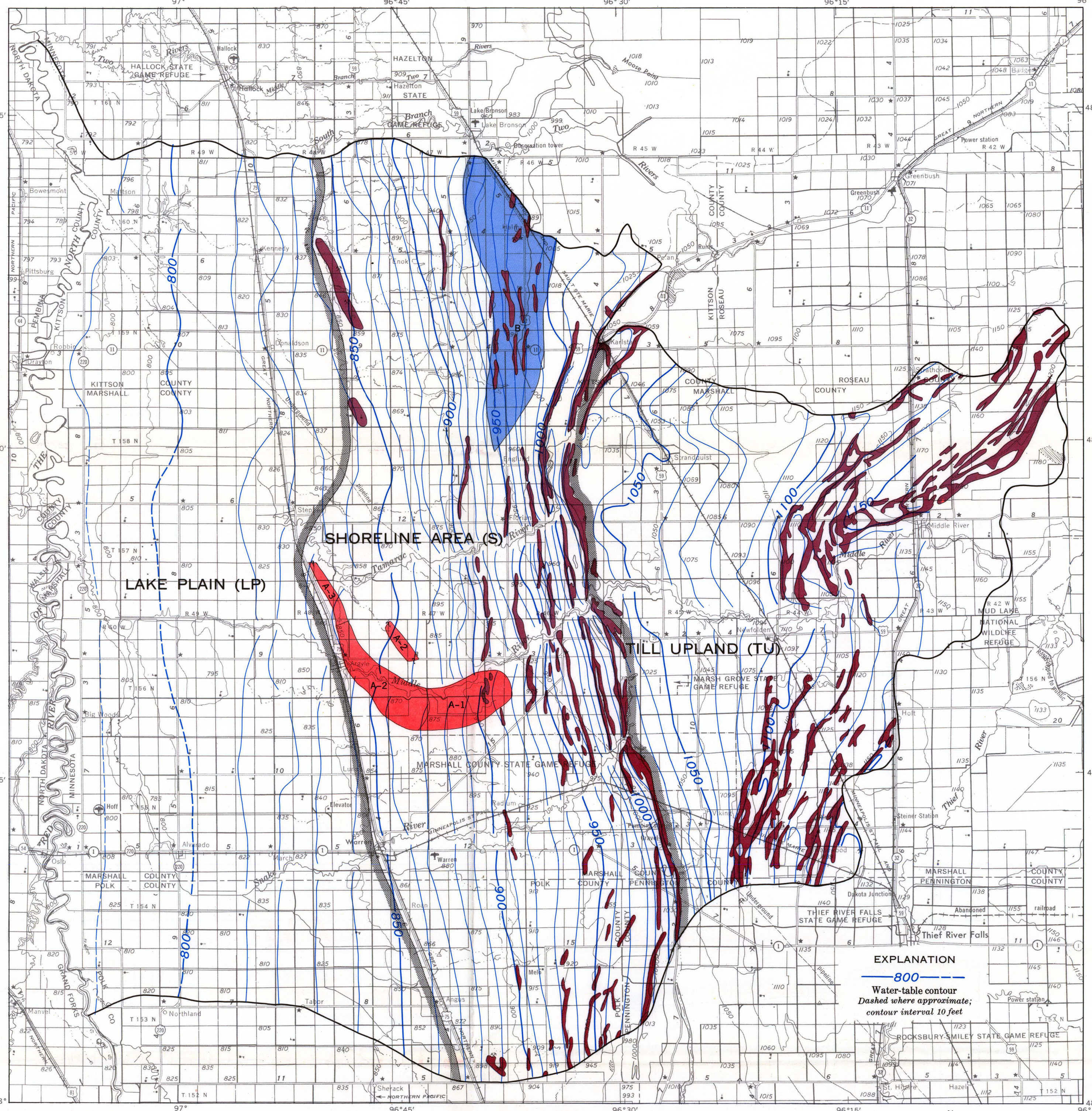
PREPARED IN COOPERATION WITH
THE MINNESOTA DEPARTMENT OF CONSERVATION
DIVISION OF WATERS

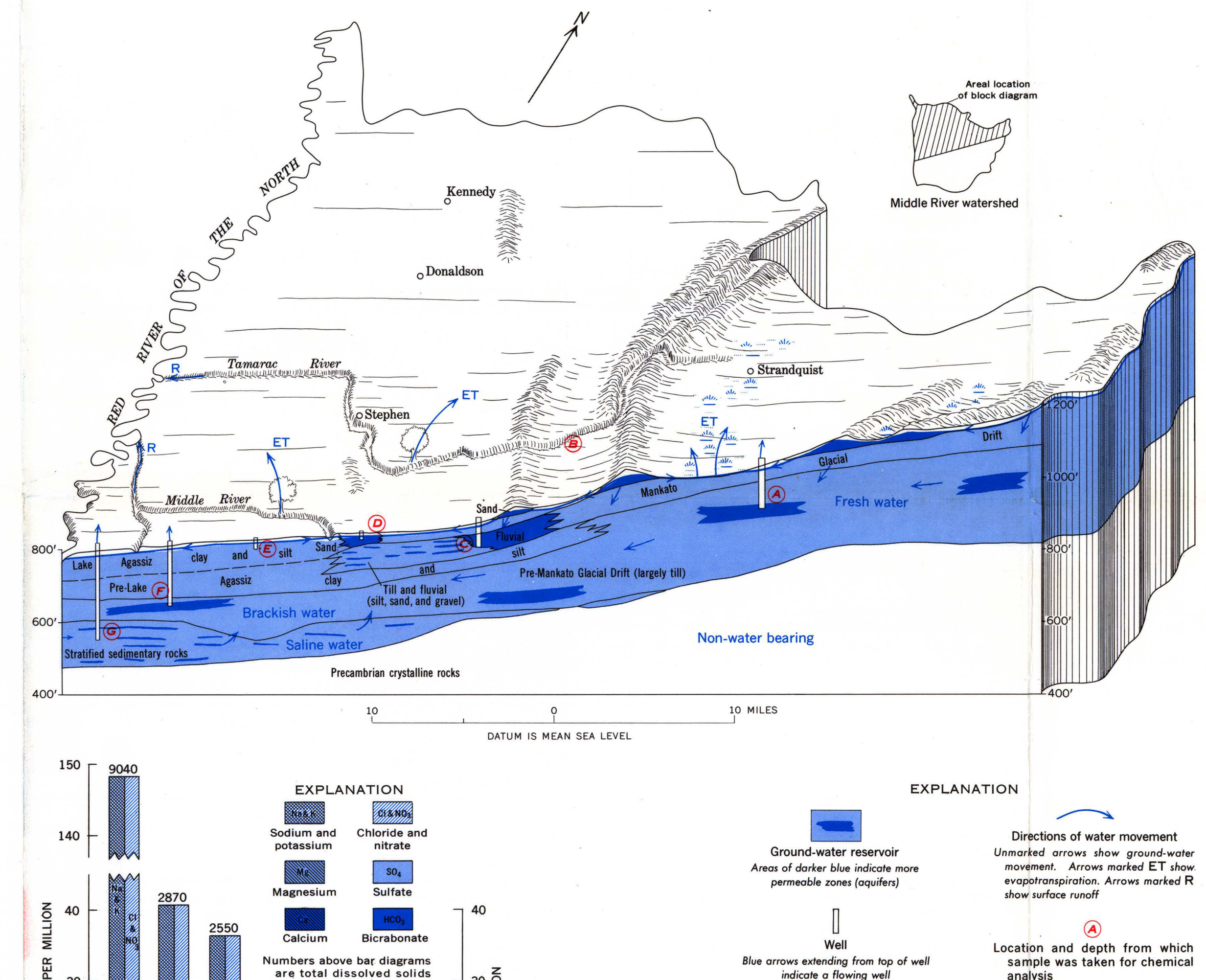
GROUND WATER

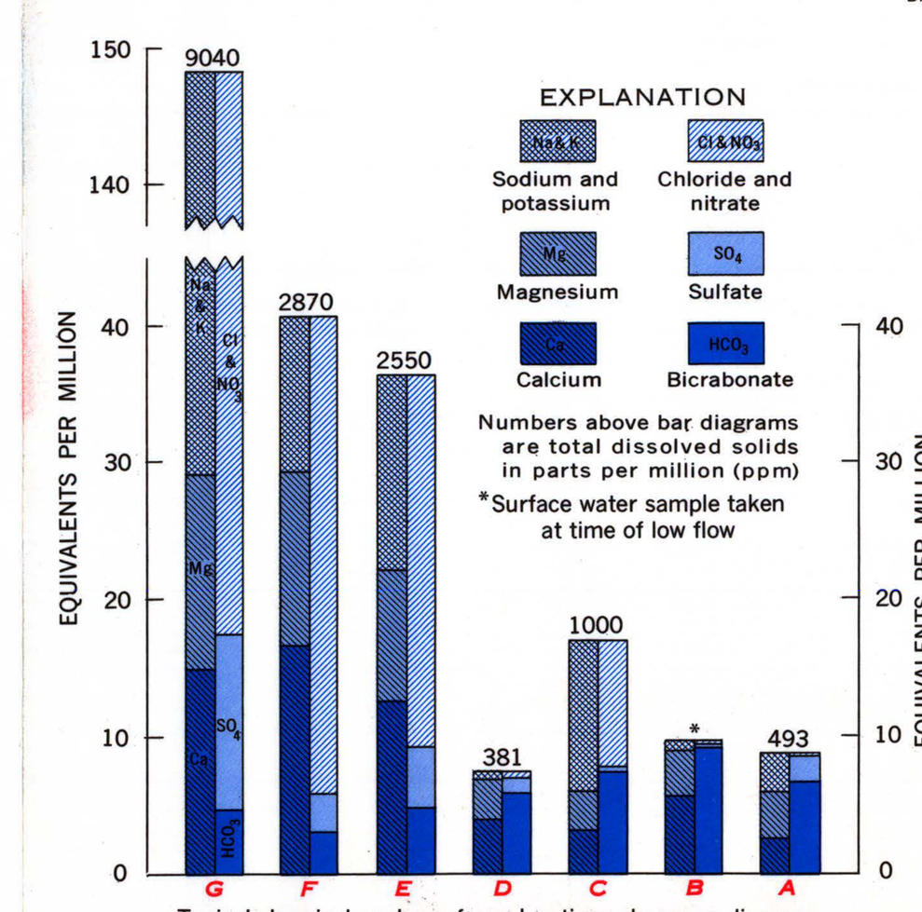


Base by Army Map Service, 1953

SCALE 1:250 000

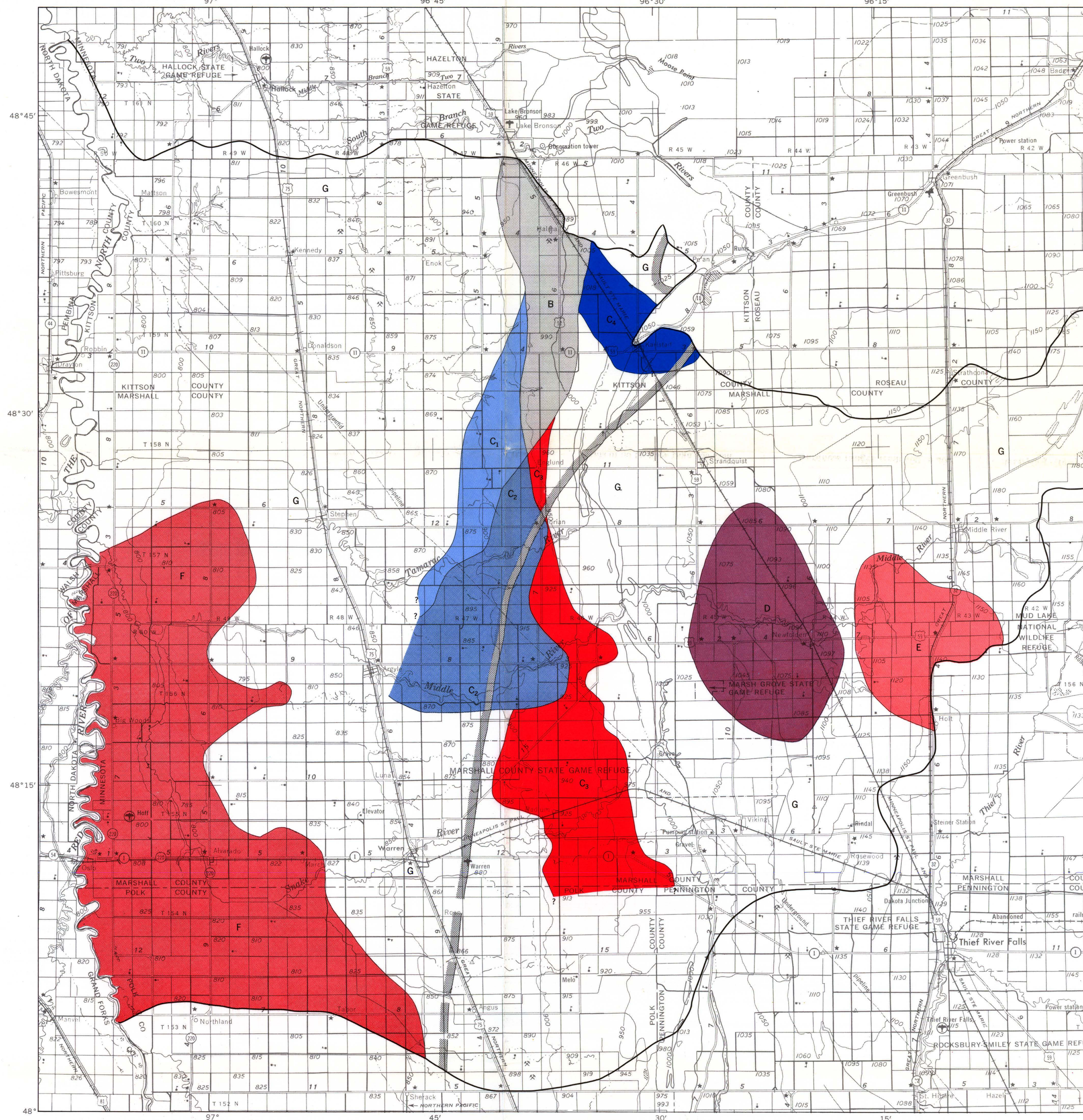
CONTOUR INTERVAL 50 FEET
DATUM IS MEAN SEA LEVEL





Typical chemical analyses from locations shown on diagram

WATER MOVEMENT.—*Most water that enters the Middle River watershed either runs off directly as streamflow or is quickly lost by evapotranspiration. Infiltration to the ground-water reservoir occurs mostly beneath beach deposits. The general direction of water movement is from east to west through the unconsolidated deposits overlying the crystalline basement rocks. In the eastern part of the watershed the water quality is very poor because of the contamination by upward seepage of highly saline water from the stratified sedimentary rocks*



Base by Army Map Service, 1953

SCALE 1:250 000

CONTOUR INTERVAL 50 FEET
DATUM IS MEAN SEA LEVEL

GENERAL AREAS

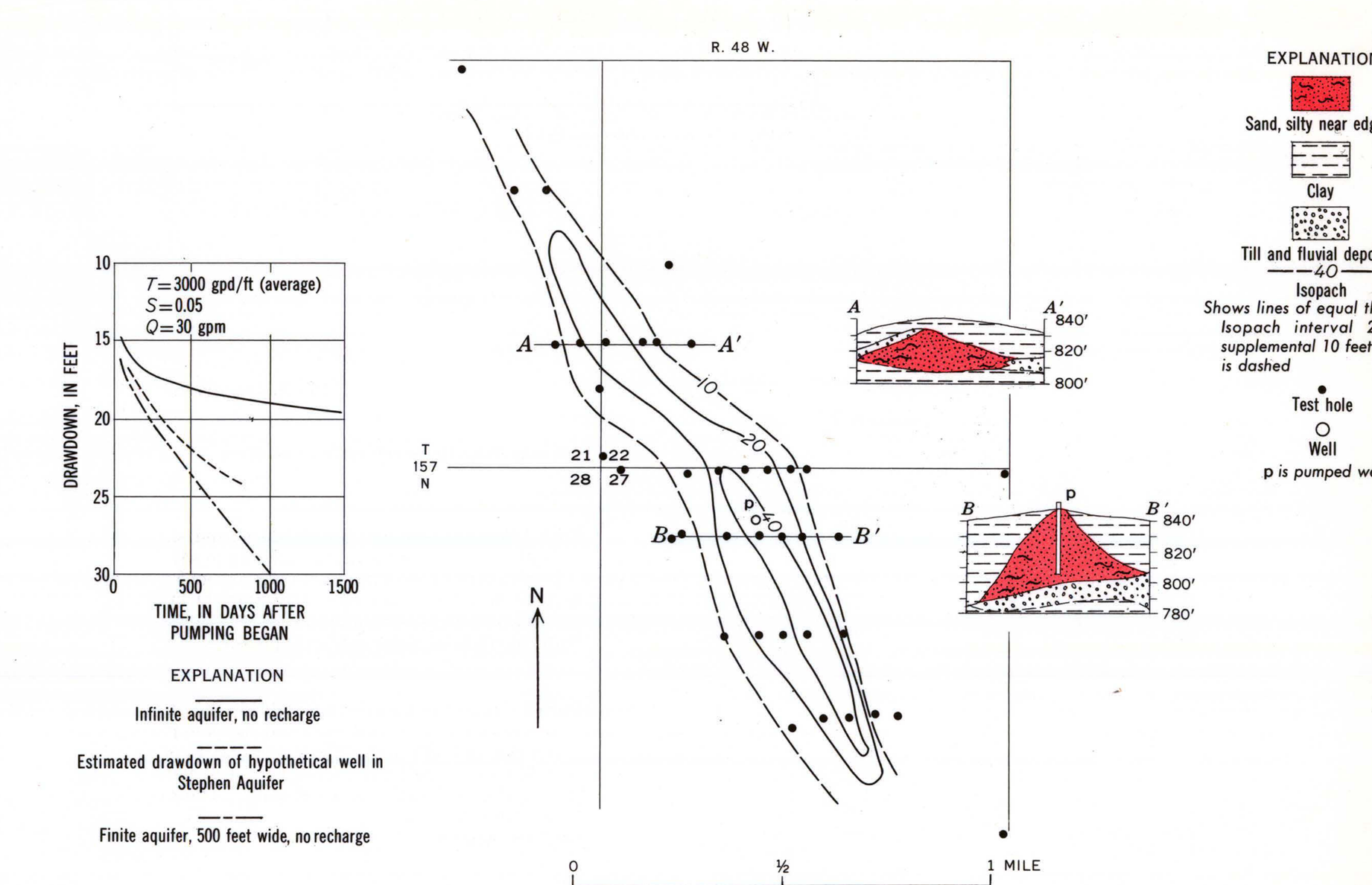
Area symbol	Aquifer characteristics	Thickness (ft.)	Yield	Quality	Basic data
LP	Deep Water Lake Deposits—Clay, gray to blue gray, plastic, dense, contains lenses of silt and very fine sand. Deposits are largely impermeable, but transmit some water in the silt and very fine sand lenses. Till (see below) underlies the lake clays. In this area the till is commonly interlayered with older lake clays.	0-100+	Clay yields no water to wells. Silt and very fine sand lenses yield less than 1 gpm to large-diameter dug wells. These wells commonly go dry during the summer months.	Poor; commonly high in chloride and sulfate. Unsuitable for domestic use.	Well data Auger logs Rotary logs
S (Excluding mapped aquifers)	Shallow Water and Shoreline Deposits—Interbedded clay, silt, and fine sand. Predominantly clay near the Lake Plain area gradually changing to fine sand in the eastern part of the Shoreline area. Unsaturated except for lower few feet in western part of Shoreline area. Shoreline area also includes unmapped sand and gravel deposits as much as 20 feet thick. Till (see below) underlies these deposits. In this area thin lenses of older lake clays are interlayed with the till.	0-30	Yields little to no water at most places. Unmapped sand and gravel deposits may yield up to 20 gpm to wells.	Poor to fair; hard and commonly high in chloride in area near Lake Plain; hard, but low in chloride near the Till Upland.	Auger logs
TU (Excluding mapped aquifers)	Till—a heterogeneous mixture of clay, silt, sand, and gravel. Till is locally capped by thin deposits of sand. Upper 2 to 10 feet of till is commonly oxidized to a buff-brown color. At some places the oxidized till is slightly more permeable than the unoxidized till.	0-300+	Small yields—generally less than 3 gpm to large-diameter wells in the oxidized till. Locally, lenses of sand and gravel may yield up to 30 gpm, but at most places yields of less than 5 gpm can be expected.	Hard water; high iron content; low in chloride.	Well data Auger logs Rotary logs
MAPPED SURFICIAL AQUIFERS					
A	Alluvial and Lake Bar Deposits—predominantly of sand and silt and containing lenses of gravel. A–1 is largely fine sand and silt of alluvial origin. It contains much silt and clay. A–2 is predominantly fine sand containing lenses of coarse sand, gravel, and silt. A–3 contains fine to medium sand, silt, and clay. Much of the northern 1½ miles of A–3 is covered by clay. Thickest deposits in unit A are found in the center of A–3. Depth to saturated zone ranges from 5 to 10 feet below land surface. Water is unconfined except in northern part of A–3.	0-60	Small to moderate yields. Yields of 50 gpm or more are available in parts of A–2. Yields of 5 to 50 gpm are available in A–3. Yields of 5 to 15 gpm are available in A–1.	Hard water; high iron; chloride content ranges from about 50 ppm in A–1 to more than 600 ppm in northern part of A–3.	Well data Pumping tests Numerous auger logs Rotary logs
B	Channel Deposits (outwash)–predominantly sand to medium gravel but includes beds of silt and clay toward channel margins. The coarser materials occur in thicker parts and include cobble and boulder beds. Deposit is almost completely saturated and water is unconfined. At low places deposit is entirely saturated.	0-130	Moderate to large yields. Yields of more than 1,000 gpm could be obtained from thick sections of coarser deposit. Yields of less than 100 gpm are available in marginal areas.	Hard water; low chloride.	Well data Pumping test Rotary logs Auger logs Electric logs
(Beach symbol)	Beach and Bar Deposits—fine to coarse sand with lenses of gravel. Deposits form northward-trending ridges that range in length from a few hundred feet to more than 10 miles and range in width from less than 200 feet to more than half a mile. Heights of ridges range from a few feet to more than 25 feet. Some beaches, such as the one east of Kennedy, overlie channel deposits of sand and gravel. At most places the beaches are underlain by till. In general, the larger beaches contain coarser and more permeable deposits than smaller beaches or bars. Saturated thickness ranges from less than 1 foot in smaller bars to more than 10 feet in larger beaches. Near Kennedy the saturated thickness of these deposits is more than 35 feet. Water is unconfined.	0-20±	Small to moderate yields. Yields of more than 50 gpm are obtained at places where beach deposits overlie shallow channel deposits. Yields of less than 20 gpm are obtained from wells in larger beach ridges underlain by till. Wells in smaller ridges go dry during dry years.	Hard water; low chloride. Water from some wells in farm yards contain a high nitrate content, indicating pollution.	Well data Auger logs Soils maps

AVAILABILITY OF WATER FROM MAJOR PHYSIOGRAPHIC SUBDIVISIONS IN THE MIDDLE RIVER WATERSHED AND AREAS WHERE WATER CAN BE OBTAINED FROM KNOWN SURFICIAL AQUIFERS

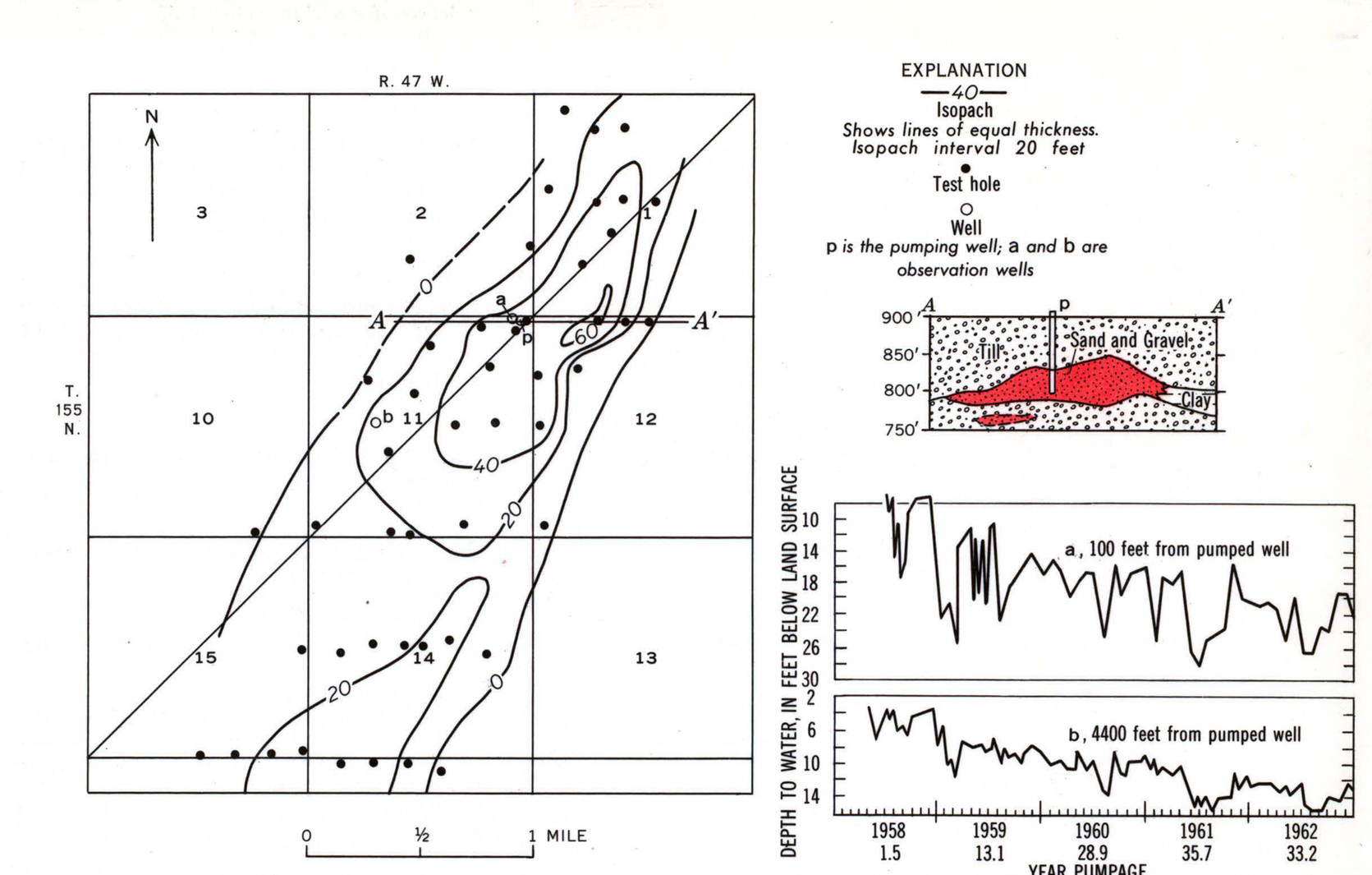
MAPPED SUBSURFACE AQUIFERS

Area symbol	Aquifer characteristics	Thickness (ft.)	Yield	Quality	Basic data
B	See map showing known surficial aquifers				
C_1	Buried Channel Deposits—Interbedded sand, silt, and clay. Predominantly fine sand in upper part grading to silt and clay in lower part. Thickness of sandy upper part ranges from 5 to 40 feet. A surficial cover of lake clay ranging in thickness from 20 to 60 feet overlies aquifers at most places. Water is confined under moderate pressure.	0-80±	Yields of more than 20 gpm probably could be developed by drilling large-diameter wells that are screened and sand packed in the thicker sand zones.	Hard; chloride content in water from sand zone in southern part of aquifer area was 320 ppm. Chloride content probably decreases toward the north. Gas pockets were tapped during drilling of several auger holes.	Rotary logs (few) Auger logs Electric logs
C_2	Buried Channel Deposits—Interbedded sand, silt, and clay. Predominantly fine to very fine sand and silt in upper part grading to silt and clay in lower part. The upper part ranges in thickness from 5 to 50 feet. Aquifer is capped by a well-compacted till containing very few permeable lenses of sand. Thickness of till cap ranges from 20 to 40 feet. Confined aquifer.	0-90+	Yields similar to those in C_1 can be expected.	Chloride content generally less than 500 ppm.	Rotary logs Electric logs Auger logs
C_3	Buried Channel Deposits—Sand and gravel containing interbedded silt and clay at places. Data are insufficient to determine accurately the general lateral and vertical variation in textures. Aquifer is capped by 70 feet or more of poorly permeable till at most places. At places water leaks slowly through the till cap and into the aquifer. At places till contains local aquifers of sand and gravel. Confined aquifer.	0-60	Yields of more than 200 gpm could be developed from thicker sand and gravel zones. Leaky character of till cap tends to stabilize water levels in pumped wells. Yields of less than 50 gpm could be developed in the marginal areas.	Hardness ranges from 150 to 500 ppm; chloride content less than 500 ppm. Suitable for domestic and stock use.	Rotary logs Electric logs Well depth completion data
C_4	Sand bed within till (possibly a Channel Deposit)—Predominantly fine to medium sand containing small lenses of sand and gravel. Coarser deposits occur along the longitudinal axis. Till overlying aquifer ranges in thickness from less than 5 feet to more than 30 feet. Confined aquifer.	0-50±	Yields up to several hundred galions per minute could be developed from coarser deposits in the thicker part of aquifer.	Hard; low chloride, similar to Area B.	Rotary logs of two test holes. Auger logs (most only penetrated upper part of aquifer.)
D	Sand bed within till—Predominantly fine to medium sand, contains lenses of gravel in eastern half. Aquifer is capped by 100 to 130 feet of till. Confined aquifer.	0-100+	Yields of 50 to more than 150 gpm can be expected. Nearly all well owners report good supply.	Hardness ranges from 150 to 250 ppm; chloride ranges from 10 to 600 ppm. At most places chloride is less than 100 ppm.	Rotary logs (few) Well depth completion data Electric logs
E	Sand and silt bed within till—Aquifer consists predominantly of silt in the western part and sand in the eastern part. Silt bed forms upper unit of the aquifer throughout mapped area. Sand bed is more than 50 feet thick in eastern part. Confined aquifer.	20-50±	Yields up to 40 gpm can be developed in the eastern part. Lower yields can be expected in the western half.	Hard; chloride content is less than 50 ppm.	Well depth competion data Rotary logs (few) Electric logs
F	Sand bed within till—Many well owners report well taps fine, white, sand. A large number of wells completed in sand at depth 160 to 175 feet below land surface. Confined aquifer.	5-10+	Yields of 50 gpm are reported at few places from pumped wells. Many wells flow at a rate less than 1 to 2 gpm.	Hardness ranges from 900 to 1,800 ppm; chloride ranges from about 1,000 to 4,000 ppm.	Well depth completion data
G	Stratified sedimentary rock—Shale, sandstone, siltstone, limestone, dolomite. Confined water. (Note: Where these rocks lie east of the shown line they are not a significant source of water)		Yields unknown. Pressure head in wells tapping permeable bed is more than 10 feet above land surface at most places.	Highly mineralized waters; unsuitable for use except possibly for cooling. Chloride ranges from 2,000 to 6,000 ppm.	Well depth competion data

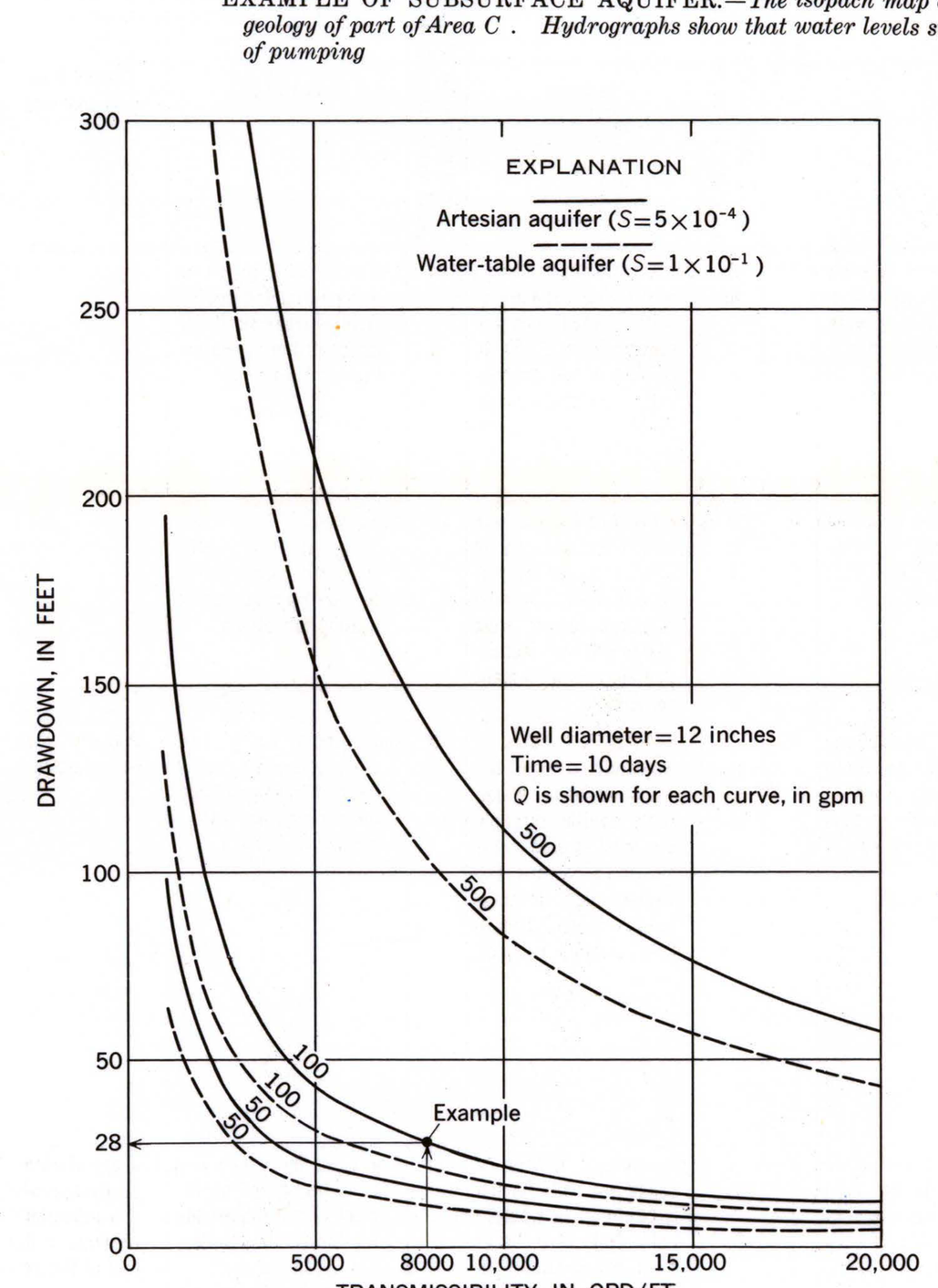
AREAS IN THE MIDDLE RIVER WATERSHED WHERE WATER CAN BE OBTAINED FROM KNOWN SUBSURFACE AQUIFERS



EXAMPLE OF SURFICIAL AQUIFER.—*The isopach map and geologic sections show the detailed geology of part of Area A–3. The time drawdown curve shows that drawdown of a pumped well in this type of aquifer is greatly affected by boundaries*



EXAMPLE OF SUBSURFACE AQUIFER.—*The isopach map and geologic section show the detailed geology of part of Area C. Hydrographs show that water levels stabilize soon after an increase in rate of pumping*



Example: Artesian aquifer southeast of Stephen T = 8,000 gpd/ft, available head = 11 ft. If 100 gpm could be pumped the drawdown would be about 28 ft. Therefore, computing by proportional parts $\frac{11}{28}=\frac{x}{100}$ and x (the theoretical well yield) = 39 gpm. Yield declines slightly with time, if no boundaries are intercepted.

THEORETICAL YIELD OF A WELL CAN BE ESTIMATED FROM TRANSMISSIBILITY AND AVAILABLE HEAD

SUMMARY OF WELL CHARACTERISTICS NEAR COMMUNITIES IN THE MIDDLE RIVER WATERSHED UNIT

Community	Well owner	Well location: ¼ section	Section	Township	Range	Rate of pumping (gpm)	Duration of tests (hours)	Drawdown (ft)	Specific capacity (gpm/ft)	Method of analysis for hydraulic coefficients	Available drawdown (ft)	Hydraulic coefficients[1]: T (gpd/ft)	S	Well depth (ft)	Size	Quality: Fe (ppm)	Cl (ppm)	Hardness as $CaCO_3$ (ppm)	pH	Remarks	Aquifer texture and range in depth, in feet below land surface
Warren	U.S.G.S test well	NE	11	155	47	217	48	35	6.25	Time, drawdown, recovery	56	16,000	0.0001	110	8 in.	0.68	252	132	7.6		Sand and gravel; 65-103′
	Municipal	NE	11	155	47	250	24	47	5.3		70			112	10 in.					80.5 ft. casing, 30 ft. screen.	Sand and gravel; 65-103′
	Municipal	NW	1	154	48	60	14							151	8 in.					15 ft. of 8-inch screen. Pumped about 29,000 gallons per day	White, fine sand; 133-151′
	Municipal (standby)	SW	36	155	48	75	3							158	8 in.					Stand-by well	Gravel; 150-158′
Stephen	U.S.G.S test well	NW	27	157	48	45	25	31	1.5	Time-drawdown, recovery	38	5,000	0.05	70	4 in.		59	357	7.6	Sand packed well, 4-inch screen from 50-70 feet	Fine sand; 10-70′
	Test well	SE	21	157	48	45	24	10.7	4.2	Time-drawdown, recovery	11	8,000	0.0001	46	4 in.		870	2,920	7.4	Sand packed well, 4-inch screen from 21-46 feet	Fine to medium sand; 21-46′
Argyle	Village well, north	SE	10	156	48	31 (est.)	1	3	30	Specific capacity	3	6,000	0.1 (est.)	16	10 feet square	3.2	20	370	8.4	WPA dug well	Medium sand and gravel; 10-26′
	Village well, south	NE	15	156	48	30								18	6 feet diam.					Well will pump dry	Sand, fine; 12-22′
Kennedy	Village	SE	27	160	48	62 (rept.)	7	2.2	28	Specific capacity	4			24	6.5 feet square	0.04	47	340	8.7	WPA dug well	Sand and gravel; 0-24′
Alvarado	Village	NW	5	154	49	145 (rept.)	12	35 (rept.)	4.1					158	8 in.	1.0	600	490	7.8	7 feet of 8-inch screen. Well flowed for a period after completion	Sand and gravel 151-158′
	School	NW	5	154	49	45 (rept.)		150+						162	6 in.					Flowing well in 1955	Gravel
Strandquist	Village	SW	22	158	45	20 (rept.)	24	100 (rept.)	0.2		358			362		0.63	62	50	7.9	4 feet of 40-slot screen	Fine sand; 358′-362′
	School	SW	22	158	45	10	2	44	0.25	Time-drawdown, recovery	300	Less than 500	0.0001 (est.)	308	6 in.						Sand
Middle River	Village	NW	11	157	43	100			3		229			244	6 in.	0.42	13	230	7.6	10 feet of 6-inch screen—50 slot 5 feet of 6-inch screen—40 slot	Gravel; 230′-244′
	School	NW	11	157	43	36	61		0.6	Specific capacity	204	1,000		227	6 in.					Not used. 4 feet of screen	Gravel; 210′-227′
Holt	Co-op Creamery	SE	32	156	43	15	¼	12	1.3	Specific capacity	265	2,000		290	6 in.	0.93	10	265		No screen	Sand and gravel
	Village	SW	33	156	43									240	6 in.					Well not connected to distribution system. Adequate yield	
Newfolden	Village	SE	5	156	44	100 (rept.)		60	1.7	Specific capacity	95			121	8 in.	0.28	10	210	7.8	10 feet of screen	Sand
	Co-op Creamery	NW	8	156	44	30					90			100	6 in.					Adequate	Sand
Viking	Village	NW	26	155	45	40 (rept.)								180	6 in.					Pumps into a pressure tank of 850-gallon capacity	Sand
	Co-op Creamery	SW	26	155	45	12	½	3.3	3.65		130			158	6 in.					Adequate	Sand

[1] For use in estimation of drawdown at pumped well. Drawdown is also affected by boundary-conditions and pumping of nearby wells. Lateral restriction of the aquifer increases drawdown and leakage into aquifer decreases drawdown. Pumping of nearby well increases drawdown.

APPRAISALS OF MAJOR AQUIFERS

Area	Map key	Areal extent (square miles)	Source of aquifer replenishment — Natural conditions — Precipitation: Estimated infiltration of precipitation to aquifer (in./sq. mi.)	Precipitation: Remarks	Underflow: Water moving into and out of aquifer (acre-ft/year)	Underflow: Remarks	Potential sources of replenishment due to development: Derived from storage in confining beds	Diversion from surface water	Salvage from evapotranspiration	Hydraulic coefficients — Average coefficient of aquifer: T (gpd/ft)	S	Remarks	Storage: Total (billions of gallons)	Storage: Remarks	Use in millions of gallons per year: Municipal and domestic	Industrial and commercial	Agricultural	Total	Water potential
Argyle-Stephen	Alluvial and lake-bar deposits (Area A on map showing water availability in surficial aquifers.)	22	2 to 4	Estimated on basis of high infiltration capacity of soils. Annual recharge ranges from 2,350 to 4,700 acre-feet depending upon climatic conditions.	84	Computed by Darcy's Law using estimated coefficient of transmissibility for contributing water-bearing formations.		It is possible to divert surface water into aquifer by maintaining surface storage in channel of the Middle River east of Argyle. Water could seep into the aquifer when cone of depression reaches surface storage.	Pumpage near Middle River east of Argyle will salvage some water discharge to springs or loss by evapotranspiration within the channel.	2,000 (avg)	0.1 (est.)	Aquifer is under water-table conditions at most places. Transmissibility estimated to range from about 1,000 to 8,000. Highest transmissibility in A-2.	4.6 (14,000 acre-ft.)	Only a small part of water storage is economically available.	9.0	3.0	0.5	12.5 (38 acre-ft.)	Based on aquifer replenishment, more than twice the annual rate of pumpage could be developed from aquifer. The most favorable area for development is A-2. Natural discharge is largely by evapotranspiration.
Beach Ridge area about 4 miles east of Kennedy	Beach Ridge (see map showing water availability in surficial aquifers.)	3	2 to 4	Estimated on basis of high infiltration capacity of sandy soils and low surface runoff. Annual recharge ranges from 320 to 640 acre-feet depending upon climatic conditions.	2.7	Computed by Darcy's Law using estimated coefficient of transmissibility for contributing water-bearing formations.			Pumpage will decrease natural discharge by evapotranspiration.	3,000 (avg)	0.1 (est.)	Aquifer is under water-table conditions. Transmissibility estimated to range from 1,000 near margins to as much as 10,000 where aquifer is 35 feet thick.	0.6 (1,800 acre-ft.)	Only a small part of storage can be utilized economically.	8.3	2.4	0.2	10.9 (33 acre-ft.)	Aquifer is largely undeveloped. It could sustain yields at more than double the present usage.
Halma-Lake Bronson	Channel Deposit (see Area B on map showing water availability in surficial aquifers.)	40	1 to 4	Estimated on basis of moderate to high infiltration capacity. Water-table aquifer throughout most of area. It is confined toward the western edge. Recharge ranges from 2,100 to 8,400 acre-feet per year.	224	Computed by Darcy's Law using estimated coefficient of transmissibility for contributing water-bearing formations.	Potential sources near the western border.	Lake Bronson and South Branch of Two Rivers are a potential source of significant recharge to ground-water reservoir. Usable storage in Lake Bronson is 3,700 acre-feet. Average flow of South Branch of Two Rivers is 65.6 cfs. Low flow of 5 cfs or less is common during August and September. Amount of diversion possible cannot be determined from available data.	Pumpage near Lake Bronson or in northern part of aquifer could reduce evapotranspiration losses.	10,000 to 100,000+	0.1	Largest transmissibility occurs in the thicker part of the aquifer.	900 (2,800,000 acre-ft.)	Storage within the Middle River Watershed Unit.	1.2		1.9	3.1 (9.5 acre-ft.)	Aquifer is undeveloped and has the largest potential capacity. It is a potential source of water for irrigation and industrial purposes.
Newfolden	Sand bed within till (Area D on map showing water availability in subsurface aquifers.)	65	1 to 2	Estimated on infiltration capacity of soil. Aquifer is confined in western half. Natural recharge from precipitation occurs in eastern half of aquifer.	134	Computed by Darcy's Law using estimated coefficient of transmissibility for contributing water-bearing formations.	Leakage of water stored in overlying confining beds is a potential source of recharge in the western half of the aquifer.	Diversion potential from surface to ground water is low because of low permeability of till within the channel of the Middle River.							8.4	6.8	3.9	19.1 (58.5 acre-ft.)	Not feasible to estimate water potential from available data. No declines in well yields are reported at present rate of pumpage. Nearly all well owners report plenty of water for their uses.
Alvarado	Sand bed within till (Area F on map showing water availability in subsurface aquifers.)	265		No local recharge from precipitation. Aquifer is covered by more than 100 feet of nearly impervious clay. Head is higher in deep aquifer.	170	Computed by Darcy's Law using estimated coefficient of transmissibility for contributing water-bearing formations.	A small amount of water could leak into the aquifer from overlying glacial till. Lake clay would yield practically no water.						Unknown		6.0	2.5	5.2	13.7 (42 acre-ft.)	Adequate supplies for present rate of use. Owners report decline in flows of many older wells.

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.—1965—W65018

WATER RESOURCES OF THE MIDDLE RIVER WATERSHED, NORTHWESTERN MINNESOTA

By
R. W. Maclay, T. C. Winter, and G. M. Pike

1965

For sale by U.S. Geological Survey, price $1.50 per set