Journal of Hydrology (N.Z.) Vol. 29, No. 2, 1990

BASEFLOW SEPARATION USING THE LOCALISED FLOW VARIANCE AS A DETECTION CRITERION FOR QUICKFLOW

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A method of baseflow separation is suggested using localised variance of the flow record as the detection criterion for quickflow. The localised variance is a function which, for any sampling period in a time dependent record, describes the variability of that section of record. The formulation of a method of baseflow separation is described and applied to a flow record from the Hurunui River, South Island, New Zealand.

INTRODUCTION

A flow record may be analysed as the sum of two parts: baseflow from aquifers and lakes, and quickflow from rain. Quickflow appears as a pulse on the flow record which can in principle be traced upstream to its source. There is little correlation between baseflow and quickflow, so their statistics should be analysed separately. This requires separation of the two parts and, if done effectively, will result in better estimates of the risk of low and high flows.

A method was sought which exploits flow records that are not just series of daily values but contain all the recorded details, with interpolation between stored values only when the flow changes smoothly. Hydrology archiving software called Tideda allows the time interval between stored values to vary along a record. A process in Tideda called Compression (see Ibbitt 1975) also allows the time interval between values to be expanded until further expansion would reduce agreement of interpolated and measured flows. For example, the flow recorder on the Hurunui River, South Island, New Zealand, reads a value every 0.25 hours, but accurate representation requires that only 2% of these readings be kept. It is only necessary to preserve the 0.25 hour resolution 4% of the time. The median spacing between data points retained is 8 hours and the average spacing is 13 hours. Ideally new methods should operate directly on data stored in this compact way.

To separate quickflow from baseflow automatically in a flow record we need an algorithm which will detect quickflow pulses. R. F. Blackwelder and R. E. Kaplan (1976) use the localised variance of the velocity to detect 'bursts' of turbulence in open channel flow. Bursts describe the most vigorous eddies, and in velocity records these are periods when the velocity changes more rapidly; these periods represent a small fraction of the record. The conditional sampling technique they used provided the inspiration for the use of the localised variance to detect quickflow.

The method of baseflow separation used at present by the Hydrology Centre of New Zealand's Department of Scientific and Industrial Research is the separation slope method of Hewlett and Hibbert (1967). This method is restricted by the need to select a separation slope. No objective criteria are available for the selection of this parameter, nor is it necessarily a constant. The localised variance method may overcome these problems.

The Detection Algorithm

The localised variance of a record is a measure of the variance over a short sampling interval of time in the record. The localised variance as a function of time t, with sampling interval T, is defined as:

$$\langle var\rangle(t,T) = \langle u^2\rangle(t,T) - \langle u\rangle^2(t,T)$$

where $\langle u\rangle^2(t,T)$ is the square of the moving mean over interval T of a time dependent record u(t), $\langle u^2\rangle(t,T)$ is the moving mean of the square of the record $u^2(t)$, and $\langle var\rangle(t,T)$ is the localised variance of the record.

A typical flow record for the Hurunui River with its associated localised variance signal is shown in Figure 1. The sampling interval T in this example is 2 days. The selection of a suitable value for the sampling interval is discussed later. The localised variance becomes very large for a sampling interval which includes flood peaks in the flow record (Fig. 1), and can therefore be used to indicate the presence of quickflow.

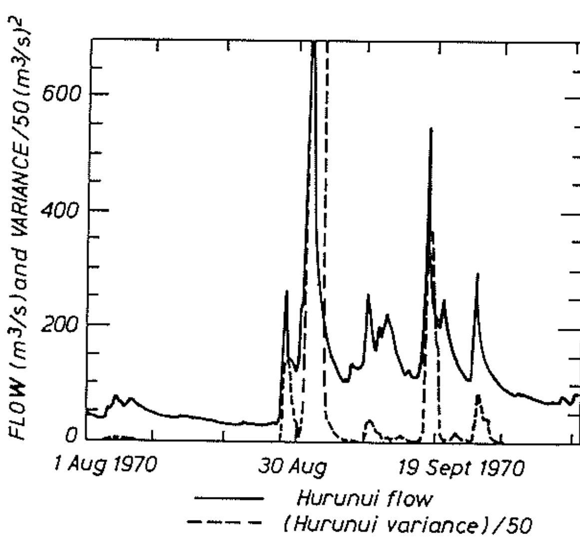

FIG 1—Hurunui River Flow and Localised Variance of Flow. The plotted values apply to the preceding sampling interval. Ticks on the time axis are 10 days apart.

By setting a threshold level of localised variance, values below which indicate only gentle flow fluctuations common to baseflow sections of record, we obtain a detection function for quickflow. Detection occurs when the localised variance of the flow exceeds that threshold.

Consider a flow record plotted as a long wiggly line, and the sampling interval as a window through which part of that line can be seen. As analysis proceeds from the earliest part of the record, the window is moved from the left of the line towards the right.

When the window first reaches a flood, the localised variance signal rises. Therefore the time of detection is the time of the right hand end of the window,

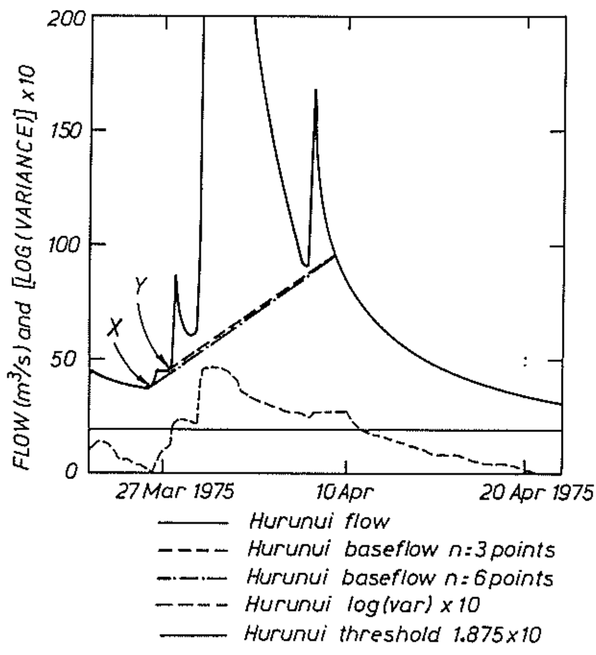

FIG 2—Obtaining the onset time of quickflow requires a suitable number of data points to calculate the regression slope. In this example the localised flow variance crosses the threshold value just to the right of point Y. The previous local flow minima calculated with a regression slope over 3 data points is at point Y. This is not the correct quickflow onset time. Using 6 data points to calculate the regression slope the algorithm does not detect a minimum at Y because the downward slope of the dip is represented by less than 6 data points. The onset time is instead placed at X which is the end of the baseflow recession. Ticks on the time axis are 10 days apart.

but this time is after the onset of quickflow. Thus the onset time is set back to the end of the previous baseflow recession where the slope of the record last passed from negative to positive, i.e. the previous local flow minimum. This slope is taken as the regression slope of the previous 6 values stored in the computer file. If the slope is calculated for fewer data points then minima at points other than the end of the baseflow recession curve are detected (Fig. 2).

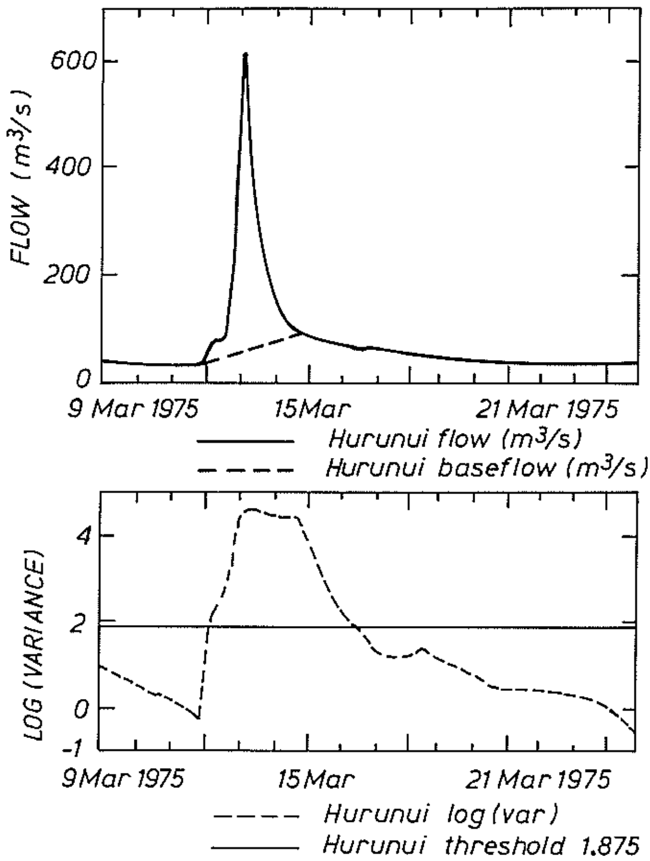

FIG 3—Top: Separated Hurunui River flow. Bottom: Logarithm of localised variance plotted at the right hand end of the window. The baseflow onset time is the end of the baseflow recession immediately before the time at which the variance signal crosses the threshold. The baseflow finish time is the time at the left hand end of the window when the variance falls below the threshold level again. The ticks on the time axis are a day apart, and the sampling interval (i.e., the window length) is 1.75 days.

The localised variance remains high until the window has completely passed over the flood so that the flood finish time is the time of the left hand end of the window when the localised variance falls below the threshold level again.

The baseflow component of the record is defined to be equal to the total flow in periods devoid of quickflow, and to change linearly with time between flood start and finish times in periods of flood. The finish time is delayed when necessary to ensure that the baseflow component of a period of record in flood, which is a straight line drawn from the start to end of quickflow, is always below the total flow line on the flow-time graph. Figure 3 illustrates the application of the baseflow separation algorithm to a typical flood.

Selection of Baseflow Separation Parameters

Komori et al. (1989) also used the localised variance detection technique of Blackwelder and Kaplan (1976) in their studies on bursts of turbulence in open channel flow. Komori et al. tried to find optimum values for the two parameters of the detection algorithm: the sampling interval T, and the threshold level of variance.

The choice of sampling interval T, affects the shape of the localised variance curve (Fig. 4). To determine an appropriate sampling interval, Komori

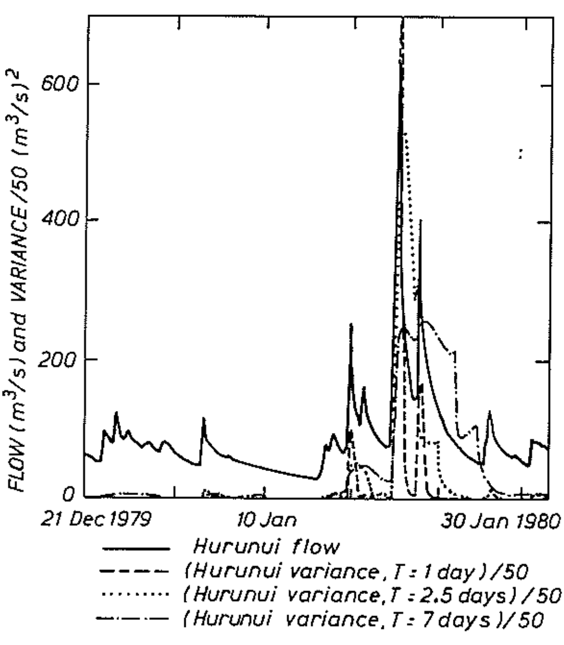

FIG 4—Changing the length of the sampling interval affects the shape of the localised variance curve. As the sampling interval is shortened the variance curve becomes steeper and narrower. The ticks on the time axis are 10 days apart.

approximated the velocity signal, which is comparable to our flow record, with a series of sine waves. The detection algorithm was applied to this synthetic velocity signal for a range of sampling intervals. The algorithm best detected the bursts placed in the velocity signal when a value of T comparable to the durations of the bursts of turbulence was used. In preliminary work on baseflow separation on the Hurunui River I used a sampling interval equal to the average flood duration i.e. 1.75 days. The average flood duration is a statistic which comes from baseflow separation, therefore the selection of this parameter is an iterative process.

The threshold level of variance was set by Komori et al. (1989) and by Blackwelder (1976) as $ku^2_{r.m.s.}$ where k is the threshold level and $u_{r.m.s.}$ is the root mean square of the signal, i.e. $u^2_{r.m.s.} = \langle var \rangle(t,T)$ where T is the total record length.

Komori found that the number of bursts detected in the same velocity signal was strongly dependent on k for most values of k. However, for values around k = 0.4 the number of bursts detected was not dependent on k. Therefore, Komori selected k = 0.4 as his threshold value.

A similar procedure was used in this study to find an objective method of determining the threshold. Baseflow separation was carried out on four years of Hurunui River flow record using a range of threshold values and several different sampling intervals. In each case the number of floods detected, the average flood duration, and the baseflow index (volume of baseflow as a percentage of volume of total flow) were calculated from the separated flow

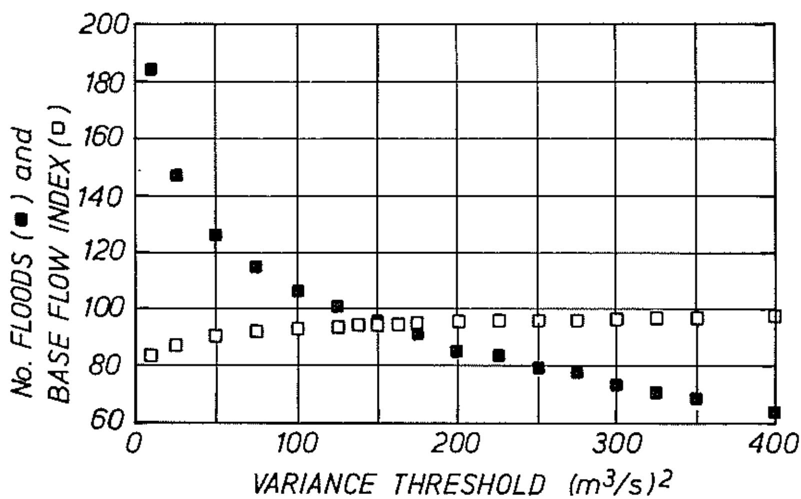

FIG 5—The number of floods detected and the baseflow index are strongly dependent on the variance threshold. The sampling interval (window length) is 1 day in this example. Similar results were obtained with other lengths of sampling interval.

record. It was hoped that there might be a value of threshold for which the number of floods detected and the baseflow index are independent of the threshold value. However these statistics were found to depend strongly on the threshold value of variance (see Fig. 5). In the baseflow separation algorithm the threshold is set as an absolute value of localised variance in units of $(m^3/s)^2$.

The selection of the threshold has a large bearing on the performance of the baseflow separation algorithm. Baseflow can be separated using average flood duration as the sampling interval and selecting a variance threshold to give separation lines which look satisfactory. A separation line is judged to be satisfactory if it starts at the end of the previous baseflow recession curve and has a slope similar to the slope of the recession curve at the flood finish time.

Baseflow Separation on the Hurunui River

The flow record of the Hurunui River was used to test this baseflow separation method. The sampling interval was set at 1.75 days, the measured average flood

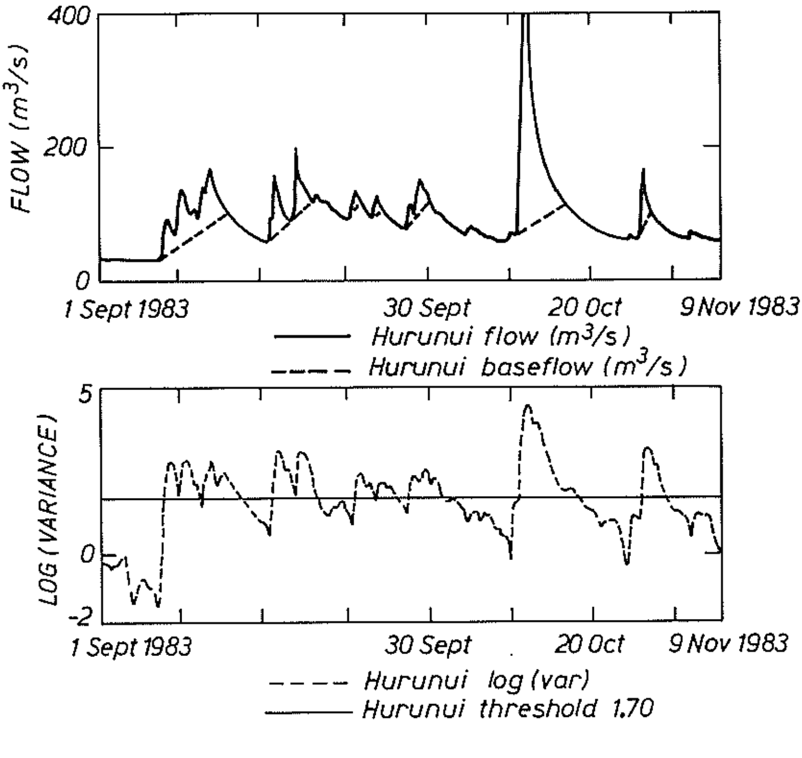

FIG 6—Top: The Hurunui River flow record showing baseflow separation. Bottom: Logarithm of localised variance plotted at the right hand end of the window also showing the threshold level of 50 $(m^3/s)^2$, which plots at log(50) = 1.70. Ticks on the time axes are 10 days apart.

duration for a 4 year period of the record. A value of threshold of 50 $(m^3/s)^2$ was found to give the best separation lines. A short sample of the result is shown in Figure 6.

The application of this baseflow separation method to the Hurunui River gave encouraging results. Each flood onset time is positioned at the end of the previous baseflow recession curve, and baseflow increases while the river is in flood (Fig. 6). The baseflow separation algorithm ignores small deviations in baseflow which may have been picked up as floods by other separation procedures, such as the separation slope method.

A major drawback at present is the need to select the variance threshold subjectively. The use of an algorithm that determines the flood finish time by comparing the localised variance after the flood finish time with the variance just before the flood start time may make the selection of a threshold parameter more objective. These variances measure the rate of flow recession at places where that rate is nearly constant.

ACKNOWLEDGEMENT

I thank Dr S. M. Thompson for suggesting this method, for helpful advice during the investigation, and for guiding this paper through the publication process in my absence.

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