Modelling of a dimensionless synthetic unit hydrograph

Gaddi Ngirane-Katashaya[1]* and Robert Cowen[2]
[1] *Dept Earth Sciences, University of Venda, P/Bag X5050, Thohoyandou 0950, South Africa*
[2] *Department of Mathematics, University of Botswana, P/Bag 0022, Gaborone, Botswana*

Abstract

When use of a synthetic unit hydrograph on ungauged and non-comparable catchments is required, a further complication is how to choose a suitable time-step to use. The computed time-step is rarely an integral multiplier or divider of the rainfall time-step thus necessitating reanalysing the rainfall chart, at the new time-step. It would be easier if the time-step of the unit hydrograph could be expressed as a continuous function.

In February 1995 there was a flash flood in mid-Eastern Botswana which resulted in all gauges being washed away. The only available data were from upland recording rain gauges from which the reconstruction of the flood hydrograph had to be done. Use of a dimensionless synthetic unit hydrograph (DSUH) was indicated. This is the first part of a two-part paper which involves analyticising (transforming a numerical/graphical function into a continuous one i.e. rendering it analytical) the dimensionless unit hydrograph i.e. developing a piecewise/zonal continuous function of time vs. the runoff.

A DSUH was piecewise modelled using usual statistical methodology and special mathematics software. In spite of having had to use several and basically different functions from piece/zone to piece/zone, the final goodness of fit was exceptional. Demonstrating the application results is shown in the unit hydrograph-based mathematical model which was developed to solve for the above flood. This will be presented in a follow-up paper, which will dwell more on the hydrology of the exercise.

Introduction

Using a unit hydrograph (UH) to compose a catchment runoff hydrograph has always relied on working from the catchment's typical hydrographs produced from rainfall of known intensity and duration, one of the principles on which unit hydrographs are based (Sherman, 1932; Linsley et al., 1982/1988). From this one can work out instantaneous UHs and UHs of various durations to suit rainfall of various durations. Although it is known that modelling has taken over from use of UH whose basic assumptions are gross, for economical and urgency reasons where accuracy is not so crucial, one may quickly get an approximate result which might serve the purpose.

Normally, one resorts to synthetic unit hydrographs (SUHs) if there are no observed discharge hydrographs. This requires that the catchment characteristics (Snyder, 1938; Linsley et al., 1982/1988) be obtained or determined which are then used to adapt the SUH to suit a particular catchment. The catchment/basin lag-time and other catchment characteristics are required to customise the UHs to that particular catchment (Taylor et al., 1952; Mockus, 1957; Wilson, 1983). Extensive use of several catchment characterisation parameters can produce a reasonable and largely reliable runoff hydrograph suitable for design purposes (FSR, 1975/85).

The time-step of rainfall in a rainfall-runoff hydrograph is important as it is the parameter which determines the time-step of the hydrograph and the runoff input. Irrespective of the duration of the rainfall, the time-step goes a long way in determining the apparent intensity of the rainfall as experienced by the catchment, compared to the real intensity. Only accurate representation of the rainfall intensity relative to the catchment can give a true reflection of the resulting discharge. It is imperative that the time-step used in rainfall, the UH, and eventually the constituted discharge, are the same in size and reflect the true relativeness of the rainfall, UH and runoff. Starting with an SUH, this is usually the cause of doubt and difficulty, as will be explained later.

This paper, therefore, is about analyticising a UH thus rendering it easy to adjust its time-step to conform with that of rainfall thus eliminating one source of uncertainty in UH-rainfall-runoff interaction.

The flood of Mahalapye-Palapye catchments

In February 1995 there was a severe flood in the Mahalapye and Palapye catchments of Botswana (200 km NE of Gaborone and 100 km SE of Francistown - the Lotsane and Mahalapye Rivers are south-flowing tributaries of the Limpopo River). The river-gauging stations were washed away as were some houses near the rivers. The only data available were the rain-gauge records and of flood marks on trees and bushes in the floodways.

The condition of the catchment was such that the floods came within a day of the start of the rainfall and since the catchments were reasonably steep, with little infiltration capacity, the rivers were back to nil discharge within a few days afterwards. A flash flood situation was thus indicated. This showed that the solution would be obtained by using a unit hydrograph, specifically an SUH as there were no prior records of similar circumstances.

The necessity for modelling the flood was to obtain a flood hydrograph thus being able to reconstruct and delineate the flood zone, flood duration, and thus work out assistance and compensation programmes. Mathematical modelling, deterministic simulation-based (for more accuracy and representativity), would have taken longer and would have been more expensive, contrary to the basic objective of the exercise.

The problem: Use of a dimensionless synthetic unit hydrograph

The commonly used dimensionless synthetic unit hydrograph (DSUH) is the US Soil Conservation Service (USSCS) type (Linsley et al., 1982/1988). It is usually presented as a graph thus

* To whom all correspondence should be addressed.
☎ 082 200 5584; fax 0838 269 1843; e-mail gaddin-k@mailexcite.com
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