A comparison of baseflow separation techniques

W.A. Rieger and L.J. Olive,
Department of Geography,
Australian Defence Force Academy,
A.C.T., Australia 2600.

ABSTRACT. A recursive digital filtering technique is proposed as a method for separating storm hydrographs into quick stormflow (quickflow) and baseflow. The filtering approach is outlined and compared with the commonly used straight-line methods of separation. Suggestions are then made as to the possible applications of the filtering technique to some areas of sediment delivery research.

INTRODUCTION

With process studies on sediment delivery, baseflow separation can play an important role in determining suspended sediment behaviour during storm events. By separating the storm hydrograph into quick stormflow (quickflow) and baseflow, researchers can examine the relationship between one of these components and suspended sediment concentrations. For example, the hypothesis of quickflow as a delivery mechanism can be tested with the relationship between quickflow and concentration. In light of the recent research on macro-pores (Imeson et al. 1981), the relationship between baseflow and concentration might be of interest.

Regardless of how researchers may use quickflow or baseflow in their analysis, the fact remains that the validity of the results is a function of the separation method. To date, the majority of researchers have used linear or straight-line techniques for baseflow separation and while these techniques are relatively easy to apply to storm hydrographs, there is some doubt as to how accurately the resulting series approximates the real behaviour of baseflow. One obvious criticism is that few phenomena in hydrology follow straight lines as evidenced by the storm hydrograph, itself.

In the following discussion, a slightly more realistic method of baseflow separation is outlined. The method uses a recursive digital filter and as such, takes into consideration the sequential nature of the observations making up the original storm hydrograph. There is nothing new in the method in that filtering theory has been used for years in time series analysis, and the suggested method has been used in the past for baseflow separation (Lyne 1979, O'Loughlin et al. 1982). However, by bringing it to the attention of researchers involved in sediment delivery, it is hoped that it might prove to be a helpful tool in analysing some aspects of delivery processes.

BASEFLOW SEPARATION BY FILTERING

General Comments

In applying a filter to a storm hydrograph to obtain baseflow, it is assumed that the original series is made up of a number of frequency components or waves. Each frequency component has a particular phase and amplitude and the hydrograph is simply the sum of these components (Terrell 1980). When viewed in this fashion, quickflow is a set of high frequency (short wavelength) components superimposed on baseflow which is a set of low frequency (long wavelength) components with small amplitudes, relative to those in the hydrograph.

The filtering operation is simply the mathematical equivalent to, say, filtering a water sample to obtain suspended sediment. In the case of the sample, water and sediment are passed through a filter and the sediment remains on the filter. In the case of the time series, or hydrograph, the filtering operation removes various frequency components of the series, giving a new series. Most people are familiar with a moving average average filter which smoothes a series or removes the high frequency (small wavelength) components.

The object, then, in using a filter to obtain baseflow from a storm hydrograph, is to design a filter which will remove all the frequency components other than the lower frequency components which manifest baseflow. The results of the filtering operation will be new series representing baseflow. This baseflow series is, itself, made up of a number of frequency components and as it takes the form of a time series, it is a decided improvement on modelling baseflow with straight lines.

Filter Description and Implementation

Given a discharge series,

$$Q(t),\ t=1,2.....n,$$

Lyne (1979) proposed a recursive digital filter for baseflow separation. The filter takes the form:

$$Qq(t) = a \cdot Qq(t-1) + [(1 + a)/2] \cdot [Q(t) - Q(t-1)], \qquad (1)$$

where $Qq(t)$ is quickflow,
and a is the filtering coefficient.

Baseflow, $Qb(t)$, is calculated by subtracting the resulting quickflow values from the original discharge series.

In applying this filter to a discharge series,the algorithim should include the following modifications:

(a)Due to the nature of the filter, negative values of baseflow may occur. This problem is overcome by restricting the range of baseflow values to $0 \leqslant Qb(t) \leqslant Q(t)$ for all t during the filtering operation.

(b)A single application or pass of the filter causes phase shift of the $Qq(t)$ series, resulting in changes in the location of peaks relative to the original series. However, if the filter is first passed forwards along the series then passed backwards along the series, phase shift is minimal.

(c)After the initial forward-backward pass of the filter, the resulting baseflow may appear as though it is responding too rapidly. The filter can be successively applied to the generated $Qb(t)$ until a less flashy response is obtained.

(d)Because the filtered values tend to taper off to zero at the end of the series, storm event data should be artificially extended. One simple method of extension is to append an additional 20

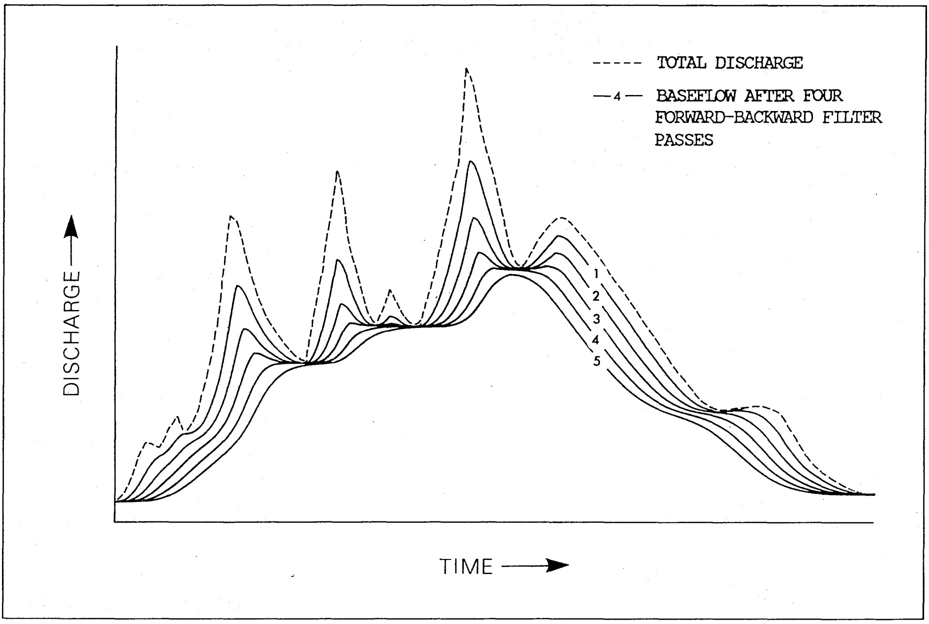

FIG 1 Baseflow separation for a multi-rise storm event.

constants to the series where the constant equals the last value of the series.

Fig. 1 shows the resulting baseflows for five successive forward-backward passes of the recursive filter. The original discharge series represents the behaviour of a multi-peaked storm event in a forested drainage basin in south eastern New South Wales. The value of the filtering coefficient was 0.92, though any values in the range $0.80 < a < 0.95$ will give approximately the same results, but require more passes of the filter with the lower range of values.

The results in Fig. 1 indicate the following general characteristics of the filtering operation:

(a)Peaks in the baseflow are lagged with respect to the those in the original hydrograph. This is similar to the results given with the fixed base length method of straight line separation except that no subjective method was used to determine the lag.

(b)The baseflow curves are, in fact, a time series which is an improvement over the linear behaviour given by straight-line separation methods.

(c)The recessional part of the baseflow curves appear to conflict with the traditional ideas of baseflow separation which would have baseflow approximately equal to the hydrograph values at a point after the final peak in the hydrograph. However, as baseflow is presently being defined with respect to stormflow (total flow attributed to a storm event), the traditional ideas of baseflow recession may not apply.

(d)The major shortcoming of the filtering technique is that a subjective decision is required concerning which of the curves represents baseflow, or how many forward-backward passes of the filter will give a realistic baseflow separation.

APPLICATIONS

With the widespread use of automatic water samplers for monitoring purposes during storm events, there are numerous applications of the baseflow and quickflow components of the hydrograph. These applications are mainly in the area of process studies and involve examining the behaviour of one of the flow components and a variable obtained from the laboratory analysis of the water samples. Some of the variables include suspended sediment concentration, solute concentration and chemical components of the solute load.

Two applications have been mentioned in the introduction. The first one involves the examination of the the relationship between quickflow and suspended sediment concentration. In this case, quickflow is postulated as a delivery mechanism and the storm event data is used to determine the variability of the response of concentration to quickflow. Examples of such an approach are given in Walling & Webb (1982) and in Rieger & Olive (1984). The second application involves the recent interest in sediment delivery via macro-pores and might examine the relationship between base flow and some function of concentration with a view to determining the level of macro-pore activity.

The actual flow component curves can also be manipulated to give an indirect measure of factors within a watershed during storm events. One such manipulation is the generation of the rate of change of quickflow which could be seen as a surrogate measure of the contraction and expansion of the contributing areas of runoff. In a similar fashion, rate of change of baseflow might be interpreted as a measure of changes in soil conditions during a storm event.

Regardless of how the flow components are applied in response studies, it is strongly suggested that hysteresis diagrams are used rather than straight line regression plots. Regression plots do not include the important sequential nature of the storm event data. To first use a recursive filter to generate a realistic approximation of baseflow and quickflow, then submit these data to simple linear regression analysis could be considered equivalent to an exercise in futility.

CONCLUSIONS

Baseflow separation using a recursive digital filter has been shown to give relatively good results compared to straight-line separation techniques. Because the filtering operation takes into consideration the sequential nature of the storm hydrograph, the relative smoothness of the baseflow curves is more appealing than that obtained by linear methods. The major shortcoming of the filtering method is the subjective criterion which is required in determining the number of passes of the filter to obtain realistic estimates of baseflow. However, when compared to the more numerous subjective criteria used in most straight-line separation techniques, this shortcoming is relatively insignificant.

The implementation of the filter on a computer is quite a simple exercise and depending on the language, can be accomplished with a subroutine of less than twenty lines. In light of both the realistic estimates of baseflow which the filter gives and its ease of implementation, it may prove to be a useful analytical tool for researchers involved with aspects of the sediment delivery problem.

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