the other tests on wells tapping the ground moraine could be matched with the type curve, and it was assumed, therefore, that all the water-level data collected during the tests reflected local boundary conditions.

The coefficients of transmissibility and storage of the valley fill of the Souris River were determined at several points in and near Minot (Akin, 1947). The weighted average of all values for the coefficient of transmissibility was 250,000 gpd per foot, and the weighted average coefficient of storage was 0.00034.

The concentrations of dissolved salts in the water were higher at the end of four of the aquifer tests than at the start. (See LaRocque, Swenson, and Greenman, 1963, table 4.) However, the only significant increase was in water from well 162-90-10cbc, in which the principal increases in concentration were in sodium, magnesium, and sulfate.

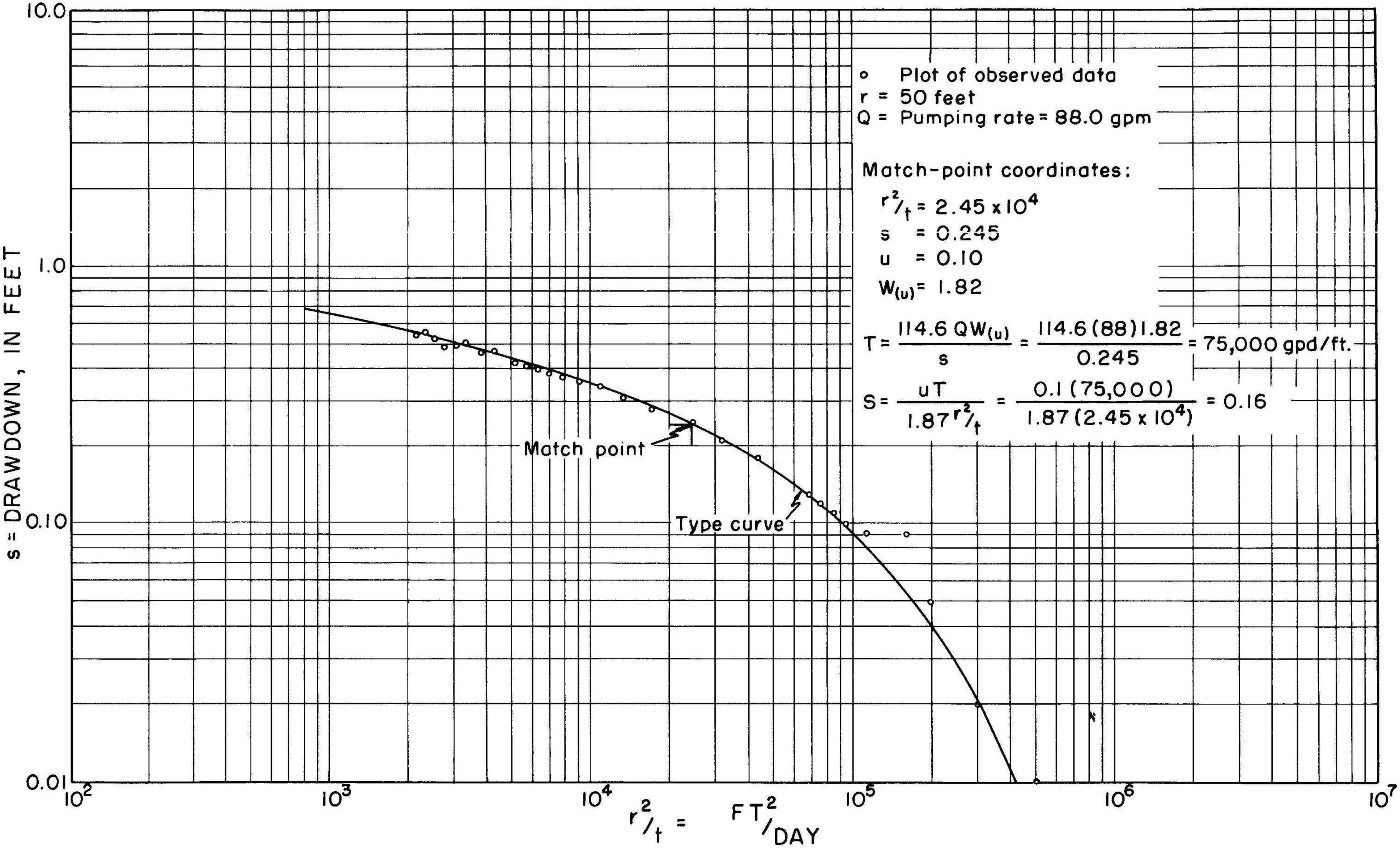


Figure 7.--Logarithmic plot of water-level drawdown in observation well 50 feet from pumped well 157-75-31ca, McHenry County.

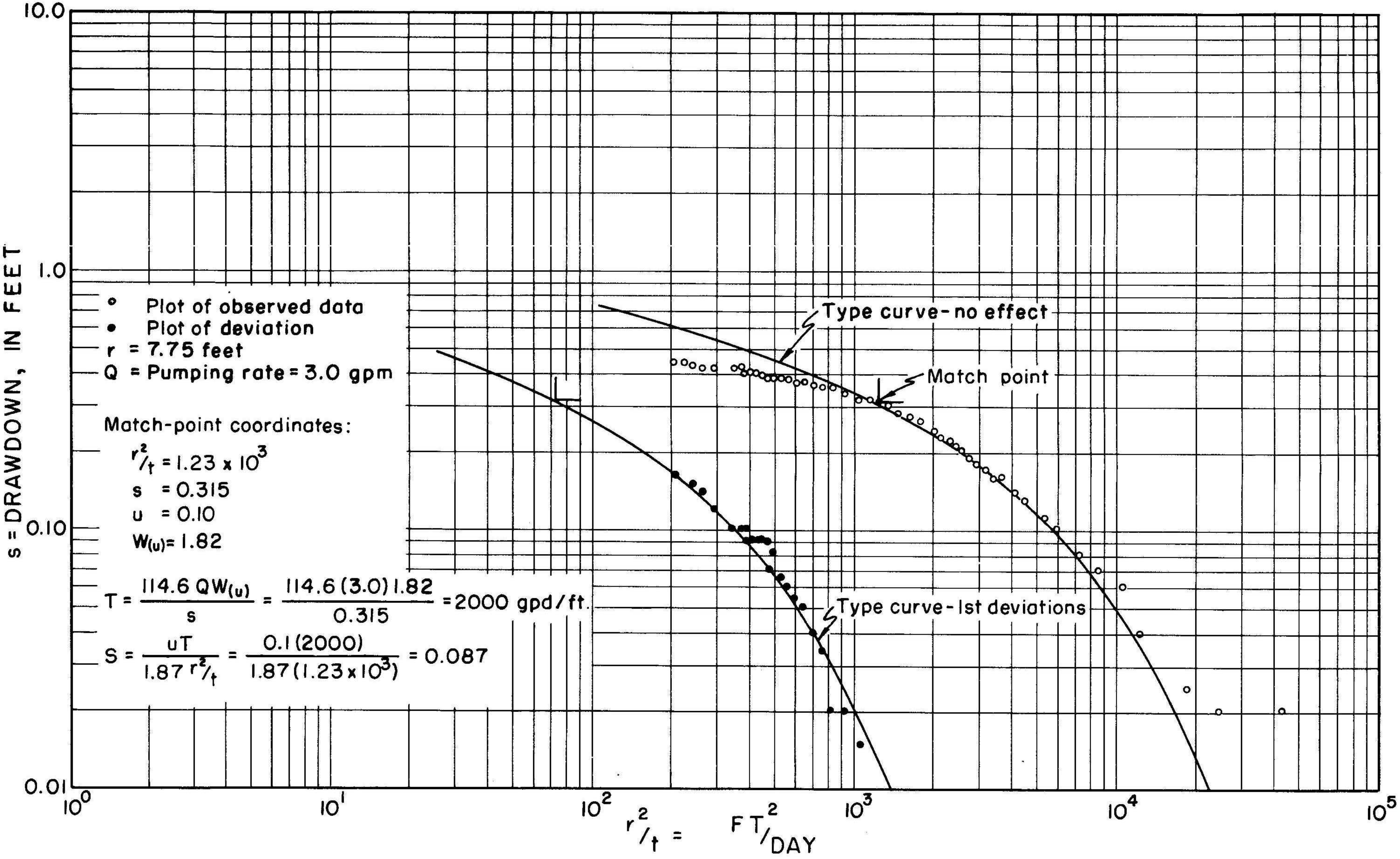


Figure 8.--Logarithmic plot of water-level drawdown in observation well 7.75 feet from pumped well 158-77-35ada, McHenry, County.

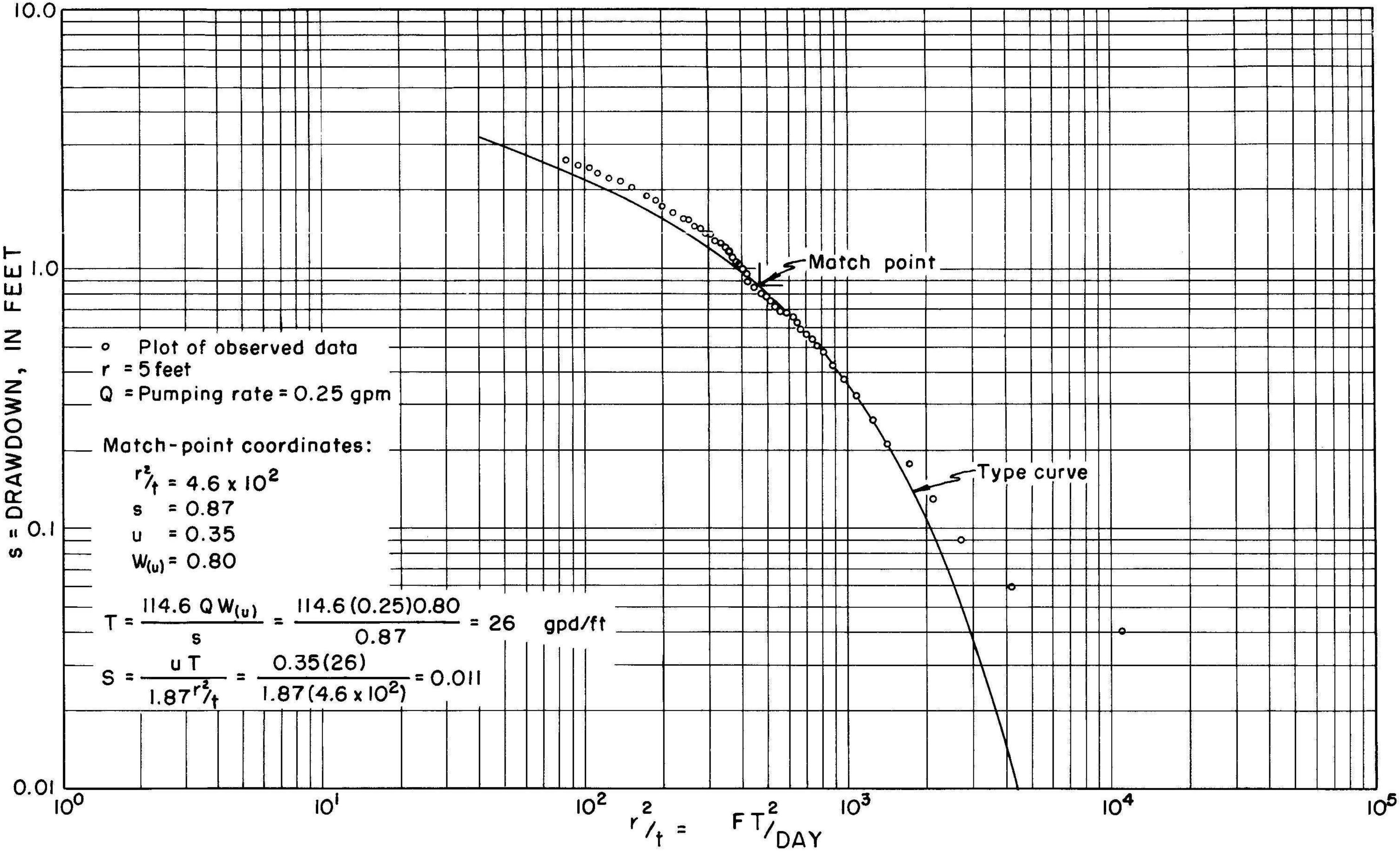


Figure 9.--Logarithmic plot of water-level drawdown in observation well 5 feet from pumped well 162-90-10cbc, Burke County.

OCCURRENCE OF GROUND WATER

Bedrock aquifers

The bedrock aquifers in the report area are recharged in part by underflow from the south and southwest. Where overlain by unconsolidated deposits of Quaternary age, the bedrock aquifers are recharged also by water percolating downward through the mantling sediments, and, where they crop out, they are recharged by infiltrating precipitation. Some water is withdrawn by pumping within the area or is discharged by seepage into adjacent deposits of Quaternary age. The remainder leaves the area by underflow to the north and northeast.

Less than one-fourth the total number of wells in the area tap bedrock. The water is yielded by sandstone strata or lignite beds; water from the lignite beds commonly has the color of weak tea. The towns of Ambrose, Crosby, Noonan, Columbus, Flaxton, Bowbells, Sherwood, and Norwich obtain all or part of their municipal supply from wells drilled into bedrock.

In some parts of the area, the water in the bedrock is under sufficient artesian or gas pressure to flow from wells; elsewhere the water level in wells is higher than the producing zone but lower than the land surface. The water level in the nonflowing wells tapping bedrock fluctuates only slightly and the highest levels during the year generally are recorded in the summer.

During the period 1911-21, Simpson (1929) collected data on the flowing wells in the Souris River drainage basin. The locations of those wells, most of which either no longer flow or are not now in existence, are shown on plate 1 of this report. Also shown on the same plate are the locations of the wells that were flowing in the period 1945-50.

Many more wells flowed in the Sherwood-Westhope-Glenburn area at the time of Simpson's study than in the 1945-50 period. The flow from wells in this part of the Souris River drainage basin is due principally to the rise of gas in the wells, and for this reason the wells are termed "gas lifts." Generally the flow is of a jetting or sputtering character.

The flow from wells elsewhere in the Souris River drainage basin is caused mainly by artesian pressure. Except along the Des Lacs River between Kenmare and Carpio, a comparison of the locations of flowing wells in the two periods of study indicates no appreciable decrease in the areas of artesian flow. The reason for the lack of flowing wells in the 1945-50 period along the Des Lacs River between Kenmare and Carpio is not known.

Several of the flowing wells in the vicinity of Crosby tap glacial deposits that fill a buried bedrock valley.

Unconsolidated aquifers

More than 75 percent of the wells in the report area tap the unconsolidated deposits of Quaternary age. Recharge to these deposits is almost entirely from snowmelt and rain. In the area underlain by glacial drift, about 60 to 70 percent of the recharge is estimated to come from water that accumulates in the numerous depressions. Water in these depressions is discharged by evaporation or by slow percolation down through the fine-grained sediments lining them. At times water penetrates the soil zone of the upland, areas tributary to the central parts of the depressions. A part of the water passing through the soil zone eventually reaches the zone of saturation. The moisture content and transmitting capacity of the soil during periods when water is available are two of the factors that govern the amount of water that will infiltrate beyond the reach of plant roots. The amount of water passing to the zone of saturation undoubtedly is small in comparison with the amount of water per unit area that seeps through the floors of the depressions. However, the gross area of the uplands is large in comparison with the gross area of the floors of the depressions. Influent seepage from streams and possible inflow from bedrock aquifers are sources of recharge only locally. The water not withdrawn from the unconsolidated deposits by pumping from wells is discharged by flow from springs, by seepage into surface drainage courses, by flow into contiguous deposits, and by evapotranspiration. Although a large part of the recharge in the area occurs through the undrained depressions when they contain excess water from precipitation and runoff, during dry seasons, these same undrained depressions collect ground-water discharge from the glacial drift and act as centers of discharge. About 70 to 80 percent of the natural ground-water discharge from the glacial drift is estimated to be lost by evapotranspiration and runoff from the undrained and drained depressions.

In the area once covered by ancient Lake Souris, a great many shallow wells tap the sediments that were deposited in the lake. Such wells are far more numerous in the southern part of the lake area and in the deltaic deposits along its western margin. In the northern part of the lake area most of the wells have been drilled through the lake sediments, which here are principally clay, into underlying aquifers. The water in the lake sediments moves eastward toward the Souris River, and recharge into the glacial outwash deposits and Recent aluvium in the valley of the Souris River.

Because the glacial outwash that underlies the valley floor of the Souris and Des Lacs Rivers is moderately to highly permeable and is amply recharged by inflow from adjacent strata and by infiltrating river water and snowmelt, it is a source of plentiful ground-water supply.

The municipal-supply wells of Minot (Akin, 1947), Velva, and Towner tap the deposits in the Souris River valley, and many stock and domestic wells tap the deposits in both valleys. The ground water moves down the valley within the valley fill.

The terrace deposits along the Souris and Des Lacs Rivers, which also are composed principally of glacial outwash, are above river level and infiltrating snowmelt and precipitation are two of the sources of recharge to them. They store only a small amount of water because the water discharges freely through springs and seeps along the terrace edges. Most of the springs are intermittent, but a few are perennial and flow as much as 2 to 3 gallons per minute.

Although gererally thin, the glacial outwash deposits that partly fill the surficial melt-water channels on the upland are moderately permeable and yield sufficient water for stock and domestic use. The municipal-supply wells of Mohall tap glacial outwash deposits in Spring Coulee near its junction with the valley of West Cut Bank Creek northeast of town (Akin, 1951), and the well of the thermoelectric plant at Voltaire taps glacial outwash deposits in the channel that heads at Velva. Although some of the water in the melt-water-channel deposits may seep into underlying and adjacent deposits, the greater part by far moves down the axis of the channels, and that not withdrawn through wells, consumed by vegetation, or evaporated is discharged into one of the surface drainage courses. Many wells that tap the deposits in the surficial channels in the upland fail during prolonged droughts.

Ice-contact deposits and recessional moraines collect and store water from rainfall and snowmelt and are reliable sources of supply where they extend below the general level of the upland plain. Some water is lost from these deposits by evapotranspiration and by seepage into the underlying fine-grained materials. Lateral movement of water from these deposits probably is negligible except where their zone of saturation extends above the level of surrounding land, providing sufficient head for outward movement.

Buried within the mass of glacial deposits other than lake sediments and valley fill are innumerable lenses and stringers of silt, sand, and gravel. Many of these are within the ground moraine (of which there probably are two or more sheets), and some are outwash deposits in melt-water channels now buried beneath till. Individually, many of the lenses and stringers of silt, sand, and gravel are only locally insignificant waterbearing bodies. But they are numerous, and have a high degree of hydraulic interconnection, and as a group, they are a dependable and significant source of water for stock and domestic use. Hundreds of stock and domestic wells in the report area tap one or more of these permeable lenses and stringers. When water is withdrawn from them they are recharged by water draining from surrounding glacial deposits; hence, the supply from the wells tapping them generally is dependable although the yield ordinarily is small.

An area 3 miles square near Flaxton, Burke County, was selected as the site of a detailed study of the occurrence of ground water in ground moraine. Of 97 shallow test holes, drilled to an average depth of about 21 feet, 56 penetrated at least one layer of sand and several penetrated more than one layer. (See LaRocque, Swenson, and Greenman, 1963, table 4.) The available evidence suggests that although the sand lenses are discontinuous, they are sufficiently numerous to provide a good degree of hydraulic continuity. Nearly all the test holes were drilled several feet into the zone of saturation and all were cased for use as water-level observation wells. The water-level measurements made in these wells are listed in table 2 of LaRocque, Swenson, and Greenman (1963). The altitude of the water level in 51 of the wells in the fall of 1949 is shown in figure 10 by contour lines. At the time the water levels were measured, a water sample was collected for chemical analysis from each of the 51 wells, and 83 samples were collected for chemical analysis in July 1950. The results of these analyses are given in tables 7 and 8 of hydrologic data compiled in LaRocque, Swenson, and Greenman (1963).

The geologic and hydrologic data collected in the Flaxton test area indicate that the direction of water movement in the ground moraine is devious. In the upper part of the zone of saturation, apparently, water principally moves vertically rather than laterally. In unpumped areas, depression contours, such as those in the hachured areas in figure 13, can be accounted for by: (1) a local high rate of evapotranspiration; (2) a local high rate of lateral and vertical movement of water to adjacent or underlying lenses; and (3) a local low rate of recharge. Vertical movement is substantiated in part by the irregular configuration of the water table; if the principal component of movement was lateral, the water table should be smoother. Lateral movement, however, occurs at depth, as is evidenced by the fairly prompt decline of the water level in shallow wells after a period of significant recharge. In places, ground water may move downward until it reaches a bedrock layer that is sufficiently permeable to transmit water laterally. In general, then, water not withdrawn from the ground moraine by pumped wells, vegetation, or evaporation moves downward until it enters laterally transmitting strata, either within or underlying the ground moraine, or until it reaches a layer so nearly impermeable that further movement can only be in a lateral direction.

Water in the deeply buried lenses of permeable material generally is under artesian pressure. Although several of the wells tapping the thick glacial deposits in the vicinity of Crosby and flowing wells, the water levels in most artesian wells are below the land surface and may be either above or below the unconfined water table in the immediate vicinity.

The Recent deposits of alluvium and dune sand generally are above the regional water table and therefore usually are not a source of water. However, because they are fairly permeable, they readily absorb precipitation and snowmelt and transmit the water downward to the regional zone of saturation.

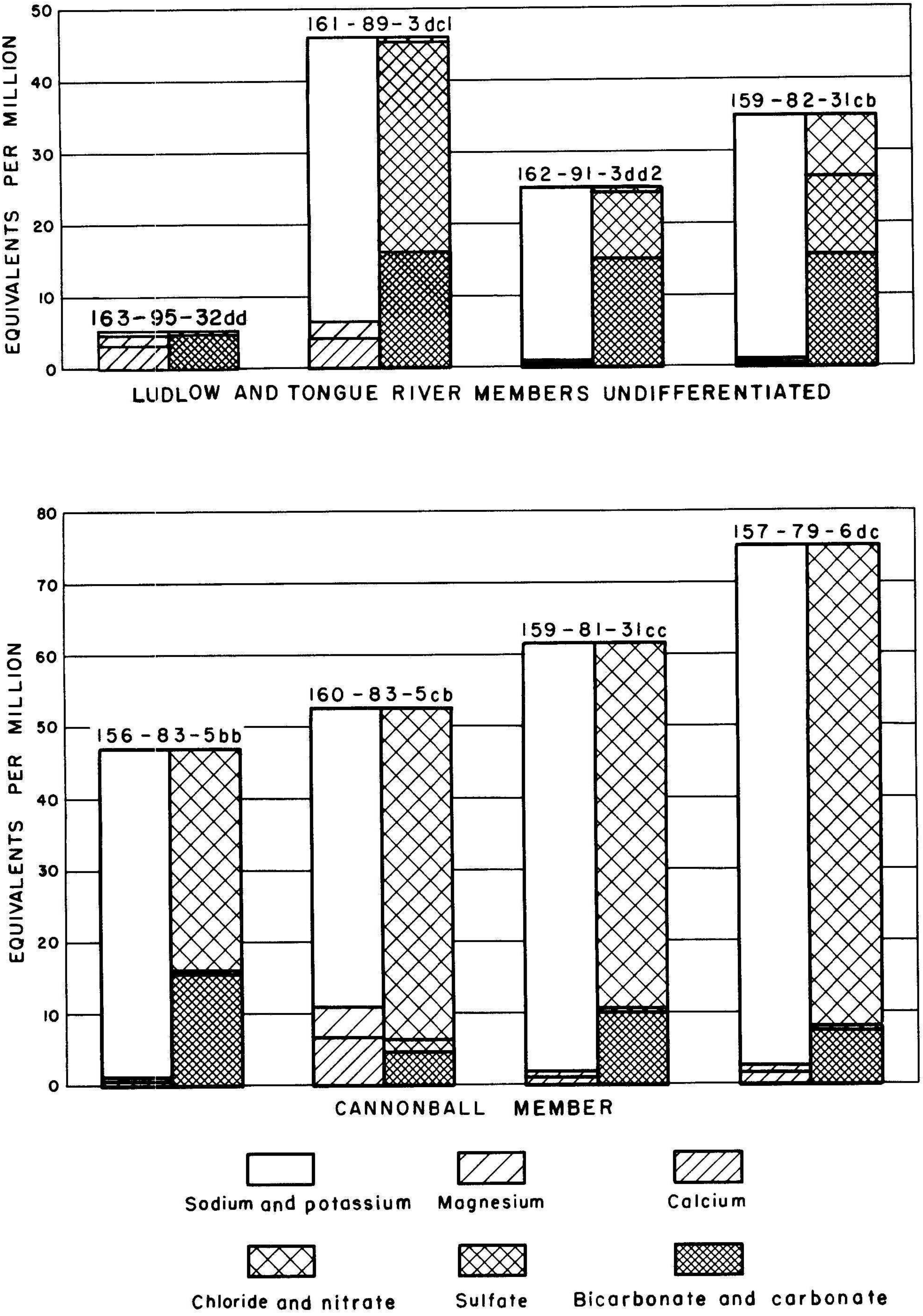


Figure 13.--Graphic representation of analyses of water from wells tapping the Fort Union Formation.

DISCHARGE OF GROUND WATER INTO THE SOURIS RIVER

The progressive downstream increase in the base flow of the Souris River is due to the inflow of ground water. By taking into account the amount of water flowing past the six gaging stations along the river (fig. 11),[1] the measured tributary inflow into the river,[1] the amount of precipitation on[2] and of evaporation from[3] the river, the changes in the amount of water in the river channel or stored behind the dams,[4] and the amount of evapotranspiration from the bottom-land areas,[5] it was possible to make estimates of the increment to the base flow of the river in the five stretches between successive gaging stations. Estimates could be made for only the period June through August because unmeasured tributary inflow then was negligible. The estimates for that period in the years 1946 through 1950 are shown graphically in figure 12.

An attempt was made to correlate the amount of ground-water discharge into the various stretches of the Souris River with the average late-summer position of the water level in wells in the vicinity of those stretches. However, no direct correlation was apparent.

1/ U.S. Geol. Survey Water-Supply Papers 1055, 1085, 1115, 1145, 1175.

2/ U.S. Weather Bureau Climatological Data for period 1946-50.

3/ Computed from data collected by U.S. Weather Bureau at Mandan and Riverdale, N. Dak.

4/ Unpublished records collected by U.S. Geological Survey, Bismarck, N. Dak.

5/ Computed from tables prepared by Lee (1942).

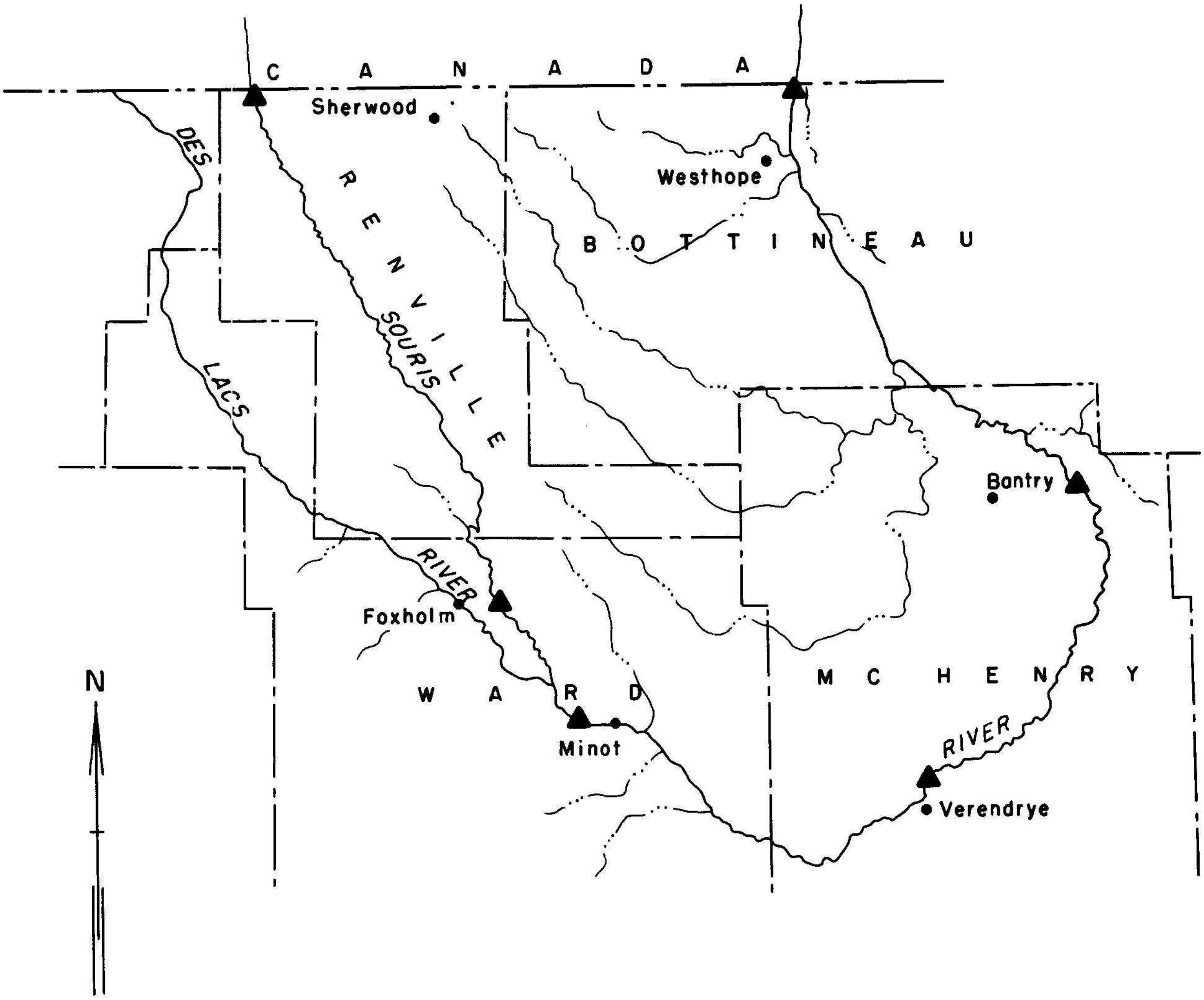
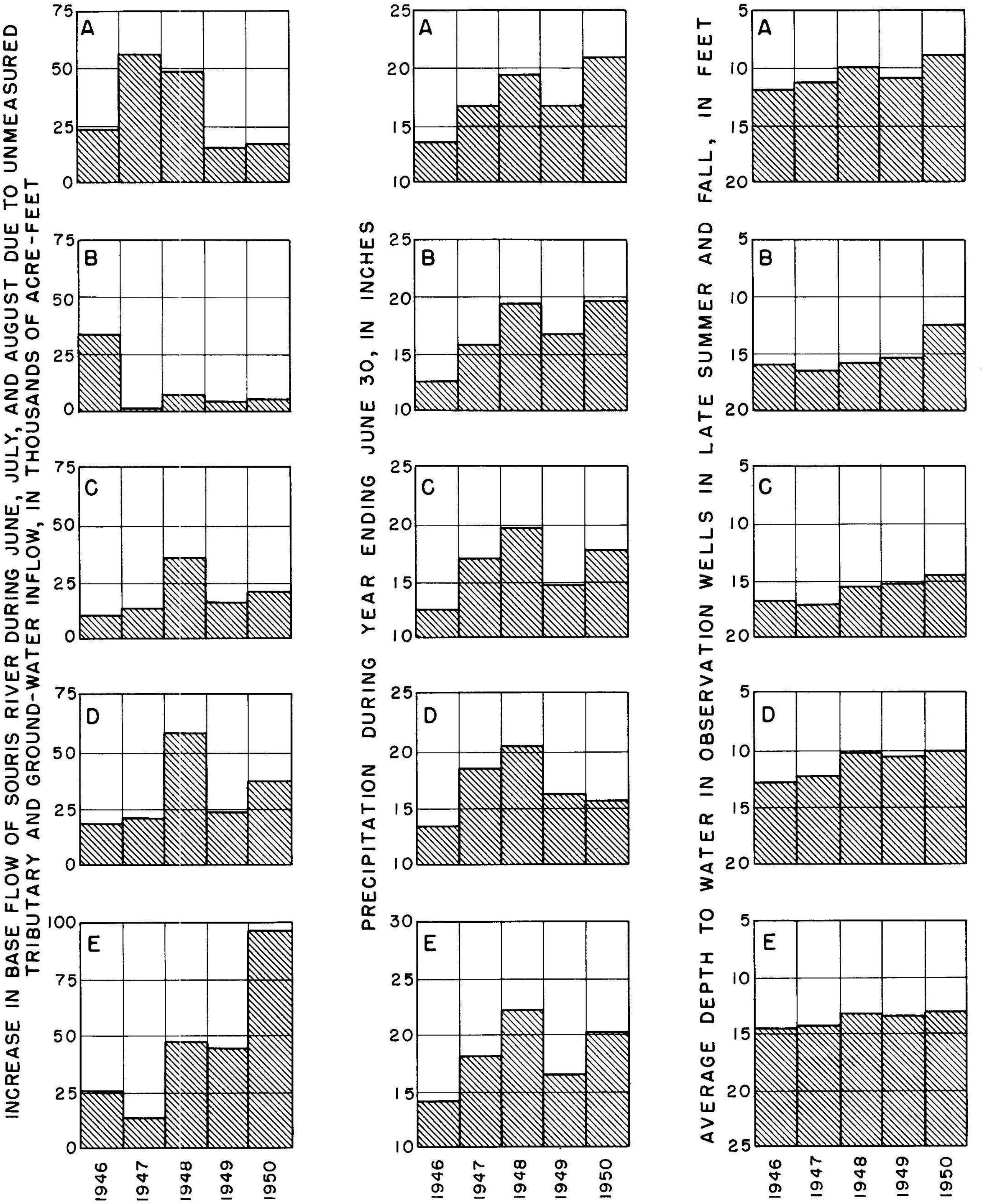


Figure 11 -- Map showing location of gaging stations along the Souris River.



A - Gaging station near Sherwood to gaging station near Foxholm (48 miles)
B - Gaging station near Foxholm to gaging station above Minot (13 miles)
C - Gaging station above Minot to gaging station near Verendrye (36 miles)
D - Gaging station near Verendrye to gaging station near Bantry (34 miles)
E - Gaging station near Bantry to gaging station near Westhope (44 miles)

Figure 12.--Graphs showing downstream increase in base flow of the Souris River, annual precipitation, and average depth to water in areas adjacent to river.

The estimates indicate that ground-water inflow to the Souris River per unit length of river is least in the stretch between Minot and Verendrye, somewhat greater upstream from Minot, and considerably greater downstream from Verendrye. The stretch downstream from Verendrye drains ground water from almost the entire Souris loop. Ground water discharges into the river only when the water table adjacent to the river slopes toward the river. When the river level is the same as that of the water table adjacent to the river, no significant interchange of water occurs, and when the river level is higher than that of the water table, river water recharges the adjoining and underlying sediments.

Chemical analyses of water from the Souris River show that the concentration of dissolved minerals may be less than 200 ppm (parts per million) in the spring when the flow consists largely of surface runoff. In late summer or fall, however, when the flow consists almost wholly of ground-water discharge, the concentration is much greater and may exceed 900 ppm. (See table 3.)

RELATION OF CHEMICAL CHARACTER OF GROUND WATER TO GEOLOGIC SOURCE

Nearly all the minerals in the rocks of the earth's crust are soluble to some degree in water, especially in water containing dissolved carbon dioxide. While infiltrating to and then percolating laterally within the zone of saturation, water partly dissolves the minerals with which it comes in contact, and the minerals thus dissolved may remain in the water, may be precipitated, or may take part in chemical reactions with other minerals in the rocks. The extent to which water is mineralized and the kinds of mineral constituents present determine its suitability for human consumption and domestic use, as well as for stock watering, irrigation, and many industrial processes.

The palatability of a drinking water is largely a matter of personal opinion. Persons who have become accustomed to drinking water that contains more than 1,000 ppm of dissolved solids generally consider water of low mineral content to be flat tasting. Small amounts of iron or manganese or excessive amounts of magnesium, sulfate, or chloride may impart an objectionable taste to water.

The U.S. Public Health Service (1946) has established standards for drinking water on common carriers engaged in interstate traffic. These standards are generally accepted as a basis for evaluating the quality of drinking-water supplies. Listed below are the recommended maximum concentrations of certain constituents specified in the standards.

Constituent	Maximum parts per million
Iron and manganese together	0.3
Magnesium	125
Sulfate	250
Chloride	250
Fluoride	1.5
Dissolved solids	500 a/

a/ 1,000 ppm may be permitted if water of better quality is not available.

Much of the ground water in the report area, including some used for public supply, contains concentrations of minerals in excess of one or more of the above limits.

The hardness of a water is an important factor in evaluating the water for uses other than drinking. Calcium and magnesium, which cause most of the hardness of water, cause the formation of scale in hot-water pipes and boilers. Many water-treatment plants in the United States reduce the hardness of the water to about 80 ppm.

About 2,000 samples of ground water were collected for chemical analysis during this investigation. (See LaRocque, Swenson, and Greenman, 1963, tables 5-8.) The altitude of the bottom of each well was compared with the altitude of the bedrock at the well site to determine whether a given well was obtaining water principally from deposits of Quaternary Age or from the underlying bedrock. (See pl. 1.)

Waterbearing formations older than Fort Union

Only three deep wells in T. 162 N., R. 87 W. tap deposits older than the Fort Union Formation. Samples of water from these wells could not be distinguished by their chemical characteristics from samples known to come from Tertiary rocks and the wells are considered to derive water principally from the Tertiary rocks.

Fort Union Formation

In the northeastern part of the Souris loop, all the wells drilled into bedrock probably tap the Cannonball Member of the Fort Union Formation. In the remainder of the area, east of the Des Lacs River, bedrock wells tap either the Tongue River Member alone or both the Cannonball and Tongue River Members. West of the Des Lacs River, all wells drilled into bedrock tap the Ludlow and Tongue River Members undifferentiated.

Sodium and chloride are the principal mineral constituents in water from the Cannonball Member; sodium, bicarbonate, and sulfate are the principal mineral constituents in water from Ludlow and Tongue River Members. (See fig. 13.) Chloride exceeds 800 ppm in all samples from wells known to tap the Cannonball alone and is less than 400 ppm in all samples from wells known to tap the Ludlow and Tongue River Members undifferentiated. Water from wells deriving part of their water from the Cannonball and the remainder from the Ludlow and Tongue River undifferentiated is characterized by sodium, bicarbonate, and chloride; the concentration of chloride ranges from about the maximum in water from the Ludlow and Tongue River Members to the minimum in water from the Cannonball Member. The maximum, average, and minimum specific conductance (a measure of the electrolytes in water and, therefore, an indication of the mineral concentration) and for the concentration of chloride in all samples from bedrock aquifers are as follows:

	Cannonball Member (442 samples)	Cannonball-Tongue River (133 samples)	Ludlow and Tongue River Members undifferentiated (432 samples)
Specific conductance (micromhos per centimeter at 25°C):			
Maximum----------------	12,800	4,990	6,730
Average----------------	5,820	3,480	2,640
Minimum----------------	3,270	2,480	131
Concentration of chloride (parts per million):			
Maximum----------------	4,290	795	400
Average----------------	1,680	617	105
Minimum----------------	805	407	.0

The chloride content of water in the Cannonball Member increases in direct proportion to the specific conductance, but a similar relationship could not be established for water in the Ludlow and Tongue River Members. (See fig. 14.)

The average concentrations of the principal mineral constituents, expressed below as percentages of the average dissolved solids, illustrate further the distinctive differences in the chemical character of water in the Cannonball Member, the Cannonball-Tongue River, and the Ludlow and Tongue River Members undifferentiated.

	Cannonball Member (33 samples)	Cannonball-Tongue River (8 samples)	Ludlow and Tongue River Members undifferentiated (45 samples)
Silica (SiO_2)	0.3	0.8	0.7
Iron (Fe)	.1	.4	.2
Calcium (Ca)	1.0	2.9	1.6
Magnesium (Mg)	.3	.9	.6
Sodium (Na)	37.8	35.0	36.5
Potassium (K)	.2	.4	.4
Carbonate (CO_3) (includes bicarbonate as carbonate)	8.7	22.5	33.5
Sulfate (SO_4)	1.1	4.6	19.2
Chloride (Cl)	50.4	32.3	7.1
Fluoride and nitrate (F + NO_3)	.1	.2	.2
Total	100.0	100.0	100.0

The average concentration of dissolved solids in the samples of water from the Cannonball Member was 3,640 ppm; from the Cannonball-Tongue River, 2,090 ppm; and from the Ludlow and Tongue River Members undifferentiated, 1,790 ppm.

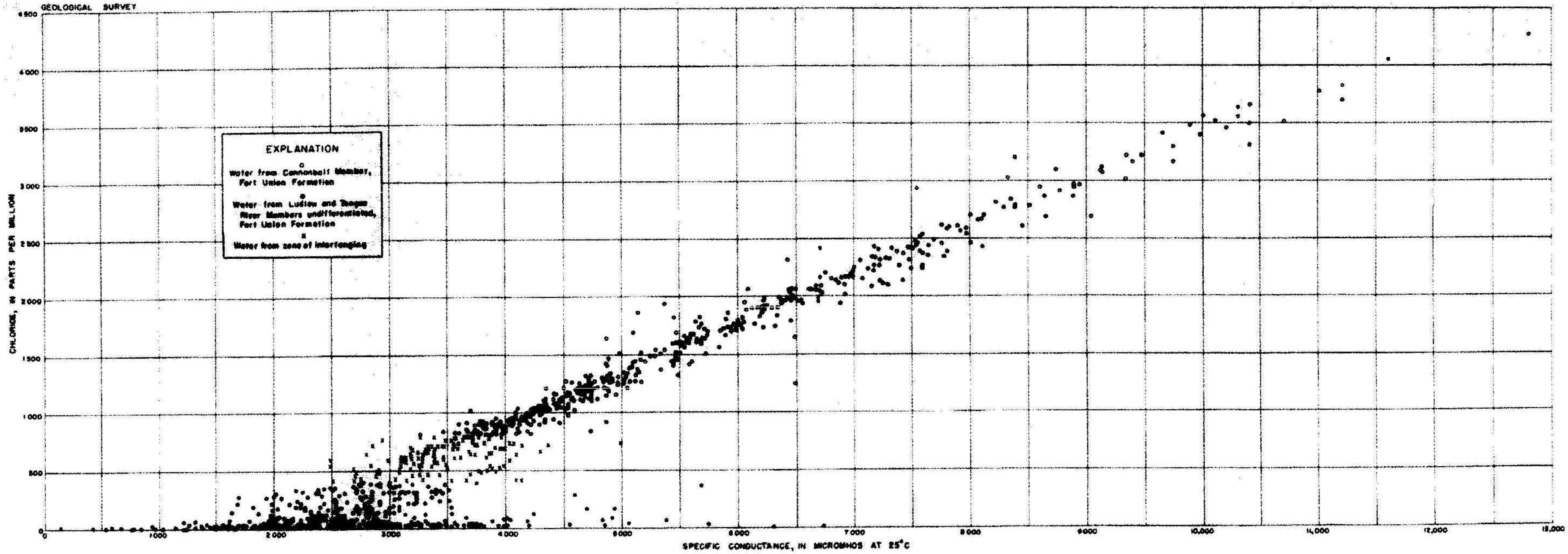


FIGURE 14 - RELATION BETWEEN CHLORIDE CONCENTRATION AND SPECIFIC CONDUCTANCE OF WATER FROM WELLS TAPPING BEDROCK IN THE CROSBY-MOHALL AREA

Cannonball Member

Although the average concentration of dissolved solids in water from the Cannonball Member (3,640 ppm) is only one-tenth that of ocean water (33,000 to 37,000 ppm), based on analyses of samples collected by the Challenger Expedition (Dittmar, 1884), the percentage compositions are similar.

	Cannonball Member (33 samples)	Ocean (77 samples)
Calcium (Ca)	1.0	1.2
Magnesium (Mg)	.3	3.7
Sodium (Na)	37.8	30.6
Potassium (K)	.2	1.1
Carbonate (CO_3) (includes bicarbonate as carbonate)	8.7	.2
Sulfate (SO_4)	1.1	7.7
Chloride (Cl)	50.4	55.3
Total	99.5	99.8

In both ocean water and water from the Cannonball Member, the percentage of chloride is greater than that of any other constituent. In ocean water, however, the percentage of sulfate is greater than the percentage of carbonate, whereas in water from the Cannonball Member, the reverse is true. In both, the percentage of sodium is greater than that of the other cations; but unlike the ground water, ocean water has a greater percentage of magnesium than calcium. The presence of calcareous material, particularly carbonate-rich concretions, in the Cannonball Member probably accounts for the prominence of the carbonate and bicarbonate in the ground water.

The Cannonball Member is recharged, in part, by precipitation where it crops out along the Souris River in the southern part of the Souris loop, and the general direction of ground-water movement within this member is northeast away from the area of outcrop. As a result, the concentrations of chloride in the water in the Cannonball Member are lower in the part of the Souris loop nearest the outcrop area. (See fig. 15.) Also, movement of low-chloride water from other members of the Fort Union Formation into the Cannonball Member may account for the lower concentrations of chloride in the water in the Cannonball Member in the area adjacent to the Cannonball-Tongue River overlap. Higher concentrations of chloride characterize water in the Cannonball Member at points distant from the diluting effects of recharge either from the Ludlow and Tongue River Members undifferentiated or from precipitation.

Although, because of its high salt content, water in the Cannonball Member generally is not considered suitable for human consumption, it can be used for watering livestock. It is not suitable for irrigation because of both high percent sodium and high mineral content. (The percent sodium is the ratio of sodium to the total concentration of the principal cations-- sodium, potassium, calcium, and magnesium -- all expressed as chemical equivalents, multiplied by 100.) Water from many wells tapping the Cannonball Member in Bottineau and Renville Counties was charged with natural gas and "bubbled" at the time the samples were collected.

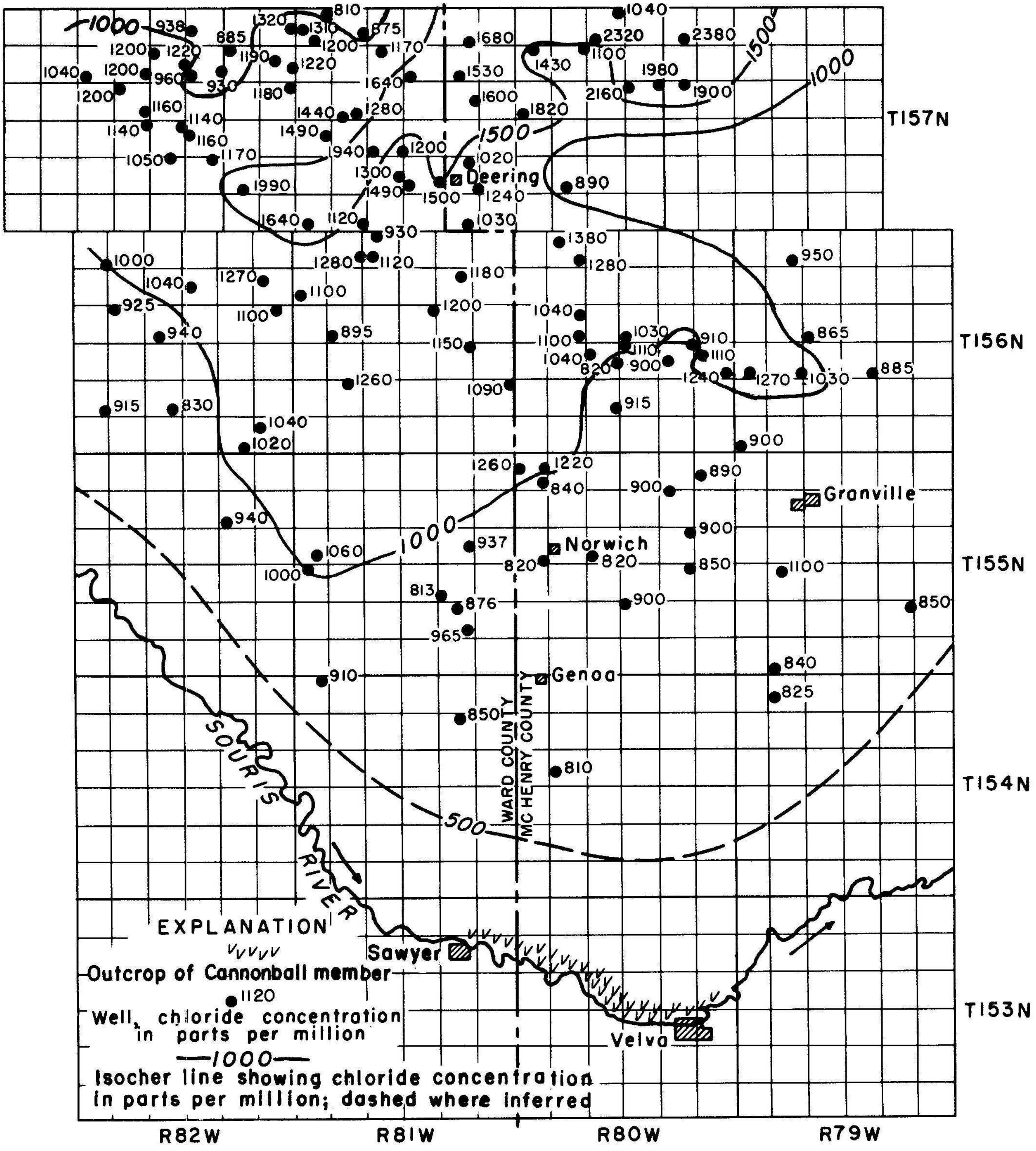


Figure 15.-- Increase of chloride concentration in ground water with distance from outcrop of Cannonball member.

Ludlow and Tongue River Members undifferentiated

Water from the Ludlow and Tongue River Members undifferentiated may be classified conveniently into two distinct types -- a hard calcium sulfate water, normally obtained from shallow wells, and a soft sodium bicarbonate water, normally obtained from the deeper wells. The soft water tastes like a dilute solution of baking soda and, according to a resident of Noonan, "sounds and acts like Seltzer water."

The hardness of the water from 45 wells tapping the nonmarine beds in the Fort Union is shown in table 5, together with the depth of the wells and the approximate tapped thickness of the aquifer.

Wells deeper than about 200 feet yield the softer water. The average hardness of water from 26 wells, 204 to 426 feet deep, was 48 ppm. Although the shallower wells usually yield hard water, there are many exceptions. The following tabulation summarizes the observed relation of water hardness to well depth in the Ludlow and Tongue River Members undifferentiated:

	Wells more than 200 feet deep	Wells less than 200 feet deep
Number of wells------------------	26	19
Range in hardness, as $CaCO_3$-- ppm-	14-138	22-806
Average hardness, as $CaCO_3$-- ppm--	48	210
Median hardness, as $CaCO_3$-- ppm --	38	132

TABLE 4.--Hardness of water in the Ludlow and Tongue River Members undifferentiated

Well No.	Depth of well (feet)	Approximate tapped thickness of aquifer (feet)	Hardness as $CaCO_3$ (parts per million)
Bottineau County			
159-82-31cb	270	50	43
160-82-31cc	265	50	94
Burke County			
161-89- 3dc1	94	44	324
5dd1	97	62	51
6da	70	55	36
8cb	102	72	403
9bb2	190	155	409
21da	100	55	33
26dc	237	177	42
90-11cd	89	74	806
91- 9aa	59	49	215
162-88-36cc	308	253	35
89-18ad	200	70	132
31da	270	225	38
91- 3dd2	360	230	23
27ac	106	61	42
93- 9ab1	100	70	29
15bd1	80	65	38
163-88-28dd	200	...	58
93- 8ad1	204	129	38
29dd	82.0	17	399
32bd	270	230	20
94- 6cb	260	185	118
33aa1	270	235	90
Divide County			
162-95- 4ac	265	215	14
14cc	122	52	430
96- 5dc1	320	145	48
163-95-32dd	61	41	220
96-13da	105	60	303
97- 6cc1	264	...	28
6dc	242	17	81
31bc	250	...	38
98-17aa	216	...	33
McHenry County			
154-80-28dc	318	228	24
156-79-10aa2	121.0	28	22
Renville County			
158-82- 7dd	345	155	30
17ab	250	45	62
84-28aa	326	76	16
159-86-33bc2	185	...	34
161-86- 6bc2	400	120	96
87- 1bc	426	171	30
17bc2	315	140	138
Ward County			
156-83-12dc	290	160	45
159-87-25dd	410	205	16
160-87-24bc1	280	55	20

TABLE 3.--Chemical analyses of water from the Souris River near Verendrye, McHenry County

(Results in parts per million except as indicated)

Date of collection	Discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids		Hardness as $CaCO_3$		Percent sodium	Specific conductance (micromhos at 25°C)	pH
															Residue on evaporation at 180°C	Tons per acre-foot	Calcium magnesium	Noncarbonate			
1946																					
July 31...	5.23	......	0.05	63	29	228		520	0	270	42	0.5	6.0	.....	951	1.29	276	0	64	1,370	8.1
Aug. 28...	8.27	......	.20	77	38	126		524	0	134	36	.5	.1	.....	698	.95	348	0	44	950	8.0
Sept. 20..	69.1	......	.00	76	45	217		468	30	199	143	.6	3.0	.....	963	1.31	375	0	56	1,340	8.3
Oct. 21...	9.9	16	.04	60	30	100	14	358	27	115	28	.2	7.0	0.30	558	.76	273	0	43	897	8.6
Nov. 20...	85	13	.05	57	34	103	8.8	422	0	126	30	.2	12	.28	614	.84	282	0	43	992	8.0
1947																					
Apr. 22...	663	17	.02	40	24	64		282	0	85	12	.2	.0	.11	448	.61	198	0	41	627	7.3
May 22....	310	11	.02	36	17	50		190	12	71	10	.1	4.6	.09	304	.41	160	0	40	496	8.8
Aug. 28...	300	14	.02	34	16	38		198	0	53	8.0	.1	4.2	.00	282	.38	151	0	35	447	7.8
1948																					
May 5.....	1,780	17	.03	42	21	40		240	0	64	8.0	.2	3.1	.11	381	.52	191	0	31	551	7.3
Aug. 24...	105	15	.06	57	23	144		422	0	150	32	.5	2.3	.23	648	.88	237	0	57	903	7.4
1949																					
Mar. 8....	240	21	.02	64	26	87		342	0	131	23	.2	8.8	.15	555	.75	266	0	42	815	8.0
Apr. 10...	3,430	6.8	.15	19	4.4	16		79	0	30	.7	.1	4.6	.05	143	.19	66	1	35	203	7.1
May 11....	562	13	.02	51	22	61		242	10	112	12	.1	3.3	.....	404	.55	218	3	38	609	8.4
July 26...	44	18	.02	66	31	152		431	13	180	39	.2	5.2	.....	732	1.00	292	0	53	1,100	8.4
Oct. 6....	21	25	.02	72	34	167		449	29	160	67	.2	5.0	.....	790	1.07	320	0	53	1,190	8.6
Dec. 19...	55	18	.04	58	27	77		299	0	125	29	.2	6.6	.....	508	.69	256	11	39	741	7.3
1950																					
Feb. 17...	a20	26	.08	71	30	114		385	0	142	54	.2	11	.....	662	.90	301	0	45	987	7.2
Apr. 5...	93	21	.04	52	21	85		282	0	113	31	.1	11	.20	504	.69	217	0	46	748	7.2
Apr. 20...	1,280	14	....	23	6.5	23		104	0	40	3.0	.2	3.9	.10	200	.27	84	0	38	278	7.0
June 9....	402	14	.04	45	20	74		233	16	110	14	.2	3.8	.....	432	.59	195	0	45	645	8.6
June 23...	120	18	.04	63	30	142		424	0	193	26	.2	4.6	.....	710	.97	281	0	52	1,070	7.8
July 27...	89	9.8	.02	48	22	92		312	0	112	24	.2	5.6	.....	480	.65	211	0	49	685	7.4
Aug. 23...	a70	13	.04	52	24	149		374	0	168	45	.2	7.3	.....	644	.88	228	0	59	1,000	7.7
Sept. 28..	43	19	.02	65	32	188		466	0	178	89	1.0	8.4	.10	824	1.12	294	0	58	1,290	7.5
Oct. 28...	31	14	.02	69	31	157		468	0	190	41	.4	2.1	.05	756	1.03	300	0	53	1,120	7.8
Nov. 30...	140	20	.02	52	24	71		296	0	110	16	.2	3.6	.05	452	.61	228	0	40	687	7.4
Dec. 22...	150	25	.02	52	24	72		302	0	110	15	.2	4.0	.05	456	.62	230	0	41	679	7.4
1951																					
Jan. 19...	140	18	.04	54	21	71		294	0	103	16	.2	5.5	.10	450	.61	222	0	41	662	7.4
Feb. 16...	55	20	.04	60	26	76		337	0	113	18	.2	5.3	.12	512	.70	258	0	39	740	7.5
Mar. 17...	42	22	.04	76	12	151		430	0	155	33	.1	6.9	.38	678	.92	238	0	58	1,020	7.7
Apr. 3....	690	......	....	....	......	59	......	262	0	101	15	.....	......	....	....	.....	....	......	38	631	7.8
May 9.....	1,420	......	....	....	......	46	......	218	0	87	11	.....	......	....	....	.....	....	......	35	533	7.3
June 7....	1,590	......	....	....	......	30	......	142	0	59	2.0	.....	......	....	....	.....	....	......	36	354	7.3
June 23...	318	......	....	....	......	74	......	301	0	117	14	.....	......	....	....	.....	....	......	41	728	7.9
July 4....	272	14	.10	48	22	68		276	0	106	13	.1	4.1	.12	434	.59	212	0	41	655	7.7
Aug. 24...	46	......	....	....	......	79	......	336	0	110	18	.....	......	....	....	.....	....	......	41	773	7.6
1952																					
Jan. 11...	112	......	....	....	......	68		312	0	110	17	.....	......	....	....	.....	246	0	38	736	7.3
Feb. 7....	134	......	....	....	......	64		307	0	101	18	.....	......	....	....	.....	243	0	36	719	7.6
Mar. 5....	55	......	....	....	......	99		394	0	137	31	.....	......	....	....	.....	293	0	42	933	7.4
Apr. 3....	a1,700	7.0	.12	14	5.6	17	9.4	80	0	34	4.0	.1	4.2	.03	150	.20	58	0	35	219	7.1
Apr. 11...	630	11	.06	28	10	38		141	0	63	6.0	.1	4.7	.04	250	.34	111	0	43	382	7.5
Aug. 19...	26	38	.02	69	35	166		484	5	167	66	.5	2.5	.28	792	1.08	315	0	53	1,210	8.2
Sept. 11..	18	24	.01	62	28	137		399	0	165	44	.5	5.1	.17	666	.91	268	0	53	1,030	7.6

a Daily mean discharge.

Renick (1924) concluded from a microscopic examination of samples of the Tongue River Member in Rosebud County, Mont., that beidellite[1] is the principal mineral that effects the exchange of calcium and magnesium for sodium. In addition to beidellite, which is plentiful in the Ludlow and Tongue River Members, other hydrated aluminum silicates, such as kaolin, feldspar, and mica, are capable of exchanging all or part of their sodium and potassium for other bases. The reactions between the hardness-forming salts in the water and the base-exchange silicates may be expressed as follows:

$$2NaX + Ca(HCO_3)_2 \longrightarrow CaX_2 + 2NaHCO_3$$

or

$$2NaX + MgSO_4 \longrightarrow MgX_2 + Na_2SO_4$$

where X is a base-exchange silicate.

In the report area, ground water from the Ludlow and Tongue River Members undifferentiated generally is suitable for most domestic purposes. As a rule, however, the water from the deeper wells is less palatable and commonly contains fluoride in excess of the desirable limit specified by the U.S. Public Health Service (1946) for drinking water. Water from the Ludlow and Tongue River Members undifferentiated is not considered to be suitable for irrigation because of its generally high mineral content and high percent sodium.

1/ Renick referred to the material as leverrierite.

Cannonball and Tongue River Members

In the area where the marine Cannonball is overlain by the nonmarine Tongue River Member (pl. 3), the water yielded by many of the wells drilled into bedrock is intermediate in chemical quality between water from the Cannonball Member and water from the Ludlow and Tongue River Members undifferentiated. Where the Cannonball is the principal aquifer, chloride exceeds bicarbonate or sulfate in the mineral composition of the water; and where the Ludlow and Tongue River undifferentiated is the principal aquifer, the reverse is true. The concentration of chloride in water from wells drawing from both the marine and nonmarine members ranges from about 400 to about 800 ppm. Although water from some of these wells is used for drinking, it generally contains considerably more chloride than may be palatable in water for human consumption. Because of its salinity and high percent sodium, the water is also unsuitable for irrigation.

Deposits of Quaternary Age

Most wells tapping the unconsolidated deposits of Quaternary age have been drilled through both glacial till and stratified fluvial or lacustrine deposits; the till, however, generally yields little or no water. Water from the Quaternary deposits is extremely variable in chemical quality; a sample from well 156-77-2ad1 contained only 290 ppm of dissolved solids, whereas a sample from well 162-90-1dad contained 24,400 ppm. However, the data in tables 5 through 8 (LaRocque, Swenson, and Greenman, 1963) are not exactly comparable because different methods of analysis were used by the different agencies making the analyses. For example, in table 5 (for samples analyzed by the U.S. Geological Survey) concentrations of dissolved solids below 1,000 ppm represent residue on evaporation at 180°C and those above 1,000 ppm represent the sum of determined constituents, whereas in table 7 and 8 all concentrations of dissolved solids represent residue on evaporation at 110°C. Because the value for the sum of determined constituents includes no water of hydration and because the value for residue on evaporation at 180°C includes less water of hydration than that at 110°C, concentrations of dissolved solids reported in table 5 are lower than those reported for water of similar quality in tables 7 and 8 (LaRocque, Swenson, and Greenman, 1963).

In general, the water yielded by wells tapping only surficial medium- to coarse-grained sediments, such as glacial outwash, ice-contact deposits, and lake deposits, is least mineralized; the water yielded by wells tapping sand and gravel lenses enclosed within glacial till is somewhat more mineralized, and the water yielded by wells tapping only glacial till is highly mineralized. Therefore, the degree of mineralization of ground water from deposits of Quaternary age seemingly is governed largely by the length of time the water has been in direct contact with glacial till. Water from a deep well would tend to be more mineralized than that from a shallow well because it has passed through a greater thickness of glacial till enroute to the permeable layer, or layers, that transmitted it to the well. Exceptions to this general rule, such as water from well 163-97-13cc, 457 feet deep, indicate that in some places even the deepest water-producing zones in the Quaternary deposits are recharged by water that has passed through little or no till or at least has passed through the till quickly, or possibly has moved laterally out of the Fort Union Formation.

Water from wells tapping the Quaternary deposits generally is extremely hard. The average hardness of 51 samples of water (collected outside the Flaxton test area) was 591 ppm, and the maximum was 2,350 ppm. Sulfate, a principal mineral constituent in some of the samples, exceeded 500 ppm in about a third and 1,000 ppm in about a tenth of the samples. Of the samples of water collected from 51 shallow observation wells in the Flaxton test area, 5 contained more than 10,000 ppm of sulfate. Although none of the samples from wells outside the Flaxton test area contained more than 1,000 ppm of sodium, 39 of the 134 samples collected from 87 wells in the Flaxton test area contained more than 1,000 ppm, and 18 of the 39 contained more than 2,000 ppm. The maximum concentration of dissolved solids in the samples collected from wells tapping Quaternary deposits outside the Flaxton test area was 3,800 ppm, whereas more than half the samples collected from wells inside the test area contained dissolved solids in excess of 3,800 ppm and 27 of the 134 samples contained more than 10,000 ppm. The samples collected in the Flaxton test area indicate that the water from glacial till generally is much more highly mineralized than water from the more permeable Quaternary deposits. (See LaRocque, Swenson, and Greenman, 1963, tables 5, 7, and 8.)

Wells tapping deltaic deposits along the western shoreline of ancient Lake Souris and those tapping lake sediments in the southern part of the lake area yield water that uniformly is only moderately mineralized. The water in these deposits obviously had not previously percolated through glacial till. Wells tapping glacial deposits underlying the lake beds in the northern part of the lake area yield water that is much more highly mineralized than that from wells tapping the lake sediments in the southern part.

RELATION OF QUALITY OF IRRIGATION WATER TO LEACHING REQUIREMENTS

The chemical character and physical properties of irrigation water to be applied to the report area cannot be accurately determined. The diverted irrigation water, regardless of source, will undergo change in quality during transit because of increased concentration of soluble salts by evaporation. Return irrigation flows will modify further the quality of the supply. Missouri River water near Williston had an average dissolved-solids content in 1950-52 of about 375 ppm (specific conductance, about 560 micromhos per centimeter) according to concentrations weighted with streamflow. If the irrigation water is assumed to have approximately this concentration initially, a twofold increase in mineralization could reasonably be expected by the time the water reaches the area to be irrigated.

A detailed discussion of leaching requirements in the Souris River basin is beyond the scope of this report. According to the U.S. Salinity Laboratory Staff (1954), the leaching requirement is defined as "the fraction of the irrigation water that must be leached through the root zone to control soil salinity at any specified level." This requirement will depend on the degree of mineralization of the irrigation water and on the maximum permissible concentration in the soil solution. Under certain assumptions, such as uniform areal application of irrigation water, no rainfall, no removal of salt in the harvested crop, no precipitation of soluble salts in the soil, and steady-state waterflow, the leaching requirement may be expressed as a fraction or as a percentage from the following equation:

$$LR = \frac{D_{dw}}{D_{iw}} = \frac{EC_{iw}}{EC_{dw}}$$

where

LR is the leaching requirement,

D_{dw} is the depth of the drainage water,

D_{iw} is depth of the irrigation water,

EC_{iw} is specific conductance of the irrigation water,

and

EC_{dw} is specific conductance of the drainage water.

For example, if a field crop can tolerate a salinity (expressed as specific conductance) of the soil solution of 8,000 micromhos and the irrigation water has a specific conductance of 800 micromhos, then

$$LR \quad \frac{EC_{iw}}{EC_{dw}} = \frac{800}{8,000} = 1/10, \text{ or 10 percent}$$

In the above example, 10 percent of the applied irigation water must be leached through the root zone to control salinity.

Salt tolerances of crops that may be cultivated if irrigation of the Souris River basin becomes a reality have not been studied by the authors. The leaching requirement and its relation to quality of the irrigation water must be given consideration to insure successful water management in the report area.

EFFECT OF IRRIGATION ON SUBSURFACE DRAINAGE

If the report area is developed for irrigation, as has been proposed, irrigation water will become a potential source of additional recharge to the underlying porous earth materials. Unless total drainage is improved, some waterlogging may result. The additional recharge will result not only from the water applied to the crops but also, and perhaps principally, from the excess irrigation water that may accumulate in presently undrained depressions. Leakage from canals and from distribution laterals also will be a source of added recharge.

In general, waterlogging may be alleviated or prevented by either one or a combination of: (1) increasing the rate of flow of water through and from the zone of saturation, or (2) reducing the quantity of water available for recharge. The report area is not underlain by aquifers sufficiently permeable to conduct water rapidly enough to prevent waterlogging due to widespread irrigation. One method for increasing the flow of water through the zone of saturation is through utilization of open-ditch or tile drains. In general, drains to remove excess ground water would need to be deep and closely spaced because the soil and subsoil are fine textured and have low permeablities. However, the cost per acre for the installation, operation and maintenance of open-ditch or tile drains would be great, and the use of these types of drains probably should depend on the demonstration of a favorable cost-benefit ratio. Another method for increasing the rate of flow through the zone of saturation is the lowering of water levels in areas of natural discharge. Facilities for the lowering of water levels would have to be combined with facilities for reducing the availability of water for natural recharge also. The reduction in water available for natural recharge could be accomplished by means of a system of ditches that would drain the depressions or intercept runoff from intense rainfall and excessive or wasteful applications of irrigation water. Lining the canals and ditches might prove necessary if seepage from them caused mounding of the water table to such an extent that waterlogging threatened the adjacent land.

CONCLUSION

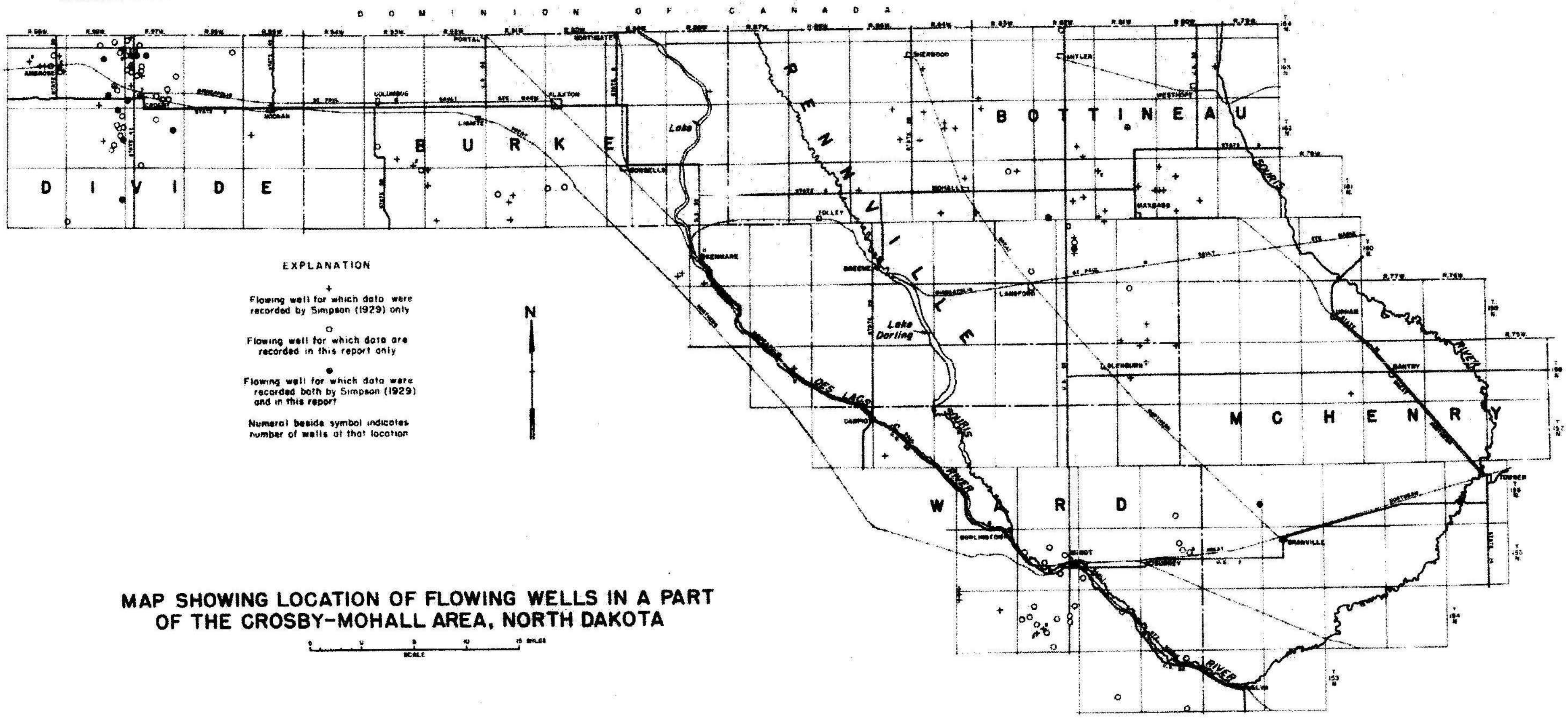
Although a tremendous amount of water is stored beneath the land surface in the report area, large quantities of water can be withdrawn through wells in only a small part of the area. In all parts of the area, however, adequate quantities for livestock and domestic use can be obtained if wells are drilled sufficiently deep into the zone of saturation.

Much of the ground water available in the area is so highly mineralized that its usefulness is limited. Water from the marine Cannonball Member of the Fort Union Formation, tapped by the deeper wells in the eastern part of the area, is soft but is so salty that generally it is used only be livestock. Wells tapping the continental Ludlow and Tongue River Members undifferentiated in the western part of the area yield either a soft sodium bicarbonate water or a hard calcium sulfate water. Both are used for domestic purposes, but the soft sodium bicarbonate water is less palatable and commonly contains more fluoride than is desirable in drinking water. In that part of the area underlain by both marine and nonmarine bedrock aquifers, water from wells that tap both is of intermediate chemical quality. Water from the Quaternary deposits is of extremely variable quality. In general, water from medium- to coarse-grained surficial deposits is the least mineralized and that from glacial till is highly mineralized.

As the zone of saturation extends to within a few feet of the land surface throughout much of the area, an increase in the amount of water entering the ground eventually would result in extensive waterlogging. In the report area, ground-water drains probably would not be economically feasible for alleviating or preventing widespread waterlogging because of a probable unfavorable cost-to-benefit ratio. Therefore, if the area is developed for irrigation, water should not be allowed to accumulate in depressions and then sink into the ground, but should be conveyed through ditches as rapidly as possible out of the area by way of natural drainage courses.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PLATE 1



EXPLANATION

\+
Flowing well for which data were recorded by Simpson (1929) only

○
Flowing well for which data are recorded in this report only

●
Flowing well for which data were recorded both by Simpson (1929) and in this report

Numeral beside symbol indicates number of wells at that location

MAP SHOWING LOCATION OF FLOWING WELLS IN A PART
OF THE CROSBY-MOHALL AREA, NORTH DAKOTA

SELECTED REFERENCES

Abbott, G. A., and Voedisch, F. W., 1938, The municipal ground-water supplies of North Dakota: North Dakota Geol. Survey Bull. 11.

Akin, P. D., 1947, Geology and ground-water conditions at Minot, N. Dak.: North Dakota Ground-Water Studies No. 6.

____________ 1951, Ground Water in the Mohall area, Bottineau and Renville Counties, N. Dak.: North Dakota Ground-Water Studies No. 17.

Alden, W. C., 1932, Physiography and glacial geology of eastern Montana and adjacent areas: U.S. Geol. Survey Prof. Paper 174.

Andrews, D. A., 1939, Geology and coal resources of the Minot region, North Dakota: U.S. Geol. Survey Bull. 906-B, p. 43-84.

Brant, R. A., 1953, Lignite resources of North Dakota: U.S. Geol. Survey Circ. 226.

Burkholder, J. L., Harding, S. T., and Selby, H. E., 1952, Report on suitability for sustained irrigation of lands in North Dakota west of the Des Lacs River: Review Board appointed jointly by State Water Conservation Commission of North Dakota and the U.S. Bureau of Reclamation. (Mimeographed rept.)

Dittmar, W., 1884, Report on researches into the composition of ocean water, collected by H. M. S. Challenger: Challenger Repts: Physics and Chem., v. 1, p. 1-251.

Fenneman, N. M., 1931, Physiography of western United States: New York, McGraw-Hill Book Co., Inc.

Holowaychuk, Nicholas, and Boatright, W. C., 1938, Erosion and related land use conditions on the Minot area, North Dakota: U.S. Dept. Agriculture, Soil Conserv. Service.

Laird, W. M., 1941, Selected deep-well records: N. Dak. Geol. Survey Bull. 12.

LaRocque, G. A., Jr., Swenson, H. A., and Greenman, D. W., 1963, Tables of hydrologic data, Crosby-Mohall area, North Dakota: U.S. Geol. Survey open-file rept., 508 p.

Larrabee, D. M., Huff, L. C., and Ahlman, C., 1946, Preliminary map showing sand and gravel deposits of North Dakota: U.S. Geol. Survey, Missouri Basin Studies No. 3.

Lee, C. H., 1942, Transportation and total evaporation, Chap. 8 in Meinzer, O. E., 1942, Hydrology: New York, McGraw-Hill Book Co., Inc.

Lemke, R. W., 1960, Geology of the Souris River area, North Dakota: U.S. Geol. Survey Prof. Paper 325, 133 p.

Leonard, A. G., Babcock, E. J., and Dove, L. P., 1925, The lignite deposits of North Dakota: North Dakota Geol. Survey Bull. 4.

Renick, B. C., 1924, Base exchange in ground water by silicates as illustrated in Montana: U.S. Geol. Survey Water-Supply Paper 520-D, p. 53-72.

Riffenburg, H. B., 1925, Chemical character of ground waters of the northern Great Plains: U.S. Geol. Survey Water-Supply Paper 560-B, p. 31-52.

Shride, A. F., Fischer, E. C., Larrabee, D. M., Weeks, R. A., Sohn, I. G., and Fox, E. L., 1947, Map showing construction materials and nonmetallic mineral resources of North Dakota: U.S. Geol. Survey, Missouri Basin Studies No. 14.

Simpson, H. E., 1929, Geology and ground-water resources of North Dakota, with a discussion of the chemical character of the water by H. B. Riffenburg: U.S. Geol. Survey Water-Supply Paper 598.

_____________ 1932, The ground waters of North Dakota: North Dakota Geol. Survey Bull. 7.

_____________ 1935, The artesian waters of North Dakota: North Dakota Geol. Survey Bull. 8.

_____________ 1937, Change in ground-water levels in North Dakota: North Dakota Geol. Survey Bull. 10.

Swenson, F. A., 1955, Geology and ground-water resources of the Missouri River valley in northeastern Montana, with a section on the quality of the ground water, by W. H. Durum: U.S. Geol. Survey Water-Supply Paper 1263, 128 p.

Theis, C. V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., v. 16, p. 519-524.

Townsend, R. C., 1954a, Geology of the Noonan quadrangle, North Dakota: U.S. Geol. Survey Geologic Quadrangle Maps of the United States, Map GQ44.

_____________ 1954b, Geology of the Crosby quadrangle, North Dakota: U.S. Geol. Survey Geologic Quadrangle Maps of the United States, Map GQ46.

_____________ 1954c, Geology of the Portal quadrangle, North Dakota: U.S. Geol. Survey Geologic Quadrangle Maps of the United States, Map GQ47.

U.S. Congress, 1944, Conservation, control, and use of water resources of the Missouri River basin in Montana, Wyoming, Colorado, North Dakota, South Dakota, Nebraska, Kansas, Iowa, and Missouri: 78th Cong., 2nd sess., S. Doc. 191.

U.S. Public Health Service, 1946, Drinking water standards: Public Health Repts., v. 61, no. 11, p. 371-384.

U.S. Salinity Laboratory Staff, 1954, Diagnosis and improvement of saline and alkali soils: U.S. Dept. Agriculture, Agriculture Handb. 60, p. 37-38.