Automated Base Flow Separation and Recession Analysis Techniques

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Abstract

An automated base flow separation technique has been developed and tested. Base flow is considered to be the ground-water contribution to stream flow. Estimates of the amount of base flow can be derived from stream flow records. Such estimates are critical in the assessment of low flow characteristics of streams for use in water supply, water management, and pollution assessment. An automated base flow separation technique using a digital filter has been tested against three other automated techniques and manual separation methods. The filter appears to be comparable to other automated techniques in its ability to reproduce the results produced from graphical separation techiques. The filter technique is easy to use and has the added advantage in that it can be adjusted by the user to take into account personnel preferences in separation of stream flow into surface flow and base flow.

The slope of the base flow recession has been used to estimate the volume of water in storage in the basin above the level of the stream channel, the amount of recharge to the shallow aquifer, and as an input into water budget models. A second automated technique was developed to calculate the slope of the base flow recession curve from stream flow record. This technique is an adaptation of the Master Recession Curve procedure. The results of this method were compared to manual estimates with an efficiency of 74 percent.

Introduction

Ground-water flow systems can be classified into three types based on depth and proximity to surface drainage features: (1) shallow, (2) intermediate, and (3) regional flow systems (Toth, 1963). The shallow flow systems are the ones that: (1) actively circulate ground water and respond rapidly to changes in discharge and recharge, (2) have relatively short travel times, and (3) supply a large percentage of base flow to the stream (Cannon, 1989, p. 136). Available evidence suggests that these shallow aquifers are generally at greatest risk of contamination by nitrates as well as synthetic organic chemicals (Moody, 1990).

Quantitative information concerning such shallow aquifer characteristics is needed to manage the development of this shallow ground-water resource. While digital ground-water models are available for evaluating stream aquifer interactions, representative values of aquifer properties necessary to calibrate the models are often difficult and expensive to obtain (Hoos, 1990, p. 51). Extrapolation of aquifer properties from averaged pump test values, limited well control to large regions with variable lithologies and aquifer thickness is difficult (Trainer and Watkins, 1974). An alternative method for assessing ground-water-stream interactions is based on the analysis of the recession curve of base flow. In addition, analysis of low flow characteristics of streams is essential to surface-water quality and water-supply management (Bingham, 1982; Bingham, 1986; White and Sloto, 1990). Base flow, or shallow ground-water discharge to streams has been shown to be useful in estimates of recharge, basin evapotranspiration, as well as aquifer parameters such as the storage coefficient, diffusivity, and transmissivity (Riggs, 1963; Trainer and Watkins, 1974; Daniel, 1976; Bevans, 1986; and Hoos, 1990). In addition, many current water resource models use these flow recession coefficients to route the recharge to the stream (Arnold et al., 1993; Leavesley et al., 1983).

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Received June 1994, revised December 1994, accepted December 1994.

The objective of this paper is to assemble an automated series of techniques for determination of base flow characteristics from stream flow data bases. The output from such analysis will be the percentage of surface runoff versus base flow on a monthly basis, and the base flow recession constant. These parameters have been shown to be useful in evaluation of aquifer properties as cited or for input to hydrologic models (Arnold et al., 1993; and Leavesley et al., 1983). An excellent review of automation of base flow and recession analysis is given by Nathan and McMahon (1990). White and Sloto (1990) and Rutledge and Daniel (1994) describe some of the current techniques used for automated separation of surface flow from base flow and methods to estimate ground-water recharge from stream flow records.

Base Flow Separation

The first step in hydrograph analysis entails separation of stream flow into the two major components: surface runoff and base flow. However, the exact separation of each component is often arbitrary and based on either the use of standard methodologies cited in the literature (McCuen, 1989) or in a few instances, the use of chemical or isotopic tracers and mass balance approaches (Pinder and Jones, 1968). All methods suffer from the lack of real knowledge of how the water moves through the watershed over time for a multitude of storm events and antecedent moisture conditions.

Numerous analytical methods have been developed to separate base flow from total stream flow (McCuen, 1989). Although most procedures are based on physical reasoning, elements of all separation techniques are subjective. Manual separation of the stream flow hydrograph into surface flow and ground-water flow is difficult and inexact; often results derived from such manual methods cannot be replicated among investigators (White and Sloto, 1990). Attempts to automate the manual methods with the computer removes some of the subjectivity inherent in these methods and substantially reduces the time required for analysis of stream flow records (White and Sloto, 1990). Recently several programs or methodologies have been written to automate this process (Nathan and McMahon, 1990; White and Sloto, 1990; and Rutledge, 1993). White and Sloto (1990) programmed three techniques developed by Pettyjohn and Henning (1979) to separate the ground-water/surface-water components of stream flow hydrographs. These are the fixed interval, sliding interval, and local minimum methods. The authors then compared the results of the three methods to one previously published example of a manual separation technique completed for a watershed in southeastern Pennsylvania (White and Sloto, 1990). The results of the computerized techniques ranged from 5 percent higher to 5 percent lower than the annual techniques for the two year time period. Rutledge (1993) used a method of stream flow partitioning similar to that developed by Knisel and Sheridan (1988). Comparison of this method to manual separation techniques in the eastern United States produced results similar to those obtained by White and Sloto (1990).

Nathan and McMahon (1990) analyzed two base flow separation techniques for use in prediction of low-flow characteristics. The first was a simple smoothing and separation technique developed by the Institute of Hydrology (1980), and the second was a recursive digital filter which could be easily adopted for the computer. The two methods compared well having a coefficient of determination of 0.94 and a slope of 1.04. The recursive digital filter was found to be a fast and objective method of continuous base flow separation by Nathan and McMahon (1990).

Automated Recursive Digital Filter

The recursive digital filter technique as described by Nathan and McMahon (1990) was originally used in signal analysis and processing (Lyne and Hollick, 1979). Although the technique has no true physical basis, it is objective and reproducible. Filtering surface runoff (high frequency signals) from base flow (low frequency signals) is analogous to the filtering of high frequency signals in signal analysis and processing. The equation of the filter is

$$q_t = \beta\, q_{t-1} + (1 + \beta)/2 * (Q_t - Q_{t-1}) \qquad (1)$$

where q_t is the filtered surface runoff (quick response) at the t time step, Q_t is the original stream flow, and β is the filter parameter. Base flow, b_t, is calculated with the equation

$$b_t = Q_t - q_t \qquad (2)$$

The filter can be passed over the stream flow data three times (forward, backward, and forward), depending on the user's selected estimates of base flow from pilot studies of stream flow data (Figure 1). In general, each pass will result in less base flow as a percentage of total flow. For the data analyzed, the highest, lowest, and average reduction in base flow for two and three passes is shown (Figure 2). Base flow is reduced approximately 17 percent by the second pass and an additional 10 percent by the third pass. This option gives the user some added flexibility to adjust the separation to more accurately approximate site conditions.

In order to test the accuracy of the filter to existing automated techniques the filter model was run on the same

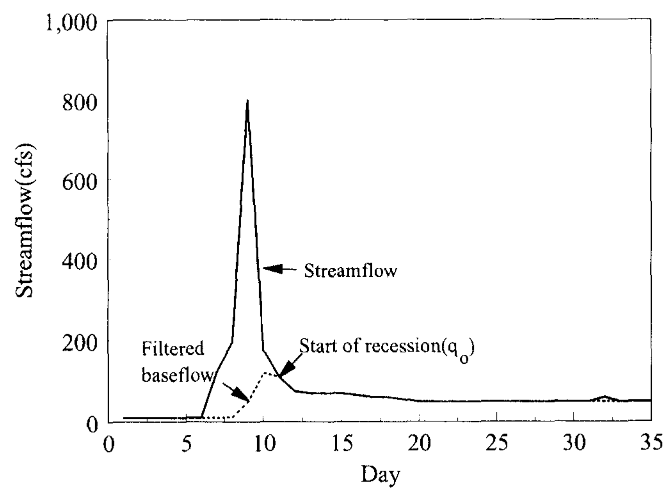

Fig. 1. Determination of the start of base flow recession. The filter subdivides surface runoff from base flow. The point at which the filter rejoins the stream flow curve is taken to be the beginning of the base flow recession segment.

Table 1. Comparison Baseflow Separation of Published Manual Methods, the PART Model and the Digital Filter

Publication (number, authors, and year)	Station	Time period	Result from publication[1]	Result from PART[1]	Result from recursive digital filter PASS1	PASS2	PASS3
1. Becher and Root, 1981	Conodoguinet Creek near Hogestown, PA.	1968-1974	13.0 66	12.9 65.6	13.1 67	10.4 53	9.4 47
2. Becher and Root, 1981	Yellow Breeches Creek near Camp Hill, PA.	1968-74	16.8 80	16.9 80.4	16.6 79	14.7 70	13.4 64
3. Carswell and Lloyd, 1979	Brodhead Creek near Minisink Hill, PA.	1963, 1969 and 1973	19.6 66	20.8 70	21.1 71	16.9 57	14.3 48
4. Dingman and Meyer, 1954	Rock Creek at Sherril Dr., MD.	1933-49	8.5 67	8.4 66	9.1 68	7.4 58	6.9 54
5. Dingman and Ferguson, 1956	Little Gunpowder Falls near Laurel Brook, MD.	1927-49	11.3 66	12.3 71	12.3 72	11.0 64	10.3 60
6. Olmsted and Hely, 1962	Brandywine Creek at Chadds Ford, PA.	1928-31	11.2 67.8	11.6 70.3	12.2 74	10.6 64	9.9 60
7. Steward et al., 1964	Etowah River near Dawsonville, GA.	1956	20.3 75	20.6 80.6	20.5 80	18.4 72	16.9 66
8. Stuart et al., 1967	Swatara Creek above Harper Tavern, PA.	1919-60	11.3 49	14.3 62	14.7 64	11.1 48	9.2 40
9. Taylor et al. 1983	Spring Creek near Axemann, PA.	1961-80	12.7 89	12.7 89	12.1 85	11.0 71	10.3 72
10. Waller, 1976	Roanoke River at Roanoake, VA.	April 1969 to March 1970	5.2 67	5.7 73	5.5 70	4.5 58	4.0 51
11. Wood, 1980	West Conewago Creek at Manchester, PA.	1931-1976	6.0 38.5	7.4 46.9	8.7 55	6.2 39	5.0 32

[1]The mean ground-water discharge (base flow) is expressed in two ways: top number is base flow in inches per year; bottom number is base flow index, which is the ratio of mean base flow to mean stream flow, expressed in percent.

stations used by White and Sloto (1990) and Rutledge and Daniel (1994); PART model (Table 1). Table 1 compares the base flow (in./year) predicted by the models to that shown in the literature. The published values were produced through manual separation techniques. The percentage by which the result of the automated techniques exceeds that of the manual method is shown. This is calculated after Rutledge (1993) and shown (Table 2):

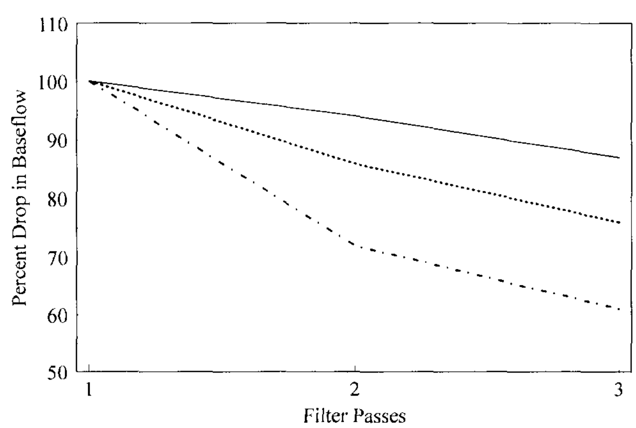

Fig. 2. Plot of mean-high-low estimates, first pass = 100 percent. Percentage change in base flow with filter passes. Passing the filter through the stream gauge data multiple times systematically lowers the percentage of baseflow. The mean for two passes is 10 percent less; for three passes 20 percent less than one filter pass.

Table 2. Percentage by Which Results of Automated Techniques Exceed Manual Technique

Station	PART	Filter	FI	SI	LM
1. Conodoguinet Creek near Hogestown, PA.	-.76	.76			
2. Yellow Breeches Creek near Camp Hill, PA.	.58	1.19			
3. Brodhead Creek near Minisink Hill, PA.	6.20	7.65			
4. Rock Creek at Sherrill Dr., MD.	-1.18	7.06			
5. Little Gunpowder Falls near Laurel Brook, MD.	8.85	8.85	-2.2	-1.07	-1.96
6. Brandywine Creek at Chadds Ford, PA.	3.57	8.93			
7. Etowah River near Dawsonville, GA.	1.48	0.98			
8. Swatara Creek above Harper Tavern, PA.	26.55	30.10			
9. Spring Creek near Axemann, PA.	0.00	-4.72			
10. Roanoke River at Roanoake, VA.	9.62	5.77			
11. West Conewago Creek at Manchester, PA.	23.33	45.00			

(FI = Fixed Interval, SI = Sliding Interval, LM = Local Minimum, after White and Sloto, 1990).

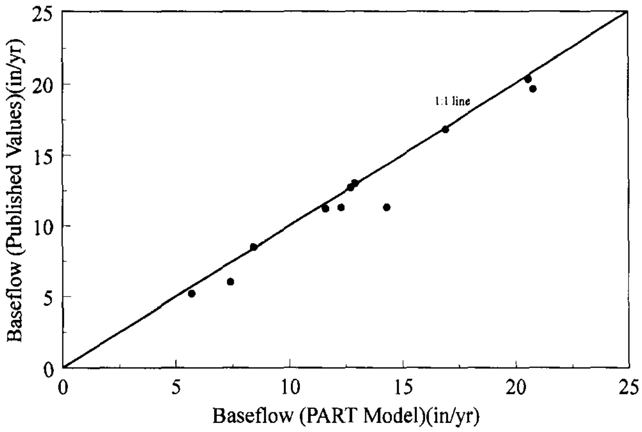

Fig. 3. Plot of base flow (in./yr) for published values vs. PART model (Rutledge, 1993).

$$P = 100(Ra - Rm)/Rm \qquad (3)$$

where P is the percent by which the result of the automated technique exceeds that of the manual; Ra are the results of the automated method; and Rm are the results of the manual method.

The general range of deviations from the 1:1 plot are similar for both the PART model and Filter (Table 2 and Figures 3, 4). The PART model (Rutledge, 1993) seems to be slightly better in approximating the manual separation values than using the Filter (Pass 1 option) and comparable to the results of White and Sloto (1990) for the one basin. For the basins analyzed, all models seem to be able to reproduce manual separation of surface runoff and base flow with equal accuracy.

Baseflow Recession Analysis

The next step in assessment of base flow is to quantify the characteristics of the base flow recession: the rate at which stream flow diminishes in the absence of recharge. Recession characteristics are an extremely useful parameter for estimates of water supply and stream-aquifer interactions, and aquifer properties as diffusivity (Trainer and Watkins, 1974; Hanson, 1987; Hoos, 1990; Bevans, 1986).

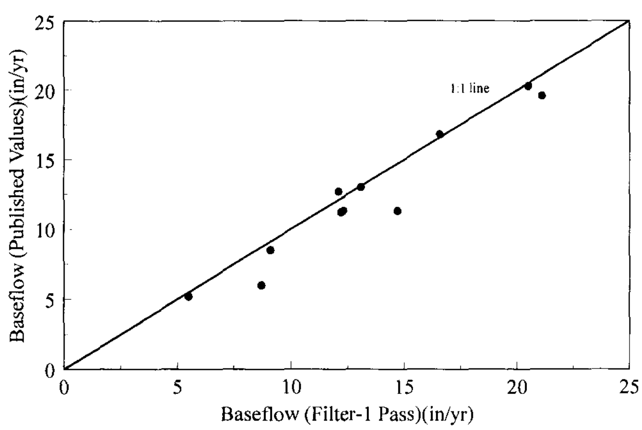

Fig. 4. Plot of base flow (in./yr) of published values vs. Filter model.

The recession constant is the term which has been used to describe the slope of the stream flow decline following a recharge event.

According to Ford and Williams (1989) the value of the recession coefficient, "alpha," derives from the properties of the aquifer, especially transmissivity and storage. A large alpha signifies a steep recession which is indicative of rapid drainage and little storage. In a carbonate system, this could be indicative of a conduit flow system. If alpha is small, then drainage is very slow. Similar analogies have been made by Wright (1970) who related the slopes of recession curves to surficial geology in Scotland. In a carbonate system, this could result in drainage from an extensive fissure or porous bedrock network with a large storage capacity.

Many curves have been suggested as representing the base flow recession. They range from simple exponential to double exponential and hyperbole. The form of the most common base flow recession curve is an exponential decay function that was developed around the turn of the century (Hall, 1968). This curve has been utilized in many studies (Meyboom, 1961; Kunkle, 1962; Knisel, 1963; Riggs, 1963; Riggs, 1985; and Singh and Stall, 1971).

$$Q_t = Q_o e^{-\alpha t} \qquad (4)$$

where Q_t is stream flow at time t, Q_o is the initial stream flow, and α is the base flow recession constant. Although the equation was derived many years ago, it was later shown to be the linear solution of the one-dimensional differential equation governing transient flow in artesian aquifers (Werner and Sundquist, 1951). The recession constant is determined by rearranging equation (4)

$$\alpha = 1/N \ln(Q_N/Q_o) \qquad (5)$$

where N is the number of days from the start of the recession.

There is considerable variation in individual recessions due to differences in ground water and bank storage, recharge rates influenced by macropore flow, length of record, ET losses, man-induced factors, and multiple aquifers (Singh, 1968; White and Sloto, 1990). A method to "average" or combine individual recessions to obtain an average representation of base flow recession for a watershed is a technique called the Master Recession Curve (MRC). The most common MRC technique is the matching strip method (Hall, 1968; Institute of Hydrology, 1980; Riggs, 1985; Nathan and McMahon, 1990). The matching strip method involves plotting the logarithms of stream flow against time which according to equation (4) results in a straight line. The method involves plotting individual recessions on tracing paper, and superimposing on each other until the recessions overlap to form a common set of lines (Nathan and McMahon, 1990). This method is obviously time-consuming to apply to a large number of watersheds. Attempts at automating this procedure have been described by Nathan and McMahon (1990) and by Rutledge (1993). Both of these methods use a combination of interactive and automatic procedures to calculate the mathematical expression of the Master Recession Curve for a stream gaging station.

Automated MRC Master Recession Curve (MRC)

The procedure to totally automate a method to predict the slope of the base flow recessions of a stream is diagrammed in Figure 5 and described as follows.

Daily stream flow is derived from U.S.G.S. stream gage data compiled on CD ROM drives available from commercial sources. The streamflow data are passed through the filter program as previously described. Typically, the recession is calculated from the point on the hydrograph where it is assumed that all surface flow has ceased or by convention (Dunne and Leopold, 1978; White and Sloto, 1990), where:

$$D = A^{0.2} \tag{6}$$

where D = days following the hydrograph peak where surface runoff ceases. The filter uses the point where the first pass rejoins the streamflow record (Figure 1). This was found to meet the objective of equation (6).

The program then searches the filtered record and picks out the base flow segments that are over 10 days in length for the winter stream flow period (low evapotranspiration). These segments of the base flow record are then rank sorted (by the highest discharge value of the segment) from lowest to highest. The record is then searched to determine if there is any lack of overlap between these sorted discharge segments derived from the stream flow record and filter passes. If the stream flow record is less than 10 years in length, this is often a factor. When a gap is encountered, the program projects a linear regression from the last existing discharge points in the segment to establish the numerical rank of the first point in the gap. Through this means, the stream flow segments from the filter can be adjusted to their proper position in the Master Recession Curve (MRC) for further analysis. When adequate yearly data exist (over 10 years), the gaps are small and the necessary projections are usually not over 10 days. The data are always plotted out at the end of this routine to check for the validity of the projections. If multiple aquifers are indicated by the presence of two or more distinct linear segments at different discharges on the Master Recession Curve, the projections can be broken manually as shown by Riggs (1985) and Trainer and Watkins (1974).

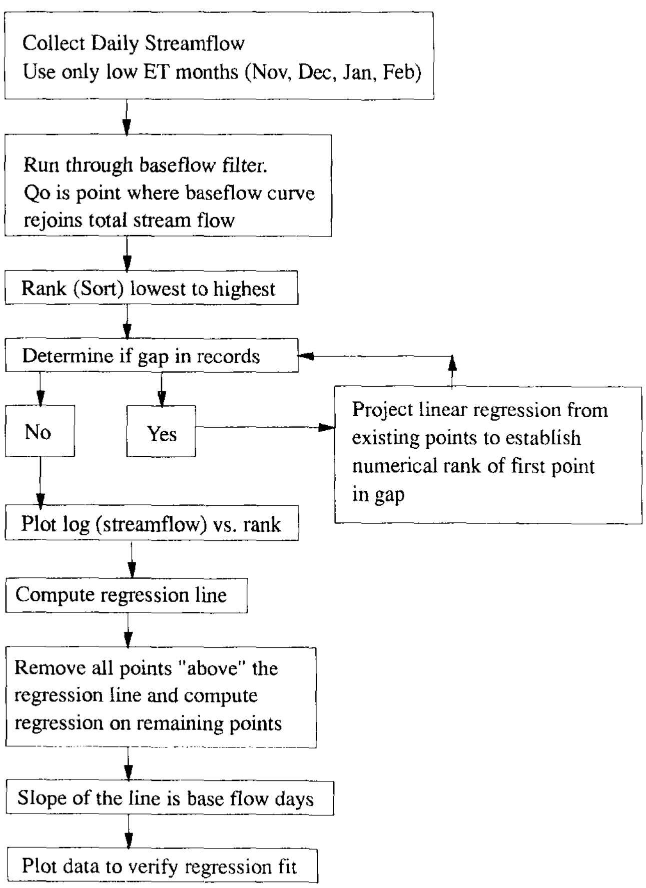

Fig. 5. Algorithm to automate the Master Recession Curve.

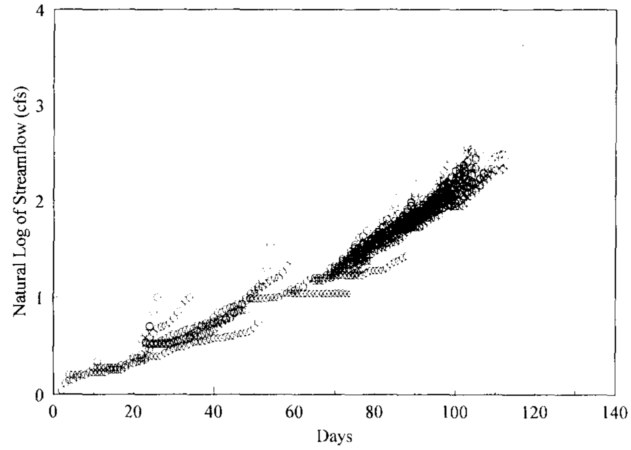

Fig. 6. Master Recession Curve for Elk River near Elk Falls, Kansas, compiled by the automated MRC technique. The automated technique slightly overpredicts the recession constant computed manually by 13 percent.

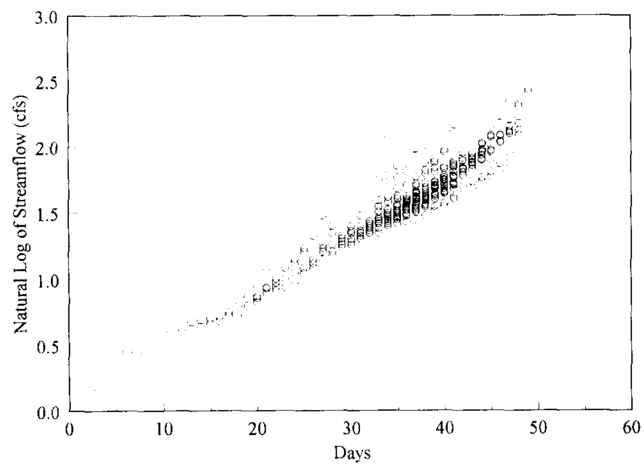

Fig. 7. Master Recession Curve for Tohickon River near Piperville, PA (drainage area 2.52 km²). The automated MRC (23 base flow days) underpredicts the manual technique (28 base flow days) by 18 percent. Note the small gaps which are the result of no data. The model projects the start of the next value following the gap by linear regression.

Table 3. Comparison of the Automated MRC and the Graphical Technique

Station name	*Drainage area (sq. km)*	*Auto MRC*	*Graphical technique*	*Percent*
Monocacy Creek at Bethlehem, PA	115	123	37	232.43
Tohickon Creek near Pipersville, PA.	252	23	28	−17.86
Neshaminy Creek near Langhorne, PA.	544	40	46	−13.04
Penns Creek at Penns Creek, PA.	780	50	39	28.21
Roanoke River at Roanoke Rapids, NC.	21715	67	49	36.73
Tar River at Tarboro, NC.	5654	51	45	13.33
Neuse River at Kinston, NC	6972	65	41	58.54
Reedy Fork near Oak Ridge, NC.	53	63	65	−3.08
Big Alamance Creek near Elon College, NC.	300	52	45	15.56
East Fork Deep R. near High Point, NC.	38	55	43	27.91
Rocky River near Norwood, NC.	3553	33	35	-5.71
Chattachoochee River at West Point, GA.	9195	96	59	62.71
French Broad River at Marshall, NC.	3450	113	49	130.61
Poplar Creek near Oak Ridge, TN.	314	32	32	0
South Chestuee Creek near Benton, TN.	82	46	46	0
Verdigris River near Coyville, KS.	1935	50	80	-37.5
Caney River near Elgin, KS.	1153	60	62	−3.23
Wakarusa River near Lawrence, KS.	1101	40	59	-32.3
Marmaton River near Fort Scott, KS.	1057	37	58	-36.21
Maraie des Cygnes River at Melvern, KS.	909	40	52	−23.08
Pottowotomie Creek near Garnett, KS.	865	32	51	−37.25
Little Osage River at Fulton, KS.	764	34	56	-39.29
Elk River at Elk Falls, KS.	570	55	53	3.77
Lightning Creek near McCune, KS.	510	27	46	−41.3
Marais des Sygnes River near Reading, KS.	458	38	45	−15.56
Otter Creek at Climax, KS.	334	59	45	31.11
Salt Creek near Lyndon, KS.	287	35	38	-7.89
Blue River near Stanley, KS.	119	31	34	-8.82
Big Hill Creek near Cherryvale, KS	96	24	32	-25
Indian Creek at Overland, KS.	70	33	27	22.22
Beaver Creek at Huntinton, TN.	21	289	350	-17.43
Big Sandy River at Bruceton, TN.	79	175	240	−27.08
Trace Creek abaove Denver, TN.	12	119	110	8.18
Horse Creek near Savannah, TN.	40	185	125	52
Shoal Creek at Iron City, TN.	134	150	138	8.7
Chisholm Creek at Westpoint, TN.	16	175	140	25
Elk River above Fayetteville, TN.	318	125	110	13.64
Tellico River at Tellico Plains, TN.	45	175	112	56.25
Little Pigeon River at Sevierville, TN	136	113	80	41.25
French Broad River near Newport, TN.	715	185	140	32.14
Mean	1619.03	79.9	73.55	12.7
Standard deviation	3818.8	61.2	61.98	50.1

(Source of graphical data from Rutledge and Daniels, 1994; Bevans, 1986; and Bingham, 1986).

If there are no gaps in the constructed stream flow series or after they have been adjusted, the records are analyzed to compute the base flow recession factor. Since there is often a considerable scatter to the recession flows, a technique was devised to pick the lowest slope of the curve (Figures 6, 7).

Results and Discussion

To validate this computational method, results were compared to values obtained by traditional graphic techniques (Bevans, 1986; Rutledge and Daniel, 1994; and Bingham, 1986). The data set, consisting of 40 streams, was compiled from the above sources to test the effectiveness of the technique in both eastern and western flow regimes and over a wide range of recession slopes. All the sites lie within the nonglaciated Central Region, the Piedmont and Blue Ridge, and Atlantic and Gulf Coastal Plain ground-water subdivisions of Heath (1984). More specific locations and descriptions of the streams are shown in the previously cited references. Kansas, for example, has a highly variable average annual runoff which ranges from 0.5 to up to 8 inches per year while the eastern streams reported have less variability but more runoff ranging from 12 inches to 25 inches (Gebert et al., 1987).

The 40 pairs of recession slopes expressed as base flow days from the graphical method and the automated method are compared (Table 3). This is the number of days for the base flow recession curve to proceed through a complete log cycle of discharge. The last column refers to the percent by which the predicted value exceeds the observed value which

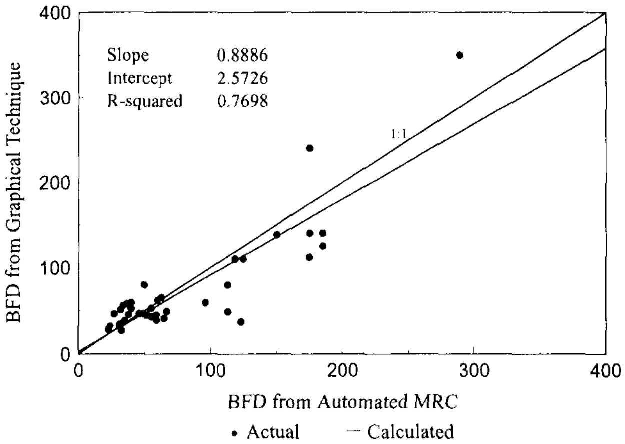

Fig. 8. Plot of the Graphical Technique versus the Automated MRC Technique. The MRC seems to underpredict the recession constants for basins from 100-200 km^2 and overpredicts for basins greater than 200 km^2.

was predicted using equation (3). The mean and standard deviation of each are given for general comparison. Overall, the automated technique overpredicts the manual technique by about 13 percent.

Another model evaluation criterion was used here after Loague and Freeze (1985), which is the coefficient of efficiency (Nash and Sutcliffe, 1970). The forecasting efficiency (EF) is calculated as:

$$EF = \frac{\sum_{i=1}^{n} (Q_{ip} - Q_m)^2 - \Sigma(Q_{ip} - Q_i)^2}{\Sigma(Q_{ip} - Q_m)^2} \quad (7)$$

where Q_{ip} is the predicted summary variable for the event i, Q_i is the observed summary variable for event i, Q_m is the mean value of the observed summary variable for n events, and n is the number of events. When $Q_{ip} = Q_i$ then EF = 1. Usually, for most data, EF < 1. If EF is negative, the model's predicted value is less representative than simply using the arithmetic mean of the data set. The calculated EF for the entire data set (n = 40) is 74.3. The results of this latter assessment are shown in Figure 8.

There are several possible sources for the discrepancy noted between the graphical methods and the automated method. The graphical method is highly subjective and output varies with each individual data set. For example, comparison of the graphical recession constants derived by Rutledge and Daniels (1994) to those derived by Bingham (1986) for two stations in Tennessee (03538225 and 03565300) gives values of 32 to 65 and 45.8 to 65 base flow days. These result in differences of 30-50 percent. While this is an extremely small sample, it does suggest a range of error inherent in the manual method even when done by extremely qualified practitioners.

The second source of the error between the two methods lies in the procedures used by each to choose the base flow recessions. The MRC takes a statistical average of the entire base flow recession record compiled from the stream gauge data base. The graphical method relies on a more subjective visual assessment of the stream flow record for the "best" recession curves which can then be manually shifted to prepare the master recession curve. The benefits of this latter method are that the user may impose interpretive bias throughout the selection of base flow recession data from the stream gauge data. This must be balanced, however, with the time it takes to prepare manual recessions and the actual expertise of the user concerning the local hydrogeology and his/her past experience in preparing such master recession curves. The automated method is objective, fast, and easy to use, and because it is nonbiased, it is completely reproducible. The plots of the data are automatic and the user can view the results to check the validity of the plots with regard to the assumptions used in constructing a master recession curve cited by Bevans (1986). The presence of multiple recession slopes can be inferred from the plots of the MRC as well as those of the manual method. Further reasons for discrepancies between the two methods cannot readily be explained without specific knowledge of the procedures used by those who analyzed the data with the graphical technique.

Assuming that the graphical method is the best solution in calculating the recession constant, the next question is how will the percent error inherent to the automated method affect the use of this recession constant in predicting other aquifer properties. Rutledge and Daniel (1994) indicate that in their calculations of shallow aquifer recharge increasing or decreasing the recession index by 25 percent causes a maximum 6 percent change in the recharge estimate (for one station). Most of their values changed less than 3 percent. A 50 percent change in the recession index for one station resulted in approximately a 10 percent change in their recharge estimate. Therefore, it appears that in the case of recharge, the level of prediction produced by the automated methods is adequate, assuming a 10 percent error is acceptable. In the case of estimating maximum aquifer storage by integrating the maximum recession curve, more significant deviations could result from this level of error (Knisel, 1963). Similar levels of error could be assumed for use of this recession value in estimating aquifer diffusivity (Bevans, 1986). Comparison of diffusivity with estimates derived from local pump tests on the aquifer is advised as has been shown by Hoos (1990). However, if the regional recession values are averaged correctly by the automated MRC as is indicated for the larger data set, the simplicity of the method coupled with its reproducibility could result in better regional estimates of the above values. Because the method is rapid and easily checked, far more tests can be done economically on a regional scale. This should allow more accurate delination of the areal extent of the shallow aquifer system when combined with soils and geology maps (Bingham, 1986).

Conclusions

A proposed automated base flow separation technique (Nathan and McMahon, 1990) was compared to an existing automated technique (Rutledge, 1993) and manually separated base flow. The Filter method was comparable in accuracy in predicting the manually separated base flow and gave results similar to the automated model of Rutledge (1993). The filter is easy to use and has the advantage of being adjustable in separating stream flow records into surface runoff and base flow. This allows the operator a choice based on his experience in the area. It is recommended that in the absence of on-site conditions that one filter pass be the default value used.

Automated techniques used to estimate the recession constant (base flow days) were compared to the manually derived constants compiled by Rutledge and Daniel (1994) and Bingham (1986) for eastern watersheds and Bevans (1986) for western streams. The MRC model gave acceptable results in predicting the manually derived recession constants. The range of error averaged 13 percent. While this accuracy appears viable for estimates of recharge using methods summarized by Bevans (1986) and recently automated by Rutledge (1993), it must be further tested to be used for estimates of diffusivity and storage (Trainer and Watkins, 1974).

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