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REGIONAL APPROACH TO ESTIMATING THE GROUND-WATER RESOURCES OF MINNESOTA

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REGIONAL APPROACH TO ESTIMATING THE GROUND-WATER RESOURCES OF MINNESOTA

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REGIONAL APPROACH TO ESTIMATING THE GROUND-WATER RESOURCES OF MINNESOTA

By

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ABSTRACT

The feasibility of making regional estimates of ground-water resources has been demonstrated in Minnesota. Average annual ground-water recharge rates were used as an indicator of ground-water resources. Ground-water resources are defined here as the amount of ground water that can be withdrawn from water-table aquifers for a long period of time without irreversible depletion of the ground-water reservoir. In contrast ground-water reserves are a function of the areal extent, thickness and hydrogeologic parameters of the aquifers and confining beds. Data from three research approaches were used to estimate ground-water resources: (1) ground-water contribution to the streamflow; (2) 30-day low-flow characteristics of Minnesota streams; (3) ground-water hydrographs. Comparison of results of the three methods shows that values derived from ground-water hydrographs and data on ground-water contribution to streams are relatively close. Values derived from low-flow data, however, were consistently smaller. This discrepancy is related to two factors: (1) the limited time for which records of low-flow measurements were available; (2) the severely limited accuracy of low-flow estimates. However, the use of all three methods in conjunction does provide meaningful estimates of ground-water resources. The study shows regional distribution of ground-water resources in the 39 watersheds in Minnesota. The general distribution of ground-water resources is due to three major factors -- hydrogeologic environment, geomorphology and climate. The general trend is a decrease in ground-water resources from southeast to west and north in Minnesota.

This report includes additional data and incorporates the paper titled "Regional approach to estimating ground-water resources" that was published in World Congress on Water Resources, 3rd, Mexico City, 1979, papers, v. 5, p. 2206-2213: Washington, D.C., International Water Resources Association.

INTRODUCTION

Recent climatic conditions and increased water use in Minnesota have caused water shortages and increased public awareness of the need for more adequate information on ground-water resources. The 1975-1976 period of drought forced much of the state, particularly the western and central parts, to develop additional ground-water sources, and currently more than two-thirds of the state's population depends on ground water.

The Minnesota Geological Survey has completed bedrock hydrogeologic (Kanivetsky, 1978) and Quaternary hydrogeologic maps of Minnesota (Kanivetsky, 1979). However, further quantitative estimates of ground-water resources and ground-water use and demand are needed to establish priority areas for ground- and surface-water research, and for development of management practices to protect these resources.

The primary purpose of this study was to make preliminary estimates of ground-water resources. Average annual ground-water recharge rates were used as an indicator of ground-water resources. Ground-water reserves, that is the total amount of water in the ground-water reservoir, are not estimated in this study (for further discussion, see below).

The accuracy of the preliminary estimates is limited for the following reasons:

(1) Paucity of ground truth from field investigations.
(2) Estimates were made only for the water-table aquifers that discharge ground water to streams within each watershed.
(3) Boundaries of watersheds do not always coincide with ground-water divides.
(4) The hydrogeologic parameters that were used in the computations, such as storage coefficients and recharge rates, are approximations.

Research and field study must be conducted before more accurate ground-water resource estimates can be made.

GROUND-WATER RESOURCES ESTIMATES

The term "available" ground water has many interpretations, as discussed by Lohman (1972, p. 61-62). Total available ground water may be expressed by the following equation:

$$Q = Q_{Res} + \frac{\alpha V_{RV}}{t},$$

where:

Q - total "available" ground water,
Q_{Res} - ground-water resources,
V_{RV} - ground-water reserves,
α - coefficient of utilization of ground-water reserves, usually 0.3-0.5,
t - time of withdrawal of ground-water reserves.

Ground-water resources (Q_{Res}) are that portion of the ground water which is added by means of infiltration to the ground-water system. Eventually, this percolating water reaches stream channels and provides the base flow of the streams. Approximate hydrologic equilibrium is assumed to exist between ground water entering (recharge) and leaving (discharge) the hydrologic system.

Ground-water reserves ($\alpha V_{RV}/t$) are a function of the areal extent, thickness and hydrogeologic parameters of the aquifers and confining beds. Reserves are the quantity of water stored in the rock in excess of the water resources added by continuing infiltration. Reserves can be withdrawn if all the water possible were withdrawn from the aquifer. Reserves can be more or less than the ground-water resources (Q_{Res}). As a first step in the evaluation of the total "available" ground water, which assumes non-depletion of the ground-water reservoir, the main goal of this study was to estimate ground-water resources. This is a conservative procedure which neglects the reserves available by aquifer depletion.

Data from three research approaches were used in this study to estimate ground-water resources:

(1) ground-water contribution to the streamflow in Minnesota (Ackroyd and others, 1967)

(2) 30-day low-flow characteristics of Minnesota streams (Lindskov, 1977)

(3) ground-water hydrographs

Ground-Water Contribution to Streamflow

Estimates of annual ground-water contribution to streamflow have been determined by Ackroyd and others (1967) for 38 drainage basins in Minnesota.

Streamflow is derived from surface runoff and ground-water runoff. Surface runoff is that part of the precipitation that finds its way into stream channels without infiltrating through the soil into the water table. Ground-water runoff is precipitation that infiltrates the soil to the water table and then percolates into stream channels. Streamflow measurement and separation of this streamflow into two components -- surface- and ground-water runoff -- were the goals of Ackroyd's study.

30-Day Low-flow Characteristics of Minnesota Streams

That 30-day low-flow of streams largely represents ground-water discharge has been demonstrated by extensive research and studies in the Soviet Union (Popov, 1968) for conditions similar to Minnesota. As stated above, it is assumed that approximate equilibrium exists between ground-water discharge and ground-water recharge. The 30-day low-flow data (Lindskov, 1977) with recurrence intervals of 2 and 10 years were therefore used in this study, despite the limitations stated in Lindskov (1977, p. 22), because they are useful in conjunction with data derived by other methods.

Ground-water Hydrograph Method

The ground-water hydrograph method is based on the assumption that the rise of ground-water levels after rainfall and snowmelt reflects the recharge rate; for water-table aquifers, close correlation betwen precipitation and ground-water level fluctuations is logical in the absence of influence either by nearby surface-water bodies (streams, lakes, marshes) or by human activities (ground-water withdrawal, replenishment).

One hundred ten wells having continuous records for at least one year are shown in Figure 1. They were selected from about 200 water-table observation wells. Fluctuations of water levels in these wells were compared with precipitation records at the nearest meteorological stations in order to establish the relationship between these two parameters.

Ground-water recharge rates as shown in Figure 2 were calculated from the equation:

$$W = S \frac{\Delta h + \Delta z}{\Delta t}$$

where W = rate of recharge (inches/year),
S = storage coefficient (dimensionless),
Δh = rise of water level after precipitation or snowmelt, usually occurring during spring and fall (inches),
Δz = water-level decline due to outflow (inches). This water-level decline can be determined from the ground-water hydrograph by extending the line of ground-water decline to the point of the corresponding maximum rise in water level,
Δt = time (year).

The ground-water hydrograph method will give relatively reasonable values for recharge rates although they are probably underestimated because of certain unavoidable limitations, such as (1) the water table can never be ideally horizontal, (2) the rise of water levels sometimes will not be a maximum and (3) ground-water outflow during the spring and early fall periods of water-level rise will always be slightly higher than in late fall and winter due to a corresponding increase of water level and flow gradient.

The applicability of the ground-water hydrograph method was limited because the water-table observation network is insufficient in many parts of Minnesota.

The storage coefficient (S) was calculated from pumping tests, literature data and the empirical equations of Lebedev (1976).

$$S = 0.13 + 0.074 \lg k \text{ and}$$
$$S = 0.1254 + 0.1152 \lg k$$

where k = coefficient of hydraulic conductivity in meters/day.

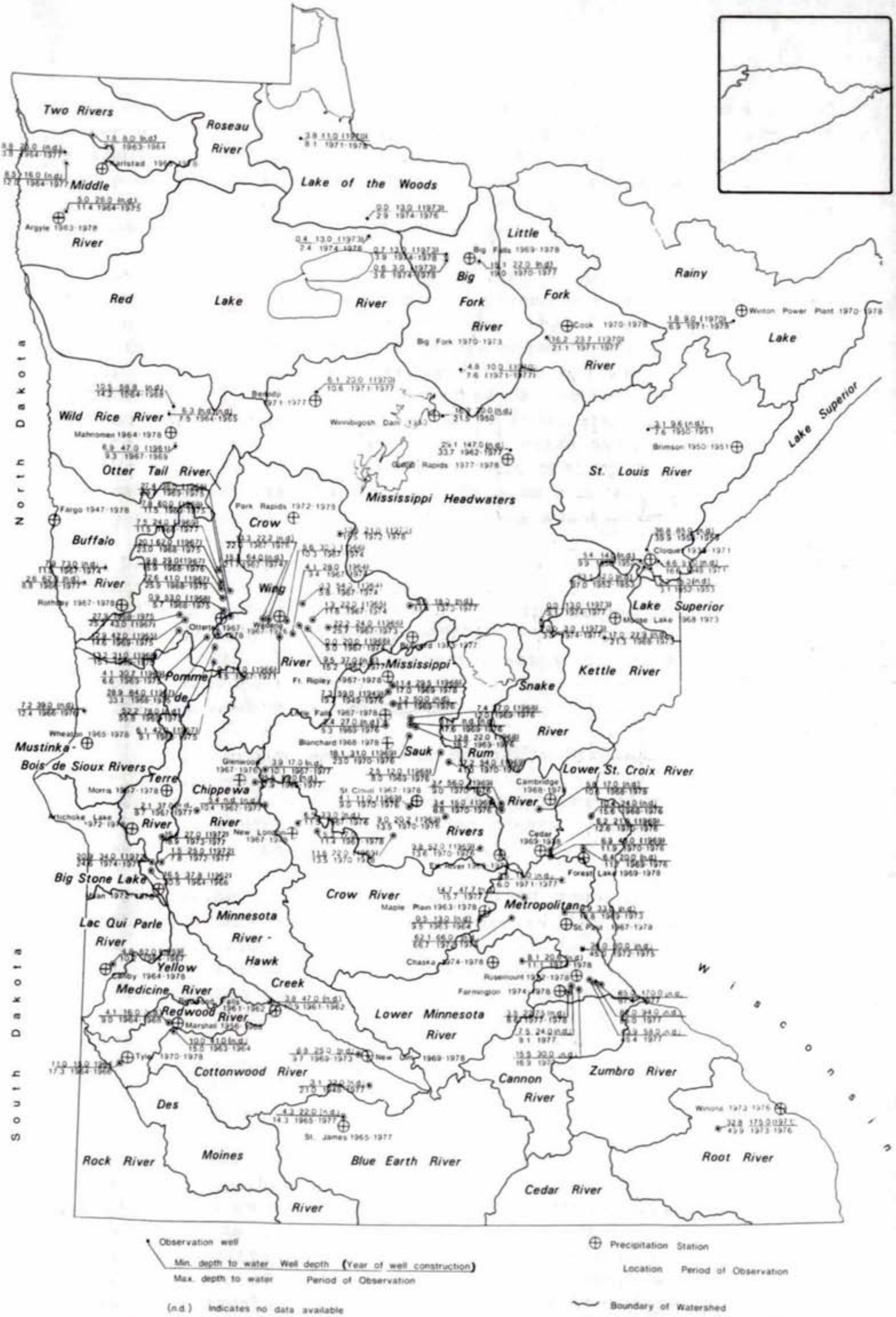
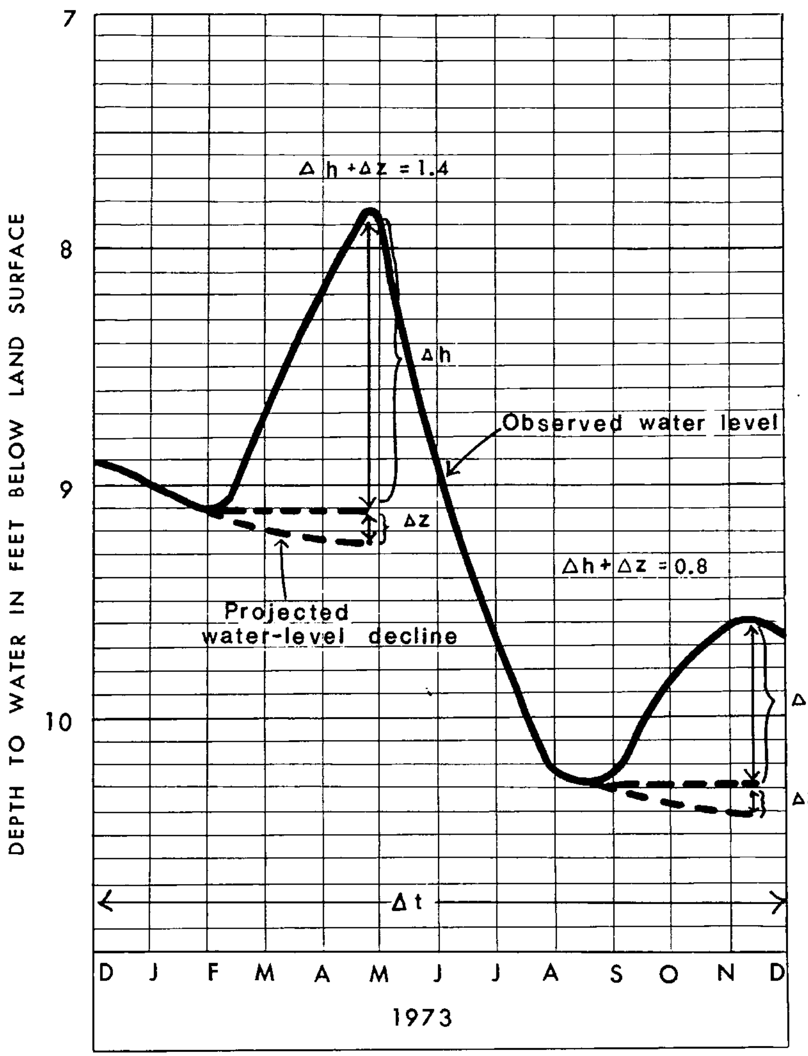


Figure 1– Water-table observation wells and precipitation stations in Minnesota.



OBSERVATION WELL T32-R23-S4AAD, RUM RIVER WATERSHED

$$W = S\,\frac{\Sigma(\Delta h + \Delta z)}{\Delta t} = 0.15\,\frac{(1.4 + 0.8)\cdot 12}{1} = 3.96 \text{ inches}$$

Figure 2 — Determination of recharge rate from a ground-water hydrograph of a water-table well.

Recharge rates for each watershed using the three above-mentioned methods were calculated. Recharge rates for watersheds that lacked sufficient data for any of the methods were estimated by extrapolation from information on neighboring watersheds. The next step in this study was to define the areal extent of the water-table aquifers within each watershed. For most of the state, the major water-table aquifers are surficial, i.e., outwash, alluvium and sandy lake deposits (Kanivetsky, 1979). Water-table conditions also exist in bedrock aquifers in the Root, Zumbro and Cannon River watersheds (Kanivetsky, 1978), and these aquifers were also included in this study.

Recharge rate values were determined for each water-table observation well. Recharge rates for each watershed were assumed to be the most reliable long-term annual average recharge values of observation wells in each watershed. These annual average recharge rates were then multiplied by the area of water-table aquifers within the watershed.

To estimate ground-water resources from low-flow stream data and ground-water contribution to streamflow, the recharge rate values were multiplied by the area of watershed above the gauging stations, and this low-flow data recharge rate was assumed to be average for the entire watershed.

All the data and resulting estimates of ground-water resources by watershed are given in Table 1.

Comparison of results of the three methods shows that values derived from ground-water hydrographs and data on ground-water contribution to streams are relatively close. Values derived from low-flow data, however, were consistently smaller. This discrepancy is related to two factors:

(1) The limited time for which records of low-flow measurements were available.

(2) The severely limited accuracy of low-flow estimates as indicated by Lindskov (1977).

It should be understood that both the second method -- ground-water contribution to the streams -- and the third method -- ground-water hydrographs -- also have some shortcomings. However, the use of all three methods in conjunction does provide an approximate range of estimated ground-water resources.

SUMMARY

The estimates of ground-water resources in Minnesota developed in this study are preliminary and will be improved as more data become available.

These preliminary estimates, however, can be used as a first step for regional planning and development. The study shows the regional distribution of ground-water resources by watershed (fig. 3). The general distribution of ground-water resources is

Table 1 — Ground-water resources of Minnesota (estimates).

1	2	3	4	5	6	7	8		9		10		11
#	HA#	WATERSHED	AREA (USGS HA* Data/DNR Bull. 10) sq. mi. / sq. km.	PRECIPITATION (HA Data) inches / mm	RUNOFF (HA Data) inches / mm	EVAPOTRANSPIRATION (HA Data) inches / mm	GROUND-WATER RUNOFF INFORMATION (Ackroyd, et al., 1967) cfs/sq mi / inches	area in sq. mi. / ground water in billion gal/yr.	30-DAY LOW FLOW DATA ON STREAMS (Lindskov, 1977) cfs / inches	area in sq. mi. / ground water in billion gal/yr	GROUND-WATER RECHARGE RATE FROM OBSERVATION WELLS cfs/sq. mi. / inches(assumed storage coeff.)	area of water table aquifer in sq. mi. / groundwater in billion gal/yr	ESTIMATED GROUND-WATER RESOURCES billion gal/yr. / million gal/yr. per sq. mile
LOWER MISSISSIPPI RIVER WATERSHED BASIN													
1	548	Root River	2570/2568 / 6655/6651	29.5 / 749	7.2 / 183	22.3 / 566	0.35-0.42 / 4.75-5.70	1270 / 105-125	268-370 / 2.33-3.22	1270 / 63.0-87.2 2568 / 128-176	0.26 / 3.6(0.03) 0.44 / 6.02(0.05)	1178 / 74 1178 / 123	100-150 / 39-58
2	543	Zumbro River	1676/1676 / 4341/4341	28.2 / 716	6.5 / 165	21.7 / 551	0.31-0.46 / 4.20-6.24	1130 / 82-122	137-192 / 1.40-1.97	1130 / 32-45 1676 / 48-67	n.d.	779 / n.d.	50-100 / 30-60
3	522	Cannon River	1462/1411 / 3786/3654	30.0 / 762	5.5 / 139	24.5 / 623	n.d.	n.d.	75.3-118.0 / 0.77-1.20	1411 / 18.8-29.0	n.d.	341 / n.d.	25-50 / 18-35
CEDAR RIVER WATERSHED BASIN													
4	552	Cedar River	1204/1204 / 3118/3118	30.3 / 770	5.9 / 150	24.4 / 620	0.26-0.33 / 3.5-4.5	425 / 26-33	28.0-43.6 / 0.89-1.39	425 / 6.6-10.3 1204 / 18.7-29.0	n.d.	569 / n.d.	25-50 / 21-42
METROPOLITAN AREA WATERSHED BASIN													
5	Bull. #11	Twin City Metro Area	1338/ - / 3465/ -	28.3 / 718	6.43 / 163	21.87 / 555	n.d.	n.d.	902 / 5.24	1338 / 123	0.47 / 6.4(0.236) 0.59 / 8.13(0.3)	654 / 73 654 / 93	50-100 / 37-75
MINNESOTA RIVER WATERSHED BASIN													
6	525	Blue Earth River	3106/3106 / 8044/8044	29.2 / 742	4.8 / 122	24.4 / 620	0.09-0.31 / 1.22-4.20	1100 / 23-80	21.3-55.8 / 0.26-0.69	1100 / 5-13 3106 / 14-17	0.29 / 3.9(0.15) 0.38 / 5.2(0.2)	661 / 45 661 / 50	25-50 / 8-16
7	526	Lower Minnesota River	2005/1487 / 5193/3851	28.8 / 731	4.5 / 114	24.3 / 617	n.d.	n.d.	81.7-220.0 / 0.07-0.20	1487 / 19-44	0.30 / 4.14(0.2) 0.46 / 6.21(0.3)	298 / 22 298 / 33	25-50 / 17-34
8	466	Cottonwood River	1880/1878 / 4869/4864	25.4 / 645	3.0 / 76	22.4 / 569	0.04-0.09 / 0.54-1.22	1280 / 12-27	3.74-13.70 / 0.04-0.14	1280 / 0.9-3.2 1878 / 1.3-4.7	0.33 / 4.455(0.2)	473 / 36	10-25 / 5-13
9	345	Redwood River	739/739 / 1914/1914	24.8 / 630	2.0 / 51	22.8 / 579	0.03-0.06 / 0.40-0.81	697 / 5-10	0.52-2.56 / 0.01-0.04	697 / 0.1-0.6 739 / 0.1-0.6	0.32 / 4.4(0.1)	156 / 12	5-10 / 7-13

*U.S.G.S. Hydrologic Atlas

Table 1— Ground-water resources of Minnesota (estimates) (cont.).

1	2	3	4	5	6	7	8		9		10		11
#	HA#	WATERSHED	AREA (USGS HA* Data/DNR Bull. 10) sq. mi. sq. km.	PRECIPI-TATION (HA Data) inches mm	RUNOFF (HA Data) inches mm	EVAPOTRANS-PIRATION (HA Data) inches mm	GROUND-WATER RUNOFF INFORMATION (Ackroyd, et al., 1967) cfs/sq mi inches	area in sq. mi. ground water in billion gal/yr.	30-DAY LOW FLOW DATA ON STREAMS (Lindskov, 1977) cfs inches	area in sq. mi. ground water in billion gal/yr	GROUND-WATER RECHARGE RATE FROM OBSERVATION WELLS cfs/sq. mi. inches(assumed storage coeff.)	area of water table aquifer in sq. mi. groundwater in billion gal/yr	ESTIMATED GROUND-WATER RESOURCES billion gal/yr. million gal/yr. per sq. mile
10	320	Yellow Medicine River	1070/1057 2771/2738	25.0 635	2.1 53.34	22.9 582	0.02-0.04 0.27-0.54	653 3-6	0.71-3.50 0.014-0.020	653 0.2-0.8 1057 0.3-1.3	n.d.	233 n.d.	5-10 5-10
11	269	Lac Qui Parle River	767/767 1986/1986	22.5 571	1.8 45.7	20.7 525.3	n.d.	n.d.	0-1.28 0-0.017	767 0-0.3	0.23 3.09(0.12)	166 11 166 8.9	5-10 6-13
12	213	Big Stone Lake	668/668 1730/1730	23.4 594	1.5 38	21.9 556	n.d.	n.d.	n.d.	n.d.	n.d.	338 n.d.	10-25 15-37
13	220	Pomme de Terre River	977/966 2530/2502	23.8 604	1.4 35	22.4 569	0.03-0.05 0.400-0.675	905 6.4-10.0	1.14-9.00 0.01-0.13	905 0.3-2.1 966 0.3-2.3	0.27 3.62(0.155)	240 15	10-25 10-26
14	286	Chippewa River	2072/2072 5366/5366	25.2 640	1.9 48	23.3 592	0.02-0.08 0.27-1.08	1870 9-35	2.83-13.40 0.02-0.09	1870 0.7-3.0 2072 0.74-3.50	0.26 3.53(0.16)	963 59	25-50 12-24
15	391	Minnesota River-Hawk Creek	1479/1479 3831/3831	27.4 696	2.7 68	24.7 628	n.d.	n.d.	n.d.	n.d.	n.d.	411 n.d.	10-25 7-17
UPPER MISSISSIPPI RIVER WATERSHED BASIN													
16	528	Crow River	2760/2756 7148/7138	27.6 701	3.3 84	24.3 617	0.05-0.10 0.68-1.36	2520 30-59	17.8-53.6 0.09-0.28	2520 4-13 2756 5-14	0.45 6.15(0.25)	885 94	50-100 18-36
17	534	Mississippi-Sauk Rivers	3890/3890 10075/10075	26.6 676	4.4 112	22.2 564	n.d.	n.d.	15.6-51.3 0.23-0.75	925 4-12 3890 15-51	0.41 5.68(0.26)	1567 154	100-150 26-39
18	509	Rum River	1550/1552 4014/4020	28.2 716	6.2 157	22.0 559	0.35-0.38 4.70-5.15	1360 112-121	64.9-75.7 0.64-1.56	1360 15-18 1552 18-20	0.4 5.49(0.17)	536 51	50-100 32-64
19	380	Crow Wing River	3760/3764 9738/9749	26.4 670	3.9 99	22.5 571	0.38-0.40 5.15-5.39	1010 90-95	175-268 2.3-3.6	1010 41-63 3764 154-235	0.28 3.83(0.2)	1761 117	100-150 27-40

Table 1—Ground-water resources of Minnesota (estimates) (cont.).

1 #	2 HA#	3 WATERSHED	4 AREA (USGS HA* Data/DNR Bull. 10) sq. mi. / sq. km.	5 PRECIPITATION (HA Data) inches / mm	6 RUNOFF (HA Data) inches / mm	7 EVAPOTRANSPIRATION (HA Data) inches / mm	8 GROUND-WATER RUNOFF INFORMATION (Ackroyd, et al., 1967) cfs/sq mi / inches	8 area in sq. mi. / ground water in billion gal/yr.	9 30-DAY LOW FLOW DATA ON STREAMS (Lindskov, 1977) cfs / inches	9 area in sq. mi. / ground water in billion gal/yr	10 GROUND-WATER RECHARGE RATE FROM OBSERVATION WELLS cfs/sq. mi. / inches(assumed storage coeff.)	10 area of water table aquifer in sq. mi. / groundwater in billion gal/yr	11 ESTIMATED GROUND-WATER RESOURCES billion gal/yr. / million gal/yr. per sq. mile
20	278	Mississippi Headwaters	7068/7068 / 18306/18306	25.3 / 643	5.34 / 136	19.96 / 507	n.d.	n.d.	554-1220 / 1.22-2.70	7068 / 130-287	0.245 / 3.33(0.22)	2489 / 144	150-200 / 21-28
RED RIVER WATERSHED BASIN													
21	272	Mustinka-Bois de Sioux Rivers	1429/1429 / 3701/3701	22.5 / 571	0.56 / 14.2	21.94 / 556.8	n.d.	n.d.	0-0	834 / 0	0.2 / 2.74(0.1)	95 / 4.5	1-5 / 1-3
22	296	Ottertail River	1920/1922 / 4973/4978	24.4 / 620	2.0 / 51	22.4 / 569	0.10-0.20 / 1.35-2.70	1830 / 43-86	17.9-85.3 / 0.08-0.63	1830 / 4.2-20.0 1920 / 4.4-21.0	0.20 / 2.77(0.19) 0.23 / 3.19(0.22)	652 / 31 652 / 36	25-50 / 13-26
23	307	Buffalo River	1690/1688 / 4377/4372	18.7 / 475	1.4 / 35	17.3 / 440	0.02-0.06 / 0.27-0.80	1040 / 4.9-14.7	1.74-11.40 / 0.02-0.15	1040 / 0.4-2.7 1688 / 0.6-4.4	0.22 / 2.98(0.12)	200 / 10	5-10 / 3-6
24	339	Wild Rice River	2600/2596 / 6734/6724	21.2 / 538	1.8 / 46	19.4 / 492	0.08-0.08 / 1.0-1.0	1600 / 30-30	3.99-29.00 / 0.033-0.240	1600 / 1-7 2596 / 1.5-11.0	0.14 / 2.03(0.15)	385 / 13.6	10-25 / 4-10
25	346	Red Lake River	5990/5988 / 15514/15509	22.0 / 559	2.6 / 66	19.4 / 493	0.04-0.10 / 0.54-1.35	5280 / 50-124	38-257 / 0.09-0.66	5280 / 9-61 5988 / 10-69	0.26 / 3.54(0.15)	467 / 29	25-50 / 4-8
26	201	Middle River	1823/1823 / 4722/4722	20.1 / 510	1.28 / 32	18.82 / 478	0.02 / 0.3 0.03-0.16 / 0.4-2.1	265 / 1.25 265 / 1.8-10.1	0	265 / 0	0.26 / 3.57(0.15) 0.44 / 5.96(0.25)	106 / 6 106 / 11	5-10 / 3-5
27	237	Two Rivers	1232/1232 / 3191/3191	21.0 / 533	1.1 / 28	19.9 / 505	n.d.	n.d.	0-0.15 / 0-0.005	644 / 0-0.035 1232 / 0-0.067	0.15 / 2.1(0.25)	53 / 1.9	1-5 / 1-4
28	241	Roseau River	1128/1128 / 2921/2921	18.0 / 457	0.7 / 18	17.3 / 439	0.07-0.07 / 0.9-0.9	573 / 9.5-9.5	0.78-2.74 / 0.018-0.060	573 / 1.84-6.46 1128 / 3.62-1.27	n.d.	n.d.	5-10 / 4-9
MISSOURI RIVER WATERSHED BASIN													
29	555	Rock River	1793/1793 / 4644/4644	25.8 / 650	3.1 / 79	22.7 / 571	n.d.	n.d.	2.49-7.58 / 0.04-0.13	788 / 0.6-1.8 1793 / 1.36-4.00	n.d.	n.d.	5-10 / 3-6

Table 1 — Ground-water resources of Minnesota (estimates) (cont.).

1	2	3	4	5	6	7	8		9		10		11
#	HA#	WATERSHED	AREA (USGS HA* Data/DNR Bull. 10) sq. mi. / sq. km.	PRECIPI-TATION (HA Data) inches / mm	RUNOFF (HA Data) inches / mm	EVAPOTRANS-PIRATION (HA Data) inches / mm	GROUND-WATER RUNOFF INFORMATION (Ackroyd, et al., 1967) cfs/sq mi / inches	area in sq. mi. / ground water in billion gal/yr.	30-DAY LOW FLOW DATA ON STREAMS (Lindskov, 1977) cfs / inches	area in sq. mi. / ground water in billion gal/yr	GROUND-WATER RECHARGE RATE FROM OBSERVATION WELLS cfs/sq. mi. / inches(assumed storage coeff.)	area of water table aquifer in sq. mi. / groundwater in billion gal/yr	ESTIMATED GROUND-WATER RESOURCES billion gal/yr. / million gal/yr. per sq. mile
DES MOINES RIVER WATERSHED BASIN													
30	553	Des Moines River	1520/1520 / 3937/3937	26.7 / 678	3.8 / 96	22.9 / 582	0.04-0.14 / 0.54-1.90	1220 / 11.5-40.0	1.95-12.30 / 0.02-0.12	1220 / 0.5-3.0 1520 / 0.6-3.2	n.d.	n.d.	10-25 / 7-16
LAKE SUPERIOR WATERSHED BASIN													
31	24	Lake Superior	2558/2558 / 6625/6625	28 / 711	13 / 330	15 / 381	n.d.	n.d.	n.d.	n.d.	n.d.	113 / n.d.	5-10 / 2-4
32	22	St. Louis River	3584/3634 / 9283/9412	28 / 711	8.7 / 220	19.3 / 491	n.d.	n.d.	399-729 / 1.58-2.88	3430 / 94-172	0.32 / 4.34(0.183) 0.48 / 6.48(0.21)	751 / 57 751 / 85	50-100 / 14-28
RAINY RIVER WATERSHED BASIN													
33	544	Lake of the Woods	2900/2903 / 7500/7519	23 / 584	6 / 152	17 / 432	0.06-0.15 / 0.81-2.00	110 / 1.5-3.9 2903 / 41-110	1.80-6.73 / 0.04-0.12	110 / 0.5-1.6 2903 / 11-42	0.23 / 3.2(0.1) 0.28 / 3.83(0.12)	480 / 26 480 / 32	10-25 / 3-9
34	549	Big Fork River	2060/2063 / 5335/5343	25.1 / 637	6.5 / 165	18.6 / 472	0.27-0.34 / 3.6-4.6	1460 / 93-117	38.2-89.6 / 0.35-0.83	1460 / 9.0-21.0 2063 / 12.7-29.8	0.20 / 2.74(0.15) 0.24 / 3.24(0.18)	193 / 9 193 / 10.8	5-10 / 2-5
35	551	Little Fork River	1850/1849 / 4790/4789	26.5 / 673	8.2 / 208	18.3 / 465	0.37-0.45 / 5.02-6.10	1730 / 151-183	46.1-76.2 / 0.31-0.60	1730 / 11-18 1849 / 12-19	n.d.	352 / n.d.	10-25 / 5-13
36	556	Rainy Lake	4500/4489 / 11700/11626	28.1 / 714	9.8 / 249	18.3 / 465	0.43 / 5.80	483 / 49-49	27.7-87.8 / 0.78-2.47	483 / 6.53-20.70 4489 / 60.7-192.0	0.79 / 10.67(0.25) 0.94 / 12.8(0.3)	97 / 17.9 97 / 21	10-25 / 2-6
ST. CROIX RIVER WATERSHED BASIN													
37	437	Kettle River	1566/1566 / 4056/4056	27.9 / 709	9.5 / 241	18.4 / 468	n.d.	n.d.	91.2-148.0 / 1.43-2.33	863 / 21.0-34.8 1566 / 38-63	0.3 / 4.14(0.15) 0.4 / 5.52(0.21)	407 / 29 407 / 39	25-50 / 16-32
38	488	Snake River	1015/1015 / 2629/2629	28.9 / 734	8.5 / 216	20.4 / 518	n.d.	n.d.	45.5-76.7 / 0.69-1.09	958 / 10.7-18.0 1015 / 11-19	n.d.	183 / n.d.	10-25 / 10-25
39	490	Lower St. Croix River	926/926 / 2398/2398	28.2 / 716	6.5 / 165	21.7 / 551	n.d.	n.d.	587-774(?) / 4.9-6.6(?)	1590 / 136-182 926 / 79-106	0.36 / 4.95(0.15) 0.49 / 6.6(0.2)	498 / 42 498 / 57	50-100 / 54-108

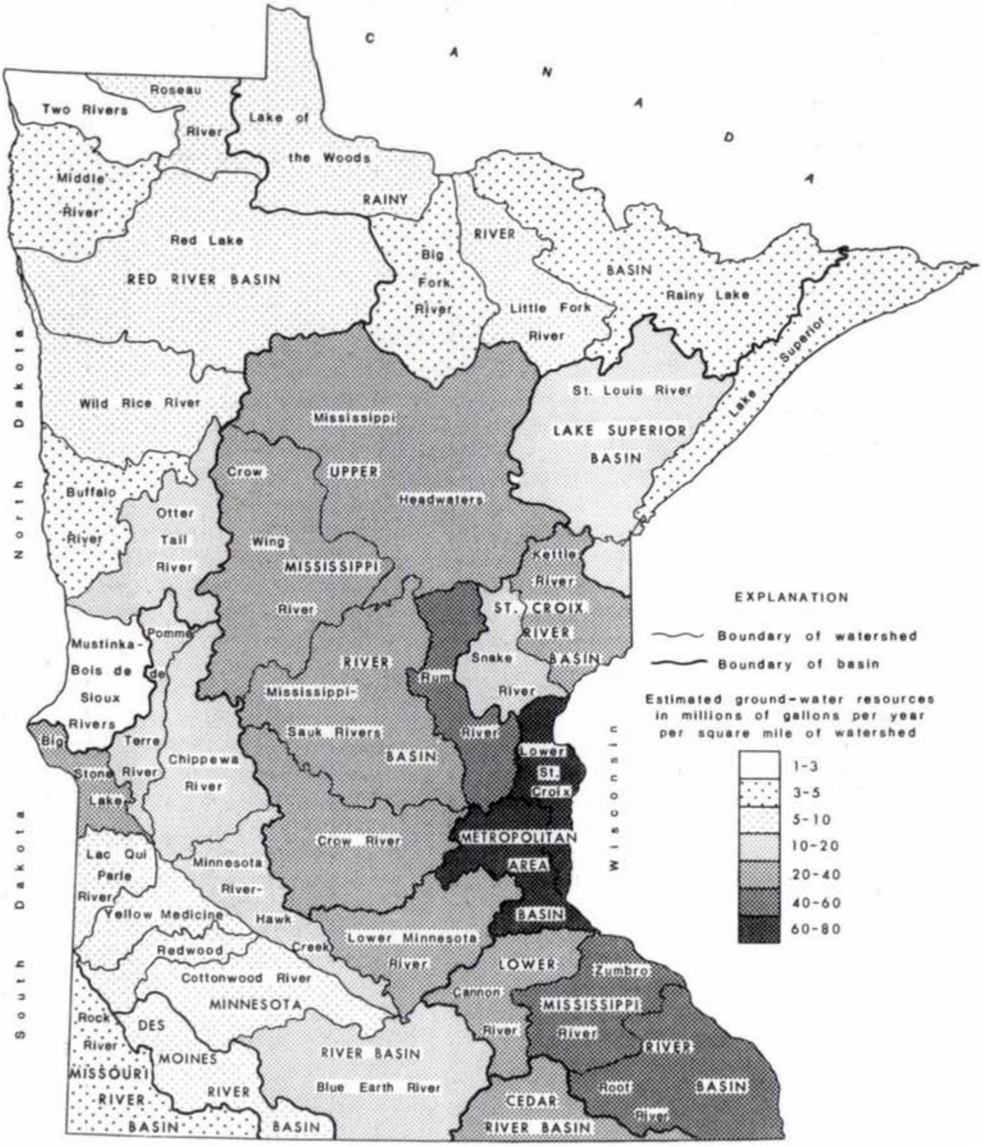


Figure 3 - Regional distribution of ground-water resources of Minnesota.

due to three major factors -- hydrogeologic environment, topographic relief, and climate.

It appears that the areas richest in ground-water resources are the Lower St. Croix and Metropolitan watersheds, and the poorest are the Two Rivers and Mustinka-Bois de Sioux watersheds. The general trend is a decrease in ground-water resources from southeast to west and north in Minnesota.

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