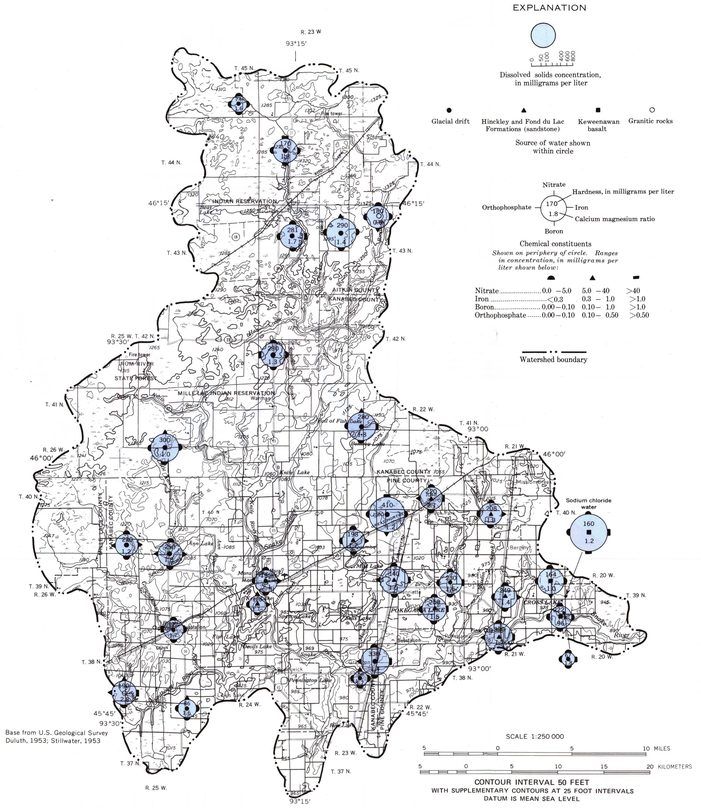
GROUND-WATER QUALITY

SUMMARY OF GROUND-WATER ANALYSES
[Results in milligrams per liter, except as indicated.]

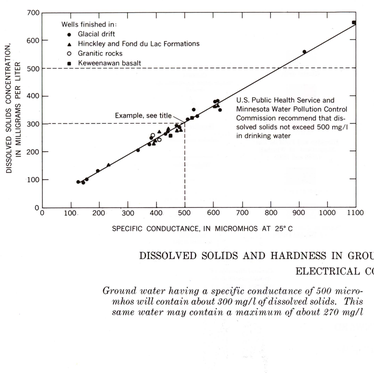
Formation	Silica	Iron	Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Sulfate	Chloride	Fluoride	Nitrate	Boron	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$	Manganese	Laboratory pH	Color
Glacial drift (18 samples)																	
Maximum	35	7.6	88	46	40	4.9	383	82	88	0.4	75	.28	555	410	.98	8.2	30
Minimum	23	.02	14	5.1	3.1	.8	46	2.8	1.0	.0	.1	.01	109	56	.00	7.5	1
Median	29	.19	58	24	7.7	1.0	268	6.1	3.9	.2	4.4	.03	300	240	.09	7.9	6
Hinckley and Fond du Lac Formations (sandstone, 9 samples)																	
Maximum	32	8.3	72	41	14	2.5	415	14	8.5	.3	14	.07	410	340	.27	8.1	45
Minimum	22	.36	30	11	.5	.1	120	2.5	0.5	.1	.1	.01	220	120	.02	7.7	1
Median	29	1.1	58	24	5.0	1.4	293	5.0	1.0	.2	3.5	.04	286	249	.11	7.9	5
Granitic rocks (2 samples)																	
	12	3.8	56	12	9.0	3.0	268	5.0	1.0	.3	11	.07	700	190	.03	7.5	15
	14	.14	27	27	21	2.0	305	5.0	1.0	.6	4.0	.07	250	180	.27	7.9	10
Keweenawan basalt (3 samples)	9.4	1.3	35	18	210	3.0	122	27	290	.2	4.0	3.6	730	160	.04	7.6	10
	—	.05	44	28	17	2.5	306	5.0	7	.2	.2	.10	256	222	.02	8.0	4
	—	.04	34	20	60	1.7	329	14	9.0	.1	.2	.63	321	164	.04	8.2	4
Recommended limits for domestic consumption (Minnesota Water Pollution Control Commission, 1967.)	—	.30	—	—	—	—	—	250	250	1.5	45	—	500	—	.05	—	15

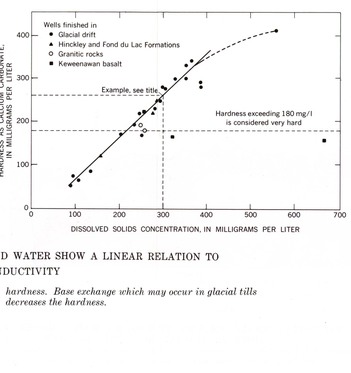


GROUND WATER ACQUIRES ITS CHEMICAL PROPERTIES PRIMARILY FROM: (1) RED-BROWN DRIFT CONTAINING SLIGHTLY SOLUBLE CRYSTALLINE ROCKS, (2) LAKE AND PEAT DEPOSITS, (3) GRAY DRIFT CONTAINING CARBONATES AND SULFATES OF CALCIUM AND MAGNESIUM, AND SODIUM CHLORIDE

Dissolved solids concentration (sum of mineral constituents) ranges from about 100 to 660 mg/l (milligrams per liter). The lower dissolved solids generally occur in water taken from shallow sand and gravel deposits and red drift deposits. Higher dissolved solids occur where gray drift and associated lake sediments contribute chlorides, sulfates, sodium and calcium to solution. Activities of these ions aid in dissolving larger concentrations of calcium and magnesium carbonates.

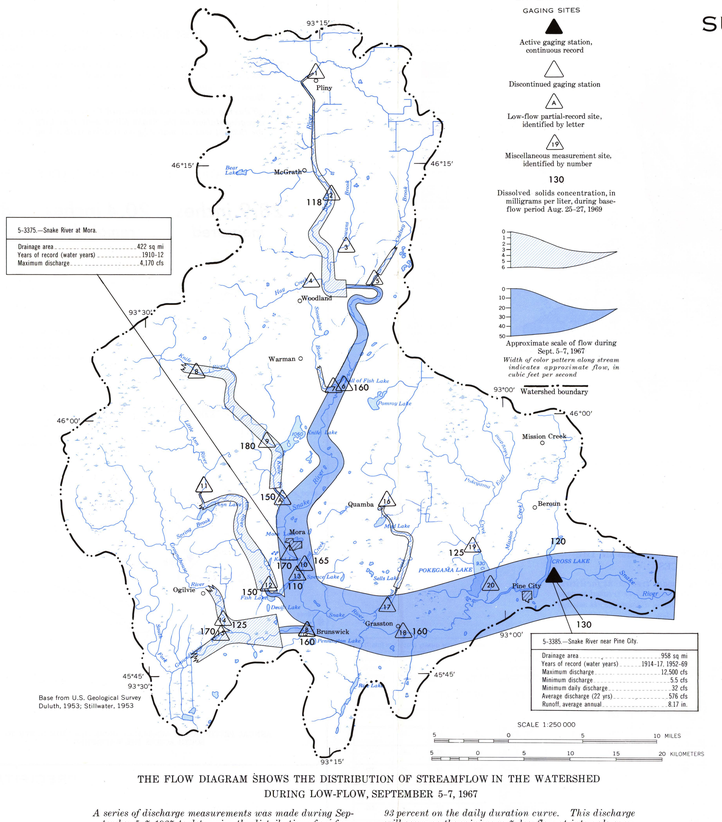
Calcium magnesium bicarbonate is the dominant water type except in one well which contains sodium chloride water. Calcium to magnesium ratios range from 0.6 to 11.4 indicating localization of calcium and magnesium minerals which were distributed by lake eutrophication and glacial action. Higher phosphate concentrations (greater than 0.10 mg/l) are generally found in the southern part of the watershed where numerous lake deposits are present. Iron concentrations exceeding recommended limits are found more frequently in wells penetrating bedrock. Nitrate concentrations exceeding recommended limits were found in one shallow drift well. Boron is found in water from all formations; however, concentrations exceeding 0.10 mg/l are generally found in the southern part of the watershed in the presence of gray drift deposits.





DISSOLVED SOLIDS AND HARDNESS IN GROUND WATER SHOW A LINEAR RELATION TO ELECTRICAL CONDUCTIVITY

Ground water having a specific conductance of 500 micromhos will contain about 300 mg/l of dissolved solids. This same water may contain a maximum of about 270 mg/l hardness. Base exchange which may occur in glacial tills decreases the hardness.



THE FLOW DIAGRAM SHOWS THE DISTRIBUTION OF STREAMFLOW IN THE WATERSHED DURING LOW-FLOW, SEPTEMBER 5-7, 1967

A series of discharge measurements was made during September 5-7, 1967, to determine the distribution of surface-water resources in the watershed within the given interval. There was no measurable precipitation for 10 days prior to this investigation so the streamflow measured was primarily ground-water discharge and represents base-flow yields from the basin.

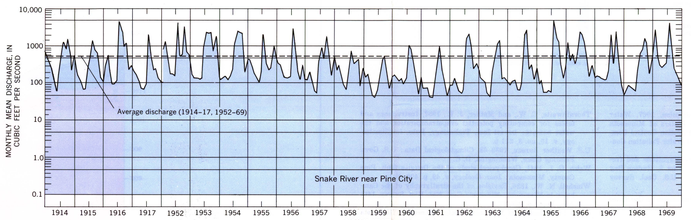
The discharge of 65 cfs (cubic feet per second) recorded at (5-3385) Snake River near Pine City gaging station during this period is 92 percent on the daily duration curve and it will occur as the minimum 7-day flow at intervals averaging about 1.7 years in length. The 10-year minimum 7-day flows computed for the discontinued gaging station (5-3375) Snake River at Mora, and low-flow partial-record sites A and B (see table below) are about 60 percent of the discharges shown.

A second series of base-flow discharge measurements was made during August 25-27, 1969. The flow at the Snake River near Pine City gaging station was 61 cfs which is 93 percent on the daily duration curve. This discharge will occur as the minimum 7-day flow at intervals averaging about 1.8 years in length.

Under base-flow conditions of August 1969, approximately half of the streamflow in the Snake River at the continuous gaging site near Pine City enters the river as ground-water inflow north of Mora. Ann, Fish, and Knife lakes contribute about one-sixth of the total and the remaining one-third is contributed by the Groundhouse River, ground-water inflow south of Mora, and minor tributary inflow.

Quality of water at times of low flow in theSnake River system is characteristic of water from till and sand deposits that dominate the shallow geologic environment. Water from peat deposits in the north is low in dissolved solids (118 mg/l) when compared to most of the ground-water inflow (150-200 mg/l) in the reach from McGrath to Grasston. Water in the Snake River at Mora has relatively high dissolved solids but is reduced downstream by water from Fish, Pokegama, and Cross Lakes and the Groundhouse River.

Number or letter key	Gaging station, partial record, or miscellaneous-discharge measurement site	Drainage area (sq mi)	Percentage of drainage area in lakes	Base-flow period Sept. 5-7, 1967		Base-flow period Aug. 25-27, 1969		7-day minimum discharge, 10-year recurrence interval (cfs)
				Discharge (cfs)	Yield (cfs per sq mi)	Discharge (cfs)	Dissolved solids (mg/l)	
5-3375	Snake River at Mora	422	0.6	32.4	0.077	38.8	170	20
5-3385	Snake River near Pine City	958	1.2	65	.068	61	130	36
A	Knife River near Mora	110	1.6	1.85	.017	2.14	150	1
B	Groundhouse River at Brunswick	145	.4	6.76	.047	7.81	160	4
1	Snake River near Pliny	36	0	.14	.004	<.5	—	—
2	Snake River near McGrath	144	.1	1.09	.008	<1	118	—
3	Cowans Brook near Woodland	15	0	Dry	—	Dry	—	—
4	Hay Creek near Woodland	22	.1	Dry	—	Dry	—	—
5	Chelsey Brook near Woodland	31	0	.89	.029	<1	—	—
6	Snake River near Warman	279	.2	14.1	.050	15.4	160	—
7	Snowshoe Brook near Warman	12	.6	.65	.054	<.5	—	—
8	Knife River near Warman	31	0	1.64	.053	—	—	—
9	Knife River above Knife Lake	86	0	—	—	2.06	180	—
10	Spring Creek at Mora	7.7	.4	—	—	2.50	165	—
11	Little Ann River near Mora	29	0	.09	.003	<.5	—	—
12	Ann River near Mora	65	.9	3.83	.059	5.10	150	—
13	Ann River at Mora	74	2.0	—	—	7.64	110	—
14	Groundhouse River near Ogilvie	72	0	1.55	.022	2.63	125	—
15	So. Fork Groundhouse River near Ogilvie	56	.8	2.24	.040	1.68	170	—
16	Mud Creek at Quamba	37	1.1	.09	.002	—	—	—
17	Mud Creek near Grasston	76	1.1	1.35	.018	<.5	—	—
18	Snake River at Grasston	813	.9	64.1	.079	61.9	160	—
19	Pokegama Creek near Pine City	59	0	Dry	—	<.5	125	—
20	Mission Creek near Pine City	31	0	Dry	—	Dry	—	—

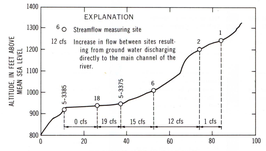


STREAMFLOW HYDROGRAPH SHOWS LARGE VARIATIONS IN MONTHLY MEAN DISCHARGE

Low flows were regulated by a powerplant at the outlet of Cross Lake during 1914-17. The powerplant was removed prior to the reestablishment of the gage in 1951 so the records since 1952 are unaffected by regulation.

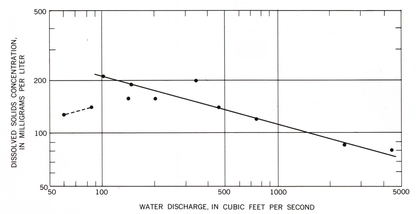
There is considerable variation in the flow of the Snake River. The minimum instantaneous flow for the period of record was 5.5 cfs on October 1, 1964, and resulted from construction of the weir at outlet of Cross Lake. The minimum daily flow was 32 cfs during February 1-6, 1961. The maximum instantaneous discharge was 11,500 cfs on April 18, 1965. A flood of this magnitude has a 50-year recurrence interval. Outside the period of record, a discharge of 12,500 cfs was measured at this site on May 9, 1950.

More than 75 percent of the annual minimum monthly flows occur during the winter period, generally in January or February. The annual minimum monthly flows outside the winter period generally occur during late summer.

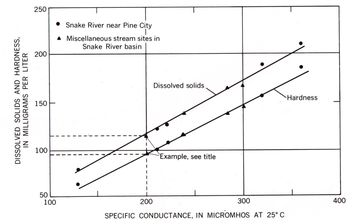


GROUND WATER DISCHARGING DIRECTLY TO THE MAIN CHANNEL OF THE SNAKE RIVER ACCOUNTS FOR MOST OF THE BASE-FLOW DISCHARGE.—*During the base-flow period, September 5-7, 1967, approximately 70 percent of the discharge at the Snake River near Pine City gaging station was attributed to ground water discharging directly to the main channel of the Snake River. The amount of ground-water seepage between main channel measuring sites is listed below the channel profile. Most of the seepage between sites 2 and 6 probably occurred downstream from mile 65. The source of this ground-water discharge is the Hinckley-Fond du Lac aquifer and the surficial outwash aquifers located along and adjacent to the main channel. Surficial outwash aquifers are also located in the Knife, Ann, and Groundhouse River basins and these tributaries were the only ones containing significant amounts of streamflow during the base-flow period.*

SURFACE WATER



DISSOLVED SOLIDS IN WATER FROM THE SNAKE RIVER NEAR PINE CITY SHOW A RELATION TO DISCHARGE.—*The concentration of dissolved solids in water from the Snake River near Pine City is related to discharge in the range of 100 to 5,000 cfs. At discharges less than 100 cfs, a decrease of dissolved solids occurs due to mixing of less mineralized lake water with river water.*



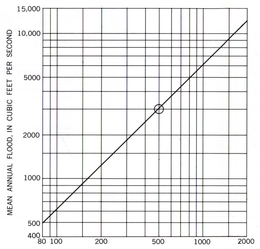
ESTIMATES OF HARDNESS AND DISSOLVED SOLIDS CAN BE OBTAINED BY MEASURING ELECTRICAL CONDUCTIVITY OF THE WATER.—*Linear relations between dissolved solids, hardness, and specific conductance enable a field observer to measure specific conductance and estimate dissolved solids and hardness from the graph. As an example, water having a specific conductance of 300 micromhos will contain about 115 mg/l of dissolved solids and 95 mg/l of hardness.*

CHEMICAL AND PHYSICAL PROPERTIES OF WATER IN THE SNAKE RIVER AND ITS TRIBUTARIES ARE REPRESENTATIVE OF DRAINAGE FROM GLACIAL TILL, PEAT, AND LAKE DEPOSITS ENVIRONMENTS FOUND IN THE WATERSHED

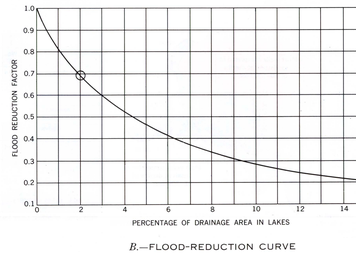
Calcium and magnesium bicarbonate are the dominant minerals in solution, with small varying concentrations of other ions, in a leached till environment. Iron and manganese concentrations exceed recommended limits for domestic consumption, in water from the Snake River and its tributaries. In general the higher concentrations of iron are associated with high color. Some of the color is probably caused by drainage from peat deposits.

Results, in milligrams per liter, except as indicated.

Stream, location, and date of collection	Discharge (cfs)	Silica	Iron	Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Sulfate	Chloride	Fluoride	Nitrate	Boron	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$	Manganese	Laboratory pH	Color
Snake River near McGrath September 5, 1967	1.1	5.3	0.12	24	8.5	4.5	1.1	116	7.2	5.2	0.1	0.5	0.06	135	95	0.15	7.4	45
Knife River near Mora September 6, 1967	1.8	8.4	.07	31	9.8	3.5	1.8	148	6.0	2.2	.1	.1	.03	147	118	.20	7.9	22
Snake River at Mora September 6, 1967	324	8.0	.00	38	12	5.5	1.8	188	6.5	.4	.2	.4	.03	176	144	.10	7.6	17
Groundhouse River at Brunswick September 6, 1967	6.8	12	.00	37	11	5.0	1.7	176	7.0	3.0	.2	.0	.02	165	138	.08	7.9	17
Snake River near Pine City																		
September 25, 1962	205	4.6	.11	28	11	3.3	1.9	129	9.8	.0	.2	2.4	.05	153	114	.04	7.4	50
March 20, 1963	152	17	.21	40	14	5.5	1.8	186	9.5	3.2	.3	3.7	.03	203	157	.06	7.1	22
November 12, 1963	402	7.5	.42	26	9.4	5.4	1.8	118	10	1.2	.2	.2	.04	138	107	.14	7.0	45
September 7, 1967	101	12	.04	47	17	5.9	1.9	215	9.8	6.0	.3	.0	.03	214	186	.01	8.2	6
October 18, 1969	620	5.2	.07	29	8.8	3.9	1.9	135	7.0	2.6	.2	1.2	.04	145	108	.03	7.7	45
	4390	8.3	.54	17	5.4	2.4	2.5	67	9.0	2.7	.3	1.2	.05	115	64	.10	7.3	90
Recommended limits for domestic consumption, (Minnesota Water Pollution Control Commission, 1967.)	—	—	.30	—	—	—	—	—	250	250	1.5	45	—	500	—	.05	—	15



A.—RELATION CURVE OF MEAN-ANNUAL FLOOD WITH DRAINAGE AREAS



B.—FLOOD-REDUCTION CURVE

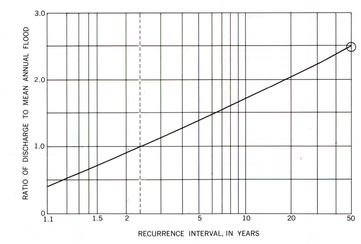
THE MAGNITUDE AND FREQUENCY OF FLOODS CAN BE DETERMINED BY USE OF RELATION CURVE *A*, FLOOD-REDUCTION CURVE *B*, AND FLOOD-FREQUENCY CURVE *C*

Example.—Find the magnitude of a flood having a 50-year recurrence interval at a site having a 500-square mile drainage area of which 2.0 percent is lakes.

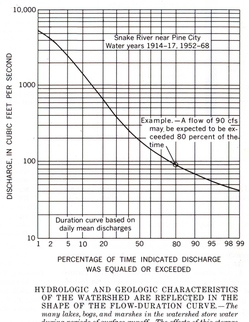
1. From curve in diagram *A*, the mean annual flood for a 500-square mile drainage area is 3,000 cfs.
2. From curve in diagram *B*, when 2.0 percent of the drainage area is lakes, the mean annual flood is reduced by a factor of 0.69. The adjusted mean annual flood becomes 0.69 × 3,000 cfs = 2,070 cfs.
3. From frequency curve in diagram *C*, the ratio of a flood having a 50-year recurrence interval to the mean annual flood is 2.5.
4. The magnitude of the 50-year flood is the mean annual flood times the ratio or 2,070 cfs × 2.5 = 5,175 cfs.

The recurrence interval of a flood of a selected magnitude can be found by reversing this procedure.

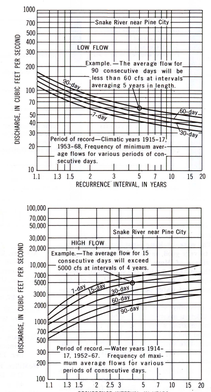
These regional curves are from Patterson and Gamble (1968).



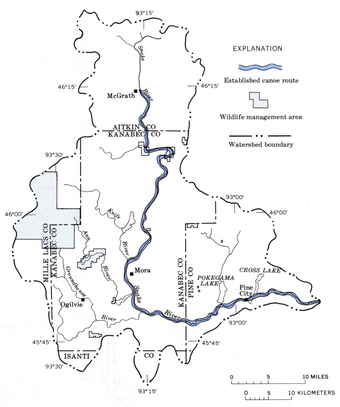
C.—FLOOD-FREQUENCY CURVE FOR SNAKE RIVER BASIN



HYDROLOGIC AND GEOLOGIC CHARACTERISTICS OF THE WATERSHED ARE REFLECTED IN THE SHAPE OF THE FLOW-DURATION CURVE.—*The many lakes, bogs, and marshes in the watershed store water during periods of surface runoff. The effects of this storage are reflected in the moderate slope of the upper part of the duration curve for the Snake River near Pine City. The lower part of the curve is relatively flat because the streamflow is sustained by ground water discharging to the stream during extended periods of no rainfall and through the winter period.*



THE LOW-FLOW AND HIGH-FLOW FREQUENCY CURVES SHOW MAGNITUDE AND FREQUENCY OF FLOWS FOR VARIOUS PERIODS OF CONSECUTIVE DAYS



THERE ARE GOOD RECREATIONAL OPPORTUNITIES IN THE SNAKE RIVER WATERSHED.—*The many rivers, streams, marshes, and approximately 50 lakes, provide areas for water-oriented recreational activities. Boating and fishing are popular in the lower reaches of the Snake River above Pine City, and in Pokegama and Cross Lakes. One of 17 rivers in the State designated as a canoe trail, the Snake River affords the canoeists scenic and exciting trips, especially from McGrath to Mora and Pine City to the St. Croix River. The wildlife management areas shown on the map are primarily wetlands and are managed for maximum wildlife production and public hunting. The meadow and woodland areas of the basin provide areas for camping, picnicking, snowmobiling, and other outdoor activities.*

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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