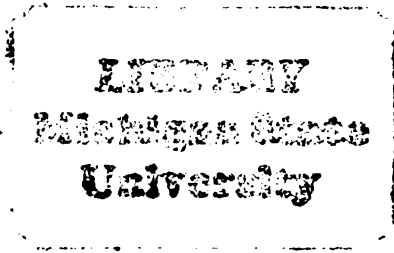




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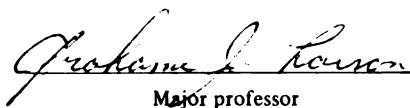
MORPHOLOGIC AND LITHOLOGIC INFLUENCES
ON RECHARGE IN A GLACIATED BASIN

presented by

Mark Alan Petrie

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MORPHOLOGIC AND LITHOLOGIC INFLUENCES
ON RECHARGE IN A GLACIATED BASIN

By

Mark Alan Petrie

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
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ABSTRACT

MORPHOLOGIC AND LITHOLOGIC INFLUENCES ON RECHARGE IN A GLACIATED BASIN

By

Mark Alan Petrie

Estimates of recharge to the drift are calculated for several sub-basins of the Upper Grand River Basin, using four methods of hydrograph separation. Comparison with flow duration ratios reveals that the method in which all peak flows are separated out as surface runoff provides the best estimate of recharge. The resulting recharge values range from 3.95 to 5.50 in/yr for a water year of near normal precipitation, and from 2.10 to 8.32 in/yr for all extremes of yearly precipitation.

The above recharge estimates were compared with several morphologic parameters and with basin permeability estimates derived from bore hole data. The comparisons indicate that basin recharge amounts depend primarily upon surface relief and permeability within the upper five feet of the drift.

ACKNOWLEDGEMENTS

I would like to thank my committee members for their suggestions and criticisms; Dr. Dave Long for reading my work despite the lack of chemical data, and especially Dr. Del Mokma, for making the it to the defense the day after his daughter Rebecca Ann was born. I owe a great debt to Grahame for his patience and sacrifice (taking valuable time out from sabbatical is no small concession), and for providing support when my enthusiasm waned. Thank you, Billy, for leading me (by the nose) through the abyss of the computer world. And special thanks to Cathy, for helping me maintain my sanity in a world too often conspiring to drive a poor boy wild.

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INTRODUCTION

Long term recharge to groundwater systems depends on several environmental and physical parameters. These include: 1) amount and type of precipitation (Mls, 1980), 2) drainage characteristics of the soil (Powell & Kirkham, 1974; Baker & Mace, 1976; Corbett, 1979), 3) vegetation cover (Coleman, 1953; Bosch & Hewlett, 1982), 4) basin morphology (Gupta, Waymire & Wang, 1980), and 5) regional geology (Walton, 1970; p. 370). The relative influence that these parameters have on recharge, however, is generally poorly understood and has been especially difficult to evaluate for heterogeneous glaciated basins (Walton, 1965).

The purposes of this paper are; 1) to estimate the recharge occurring within several small glaciated basins in south-central Michigan, 2) to quantify two major basin parameters (basin morphology and permeability) for each of these basins, and 3) to determine which of the two parameters has the greater influence on basin recharge.

THE UPPER GRAND RIVER BASIN

The Upper Grand River Basin lies in the south-central portion of Michigan's lower peninsula and covers approximately 2,840 square miles (7,356 square km). It is composed of nine sub-basins (Figure 1), each of which has slightly varying physical characteristics. In general, the surficial material throughout the Upper Grand River Basin range from nearly flat, clay rich glacial-lake sediments in the north to more hilly morainic and outwash deposits in the south (Martin, 1955). The thickness of the drift ranges from 0-50 feet (0-15 m) in the southern part of the basin to 350-400 feet (107-122 m) in the northern part (Michigan Water Resources Commission, 1961).

The uppermost bedrock unit underlying the drift is predominantly the Saginaw Formation (Pennsylvanian: Vanlier et al., 1973). It is composed chiefly of interbedded sandstone and shale, with occasional thin beds of limestone and coal. It's thickness ranges from 0 feet in the south to over 500 feet (152 m) in the north. In the northern half of the basin, low areas on the Saginaw surface contain younger Pennsylvanian sandstones and shales of the Grand River Formation which are up to 125 feet (38 m) thick in places (Kelly, 1936). In most areas both the Saginaw and Grand River Formations are hydraulically connected and act as a single aquifer (Vanlier et al., 1973). Near the southern and eastern borders of the basin the Saginaw is completely eroded away, exposing older Mississippian limestones, sandstones and shales.

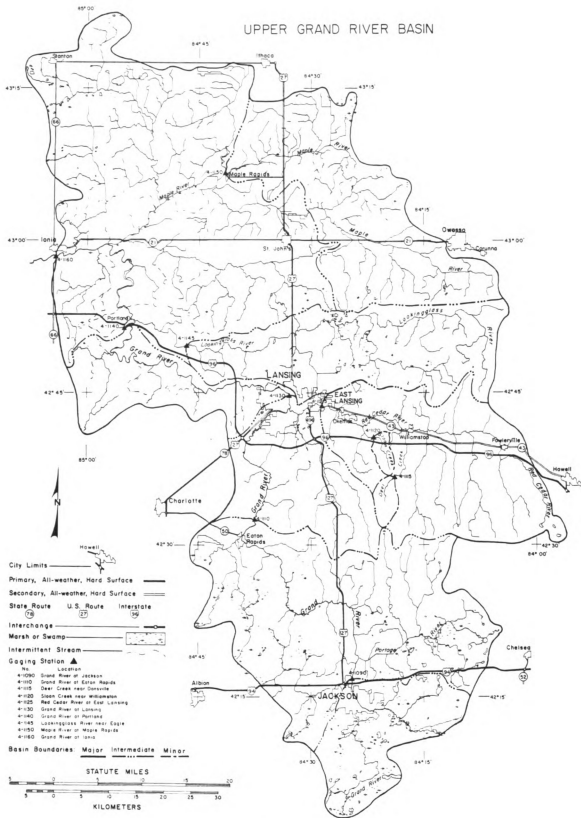


Figure 1. Study Area.

BASIN RECHARGE

Since changes in groundwater storage tend to be nearly zero ("insignificant") when calculated over the course of an entire water year, recharge to an aquifer can be found by separating groundwater runoff ("discharge to the stream") from total runoff for a water year (Walton, 1970; p. 183). This was done for each sub-basin of the Upper Grand River Basin for water years of below-, near- and above normal precipitation (U.S. Dept. Comm., 1950-1980). Choosing three years of different inputs to the system allows observation of its response to all extremes.

The estimates of recharge were achieved using four different methods of hydrograph separation. The first three, Local Minima (LO), Fixed Interval (FI) and Sliding Interval (SL) are described by Pettyjohn & Henning (1979). The fourth, Hand Separation (HA), is based upon a method described by Walton (1970). In all four methods a groundwater runoff curve is drawn under the discharge hydrograph curve; the volume below this line is groundwater runoff and the remainder above it is surface runoff.

The results of each hydrograph separation are presented in Table 1, together with flow duration ratios calculated for each of the sub-basins. These ratios were obtained using the equations:

$$Q_{10/90} = \left(\frac{Q_{10}}{Q_{90}} \right)^{\frac{1}{2}} \qquad Q_{25/75} = \left(\frac{Q_{25}}{Q_{75}} \right)^{\frac{1}{2}}$$

where Q10, Q25, Q75 and Q90 are the discharges equalled or exceeded 10, 25, 75 and 90 percent of the time, respectively.

PRECIPITATION

The calculated recharge for the 9 sub-basins and the overall basin derived from the four separation techniques are shown in Table 1 for the water years of below-, near-, and above normal precipitation. It is evident from the data that the recharge estimates vary least among the different separation techniques for the water year of normal precipitation (1956-57). In contrast, the variations in recharge estimates for the sub-basins are greatest for both the above- and below normal precipitation years (1955-56 and 1961-62).

As expected, recharge values tend to be greatest for the year of above normal precipitation, 1955-1956 (Table 1), and are generally least for the year of below normal precipitation (1961-62). In several sub-basins (Jackson, Eaton Rapids, Sloan Creek, Deer Creek, Red Cedar, Lansing and Portland), however, the recharge values from some of the separation techniques are less in the year of normal precipitation (1956-57) than those for the year of below normal precipitation (1961-62). This may be the result of soil moisture deficit affecting infiltration rates during periods of low precipitation (Bouma, 1980; Rao, Tao & Rukvichai, 1980).

TABLE 1. RECHARGE (IN/YR) AND FLOW DURATION RATIOS

BASIN	WATER YEAR	SEPARATION		METHOD		RATIOS	
		LO	FI	SL	HA	Q10/90	Q25/75
JACKSON	1955-56	8.21	8.67	8.70	8.30	2.46	1.63
	1956-57	4.85	5.40	5.44	5.38	2.06	1.56
	1961-62	4.89	5.54	5.61	5.48	2.11	1.50
EATON RAPIDS	1955-56	8.32	9.32	9.28	8.44	2.85	1.66
	1956-57	4.87	5.54	5.59	5.12	2.32	1.72
	1961-62	5.54	5.78	5.88	5.12	2.60	1.57
DEER CREEK	1955-56	5.33	5.63	5.48	5.27	4.57	2.11
	1956-57	3.09	3.72	3.72	4.14	4.21	2.58
	1961-62	3.86	4.45	4.49	4.79	4.26	2.07
SLOAN CREEK	1955-56	4.60	5.08	4.89	4.81	9.74	3.03
	1956-57	2.48	3.32	3.40	3.41	6.69	3.40
	1961-62	2.84	3.53	3.46	3.88	5.61	2.29
RED CEDAR	1955-56	5.56	7.39	7.33	6.68	4.21	2.01
	1956-57	3.95	4.87	4.96	4.72	3.13	2.02
	1961-62	4.07	4.28	4.47	4.18	2.62	1.60
LANSING	1955-56	6.95	8.48	8.42	7.10	3.36	1.78
	1956-57	4.56	5.44	5.48	4.49	2.67	1.92
	1961-62	5.12	5.27	5.40	4.83	2.61	1.55
PORTLAND	1955-56	7.24	8.70	8.72	7.94	3.14	1.72
	1956-57	4.77	5.65	5.67	4.98	2.73	1.87
	1961-62	5.42	5.61	5.71	5.10	2.45	1.45
LOOKING- GLASS	1955-56	6.13	8.17	8.23	8.15	3.86	1.90
	1956-57	5.21	6.45	6.42	6.28	3.10	2.09
	1961-62	4.70	4.85	4.96	4.91	3.79	1.61
MAPLE RAPIDS	1955-56	5.88	8.40	8.48	8.99	5.44	2.58
	1956-57	4.35	5.56	5.56	5.44	3.86	2.74
	1961-62	2.10	5.06	5.00	4.91	5.44	1.93
IONIA	1955-56	7.16	9.09	9.18	7.37	3.54	1.68
	1956-57	5.50	6.34	6.34	5.19	2.88	1.88
	1961-62	4.79	5.40	5.46	4.81	2.71	1.43

Note: 1955-56 is the above normal-, 1956-57 near normal-, and 1961-62 below normal precipitation year.

Because of these inconsistencies, recharge values for the years of above- and below normal precipitation were not used in this investigation to define the general relationship between sub-basin physical parameters and sub-basin recharge. Only the water year 1956-57 was used in the analysis, because fewer interferences are active during years of near-normal precipitation.

RECHARGE VERSUS FLOW DURATION

Chow (1964; p. 14-42 to 14-44) has shown that both the discharge hydrograph and the flow duration curve of a basin are closely related. It can be concluded, therefore, that the separation method which is in closest agreement with the flow duration characteristics of a stream probably best reflects the recharge characteristics of a basin. Table 2 lists the correlation coefficients of recharge (in/yr) versus the flow duration ratios $Q_{10}/90$ and $Q_{25}/75$ for all of the sub-basins in the Upper Grand River Basin. It is evident from Table 2 that the recharge values obtained using subroutine L0 correlate much better with flow duration ratios than do the values obtained using the other subroutines. This would suggest that recharge calculated by L0 probably provides the best estimate for recharge within each of the sub-basins.

In Table 3, both the amount of groundwater runoff as percent of total runoff and the recharge rate calculated by L0 are shown, for each of the nine sub-basins as well as the whole basin. The basin areas and mean daily discharges are also given. From the data it is evident that Jackson, Eaton Rapids, Lookingglass and Ionia sub-basins

have generally high recharge rates (4.85 to 5.50 in/yr), while Sloan Creek, Deer Creek and Red Cedar sub-basins have generally low recharge rates (2.48 to 3.95 in/yr).

TABLE 2.
CORRELATION COEFFICIENTS;
RECHARGE RATES VERSUS FLOW DURATION RATIOS
FOR WATER YEAR 1956-57

RATIO	SEPARATION METHOD			
	LO	FI	SL	HA
Q10/90	-.843	-.755	-.761	-.679
Q25/75	-.811	-.697	-.706	-.584

It appears that the very small drainage areas of Deer Creek and Sloan Creek sub-basins (16.3 and 9.34 sq.mi.) result in artificially low recharge estimates. This is probably because most precipitation enters into the stream channel before it has time to infiltrate. Excluding these two sub-basins, the calculated recharge values in the eight remaining sub-basins range from 3.95 to 5.50 in/yr. Previous investigations have reported similar recharge values: Firouzian (1963) used flow net analysis to calculate an average recharge rate of 4.8 in/yr for the drift in Ingham County (the Lansing metropolitan area lies in the NW corner of the county in Figure 1); based on an analog model, Vanlier et al. (1973) estimated 4.0 in/yr of recharge to the drift in Ingham, Eaton and Clinton Counties (these three counties surround the Lansing metropolitan area).

TABLE 3.
RECHARGE RATES, MORPHOLOGIC PARAMETERS AND PERMEABILITIES OF BASINS

	JACKSON	EATON RAPIDS	DEER CREEK	SLOAN CREEK	RED CEDAR	LANSING	FORTLAND	LOOKING- GLASS	MAPLE RAPIDS	TORIA
Basin Area (sq.mi.)	174.	661.	16.3	9.34	355.	1230.	1385.	281.	434.	2040.
Mean Daily Discharge (cfs)	87.13	326.68	8.78	6.08	186.22	635.44	745.01	163.07	215.12	1696.52
Percent Ground- Water Runoff	71.23	72.78	42.31	28.04	55.36	64.95	65.15	66.20	64.58	67.97
Recharge Rate (inches)	4.85	4.87	3.09	2.48	3.95	4.56	4.77	5.21	4.35	5.50
Stream Frequency	0.08	0.14	--	--	0.09	0.11	0.11	0.12	0.20	0.16
Bifurcation Ratio	3.75	4.17	--	--	5.17	4.86	5.13	5.50	4.20	5.01
Form Ratio	0.71	0.53	0.46	0.46	0.42	0.52	0.35	0.21	0.35	0.51
Circularity Ratio	0.65	0.47	0.93	0.83	0.59	0.48	0.32	0.37	0.45	0.37
Elongation Ratio	0.95	0.82	0.77	0.73	0.68	0.82	0.67	0.51	0.67	0.81
Relief Ratio	23.1	11.9	6.4	7.0	8.0	9.7	9.1	6.0	7.3	8.7
Surface Area Ratio	1.30	1.30	1.21	1.07	1.18	1.33	1.29	1.25	1.21	1.33
Average Permeability 0 - 5 feet	46.28	35.41	27.36	20.26	26.02	31.11	30.02	31.58	25.08	28.43

FACTORS INFLUENCING BASIN RECHARGE

BASIN MORPHOLOGY

The following morphologic parameters were determined for each sub-basin in the Upper Grand River Basin following the methods described by Morrisawa (1968): stream frequency (F_s), bifurcation ratio (R_b), form ratio (R_f), circularity ratio (R_c), elongation ratio (R_e) and relief ratio (R_r). The first two parameters quantify the sub-basin drainage characteristics while the others define the shape. The methods of quantification are briefly discussed in appendix A, and the values of these parameters are shown in Table 3. Note that no stream frequencies or bifurcation ratios are reported for the two smallest sub-basins, Deer Creek and Sloan Creek. On the base map scale (Figure 1) these sub-basins have no tributaries, which makes these two ratios meaningless. In addition to these, surface roughness was quantified by calculating the "surface area ratio" (R_s), following the procedure presented in appendix B.

While no clear pattern is evident in the morphologic data shown in Table 3, there are some general trends. Stream frequencies are fairly consistent among the sub-basins except for Maple Rapids, which has an unusually high value. Jackson and Red Cedar sub-basins, on the other hand, have relatively low values. The bifurcation ratios also

are about the same for each of the sub-basins except for the low value for Jackson sub-basin. In the case of Jackson sub-basin, the low stream frequency value and bifurcation ratio may be related to a high water table which is evidenced by large areas of marshland (Figure 1).

The high stream frequency value for Maple Rapids sub-basin is probably due to the local low relief (surface area ratio of 1.21), while the low stream frequency for Red Cedar sub-basin probably reflects the trellis drainage pattern related to the parallel Charlotte and Lansing moraines (Martin, 1955).

In general, the highest shape parameter values occur in Jackson sub-basin and the lowest in Lookingglass sub-basin. The Portland sub-basin, not the Lookingglass, has the lowest circularity ratio (R_c), which is probably due to the sharp westward bend of the sub-basin boundary near the gaging station at Portland. If this bend were less sharp the Portland sub-basin R_c value would probably increase significantly. The surface area ratios (R_s), however, do not follow the same general trend of the shape parameters. The Ionia and Portland sub-basins have high R_s values while the two smallest sub-basins, Deer Creek and Sloan Creek, have the lowest values.

AVERAGE DRIFT PERMEABILITY

The permeability of the drift underlying each sub-basin in the study area was estimated using the data set of water- and oil well logs shown in Figure 2. This data set is part of a computer file established for the National Coal Resources Data System (NCRDS, 1980), and includes information on thickness- and texture of each drift and

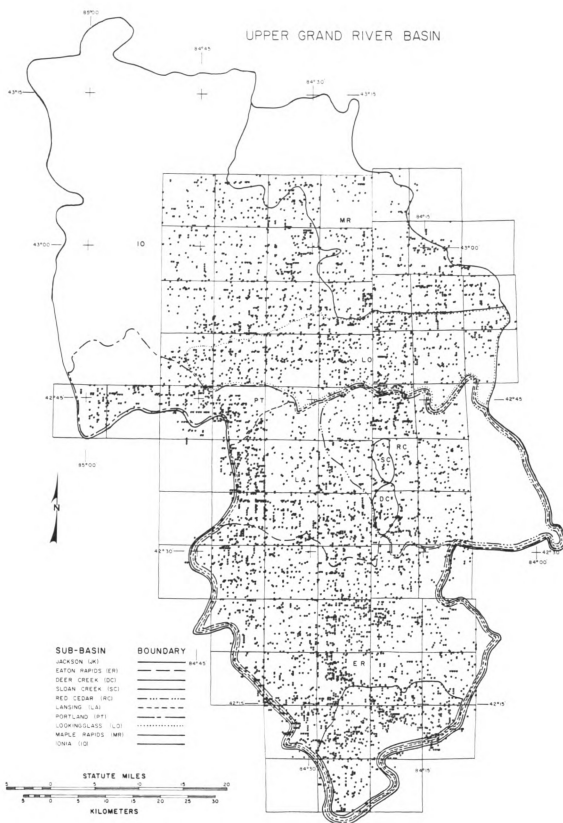


Figure 2. Bore Hole Locations.

bedrock unit penetrated.

The drift permeability was estimated from the lithologies reported in the first 5-, 10- and 15 feet as well as the whole drift thickness reported for each drill hole. Drift lithologies were grouped into three categories and were assigned a corresponding value for permeability; 7.0 in/yr for clay, 38.5 in/yr for sand and clay, and 70.0 in/yr for sand and gravel. These values are based on permeability values used in a finite element model of recharge through the drift in the Lansing metropolitan area (Kehers et al., 1983). This area lies near the center of the Upper Grand River Basin (Figure 1).

A weighted average permeability for each point was produced by multiplying the thickness of each drift unit in a well by the appropriate permeability value, then adding the results and dividing by the sum of the thicknesses. The resultant values were then summed and divided by the number of wells in the sub-basin to achieve an average sub-basin permeability. The results of these calculations are shown in Table 3 above.

To test the validity of the above calculations, county- and township-wide average permeabilities compiled from well data were compared with county- and township-wide average Soil Management Group (SMG) values. In theory, there should be a definite correlation between these values since SMG reflects soil permeability (Mokma & Robertson, 1976). These comparisons are presented in Figure 3, and the data are tabulated in appendix C.

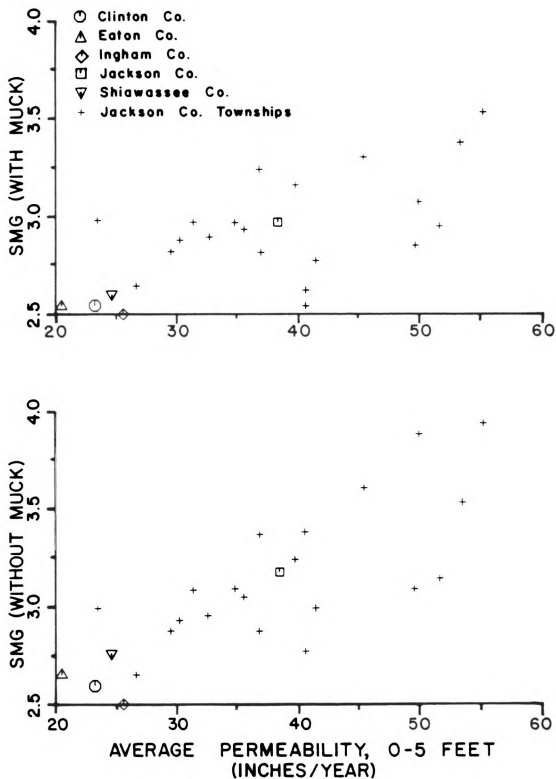


Figure 3. Soil Management Group Versus
Average Permeability, 0 - 5 Feet.

- (a) Coefficient of Correlation = +0.653
(b) Coefficient of Correlation = +0.796

It is evident from the correlation coefficient in Figure 3 (0.653) that the permeability values calculated from well logs are fairly reliable indicators of actual basin permeability. Using the average SMG values which exclude muck soils provides an even better correlation coefficient (0.796). This is probably because none of the wells used to calculate permeability are located in muck soils. Given this good correlation, the lack of data coverage in Figure 2 can be considered insignificant, because the soil associations reported in county soil surveys are continuous across the boundaries from adequately to inadequately covered areas. This suggests that the calculated permeabilities for these sub-basins (Red Cedar, Lansing, Portland, Maple Rapids and Ionia) represent fairly accurately the whole sub-basin values.

VEGETATION

There is currently no compiled data on vegetation distribution in the Upper Grand River Basin. However, a qualitative survey of areal photographs of the 9 counties that lie either totally or partially within the Upper Grand River Basin (Table 4) reveals a generally even distribution of forest and pasture. It is therefore reasonable to assume that the broad divisions of vegetation in Table 4 can be extended to the sub-basins.

From the data in Table 4 it is evident that, in each of the counties (and thus in each sub-basin), $2/3$ of the area is generally cropland, $1/4$ is forest and pasture, and the remainder is urban land, water, marsh land and others (U.S. Soil Conservation Service, 1968).

Although Montcalm and Ionia counties show slightly more than 25% forest and pasture, most of this occurs outside the study area. It appears, therefore, that vegetation, being generally similar among sub-basins, has little effect on basin recharge and can be considered insignificant in this study.

PRECIPITATION

The recharge rates estimated by hydrograph separation seem to indicate that recharge and precipitation vary directly. As was previously noted, however (page 5), there are several inconsistencies in the data (Table 1) that make an assessment of the true relationship between precipitation and recharge difficult to accomplish with any degree of certainty.

TABLE 4. 1958 DATA ON LAND USE IN MICHIGAN*

COUNTY	(1) THOUSANDS OF ACRES	PERCENT OF COUNTY TOTAL			
		CROP	FOREST, PASTURE	(2) URBAN	(3) OTHER
Clinton	365.44	72.0	16.6	4.1	7.3
Eaton	362.88	63.2	23.2	5.5	8.1
Gratiot	362.24	70.5	20.9	3.0	5.6
Ingham	357.76	61.6	15.9	10.8	11.7
Ionia	368.00	55.4	32.0	3.1	9.5
Jackson	451.20	49.3	20.0	9.8	20.9
Livingston	365.44	48.4	23.9	6.4	21.3
Montcalm	455.68	56.9	36.1	1.6	5.4
Shiawassee	345.60	69.7	18.4	5.5	6.4

* After The Michigan Conservation Needs Inventory Of 1968 (U.S. Soil Conservation Service, 1968).

Notes:

1. The acreage listed excludes water bodies in excess of 40 acres and river reaches over 1/8 mile wide.
2. Includes cities and built-up areas, roads and highways.
3. Includes rural homesteads, farmsteads, farm roads, feed lots, ditches and banks, fence and hedge rows, small water bodies (see no. 1 above), marshes, strip mines, gravel pits, borrow land, etc.

RELATION BETWEEN BASIN RECHARGE AND BASIN PARAMETERS

The correlation coefficients between basin recharge and the various basin parameters discussed below are presented in Table 5. All the correlations were made both including and excluding the data for Jackson sub-basin, because of the anomalous behavior exhibited by that sub-basin. This odd behavior is probably due to a high water table in the sub-basin (Figure 1), which acts as an impermeable layer near the surface. Because the high water table modifies the stream hydrograph to a shape normally associated with "flashy" streams, the hydrograph separations result in estimates of base flow that are lower than the probable actual amounts.

A combination of two factors are proposed to maintain this high water table. First, the hydraulic gradient in this sub-basin is probably directed from the Saginaw sandstone into the overlying more permeable sand and gravel drift (Michigan Water Resources Commission, 1961). In addition, the locally thin drift cover further limits the amount of infiltration into the drift aquifer.

BASIN MORPHOLOGY

The correlation coefficients between morphologic parameters and recharge, listed in Table 5, are extremely low for all but the circularity ratios (-.856 and -.918) and surface area ratios (0.859

TABLE 5.
COEFFICIENTS OF CORRELATION BETWEEN
EACH PARAMETER AND BASIN RECHARGE

PARAMETER	WITH JACKSON VALUES	WITHOUT JACKSON VALUES
STREAM FREQUENCY	0.164	0.229
BIFURCATION RATIO	0.118	0.220
FORM RATIO	-.185	0.075
CIRCULARITY RATIO	-.856	-.918
ELONGATION RATIO	-.114	0.021
RELIEF RATIO	-.405	0.310
SURFACE AREA RATIO	0.859	0.854
AVERAGE PERMEABILITY 0 - 5 FEET	0.568	0.728
AVERAGE PERMEABILITY 0 - 10 FEET	0.509	0.665
AVERAGE PERMEABILITY 0 - 15 FEET	0.399	0.489
AVERAGE PERMEABILITY WHOLE DRIFT	0.205	0.103

and 0.854). This suggests that none of the morphologic parameters except these two influence sub-basin recharge to any appreciable degree. This is to be expected, since the surface glacial deposits in the study area are too young (13,000 - 15,000 years old; Farrand & Eschman, 1974) for an equilibrium to have been established in the drainage system (Leopold et al., 1964; p. 423-426).

The nearly perfect relationship between sub-basin values of circularity ratio (R_c) and recharge, however, seems anomalous when compared with the poor correlations between recharge and the other shape parameters. A low R_c value can result from either an elongated (less circular) basin shape, or an irregular (highly incised) basin perimeter, or both. If the low R_c is due more to elongation, basin recharge would be relatively low, because the short overland travel path from the perimeter to the stream channel would allow less time for water to infiltrate before reaching the stream. The exact opposite is seen in the sub-basin values; as R_c decreases, recharge increases. Basin shape, therefore, can not be the cause of the good correlation between R_c and recharge. This conclusion is also supported by the lack of any clear relation between the other shape parameters and recharge, especially the elongation ratios, which show coefficients of correlation with recharge of -0.114 and $+0.021$.

The ratio R_s measures surface irregularity, not the general surface slope. Thus the correlation between R_s and recharge is positive: as relief increases, opportunities for ponding of water increase, causing increased recharge. In addition, as surface irregularity increases the basin perimeter should become more

irregular, resulting in lower R_c values. Comparison of R_s with R_c shows correlation coefficients of -0.625 and -0.699, which seems to support this contention.

It is sub-basin relief, therefore, not sub-basin shape that causes the strong relationship between sub-basin circularity ratios and sub-basin recharge. This means that the relief ratios, which show a poor correlation with recharge (-.405 and +.310), do not accurately indicate the sub-basin surface relief at all. Rather, they indicate only the general slope from sub-basin perimeter to the sub-basin outlet. It is the surface area ratio that quantifies sub-basin relief in this area, and, to some extent, the circularity ratio.

A third morphologic parameter, sub-basin size, also appears to influence recharge rates. In the case of the two smallest sub-basins, Deer Creek and Sloan Creek, the calculated recharge values are considerably lower than the value for Red Cedar sub-basin, in which they both lie. Precipitation falling on these small sub-basins reaches the stream channel very quickly, both over the surface and as interflow through the soil, and so has less time to infiltrate. It is possible that the lower than expected recharge value estimated for Jackson sub-basin is due, not to the high water table, but to a relatively small sub-basin area. This does not seem likely, however, since the next largest sub-basin, the Lookingglass, is essentially the same size, yet it has the second highest recharge rate (Table 3).

Figure 4. (a) Circularity Ratio vs. Basin Recharge.
(b) Basin Permeability, 0 - 5 Feet vs. Basin Recharge.

(JK is the Jackson sub-basin value.)

- (a) Coefficient of Correlation = -0.856
with JK, -0.918 without JK.
- (b) Coefficient of Correlation = +0.568
with JK, +0.728 without JK.

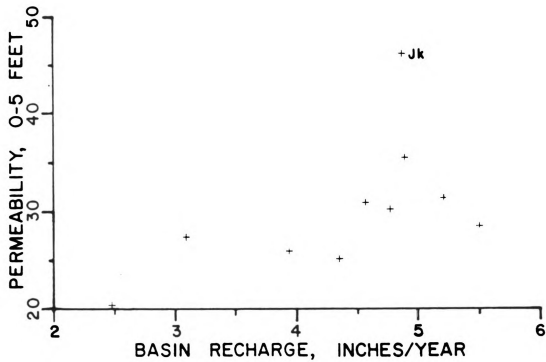
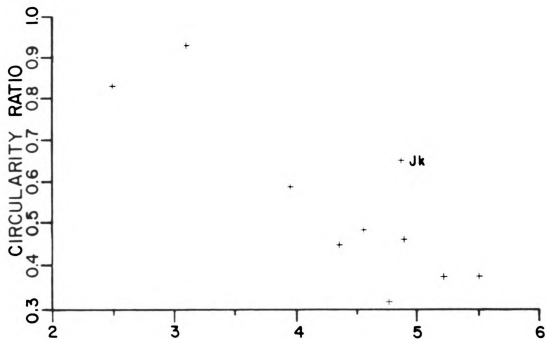


Figure 4.

AVERAGE DRIFT PERMEABILITY

In Figure 4b, the surface permeabilities calculated for the first 5 feet of drift in each sub-basin are plotted against sub-basin recharge. The permeability in the first 5 feet is used because, as the correlation coefficients (Table 5) indicate, the best estimate of sub-basin permeability is achieved in the first 5 feet of the drift, as opposed to the first 10 feet, the first 15 feet, or the whole drift thickness.

The correlation between sub-basin permeability and recharge is not as high as that between sub-basin circularity ratio and recharge (Figure 4). If the values for Jackson sub-basin are omitted, however, the permeability-recharge relation improves significantly, with the correlation coefficient rising from 0.568 to 0.728. The circularity ratio-recharge correlation coefficient also improves, from -0.856 to -0.918, while the surface area ratio-recharge correlation changes very little, from 0.859 to 0.854. This seems to indicate that discarding the data for Jackson sub-basin is indeed justified; the high water table in the sub-basin, acting as an impermeable layer near the surface, causes the hydrograph separation to yield anomalously low recharge rates.

CONCLUSIONS

Recharge to the drift, always a difficult parameter to quantify, has been calculated using the best of four different hydrograph separation techniques, as determined by comparison with the related hydrologic parameter -- flow duration ratio. The resulting values for sub-basin recharge range from 3.95 in/yr to 5.50 in/yr in a water year of near normal precipitation (excluding the values for the two sub-basins with extremely small areas). The recharge estimates for below- and above normal precipitation years range from 2.10 to 5.54 in/yr and 5.56 to 8.32 in/yr, respectively. All of these values agree with those reported for the area in previous studies.

Comparison of sub-basin recharge values with various physical sub-basin parameters yielded the following results: 1) Surface relief correlated positively with recharge (0.854). This relationship was also evident in the strong negative correlation between circularity ratio and recharge (-.918). 2) Correlation between recharge and drift permeability in the first 5 feet (0.782) was the highest of all permeability-recharge correlations. 3) Recharge generally increased as precipitation increased. 4) Sub-basin shape and drainage characteristics showed no appreciable influence on recharge.

From the above observations, it is evident that recharge

estimates by hydrograph separation vary directly with surface relief and soil permeability, and that surface ruggedness (high relief) has a greater effect on recharge than soil permeability. By allowing more infiltration due to longer holding time, the degree of surface irregularity seems to override the influence of soil texture on recharge rates.

One surprising result is that the best estimate of base flow is achieved using the simplest of the four separation methods tested. The goal of any separation is to model the actual conditions as accurately as possible, while remaining easy to use. The method which Walton (1970) describes as most accurately representing actual bank storage-discharge conditions serves as the basis for the subroutine "hand separation" (HA), the most complex of the four. The fact that this method resulted in the poorest correlation with flow duration parameters suggests that future modelling efforts should strive for simplicity, rather than sophistication.

FURTHER WORK

Additional support for the recharge estimates could be provided by chemical analysis of the stream waters on a daily basis, concurrent with streamflow measurements. The resulting data should show a general decrease in total dissolved solids as stream discharge increases, due to the diluting of the groundwater runoff by relatively "clean" surface runoff.

APPENDICES

APPENDIX A

APPENDIX A

MORPHOLOGIC PARAMETERS

STREAM FREQUENCY (F_s) -- Stream frequency is the total number of streams of all orders divided by the basin area. Stream order was determined by the method of Strahler (1957), in which each headwater stream is first order, two first order streams join to form a second order stream, two second order streams join to form a third order stream, and so on. When two streams of different orders join, the downstream reach is given the higher of the two orders. Table A contains the number of streams of each order for all basins taken from the base map.

Table A. Stream Orders For The Sub-basins

BASIN	NUMBER OF STREAMS OF EACH ORDER					TOTAL NO. OF STREAMS
	1	2	3	4	5	
Jackson	11	2	1	-	-	14
Eaton Rapids	70	17	5	1	-	93
Deer Creek	1	-	-	-	-	1
Sloan Creek	1	-	-	-	-	1
Red Cedar	26	6	1	-	-	33
Lansing	110	24	6	1	-	141
Portland	122	27	7	1	-	157
Lookingglass	28	4	1	-	-	33
Maple Rapids	62	19	3	1	-	85
Ionia	345	83	19	2	1	450

BIFURCATION RATIO (Rb) -- This value was found by averaging the following ratios:

$$Rsb = \frac{N(x)}{N(x+1)}$$

where $N(x)$ = the number of streams of order x , $N(x+1)$ = number of streams of the next higher order, and Rsb = the bifurcation ratio for each stream order x . For example, Jackson basin has 11 first-, 2 second- and 1 third order streams (Table A), and thus has a bifurcation ratio of:

$$Rb = \frac{11}{2} + \frac{2}{1} / 2 = (5.50 + 2.00) / 2 = 3.75$$

Both the bifurcation ratio and stream frequency values define the basin's drainage pattern: the remaining parameters quantify the basin's physical shape.

FORM RATIO (Rf) -- The form ratio was found by dividing the basin area by the square of the basin's long axis. Basin length was measured on the base map, area was assumed to be correct as reported in the USGS Surface Water Records (1956, 1957, 1962).

CIRCULARITY RATIO (Rc) -- This was calculated by dividing the basin area by the area of a circle with the same perimeter as the basin. The value for any circle, regardless of size, is 0.785, thus basin values drop from 0.785 as the perimeter becomes less and less

circular. Basin perimeters were measured on the base map, basin areas were taken from the USGS Surface Water Records (1956, 1957, 1962).

ELONGATION RATIO (Re) -- Somewhat similar to the circularity ratio, this parameter is the ratio between the diameter of a circle of area equal to the basin, divided by the basin length. As in the form ratio, basin length was measured on the base map, basin area was taken from the USGS Surface Water Records (1956, 1957, 1962).

RELIEF RATIO (Rr) -- This parameter quantifies the overall slope of the basin. The ratio is calculated by the equation:

$$Rr = \frac{Ep - Eg}{Lb}$$

where Ep is the highest elevation on the basin perimeter, Eg is the elevation of the stream gaging station, and Lb is the length of the basin. The perimeter and gage elevations, in feet above mean sea level, were taken from topographic maps (USGS 7.5 minute series), and the basin length was measured on the base map.

APPENDIX B

APPENDIX B

SURFACE AREA RATIO ALGORITHM

The surface area ratio was calculated by first reducing the bore hole data points to an X - Y - Z grid using the program SURFACE II (Sampson, 1978). Each grid calculation was performed with the following parameters:

- 1) Node spacing = 0.075 units of data X-Y values. The data are located in inches from the SW corner of the state, on a scale of 1:250,000.
- 2) Initial search radius of 0.25, to a max of 0.75, in steps of 0.25, looking for a minimum of 4 points and a maximum of 8.
- 3) Nearest neighbor search. Duplicate data points averaged.

These grid nodes were then read into the program which calculated the area of the X - Y - Z surface as follows:

- 1) Z is the only variable (elevation). X and Y are defined as constants, the distance between columns and between rows, respectively.

The distances LX and LY are calculated by:

$$\begin{aligned} LX &= \text{SQRT}((\text{ABS}(Z(1) - Z(2))^{**2}) + X^{**2}) \\ LY &= \text{SQRT}((\text{ABS}(Z(1) - Z(3))^{**2}) + Y^{**2}) \end{aligned}$$

where: SQRT = Square Root Of...
ABS = Absolute Value Of...
**2 = Quantity Squared
Z(1) = Lower Left Corner Node
Z(2) = Upper Left Corner Node
Z(3) = Lower Right Corner Node

- 2) The area of the triangle formed by these three grid nodes is then:

$$\text{AREA} = (0.5 * LX * LY)$$

3) Next, the adjoining triangle's area is found by:

```
LX = SQRT((ABS(Z(4) - Z(2))**2) + X**2)
LY = SQRT((ABS(Z(4) - Z(3))**2) + Y**2)
AREA = (0.5*LX*LY)
```

where: Z(4) = Upper Right Corner Node

4) These areas are summed for each set of four nodes throughout the file. Since X and Y are constant, the areas of the X-Y-Z triangles projected onto a flat surface are a constant, equal to 1/2 X times Y. The sum of the X-Y-Z areas is then divided by the product of the constant projected area times the number of triangle areas calculated in steps 2 and 3 above. This ratio is the final result, the "surface area ratio". As the value of Rs increases, the surface is becoming more irregular.

APPENDIX C

APPENDIX C

SOIL MANAGEMENT GROUP VALUES

Table B.
County And Township Values of
Average Soil Management Group (SMG)
And Average Permeability, 0 - 5 Feet

COUNTY	AVERAGE SMG		AVERAGE PERMEABILITY 0 - 5 FEET
	WITH MUCK	WITHOUT MUCK	
Clinton	2.55	2.60	23.02
Eaton	2.55	2.65	20.36
Ingham	2.50	2.50	25.48
Jackson	2.97	3.18	38.43
Shiawassee	2.61	2.76	24.63
Jackson Co. Townships			
T1S R3W	2.62	2.77	40.60
T1S R2W	3.25	3.38	36.72
T1S R1W	2.97	3.09	31.14
T1S R1E	2.97	3.09	34.86
T1S R2E	2.53	3.39	40.57
T2S R3W	2.88	2.93	30.18
T2S R2W	2.99	2.99	23.38
T2S R1W	2.82	2.87	29.65
T2S R1E	3.08	3.88	49.98
T2S R2E	2.86	3.09	49.45
T3S R3W	2.90	2.96	33.72
T3S R2W	2.65	2.65	26.81
T3S R1W	3.17	3.23	39.92
T3S R1E	3.40	3.54	53.47
T3S R2E	3.53	3.94	55.16
T4S R3W	2.78	3.00	41.35
T4S R2W	2.83	2.88	36.75
T4S R1W	2.94	3.06	35.43
T4S R1E	3.32	3.61	45.25
T4S R2E	2.97	3.15	51.56

SMG values were estimated on a township scale from the published soils maps (U.S.D.A., 1974, 1978, 1978, 1979, 1981). Township values were then averaged to yield county-wide values. The values for average SMG with muck include all muck soils, whether drained or not. A non-drained muck soil is assigned an SMG value of 1.0. Drained muck soils are assigned an SMG value according to the permeability of the sub-soil under the surface organic layer. The values for average SMG without muck exclude all non-drained muck soils.

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