WATER RESOURCES OF WALWORTH COUNTY, SOUTH DAKOTA

By Jack Kume and Lewis Howells

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CONVERSION FACTORS

For those readers interested in converting inch-pound units to the International System of units (SI), the following factors are used:

Multiply	By	To obtain
acre	4,047	square meter
acre	0.4047	square hectometer
acre-foot (acre-ft)	1,233	cubic meter
acre-foot (acre-ft)	0.001233	cubic hectometer
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year
foot (ft)	0.3048	meter
foot per year (ft/yr)	0.3048	meter per year
gallon per minute (gal/min)	0.06309	liter per second
gallon per day (gal/d)	0.0038	cubic meter per day
inch	2.54	centimeter
inch	25.4	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
square foot per day (ft^2/d)	0.0929	cubic meter per day
micromhos per centimeter at 25° Celsius (µmho/cm at 25°C)	1.000	microsiemens per centimeter at 25° Celsius

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "mean sea level." NGVD of 1929 is referred to as sea level in this report.

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ABSTRACT

The water resources of Walworth County are for the most part undeveloped. In 1978, only about 10,000 acre-feet of water was used for irrigation, stock, domestic, and public supplies; most of this was pumpage for irrigation from Lake Oahe, on the Missouri River. Lake Oahe stores about 22 million acre-feet of water; the average annual flow of the Missouri River is about 16 million acre-feet. Tributary streams normally are dry at least 10 months per year. Average annual net surface runoff from the county is 7,900 acre-feet. At least 99 percent of the precipitation per year is lost by evapotranspiration.

An estimated 1.2 million acre-feet of water is stored in eight aquifers in the glacial drift. The water generally is suitable for irrigation, stock, and domestic use.

It is estimated that more than 55 million acre-feet of water is stored in nine aquifers in the bedrock. These aquifers are in the Dakota Formation, Inyan Kara Group, Sundance and Minnelusa Formations, Madison Group, Devonian strata, and Stony Mountain, Red River, and Deadwood Formations. The water is slightly to very saline and, at best, is suitable for livestock and marginally acceptable for domestic supplies.

INTRODUCTION

Purpose and Scope

In July 1975, the South Dakota Geological Survey and the U.S. Geological Survey began a 4-year study to evaluate the water resources and geology of Walworth County. The purpose of this report is to provide hydrogeologic information for future water development in the county. This study is part of an evaluation of the water resources and geology of eastern South Dakota (fig. 1).

Work included collection, compilation, and an evaluation of data on the geology and hydrology of the area. Wells were inventoried, water levels were measured in wells, and test holes were drilled at selected sites. All wells, test sites, and data sites are numbered according to the Federal land-survey system (fig. 2). The authors gratefully acknowledge the cooperation of residents of Walworth County for providing information on their water wells. Local drilling companies supplied supplemental test-hole information.

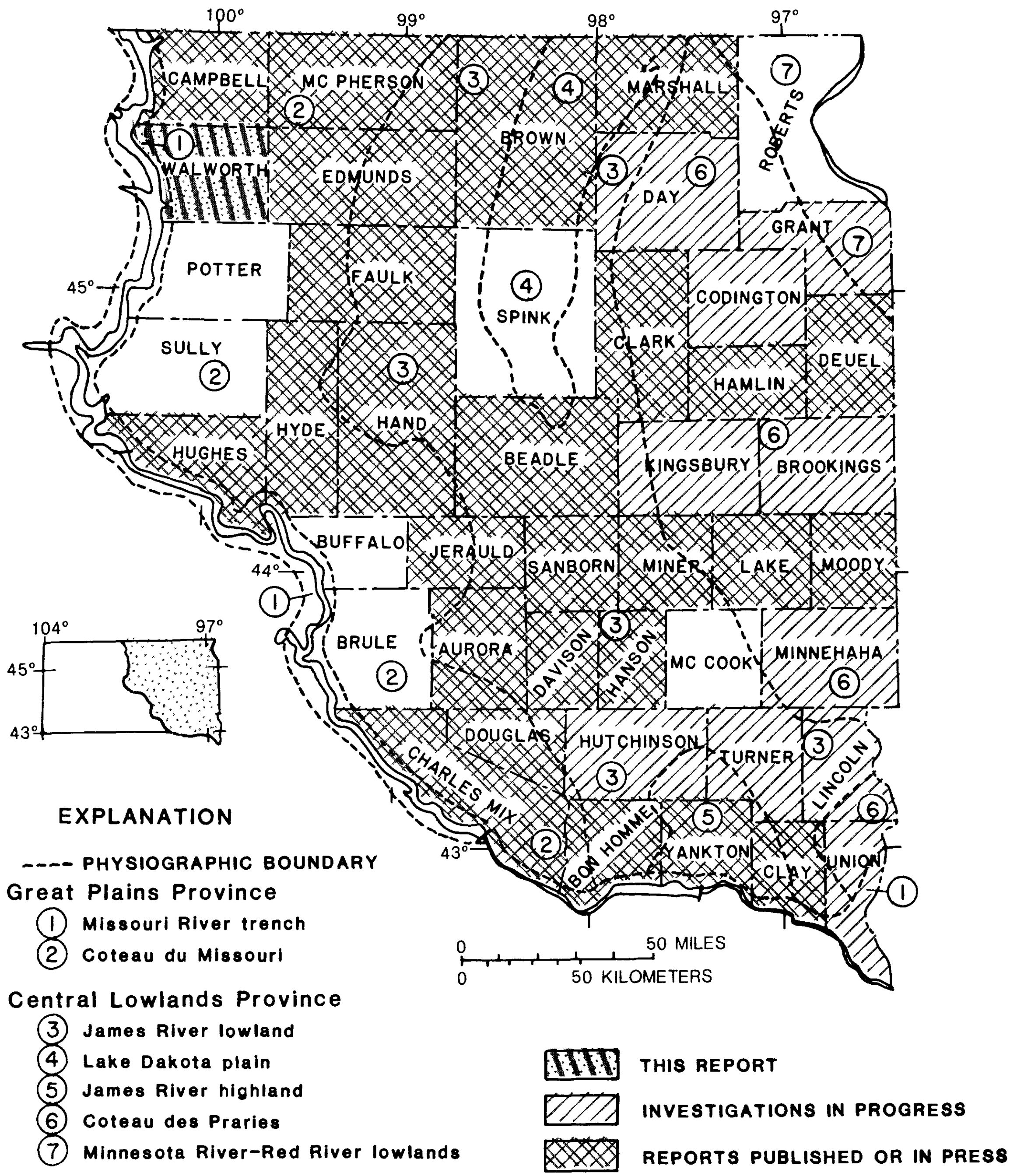


Figure 1.--Location of the study area, status of the county water-resources study South Dakota (after Flint 1955).

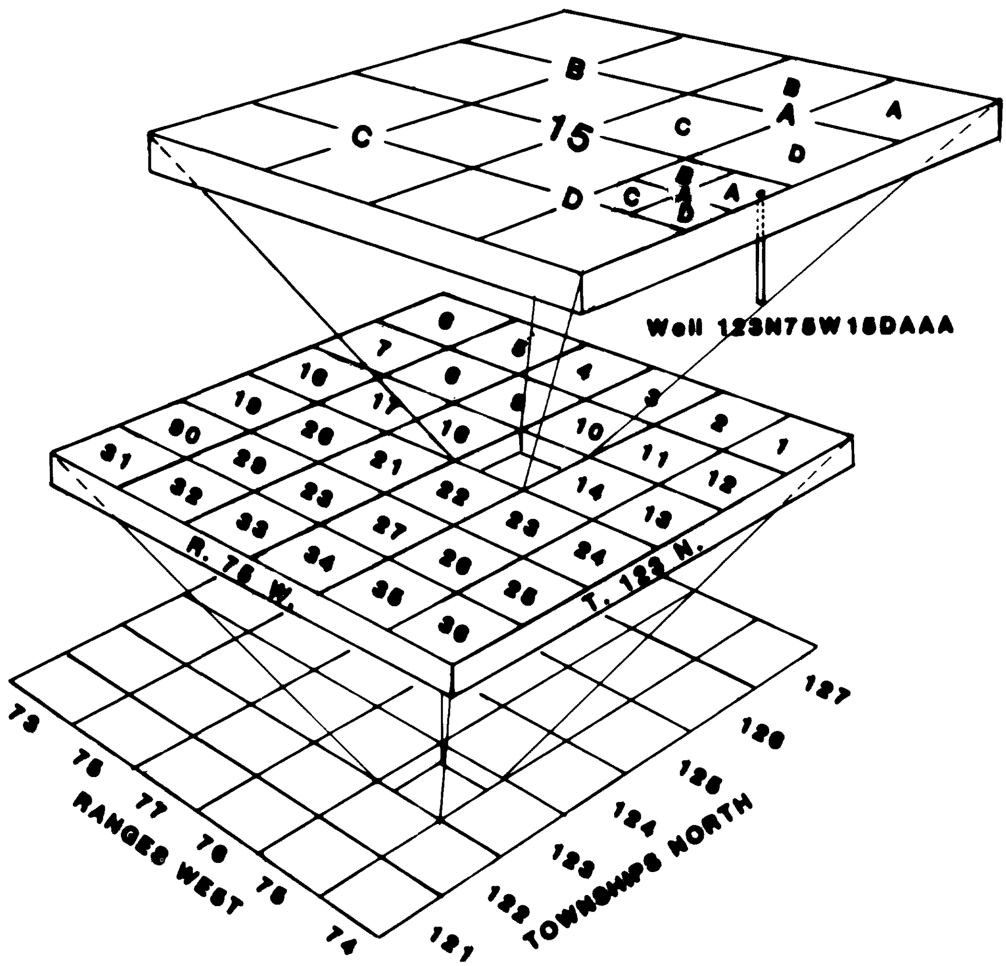


Figure 2.--Well- and site-numbering diagram. The number consists of township followed by "N," range followed by "W," and section number, followed by a maximum of four uppercase letters that indicate, respectively, the 160-, 40-, 10-, and 2½-acre tract in which the well is located. These letters are assigned in a counterclockwise direction beginning with "A" in the northeast quarter. A serial number following the last letter is used to distinguish between wells in the same tract.

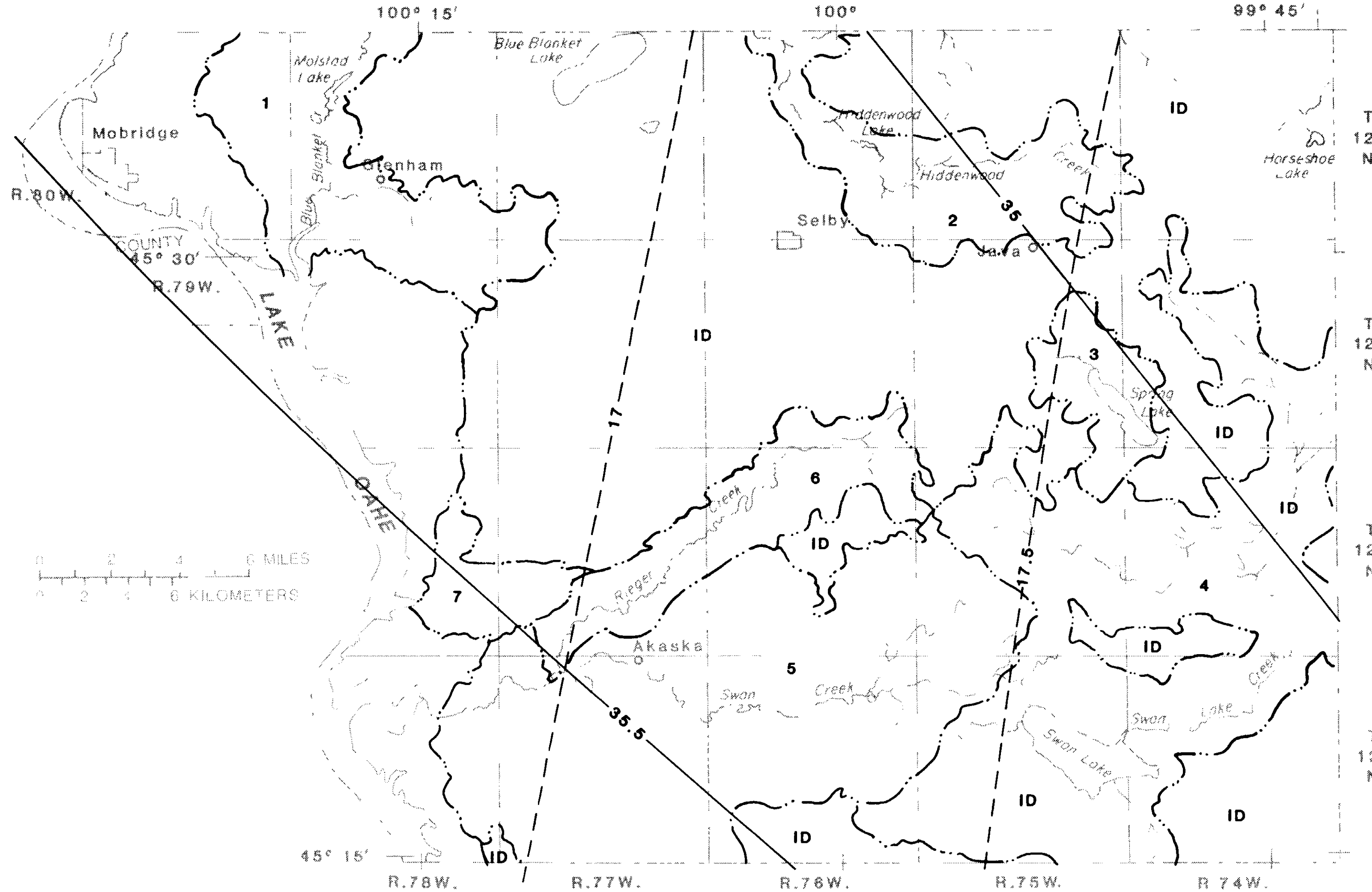
Geography

Walworth County has an area of about 750 mi^2 and lies mostly on the rolling uplands of the western Coteau du Missouri, part of the glaciated Missouri Plateau section of the Great Plains physiographic province (fig. 1). The western margin of the county is in the Missouri River trench. The topography is a rolling, glaciated upland cut by the deep valley of the Missouri River on the west, three northeast-trending valleys, in which are located the Blue Blanket, Rieger, Swan, and Swan Lake Creek drainage basins, and the northwest-trending Hiddenwood Creek drainage basin (fig. 3). Erosion has carved the Missouri River trench into a badlands to semi-badlands area, which is known locally as "the breaks". Terraces parallel the Missouri River and, to a much lesser degree, parallel the major tributaries in the county.

WATER RESOURCES

Usable water in Walworth County is available from streams, lakes, ponds, and reservoirs and as ground water in unconsolidated surficial deposits and bedrock strata. Except for Lake Oahe, the surface water and the ground water in surficial deposits comes from precipitation in Walworth County and adjacent areas. The sum of all the paths followed by water through an area is called "the hydrologic cycle." When quantities of water are measured, calculated, or estimated for each of the flow paths, the resulting diagram, table, or equation is called a "hydrologic budget." Table 1 shows the estimated average annual hydrologic budget.

The average annual hydrologic budget includes inflow and outflow of water for Walworth County. About 17.1 million acre-ft (5.6 trillion gallons) of water per year move through the area. Except for Lake Oahe, of precipitation falling in Walworth County, about 99 percent is returned to the atmosphere by evaporation and transpiration (table 1). About 80 percent of the annual lake evaporation rate of 35.3 inches occurs during the May to October growing season (Kohler and others, 1959). Less than 1.5 percent of the precipitation becomes streamflow or aquifer outflow from the area; however, this quantity may vary widely from year to year because of variations in precipitation. Less than 1 percent of the precipitation percolates downward to become ground water. Much of this ground water moves laterally in local flow systems before being discharged by springs and seeps to lakes and streams and by evapotranspiration. In any given year the water budget most likely would show a change in ground-water storage, which can be detected by and calculated from changes in water levels in observation wells in the aquifers. If water levels rise, storage increases; if water levels decline, storage decreases. Over the long term, however, changes in storage will be zero unless there is a significant increase in pumpage.



EXPLANATION

— —17.5 — — LINE OF EQUAL AVERAGE ANNUAL PRECIPITATION--Interval 0.5 inches. Base period 1927-65

—— 35 —— LINE OF EQUAL AVERAGE LAKE EVAPORATION--Interval 0.5 inches. Base period 1946-55

.. —— .. —— .. SURFACE-WATER DIVIDE

ID BASIN OF INTERNAL DRAINAGE

Figure 3.--Drainage basins, average annual precipitation, and average annual lake evaporation. Numbered drainage basins are those for which estimated average annual flow is given in table 1. Precipitation and evaporation data from U.S. National Oceanic and Atmospheric Administration.

Table 1.--Estimated average annual hydrologic budget for Walworth County

Budget component	Acre-feet
Inflow	
Precipitation	
On Lake Oahe (adjacent to Walworth County)	88,100
On land	664,000
On streams, lakes, dugouts	7,250
Rivers, lakes, and basins	
Missouri including Oak Creek	16,048,000
Grand River	170,720
Moreau River	149,500
Swan Creek	200
Swan Lake	1,820
Swan Lake Creek	100
Blue Blanket Lake	450
Blue Blanket Creek	410
Minor tributaries to Missouri River	550
Miscellaneous basins of internal drainage	40
Ground water[1/]	4,420
Overland runoff from the west to Lake Oahe	11,800
Total inflow	17,147,360
Outflow	
Rivers and lakes	
Missouri River	16,277,000
Hiddenwood Creek	770
Miscellaneous small streams	160
Ground water[1/]	2,480
Evaporation-transpiration	
Lake Oahe (adjacent to Walworth County)	182,000
Streams, lakes, dugouts	14,700
Land surface	651,000
Consumptive use[2/]	
From Lake Oahe to Dewey County	6,700
From Lake Oahe to Walworth County	9,000
From streams, lakes, and dugouts	1,000
From ground water	2,550
Total outflow	17,147,360

1/ Ground-water inflow and outflow is water that enters or leaves Walworth County as ground water.
2/ At the rate for 1978.

Surface Water

The surface water resources of Walworth County are outlined in and summarized by figure 3 and tables 2 and 3. The county is in the drainage basin of the Missouri River. However, about 60 percent of the county usually does not contribute water to the Missouri, but is in basins of internal drainage (fig. 3). Runoff from land within basins of internal drainage flows to sloughs, lakes, or ponds and evaporates or infiltrates to aquifers. The area of internal drainage can vary greatly from year to year depending on the quantity and the distribution (in both time and area) of precipitation.

Table 2.--Estimated average annual streamflows of selected drainage basins[1/]

Basin number shown in figure 3	Drainage basin	Drainage area (square miles)	Average annual streamflow: acre-feet per square mile	cubic feet per second	acre-feet
1	Blue Blanket Creek	55	23.3	1.7	1,280
	Blue Blanket Creek, flow originating within the county	40	21.8	1.2	870
2	Hiddenwood Creek	31	24.8	1.0	770
3	Spring Lake	10	27.0	.4	270
4	Swan Lake	172	26.5	6.2	4,560
	Swan Lake basin, flow originating within the county	99	26.6	3.6	2,630
	Swan Lake Creek	103	26.5	3.7	2,730
5	Swan Creek	141	25.7	4.9	3,620
	Swan Creek, flow originating within the county	132	25.8	4.6	3,410
6	Rieger Creek	27	25.9	.9	700
7	Pero Creek	9	18.9	.2	170

1/ Estimated using the method described by Larimer (1970).

Most local streamflow is from snowmelt and from spring rain. In most years more than 90 percent of the streamflow reaching the Missouri River from Walworth County occurs in March, April, and May. Runoff from summer storms usually evaporates, is transpired back to the atmosphere by plants, or is stored by surface-water impoundments such as stock ponds before it reaches the river. Springs and seeps, usually having small discharge, flow in spring and early summer. Most springs and seeps dry up by midsummer, although a few streams do have permanent natural "water holes" which are 5- to 100-ft segments that intercept the local water table. All streams in the area except the Missouri River commonly have periods of no flow for 10 to 11 months per year. During periods of extended drought all streams except the Missouri River may be dry the entire year.

Table 3.--Estimated potential average annual net evaporation loss from lakes[1/]

Lake	Area (square miles)	Net evaporation loss (acre-feet)
Blue Blanket	6.5	6,400
Hiddenwood	.04	35
Horseshoe	.10	93
Molstad	.16	150
Spring	1.1	2,000
Swan	3.9	3,700

1/ Excess of evaporation over precipitation on the lake surface; calculated for the area of each lake as measured from the U.S. Geological Survey 7½' topographic maps. For Blue Blanket Lake the area used is that below the 1,700-foot contour line; although the potential lake outlet is about 1,725 feet above sea level, the apparent "historic" lake size is delimited by the 1,700-foot contour.

The estimated flows of selected streams and the estimated collective flows of several streams in selected basins are summarized in table 2. The flow volumes given were calculated for points where the streams crossed the county line or where they emptied into a lake such as Swan Lake or Lake Oahe. Collective flows were calculated where several small streams discharged into a lake (such as Spring Lake) or where several tributaries entered or left the study area before joining the main stream (such as the streams flowing to Swan Lake from Potter County). For the basins that include Spring and Swan Lakes, the flows given in the table are those of the streams that flow into the lakes, not the outflow from the lakes. Evaporation loss from the lakes is very large (see table 3). Spring Lake has never been known to overflow (Robert Krumm, South Dakota Department of Game, Fish, and Parks, personal commun., 1983). Swan Lake overflows about three out of every 10 years (Robert Krumm, personal commun., 1983). Blue Blanket Lake, a source of recharge to the Grand and Selby aquifers, has never been known to overflow and, since 1970, has filled only once during the winter and spring of 1978. Horseshoe Lake is very shallow and frequently goes dry.

Hiddenwood and Molstad Lakes are small impoundments behind earthfill dams. These lakes are permanent, but Hiddenwood Lake has accumulated much silt and now is shallow. The principal use of both lakes is recreation.

The total area of open water, such as lakes, ponds, and sloughs, in Walworth County excluding Lake Oahe is estimated as 7,600 acres. In any given year the area of open water may vary from the 7,600-acre average because large amounts of precipitation may fill all of the lakes and sloughs or a severe drought may dry up the lakes, sloughs, and ponds.

The area of open water probably is increasing as farmers install ditches and drainage tile. Installation of ditches and drainage tile causes water to reach lakes, ponds, or streams faster. Stockponds commonly are located in topographic low points to intercept water for stock use and to act as a collection site for farmland drainage.

Table 4.--Summary of hydrologic information for the aquifers in Walworth County

Aquifer	Lithology and type	Depth to the top, in feet: Range	Depth to the top, in feet: Average	Thickness of deposit, in feet: Range	Thickness of deposit, in feet: Average	Area, in acres	Average saturated thickness, in feet	Effective porosity	Estimated volume of water in storage, in acre-feet	Potential for development: Estimated yield range, in gallons per minute	Potential for development: Will support additional development
Bowdle	Sand and gravel; unconfined	0 to 24	2	2 to 62	23	20,400	15	0.20	60,000	5 to 250	moderate amount
Selby	Sand and gravel; unconfined	0 to 22	5	16 to 59	32	14,000	18	.20	50,000	5 to 400	major amount
Grand	Sand and gravel; unconfined to confined	19 to 207	106	1 to 157	39	91,000	39	.20	700,000	5 to 600	major amount
Java	Sand and gravel; confined	11 to 174	61	5 to 69	22	83,000	22	.20	360,000	5 to 50	moderate amount
Other drift and alluvium	Sand and gravel; unconfined and confined	0 to 40	9	3 to 70	15	11,500	7	.20	16,000	1 to 30	moderate amount
Dakota Formation	Sandstone; confined	1,600 to 2,200	--	90 to 270	182	480,000	137	.16	10,000,000	5 to 100+	moderate amount 2/
Inyan Kara Group	Sandstone; confined	2,050 to 2,350	--	40 to 65	52	480,000	34	.12	2,000,000	5 to 100	moderate amount 2/
Sundance Formation	Sandstone; confined	2,100 to 2,400	--	75 to 180	123	480,000	74	.10	3,500,000	20 to 100+	moderate amount 2/
Minnelusa Formation	Sandstone, limestone, and dolomite; confined	2,200 to 2,700	--	140 to 340	245	480,000	147	.10	7,000,000	20 to 200+	major amount 2/
Madison Group	Dolomite and limestone; confined	2,350 to 3,050	--	350 to 660	520	480,000	300	.07	10,000,000	50 to 1,000+	major amount 2/
Three Forks, Birdbear, Duperow	Sandstone, dolomite, and limestone; confined	2,650 to 3,550	--	100 to 305	160	480,000	112	.10	5,000,000	unknown	unknown 2/
Stony Mountain Formation	Sandstone and limestone; confined	3,200 to 3,800	--	0 to 80	about 40	247,000	unknown	.07	unknown	unknown	unknown 2/
Red River Formation	Dolomite and limestone; confined	2,750 to 3,900	--	340 to 520	447	480,000	447	.07	15,000,000	200 to 1,000+	major amount 2/
Deadwood Formation	Sandstone and conglomerate; confined	3,200(?) to 4,500	--	10 to 360	100	480,000	100	.07	3,000,000	1 to 100+	moderate amount 2/
"granite wash"	Sand and gravel; confined	3,250 to 4,750	--	0 to 50	--	unknown	unknown	.15	unknown	unknown	-- 2/

1/ Locally may be unacceptable due to high nitrate concentration.
2/ Increased development will result in rapidly decreasing head.

Lake Oahe overshadows all other sources of surface water available in Walworth County because of its volume and the potential for development. Lake Oahe stores more than 22 million acre-ft, and has an average annual flow more than 16 million acre-ft. As use of water for irrigation from Lake Oahe increases, the economic importance of the reservoir will greatly increase.

Lake Oahe is an almost untapped water resource. Development of Lake Oahe as a water supply was negligible in 1978. Only 8,000 acre-ft of water was diverted for irrigation, less than 1,000 acre-ft was used for public supplies, and probably less than 60 acre-ft was consumed by livestock in 1978. Lake Oahe provides fishing, boating, camping, water sports, and waterfowl hunting.

Ground Water

The ground-water resources of Walworth County include four major aquifers in glacial drift and alluvium--the Grand, Selby, Bowdle, and Java aquifers and several minor aquifers and at least nine aquifers in bedrock strata--the Dakota Formation, Inyan Kara Group, Sundance Formation, Minnelusa Formation, Madison Group, rocks of Devonian age, Stony Mountain Formation, Red River Formation, and Deadwood Formation. A summary of the hydrologic information for these aquifers is given in table 4.

The geology of Walworth County is described in detail by Hedges, in press, so it is discussed only briefly in this report. The stratigraphic column, table 5, shows the various formations and deposits and summarizes age, thickness, and other characteristics of the rocks. Pleistocene (glacial) drift, Holocene (post-glacial) alluvium, and pre-glacial and interglacial alluvium up to 290 ft thick comprise the surficial deposits. Underlying the unconsolidated surficial deposits, and overlying the crystalline Precambrian basement rocks, are 3,000 to 4,600 ft of marine and continental strata ranging in age from Precambrian to Cretaceous. These bedrock deposits are part of a thick sequence of sedimentary beds that occupies a major geologic structure known as the Williston Basin. Walworth County is on the southeastern limb of that basin.

Table 4.--Summary of hydrologic information for the aquifers in Walworth County--Continued

Aquifer	Depth to water from land surface, in feet	Suitable for use in				Major ions
		Irrigation	Livestock	Industry	Domestic or public supply	
Bowdle	0 to 40	yes	yes[1/]	acceptable	good to acceptable[1/]	Calcium, magnesium, and bicarbonate.
Selby	6 to 45	yes	yes[1/]	acceptable	good to acceptable[1/]	Calcium, magnesium, and bicarbonate.
Grand	4 to 232	acceptable to unacceptable	yes	acceptable to unacceptable	acceptable to unacceptable	Sodium and bicarbonate; locally may be sodium sulfate or calcium, magnesium, and sulfate.
Java	4 to 160	good to unacceptable	yes	fair to unacceptable	fair to unacceptable	Calcium, magnesium, and bicarbonate.
Other drift and alluvium	2 to 200	good to unacceptable	yes	good to unacceptable	good to unacceptable[1/]	Sodium and bicarbonate; calcium, magnesium, and bicarbonate; calcium, magnesium, and sulfate; sodium and sulfate.
Dakota Formation	90 above to 450 below	no	acceptable to marginal	limited	no	Sodium and chloride.
Inyan Kara Group	600 above to 75 below	no	acceptable to marginal	limited	poor to unacceptable	Sodium and sulfate; calcium, magnesium, and sulfate.
Sundance Formation	>600 above to 75 below	no	acceptable to marginal	limited	poor to unacceptable	Sodium and sulfate; calcium, magnesium, and sulfate.
Minnelusa Formation	150 to 900 above	no	acceptable to unacceptable	limited	poor to unacceptable	Sodium and chloride; sodium and sulfate; calcium, magnesium, and sulfate.
Madison Group	150 to >900 above	no	acceptable to marginal	limited	poor to unacceptable.	Calcium, magnesium, and sulfate.
Three Forks, Birdbear, Duperow	150 to >900 above	no	acceptable to marginal	limited	poor to unacceptable	Calcium, magnesium, and sulfate.
Stony Mountain Formation	>150 to >900 above	no	acceptable to marginal	limited	poor to unacceptable	Calcium, magnesium, and sulfate.
Red River Formation	>150 to >900 above	no	acceptable to marginal	limited	poor to unacceptable	Calcium, magnesium, and sulfate.
Deadwood Formation	>150 to >900 above	no	acceptable to marginal	limited	poor to unacceptable	Estimated to be sodium and sulfate.
"granite wash"	>150 to >900 above	no	acceptable to marginal	limited	poor to unacceptable	Estimated to be sodium and sulfate.

1/ Locally may be unacceptable due to high nitrate concentration.
2/ Increased development will result in rapidly decreasing head.

Table 5.--Generalized stratigraphic column for Walworth County describing rock units and some of their hydrologic characteristics

System		Estimated age of boundaries in millions of years	Deposit or formation	Approximate thickness (feet)	Description	Hydrologic significance
Quaternary	Holocene		Alluvium, colluvium, eolian deposits	0 to 100	Gravel, sand, silt, and clay, bedded, poorly to well-sorted deposits confined to present-day stream channels, flood plains, and ponds or sloughs. Colluvium is an unstratified jumble of slump or landslide material most commonly found in hilly areas such as the "breaks" of the Missouri River. Eolian deposits are a thin but widespread blanket of silt and very fine to fine sand (and some clay).	Alluvium locally is part of the Selby and Bowdle aquifers and of unnamed minor aquifers such as the one in the valley of Swan Creek. Colluvium and eolian deposits are not known to be part of any aquifer.
		.01				
	Pleistocene		Glacial drift and interglacial alluvium	0 to 290	Drift is made up mostly of till and outwash. Drift is water-laid glacial debris, commonly in poorly to well-sorted beds of brown to gray clay, silty, sand, and gravel. Interglacial alluvial deposits are the remnants of alluvial deposits laid down during intervals when the area was not occupied by continental ice sheets.	Till is relatively impermeable and is a barrier to the movement of water. Outwash sand and gravel deposits are aquifers, as are sand and gravel in interglacial alluvial deposits.
		2				
Tertiary			Pre-glacial alluvium	0 to 185	Remnants of the tan, stratified deposits of silt and quartzose sand and gravel, which were deposited prior to the ice age. Deposits are remnants of terraces, flood plains, and channelfill of the ancient Grand and Moreau Rivers and their tributaries. No other deposits of known Tertiary age have been found in Walworth County, though the Fort Union Formation probably once covered the area.	The Grand and Java aquifers are made up of outwash, pre-glacial alluvium, and probably some inter-glacial alluvium.
		63				
Cretaceous	Upper		Hell Creek Formation	(?)	No remnant known in the county, though the formation must have overlain the county at the end of the Cretaceous.	None.
			Fox Hills Formation	0 to 50(?)	Dark-colored shale and sandy, silty shale. Identified as "probably present" on the bed-rock topographic high in the east-central part of the county. Marine.	None.
			Pierre Shale	500 to 900	Gray, brown, and black friable shale. Marine.	Relatively imperable; a barrier to the movement of water.

System	Series	Age (millions of years)	Geologic unit	Thickness (feet)	Description	Hydrologic significance
Cretaceous	Upper		Niobrara Formation	84 to 210	Tannish- to bluish-gray and light- to dark-gray highly calcareous shale; contains abundant microfossils. Marine.	Relatively impermeable; a barrier to the movement of water.
			Carlile Shale	420 to 466	Light-blue or light-gray to black shale, generally noncalcareous; contains one or more sandstone or sandy or silty intervals (probably equivalent to the Codell Sandstone Member found elsewhere) in the top half. Marine.	Relatively impermeable; a barrier to the movement of water.
			Greenhorn Formation	110 to 160	Buff to bluish, white, or gray calcareous shale; commonly marly and fossiliferous. May be interbedded with thin limestone layers. Marine.	Though locally an aquifer in some parts of South Dakota, the Greenhorn is not known to yield water in Walworth County.
			Graneros Shale	190 to 350	Medium- to dark-gray, noncalcareous shale. Calcareous concretions and pyrite and marcasite crystals common. Generally divided into two units by a widely persistent bentonite bed. The upper unit contains many thin beds; the lower unit is more siliceous and may contain thin sandstone or very sandy or silty beds. Marine.	Relatively impermeable; a barrier to the movement of water.
			Dakota Formation	90 to 270	White, tan, or light-gray sandstone, very fine to medium-grained, loose to tightly cemented; interbedded with dark-colored shale. Thins from southeast to northwest. Deltaic to nearshore marine.	A major artesian aquifer. Yields slightly to moderately saline water to wells throughout the county.
		96				
	Lower		Skull Creek Shale	130 to 150	Dark bluish-gray shale. Marine.	Relatively impermeable; a barrier to the movement of water.
			Inyan Kara Group	40 to 65	White to light-gray or tan sandstone and siltstone; contains beds of gray to black and reddish to buff shale. Continental to marginal marine.	An artesian aquifer that can yield slightly to moderately saline water.
		138				
Jurassic			Sundance Formation	75 to 180	White, buff, dark-pink or red, glauconitic, fine-grained sandstone and siltstone interbedded with gray, green, and brown shale. May contain limestone concretions and thin beds of coquinoid or oolitic limestone in the upper part. Marine.	The aquifer consists of sandstone beds that can yield slightly to moderately saline water.
			Piper	0 to 20(?)	Limestone and green or gray shale; may contain thin gypsum beds and disseminated gypsum. Marine. Present in the northwestern corner of the county (see fig. 21).	Hydrologic potential unknown but probably poor.
		205				
Triassic			Not represented	0		
		240				

Table 5.--Generalized stratigraphic column for Walworth County describing rock units and some of their hydrologic characteristics--Continued

System	Estimated age of boundaries in millions of years	Deposit or formation	Approximate thickness (feet)	Description	Hydrologic significance
Permian	290	Minnelusa Formation	140 to 340	A complex sequence of predominantly marine beds. Contains as many as five major sandstone zones separated by limestone, dolomite, shale, and anhydrite beds. Sandstones are white to yellow to red; carbonates are white to brown to gray; shales are brick-red to orange, green, or black. A prominant "red marker" shale, where found above the base of the formation, commonly is interpreted as marking the top of the Pennyslvanian beds; its top is the base of Permian strata.	A major ground-water reservoir. The thicker sandstone beds and some of the carbonate beds form an aquifer that can yield slightly to very saline water. The evaporite and shale beds are barriers to the movement of water.
Pennsylvanian	330				
Mississippian	360	Madison Group (Charles Formation and Mission Canyon and Lodgepole Limestones)	350 to 660	White to tan, brown, and gray limestone and dolomite; interbedded with brown shale and light-blue to white and light-brown anhydrite, some halite. Marine.	May be the most important bedrock aquifer in South Dakota.
Devonian		Undifferentiated Devonian strata: Three Forks Formation	10 to 90 (Undifferentiated Devonian strata: 100 to 305)	Red and green shale interbedded with gray, fine to medium-grained sandstone or siltstone. May be calcareous or dolomitic. Marine.	Hydrologic potential unknown. Evaporite and shale beds are barriers to the movement of water, but sandstone and carbonate-rock beds probably are artesian aquifers.
		Undifferentiated Devonian strata: Bird Bear Formation	10 to 45	Light-gray to medium brownish-gray, finely crystalline, fossiliferous dolomite and limestone. Marine.	
	410	Undifferentiated Devonian strata: Duperow Formation	60 to 185	Light-gray to gray-brown, dense, fine-grained limestone and dolomite; interbedded with anhydrite and thin shale beds. Locally argillaceous. Marine.	
Silurian	435	Interlake Formation	0 or 0 to 10	Light-tan to brown dolomite, anhydrite, and calcareous sandstone. Marine. Probably missing but may underlie the northwestern corner of the county.	Hydrologic potential unknown, but probably is an aquifer.

Ordovician		Stony Mountain Formation	0 to 80	Brown to gray dolomitic limestone; commonly divided into two units. The lower unit contains sandstone, siltstone, and shale near the base. Marine. Underlies the northwestern half of the county.	Hydrologic potential unkown, but the sandstone and limestone beds may constitute an aquifer.
		Red River Formation	340 to 520	An upper unit of pale-red, pink, buff, or light-brown fossiliferous dolomite and lower unit of light-gray to pinkish, clay-streaked dolomitic limestone. Marine.	A major artesian aquifer. Data are scanty, but oil-well tests show permeable horizons.
		Winnipeg Shale	110 to 145	Thick lower unit of green to gray, bentonitic shale that contains black phosphate nodules; thin upper unit of siltstone and very silty shale. Marine.	Relatively impermeable; a barrier to the movement of water.
Cambrian	500	Deadwood Formation	10 to 360	White to buff to reddish-orange, light-gray, grayish-red, and brownish-red sandstone, siltstone, flaggy dolomite and limestone, and limestone-pebble conglomerate; contains beds and partings of greenish-gray and gray glauconitic shale. Sandstone, commonly conglomeritic, at the base. Marine. The top of the Deadwood may be Early Ordovician in age.	The sandstone and conglomerate beds probably constitute one or more major artesian aquifers.
Precambrian	570	Transgressive facies of clastic rocks	0 to 50	Sandstone and conglomerate, generally coarse-grained, but ranges from fine-grained to gravelly. Composition reflects the lithology of underlying and nearby Cambrian and Precambrian rocks. This is a coarse clastic facies that overlies the crystalline basement complex throughout much of South Dakota.	Probably a major aquifer. Is a major conduit for transmission of water upward through the stratigraphic column because it is in physical and hydraulic contact with other aquifers where they pinch out against the Precambrian surface. Locally known as "wash" and "granite wash".
		Igneous and metamorphic rocks		Various colored granite, gneiss, schist, and other igneous and metamorphic rocks.	Impermeable. Locally might yield water from fractures or joints.

Glacial Aquifers

The glacial aquifers are those in the unconsolidated deposits of glacial and alluvial origin. These deposits range from zero, where the Pierre Shale crops out in the walls of the Missouri trench, to more than 250 ft in thickness (fig. 4). They are composed of alluvial valley fill, glacial till, and outwash. The till, an unsorted, unstratified mixture of clay, silt, sand, and gravel deposited by glaciers, makes up more than 80 percent of the surficial material. Numerous deposits of outwash sand and gravel occur either at land surface or buried beneath till. Many such deposits are lenticular, thin, and discontinuous, but where tapped by a well, they commonly provide adequate water supplies suitable for domestic and stock use.

There are four major aquifers, the Selby, Bowdle, Grand, and Java aquifers, and several minor aquifers in the unconsolidated deposits in Walworth County. The present-day bedrock surface probably shows the general pattern of the preglacial topography. Ancient streams carved valleys in the bedrock surface and glacial meltwater deposited sand and gravel. Present-day streams may occupy parts of preglacial valleys such as Blue Blanket Creek, although the direction of streamflow, in some places, is reversed.

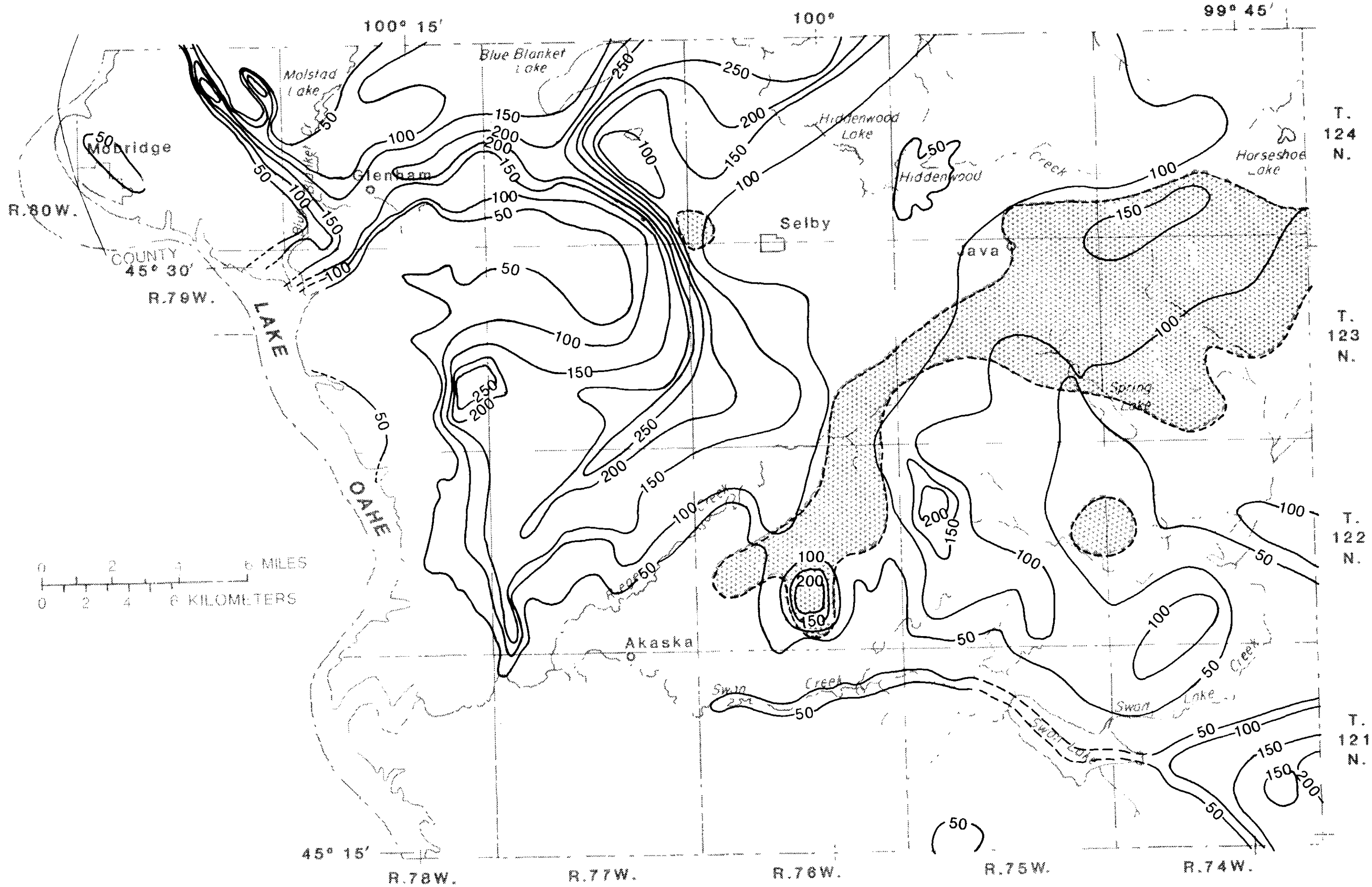
Bowdle aquifer

The most readily available ground water occurs in surficial bodies of outwash and alluvium, the largest of which is the Bowdle aquifer (named by Hamilton, 1974 and 1982).

The Bowdle aquifer underlies an area of 32 mi^2 in eastern and southeastern Walworth County (fig. 5) and extends into Potter and Edmunds Counties. The aquifer is composed mainly of glacial outwash deposits consisting of fine to medium sand and gravel. Throughout much of its extent the Bowdle aquifer is underlain by till and other glacial deposits, but in some areas the aquifer is underlain by Pierre Shale (fig. 6). The aquifer is exposed at the surface or is overlain by a thin cover of till. The saturated thickness of the permeable material ranges from 1 to 31 ft and averages about 15 ft (fig. 6). See table 4 for other hydrologic information about the aquifer. Figure 7 shows the location of geologic sections in this report.

The water table in the Bowdle aquifer is highest in late spring and early summer because of infiltration of snowmelt and spring rain. Low water levels in the aquifer usually occur in late summer or midwinter because plants have used more water during the growing season. The use of water by plants, together with direct evaporation of water, is called evapotranspiration. During warm weather, smaller amounts of precipitation are available to recharge the aquifer, and more moisture is held by the soil. This annual cyclic trend is not apparent in the observation-well hydrographs shown in figure 8 because of the overriding effects of the drought that began in 1974 and continued through 1976. To permit comparison of water-level changes with precipitation, a graph of cumulative departures from normal precipitation at Onaka is shown for the period of time that the observation wells were measured. The trends in the water level graphs are similar to the trend of cumulative departures from mean monthly precipitation. Because of the extended drought, water levels and total water stored in the aquifer probably were below the long-term average by 1978.

The altitude of the water table in various wells in the Bowdle aquifer is shown in figure 5. The general direction of movement of water in the aquifer is from north to south toward Swan Lake.



EXPLANATION

UNDIFFERENTIATED DEPOSITS--Area underlain by glacial drift and preglacial stream deposits

GLACIAL DRIFT DEPOSITS

—50— — — LINE OF EQUAL THICKNESS OF GLACIAL DRIFT AND PREGLACIAL STREAM DEPOSITS--Dashed where approximately located. Interval 50 feet

Figure 4.--Thickness and type of surficial deposits.

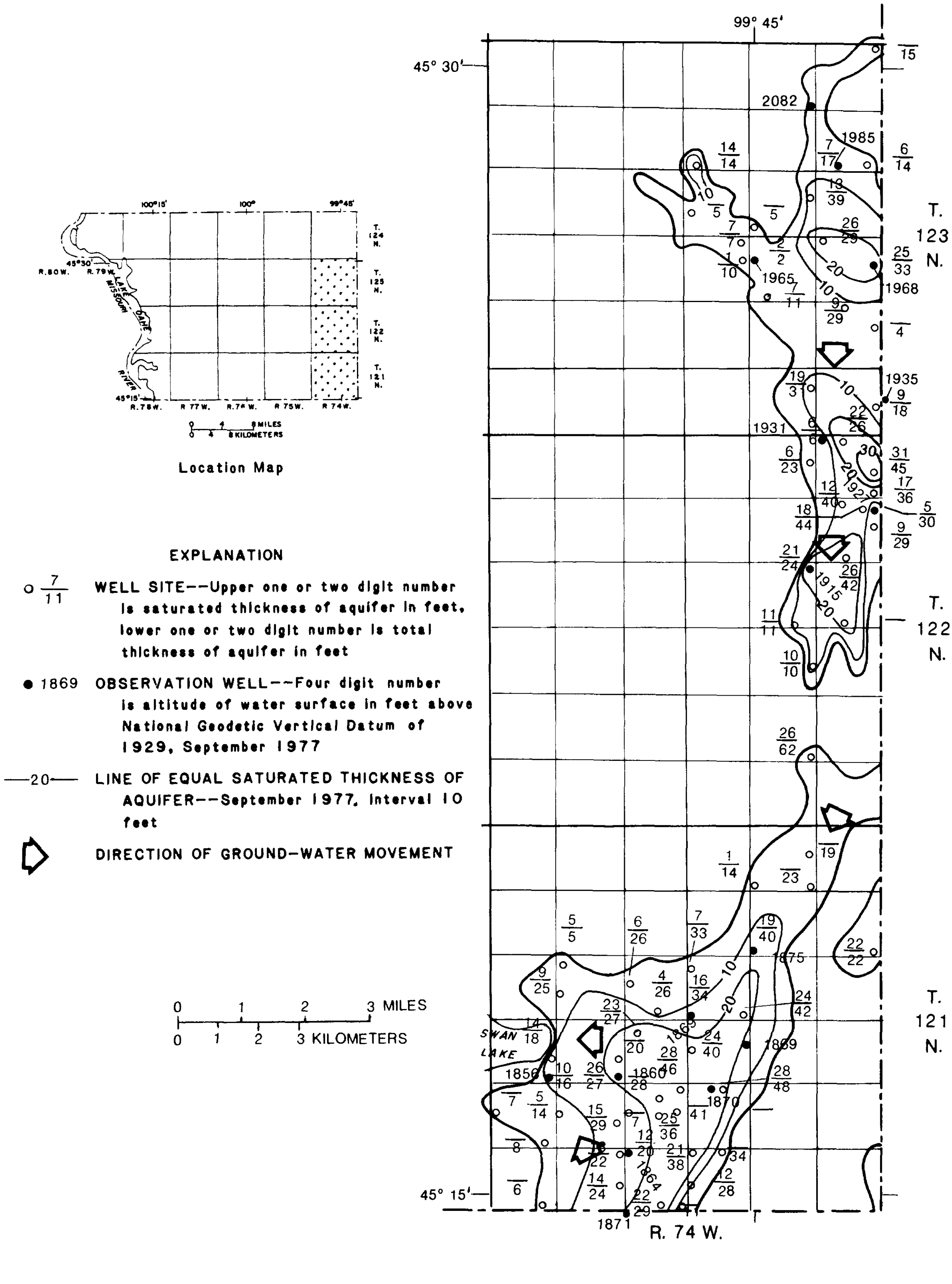


Figure 5.--Extent, thickness, and direction of ground-water movement of the Bowdle aquifer.

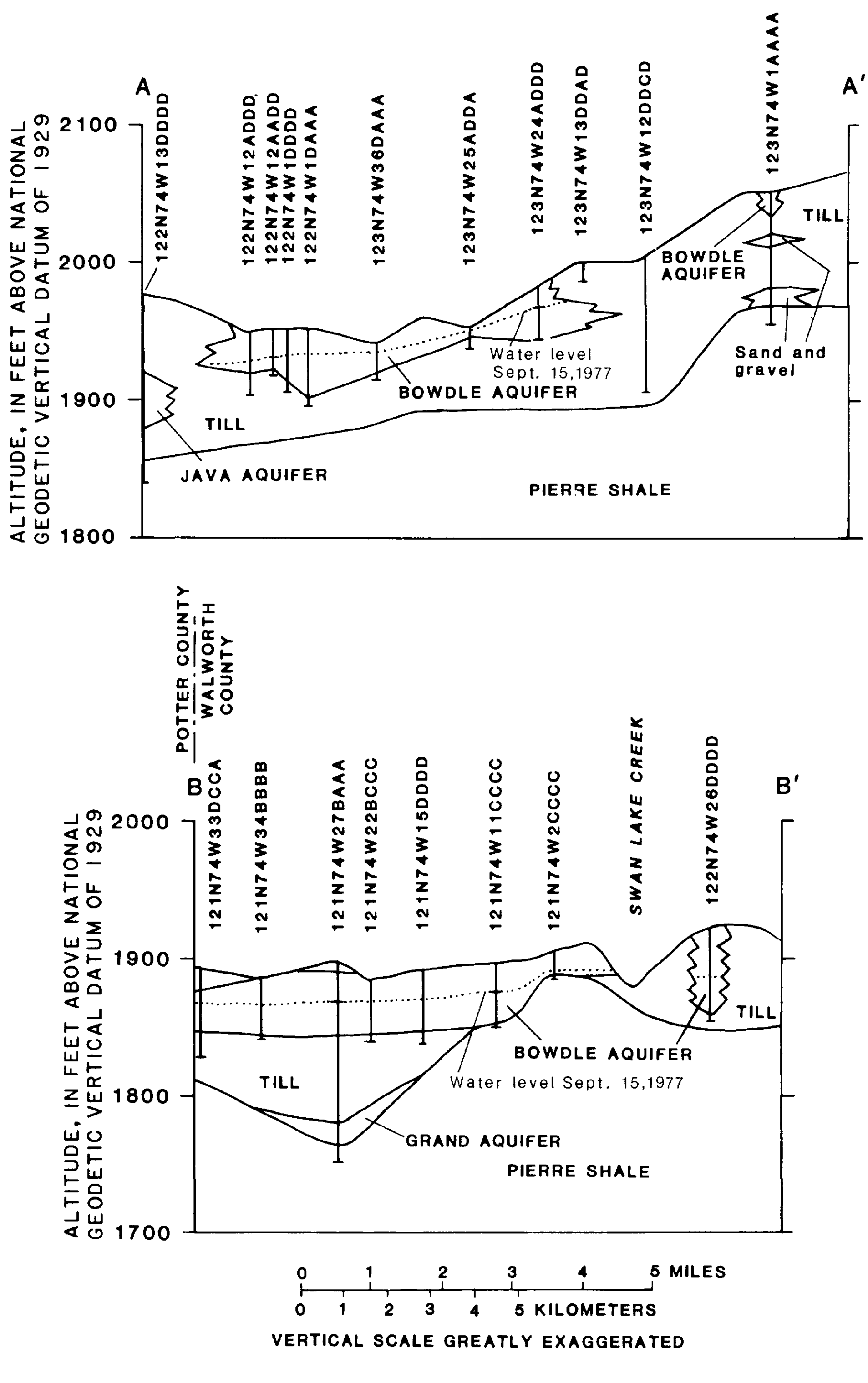


Figure 6.--Geologic sections A-A' and B-B' showing the Bowdle aquifer. Locations of sections are shown in figure 7.

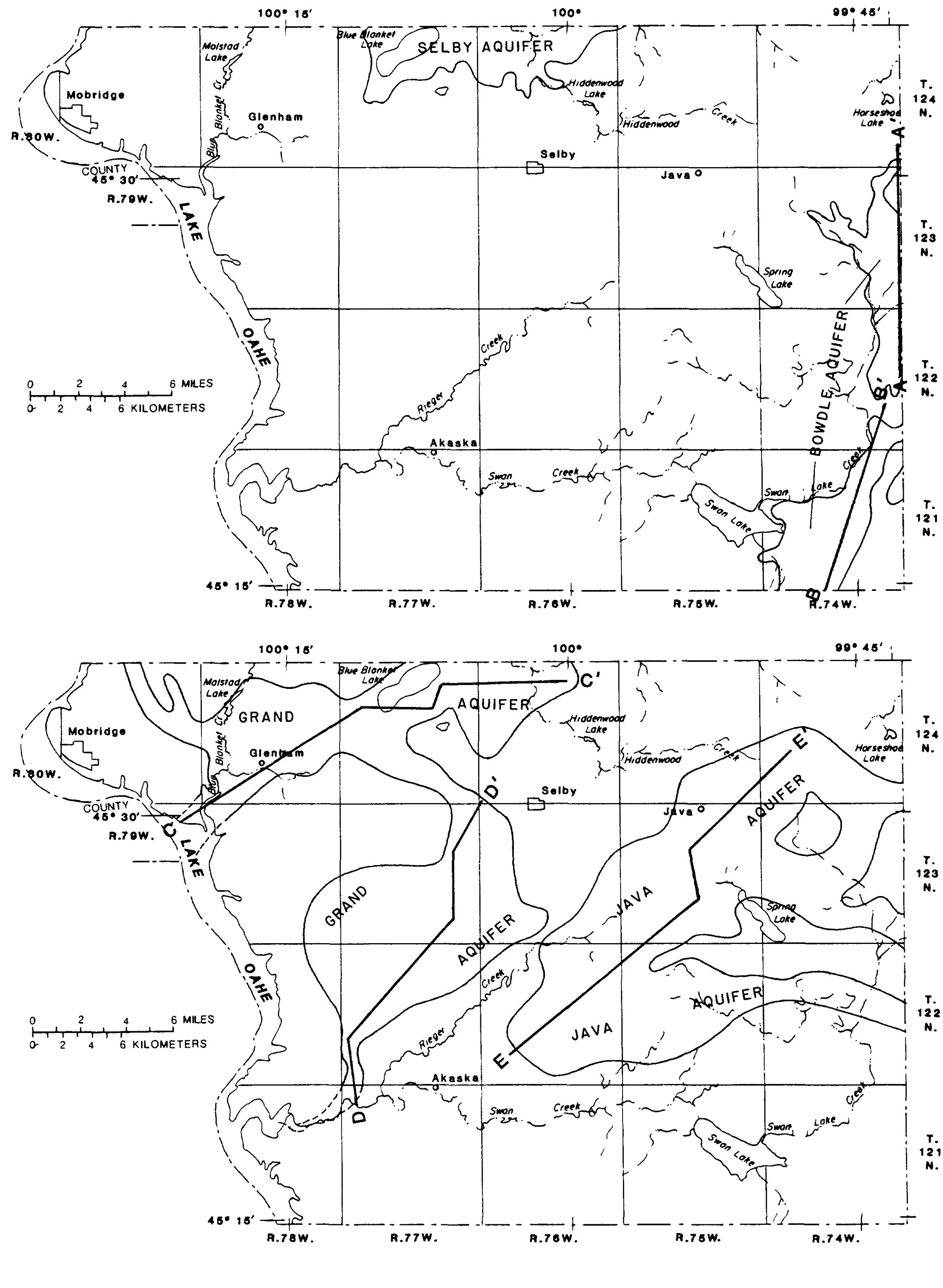


Figure 7.--Locations of geologic sections A-A' to E-E'.

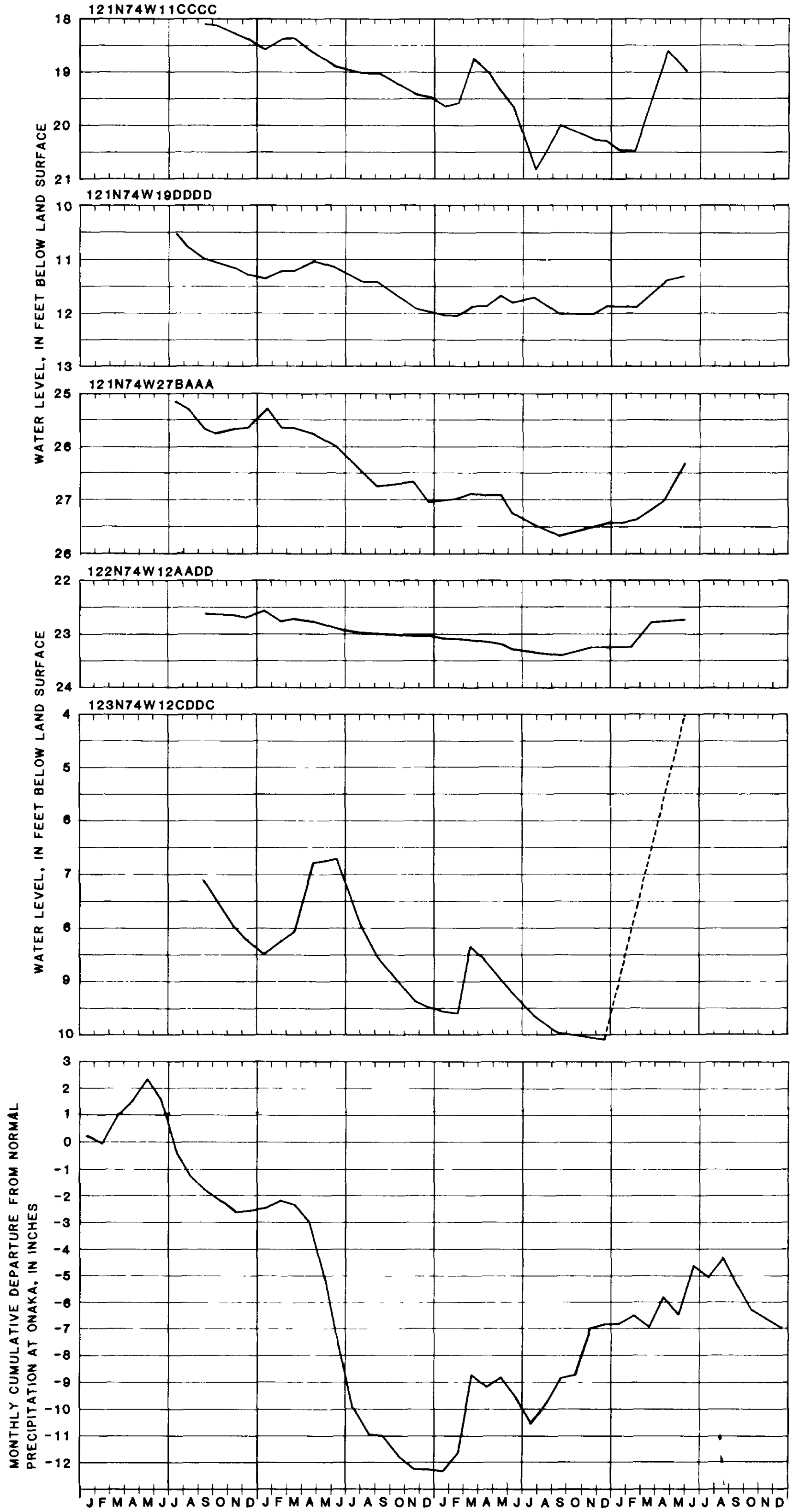


Figure 8.--Water-level fluctuations in wells in the Bowdle aquifer and monthly cumulative departure from normal precipitation at Onaka.

Recharge occurs where the aquifer is exposed at the land surface or is overlain by permeable material. Thus recharge occurs in the northern segment of the aquifer shown in figure 5. Water also moves into the aquifer from its extension in Edmunds County when the water table is higher than in Walworth County. Natural discharge from the northern segment of the aquifer is by evapotranspiration and by ground-water outflow to the aquifer in Edmunds County. Recharge to the southern segment of the aquifer is by infiltration of precipitation also, and by inflow from the aquifer in Edmunds County and Potter County where the water table is higher. Natural discharge from the southern segment of the Bowdle aquifer is by evapotranspiration, which is particularly large near Swan Lake.

Selby aquifer

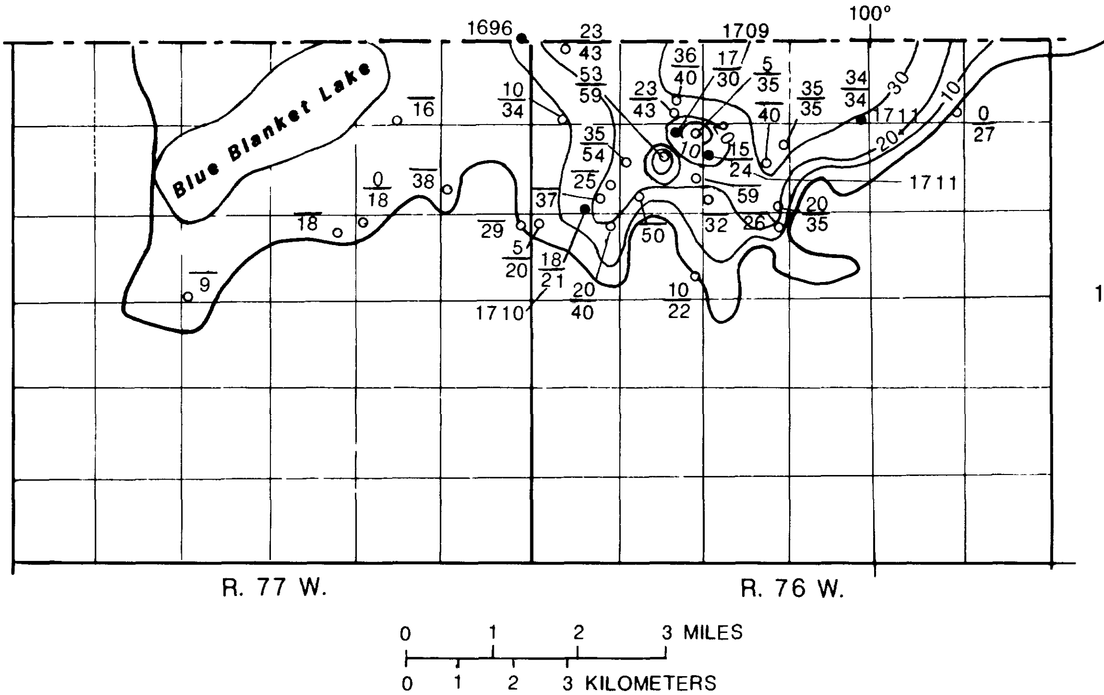
The second major aquifer is the Selby aquifer, named by Koch (1970) during a study of the water resources of Campbell County. The Selby aquifer underlies an area of about 22 mi^2 in north-central Walworth County (fig. 9), 200 mi^2 in southeastern Campbell County (Koch, 1970), and 47 mi^2 in southwestern McPherson County (Hamilton, 1982). In Walworth County the aquifer is composed of fine to coarse sand and gravel. The aquifer is exposed at land surface or is overlain by till, alluvium, or wind-blown material. The aquifer is underlain by till. The saturated thickness of permeable material ranges from 5 to 35 ft and averages about 18 ft (table 4). The geologic section (fig. 10) of the Selby aquifer shows the aquifer thickness, water levels, and overlying and underlying material.

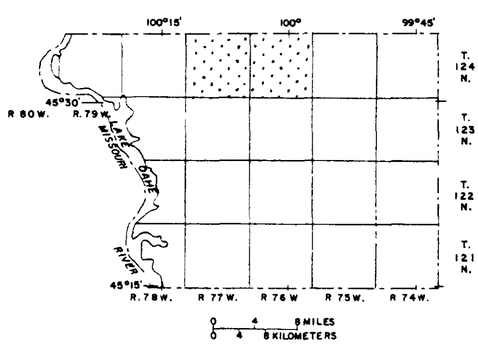
The water level in wells in the Selby aquifer tends to be highest in spring or early summer and lowest in late summer or mid-winter. This cyclic trend is masked by the effects of the drought that began in 1974, as can be seen on the hydrographs of figure 11. Because of the extended drought, water levels and total water stored in the aquifer probably were below the long-term average by 1978.

The altitude of the water table in various wells is shown in figure 9. The general directions of movement of water in the aquifer are to the north into Campbell County and to the west toward Blue Blanket Lake.

In 1961 an aquifer test to determine the transmissivity and specific yield of the aquifer was conducted using Selby public well 124N76W8ACBB. Here the aquifer is 59 ft of sand and gravel, of which 26 ft is coarse sand to gravel. The well was pumped for 24 hours at 333 gal/min; the maximum water-level drawdown was 14.30 ft. Analysis of test data showed that the aquifer transmissivity is about 8,000 ft^2/d and the aquifer has a specific yield of 0.18.

Recharge to the aquifer occurs from precipitation where the aquifer is exposed at the land surface or is overlain by permeable material. Thus recharge occurs throughout much of the extent of the aquifer in Walworth County. In the western part of the aquifer, recharge is by ground-water flow from Campbell County where the water levels are higher. Discharge from the aquifer is by evapotranspiration and, in the eastern half of the aquifer, by ground-water movement to Campbell County. Discharge by evapotranspiration is especially high where the aquifer underlies Blue Blanket Lake.





Location Map

EXPLANATION

o $\frac{18}{21}$ WELL SITE--Upper one or two digit number is the saturated thickness of the aquifer, lower two digit number is total thickness of aquifer

1696 ● OBSERVATION WELL--Four digit number is altitude of water surface in feet, September 15, 1977. National Geodetic Vertical Datum of 1929

——20—— LINE OF EQUAL SATURATED THICKNESS OF AQUIFER--Interval 10 feet

Figure 9.--Extent, thickness, and altitude of water surface of the Selby aquifer.

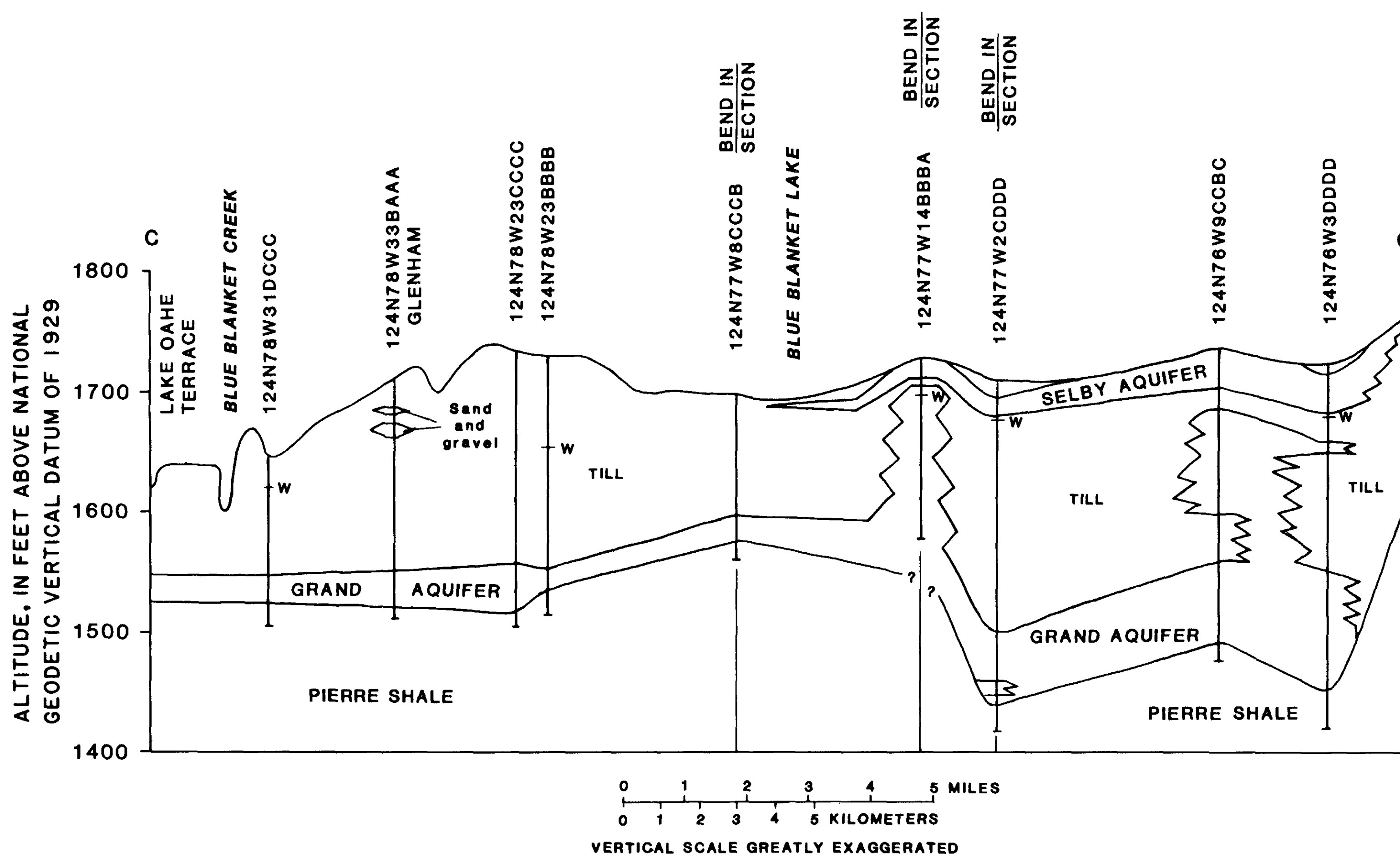


Figure 10.--Geologic section C-C' showing the Selby and Grand aquifers. "W" is water level in well in the Grand aquifer, Sept. 15, 1977. Location of section is shown in figure 7.

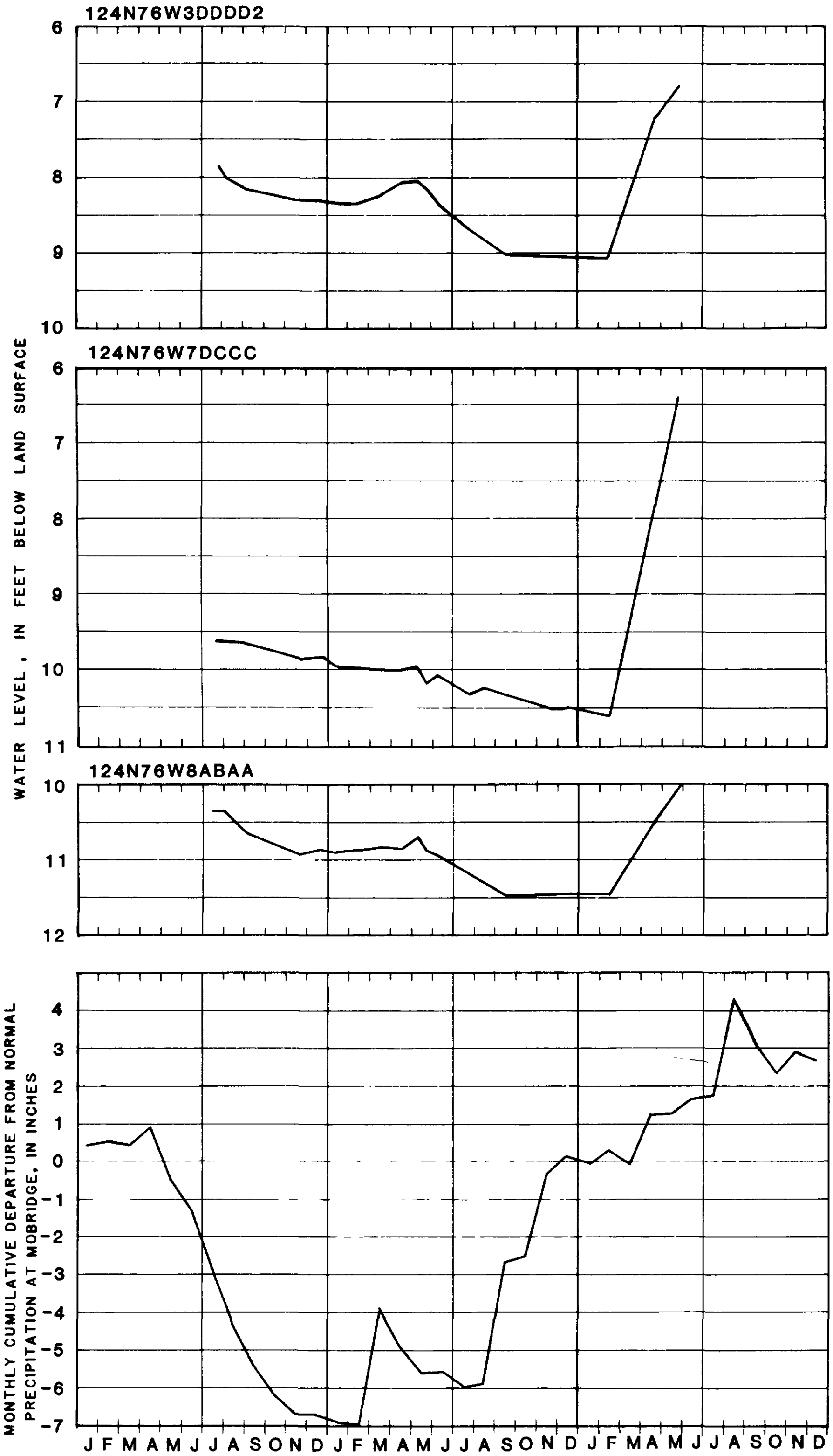


Figure 11.--Water-level fluctuations in wells in the Selby aquifer and monthly cumulative departure from normal precipitation at Mobridge.

Grand aquifer

The Grand aquifer, named by Hamilton (1974, 1982), occupies the channels of the preglacial Grand and Moreau Rivers. The aquifer underlies about 130 mi^2 in western Walworth County, about 160 mi^2 in Campbell County (Koch, 1970), and about 360 mi^2 in McPherson, Edmunds, and Faulk Counties (Hamilton, 1974, 1982).

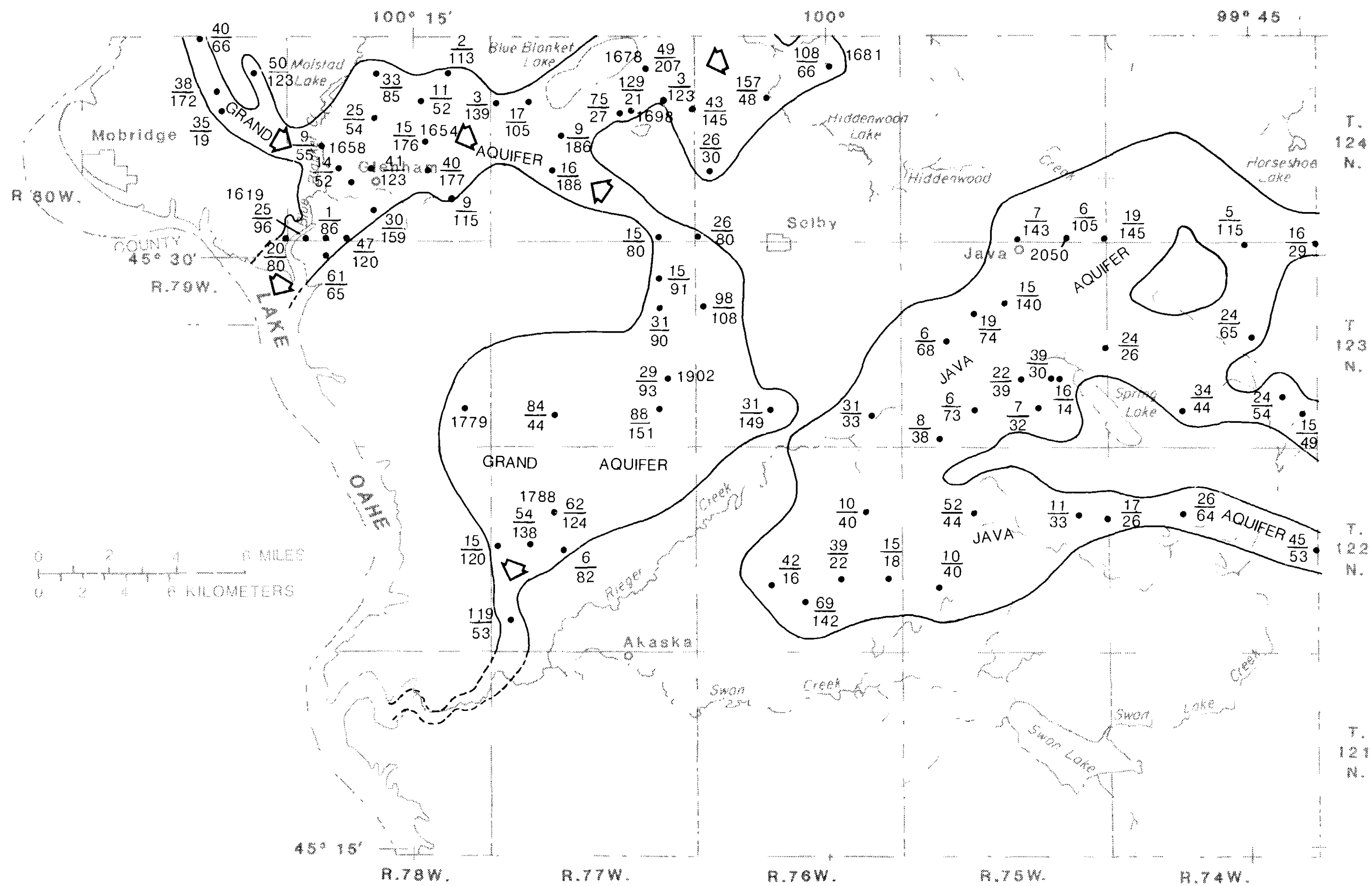
The extent and thickness of the Grand aquifer are shown in figure 12. The relation of the aquifer to the bedrock surface, to the land surface, and to other deposits is shown in the geologic sections of figures 10 and 13. See table 4 for a summary of hydrologic information about the Grand aquifer. The aquifer is underlain by Pierre Shale and till and is overlain by till and alluvium (fig. 10). In Walworth County the Grand aquifer consists of coarse sand and gravel.

Water levels in the Grand aquifer range from 4 to 232 ft below land surface. Annual cyclic trends of water level mentioned in Bowdle and Selby aquifer sections are not noticeable in the observation-well hydrographs shown in figure 14 because: (1) Water moves slowly downward through the thick cover of till to the Grand aquifer and, where the Grand aquifer is overlain by another aquifer, such as the Selby aquifer, movement through the material separating the aquifers is also slow. Water movement through till usually is very slow and may only be a few inches per year. (2) Lateral movement of water within the aquifer is slow. Water moving at a speed of 100 ft per year under natural conditions is considered to be a very fast rate of speed, although pressure (head) changes in an artesian aquifer will travel at much faster speeds. (3) Fluctuations in the level of Lake Oahe cause changes of water level in the Grand aquifer. These fluctuations can be seen by comparing the hydrograph of well 124N78W31DCCC 1.5 mi east of Lake Oahe with the hydrograph for Lake Oahe (fig. 14). This relationship was first described by Koch (1970) in Campbell County where he was able to show that changes of the water level in Lake Oahe could be seen in wells up to 22 mi from Lake Oahe. Now the effect of Lake Oahe water levels on well water levels can be seen only in wells 1 to 5 mi from the reservoir. Koch's investigation was made during the period in which Lake Oahe was filling and the water level in Lake Oahe rose more than 60 ft. Lake Oahe water level varied about 21 ft between 1976 and 1978 which caused a 6-ft variation in the water level in well 124N78W31DCCC.

Water levels in the aquifer respond to changes in precipitation. Nevertheless, wells which are distant from the recharge area, such as wells near Lake Oahe, show less response to variations in precipitation as the distance from the recharge area increases. Variations in man-made discharge obscure the response to precipitation even more. The water-level record in wells is too short to determine the delay between changes in infiltration of precipitation and the resulting water-level fluctuations in the Grand aquifer.

Water in the northwestern segment of the Grand aquifer is moving from the north, near Campbell County, to the southwest, toward Lake Oahe. Water in the Grand aquifer located in central Walworth County is moving from the northwest to the southwest.

Recharge to the Grand aquifer in Walworth County may be by infiltration of precipitation through overlying material and by movement of water from overlying aquifers such as the Selby aquifer in northwestern Walworth County, and the Bowdle aquifer in southeastern Walworth County. But the largest known source of recharge is the flow from the Grand aquifer in Campbell County, which Koch (1970) estimated at 3½ Mgal/d or 3,920 acre-ft/yr. Natural discharge from the aquifer is by ground-water movement to Lake Oahe.



EXPLANATION

1788 • $\frac{62}{124}$ WELL SITE--Upper number is thickness of sand and gravel in feet. Lower number is depth to the top of the aquifer in feet. Four digit number is altitude of water surface, in feet above National Geodetic Vertical Datum of 1929

⇨ DIRECTION OF WATER MOVEMENT

Figure 12.--Thickness of the Grand and Java aquifers and direction of water movement in the Grand aquifer.

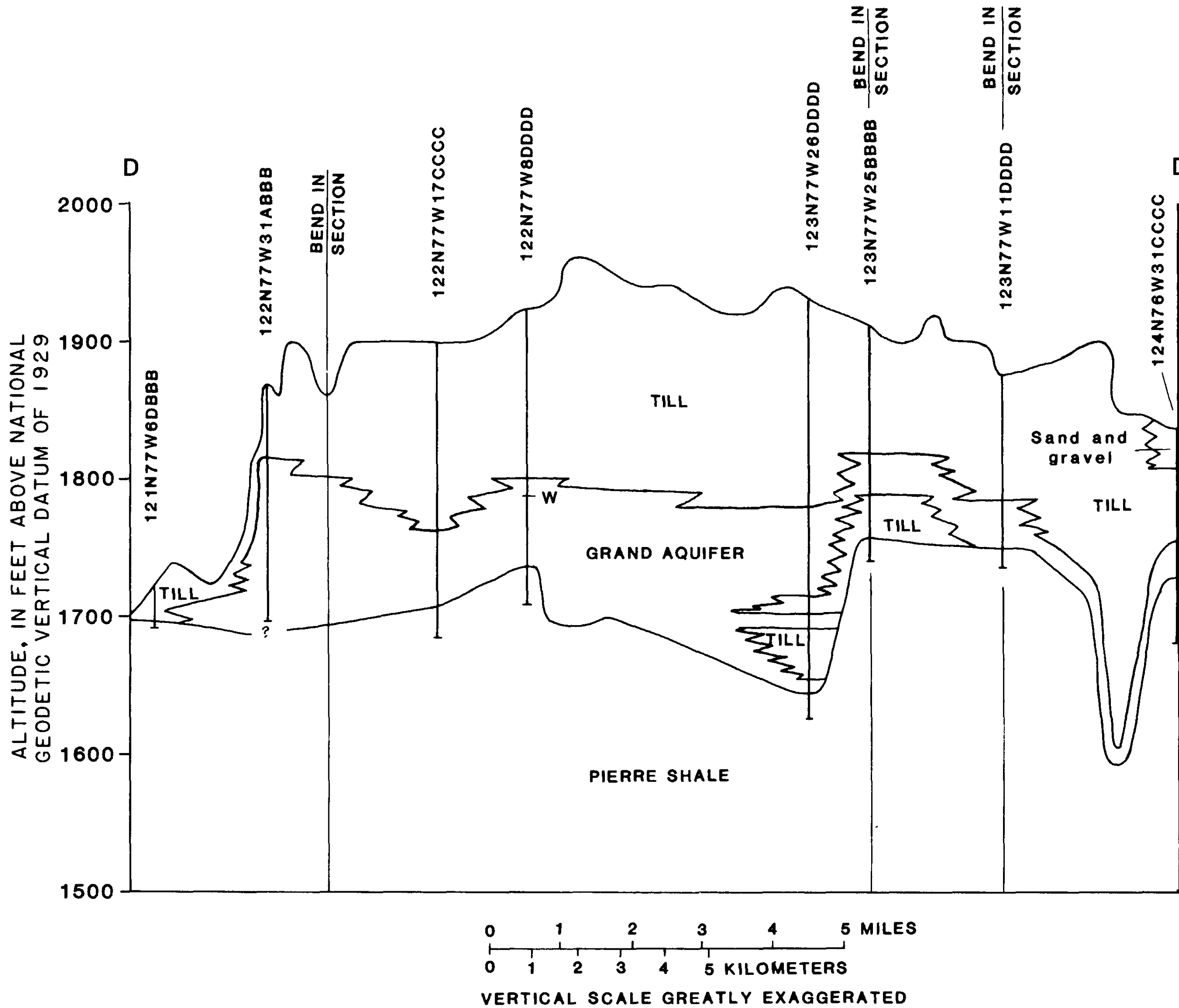


Figure 13.--Geologic section D-D' showing Grand aquifer. "W" is water level in well, Sept. 15, 1977. Location of section is shown in figure 7.

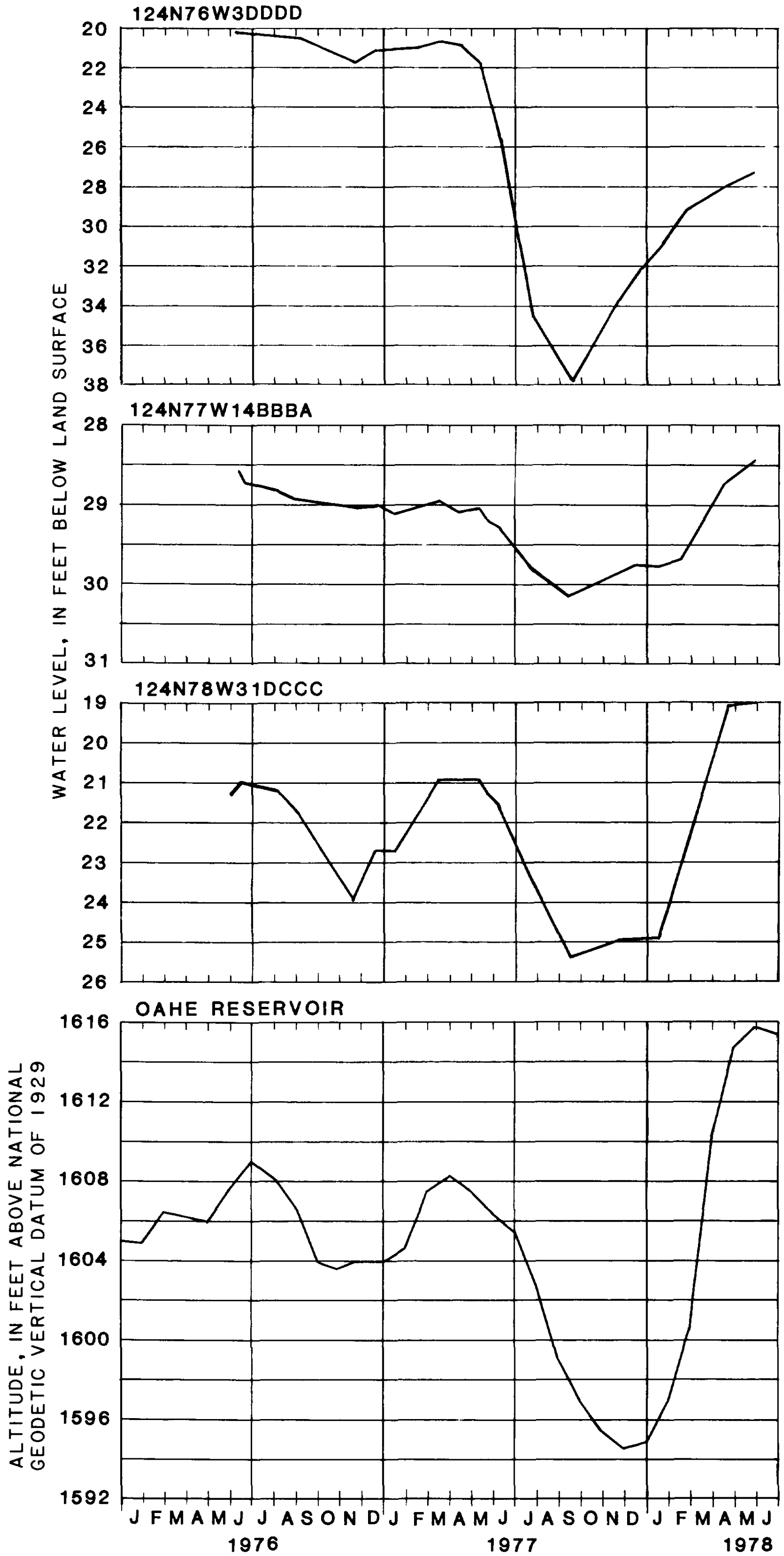


Figure 14.--Water-level fluctuations in wells in the Grand aquifer and the Oahe Reservoir.

Java aquifer

The Java aquifer is a complex group of buried deposits of alluvium and glacial outwash located in east-central Walworth County (fig. 12). This aquifer underlies about 120 mi^2 of the county, and is buried beneath 11 to 174 ft of till or alluvium (fig. 15 and table 4).

Rocks were eroded from the Tertiary (Fort Union) and Late Cretaceous (Hell Creek, Fox Hills, and Pierre Shale) formations in western South Dakota and deposited in flood plains of preglacial or interglacial streams. Most of the deposits shown in figure 15 probably are remnants of flood plains and terraces; explaining why they are draped on high points of bedrock topography. The alluvial material ranges from clay to gravel, but is mostly fine sand to fine gravel. The contacts between the alluvium and outwash appears to be gradational. In some places, these contacts are marked by a bed of tan silt. In other places, the alluvium appears to have been reworked, mixed with outwash, and redeposited.

The Java aquifer complex may have hydrologic continuity throughout much of its extent. These deposits seem to be hydrologically well connected horizontally as well as vertically. Therefore, it is possible that water may be able to move freely between the deposits that make up the Java aquifers.

The Java aquifer is recharged by infiltration of precipitation through poorly permeable overlying material, and the Bowdle aquifer, where it overlies the Java aquifer and where material separating the aquifer is permeable enough to permit the movement of water to the Java aquifer.

Water is discharged from the Java aquifer by evapotranspiration and by an estimated 300,000 gal/min or 340 acre-ft/yr ground-water outflow to Edmunds County.

Minor glacial aquifers

Four minor glacial aquifers in Walworth County are located on a terrace of the Missouri River near Mobridge (see fig. 16), along a tributary to Blue Blanket Creek that stretches eastward through Glenham to about 3 mi east of Selby, along Swan Creek from Lake Oahe to Swan Lake, and a buried outwash deposit in the southeastern corner of the county. The surficial deposits contain many other, smaller deposits of permeable material not hydrologically connected to one of the major aquifers. The combined area of these four aquifers is about 30 mi^2. The deposits of outwash and alluvium range in thickness from 3 to 70 ft with an average of about 15 ft. The saturated thickness ranges from 1 to 30 ft with an average of about 9 ft. The aquifer material ranges from silt to gravel, but generally is fine to coarse sand. Properly constructed wells that tap a minor aquifer obtain yields of 1 to more than 30 gal/min. Water levels in these aquifers range from 2 ft to more than 200 ft below land surface.

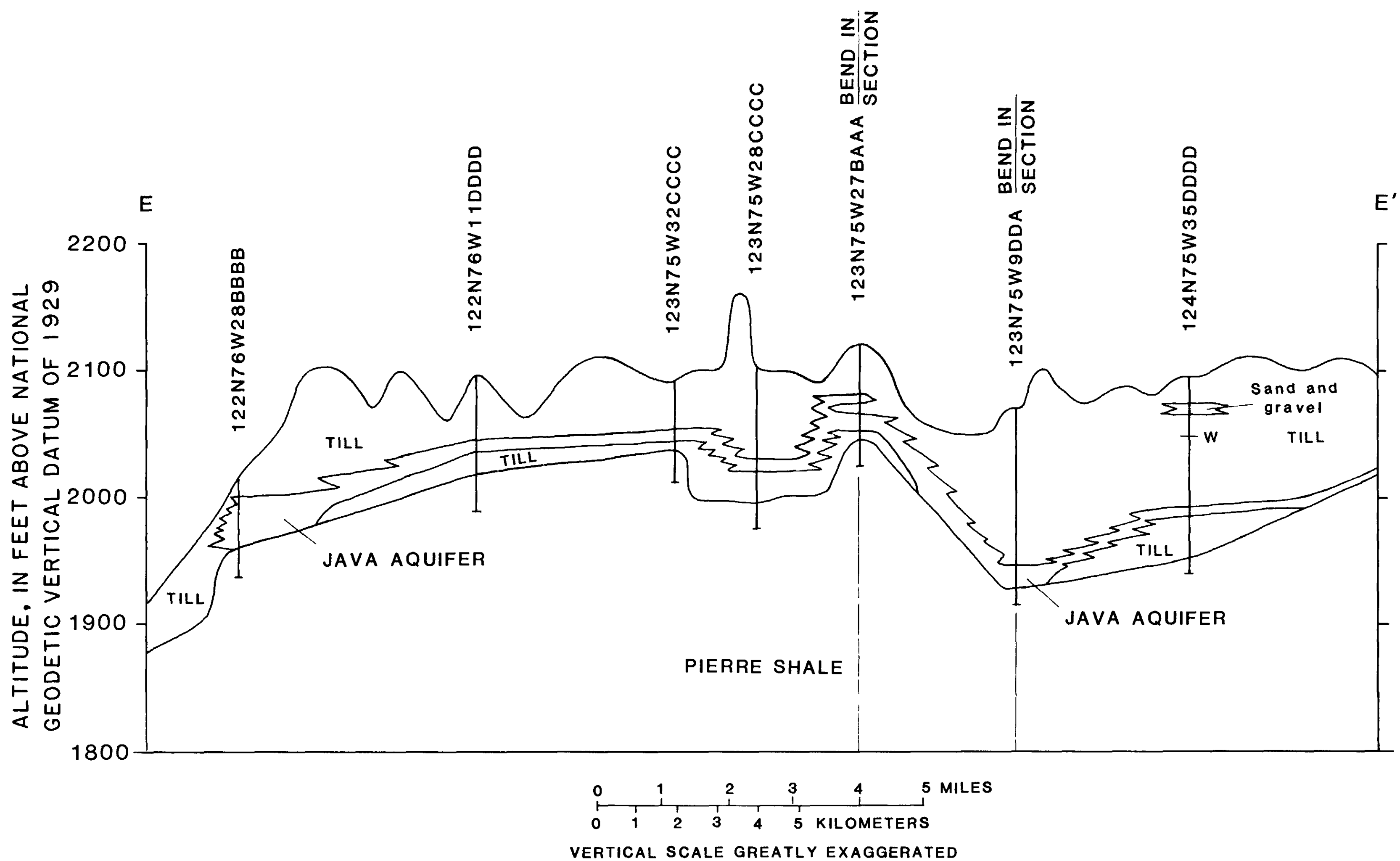
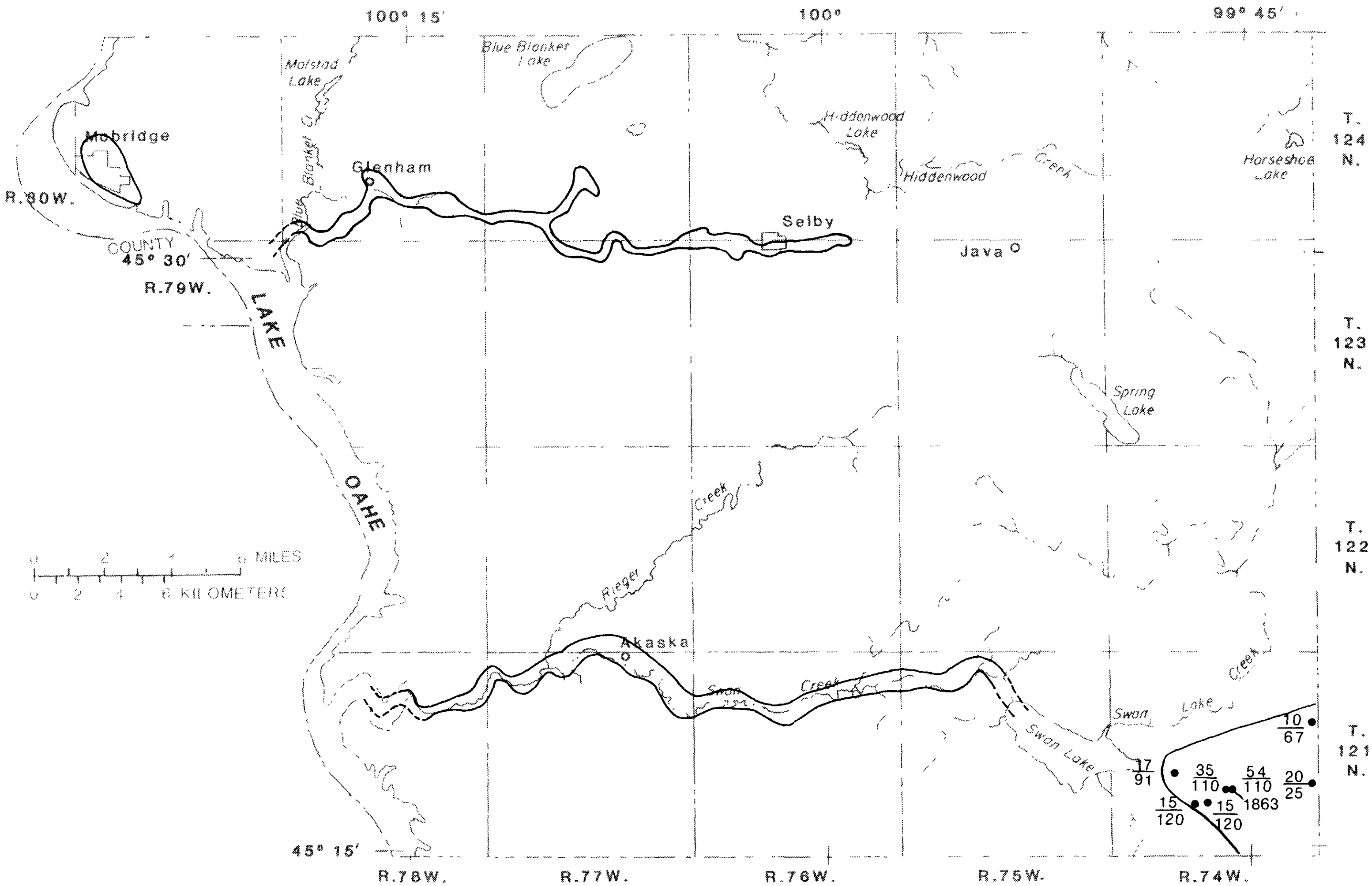


Figure 15.--Geologic section E-E' showing the Java aquifer. "W" is water level in well, Sept. 15, 1977. Location of section is shown in figure 7.



EXPLANATION

• 54/110 1863 WELL SITE--Upper number is thickness of sand and gravel in feet. Lower number is depth to the top of the aquifer in feet. Four digit number is altitude of water surface in feet above National Geodetic Vertical Datum of 1929

Figure 16.--Extent of the four minor aquifers.

Bedrock Aquifers

By Lewis Howells

Information about the bedrock formations and the bedrock aquifers is too scant in Walworth County to permit a useful evaluation. Therefore, all available data for a much larger area (shown in fig. 17) were analyzed to develop the following discussion of the water resources of the bedrock formations.

All of the bedrock formations found in central South Dakota that contain large volumes of recoverable water have good transmissive hydraulic connections with one another somewhere in the state. The Madison Group and overlying rock units are hydraulically connected near the Black Hills and where these formations thin to zero thickness in the central and east-central part of the state. But in much of the state these formations function as separate aquifers even though such connections exist. Some aquifers are assumed to have a good hydraulic connection in the eastern section of Walworth County, but in the western section of the county these aquifers are hydraulically separated. For this report, the Dakota, Inyan Kara, Sundance, Minnelusa, and Madison aquifers are considered to be separate aquifers that locally have good vertical hydraulic connection.

The carbonate aquifers, those composed of dolomite and limestone, include the Madison Group, Devonian formations, Interlake, Stonewall, Stony Mountain, and Red River Formations. Collectively, these units probably form one or two aquifers, however, there is insufficient information to confirm or reject this view. This report therefore treats each of these units as separate aquifers with vertical leakage between them. See table 4 for a summary of hydrologic information for the aquifers.

Dakota aquifer

The first bedrock (or uppermost) aquifer is the sandstone beds of the Dakota Formation (see table 5). The Dakota aquifer underlies the entire county and consists of very fine- to medium-grained, poorly to well cemented sandstone interbedded with dark-colored shale.

In 1978, water levels in wells in the Dakota aquifer ranged from about 90 ft above land surface near Lake Oahe, to more than 450 ft below land surface, near the topographically high areas in the county. The altitude of the potentiometric surface, the altitude water rises in wells, of the Dakota is shown in figure 18.

Water levels in the Dakota aquifer have declined since the early 1880's when the first deep wells were drilled in South Dakota. In Walworth County, the decline in head between 1880 and 1976 is estimated to have been from 50 ft in the northeastern section of the county to 150 ft in the southeastern section of the county to about 300 ft along the western edge of the county. The rate of head decline is much less now than it was in the early years of development. The water level in well 123N78W12BDCC declined about 0.8 ft per year between 1962 and 1978. Observation-well data from Walworth and adjacent counties indicates that the artesian head may be stabilizing and that appreciable further decline in head may not occur unless water withdrawal from the Dakota aquifer is increased significantly.

The Dakota aquifer receives recharge from underlying aquifers (Hamilton, 1982 and Koch, 1980) east and south of Walworth County. Dewatering of adjacent shale beds may have been a source of recharge to the Dakota aquifer before water levels stabilized. Water is discharged from the Dakota aquifer in wells, particularly along the western edge of the county.

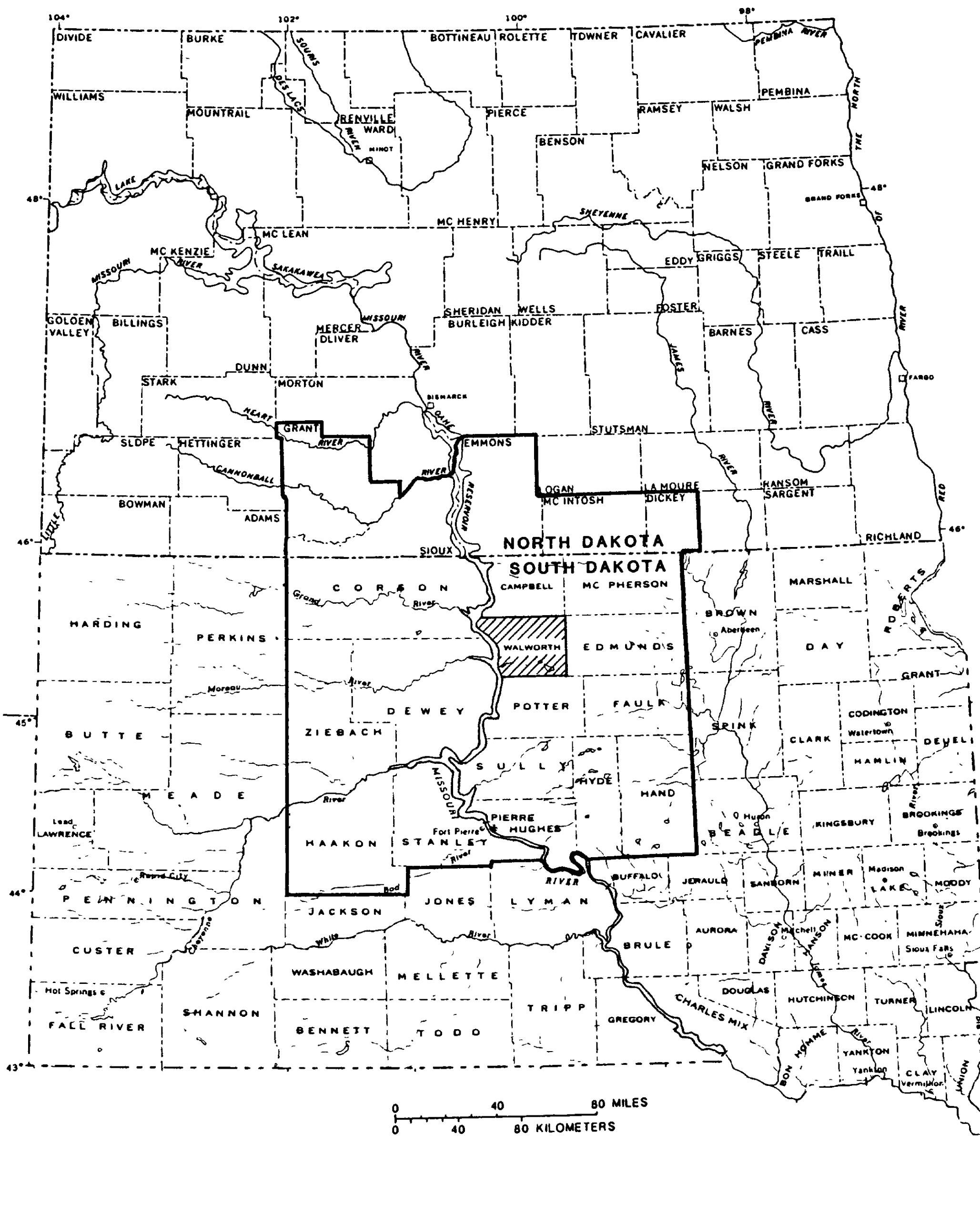
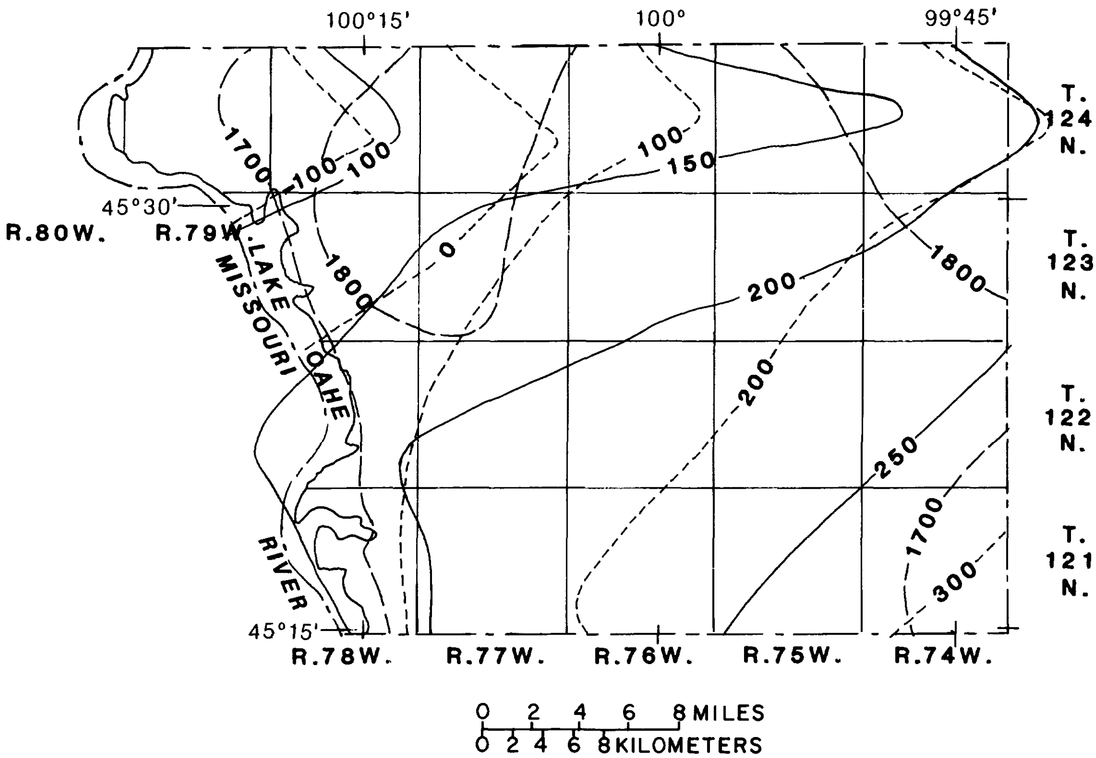


Figure 17.--The area used to interpret the bedrock aquifers in this report.



EXPLANATION

----100--- STRUCTURE CONTOUR--Shows altitude of the top of the Dakota Formation. Contour interval 100 feet. National Geodetic Vertical Datum of 1929

——150—— LINE OF EQUAL THICKNESS OF DAKOTA FORMATION--Interval 50 feet

——1700——GENERALIZED POTENTIOMETRIC CONTOUR--Shows altitude of artesian head in Dakota Formation. National Geodetic Vertical Datum of 1929

Figure 18.--Thickness, potentiometric surface, and structure contour of the top of the Dakota Formation.

Inyan Kara aquifer

The next aquifer below the Dakota is the sandstones and siltstones of the Inyan Kara Group (fig. 19 and table 5). The Inyan Kara Group is separated from the Dakota aquifer by 130 to 150 ft of the relatively impermeable Skull Creek Shale. The Inyan Kara Group underlies the entire county and contains shale beds interbedded with the sandstone and siltstone beds. In Walworth County the Inyan Kara Group probably is represented solely by its uppermost stratigrapic unit, the Fall River Formation, but, as it was not possible during this study to determine that such interpretation is correct, the unit is classified in this report as undifferentiated Inyan Kara Group.

Water-level data for the Inyan Kara aquifer could not be obtained because the wells in the county that tapped the Inyan Kara aquifer also are open to the Sundance aquifer or the Sundance and Minnelusa aquifers. However, it is possible to estimate the water level of the Inyan Kara from water levels measured in wells that are open to the Inyan Kara aquifer. In 1978, water levels in the Inyan Kara aquifer are estimated to have ranged from about 75 ft below land surface in the eastern south-central part of the county to about 600 ft above land surface along the western edge of the county. The altitude of the potentiometric surface ranged from below 2,100 ft above sea level to more than 2,200 ft above sea level.

Water levels in the Inyan Kara aquifer have declined since development of the aquifer. The first well reported to tap the aquifer was drilled in 1901, the second in 1940, and at least thirteen others in 1963 or later. Thus, although development is still in an early stage, the water level is declining at a rapid rate. For example, in well 123N78W3BABA, the water level is dropping about 7 ft/yr. At the current rate of withdrawal, the head loss rate will decrease gradually until a balance is reached between water withdrawal and recharge to the aquifer. If development increases, the rate of decline of the water level will increase, but eventually a balance between water withdrawal and increased recharge or decreased discharge, or both will be achieved. If water withdrawal from the Inyan Kara aquifer continues to increase, the water level will drop below the land surface and wells will have to be pumped.

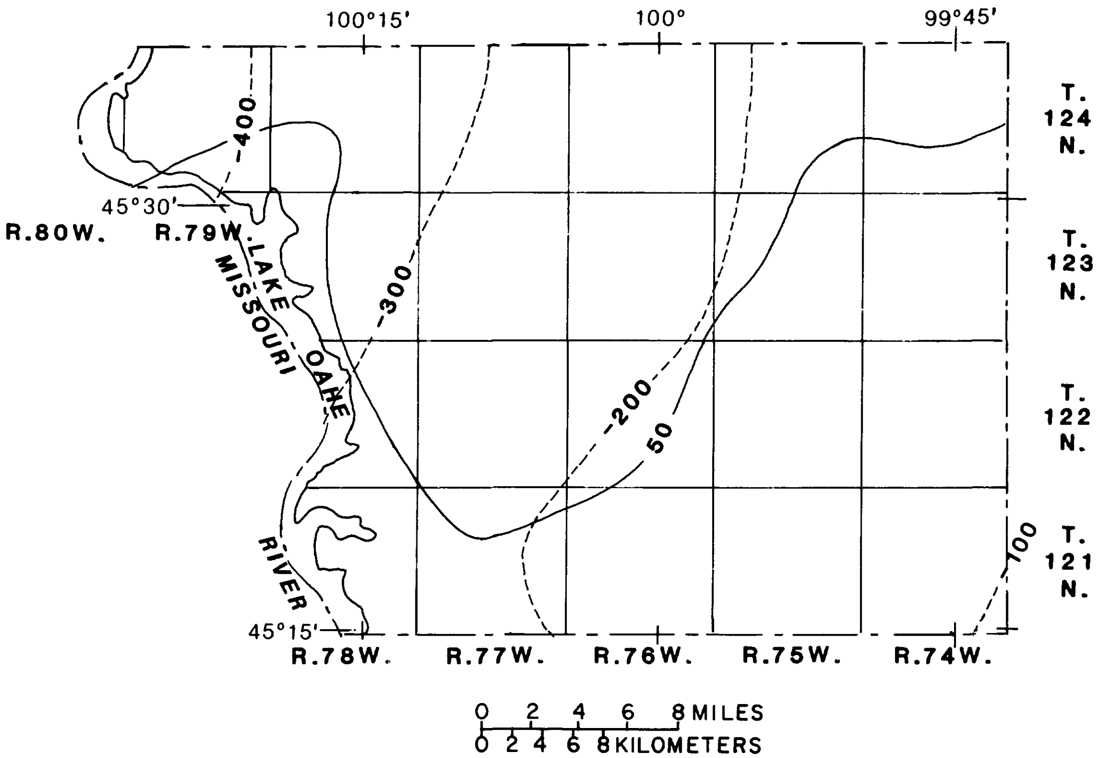
The Inyan Kara aquifer is recharged by the underlying Sundance aquifer and by ground-water movement in the Inyan Kara aquifer from counties west of Walworth County. Water is discharged from the aquifer by pumping wells, by the lateral outflow of ground water toward the northeast, and by flowing wells in counties to the southwest.

Sundance aquifer

The third major aquifer in the bedrock is in the sandstone and siltstone beds of the Sundance Formation (see table 5). The Sundance aquifer underlies the entire county (fig. 20), and is separated from the Inyan Kara aquifer by the relatively impermeable shale beds at the base of the Inyan Kara and in the upper part of the Sundance.

In 1978, the water level in the Sundance ranged from about 75 ft below land surface in the southeastern part of the county to more than 600 ft above land surface along the western edge of the county. The altitude of the potentiometric surface (see fig. 20) ranged from more than 2,200 ft above sea level in about three-quarters of the county to about 2,070 ft above sea level in the eastern south-central part of the county.

Water levels in the Sundance aquifer decline at a rapid rate near pumping or flowing wells because of the recent aquifer development. Although a well deep enough to tap the Sundance aquifer reportedly was drilled in 1928, the first well known to have done so was drilled in 1964. The decline in head is estimated to have averaged 14 ft/yr between 1964 and 1976 in the deepest cone of depression in the county (see fig. 20).

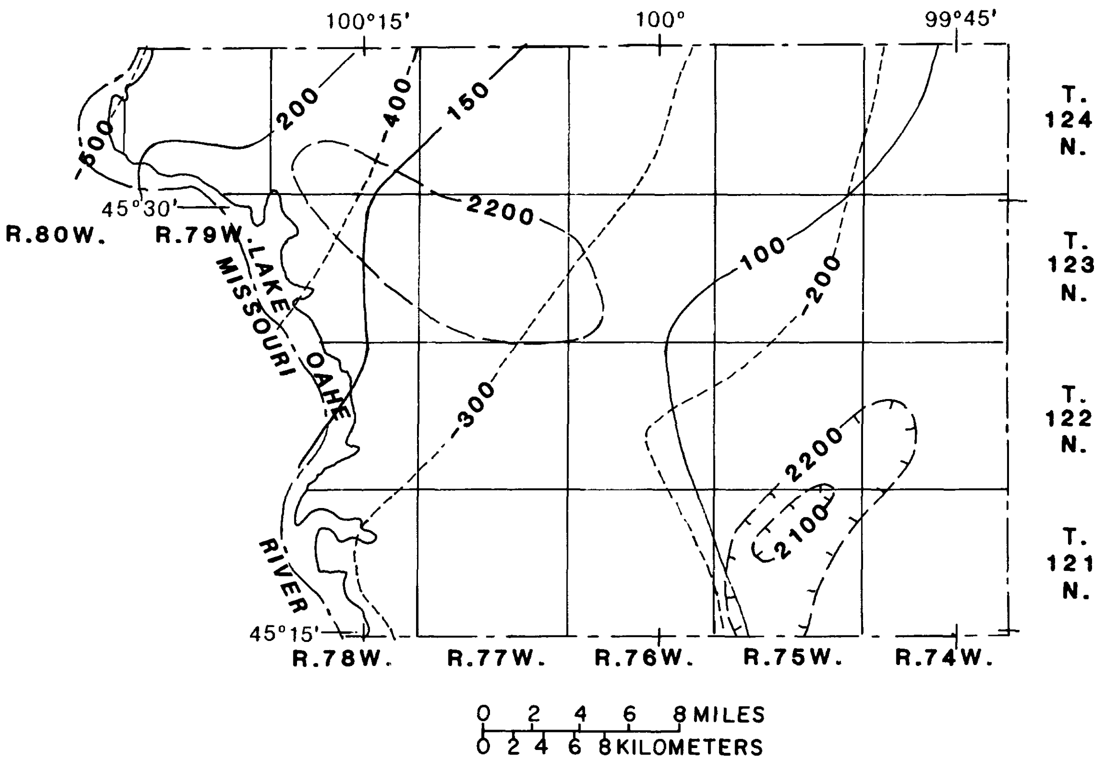


EXPLANATION

- - - -400 - - - STRUCTURE CONTOUR--Shows altitude of the top of the Inyan Kara Group. Interval 100 feet. National Geodetic Vertical Datum of 1929

——— 50 ——— LINE OF EQUAL THICKNESS OF THE INYAN KARA GROUP--Interval 50 feet

Figure 19.--Thickness and structure contour of the top of the Inyan Kara Group.



EXPLANATION

----400--- STRUCTURE CONTOUR--Shows altitude of the top of the Sundance Formation. Interval 100 feet. National Geodetic Vertical Datum of 1929

——150—— LINE OF EQUAL THICKNESS OF THE SUNDANCE FORMATION--Interval 50 feet

— — 2200 — GENERALIZED POTENTIOMETRIC CONTOUR--Shows altitude of artesian head in the Sundance Formation. Interval 100 feet. National Geodetic Vertical Datum of 1929

Figure 20.--Thickness, potentiometric surface, and structure contour of the top of the Sundance Formation.

Recharge to the Sundance aquifer in Walworth County probably comes from the underlying Minnelusa aquifer and from lateral inflow to the Sundance aquifer from counties to the north, west, and south. Water is discharged from the aquifer by pumping wells and flowing wells in Walworth County, by lateral outflow to the northeast, and by flowing wells in Potter County.

Minnelusa aquifer

The fourth aquifer in the bedrock is in the sandstone and siltstone beds, and possibly the limestone and dolomite beds, of the Minnelusa Formation (see table 5). This aquifer underlies the entire county (fig. 21) and, in some parts of the county, is separated from the Sundance aquifer by shale beds at the base of the Sundance and in the upper Minnelusa.

In 1978, the water level in the Minnelusa ranged from about 150 ft above land surface at topographically high points in the county to more than 900 ft above land surface in the northwestern corner of the county. The altitude of the potentiometric surface (fig. 21) ranged from about 2,110 ft above sea level in a local cone of depression in the northwestern part of the county to more than 2,500 ft in the northern part of the county.

The water level in the Minnelusa is declining at a fairly rapid rate near pumping and flowing wells because the aquifer has been developed recently and most of the water pumped is derived from artesian storage. In the deepest cone of depression in the county (see fig. 21), the decline in head averaged about 31 ft/yr between 1964 and 1976.

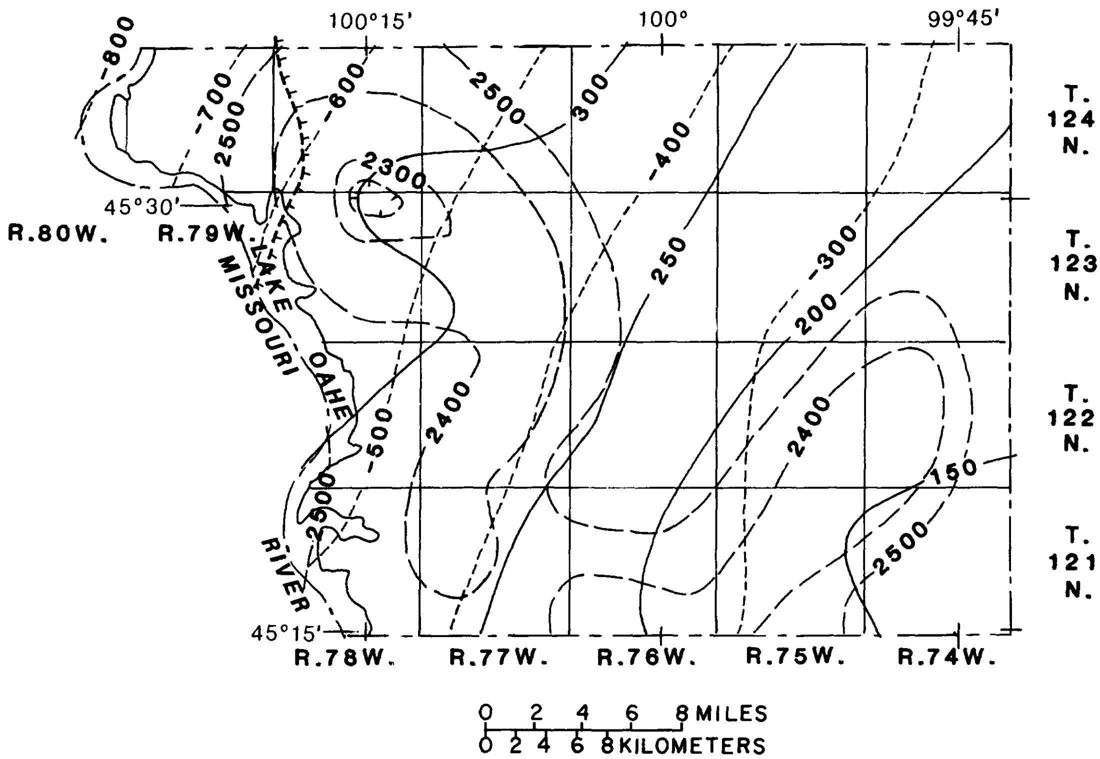
The Minnelusa aquifer is recharged by the underlying Madison aquifer and by lateral inflow in the Minnelusa aquifer from counties to the north and west, and, possibly, from northern Potter County. Discharge from the aquifer is by pumping and flowing wells, by lateral outflow to the east, and by flowing wells in Potter County.

Madison aquifer

The fifth, and probably most important, bedrock aquifer is in solution channels and fractures in the dolomite and limestone beds in the Madison Group (table 5). This aquifer underlies the entire county (fig. 22), and in some areas may be separated from the Minnelusa aquifer by relatively impermeable shale beds at the base of the Minnelusa and shale evaporite (salt, anhydrite or gypsum), and possibly some relatively impermeable limestone beds at the top of the Madison Group.

The Madison aquifer is not only important because of its large areal extent, thickness (fig. 22), storage volume, and high well yields, but also because the Madison aquifer has a high transmissivity. The travel time of water from the recharge area in the Black Hills to Walworth County is estimated as about 35,000 years or 45 ft/yr. This is an unusually high speed for ground-water flow.

There is not sufficient information to estimate the declines in the water levels in the Madison aquifer. Two wells have been reported to penetrate the Madison aquifer, but there is some doubt whether the Madison aquifer contributes water to either well. The Madison aquifer recharges the overlying Minnelusa aquifer where they are directly in contact. Water is discharged from the Madison aquifer in Walworth County by lateral outflow to the east and vertically to the Minnelusa aquifer.



EXPLANATION

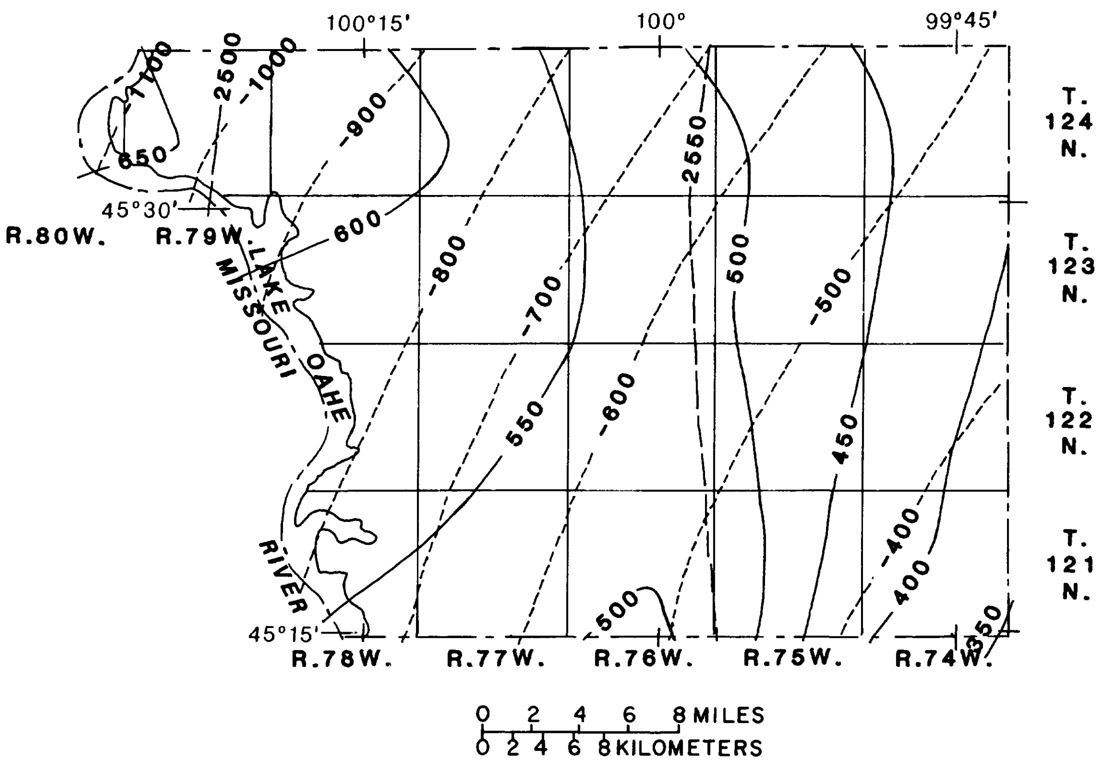
- - - -600- - - STRUCTURE CONTOUR--Shows altitude of the top of the Minnelusa Formation. Interval 100 feet. National Geodetic Vertical Datum of 1929

——250—— LINE OF EQUAL THICKNESS OF THE MINNELUSA FORMATION--Interval 50 feet

— —·2400— GENERALIZED POTENTIOMETRIC CONTOUR--Shows altitude of artesian head in the Minnelusa Formation. Interval 100 feet. National Geodetic Vertical Datum 1929

⊥⊥⊥⊥⊥⊥⊥ APPROXIMATE EASTERN LIMIT OF THE PIPER FORMATION

Figure 21.--Thickness, potentiometric surface, and structure contour of the top of the Minnelusa Formation.



EXPLANATION

--- -700--- STRUCTURE CONTOUR--Shows altitude of the top of the Madison Group. Interval 100 feet. National Geodetic Vertical Datum of 1929

——500—— LINE OF EQUAL THICKNESS OF THE MADISON GROUP--Interval 50 feet

—— — 2500 — GENERALIZED POTENTIOMETRIC CONTOUR--Shows altitude of the artesian head in the Madison Group. Interval 50 feet. National Geodetic Vertical Datum of 1929

Figure 22.--Thickness, potentiometric surface, and structure contour of the top of the Madison Group.

Devonian aquifer

The dolomite and limestone beds of the Birdbear and Duperow Formations of Devonian age (see table 5) are aquifers. These major aquifers are important because they permit water to move vertically to the overlying Madison aquifer from the underlying Red River aquifer. Devonian beds underlie all of the county (fig. 23). However, some oil test holes in western South Dakota and adjacent states show that the solution channels and fractures in the Birdbear and Duperow Formations had been filled by calcite and anhydrite. Also, shale, shaly siltstone and sandstone, and evaporite beds in the overlying Three Forks Formation may be a relatively impermeable barrier to the upward movement of water.

The Devonian aquifer is possibly recharged by the underlying Stony Mountain and Red River aquifers. Discharge from the aquifer is probably to the overlying Madison aquifer. Lateral flow in the aquifer is from the west to the east.

Stony Mountain aquifer

The Stony Mountain Formation contains a minor aquifer where it occurs in north-central and western Walworth County (see fig. 24; table 5). Carbonate rocks, sandstone, and siltstone make up the aquifer, and the shale, shaly siltstone, and shaly sandstone beds act as a barrier to the vertical movement of water to the Stony Mountain and underlying Red River aquifers.

The Stony Mountain aquifer is recharged by lateral flow from the west, by the overlying Devonian aquifer when Devonian aquifer water level is lower than the Stony Mountain aquifer water level and shale beds between aquifer are absent, and by the underlying Red River aquifer when Red River aquifer water levels are higher than Stony Mountain water levels and shale beds between aquifers are absent.

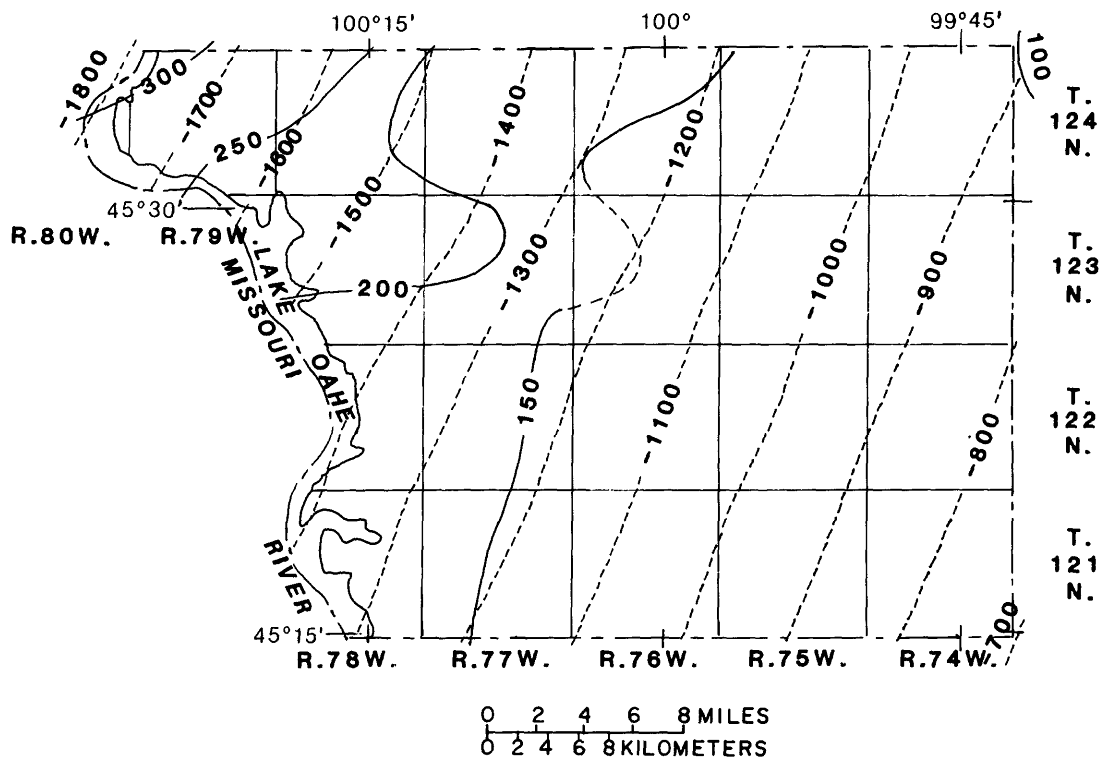
Water is discharged from the Stony Mountain aquifer in Walworth County either to the overlying Devonian and Madison aquifers or to the underlying Red River aquifer.

Red River aquifer

The seventh major aquifer in the bedrock in Walworth County is in the fractures and solution channels of the dolomite and limestone beds in the Red River Formation (see table 5) which underlies the entire county (fig. 24). East of the Stony Mountain aquifer pinchout (fig. 24), the Madison aquifer is in contact with the Red River aquifer.

Little information is available about the water level in the Red River aquifer; however, it is at least as high as that in the Madison aquifer and may be somewhat higher. Artesian head in the aquifer is at least 2,500 ft above sea level and in the western part of the county may be about 2,600 ft. If any decline in water level has occurred in the last century, it would have been induced by declines in the water level in the Madison in Walworth and adjacent counties and in the Minnelusa and higher aquifers to the east and southeast of Walworth County. These are areas where the Madison and Devonian aquifers are missing and the Minnelusa or a higher aquifer directly overlies the aquifer in the Red River Formation.

Recharge to the Red River aquifer in Walworth County is by lateral inflow from the west and possibly by inflow from the overlying Stony Mountain or Devonian aquifers if the artesian pressure in the Red River locally is lower than the artesian pressure in the overlying aquifers.

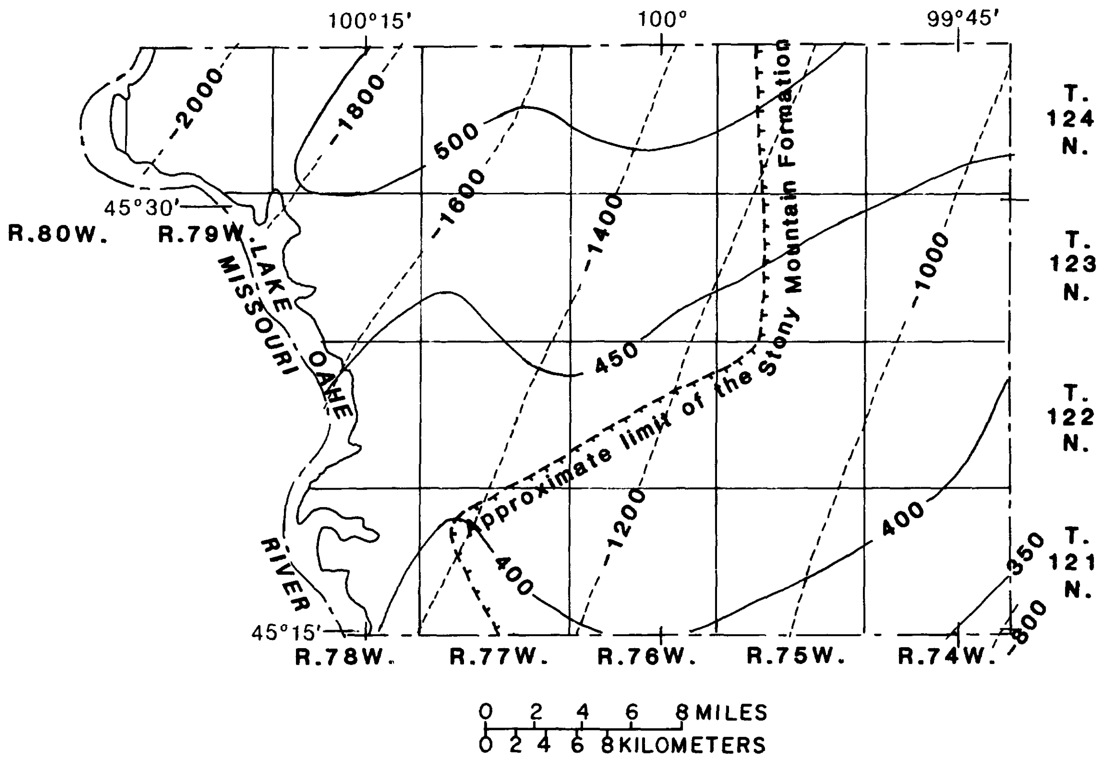


EXPLANATION

---- -800 --- STRUCTURE CONTOUR--Shows altitude of the top of strata of Devoninan age. Interval 100 feet. National Geodetic Vertical Datum of 1929

—— 200 —— LINE OF EQUAL THICKNESS OF DEVONIAN ROCKS--Interval 50 feet

Figure 23.--Thickness and structure contour of the top of the Devonian rocks.



EXPLANATION

- - - - -1400- - - STRUCTURE CONTOUR--Shows altitude of the top of the Red River Formation. Interval 200 feet. National Geodetic Vertical Datum of 1929

——500—— LINE OF EQUAL THICKNESS OF THE RED RIVER FORMATION--Interval 50 feet

Figure 24.--Thickness and structure contour of the top of the Red River Formation.

Discharge from the Red River is by lateral outflow to the east and to the overlying Stony Mountain and Devonian aquifers where the artesian pressure in the Red River is higher than that in the overlying aquifers and where shale or shaly beds do not prevent the vertical movement of water.

Deadwood aquifer

The eighth and deepest major bedrock aquifer is the siltstone, sandstone, and conglomerate beds in the Deadwood Formation. The Deadwood aquifer is separated from the Red River aquifer by 105 to 145 ft of relatively impermeable shale in the Winnipeg Formation (fig. 25). The Deadwood aquifer underlies the entire county (fig. 26). The aquifer is absent 5 to 8 mi south of Walworth County, but apparently extends 35 to 45 mi east of the county.

Very little information is available about the water level in the Deadwood aquifer; however, it is believed to be as high as that in the Red River aquifer or possibly higher. Artesian head in the aquifer is at least 2,500 ft above sea level and in the western part of the county, may be above 2,600 ft. The only wells known to tap the Deadwood aquifer are in the Black Hills and one well in eastern North Dakota. The aquifer is separated from the overlying Red River aquifer by shale in the Winnipeg Formation so it is unlikely that a decline in the Deadwood aquifer water level has occurred as a result of the decline in artesian head in the other bedrock aquifers.

Recharge to the Deadwood aquifer occurs at its outcrop in and near the Black Hills, and in southwestern and south-central South Dakota where the Madison, Devonian, or Red River aquifers overlie the Deadwood aquifer. Therefore, in Walworth County, the Deadwood probably receives recharge only by lateral inflow from the west.

The Deadwood aquifer is underlain by crystalline Precambrian rocks. Except for local fractures, these rocks can neither yield nor accept water. Therefore, the Precambrian surface (fig. 27) is the base (or bottom) for possible aquifers.

Discharge from the Deadwood aquifer in or near Walworth County may be small. The Winnipeg Formation shale permits little, if any, vertical discharge of water to overlying aquifers, and extends beyond the Deadwood aquifer pinchout in east-central South Dakota. The only known conduit for the movement of water from the Deadwood to overlying aquifers is "quartzite wash" or "granite wash," deposits of sand- to pebble-sized material eroded from Precambrian rocks and deposited on the Precambrian surface. These deposits can be a major conduit for transmission of water upward because they are in physical and hydraulic contact with other aquifers where these aquifers pinch out against the Precambrian surface.

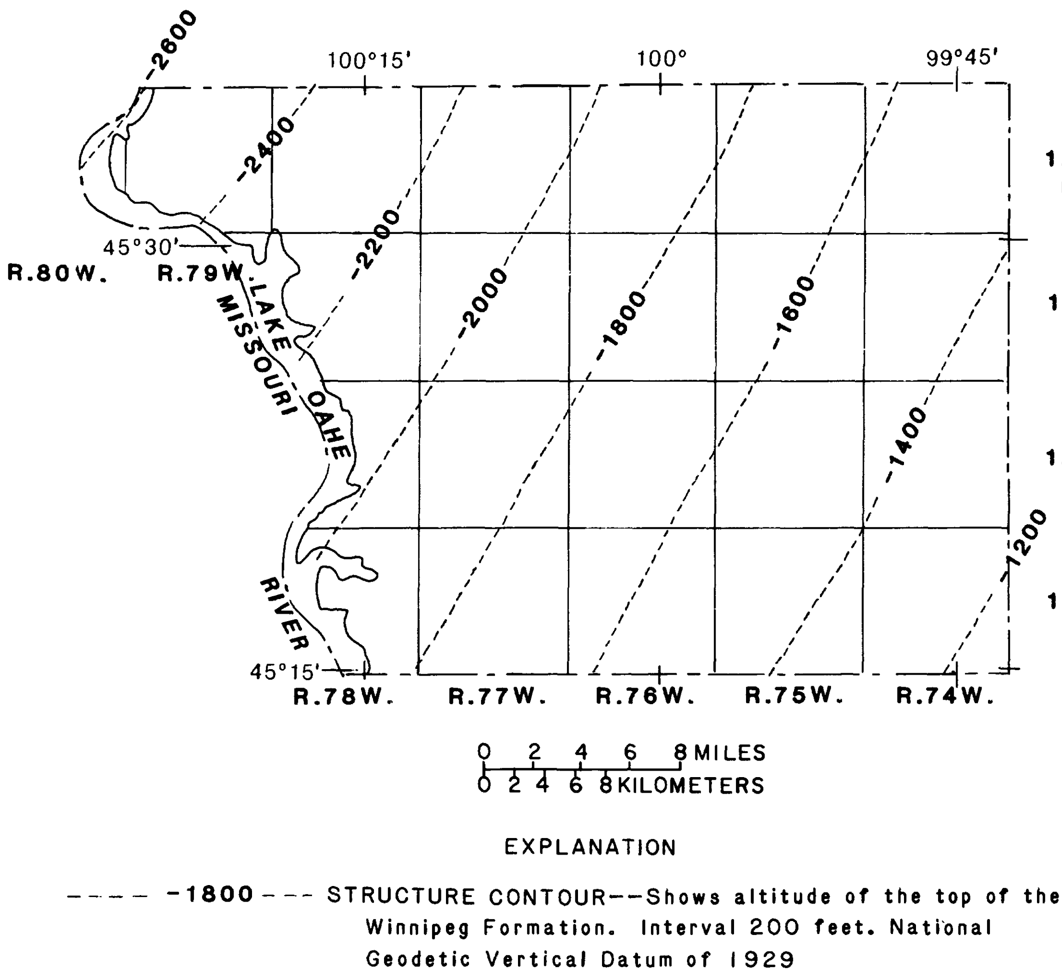
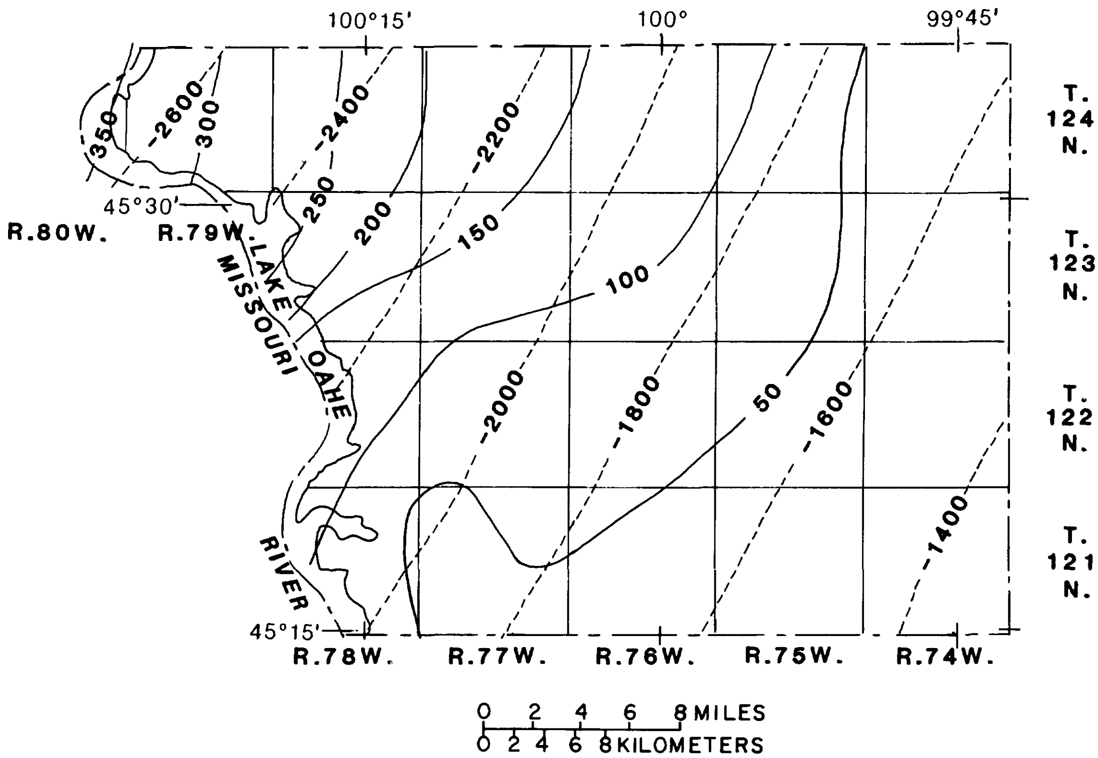


Figure 25.--Structure contour of the top of the Winnipeg Formation.

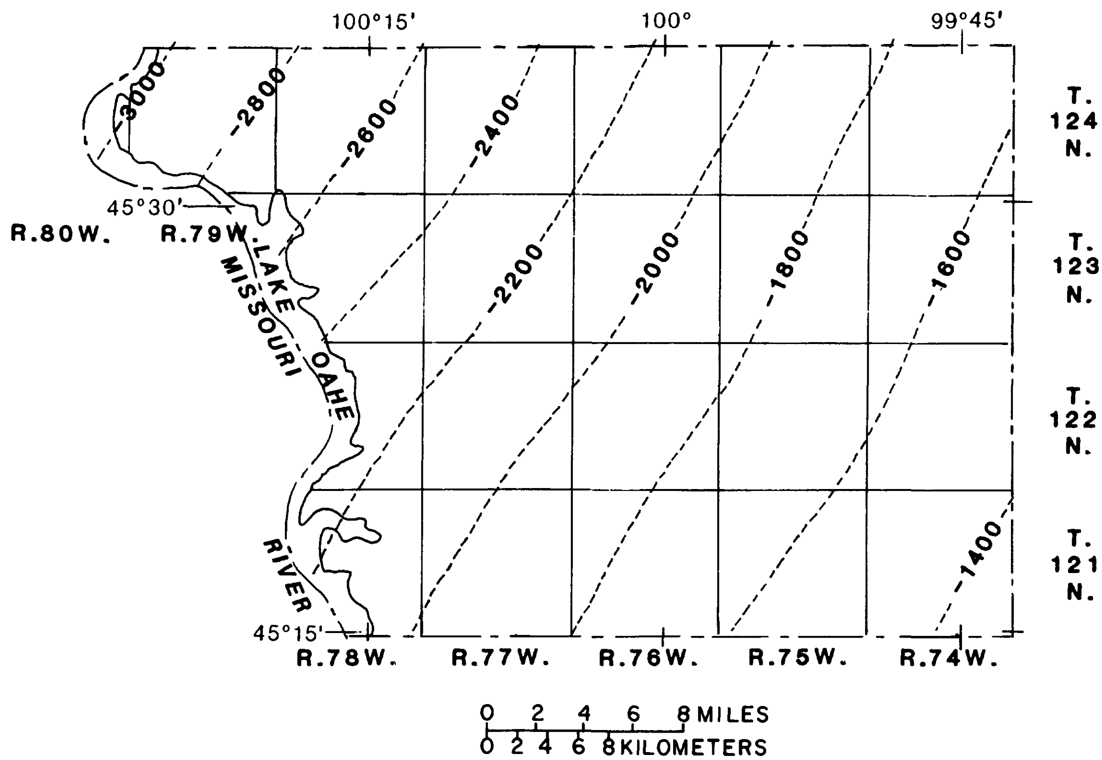


EXPLANATION

- - - - -1800 - - - STRUCTURE CONTOUR--Shows altitude of the top of the Deadwood Formation. Interval 200 feet. National Geodetic Vertical Datum of 1929

——— 100 ——— LINE OF EQUAL THICKNESS OF THE DEADWOOD FORMATION--Interval 50 feet

Figure 26.--Thickness and structure contour of the top of the Deadwood Formation.



EXPLANATION

----- -2400 --- STRUCTURE CONTOUR--Shows altitude of the Precambrian surface. Interval 200 feet. National Geodetic Vertical Datum of 1929

Figure 27.--Structure contour of the Precambrian surface.

Water Quality

The standards for municipal water supplies are set by the U.S. Environmental Protection Agency (1976, 1979). These standards contain both mandatory and recommended limits for dissolved or suspended materials in drinking water. Some of these standards are shown in table 6, which summarizes the significance of the more important chemical and physical properties of water. Representative chemical analyses of surface and ground water from Walworth County are shown in table 7.

Water used by livestock is subject to quality limitations of the same type as those relating to the quality of drinking water for human consumption. Livestock can, however, generally tolerate a greater amount of dissolved solids in their water than can humans.

The factors that determine the suitability of water for irrigation are its dissolved-solids concentration, boron concentration, the concentration of calcium and magnesium relative to the concentration of sodium, and the chemical changes that may take place in the soil and water after the water has been applied.

High concentrations of dissolved solids in irrigation water may adversely affect plant growth. The tolerances of crops to the amount of dissolved solids varies widely, and can vary for the same crop variety depending upon such factors as temperature, soil type, soil fertility, subsoil permeability, and rainfall (U.S. Salinity Laboratory Staff, 1954).

Sodium hazard is a measure of the capacity of irrigation water to replace exchangeable calcium and magnesium ions with sodium ions. The sodium hazard is expressed in either of two ways: as percent sodium (%Na) or as sodium-adsorption ratio (SAR). Soil that has a high content of exchangeable sodium is undesirable for agriculture because it tends to develop a hard crust, and to become nearly impermeable to water. This may result when the percent sodium in irrigation water rises considerably above 50 (Wilcox, 1949). The salinity hazard and sodium hazard classification of representative samples of water from the various aquifers is shown in figure 28.

Surface Water Quality

The system of large reservoirs on the Missouri River has stabilized the quality of the river water to a year-round average of about 450 mg/L (milligrams per liter) dissolved solids. The water quality of streams, stock ponds, and dugouts, however, varies greatly during the year. Water quality is best in spring during snowmelt and is poorest in late summer or fall when pools and ponds usually have been stagnant for several months. During the occasional runoffs that may occur during a drought or during the early runoff period following a drought, the water from streams may be more saline and may carry much larger concentrations of some constituents such as nitrate.

Water in Lake Oahe is fresh, very hard, low in sodium hazard, low in boron, and is suitable for livestock, irrigation use, and domestic and public supplies.

Only two lakes in the county, Hiddenwood and Molestad, were sampled for this study. Most of the other lakes, ponds, and reservoirs were dry or very low and muddy. Hiddenwood Lake has a calcium-magnesium sulfate type water and has 934 mg/L dissolved solids. Lake Molstad has a sodium sulfate type water and is slightly saline (1,420 mg/L dissolved solids). Water from both lakes are suitable for livestock, but only the water from Hiddenwood Lake is suitable for irrigation. Both lakes were sampled in the fall during a drought, so the water quality presented in table 5 may not be typical of the "average" water quality from these lakes.

Table 6.--Significance of chemical and physical properties of water

[Modified from Howells, 1979. Limits, where given, are primary (mandatory) and secondary (recommended) limits for concentrations of substances in drinking water as set forth by the U.S. Environmental Protection Agency (1976, 1977). The unit milligrams per liter (mg/L) is approximately equivalent to parts per million. The unit micrograms per liter (µg/L) is approximately equivalent to parts per billion. The unit milliequivalents per liter (meq/L) is obtained by dividing the concentration, in milligrams per liter, by the combining weight of the ionic species]

Constituent or property	Limit	Significance
Temperature		Affects the usefulness of water for many purposes. Generally, users prefer water of uniformly low temperature. Temperature of ground water tends to increase with increasing depth to the aquifer.
Silica (SiO_2)		Forms hard scale in pipes and boilers and may form deposits on blades of steam turbines. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	0.3 mg/L (recommended)	Forms rust-colored sediment; stains laundry, utensils, and fixtures reddish brown. Objectionable for food and beverage processing.
Manganese (Mn)	0.05 mg/L (recommended)	Causes gray or black stains on porcelain, enamel, and fabrics. Can promote growth of certain kinds of bacteria.
Calcium (Ca) and magnesium (Mg)		Cause most of the hardness and scale-forming properties of water (see hardness).
Sodium (Na) and potassium (K)		Large concentrations may limit use of water for irrigation and industrial use and, in combination with chloride, give water a salty taste. Abnormally large concentrations may indicate natural brines, industrial brines, or sewage.
Bicarbonate (HCO_3)		In combination with calcium and magnesium forms carbonate hardness.
Sulfate (SO_4)	250 mg/L (recommended)	Sulfates of calcium and magnesium form hard scale. Large concentrations of sulfate have a laxative effective on some people and, in combination with other ions, give water a bitter taste.
Chloride (Cl)	250 mg/L (recommended)	Large concentrations increase the corrosiveness of water and, in combination with sodium, give water a salty taste.
Fluoride (F)	1.5 mg/L (mandatory)	Reduces incidence of tooth decay when optimum fluoride concentration is present in water consumed by children during the period of tooth calcification. Limit varies inversely with average annual maximum air temperature. Excessive concentrations of fluoride may cause mottling of teeth.
Nitrate (NO_3) (as N)	45 mg/L 10 mg/L (mandatory)	Concentrations greater than local average may indicate pollution by feed-lot runoff, sewage, or fertilizers. Concentrations greater than 45 mg/L may be injurious when used in feeding infants.
Boron (B)		Essential to plant growth, but may be toxic to crops when present in excessive concentrations in irrigation water. Sensitive plants may show damage when irrigation water contains more than 0.67 mg/L and even tolerant plants may be damaged when boron exceeds 2.0 mg/L.

Table 6.--Significance of chemical and physical properties of water--Continued

Constituent or property	Limit	Significance
Dissolved solids	500 mg/L (recommended)	The total of all dissolved mineral constituents, usually expressed in milligrams per liter or in parts per million of weight. The concentration of dissolved solids may affect the taste of water. Water that contains more than 1,000 mg/L is unsuitable for many industrial uses. Some dissolved mineral matter is desirable, otherwise the water would have a flat taste.
Hardness as $CaCO_3$		Related to the soap consuming characteristic of water, results in formation of scum when soap is added. May cause deposition of scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate in water is called carbonate hardness; hardness in excess of this concentration is called noncarbonate hardness. Water that has a hardness less than 61 mg/L is considered soft; 61-120 mg/L moderately hard; 121-180 mg/L hard; and more than 180 mg/L very hard.
Percent sodium (Na)		Ratio of sodium to total cations in milliequivalents per liter expressed as a percentage. Important in irrigation waters; the greater the percent sodium, the less suitable the water for irrigation.
Sodium-adsorption ratio (SAR)		A ratio used to express the relative activity of sodium ions in exchange reactions with soil. Important in irrigation water; the greater the SAR, the less suitable the water for irrigation.
Residual sodium carbonate (RSC)		The quantity expressed in milliequivalents per liter of carbonate and bicarbonate a water would contain after the removal of an equivalent quantity of calcium and magnesium. RSC is a measure of the "black alkali" hazard of water. Water having an RSC greater than 2.5 meq/L is not considered suitable for irrigation; an RSC of 1.25 to 2.5 meq/L is considered marginal; and an RSC of less than 1.25 meq/L is considered "probably safe" for irrigation.
Specific conductance		A measure of the ability of a unit cube of water to conduct an electrical current; varies with temperature, therefore reported at 25° Celsius. Values are reported in microsiemens per centimeter. Magnitude depends on concentration, kind, and degree of ionization of dissolved constituents; can be used to determine the approximate concentration of dissolved solids.
pH	6.5-8.5 units (recommended)	A measure of the hydrogen ion concentration; pH of 7.0 indicates a neutral solution, pH values smaller than 7.0 indicate acidity, pH values larger than 7.0 indicate alkalinity. Water generally becomes more corrosive with decreasing pH; however, excessively alkaline water also may be corrosive.
Aluminum (Al)		No known necessary role in human or animal diet. Nontoxic in the concentrations normally found in natural water supplies. Concentrations greater than 1,000 μg/L may decrease yields of some crops. Long-term exposure to concentrations of more than 100 μg/L can be lethal to some types of fish.

Table 6.--Significance of chemical and physical properties of water--Continued

Constituent or property	Limit	Significance
Arsenic (As)	50 µg/L (mandatory)	No known necessary role in human or animal diet, but is toxic. A cumulative poison that is slowly excreted. Can cause nasal ulcers; skin cancer; damage to the kidneys, liver, and intestinal walls; and death.
Barium (Ba)	1,000 µg/L (mandatory)	Toxic; used in rat poison. In moderate to large concentrations can cause death; smaller concentrations cause damage to the heart, blood vessels, and nerves.
Bromide (Br)		Not known to be essential in human or animal diet. Is nontoxic in small concentrations; less than 1,000 µg/L has no detectable affect even on fish.
Cadmium (Cd)	10 µg/L (mandatory)	A cumulative poison of very toxic potential. Not known to be either biologically essential or beneficial. Believed to promote renal arterial hypertension. In animal experiments, concentrations of 100 to 10,000 µg/L for 1 year caused liver and kidney damage; greater concentrations cause anemia, retarded growth, and death.
Chromium (Cr) in hexavalent form	50 µg/L (mandatory)	No known necessary role in human or animal diet. In the hexavalent form is toxic, leading to intestinal damage and to nephritis.
Copper (Cu)	1,000 µg/L (recommended)	Essential to metabolism; copper deficiency in infants and young animals results in nutritional anemia. Large concentrations of copper are toxic and may cause liver damage.
Iodide (I)		Essential and beneficial element in metabolism; deficiency can cause goiter.
Lead (Pb)	50 µg/L (mandatory)	A cumulative poison, toxic in small concentrations. Can cause lethargy, loss of appetite, constipation, anemia, abdominal pain, gradual paralysis in the muscles, and death.
Lithium (Li)		Reported as probably beneficial in small concentrations (250 to 1,250 µg/L). Reportedly may help strengthen the cell wall and improve resistence to genetic damage and to disease. Lithium salts are used to treat certain types of psychosis.
Mercury (Hg)	2 µg/L (mandatory)	No known essential or beneficial role in human or animal nutrition. Liquid metallic mercury and elemental mercury dissolved in water are comparatively nontoxic, but some mercury compounds, such as mercuric chloride and alkyl mercury, are very toxic. Elemental mercury is readily alkylated, particularly to methyl mercury, and concentrated by biological activity; fish and shellfish can contain more than 3,000 times the concentration of mercury as the water in which they live. Toxic affects of mercury compounds include chromosomal abnormalities, congenital mental retardation, progressive weakening of the muscles, loss of vision, impairment of cerebral functions, paralysis, and death.

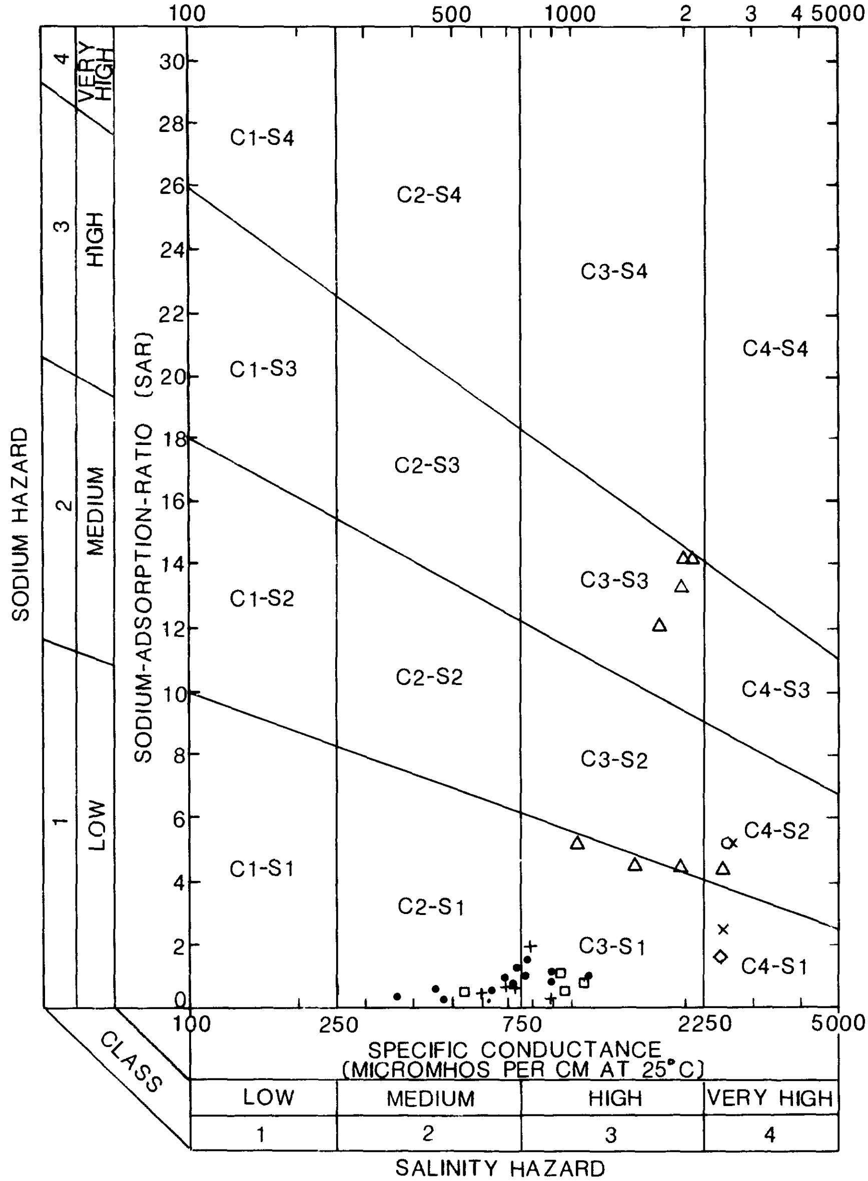
Table 6.--Significance of chemical and physical properties of water--Continued

Constituent or property	Limit	Significance
Molybdenum (Mo)		In minute concentrations, appears to be an essential nutrient for both plants and animals, but in large concentrations may be toxic.
Nickel (Ni)		Very toxic to some plants and animals. Toxicity for humans is believed to be very minimal.
Phosphate (PO_4)		Essential to plant growth. Concentrations greater than local average may indicate pollution by fertilizer seepage or sewage. Concentrations greater than 200 mg/L may have a laxative effect.
Selenium (Se)	10 µg/L (mandatory)	Essential to human and animal nutrition in minute concentrations, but even a moderate excess may be harmful or potentially toxic if ingested for a long time. Selenium poisoning in livestock can cause loss of hair; loss of weight; abnormal hoof growth; hoof loss; liver, kidney, and heart damage; poor health and decreased disease resistance; and death. In humans, selenium can interfere with the normal function of the pancreas and other organs and effect changes in the insulin requirements of people with diabetes mellitus. Selenium is known to be a hazard in parts of South Dakota.
Silver (Ag)	50 µg/L (mandatory)	Causes permanent bluish darkening of the eyes and skin (argyria). Where found in water is almost always from pollution or by intentional addition. Silver salts are used in some countries to sterilize water supplies. Toxic in large concentrations.
Strontium (Sr)		Importance in human and animal nutrition is not know, but believed to be essential. Toxicity believed very minimal--no more than calcium.
Vanadium (V)		Not known to be essential to human or animal nutrition, but believed to be beneficial in trace concentrations. May be an essential trace element for all green plants. Large concentrations may be toxic.
Zinc (Zn)	5,000 µg/L (recommended)	Essential and beneficial in metabolism; its deficiency in young children or animals will retard growth and may decrease general body resistance to disease. Seems to have no ill effects even in fairly large concentrations (20,000 to 40,000 µg/L), but can impart a metallic taste or milky appearance to water. Zinc in water commonly is derived from galvanized coatings of piping; unfortunately, common contaminants of zinc used in galvanizing are cadmium and lead.

Table 7.--Selected chemical analyses. Analyses by U.S. Geological Survey Laboratory

Location	Date of collection	Source of water	Total depth of well (feet)	Specific conductance (micromhos per cm at 25°C)	pH (units)	Percent sodium	Sodium-adsorption ratio	Hardness	Noncarbonate hardness	Dissolved calcium	Dissolved magnesium	Dissolved sodium	Dissolved potassium
								SURFACE WATER					
121N78W21DDDB	10- 7-76	Lake Oahe nr Akaska	--	670	8.0	36	1.7	230	66	55	22	60	4.4
124N80W13CDDC	10- 7-76	Lake Oahe at Mobridge	--	650	8.0	36	1.6	200	37	48	19	52	3.8
124N78W17BCAA	10-20-76	Lake Molestad nr Glenham	--	2,000	8.7	70	8.9	290	0	47	43	350	25
124N76W23ACAC	10-20-76	Hiddenwood Lake nr Selby	--	1,340	8.5	32	2.2	460	300	87	60	110	31
122N76W11DDAB	5-24-77	Spring Creek nr Bowdle	--	--	--	11	.4	310	52	83	26	18	6.2
								GROUND WATER					
121N74W11CCCC	11-25-75	Bowdle aquifer	19	770	8.2	23	1.1	330	130	80	31	48	10
121N74W15CCCC	11-25-75	Do.	35	700	7.5	20	.9	300	68	75	27	36	9.0
121N74W19DDDD	4- 1-70	Do.	18	760	8.3	29	1.3	240	93	68	20	50	9.0
121N74W20DDAD	11-25-75	Do.	13	1,190	7.4	19	1.1	540	180	140	46	60	12
121N74W22AACC	7-25-75	Do.	54	740	--	19	.8	330	47	89	25	35	6.9
121N74W27BAAA	4- 1-70	Do.	44	540	7.7	12	.4	230	34	58	17	14	4.0
121N74W33BBBB	5-24-77	Do.	24	783	--	29	1.5	310	10	86	22	59	7.6
121N74W33DCCB	10-13-76	Do.	46	910	8.2	22	1.1	390	73	110	27	50	7.4
122N74W 1BBBB	11-25-75	Do.	12	630	8.2	12	.5	310	47	73	30	21	12
122N74W12AADD	11-25-75	Do.	31	470	8.2	15	.5	210	14	56	16	17	6.0
122N74W12ABDD2	5-26-77	Do.	47	580	--	8	.3	300	100	80	24	12	4.6
123N74W 2DDDD	5-24-77	Do.	12	1,180	--	19	1.1	520	240	96	67	59	26
123N74W12CDDC	11-25-75	Do.	12	910	7.5	18	.9	360	60	80	39	39	20
123N74W23CDCD	11-25-75	Do.	10	480	8.0	3	.1	260	12	68	21	4.0	12
123N74W24A	8-13-65	Do.	24	420	7.5	7	.2	200	14	52	18	6.9	6.0
123N74W24ADDD	4- 1-70	Do.	25	630	8.4	7	.2	330	119	87	27	12	6.0
124N76W 3DDDD2	5-25-77	Selby aquifer	36	805	--	36	1.9	280	0	75	23	75	5.7
124N76W 7DCCC	5-25-77	Do.	23	710	--	32	1.6	260	0	67	22	58	6.6
124N76W 8ACBB	10-20-76	Do.	58	820	8.1	23	1.1	360	88	84	37	50	8.5
124N76W 8ACCC	10-20-76	Do.	63	900	7.6	24	1.3	390	110	88	42	60	9.6
124N76W 9BCBC	5-25-77	Do.	22	735	--	16	.7	340	110	89	28	30	7.4
122N77W 3BBBA	11- 3-76	Grand aquifer	150	2,000	7.2	45	4.3	640	48	170	53	250	16
123N76W20BCDC	11- 3-76	Do.	159	2,600	7.2	41	4.4	990	400	270	76	320	27
124N76W 3DDDD	5-25-77	Do.	202	1,700	--	60	6.3	410	0	110	32	290	16
124N77W 2CDDD	5-26-77	Do.	235	1,960	--	82	13	170	0	42	17	400	12
124N77W14BBBA	5-26-77	Do.	99	1,120	--	62	5.0	210	0	58	17	170	10
124N78W19AADA	5-26-77	Do.	62	1,790	--	81	12	170	0	45	13	350	7.5
124N78W23BBBB	5-26-77	Do.	172	3,550	--	27	3.2	1,700	1,300	450	140	300	19
124N78W28ABBA	10-20-76	Do.	158	2,000	7.5	81	14	230	0	62	19	480	12
124N78W28ACBA	10-20-76	Do.	165	1,950	7.5	81	14	220	0	60	18	480	11
124N78W31DCCC	5-26-77	Do.	115	2,130	--	82	14	200	0	51	17	440	10
122N75W13AAAA	5-25-77	Java aquifer	42	950	--	20	1.1	430	58	110	37	52	10
123N75W 3BADC	10-19-76	Do.	175	1,150	7.5	13	.8	590	190	150	53	42	17
123N75W 3BDBD	10-19-76	Do.	108	1,240	7.5	13	.8	660	290	170	58	45	18
124N75W35DDDD	5-25-77	Do.	110	975	--	11	.6	610	210	140	62	34	20
121N76W 7ADDD	5-25-77	Pleistocene aquifer	75	885	--	40	2.4	300	10	76	26	93	8.7
123N78W12BCDD2	5- 7-69	Do.	110	10,300	7.9	97	85	140	0	30	17	2,300	15
124N77W36DDDD	5-26-77	Do.	21	1,000	--	41	2.4	290	93	70	28	95	7.8
124N79W19ADCC	6- 9-77	Do.	85	2,230	--	17	1.4	1,200	760	330	83	110	8.6
121N76W11ABBD	10-13-76	Outwash deposits	60	860	8.0	53	3.4	200	0	49	19	110	10
121N77W 3AADA	10-13-76	Do.	40	1,060	7.6	44	2.8	290	0	75	25	110	9.0
121N77W19DDB	7- 5-69	Dakota aquifer	1,930	8,290	8.1	97	84	83	0	18	9.4	1,800	16
123N78W12BCDD	8-15-62	Do.	2,125	10,500	7.9	97	85	150	0	35	16	2,400	8.9
122N77W 7ABDB	1-28-70	Inyan Kara aquifer Sundance aquifer	2,300	2,760	7.5	45	5.3	1,000	0	290	68	380	28
123N76W30AADB	7-11-74	Do.	2,357	2,400	7.3	25	2.5	1,300	1,100	370	93	210	30
123N76W30AADB	11- 3-76	Do.	2,357	2,250	7.8	26	2.4	1,200	1,000	310	89	190	24
121N76W31ABAC	11- 4-76	Inyan Kara aquifer Sundance aquifer Minnelusa aquifer	2,300	2,250	7.3	17	1.5	1,200	1,100	320	99	120	24
123N78W 3BABA	9-27-74	Inyan Kara aquifer Minnelusa aquifer Madison aquifer	2,736	5,000	7.4	80	21	630	440	170	49	1,200	27
122N74W30BBBC	7-23-75	Sundance aquifer	2,200	2,690	--	46	5.0	810	660	230	58	330	22
124N74W15BDB	6- 9-77	Minnelusa aquifer	2,419	2,440	--	17	1.5	1,280	1,140	360	94	120	21

Milligrams per liter																		
Bicarbonate	Carbonate	Alkalinity as $CaCO_3$	Carbon dioxide	Dissolved sulfate	Dissolved chloride	Dissolved fluoride	Dissolved silica	Dissolved solids (residue at 180°C)	Dissolved solids (sum of constituents)	Dissolved nitrate	Dissolved nitrite plus nitrate	Total phosphorus	Dissolved phosphorus	Dissolved orthophosphorus	Dissolved orthophosphate	Dissolved boron (micrograms per liter)	Dissolved iron (micrograms per liter)	Dissolved manganese (micrograms per liter)
198	0	162	3.2	170	10	0.5	7.1	--	432	--	1.2	0.05	0.00	0.00	0.00	110	--	--
196	0	161	3.1	180	11	.6	7.1	--	419	--	.22	.01	.00	.01	.03	120	--	--
331	20	305	1.2	710	60	.5	.5	--	1,420	--	.08	.19	.16	.09	.28	1,700	--	--
200	0	164	1.0	500	20	.4	24	--	934	--	.43	.11	.04	.07	.21	740	--	--
320	--	260	--	78	3.5	--	--	394	--	--	.82	.03	--	--	--	80	--	--
234	5	200	--	150	18	--	--	--	500	8.0	--	--	--	--	--	160	680	--
281	0	230	--	130	9.0	--	--	--	427	.30	--	--	--	--	--	170	110	--
180	30	196	--	110	19	--	--	--	573	1.0	--	--	--	--	--	400	6,900	--
439	0	360	--	320	8.0	--	--	--	832	1.7	--	--	--	--	--	320	160	--
339	0	278	--	110	6.9	--	--	485	--	--	0.63	--	--	--	--	150	--	1,200
239	0	196	--	58	7.0	--	--	--	280	1.5	--	--	--	--	--	200	2,100	--
360	0	300	--	120	11	--	--	509	--	--	.24	0.10	--	--	--	180	--	--
382	0	313	--	140	21	0.3	28	--	576	--	.44	--	0.00	0.04	0.12	170	60	1,500
305	5	250	--	110	4.0	--	--	--	400	.20	--	--	--	--	--	170	60	--
224	5	192	--	43	2.0	--	--	--	--	2.0	--	--	--	--	--	220	100	--
240	0	200	--	98	1.6	--	--	383	--	--	4.1	.03	--	--	--	60	--	--
340	--	280	--	290	38	--	--	820	--	--	4.8	.09	--	--	--	80	--	--
366	0	300	--	140	6.0	--	--	--	512	23	--	--	--	--	--	150	60	--
298	0	244	--	20	2.0	--	--	--	256	17	--	--	--	--	--	90	100	--
227	0	186	--	32	2.6	.0	28	263	262	3.5	--	--	--	--	--	0	30	710
175	29	189	--	97	2.0	--	--	--	370	1.6	--	--	--	--	--	200	14,000	--
370	0	300	--	120	120	--	--	517	--	--	.06	.03	--	--	--	290	--	--
340	0	280	--	100	4.8	--	--	448	--	--	.00	.08	--	--	--	160	--	--
334	0	274	--	220	3.3	.2	28	--	598	--	.02	--	.06	.03	.09	120	2,000	--
349	0	286	--	260	3.9	.2	29	--	668	--	.09	--	.05	.06	.18	140	2,200	--
280	0	230	--	160	5.0	--	--	489	--	--	.05	.12	--	--	--	80	--	--
725	0	595	--	610	27	--	--	1,530	--	--	.20	--	--	--	--	890	--	2,200
717	0	588	--	1,100	26	--	--	2,300	--	--	.01	--	--	--	--	780	--	3,200
690	0	570	--	410	20	--	--	1,270	--	--	.03	.08	--	--	--	1,100	--	--
830	0	680	--	340	35	--	--	1,290	--	--	.01	.09	--	--	--	1,000	--	--
500	0	410	--	170	15	--	--	740	--	--	.01	.03	--	--	--	350	--	--
500	0	410	--	510	14	--	--	1,210	--	--	.14	.05	--	--	--	620	--	--
530	--	430	--	1,700	110	--	--	3,330	--	--	.02	.07	--	--	--	720	--	--
880	0	722	--	510	50	.4	26	--	1,600	--	.10	--	.01	.04	.12	1,300	60	--
874	0	717	--	510	49	.4	27	--	1,590	--	.10	--	.01	.03	.09	1,400	30	--
810	0	660	--	430	44	--	--	1,420	--	--	.02	.10	--	--	--	1,200	--	--
450	0	370	--	170	3.9	--	--	630	--	--	.01	.06	--	--	--	160	--	--
496	0	407	--	310	4.6	.2	53	--	876	--	.34	--	.04	.06	.18	200	230	--
461	0	378	--	350	5.2	.2	53	--	929	--	.28	--	.04	.06	.18	210	680	--
480	0	390	--	240	4.0	--	--	810	--	--	.03	.07	--	--	--	120	--	--
350	0	290	--	160	25	--	--	590	--	--	.03	.03	--	--	--	160	--	--
582	0	478	--	.0	3,400	7.0	9.8	6,120	6,050	.00	--	--	--	--	--	3,100	450	10
240	0	200	--	270	9.9	--	--	685	--	--	.35	.12	--	--	--	150	--	--
500	0	410	--	760	56	--	--	1,820	--	--	22	.00	--	--	--	250	90	--
423	0	347	--	76	15	.7	28	--	527	--	1.8	--	.07	.10	.31	280	830	990
387	0	317	--	220	7.2	.4	28	--	677	--	1.6	--	.19	.04	.12	240	3,300	1,100
668	0	547	--	1.5	2,500	1.0	12	4,800	4,230	.00	--	--	--	--	--	3,200	100	0
571	0	468	--	9.0	3,400	.5	12	6,100	6,170	1.4	--	--	--	--	--	5,300	980	20
196	0	161	--	1,400	130	--	--	--	2,320	.00	--	--	--	--	--	--	650	--
200	0	164	--	1,300	102	--	--	--	--	.00	--	--	--	--	--	--	1,200	--
178	0	146	--	1,300	110	3.0	13	--	2,140	--	.02	.00	--	.04	.12	340	1,200	190
171	0	140	--	1,300	66	--	--	2,200	--	--	.01	--	--	--	--	270	--	180
229	--	188	--	1,720	540	--	--	--	--	.40	--	--	--	--	--	--	700	--
192	0	157	--	1,300	80	2.7	12	--	2,130	--	.04	--	.01	.01	.03	470	30	160
180	0	150	--	1,300	63	--	--	2,230	--	--	.62	.00	--	--	--	240	7,600	--



EXPLANATION

- • BOWDLE AQUIFER
- + SELBY AQUIFER
- △ GRAND AQUIFER
- □ JAVA AQUIFER
- × INYAN KARA AND SUNDANCE AQUIFERS
- ○ SUNDANCE AQUIFER
- ◇ MINNELUSA AQUIFER

Figure 28.--Diagram for classifying irrigation water with respect to salinity hazard and sodium hazard. Salinity hazard classes are indicated by the letter "C" and a subscript, and sodium hazard classes are indicated by the letter "S" and a subscript; in both classes, a higher hazard is indicated by a higher subscript. Thus, water classified as C_1-S_1, under average conditions, is more suitable for irrigation than water classified as C_3-S_2. Water from the aquifer in the Dakota Formation is not shown because it would plot far above and to the right of the upper right-hand corner of this diagram.

Ground Water Quality

The predominant constituents of water from the Bowdle aquifer are calcium, magnesium, and bicarbonate. The dissolved-solids concentration generally is from 250 to 850 mg/L, although locally concentrations may be higher. Hardness ranges from 200 to 650 mg/L indicating the water is very hard. Sulfate concentration ranges from 20 to about 350 mg/L. The bicarbonate concentration ranges from 170 to about 400 mg/L. The chloride concentration ranges from 2 to about 60 mg/L. Although the measured concentration of nitrate ranged from 0.04 to more than 100 mg/L, the natural concentration probably is less than 0.5 mg/L (and may be less than 0.1 mg/L). Nitrate concentrations higher than the natural level are caused by infiltration to the aquifer of nitrate-rich dissolved mineral matter from surface or near-surface sources such as barnyards, septic-tank overflow, feedlots, and fertilizer applied to crops. Boron concentration is low (below 500 µg/L (micrograms per liter) in all samples). Fluoride concentration is below the recommended level of 1.3 mg/L for domestic use (only 0.3 mg/L was measured); thus, water from the Bowdle aquifer generally is suitable for livestock and irrigation and, if the nitrate concentration at the given site is not more than 10 mg/L, is acceptable for domestic and public supplies.

The predominant constituents of water from the Selby aquifer are calcium, magnesium, and bicarbonate. The dissolved-solids concentration generally is from 400 to 670 mg/L, but locally may be as much as 1,500 mg/L (particularly on the southern or western margins of the aquifer). The water is very hard; hardness usually is from 230 to 390 mg/L, but locally may be as much as 800 mg/L in the more saline parts of the aquifer. The sulfate concentration is fairly low, ranging from about 100 to 260 mg/L, but locally may be more than 500 mg/L in the more saline parts of the aquifer. The bicarbonate concentration is from about 200 to 500 mg/L except in the more saline parts of the aquifer where it locally may exceed 700 mg/L. The chloride concentration commonly is low, from 4 to about 50 mg/L, but locally may exceed 300 mg/L in the more saline parts of the aquifer. Nitrate concentrations were low in all samples tested; they ranged from 0.09 to 0.40 mg/L. Boron concentration is low, ranging from about 100 to 300 µg/L. Fluoride concentration is below the recommended level of 1.3 mg/L for domestic use (only 0.2 mg/L was measured). Thus, water from the Selby aquifer generally is suitable for livestock, irrigation, domestic, and public supplies.

Water from the Grand aquifer is predominantly sodium bicarbonate, although locally it can be a sodium sulfate or calcium magnesium sulfate. The dissolved-solids concentration generally is from 900 to 2,000 mg/L but locally may be less than 650 mg/L or greater than 3,300 mg/L. The water is hard to very hard; hardness commonly is from 130 to 400 mg/L, but locally may be as much as 1,700 mg/L. The sulfate concentration normally is from 170 to 610 mg/L, but locally can be as much as 1,700 mg/L. The bicarbonate concentration usually is between 450 and 900 mg/L, but locally can be as much as 1,100 mg/L. The chloride concentration is low, generally between 14 and 50 mg/L, though locally it may exceed 150 mg/L. Nitrate concentrations were fairly low in all samples tested; it ranged from 0.04 to 0.9 mg/L. Boron concentrations in samples ranged from 350 to 1,400 µg/L. Fluoride concentration is below the limit of 1.3 mg/L recommended for domestic use (0.4 mg/L was measured). Thus, water from the Grand aquifer is suitable for livestock, is of marginal quality to unsuitable for irrigation, is of acceptable to poor quality for domestic supplies, and is acceptable to unacceptable for public supplies.

The predominant constituents of water from the Java aquifer are calcium, magnesium, and bicarbonate. The dissolved-solids concentration generally is from 600 to

1,000 mg/L, but locally may be more than 3,500 mg/L. Most of the samples that were high in dissolved solids and other major chemical constituents were collected along the northern and western edges of the Java aquifer complex. The water is hard to very hard; hardness commonly is from 240 to 650 mg/L, but locally may be more than 2,800 mg/L. The sulfate concentration normally is between 150 and 350 mg/L. The bicarbonate concentration usually is from 240 to 500 mg/L, but locally may exceed 800 mg/L. The chloride concentration usually is low, from 4 to 60 mg/L, but locally may be more than 400 mg/L. Nitrate concentrations ranged from 0.04 to 2.0 mg/L in the samples tested. The natural concentration of nitrate probably is less than 0.5 mg/L (and may be less than 0.1 mg/L), therefore, concentrations of more than 1.0 mg/L may represent seepage of nitrate-rich effluent from surface or near-surface sources such as barnyards, feedlots, septic tank overflow, or fertilizer applied to crops. Boron concentration is low (below 300 µg/L in all samples). Fluoride concentration is below the level of 1.3 mg/L recommended for domestic use (0.2 mg/L was measured). Thus, water from the Java aquifer generally is suitable for livestock and irrigation, and for domestic and public supplies.

The minor aquifers in the drift contain water of widely varying quality, from good for most uses to unacceptable. However, the water in two of the three minor aquifers shown in figure 16 is acceptable for stock and domestic supplies. In the minor aquifer along Swan Creek, the water is of good quality and is a sodium bicarbonate type near the eastern end of the aquifer and predominantly of calcium, magnesium, and bicarbonate type west of Lowry. Dissolved-solids concentration is about 600 to 800 mg/L, hardness is about 200 to 450 mg/L, chloride concentration usually is less than 40 mg/L, bicarbonate concentration is from 350 to more than 450 mg/L, and sulfate concentration is from about 70 to more than 220 mg/L. As in other aquifers exposed at land surface, the nitrate concentration varies widely because of the infiltration of fertilizer, barnyard and feedlot runoff, and sewage. Nitrate concentrations ranged from 0.01 to more than 8 mg/L in the three samples analyzed. Locally, the nitrate concentration could be higher. The water in this aquifer is suitable for most uses.

The predominant constituents in the water from the minor aquifer that stretches from east of Selby to Glenham to the mouth of Blue Blanket Creek are calcium, magnesium, bicarbonate, and sulfate. The dissolved-solids concentration is from about 550 to 1,100 mg/L, hardness is from 275 to more than 600 mg/L, chloride concentration is less than 50 mg/L, bicarbonate concentration is from about 200 to 350 mg/L, and sulfate concentration is from less than 200 to more than 300 mg/L. Only one nitrate analysis is available (1.6 mg/L), but the comments previously made about nitrate in near-surface aquifers are applicable. The water in this aquifer is suitable for most uses.

The Mobridge terrace aquifer contains slightly saline water, the predominant constituents of which are calcium, magnesium, and sulfate. Only one chemical analysis was collected so the concentrations of ions elsewhere in the aquifer might vary significantly from those of this sample. The dissolved-solids concentration was 1,820 mg/L, the hardness was 1,200 mg/L (extremely hard), the chloride concentration was 56 mg/L, the bicarbonate concentration 500 mg/L, and the sulfate concentration 760 mg/L. Nitrate concentration was 97 mg/L, which means that the water is unacceptable for human consumption and of marginal quality for livestock use. The water is acceptable to marginal for irrigation use.

Water from the rest of the minor aquifers is not only variable in quality from aquifer to aquifer, but can vary greatly between wells only a short distance apart. For example, in 124N75W30ADDB, where there are two wells less than 300 ft apart, water from an 80-ft deep well had a specific conductance of 1,620 umhos/cm and dissolved solids 1,100 mg/L, but water from a 39-ft deep well had a specific conductance of 6,800 µmhos/cm and dissolved solids 4,700 mg/L. Of 77 wells tapping these minor aquifers, the dissolved-solids concentrations ranged from about 500 to more than 5,600 mg/L with almost half of the samples containing more than 1,500 mg/L dissolved solids. The water was very hard; only one sample had a hardness less than 180 mg/L. The hardness of 75 percent of the samples was from 180 to 1,000 mg/L; the greatest hardness analyzed was 2,200 mg/L. The chloride concentration usually is fairly low; about 70 percent of the samples contained from 4 to 100 mg/L of chloride. The maximum chloride concentration measured was 365 mg/L. The bicarbonate concentration in most samples (89 percent) was between 330 and 680 mg/L; the largest concentration measured was 1,050 mg/L.

The predominant constituents in water from the Dakota aquifer are sodium and chloride. Dissolved-solids concentration ranges from less than 2,500 mg/L in the southeast to more than 6,000 mg/L in the northwest (fig. 29). The water is soft to very hard; hardness ranges from 35 to more than 150 mg/L. The greatest hardness is found along the western edge of the county where the dissolved-solids concentration is highest. The sulfate concentration is low, ranging from 20 mg/L or less in the western half of the county to about 100 mg/L along the eastern edge of the county. The bicarbonate concentration ranges from about 550 mg/L in the northwestern corner of the county to 1,000 mg/L along the eastern edge of the county. The chloride concentration is high, ranging from about 3,800 mg/L in the northwestern corner of the county to about 850 mg/L in the southeastern corner of the county. The natural concentration of nitrate in the aquifer is less than 0.05 mg/L. The boron concentration exceeded 3,000 µg/L in all analyses. Fluoride concentration is below the recommended limit throughout the area; the lowest concentration measured was 0.5 mg/L. Thus, water from the Dakota aquifer throughout the county probably is of acceptable to poor quality for livestock use and is unacceptable for irrigation, domestic, or public supplies.

The ionic character of the water from the Inyan Kara aquifer changes from sodium and sulfate dominance in the west to calcium magnesium sulfate dominance in the east because in the east the Inyan Kara aquifer receives recharge from the underlying Sundance aquifer which influences the water quality in the Inyan Kara aquifer (fig. 30). This water-quality difference in the same aquifer is called a change in geochemical facies. The water is hard to very hard; the hardness ranges from less than 200 mg/L in the northwestern corner of the county to more than 1,300 mg/L in the southeastern corner of the county. The dissolved-solids concentration ranges from 2,300 to 2,500 mg/L in the eastern three-quarters of the county to more than 5,000 mg/L in the northwestern corner. The sulfate concentration is very high; it ranges from more than 2,000 mg/L in the northwestern corner of the county to about 1,300 mg/L in the eastern half of the county. The bicarbonate concentration is about 350 mg/L in the northwest and about 200 mg/L or less in the eastern half of the county. The chloride concentration ranges from about 700 mg/L in the northwest to less than 200 mg/L in the eastern half of the county. The natural concentration of nitrate in the aquifer is less than 0.05 mg/L; of boron, generally less than 500 µg/L; and of fluoride, generally more than 2.5 mg/L, somewhat above the recommended limit. Thus, water from the Inyan Kara throughout the county is acceptable for livestock use, is unacceptable for irrigation, and is of poor to unacceptable quality for domestic and public supplies.

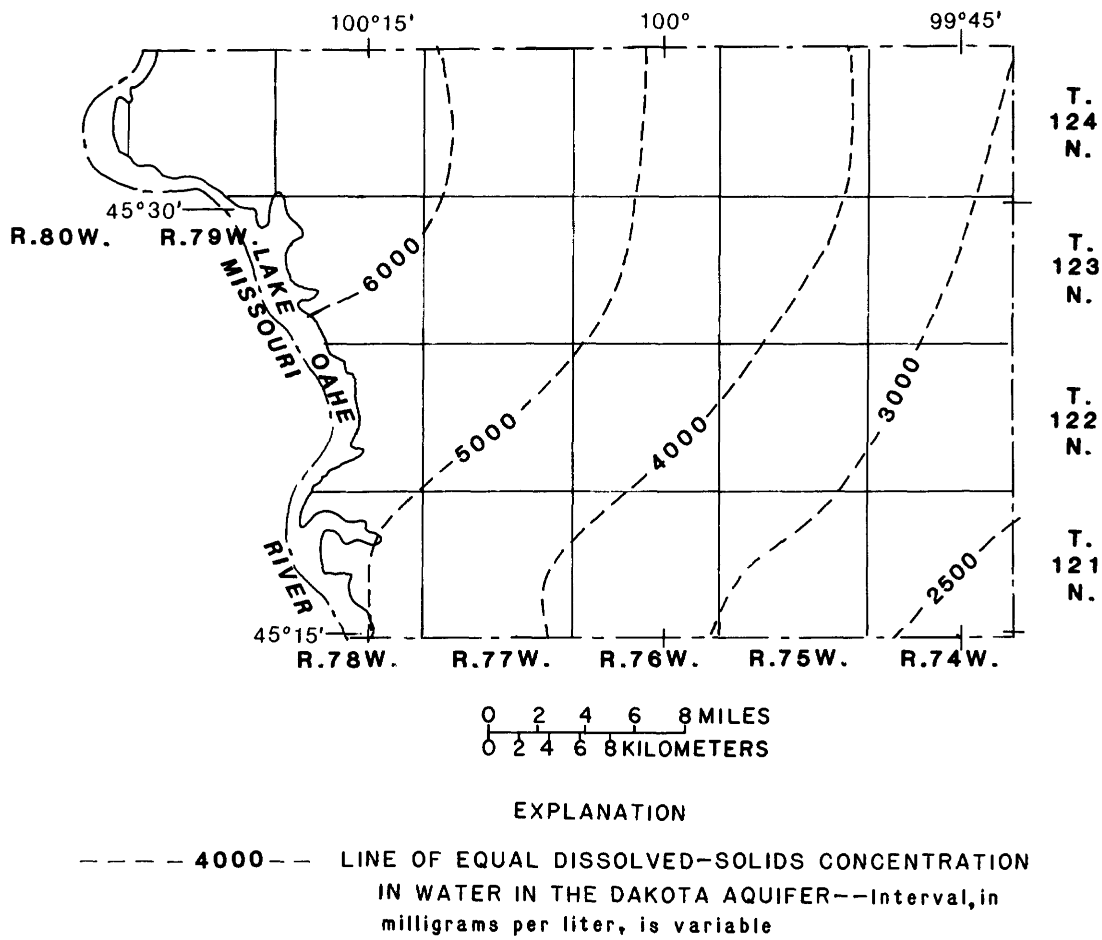


Figure 29.--Dissolved-solids concentration in water of the Dakota aquifer.

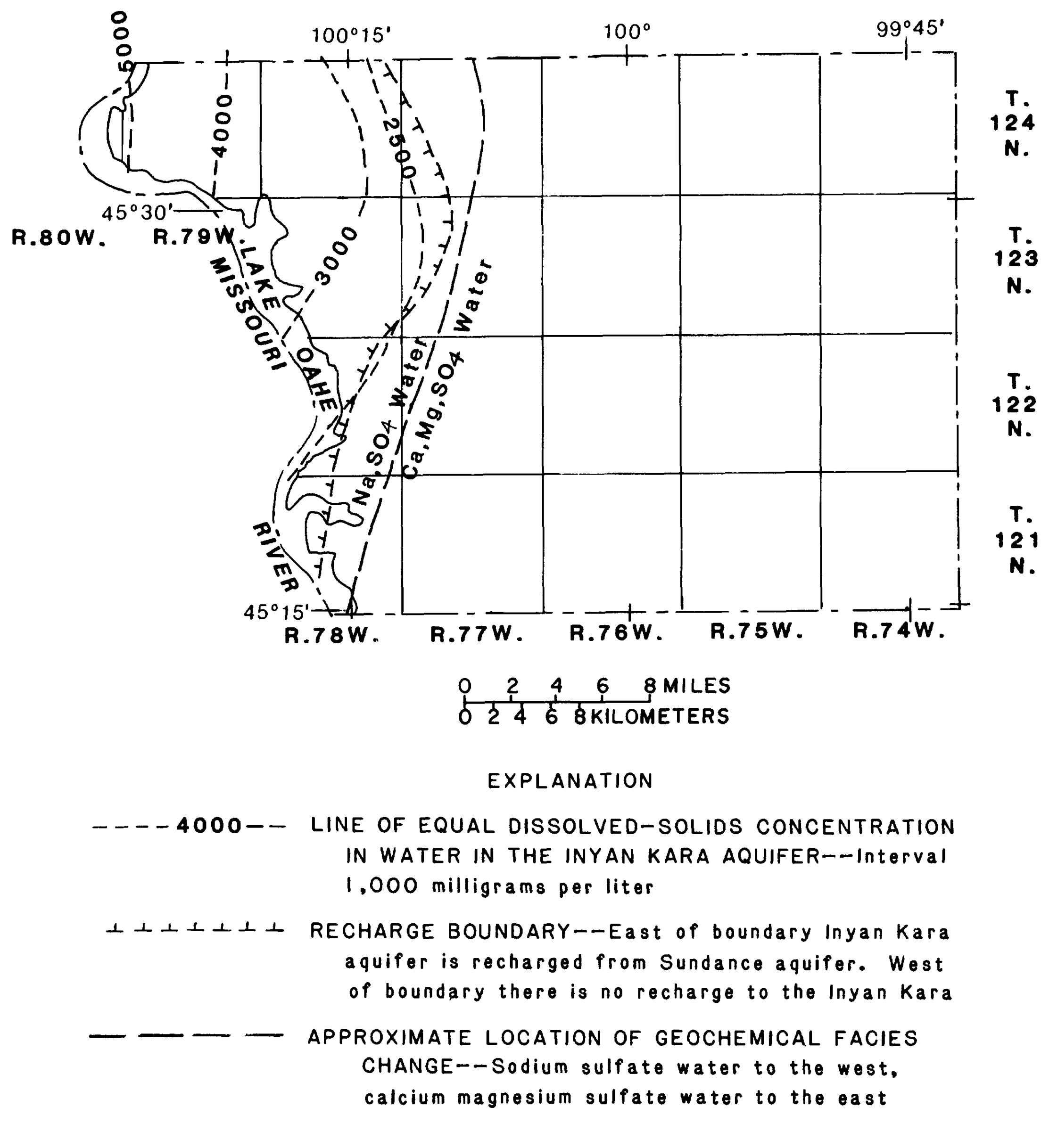


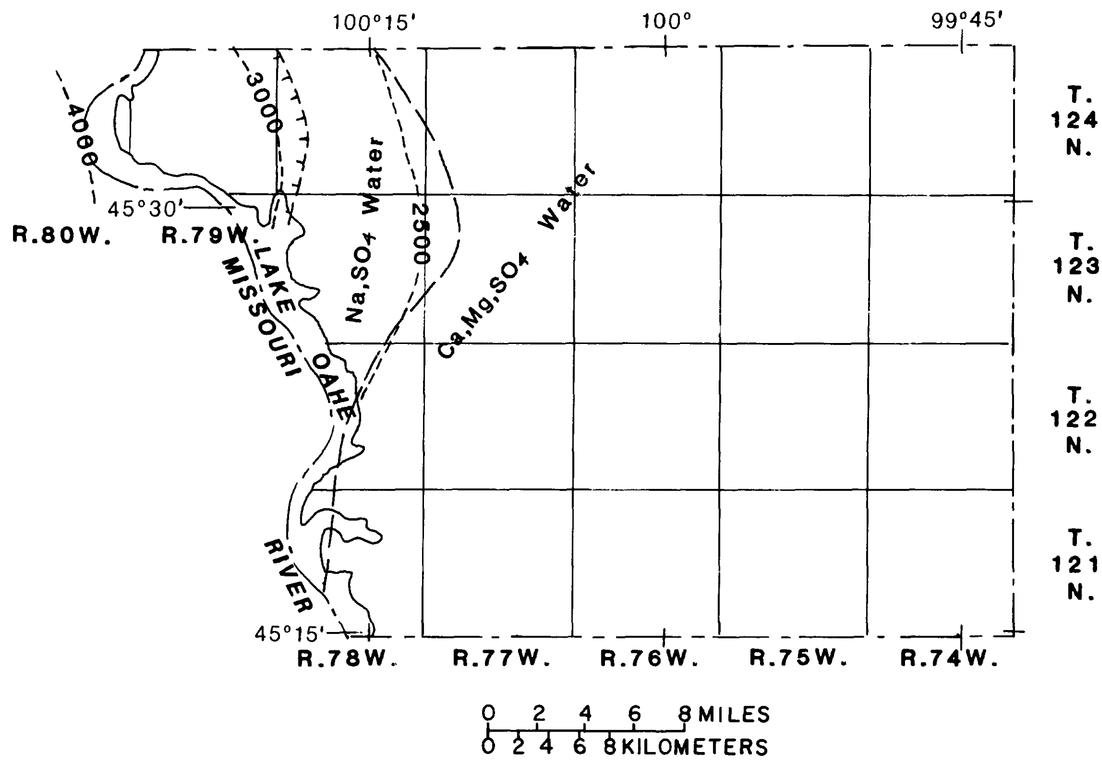
Figure 30.--Dissolved-solids concentration and geochemical facies in water of the Inyan Kara aquifer.

The ionic character of the water from the Sundance aquifer changes from sodium and sulfate dominance in the west to calcium magnesium sulfate dominance in the east because in the east the Sundance aquifer receives recharge from the underlying Minnelusa aquifer (by water that originated in Madison aquifer) near the eastern boundary of Range 79 West (fig. 31). The water is hard to very hard; the hardness ranges from less than 200 mg/L in the northwestern corner of the county to more than 1,300 mg/L in the eastern part of the county. The dissolved-solids concentration ranges from 2,300 to 2,500 mg/L in the eastern three-quarters of the county to about 4,000 mg/L in the northwestern corner. The sulfate concentration is very high; it ranges from more than 3,500 mg/L in the northwestern corner of the county to about 1,300 mg/L in the eastern half of the county. The bicarbonate concentration is about 350 mg/L in the northwest and about 200 mg/L or less in the eastern half of the county. The chloride concentration ranges from about 700 mg/L in the northwest to less than 200 mg/L in the eastern half of the county. The natural concentration of nitrate in the aquifer is less than 0.05 mg/L; of boron generally less than 500 µg/L; and of fluoride probably more than 2.5 mg/L, somewhat above the recommended limit. Thus, water from the Sundance throughout the county is of acceptable quality for livestock use, is unacceptable for irrigation, and is of poor to unacceptable quality for domestic and public supplies.

The ionic character of the water in the Minnelusa aquifer changes from sodium and chloride dominance in the northwest, to sodium, chloride, and sulfate dominance, to sodium and sulfate dominance to calcium magnesium sulfate dominance because near the northwest corner of Walworth County, the Minnelusa aquifer receives recharge from the underlying Madison aquifer a few miles west of the northwestern corner of Walworth County (fig. 32). The dissolved-solids concentration ranges from 2,300 to 2,500 mg/L in the eastern half of the county to almost 20,000 mg/L in the northwestern corner. The water is very hard to extremely hard; the hardness ranges from less than 500 mg/L in the northwestern corner of the county to about 1,200 mg/L in the middle of the county to about 1,300 mg/L along the eastern edge of the county. The sulfate concentration is very high; it ranges from more than 3,000 mg/L in the northwestern corner of the county to about 1,400 mg/L in the middle to 120 to 180 mg/L in the eastern half of the county. The chloride concentration is estimated to be about 10,000 mg/L in the northwestern corner of the county to about 300 mg/L in the middle to 100 mg/L or less along the eastern edge. The natural concentration of nitrate in the aquifer is less than 0.05 mg/L; of boron generally less than 500 µg/L; and of fluoride, generally more than 2.5 mg/L. Thus, water from the Minnelusa throughout the county ranges from acceptable in the east to unacceptable in the northwest for livestock, is unacceptable for irrigation, and is of poor to unacceptable quality for domestic and public supplies.

The interpretation of water quality given for the Minnelusa aquifer is provisional because of the small amount of reliable data available. In particular, the presence of the area containing more than 4,000 mg/L dissolved solids and the sodium chloride and sodium-chloride-sulfate geochemical facies are inferred from a few oil test-hole drill-stem tests made some distance west and northwest of Walworth County. The permeable zones tested may contain, or may be in contact with, beds of rock salt and the water might not be representative of the chemical quality of most of the water in the Minnelusa aquifer.

Because areal changes in the concentrations of the various dissolved constituents seem to be gradual in the Madison aquifer in north-central South Dakota, it was possible to develop a reasonable description of water quality even though no Madison aquifer water analyses were available within 30 mi of Walworth County. The dominant ions are



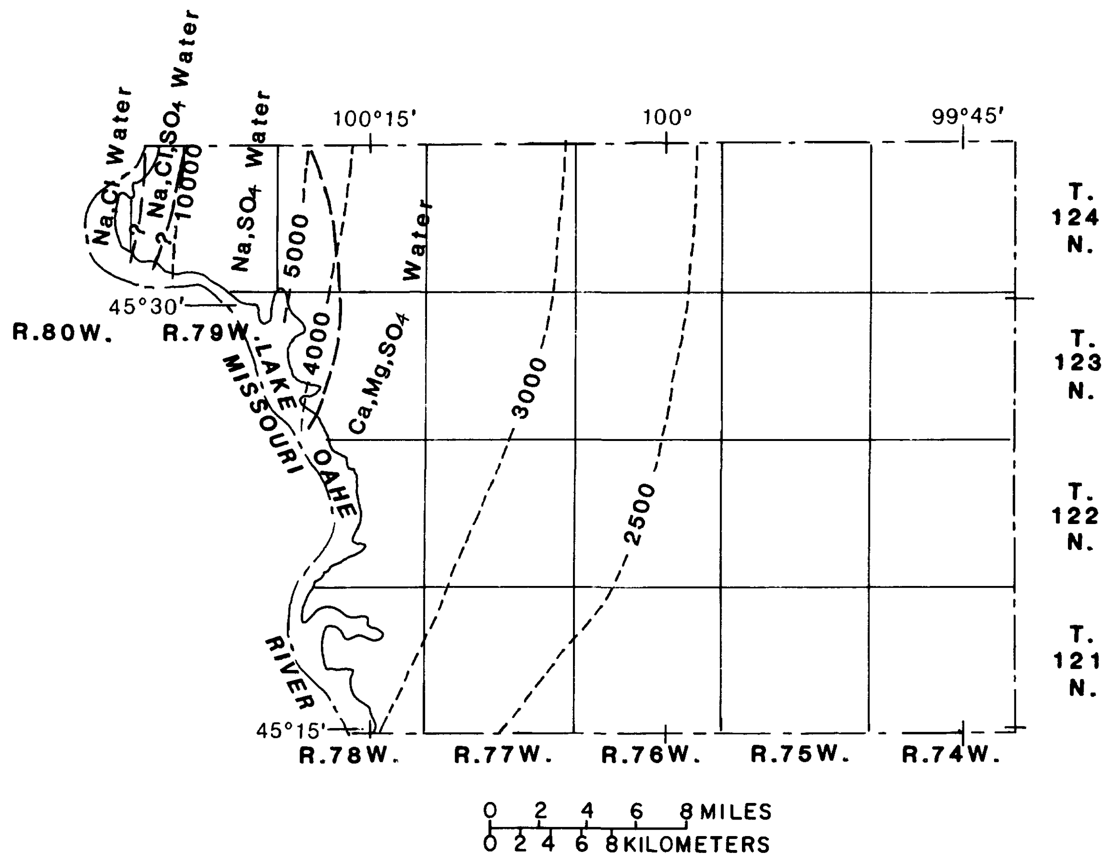
EXPLANATION

--- 4000 -- LINE OF EQUAL DISSOLVED-SOLIDS CONCENTRATION IN WATER IN THE SUNDANCE AQUIFER--Interval 1,000 milligrams per liter

⊥ ⊥ ⊥ ⊥ ⊥ RECHARGE BOUNDARY--East of boundary Sundance aquifer is recharged from Madison aquifer. West of boundary there is no evidance of recharge from the Madison to the Sundance

— — — — APPROXIMATE LOCATION OF GEOCHEMICAL FACIES CHANGE--Sodium sulfate water to the west, calcium magnesium sulfate water to the east

Figure 31.--Dissolved-solids concentration and geochemical facies in water of the Sundance aquifer.



EXPLANATION

— - - —3000— — LINE OF EQUAL DISSOLVED-SOLIDS CONCENTRATION IN THE MINNELUSA AQUIFER--Interval, in milligrams per liter, is variable

— — — — APPROXIMATE LOCATION OF GEOCHEMICAL FACIES CHANGE

Figure 32.--Dissolved-solids concentration and geochemical facies in water of the Minnelusa aquifer.

calcium, magnesium, and sulfate and the water is extremely hard. The hardness is 1,400 mg/L or more throughout the county and the sulfate concentration is generally between 1,300 and 1,500 mg/L, although it could be as much as 1,800 mg/L in the northwestern corner of the county. There may be a trend of decreasing sulfate and other major constituent concentrations from northwest to southeast. The dissolved-solids concentration decreases from about 4,000 mg/L in the northwestern corner of the county to 2,500 mg/L in the middle to slightly below 2,400 mg/L along the eastern or southeastern boundary of the county (fig. 33). The bicarbonate concentration ranges from 300 to 180 mg/L. The chloride concentration ranges from about 500 to less than 200 mg/L. The natural concentration of nitrate in the aquifer is less than 0.05 mg/L; of boron generally less than 50 µg/L; and of fluoride, generally more than 2.5 mg/L (and as much as 4 mg/L). Thus, water quality in the Madison aquifer is acceptable for livestock, unacceptable for irrigation, and of poor to unacceptable quality for domestic and public supplies.

The water quality from the Devonian, Stony Mountain, and Red River aquifers is believed to be like that in the Madison aquifer except where local inclusions of beds of evaporite minerals (such as rock salt or anhydrite) may locally influence the concentrations of dissolved solids.

The chemical quality of water from the Deadwood aquifer in Walworth County is unknown. The nearest water samples were collected from two oil-test wells more than 70 mi to the northwest of Walworth County, in the Williston Basin, and from a domestic well in North Dakota about 65 mi northeast of Walworth County. Drill-stem tests in the two oil-test wells recovered sodium chloride water that had dissolved-solids concentrations of 40,000 and 95,000 mg/L. The domestic well sample was of sodium sulfate water that had a dissolved-solids concentration of 3,800 mg/L. The probable flow path of water in the Deadwood aquifer from the recharge area in the Black Hills to Walworth County is south of the part of the Williston Basin where the aquifer contains water of high chloride and dissolved-solids concentrations. Therefore, water in the Deadwood aquifer in Walworth County probably is of sodium sulfate type, and has a dissolved-solids concentration between 2,500 and 3,500 mg/L, hardness less than 300 mg/L, bicarbonate concentration less than 200 mg/L, chloride concentration less than 600 mg/L, boron concentration of about 2,000 µg/L, and a fluoride concentration of more than 2.5 mg/L. The water probably is suitable for livestock but unacceptable for irrigation and of poor to unacceptable quality for domestic and public supplies.

SUMMARY

Walworth County has widely distributed and relatively undeveloped surface-water and ground-water resources. However, these resources probably could not support large scale uses such as irrigation in at least three-fourths of the area because of low yields or water-quality criteria.

The largest, and only reliable, source of surface water is Lake Oahe. Its average annual inflow to Walworth County is more than 16 million acre-feet and its average storage volume is more than 22 million acre-feet. Lake Oahe is the source of water for several irrigation withdrawals. Development of Lake Oahe appears to be an attractive solution to water shortages and a source of water for irrigation. However, the cost of such development probably will restrict it to large projects or to individual users within a mile or so of the lake.

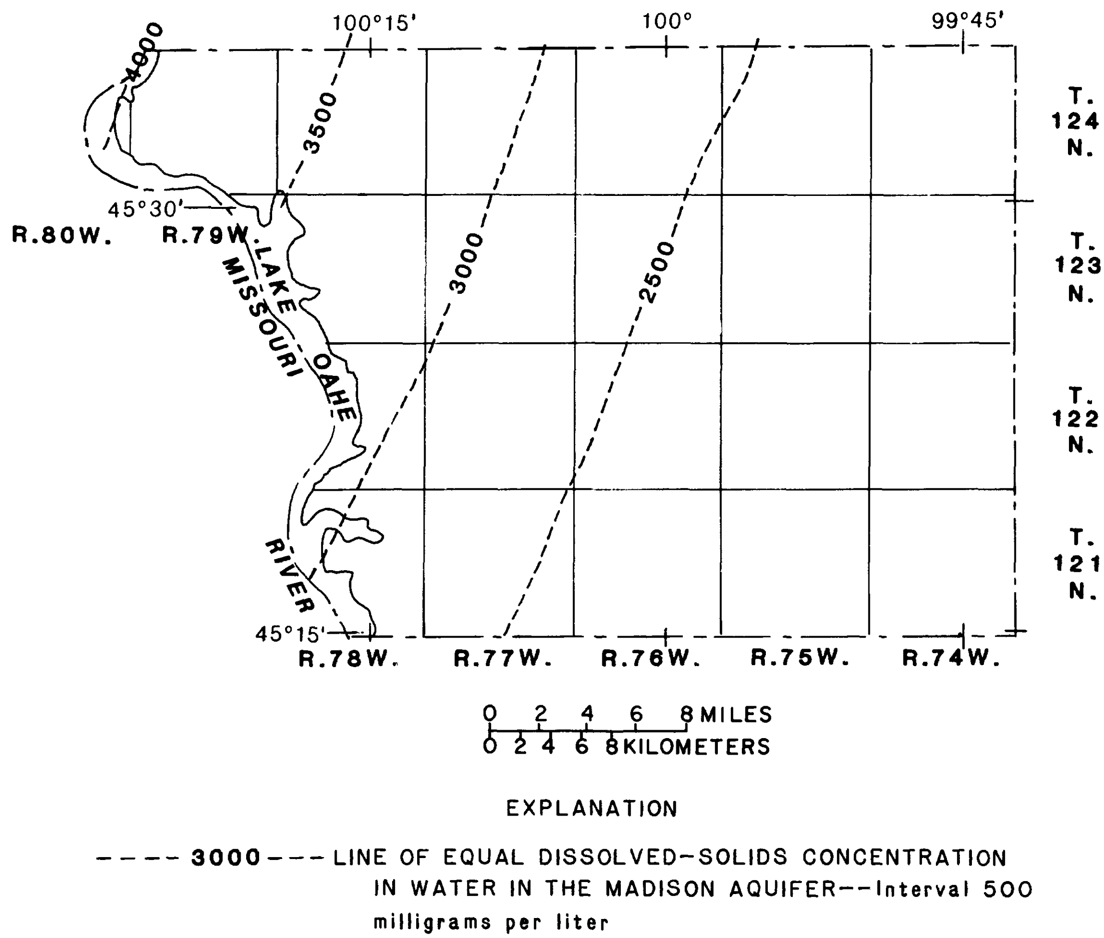


Figure 33.--Dissolved-solids concentration in water of the Madison aquifer.

Other streams are used mostly as sources to fill stock dugouts and stock ponds, and usually are dry except at times of spring snowmelt or heavy rain. The surface runoff is widely developed for livestock supplies. Although lake-evaporation loss rates are high, as much as 36 inches a year, dams and dugouts are a comparatively inexpensive way to hold snowmelt and storm runoff for later use at widely dispersed sites.

The few natural lakes in the county are used for livestock and recreation. Although some lakes and ponds are saline, the water normally contains less than 1,500 milligrams per liter dissolved solids.

The four major and four minor aquifers in the drift underlie about 300 square miles (192,000 acres) or 40 percent of the county and contain an estimated 1,186,000 acre-feet of water. Locally, water in the shallow aquifers may contain high concentrations of nitrate.

Aquifers in the bedrock contain slightly saline to very saline water (dissolved-solids concentrations ranging from about 2,300 to more than 20,000 milligrams per liter). Eight major bedrock aquifers underlie the entire county and two minor bedrock aquifers underlie parts of the county. The bedrock aquifers are estimated to contain more than 55 million acre-feet of water within the county.

Hydrologic information about the ground-water supplies in Walworth County is summarized in table 4.

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