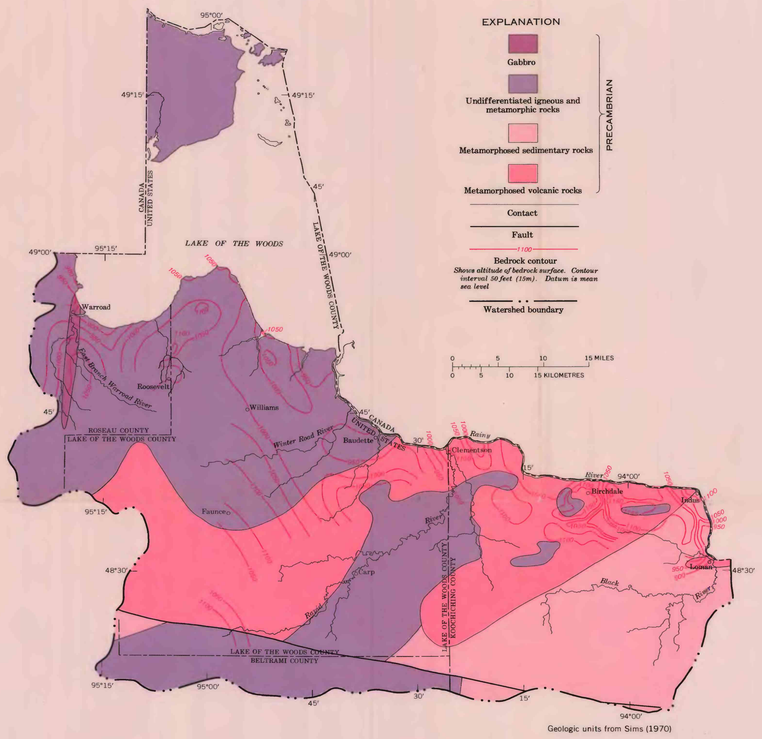
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

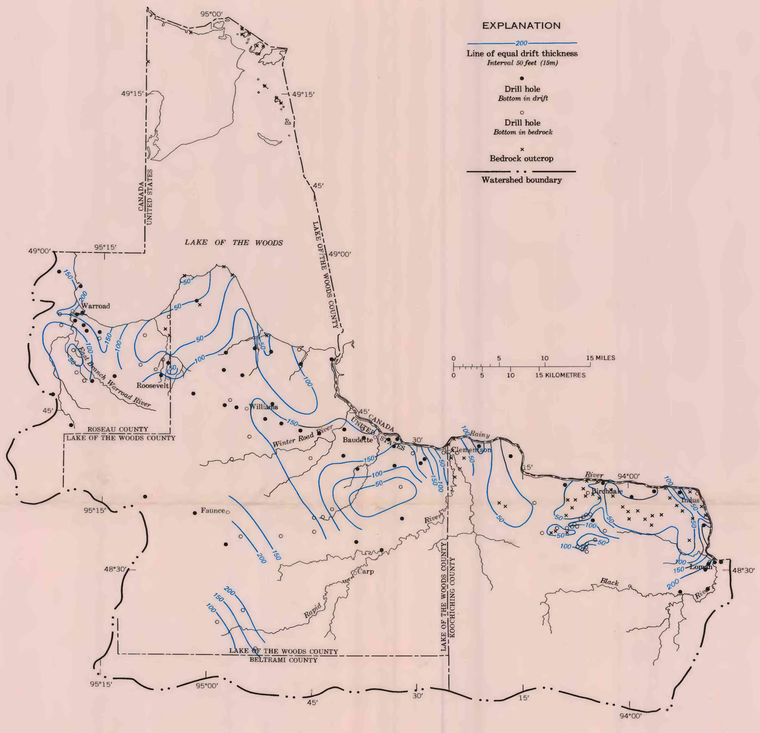
PREPARED IN COOPERATION WITH THE
MINNESOTA DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATERS, SOILS, AND MINERALS

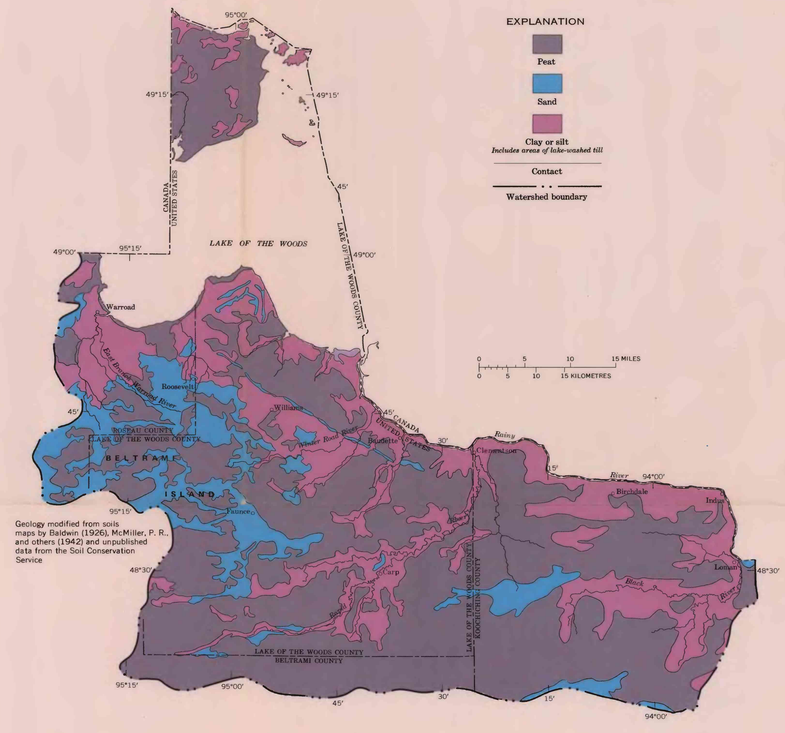
HYDROLOGIC INVESTIGATIONS
ATLAS HA-544 (SHEET 2 OF 2)

GEOLOGY AND GROUND WATER



Geologic units from Sims (1970)



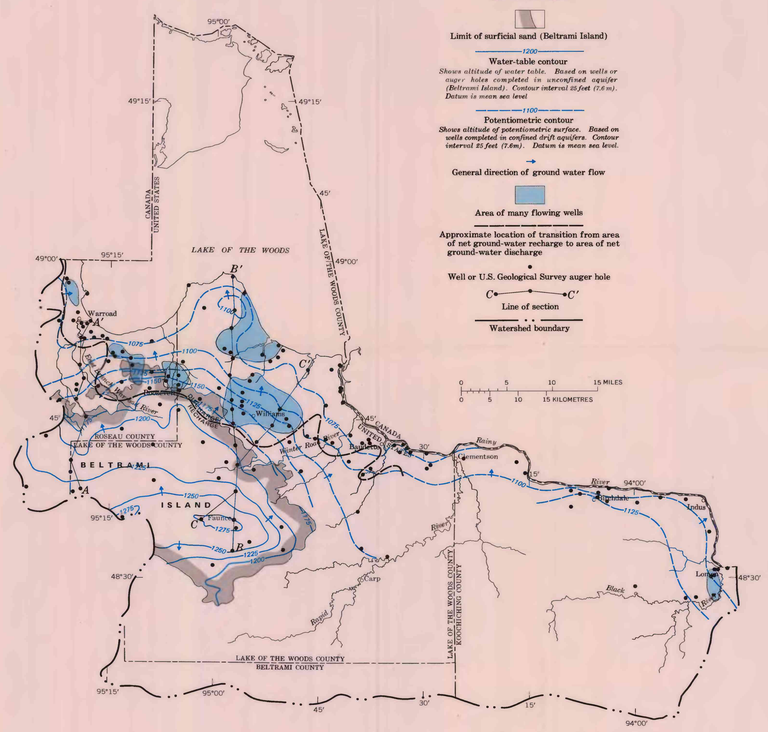


Geology modified from soils maps by Baldwin (1926), McMiller, P. R., and others (1942) and unpublished data from the Soil Conservation Service

BEDROCK IN THE WATERSHED CONSISTS OF A COMPLEX OF PRECAMBRIAN IGNEOUS AND METAMORPHIC ROCKS—*Bedrock distribution is mainly inferred from gravity and aeromagnetic data (Sims, 1970). Occurrences of Cretaceous sediments (clay, sand, and lignite) are reported in the vicinity of Warroad, but data are not sufficient to delineate them. Although a general northwest-southwest trend of bedrock surface contours is evident, locally the surface is highly irregular.*

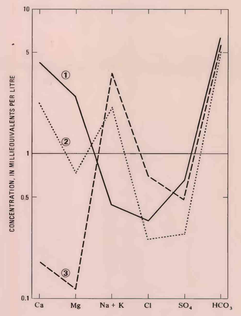
GLACIAL DRIFT THICKNESS RANGES FROM ZERO TO GREATER THAN 200 FEET (60 M) IN THE WATERSHED—*Thinnest drift is near Rainy River and Lake of the Woods. In the eastern part of the watershed, where subsurface control permits relatively close definition, extreme variability in drift thickness is evident. Within a mile of a bedrock outcrop, drift thickness may exceed 100 feet (30 m).*

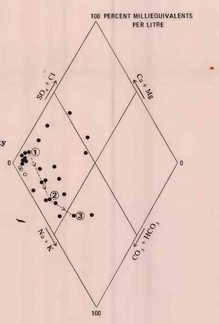
PEAT COVERS ABOUT HALF THE WATERSHED AND IS MOST EXTENSIVE IN THE SOUTHEASTERN PART—*Thickness of peat ranges from 0 to about 15 feet (5 m) (Baldwin, 1926). Sand and till underlie the peat and form the surficial material elsewhere. The largest sand area is part of Beltrami Island, which extends beyond the western watershed boundary. Beltrami Island is a complex of beach and bar deposits which formed an island in glacial Lake Agassiz. Single beach ridges are as much as 15 feet (5 m) above the general land surface. Lake deposits in most other areas are absent or generally only a few feet thick, and the surface consists chiefly of lake-washed till. Allison (1932) reported lacustrine clay as much as 50 feet (15 m) thick north of Baudette, adjacent to Rainy River and Lake of the Woods. Till, generally exposed along major streams and near Lake of the Woods, has a high clay content, is calcareous, and contains numerous carbonate rock fragments.*



Source of ground water	Statistical parameter or U.S. Geological Survey well number	Chemical constituents and hardness, in milligrams per litre														pH
		Dissolved silica	Iron	Manganese	Calcium	Magnesium	Dissolved sodium	Dissolved potassium	Bicarbonate	Dissolved sulfate	Dissolved chloride	Fluoride	Nitrite + nitrate as nitrogen	Boron	Dissolved solids (residue)	Total hardness as $CaCO_3$	
Glacial drift[1]	Maximum	26	2.1	0.47	120	56	120	14	539	290	27	1.5	26	0.45	764	510	8.0
	Median	19	.2	.07	62	28	38	4.2	357	23	6.0	.2	.06	.13	440	270	7.7
	Minimum	8	Trace	0	30	9.4	1.9	.3	130	3.5	1.0	0	0	.01	160	110	7.2
Bedrock	160.33.18 bdc 2	32	1.7	.07	80	29	10	2.9	425	4.1	1.4	.2	.02	.07	442	320	7.4
	162.35.28 aba	25	.94	.10	72	30	14	3.3	395	7.1	1.7	.3	0	.08	352	300	7.6
	162.36.29 dcd	24	2.7	.06	73	42	9.1	3.0	449	6.9	1.6	.2	0	.03	372	350	7.5
Recommended limits for domestic consumption (Minn. Water Pollution Control Comm., 1967)			.30	.05						250	250	1.5	10		500		

[1] Data based on 25 samples, except data for silica and potassium, which are based on 24 samples, and manganese, fluoride, boron, and pH which are based on 19 samples

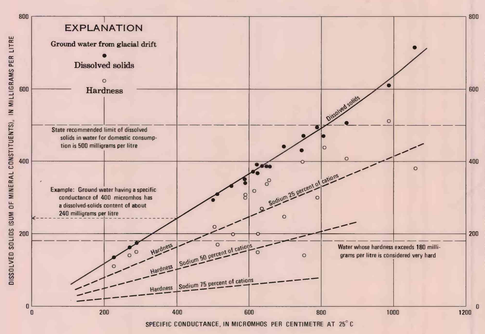




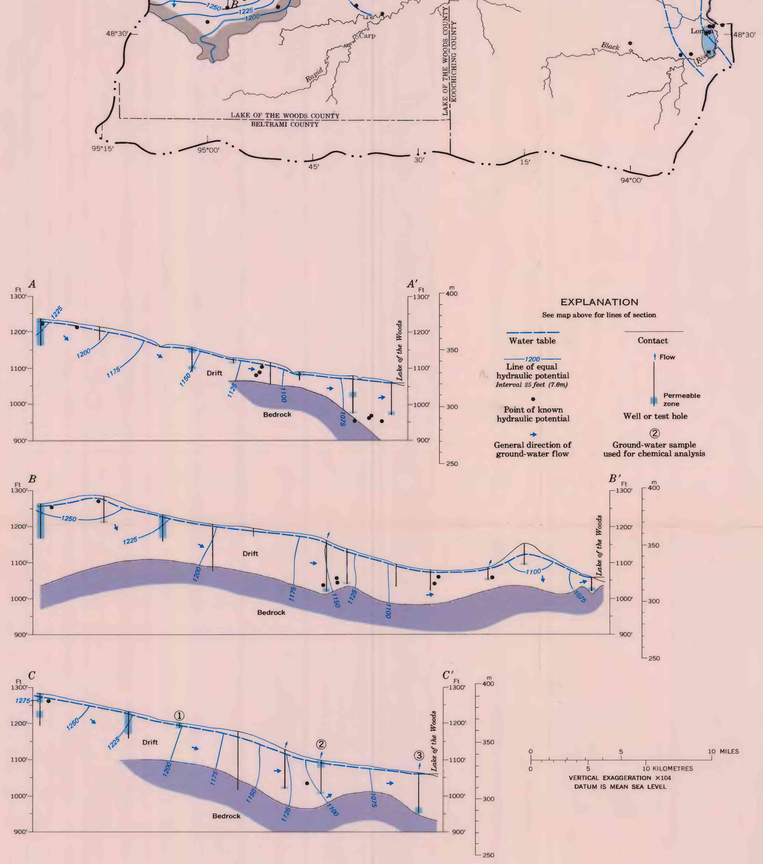
MOST GROUND WATER IN THE WATERSHED IS OF THE CALCIUM MAGNESIUM BICARBONATE TYPE—*Exceptions occur near Rainy River and Lake of the Woods, where sodium bicarbonate water results from cation exchange (calcium and magnesium for sodium) as the water moves through clay-rich till. The transition from calcium magnesium bicarbonate water, typical of the recharge area, to sodium bicarbonate water is related to regional ground-water movement, as demonstrated on the accompanying graphs and section C-C' lower left. In the vicinity of Baudette, some ground water is of the calcium magnesium sulfate type, probably a reflection of variable mineral composition of drift.*

Water from bedrock, on the basis of three samples, does not seem to be of significantly different chemical quality than that from glacial drift. Ground water in the watershed is generally very hard (greater than 180 milligrams per liter), and iron and manganese are commonly troublesome (iron greater than 0.3, and manganese greater than 0.05, milligrams per litre).

A summary of ground-water quality is presented in the table above.



ESTIMATES OF DISSOLVED SOLIDS CAN BE MADE FROM DETERMINATIONS OF SPECIFIC CONDUCTANCE—*Hardness estimates are impracticable because of the wide variation of dissolved sodium. The slope of the line defining the specific conductance-hardness relationship decreases as sodium percentage increases. Because sodium percentage is related to the amount of cation exchange, the specific conductance-hardness relationship depends upon position in the regional flow system.*



DISSOLVED-SOLIDS CONTENT OF GROUND WATER GENERALLY INCREASES IN THE DIRECTION OF REGIONAL GROUND-WATER MOVEMENT (SEE WATER-MOVEMENT MAP)—*This is partly attributed to increased contact time with soluble minerals as ground water moves from the recharge to the discharge area. In addition, least mineralized water is generally in surficial sands containing little soluble material. More highly mineralized water occurs in association with till, which contains (1) more soluble minerals and (2) more clay particles, resulting in greater surface area in contact with the water.*

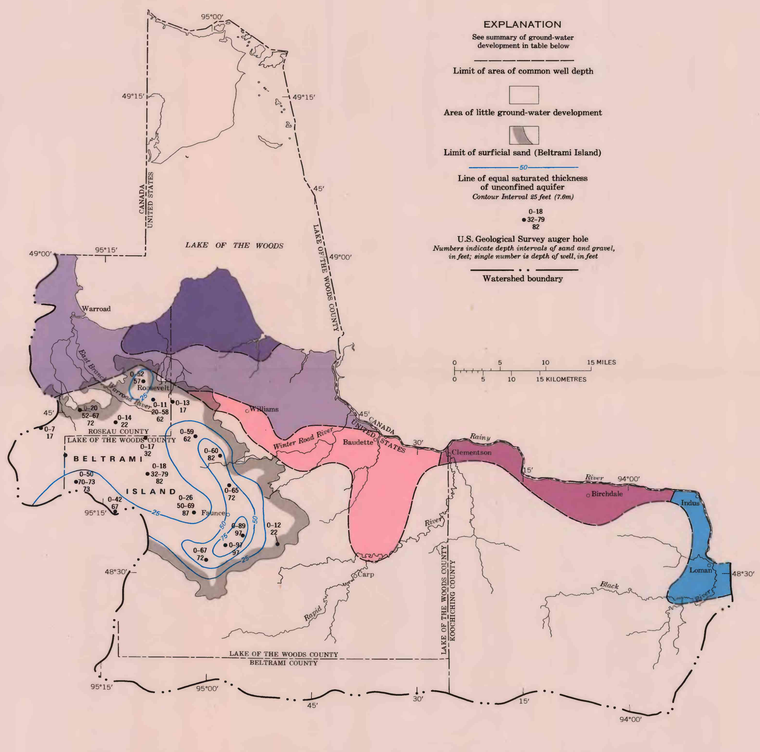
Area of common well depth	Numbers of wells on record	Depth range and median for 80 percent of wells (feet below land surface)	Static water level range and median for 80 percent of wells (feet above (+) or below (-) land surface)	Available drawdown[1] range and median for 80 percent of wells (feet)
	16	25 to 60 35	+2 to −18 −2	16 to 45 34
	82	53 to 115 83	+2 to −15 −5	34 to 106 70
	41	84 to 155 116	+2 to −30 −11	69 to 135 107
	17	29 to 82 52	−3 to −28 −12	19 to 77 38
	12	61 to 209 186	+2 to −15 −6	49 to 200 182

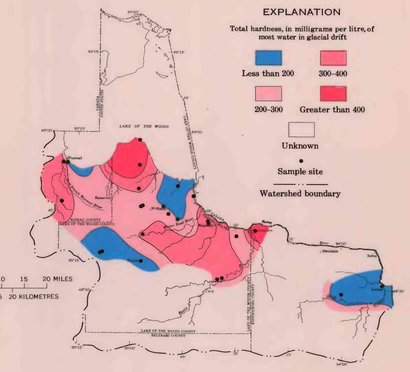
[1] Vertical distance between static water level and top of aquifer.

ANALYSIS OF CURRENT DEVELOPMENT IS USED TO DELINEATE APPROXIMATE EXTENT AND DEPTH OF INTERVALS CONTAINING AQUIFERS—*Virtually all ground water withdrawn is from confined drift aquifers. Although data are insufficient to map individual aquifers, areas of common well depth indicate that some lateral continuity exists. Yields adequate for domestic and stock use, generally less than 15 gallons per minute (60 liters per minute), can be obtained in most parts of the developed area. Available drawdown, governed by well depth and static head, is commonly sufficient to make sustained small-yield withdrawals possible without penetrating a large part of an aquifer. About half the small-yield wells are open-ended, whereas most others are screened. Although large-yield wells have been completed only at Baudette and Warroad, it is probable that yields of several hundred gallons per minute could be obtained from confined drift aquifers elsewhere in the watershed.*

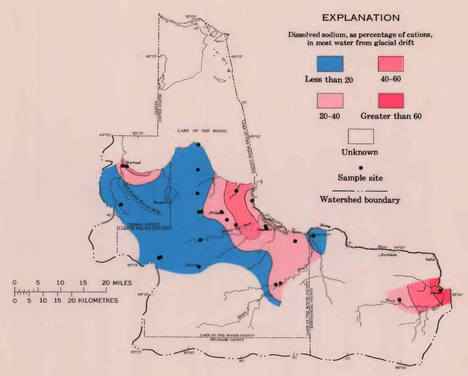
Saturated thickness of surficial sand on Beltrami Island is as much as 90 feet (27 m), as determined by test augering. The sand is predominantly fine to medium and includes some gravel. Although the aquifer is underdeveloped, that part within the watershed is estimated to contain about 1.3 million acre-feet (1,603 hm) of recoverable water. The thickest part of the aquifer is theoretically capable of short-term yields of as much as 1,000 gallons per minute (4,000 liters per minute) to individual wells. Where saturated thickness is less than 25 feet (8 m), theoretical well yields are generally less than 100 gallons per minute (40 liters per minute). Confined sand and gravel aquifers were found beneath the unconfined aquifer in several test holes.

Only a few wells withdraw water from bedrock, and water-yielding capability of the bedrock is probably very low. Yields depend largely on the amount and interconnection of fractures.





WATER FROM THE UNCONFINED AQUIFER (BELTRAMI ISLAND) IS GENERALLY SOFTER THAN WATER FROM CONFINED DRIFT AQUIFERS—*Hardness increases as ground water begins to move through the regional flow system and dissolve carbonate minerals in the drift. As it moves northward, ground water becomes softer in some areas as a result of cation exchange. Softening is greatest as ground water approaches Rainy River and Lake of the Woods, end points in the regional flow system.*



THE PERCENTAGE OF DISSOLVED SODIUM IN GROUND WATER REFLECTS THE AMOUNT OF SOFTENING THAT HAS OCCURRED THROUGH CATION EXCHANGE—*In some areas sodium percentage increases in the direction of regional ground-water flow, being highest near the Rainy River and Lake of the Woods. Sodium constituted from 3 to 65 percent of the cations in the samples analyzed.*

REGIONALLY, GROUND WATER MOVES NORTHWARD TOWARD THE RAINY RIVER AND LAKE OF THE WOODS, END POINTS IN THE FLOW SYSTEM—*Some water moves within small flow systems controlled by local topography. The regional ground-water flow system is recharged in the southern part of the watershed and is discharged farther north. Beltrami Island, because of its high altitude and sand composition, is particularly effective as an area of recharge. On Beltrami Island, shallowest ground water is unconfined, and its movement is defined by water-table contours; deeper water is confined by till. As ground water moves from Beltrami Island, virtually all water becomes confined by till, and its movement is defined by potentiometric contours. Approximate correspondence of water-table and potentiometric contours demonstrates hydraulic connection between the unconfined and confined aquifers. Although movement is nearly horizontal, the vertical distribution of head (see sections) demonstrates the regional change from ground-water recharge (downward flow component) to ground-water discharge (upward flow component). Vertical head distribution in the discharge area is such that water in wells rises near or above the land surface, depending on local topography. Natural yields of flowing wells are generally less than 5 gallons per minute (20 liters per minute). Potentiometric data in the eastern part of the watershed are insufficient to define the recharge and discharge areas.*

Irregularities of the bedrock surface affect ground water flow. In section C-C', for example, the upward component of groundwater flow is increased by the damming effect of a bedrock high.

Base from U.S. Geological Survey, 1:250,000
Kenora (1963), International Falls (1954), and Roseau (1954)

Interior—Geological Survey, Reston, Va.—1975

WATER RESOURCES OF THE LAKE OF THE WOODS WATERSHED, NORTH-CENTRAL MINNESOTA

By
J. O. Helgesen, G. F. Lindholm, and D. W. Ericson

1975