NOAA Technical Memorandum ERL GLERL-100

COMPUTER PROGRAM FOR PERFORMING HYDROGRAPH SEPARATION USING THE RATING CURVE METHOD

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1.0 INTRODUCTION

Understanding the earth's hydrologic cycle is important to water resource planners and managers. This report presents a computerized methodology for partitioning streamflow into overland flow or runoff, and baseflow flow.

Partitioning is accomplished by creating a rating curve from groundwater elevations and discharges. This hydrograph separation method differs from other published methods in that baseflow and runoff estimates are not only based upon spatial and temporal hydrologic parameters, but also on the physical properties of the watershed.

2.0 WATER BALANCE

Pathways and processes through which water enters and leaves the land and water surfaces is known as the hydrologic cycle. Basically, water enters the land and water surfaces in the form of precipitation. Water then leaves the land surface through the processes of runoff, baseflows, groundwater recharge, and evapotranspiration. This water exchange is accounted for by a water budget that is an application of the conservation of mass law expressed by the equation of continuity (Brooks et al., 1991) where the difference between inflows (I) and outflows (O) is equal to the change of storage (DS) in the system.

$$I - o = \Delta S \qquad 1$$

This equation can be rewritten for the watershed or any defined area as:

$$P = R_{off} + B_f + ET + R_{ech} \pm \Delta S \qquad 2$$

where P is precipitation, R_{off} is runoff (composed of water that moved over the land surface), B_f is baseflow (water that infiltrated the ground and entered the stream as groundwater; this combines with runoff to produce total streamflow), ET is evapotranspiration, and R_{ech} is aquifer recharge.

3.0 HYDROGRAPH ANALYSIS

Perennial streams, or streams that flow continuously throughout the year, are most likely to be fed by groundwater. These streams contain a baseflow component and are candidates for a hydrograph separation method. The hydrograph separation method has its basis in the physical world. Figure 1 is a stormflow hydrograph that illustrates various rainfall pathways into a stream. Channel interception or rainfall that falls directly on the stream is represented by the A curve. Overland flow or runoff is represented by the B curve. Subsurface flow or precipitation that infiltrates the land surface yet arrives at the stream in a short time is the C curve, and the baseflow or groundwater component that enters the stream is the D curve. All of these components add together to form the shape of the stormflow hydrograph.

The shape of this hydrograph varies due to climate, topography, vegetation, and land use practices. For example, a forested watershed with deep permeable soils might have relatively high infiltration capaci-

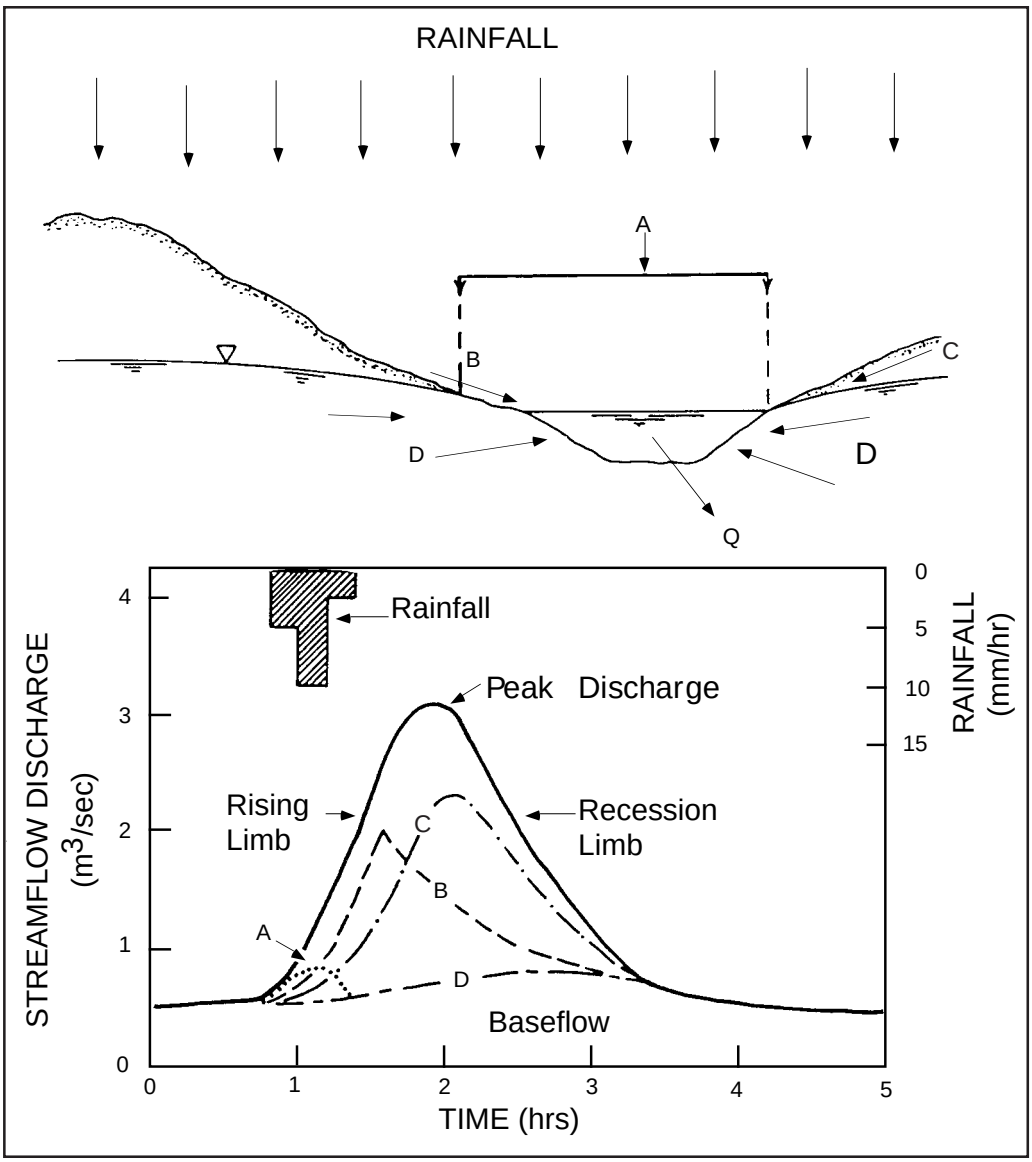

Figure 1. Modified from Brooks et al., 1991 (A) direct runoff, (B) runoff, (C) subsurface flow, (D) baseflow.

ties and exhibit mostly subsurface flow. On the other hand, a watershed that is composed mostly of rocky outcrops or urban paved areas can exhibit mostly overland flow. Hydrographs that are slightly skewed to the left have a high runoff component, and conversely, ones skewed to the right will have more subsurface flow.

4.0 METHOD

Separating baseflow from storm flow can be accomplished by several methods including (1) recession analysis where a function was applied to streamflow data to obtain the baseflow recession constant (Nathan and McMahon, 1990), (2) a graphical method where streamflow is plotted on a logarithmic axis against time, and a recession line is subjectively drawn at a point in which runoff ceases and baseflow begins (Mayboom, 1961), and (3) using daily rainfall and streamflow volumes to partition total streamflow into runoff and baseflow (Shirmohammadi et al., 1984).

The method used in this report requires creating a rating curve from groundwater elevations and discharge measurements (Heath and Trainer, 1968). This method requires two assumptions: (1) that groundwater discharge is proportional to groundwater levels, and (2) that the entire flow from a stream is composed of groundwater discharge during fair weather periods. Simply, baseflows are separated from streamflows by identifying consecutive days of no precipitation then selecting the latter portion of these rainless days as baseflow. The time basis for selecting the latter days is determined by computing the time it takes for runoff to cease after a rain event. This computation is done using the general rule of thumb that the number of days is equal to the watershed area to a power (Linsley et al., 1975).

$$N_{days} = A^{0.2} \qquad 3$$

Where N is the number of days runoff ceases after a storm, and A is the area of the watershed. Once the consecutive days are identified, a rating curve is derived.

A rating curve is a parabolic equation with asymptotes as shown in equation 4.

$$y - y_o = B_o(x - x_o)^{B_1} \qquad 4$$

Where y and y_o are the water level stages; x and x_o are the groundwater discharges, previously identified from streamflow records, N_{days} and longer after the event; and B_o and B_1 are the regression coefficients that describe the relationship between the stage and fall. The asymptote x_o is always positive and in most cases zero since flows cannot be negative. The asymptote y_o is the stream bottom elevation. It is important to note that if the river's bottom elevation is higher than the well water stages, then baseflows will **not** be computed since water does not naturally flow from a lower elevation to a higher one.

Data required for accomplishing this are daily precipitation, well water levels, streamflows, the watershed's area, and the river bottom elevation. These data are readily available for most watersheds in the U.S.; the National Oceanic and Atmospheric Administration (NOAA) collects hourly and daily precipitation data, and the U.S. Geological Survey (USGS) collects streamflow and well water level data (Coordinating Committee on the Great Lakes Basic Hydraulic and Hydrologic Data, 1991).

The data can be averaged if a watershed has more than one data collection station. Precipitation can be averaged through Thiessen weighting (Croley and Hartmann, 1984), using the arithmetic mean method, or with the isohyetal method (Linsley, 1975). Well water level data collected at various locations at equal spacings can be arithmetically averaged to obtain one value for daily levels.

5.0 FORTRAN PROGRAM *"SEPARATE"*

The FORTRAN program *Separate* consist of three subroutines. The first subroutine, *Rainless*, selects stage and flow data for rainless periods. The second subroutine, *Regress*, is where the regression analysis for the rating curve is completed. The regression coefficients are then applied in the third subroutine, *Component*, to compute baseflows for the entire stage data set.

Data required for *Separate* must be in specific units and formats. It is important to note that missing data or negative numbers should not be included in these files. The watershed area should be in units of square kilometers, and the river bottom elevation should be in meters above a common datum. Precipitation and streamflow values should be in the same file and in units of millimeters per day and cubic meters per second, respectively. The data file *met.dat* contains precipitation and streamflow data. The format is listed below:

1988	9	6	0.00	5.47
1988	9	7	0.00	5.08
1988	9	8	0.00	4.24
1988	9	9	0.00	3.84
1988	9	10	0.00	3.64
1988	9	11	0.00	3.37
1988	9	12	0.54	3.43
1988	9	13	0.23	3.32
1988	9	14	0.00	3.22
1988	9	15	0.00	2.99
1988	9	16	3.59	3.19
1988	9	17	2.86	3.37
1988	9	18	13.14	4.38
1988	9	19	13.06	5.68
1988	9	20	4.30	6.56
1988	9	21	3.06	6.08

Columns 1-3 are year, month, and day, respectively. Columns 4 and 5 are precipitation and streamflow values in millimeters and cubic meters per second, respectively.

Stage data units should be in meters above a common datum; the data file *levels.dat* contains the water level data in this format:

1988	9	6	191.44
1988	9	12	191.44
1988	9	21	191.47
1988	9	27	191.48
1988	10	4	191.54

1988	10	18	191.55
1988	10	25	191.62
1988	10	27	191.64
1988	11	8	191.71
1988	11	22	191.83
1988	11	30	191.92
1988	12	2	191.92
1988	12	6	191.97
1988	12	12	192.02

Again columns 1-3 contain year, month, and day, and column 4 contains well water levels in meters above a common datum. Note: other than column placement, no exact number of spaces has to exist between columns.

The output file for this program contains year, month, day, and years in thousandths of years in column 1-4. Column 5, 6, and 7 contain water levels, streamflow, and baseflows, respectively.

1988	9	6	1988.682	191.440	5.470	4.290
1988	9	12	1988.699	191.440	3.430	4.290
1988	9	21	1988.723	191.470	6.080	4.486
1988	9	27	1988.740	191.480	9.310	4.553
1988	10	4	1988.759	191.540	8.210	4.977
1988	10	18	1988.797	191.550	7.190	5.052
1988	10	25	1988.816	191.620	15.080	5.602
1988	10	27	1988.822	191.640	12.600	5.770
1988	11	8	1988.855	191.710	34.060	6.395
1988	11	22	1988.893	191.830	35.440	7.619
1988	11	30	1988.915	191.920	34.290	8.682
1988	12	2	1988.923	191.920	28.740	8.682
1988	12	6	1988.934	191.970	25.190	9.332
1988	12	12	1988.951	192.020	9.230	10.029

The area used in this simulation is 4276.00 km^2, and the river bottom elevation is 176.0 meters. Errors that might be encountered when executing the program are (1) input data files that are in the wrong format or contain an alphanumeric text, (2) giving an output file name that already exists, (3) inclusion of negative data, and (4) a river bottom elevation that is higher in elevation than the water table.

Figure 2 illustrates the results of the hydrograph separation program. The thicker line, baseflow component, is less than 10% of the runoff component. In order to compare these results, a hydrograph was analyzed with a different method (recession constant method) for the same data. This was accomplished by obtaining the baseflow recession constant from the baseflow recession model

$$Q = Q_o e^{-kt} \qquad 5$$

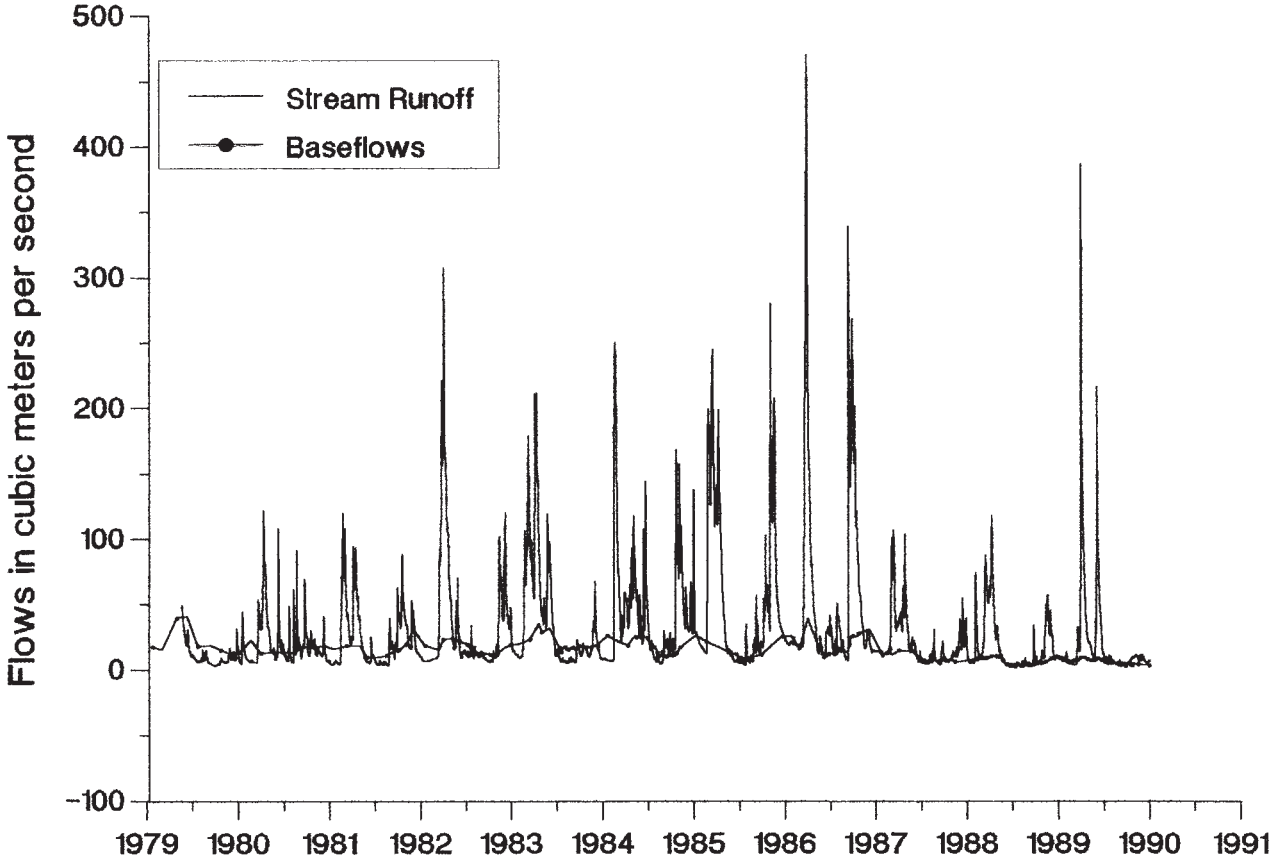

Figure 2. Results of the hydrograph separation program.

where Q_o is the initial discharge beginning after N_{days}, Q is streamflow discharge at any period of time, k is the recession constant per unit of time, and t is the time interval since the recession began. The recession constant can be obtained by plotting streamflows logarithmetically, then subjectively drawing a straight line from the point where runoff ends and baseflow begins to the point where recharge begins (Figure 3). The start and finish arrows in **Figure 3** show the location of these points. The slope of this line is the baseflow recession constant. This method yielded a baseflow rate of 3 cubic meters per second (cms) for the year 1988, which compares favorably with the 7 cms obtained from the program *Separate*; the 4 cms difference being attributed to the subjectivity of where to start and end the recession using the recession constant method.

6.0 CONCLUSION

Partitioning precipitation into its component parts has been made easier with the use of data availability and computing technology. This computer program produces baseflow estimates using the rating curve method, a method that has been successfully applied to surface streamflows for computing surface discharges. These estimates are unique because they are not only derived from spatial and temporal hydrologic parameters, but also because the physical properties of the watershed are incorporated in them.

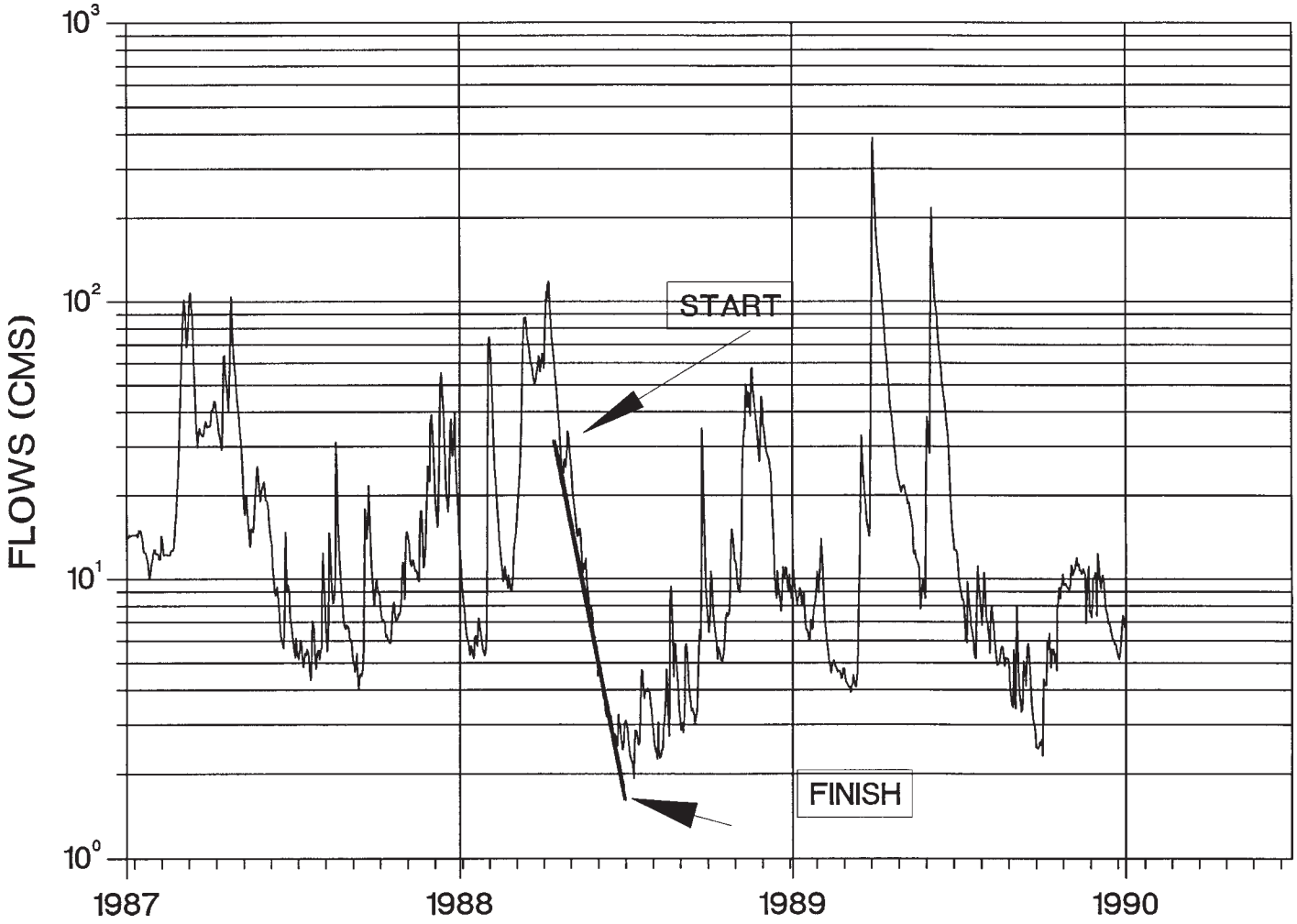

Figure 3. Baseflow recession constant.

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INSTRUCTIONS
Obtain the program fromGLERL's anonymous ftp area:
ftp://ftp.glerl.noaa.gov/publications/tech_reports/glerl-100

FORTRAN Program Execution File: Separate.exe
FORTRAN Program:Separate.for
Water Level Data File:Levels.dat
Precipitation and Streamflow Data:met.dat