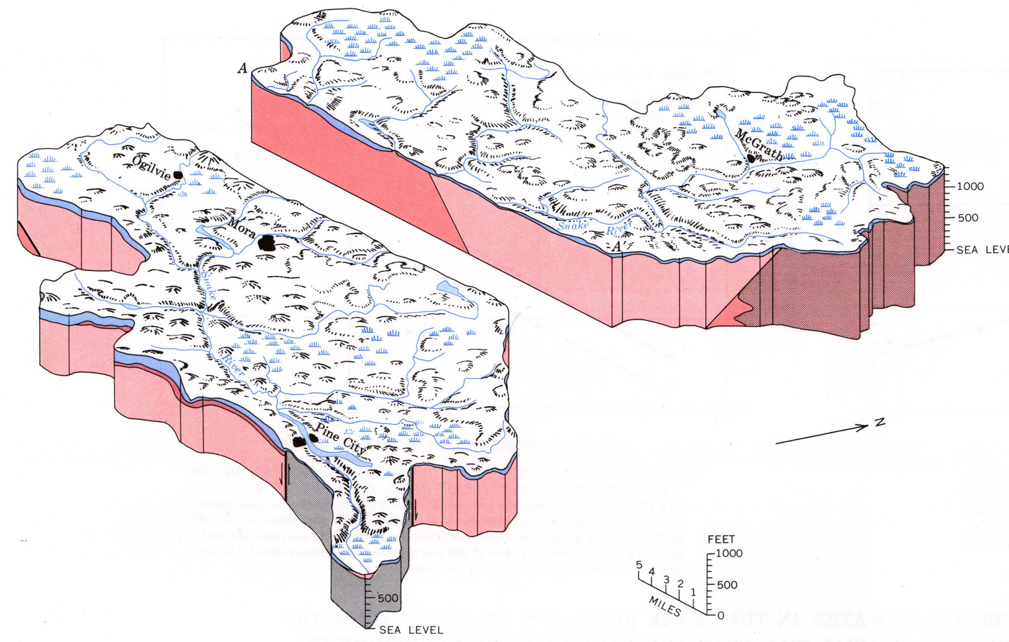
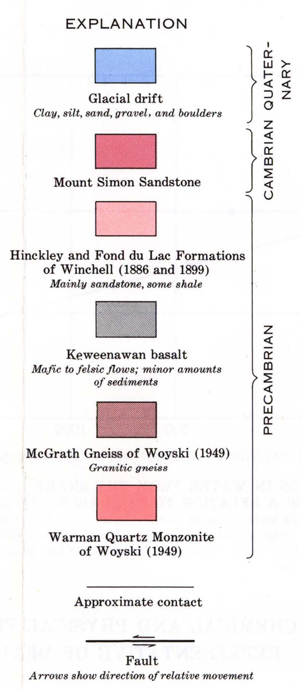
PREPARED IN COOPERATION WITH
THE MINNESOTA DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATERS, SOILS, AND MINERALS

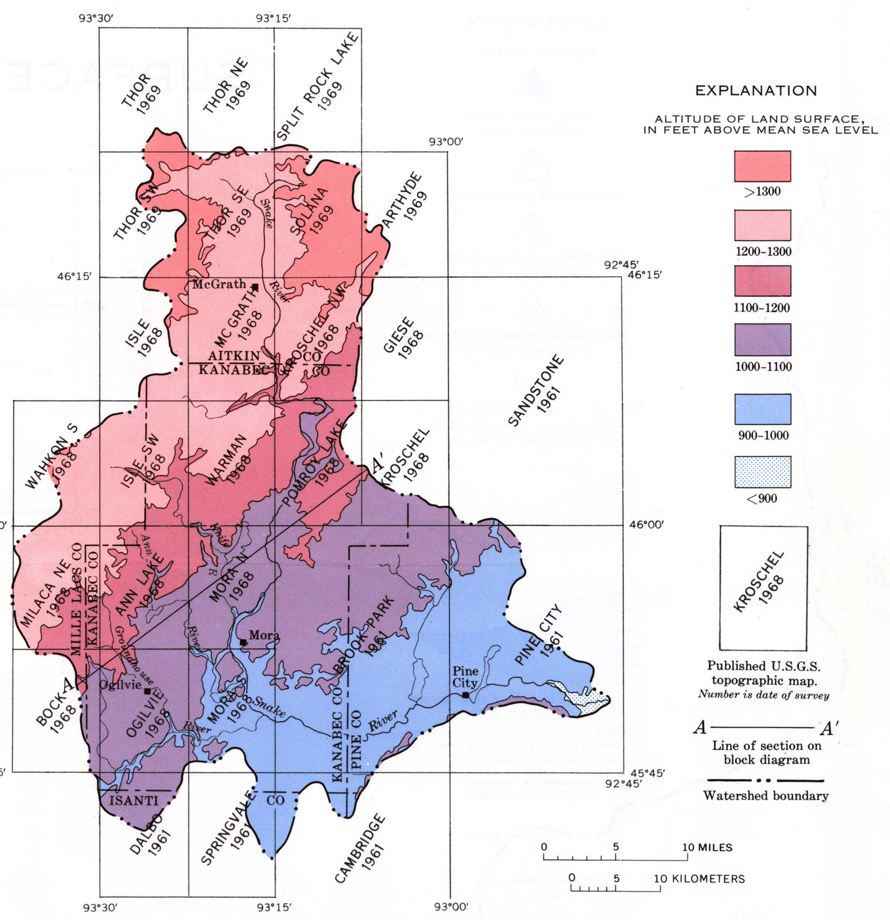
INTRODUCTION



GLACIAL DRIFT OVERLIES SEDIMENTARY, IGNEOUS, AND METAMORPHIC ROCKS IN THE SNAKE RIVER WATERSHED

The Snake River, which drains an area of about 1,020 square miles, originates in an extensive area of peat bogs in the northern part of the watershed. It flows southward across gently rolling glacial terrain in which the major relief is near the river. Near the southern boundary of the watershed, the Snake River turns eastward to its confluence with the St. Croix River. The northwest half of the watershed is heavily forested, whereas much of the southeast half has been cleared. The largest communities in the watershed, Mora and Pine City, had 1970 populations of 2,582 and 2,143, respectively.



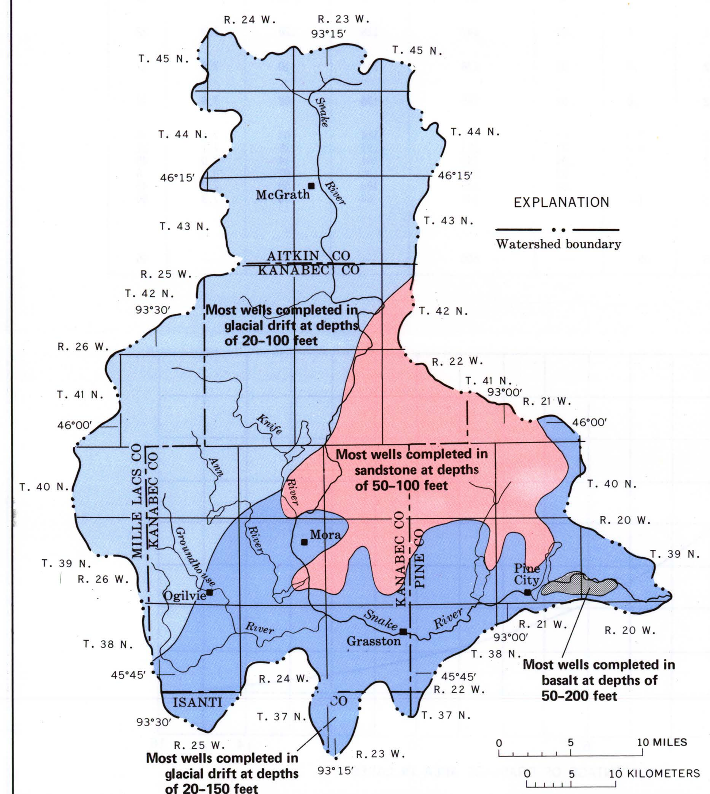


THE LAND SURFACE IN THE WATERSHED SLOPES GENERALLY TO THE SOUTHEAST.—*Details of topography can be obtained from U.S. Geological Survey 7½- and 15-minute quadrangle maps that are indexed above.*

WATER USE

ALL PRESENT DOMESTIC, MUNICIPAL, AND INDUSTRIAL WATER SUPPLIES IN THE WATERSHED ARE FROM GROUND-WATER SOURCES

Depth of well is dependent upon thickness and lithology of the glacial drift, type of underlying bedrock, and desired yield. Specific data pertaining to known large-yield wells are tabulated below. The three communities having municipal water supplies also have secondary sewage treatment facilities. Mora and Pine City discharge their treated sewage into the Snake River; Ogilvie discharges its sewage into the Groundhouse River.



Municipality or owner		Location: ¼ Section	Section	Township	Range	Year completed	Well diameter (inches)	Well depth (feet)	Aquifer	Well construction	Static water level (feet below land surface)	Well test data: Test pumping rate (gpm)	Draw-down (ft)	Year of testing	Specific capacity (gpm per ft of drawdown)	1968 withdrawal (millions of gallons)	Selected water quality properties (mg/l): Total hardness as CaCO3	Iron	Manganese	Dissolved solids (residue) at 180°C
Farmers Co-Op Creamery, Grasston		SE	12	38	23	1944	6	127	Buried sand and gravel 117-127 feet	Screened 117-127 feet	20	350	6.5	1944	54	6.4	330	4.1	0.21	370
Mora	Well 1	SE	11	39	24	1930	10	205	Buried sand and gravel 170-205* feet	Screened 183-205 feet	52	230	41	1966	5.6	2.2	—	—	—	—
	Well 2	NE	14	39	24	1951	12	180	Buried sand and gravel 160-180 feet	Screened 170-180 feet	36	550	27	1966	20	160.2	190	.12	.28	—
	Well 3	SE	11	39	24	1957	12	170	Buried sand and gravel 129-170* feet	Screened 150-170 feet	41	650	29	1966	22*	2.5	180	.94	.47	—
	Well 4	SE	11	39	24	1964	12	195	Buried sand and gravel 170-195* feet	Screened 170-195 feet	49	500	21	1966	24	9.1	200	.44	.45	232
Lakeland Dairy, Mora		NW	14	39	24	1937	8	158	Buried sand and gravel 125-158* feet	Screened 147-158 feet	30	180	6	1937	30	—	—	—	—	—
Ogilvie		NW	35	39	25	1917	8	120	Buried sand 25-100* feet	—	20	—	—	—	—	Approx. 14	170	.07	.28	205
Pine City	Well 1	NE	33	39	21	1913	12	135	—	—	18	250	11	1966	23	Approx. 73 (most from Well 3)	310	2.0	.11	—
	Well 2	NE	33	39	21	1936	—	135	—	—	18	500	66	1966	7.6		—	—	—	—
	Well 3	SW	33	39	21	1947	16	276	—	—	33	750	21	1966	36		330	1.5	.08	362
Land O' Lakes Creamery, Pine City		NE	33	39	21	1952	16	300	Sandstone 129-300* feet	Open hole 129-300 feet	16	—	—	—	—	46.5	—	—	—	—

*120 at time of drilling, nearly linear decrease to value listed

SUMMARY

RELATIVE ADEQUACY OF WATER RESOURCES

PURPOSE	CONSIDERATIONS	SURFACE WATER: Snake River below Chelsey Brook	Major tributaries to Snake River	Minor streams	Lakes	GROUND WATER: Surficial outwash	Undifferentiated drift	Sedimentary bedrock (sandstone)	Igneous or metamorphic bedrock
Municipal and industrial supply	For a moderate supply, principal needs are: Quantity: Minimum available surface-water supply of 1 cfs or wells yielding 250 gpm. Quality: Dissolved-solids content less than 500 mg/l. Hardness less than 180 mg/l	Adequate flow / High iron content. Treatment necessary	Adequate for most uses. Additional storage possible / Treatment necessary	Wide areal distribution / Supply generally inadequate. No flow during parts of most years. At low flow water is hard. Treatment necessary	Larger lakes adequate for most uses. Ground-water inflow helps maintain lake levels / Limited areal distribution. Treatment necessary	Commonly highly permeable. Adequate quantity where saturated thickness is sufficient. Rapid recharge from precipitation. Generally good quality. Inexpensive to develop relative to other sources / Small areal extent. Easily polluted. Treatment for hardness and iron may be necessary	Buried sand or gravel may yield adequate supply. Wells may be open to more than one aquifer zone. Generally good quality / Aquifer extent generally small. Recharge may be slow. Treatment for hardness and iron may be necessary. May be costly to develop. Drift thin in large areas	Relatively permeable. Thickness of unit enhances possibility of large yield. Wells may be open to more than one aquifer zone. Good quality / Variations in cementation and texture may limit water-yielding capability. May require wells several hundred feet deep. Characteristics of deeper strata are unknown	Adequate quality / Supply probably inadequate, dependent upon degree of fracturing or jointing
Rural domestic and stock supply	For an adequate farm supply, needs are: Quantity: About 5 gpm or more. Quality: Dissolved-solids content less than 1000 mg/l	Adequate flow. Suitable quality / Available only to riparian lands. Treatment necessary for domestic use	Adequate flow. Suitable quality / Available only to riparian lands. Treatment necessary for domestic use	Suitable quality / No flow during parts of most years. Available only to riparian lands. Treatment necessary for domestic use	Adequate supply. Suitable quality / Available only to riparian lands. Treatment necessary for domestic use	Commonly highly permeable. Adequate quantity and quality. Inexpensive to develop relative to other sources / Easily polluted. Treatment for hardness and iron may be necessary for domestic use	Generally adequate quantity. Generally good quality / Treatment for hardness and iron may be necessary for domestic use. Drift thin in large areas	Relatively permeable. Adequate quantity. Good quality / May require deep well	Adequate quality / Supply may be inadequate
Irrigation supply	For an average farm, needs are: Quantity: Minimum flow of 2 cfs during growing season or wells yielding 250 gpm or more. Quality: Dissolved-solids content less than 2000 mg/l. Suitability of water quality for irrigation as indicated by classification of U.S. Dept. of Agriculture	Adequate flow. Suitable quality / Restricted to riparian lands	Adequate supply in lower reaches of streams. Suitable quality / Restricted to riparian lands. May require storage facilities	Suitable quality / Restricted to riparian lands. Intermittent flow, supply generally inadequate	Larger lakes have adequate supply. Suitable quality / Restricted to riparian lands	Commonly highly permeable. Adequate quantity where saturated thickness is sufficient. Rapid recharge from precipitation. Good quality. Inexpensive to develop relative to other sources / Small areal extent	Buried sand or gravel may yield adequate supply. Wells may be open to more than one aquifer zone. Good quality / Aquifer extent generally small. Recharge may be slow. May be costly to develop. Drift thin in large areas	Relatively permeable. Thickness of unit enhances possibility of large yield. Wells may be open to more than one aquifer zone. Good quality / May require wells several hundred feet deep	Adequate quality / Supply probably inadequate, dependent upon degree of fracturing or jointing
Fish and wildlife habitat	Adequate depth and quality of water for fish in lakes and streams. Adequate cover needed for wildlife habitat is provided by: Wetlands—lakes or potholes surrounded by marsh areas. Streams—marsh and woodland along banks	Adequate depths. Baseflow sustained by ground-water inflow. Suitable quality. Excellent wildlife habitat along banks. Excellent migratory water-fowl resting and feeding areas / Occasional flooding	Generally adequate depths in lower reaches. Suitable quality. Excellent wildlife habitat along banks. Excellent migratory water-fowl resting and feeding areas / Occasional flooding. Intermittent flow in headwaters	Excellent wildlife habitat along banks. Wide areal distribution / Shallow. Intermittent flow	Adequate depths in larger lakes. Suitable quality. Good wildlife habitat along shores. Good wetlands around smaller lakes / Considerable lakeshore development on larger lakes				
Recreation	Adequate access to lakes and streams. Availability of areas suitable for hunting, fishing, and other water sports. Available resorts, lake cottages, and campgrounds. Esthetic values and absence of pollution	Public access at many sites. Suitable for hunting and fishing. Suitable quality. Excellent canoeing / Floods	Public access at many sites. Suitable for hunting and fishing. Excellent esthetic values / Floods. Intermittent flow in headwaters	Public access at many sites. Many suitable for hunting and fishing. Wide areal distribution / Intermittent flow. Easily polluted	Public access at many sites. Suitable for hunting, fishing, and water sports. Lakeshore resorts and residences. Suitable quality. Esthetic values generally good / Easily polluted				

E X P L A N A T I O N

Buried sand or gravel may yield adequate supply
Wells may be open to more than one aquifer zone
Good quality — Desirable features above line

Aquifer extent generally small
Recharge may be slow
May be costly to develop
Drift thin in large areas — Undesirable features below line

Good / Fair / Poor — Color indicates overall adequacy of water source as evaluated for specific purpose

CONCLUSIONS

1. All domestic, municipal, and industrial water supplies in the Snake River watershed are obtained from ground-water sources. Water use is greatest at Mora, where withdrawals doubled from 1964 to 1969.
2. Precipitation, the primary source of recharge to the watershed, averaged about 28.9 inches per year during 1939–68. Evapotranspiration, the main discharge process, is generally greatest in July and August, commonly resulting in moisture deficits for optimum plant growth. The average annual runoff from the Snake River basin is about 8.5 inches.
3. Most ground water moves within local flow systems operating within the watershed; a relatively small amount moves downward into permeable bedrock becoming underflow.
4. Sandstones of the Hinckley and Fond du Lac Formations of Winchell (1886 and 1899), where poorly cemented, are the most productive bedrock aquifers. Possible thicknesses of several thousand feet enhance the probability of obtaining well yields of several hundred gallons per minute. Granitic and basaltic rocks, though commonly yielding quantities adequate for domestic use, are generally unreliable sources for larger water supplies.
5. Several bedrock valleys, formed by glacial melt waters, occur chiefly in the relatively low-resistant Hinckley and Fond du Lac Formations. The water-yielding capability of drift filling these valleys may be very good, as exemplified by the supply from which the village of Mora obtains its water supply.
6. In small areas in the southern half of the watershed, surficial outwash (primarily sand and gravel) is capable of yielding several hundred gallons of water per minute to large diameter wells.
7. Ground water is generally very hard (greater than 180 mg/l) and of the calcium magnesium bicarbonate type.
8. The most highly mineralized water is found in the southern part of the watershed and can be related to the presence of gray drift and glacial-lake sediments. Water from wells completed in bedrock is commonly high in iron as is water from the Snake River and its tributaries.
9. The larger base-flow yields in the basin are from streams draining outwash areas. During base-flow periods, a substantial amount of the flow in the Snake River is from ground water discharging directly to the main channel.
10. Seventy-five percent of the annual minimum flows in the lower reaches of the Snake River occur late in the winter.
11. Lakes and streams in the watershed offer good opportunity for water-based recreation.

SELECTED REFERENCES

Atwater, G. I., and Clement, G. M., 1935, Precambrian and Cambrian relations in the Upper Mississippi Valley, Geol. Soc. America Bull., v. 46, p. 1659–1687.
Bodman, G. B., and others, 1927, Soil survey of Mille Lacs County, Minnesota: U.S. Dept. Agriculture Bur. Chem. Soils, Ser. 1927, no. 37, 46 p.
Cooper, W. S., 1935, The history of the upper Mississippi River in late Wisconsin and post-glacial time: Minnesota Geol. Survey Bull. 26, 116 p.
Farnham, R. S., and others, 1958, Soil survey of Isanti County, Minnesota: U.S. Dept. Agriculture Soil Conservation Service, Ser. 1953, no. 1, 60 p.
McMiller, P. R., 1939, Soil survey of Kanabec County, Minnesota: U.S. Dept. Agriculture Bur. Chem. Soils, Ser. 1933, no. 27, 43 p.
Minnesota Division of Waters, 1959, Hydrologic Atlas of Minnesota: Minnesota Div. Waters, Bull. 10, 182 p.
Minnesota Pollution Control Agency, 1970, Wastewater disposal facilities inventory, State of Minnesota, January 1, 1970: 45 p.
Minnesota Water Pollution Control Commission, 1967, Water Quality Standards for the Interstate Waters of Minnesota established by the Minnesota Water Pollution Control Commission in accordance with the Federal Water Pollution Control Act of June 1967: 174 p.
Patterson, J. L., and Gamble, C. R., 1968, Magnitude and frequency of floods in the United States, Part 5, Hudson Bay and Upper Mississippi River Basins: U.S. Geol. Survey Water-Supply Paper 1678, 546 p.
Reedstrom, D. C., 1964, A biological reconnaissance of the Snake River: Minnesota Conservation Dept., Div. Game and Fish Inv. Rep. no. 275, 67 p.
Simmons, C. S., and others, 1941, Soil survey of Pine County, Minnesota: U.S. Dept. Agriculture Bur. Plant Industry, Ser. 1926, no. 15, 44 p.
Sims, P. K., 1970, Geologic map of Minnesota: Minnesota Geol. Survey Misc. Map Ser., Map M-14.
Sims, P. K., and Zietz, Isidore, 1967, Aeromagnetic and inferred Precambrian paleogeologic map of east-central Minnesota and part of Wisconsin: U.S. Geol. Survey Geophys. Inv. Map GP–563.
Thiel, G. A., 1947, The geology and underground waters of northeastern Minnesota: Minnesota Geol. Survey Bull. 32, 247 p.
Thornthwaite, C. W., and Mather, J. R., 1957, Instructions and tables for computing potential evapotranspiration and the water balance: Drexel Inst. Technology, Pubs. in Climatology, v. 10, no. 3, 311 p.
U.S. Weather Bureau, 1939–68, Climatological Data: U.S. Govt. Printing Office, Washington, D. C.
Welch, G. I., 1941, Geophysical study of the Douglas fault, Pine County, Minnesota: Jour. Geology, v. 49, p. 408–413.
Winchell, N. W., 1886, Revision of the stratigraphy of the Cambrian in Minnesota: Minnesota Geol. Nat. Hist. Survey, 14th Ann. Rept., p. 336–37.
———1899, Geology of St. Louis County, Minnesota: Minnesota Geol. Nat. Hist. Survey, Final Rept., vol. 4, p. 567.
Woyski, M. S., 1949, Intrusives of central Minnesota: Geol. Soc. America Bull. v. 60, p. 1002.

ACKNOWLEDGMENTS

The authors appreciate the cooperation of well drillers, municipal and industrial officials, and well owners who provided much basic data used in this study. Special thanks are extended to Mora village officials for use of municipal wells for an aquifer test.

WATER CYCLE

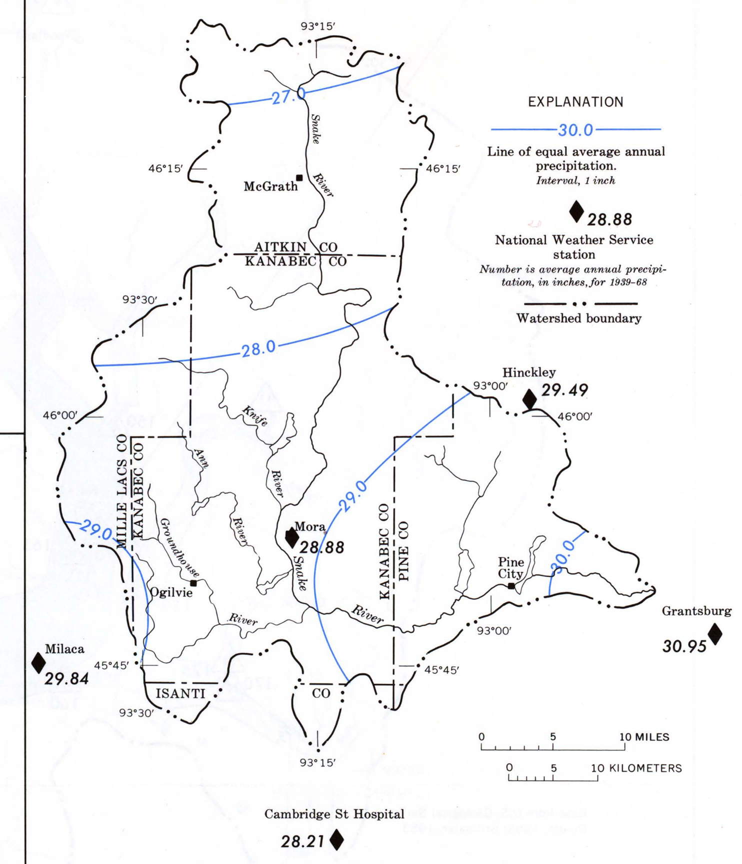
MOST RECHARGE IN THE SNAKE RIVER WATERSHED OCCURS AS PRECIPITATION AND MOST DISCHARGE AS EVAPOTRANSPIRATION

The long-term (1939–68) annual water budget of the watershed is shown below. Climatic records used in estimating the budget are those for the National Weather Service station at Mora.

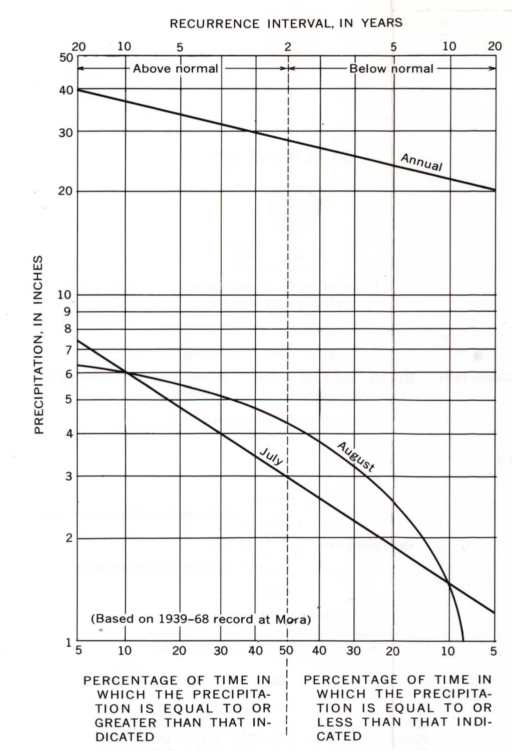
Runoff during 1952–68 was determined from records obtained at a gaging station on the Snake River near Pine City. Runoff for 1939–51 was estimated by correlation with a long-term station outside the watershed. The remainder needed to balance the equation is the approximate long-term annual evapotranspiration. Net change in storage and underflow are assumed to be negligible.

Recharge and discharge occur continuously within the watershed as phases of a dynamic system shown schematically below (recharge—blue arrow; discharge—red arrows).

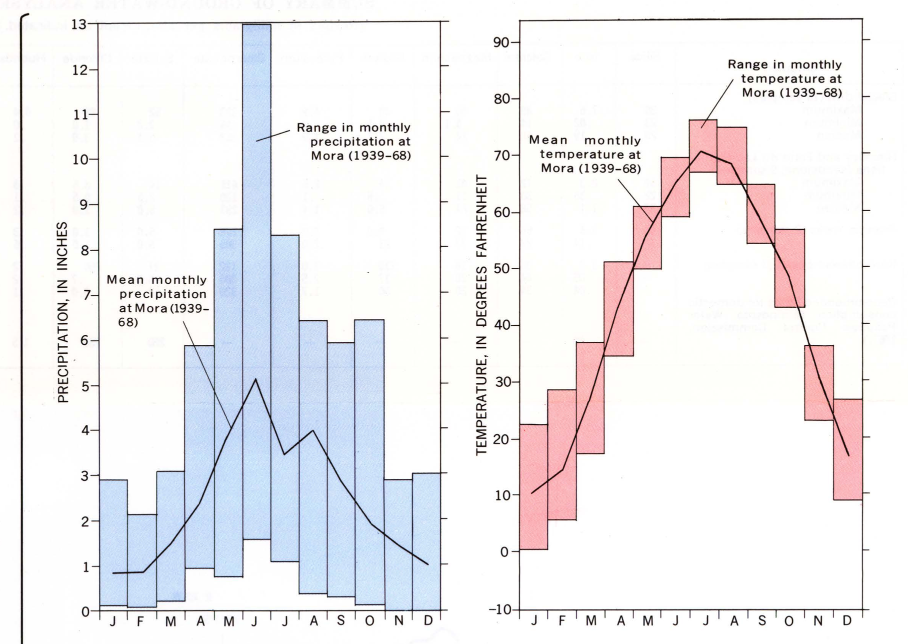
PRECIPITATION	=	EVAPOTRANSPIRATION	+	RUNOFF	±	NET UNDERFLOW	±	NET CHANGE IN STORAGE
28.9 inches measured		20.4 inches remainder		8.5 inches measured				0 assumed



ANNUAL PRECIPITATION GENERALLY INCREASES FROM NORTH TO SOUTH ACROSS THE WATERSHED



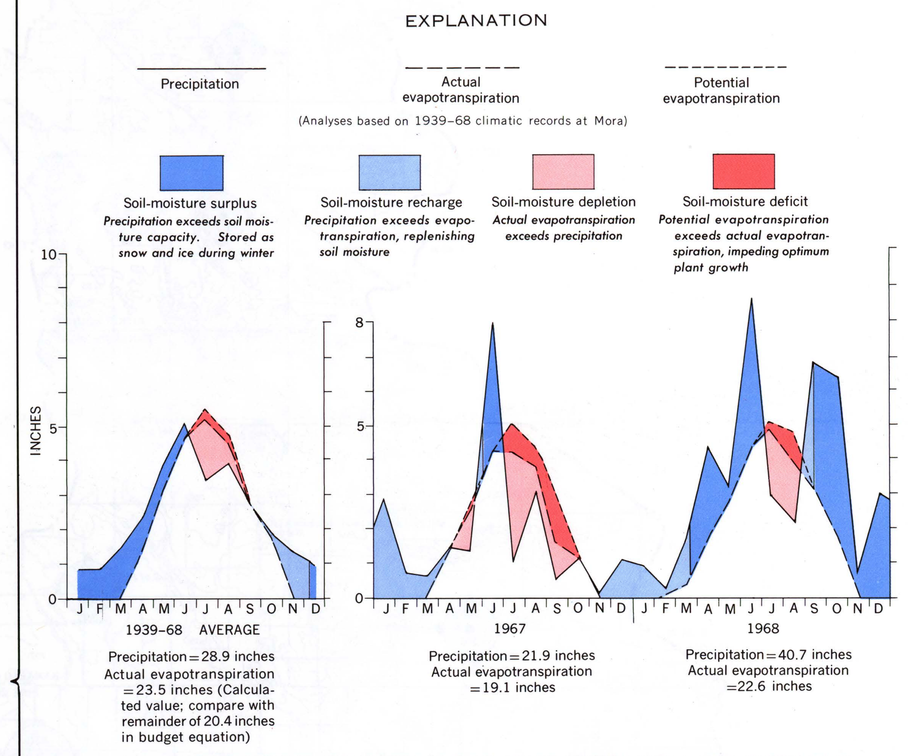
THE ANNUAL PRECIPITATION FREQUENCY CURVE INDICATES THE APPROXIMATE RECURRENCE OF GIVEN AMOUNTS OF ANNUAL PRECIPITATION IN THE WATERSHED.—*Frequency curves for July and August show the large range in precipitation during this critical part of the growing season. The effects of precipitation variabilities on soil-moisture conditions are considered at right.*



PRECIPITATION AND TEMPERATURE, IMPORTANT FACTORS IN THE EVAPOTRANSPIRATION PROCESS, VARY WIDELY THROUGHOUT THE YEAR.—*During the growing season (May-Sept.) when the timeliness and amount of precipitation is especially critical, the range in monthly precipitation is the greatest.*

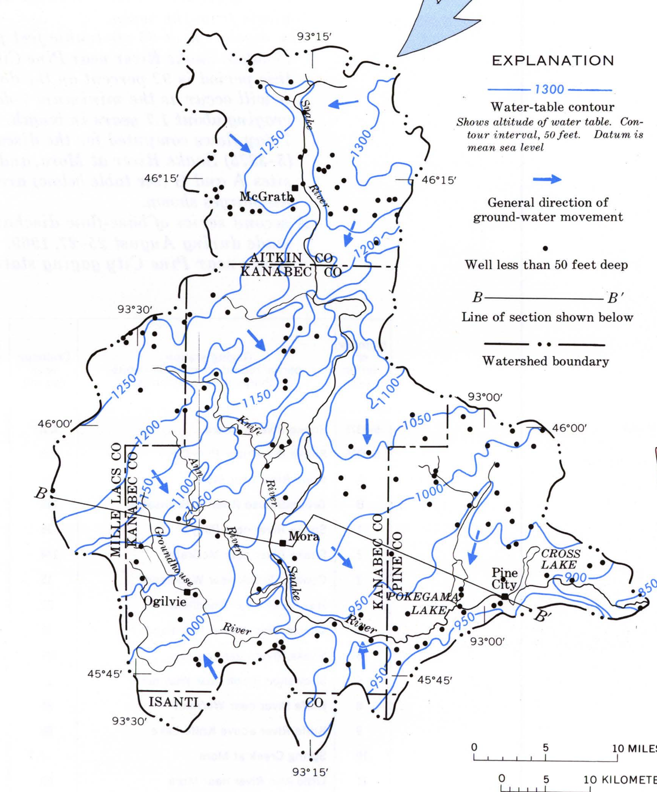
PRECIPITATION

EVAPOTRANSPIRATION



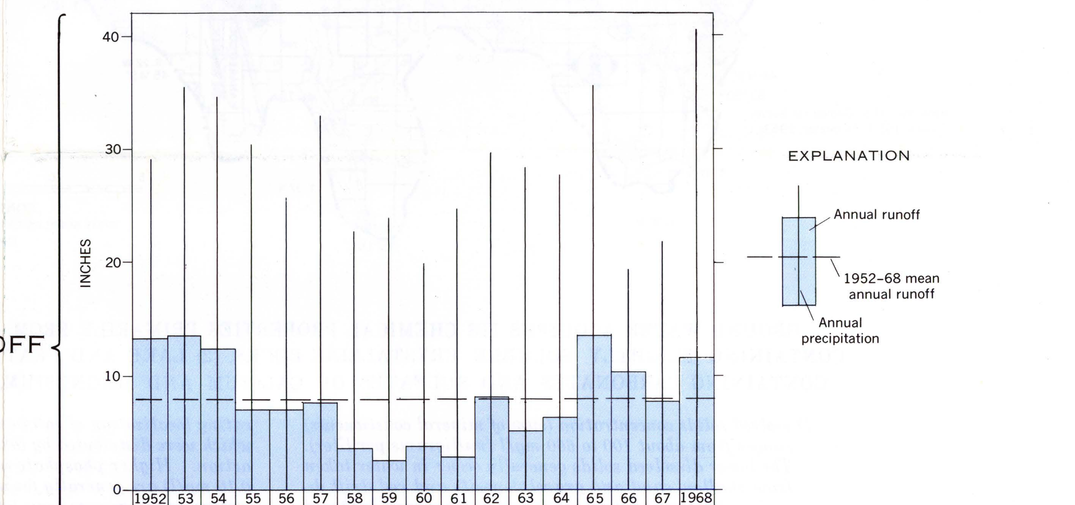
SOIL-MOISTURE DEFICITS PREVENTING OPTIMUM PLANT GROWTH OCCUR MOST COMMONLY IN JULY AND AUGUST

Evapotranspiration losses were calculated by the method of Thornthwaite and Mather (1957) assuming a soil moisture retention of 8 inches. Deviations from long-term average conditions are exemplified by the analyses of data for 1967 and 1968. Extremely low precipitation in 1967 resulted in a serious soil-moisture deficit. Although total precipitation in 1968 was abnormally high, a deficit still occurred because of inadequate rainfall during the growing season.

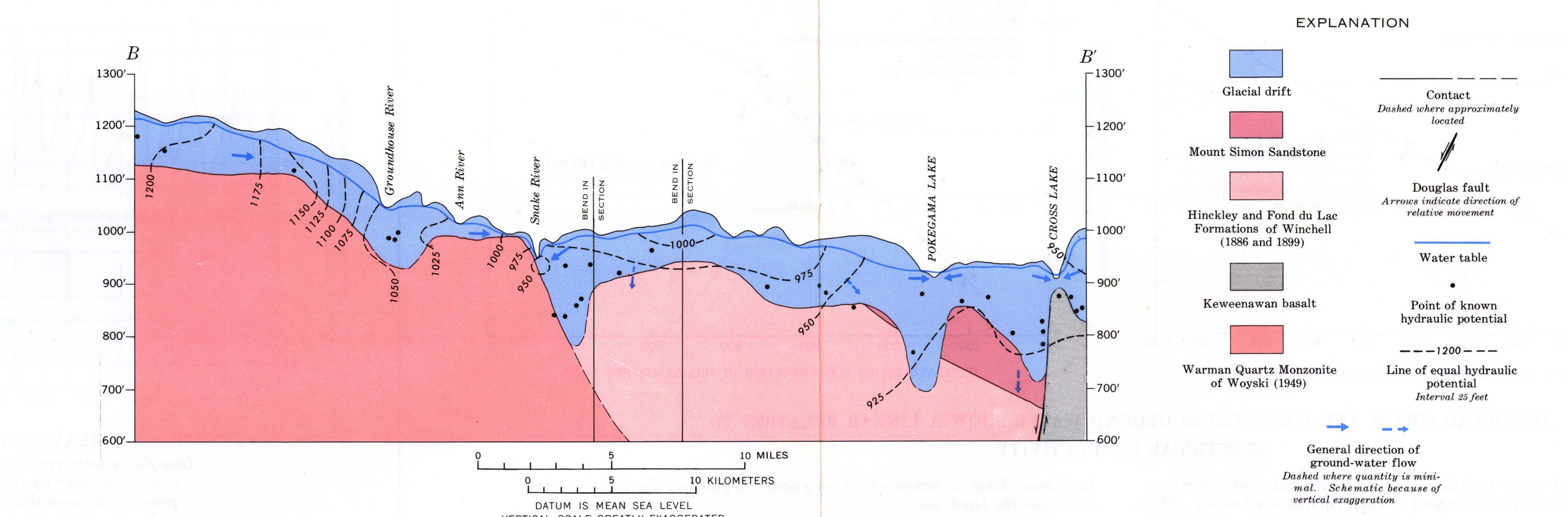


SHALLOW GROUND-WATER MOVEMENT IS GENERALLY SOUTHWARD AND TOWARD THE SNAKE RIVER.—*Local variations in flow occur because of surface irregularities and resultant movement of ground water toward topographic lows. Most ground water is recharged from precipitation, moves laterally a short distance, and is discharged within the watershed as base flow or evapotranspiration. Movement of ground water apart from local flow systems is considered below.*

RUNOFF



AVERAGE ANNUAL RUNOFF FROM THE SNAKE RIVER WATERSHED SHOWS A GENERALLY DIRECT RELATIONSHIP TO PRECIPITATION.—*Discharge of the Snake River near Pine City from 1952 through 1968 averaged 8.0 inches per year. Correlation with the Apple River near Somerset, Wisconsin, indicates that average annual discharge for the time period considered in the budget equation was 8.5 inches. Streamflow is considered in greater detail on Sheet 3.*



A RELATIVELY SMALL AMOUNT OF GROUND WATER MOVES DOWNWARD THROUGH GLACIAL DRIFT INTO BEDROCK

Permeable bedrock (Hinckley and Fond du Lac Formations) in the southeastern half of the watershed permits some water to move downward to a regional flow system.

WATER RESOURCES OF THE SNAKE RIVER WATERSHED, EAST-CENTRAL MINNESOTA

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

1974

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C.—1974—W73

For sale by U.S. Geological Survey, Reston, Va. 22092, price $2.00 per set